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Recent incidental catch of sharks in gillnet fisheries of Newfoundland and Labrador, Canada

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ABSTRACT: Waters of Newfoundland and Labrador, Canada, are home to a variety of shark species, many of which have been previously reported as incidental catch in several gillnet fisheries. However, defensible estimates of incidental catch rates are unavailable. This mortality is of concern, given reports of considerable declines in abundance of several large shark species in this area. On the basis of several data sources (incidental catch rates derived using different methods of reporting; fish landings and net days as measures of effort, with fishing trips as sampling units), the total numbers of incidentally caught sharks were estimated in 8 gillnet fisheries for 2001, 2002, and 2003. Confidence intervals were estimated using resampling techniques. Most fisheries reported incidental catch of some sharks, although there were distinct differences between different fisheries in diversity and abundance of species encountered. Spiny dogfish *Squalus acanthias* was the most commonly captured species, occurring in various fisheries along the south coast of the island of Newfoundland. Large sharks, including basking shark *Cetorhinus maximus*, shortfin mako *Isurus oxyrinchus*, porbeagle *Lamna nasus*, and blue shark *Prionace glauca*, were reported in small numbers in all fisheries. Deepwater fisheries targeting e.g. Greenland halibut *Reinhardtius hippoglossoides* caught mainly sharks of the continental slope, such as Greenland shark *Somniosus microcephalus*, black dogfish *Centroscyllium fabricii*, and several other deepwater species. Catch rates of several species appear high and may warrant conservation action. For the majority, however, there is insufficient information on abundance, and sometimes even basic biology, to accurately assess the impact of this incidental mortality.

KEY WORDS: Sharks · Incidental catch · Bycatch · Canada · Northwest Atlantic · Mortality · Dogfish · Gillnets

INTRODUCTION

High levels of incidental catch of elasmobranchs (sharks, rays, and chimaeras) in fisheries have become a conservation concern in recent years (FAO 1998, Kulka et al. 2005, IUCN 2010). Stocks of many species are reported to be declining, and several are considered globally threatened or endangered (e.g. Simpfendorfer 2000, Stevens et al. 2000, Kiraly et al. 2003, IUCN 2010). Sharks and rays are caught in a wide variety of fishing gears including gillnets, longlines, and trawls (Bonfil 1994, Stevens et al. 2000, Carretta et al. 2004, Diaz & Serafy 2005, Shepherd & Myers 2005, Kulka et al. 2006). Worldwide, reported elasmobranch landings have declined from a high of approximately 900 000 metric tonnes (t) in 2003 to 750 000 t in 2006 (FAO 2009). However, actual landings may be almost twice as high, owing to substantial incidental and unreported catches (Bonfil 1994, FAO 2004). Despite considerable recent improvements, elasmobranch catches are often not identified to species in fisheries statistics, frustrating attempts to assess the potential impact of fisheries on these species (Stevens et al. 2000, FAO 2004, 2006, ICES 2006).

Sharks and rays are considered vulnerable to overexploitation because of specific life-history traits. Most

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species grow slowly, mature late, and exhibit low fecundity; thus, even under ideal circumstances, population growth rates are low. These factors make it difficult for their populations to resist widespread juvenile or adult mortality in fishing gear (Castro et al. 1999, Stevens et al. 2000, Lewison et al. 2004, Kulka et al. 2005). While some directed fisheries for sharks, skates, and rays have been managed for many years at a sustainable level, most elasmobranchs are caught in fisheries targeting an assemblage of different teleost species (Walker 1998). Management strategies intended to maximize catches of teleosts can deplete elasmobranch stocks, because teleost populations are able to withstand higher levels of fishing mortality (Walker 1998). Furthermore, information on biological parameters, including stock structure, reproductive rates, or estimates of abundance, is often not available. These factors complicate attempts to establish conservation strategies for many species of elasmobranchs (FAO 2004, 2009).

During the course of research aimed at estimating incidental catches of small cetaceans in Newfoundland and Labrador gillnet fisheries during the 2001 to 2003 seasons, anecdotal reports from commercial fishers and observations at sea by fishery observers indicated that incidental catches of several species of sharks occurred regularly in several fisheries. These reports were used to estimate incidental catch of these species.

Several species of sharks have been recorded in Atlantic Canadian waters off Newfoundland and Labrador: large, pelagic species, including basking shark *Cetorhinus maximus*, blue shark *Prionace glauca*, porbeagle *Lamna nasus*, shortfin mako *Isurus oxyrinchus*, and thresher shark *Alopias vulpinus*; small demersal species, such as spiny dogfish *Squalus acanthias* and smooth dogfish *Mustelus canis*; and sharks from deeper waters, such as Greenland shark *Somniosus microcephalus*, black dogfish *Centroscyllium fabricii*, Portuguese shark *Centroscymnus coelolepis*, deepsea catshark *Apristurus profundorum*, and great lantern shark *Etmopterus princeps*. Kulka (2006) provides a description of the distribution and abundance of all small demersal shark species in the waters surrounding Newfoundland and Labrador, with spiny dogfish and black dogfish by far the most commonly encountered species in this area. Schools of spiny dogfish, which may consist of thousands of individuals, seasonally appear in nearshore waters during summer, particularly along the south coast of the island (Templeman 1984). All spiny dogfish in this region are thought to belong to a single stock (DFO 1996a, Castro et al. 1999, Kulka 2006, Campana et al. 2007). Black dogfish are occasionally found in nearshore waters but are far more common in deeper, colder waters along the Newfoundland and Labrador continental slope and in the Laurentian Channel in the Gulf of St. Lawrence; the latter appears to be an important nursery area for this species (DFO 1996b, Kulka 2006). Other demersal sharks from these waters include Greenland shark, Portuguese shark, and deepsea catshark; information on stock structure is unavailable for these species.

The larger pelagic sharks (e.g. basking, blue, porbeagle, and shortfin mako sharks) are typically associated with warmer waters off the south coast of Newfoundland, although porbeagles are known to tolerate colder waters and are found across the Grand Banks (Campana et al. 2003, 2005a,b). Porbeagles are most abundant during the summer and fall months. The southern Grand Banks and adjacent areas appear to serve as a mating ground for porbeagles (Campana et al. 2003; Fig. 1), but it is unknown if other species breed here. Basking sharks forage along oceanic fronts where zooplankton concentrations are highest, and their occurrence in nearshore waters is therefore dependent on these conditions (Sims et al. 1997, Sims & Quayle 1998, Campana et al. 2008). Basking sharks are most commonly reported from the south coast of the island and on the Grand Banks. There is limited information about seasonal distribution of other species in Newfoundland waters.

Historically, there have not been widespread directed fisheries for sharks in Newfoundland and Labrador waters. From 1961 onwards, some Canadian

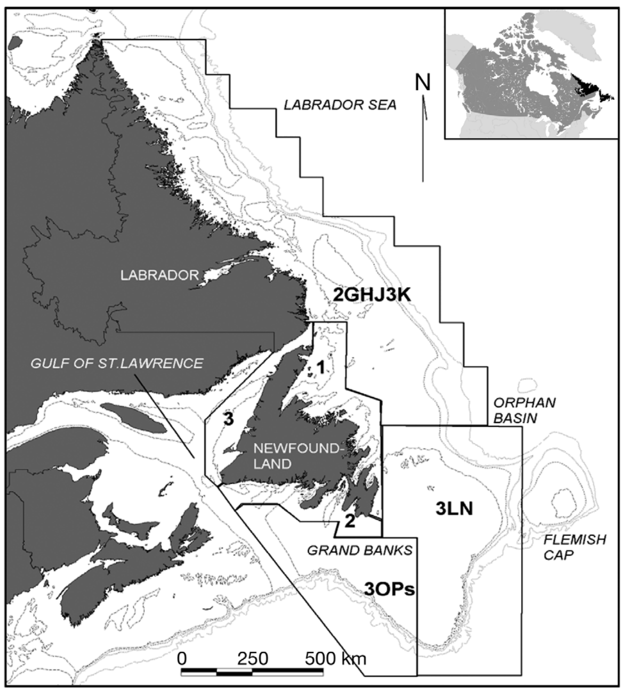

Fig. 1. Newfoundland and Labrador waters, and geographical aggregations of fishing effort data and incidental catches of sharks in nearshore (1–3) and offshore (2GHJ3K, 3LN, 3OPs) areas, based on Northwest Atlantic Fisheries Organization (NAFO) Divisions of Newfoundland and Labrador waters. 1 = northeast coast, 2 = south coast, 3 = west coast

trawling effort was directed towards spiny dogfish in the northwest Atlantic, but total landings remained below 30 t until 1986 (DFO 1996a). Canadian landings have averaged about 2500 t annually since 2000, with the majority being directed catch by handline and longline, followed by gillnets, primarily based in Nova Scotia and the southern Gulf of St. Lawrence (DFO 2007a). Following implementation of US quota restrictions in 2000, these catches currently represent a considerable fraction of dogfish landings in the northwestern Atlantic. The species is often caught incidentally in various fisheries throughout Atlantic Canada including Newfoundland and Labrador. Most of this catch is discarded because of poor local market conditions, with discard levels averaging 2000 to 3000 t in recent years. Given the hardy nature of spiny dogfish, this has been estimated to result in annual discard mortality levels of about 850 t (DFO 2007a). Canadian catches were unrestricted prior to 2002, but precautionary directed catch quotas based on past catches have subsequently been put in place; since 2004, these have been set at 2500 t. However, these quotas have not been based on scientific advice, and to date there are no restrictions on discarding and bycatch in other fisheries (Campana et al. 2007, DFO 2007a). Its life history traits make spiny dogfish highly vulnerable to overexploitation, and the species is classified as 'Vulnerable' in the northwestern Atlantic by the International Union for the Conservation of Nature (IUCN) (Bundy 2003, NEFSC 2003, Kulka 2006, IUCN 2010).

Porbeagles in Atlantic Canada were historically targeted by Norwegian and Faroese vessels using pelagic longlines (Templeman 1966, Castro et al. 1999). Porbeagle catches peaked at 9281 t in 1964 but declined rapidly because of overexploitation (Castro et al. 1999, Campana et al. 2003, COSEWIC 2004). Catches in Atlantic Canadian waters remained at low levels in subsequent decades but increased substantially from 1990 onward, with the development of a directed longline fishery. Licensed vessels were primarily Canadian, although Faroese vessels also participated until 1994 (Joyce 1999). Catches peaked at 1615 t in 1994 but have declined in recent years to <300 t (DFO 2005). Most catches took place off the Scotian Shelf, but some occurred in deep waters surrounding the Grand Banks (Hurley 1998). This fishery also targeted small quantities of blue sharks (~250 t), with shortfin mako being caught incidentally (Campana et al. 2003, DFO 2005). These species are also incidentally captured in considerable numbers in numerous other fisheries in the area, particularly longline fisheries for swordfish and tunas (e.g. Campana et al. 2003, 2004, 2005b). Porbeagles and shortfin mako incidentally caught in such fisheries are typically retained and landed, while most blue sharks are discarded (DFO 2007b). Mortality rates of bycaught and discarded sharks are generally poorly known but considered to be high (Campana et al. 2006). Populations of these species appear to have declined substantially because of historic overexploitation (Campana et al. 2004, 2005b, 2006, COSEWIC 2004, 2006a,b). Directed catches have been reduced throughout the region owing to the implementation of management practices designed to preserve shark stocks, including quota restrictions (DFO 2005). Shark finning, the practice of removing the fins and discarding the remainder of the carcass while at sea, has been banned in Canada since 1994 (DFO 2007b).

Other shark species are found as incidental catch in Newfoundland fisheries. Basking sharks have been regularly recorded as incidental catch in fish traps targeting Atlantic cod *Gadus morhua* and capelin *Mallotus villosus*, as well as gillnets (e.g. Lien et al. 1982, 1985, 1995, Lien & Fawcett 1986). Historically, such catches were sometimes sold but often discarded, typically after expending considerable effort to disentangle the carcass from the fishing gear. However, the species does not appear to have ever been directly targeted in Newfoundland waters, unlike elsewhere in its range (ICES 1995, Castro et al. 1999). Greenland sharks and black dogfish, in particular, are regularly reported as incidental catch in numerous offshore fisheries, particularly those targeting Greenland halibut *Reinhardtius hippoglossoides*. The majority of these catches are discarded at sea owing to poor local markets; the impact of these catches on the species' populations is unknown at present (Kulka 2006).

METHODS

Data used to derive incidental catch estimates of sharks for 2001 to 2003 were derived from fishery observers deployed to commercial fishing vessels contracted to the Canadian federal Department of Fisheries and Oceans, Newfoundland and Labrador Region (DFO-NL), and from bycatch collectors, an existing network of selected commercial fishers. Fishery observers were independent recorders of detailed fishing catch and effort, assigned to fisheries as required under existing management regulations (Kulka & Firth 1987). Bycatch collectors were fishers originally recruited by the Marine Mammal Section of DFO-NL to report incidental catch of seals, as well as fishing effort, in their commercial fisheries, but who had been requested to maintain accurate records of incidental catches of all species. Both bycatch collectors and fishery observers reported incidental catch of sharks, invertebrates, marine mammals, seabirds, and reptiles, captured during normal fishing operations. Fishery observers received training in the identification of sharks and were equipped with identification guides while at sea, while bycatch collectors received similar identification materials from DFO technicians. Despite these aids, carcass decomposition and/or lack of observer knowledge prevented the identification to species of some sharks. Such records of 'unidentified sharks' were not used to estimate incidental catch in this study.

As sharks are not homogeneously distributed in the Newfoundland and Labrador area, all fisheries effort data were organized geographically based on Northwest Atlantic Fisheries Organization (NAFO) Divisions of Newfoundland waters (Table 1, Figs. 1 & 2). In this study, 'nearshore' fisheries were defined as those occurring in NAFO subareas immediately adjacent to land (Fig. 2), whereas 'offshore' fisheries occurred in NAFO subareas further from land (Fig. 1). Bycatch collectors mainly fished in nearshore waters, while fishery observers typically monitored larger vessels further offshore. We studied nearshore gillnet fisheries for Atlantic cod, lumpfish *Cyclopterus lumpus*, Atlantic herring *Clupea harengus*, redfish *Sebastes* sp., Greenland halibut, and winter flounder *Pseudopleuronectes americanus*, and analyzed these using bycatch collector data where possible. Because of low observer coverage in nearshore fisheries, we used only observer data for these fisheries when bycatch collector data were unavailable. We studied offshore gillnet fisheries for Atlantic cod, monkfish *Lophius americanus* and skates (Rajidae), white hake *Urophycis tenuis*, redfish, and Greenland halibut, using fishery observer data. Observer coverage levels varied greatly between fisheries, from year to year, and also between bycatch collectors and fishery observers (Table 1).

The incidental catch rate *R* for each species in each fishery was calculated as:

$$R = \text{no. of events/no. of net-d}$$

where 1 net-d equates to 1 net fishing for 24 h. 'Number of events' was based on individual records of capture events by bycatch collectors and fishery ob-

Table 1. Total landed catches (t, round weight) and estimated fishing effort (net-d) for various Newfoundland gillnet fisheries in 2001, 2002, and 2003, including fractions of landed catch and net-d as reported by bycatch collectors (BC) and fishery observers (FO), respectively. 'ND' indicates that no bycatch collector or fishery observer data were available. Note the difference in coverage between bycatch collectors and fishery observers in terms of % catch observed in different fisheries (e.g. the monkfish/skate fishery)

Fishery	Total catch (t, round weight)									Fishing effort (net-d, estimated)								
	2001			2002			2003			2001			2002			2003		
	Catch	% catch observed (BC)	% catch observed (FO)	Catch	% catch observed (BC)	% catch observed (FO)	Catch	% catch observed (BC)	% catch observed (FO)	Effort	% effort observed (BC)	% effort observed (FO)	Effort	% effort observed (BC)	% effort observed (FO)	Effort	% effort observed (BC)	% effort observed (FO)
Cod (nearshore)	10 264	0.9	0.9	10 233	1.2	0.6	6284[a]	1.4	0.5	907 309	0.7	0.5	1 073 606	0.8	0.4	793 147	0.9	0.5
Cod (offshore)	1394	ND	5.6	1913	ND	5.9	1780	ND	6.3	14 299	ND	5.4	22 256	ND	3.8	17 546	ND	5.5
Lumpfish (nearshore)	872	2.6	0.8	171	3.3	1.3	554	2.1	2.2	218 263	10.2	0.8	123 315	10.4	1.2	126 353	12.6	1.7
Herring (nearshore)	1430	4.2	0.1	1660	3.6	ND	1025	1.9	ND	32 073	2.0	0.1	23 052	2.8	ND	14 140	7.9	ND
Monkfish/skate (offshore)	942	6.1	30.2	3027	1.1	36.9	2659	0.1	39.6	154 467	1.7	16.3	251 575	0.5	36.2	211 549	0.1	29.7
White hake (offshore)	305	ND	6.9	345	ND	18.0	278	ND	12.8	5907	ND	7.1	12 371	ND	16.6	9989	ND	14.9
Greenland halibut (nearshore)	1687	1.1	3.3	868	0.2	0.7	1321	1.8	0.4	416 933	0.8	2.0	315 928	0.8	1.3	1 695 817	0.3	0.1
Greenland halibut (offshore)	7237	ND	3.0	5277	ND	7.1	3517	ND	3.1	2 563 700	ND	4.0	2 135 685	ND	6.8	6 674 892	ND	0.7
Redfish (nearshore/offshore)	447	2.3	0.4	337	1.9	2.8	486	ND	1.2	82 024	0.5	0.4	23 444	2.2	2.8	68 054	ND	1.2
Winter flounder (nearshore)	504	0.1	0.5	340	0.7	0.3	205	1.3	0.7	31 216	0.3	0.5	80 283	0.4	0.2	65 141	0.9	0.2

[a]Conservation concerns led to the closure of the cod fishery along the northeast and west coasts of Newfoundland in 2003, leading to lower overall catches in this year

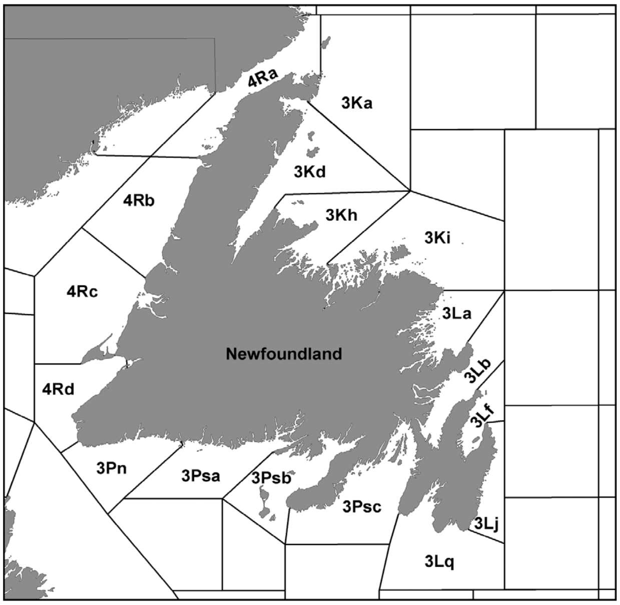

Fig. 2. Nearshore Newfoundland waters, including NAFO subareas discussed in the text. Any fishing effort recorded within these NAFO subareas was classified as 'nearshore' in subsequent analyses (see also Table 2)

servers. All analyses used individual fishing trips of fishers as sampling units. Bycatch collectors reported the total number of individual sharks in their catch, while fishery observers recorded total weight of caught sharks. In order to compare these results, the latter data set was analyzed using total weight, and subsequently converted to estimated minimum number of sharks using average body mass values from the literature. The following multipliers were used to estimate the number of sharks caught based on recorded weight:

2 kg ind.$^{-1}$ for spiny dogfish (Nammack et al. 1985, Kulka 2006);

0.4 kg ind.$^{-1}$ for juvenile black dogfish, concentrated in the Laurentian Channel (included within area 3OPs; see below; Kulka 2006);

1.2 kg ind.$^{-1}$ for adult black dogfish along the 2GHJ3K shelf edge (Kulka 2006);

1.2 kg ind.$^{-1}$ for deepsea catshark (based on length–weight relationships of black dogfish; Kulka 2006);

4 kg ind.$^{-1}$ for Portuguese shark (estimated, based on length–weight relationships of black dogfish; Kulka 2006)

750 kg ind.$^{-1}$ for Greenland shark (the maximum reported weight; Froese & Pauly 2006).

Recorded capture weights of other species were sufficiently low to assume that they involved a single animal, and this was always assumed in order to provide minimum incidental catch estimates. However, this method can provide only a general estimate of total numbers of sharks caught.

Using log records from DFO fisheries, the amount of fishing effort E was estimated for individual fisheries within predefined geographical and temporal limits. The total incidental catch estimate N was then calculated by:

$$N = E \cdot R$$

Wherever possible, 95% confidence intervals for these estimates were calculated using resampling software (Blank et al. 2001). We did not calculate confidence intervals when insufficient data were available ($n < 20$ trips).

Incidental catch estimates in nearshore fisheries were calculated on the basis of geographical area (3 coastlines of the island of Newfoundland: Northeast, South, and West; Fig. 1) and time of year (4 quarters where relevant, depending on the fishery: January to March, April to June, July to September, and October to December). Only limited fishery observer data were available for the west coast (NAFO Division 4R). Gillnet fishing is limited in nearshore waters of Labrador, and this region is underrepresented in data collection efforts. We have therefore excluded this area from further analysis.

For offshore fisheries, we stratified data geographically into the following areas, based on a combination of oceanographic and NAFO jurisdictional boundaries (Fig. 1): 2GHJ3K (subarctic waters off Labrador and northeastern Newfoundland, characterized by a relatively narrow continental shelf, influenced by the Labrador Current); 3LN (cold temperate waters of the eastern and northeastern part of the Grand Banks, characterized by a wide continental shelf, influenced by the Labrador Current); and 3OPs (temperate waters of the southern and southwestern part of the Grand Banks, characterized by a wide continental shelf, influenced by the North Atlantic Current).

RESULTS

Reported incidental catch of sharks in Newfoundland and Labrador gillnet fisheries

Bycatch collectors only rarely reported catching sharks in their gillnet fisheries (Table 2). Most cases involved small numbers of 'dogfish' (here presumed to be spiny dogfish) caught in nearshore gillnets targeting cod along the south coast. Occasional records of porbeagle, blue shark, basking shark, and 'unknown shark' were reported from the nearshore fisheries for cod, herring, and Greenland halibut.

In contrast, fishery observers reported far more incidental catch events of sharks, as well as a wider range of species (Table 3). The most commonly reported spe-

Table 2. Summary of reported incidental catch events of sharks in different fisheries, by nearshore Northwest Atlantic Fisheries Organization (NAFO) subareas, from 2001 through 2003, from bycatch collectors. Nearshore NAFO subareas where catches occurred are indicated (see Fig. 2). Values indicate number of reported catches of individual sharks. Note that data referring to 'unknown sharks' were not used for further analysis

Species	NAFO area	Target species					
		Cod			Herring	Greenland halibut	
		2001	2002	2003	2001	2001	2002
Porbeagle	3Psb			2			
Blue shark	3Lq	1					
	3Psc			1			
Basking shark	3Kh	5					
Spiny dogfish	3Kh	2					
	3Psb	9.5[a]	52.6[a]	11.3[a]			4.1[a]
	3Psc		47.4[a]				
	4Rb		20[a]				
Unknown shark	3La					1	
	3Psb			1			
	3Psc			1			
	4Ra				1		
	4Rc	1					

[a]Indicates total round weight (in kg) for spiny dogfish catches, where relevant

cies overall were spiny dogfish (primarily in nets fishing for cod and redfish along the south coast) and black dogfish (mainly in nets fishing for Greenland halibut in deep waters along the shelf edge in NAFO Divisions 2GHJ3K and 3OPs). Larger species of sharks were reported less frequently; most of these (excluding Greenland sharks) were captured in both nearshore and offshore waters off the south coast, in fisheries for cod, monkfish, skates, white hake, Greenland halibut, and redfish. Greenland sharks were reported in deep water along the shelf edge in NAFO Divisions 0A/B, 2GHJ3K, and 3OPs from fisheries targeting Greenland halibut, monkfish, skates, and white hake. Catches of sharks were only occasionally reported in the nearshore lumpfish fishery, and no sharks were reported in the herring and winter flounder fisheries.

Current gillnet fishing effort in Newfoundland and Labrador

Gillnet fisheries for Atlantic cod, lumpfish, and winter flounder were widespread in nearshore waters throughout the island of Newfoundland and southern Labrador (Table 1). Offshore fisheries for cod occurred only on the western Grand Banks (NAFO Division 3Ps). Gillnet fisheries for herring and redfish were concentrated along the northwest coast (NAFO subarea 4Ra), and the southeast and south coasts (NAFO subareas 3Pn/3Psa and adjacent offshore sections of Division 3Ps), respectively (Fig. 2). Offshore fisheries for white hake, monkfish, and skates were concentrated along the shelf edge of the southwestern Grand Banks (NAFO Divisions 3OPs), while fisheries for Greenland halibut occurred along the continental shelf edge from the southern Grand Banks to northern Labrador (Fig. 1). Nearshore fisheries for Greenland halibut took place locally wherever deep waters (>200 m) occurred close to shore, such as near Fogo Island (NAFO subarea 3Ki), in Fortune Bay (NAFO subarea 3Psb), and off the west coast (particularly NAFO subarea 4Rb; see Fig. 2).

Estimated incidental catch of sharks in Newfoundland and Labrador gillnet fisheries

Incidental catch estimates of sharks in gillnet fisheries varied considerably from species to species, but small sharks comprised the majority of catches. Black dogfish were captured in large numbers (an estimated 10 000 to >100 000 ind. yr^{-1}), mainly in the Greenland halibut fishery along the 2GHJ3K and 3OPs shelf edge (Table 4). More than 40 000 spiny dogfish were estimated to have been captured annually in 2001 and 2002, with approximately 15 000 caught in 2003. The vast majority of these were caught in the gillnet fisheries for cod and redfish, mostly in nearshore waters along the south coast (Tables 4 & 5). Other small deepwater shark species were captured in small numbers (hundreds annually) in the Greenland halibut fishery along the 2GHJ3K shelf edge (Table 4).

Large sharks were captured far less frequently, principally in offshore fisheries operating off the south coast of the island. Total annual estimates varied from species to species and were highly dependent on infrequent capture events, leading to considerable interannual variability and wide confidence intervals (Tables 4 & 5). Nevertheless, between several tens and several hundred porbeagle, blue, shortfin mako, and basking sharks were estimated to have been caught on a yearly basis in all fisheries operating in this area between 2001 and 2003. Occasional catches of thresher sharks were not used to extrapolate, owing to their rarity, but indicate that this species does infrequently occur in Newfoundland waters, presumably during temporary influxes of warm water (Scott & Scott 1988). Estimates of Greenland sharks presented in this study represent an absolute minimum of catches (50 to 100 yr^{-1}), based on the maximum reported individual

Table 3. Summary of reported incidental catch of small sharks from 2001 through 2003 used to estimate incidental catch, based on fishery observer data. Areas where catches occurred are indicated (see Figs. 1 & 2). Numbers denote total recorded weight (in kg) of caught sharks; values in brackets indicate number of sets in which the species was found. Note that instances in which shark catches were not identified to species were not used in subsequent analyses

Species	Area	Target species															
		Cod			Lumpfish	Monkfish/skate			White hake			Greenland halibut			Redfish		
		2001	2002	2003	2001	2001	2002	2003	2001	2002	2003	2001	2002	2003	2001	2002	2003
Black dogfish	0A/B											4 (1)	223 (44)				
	2GHJ3K											3086 (65)	1172 (60)	90 (19)			
	3LN												35 (7)				
	South coast nearshore	15 (5)														4 (1)	
	3OPs offshore					1 (1)	28 (7)	13 (13)			2 (1)	4831 (78)	2330 (41)	2190 (43)			
	4R											1 (1)	2 (2)				
Deepsea catshark	2GHJ3K											2 (1)					
	3OPs offshore											260 (6)					
Portuguese shark	2GHJ3K											16 (3)	30 (2)				
Spiny dogfish	2GHJ3K											2 (1)	129 (15)				
	3LN												55 (6)				
	South coast nearshore	182 (14)	438 (20)	119 (21)	7 (1)									5 (1)	318 (11)	425 (12)	5 (1)
	3OPs offshore	1 (1)	2 (1)	22 (3)		17 (8)	17 (7)	12 (2)	27 (7)	210 (40)	18 (7)						
Dogfish indet. (Squalidae)	South coast nearshore	2 (1)	5 (1)														
	3OPs offshore									63 (3)			92 (8)				
Greenland shark	0A/B												2766 (7)				
	2GHJ3K											2636 (4)	12 430 (4)				
	3LN												1816 (1)				
	3OPs offshore					2 (1)	3134 (4)		20 (1)			1050 (2)	1200 (2)				
Basking shark	2GHJ3K												2730 (6)				
	3OPs offshore		100 (1)				4173 (5)	475 (4)				5443 (1)					
Blue shark	South coast nearshore		20 (1)														
	3OPs offshore		205 (4)	122 (5)		97 (2)	361 (4)	263 (6)	70 (1)								
Porbeagle	South coast nearshore	145 (1)	68 (1)												107 (1)	424 (2)	
	3OPs offshore	457 (4)	75 (1)	30 (1)		120 (2)	1035 (9)	444 (9)						200 (1)			
Shortfin mako	South coast nearshore		150 (1)	46 (2)										120 (1)			200 (1)
	3OPs offshore		200 (1)	1285 (10)		78 (3)	304 (4)	1283 (9)									
Thresher shark	South coast nearshore			5 (1)				50 (1)		2 (1)							
Shark (unknown)	3OPs offshore			11 (1)		25 (1)											

Table 4. Incidental catch estimates (of number of individuals) of small sharks in Newfoundland gillnet fisheries, 2001 to 2003, based on fishery observer records. Where available, 95 % confidence intervals are included in brackets. 'N/A' indicates insufficient data for resampling analyses

Species	Area	Target species															
		Cod			Lumpfish	Monkfish/skate			White hake			Greenland halibut			Redfish		
		2001	2002	2003	2001	2001	2002	2003	2001	2002	2003	2001	2002	2003	2001	2002	2003
Black dogfish	0A/B											199 (N/A)	2881 (N/A)				
	2GHJ3K											136 230 (22 996–343 359)	9133 (3902–15 948)	10 026 (N/A)			
	3LN												521 (N/A)				
	South coast nearshore	1865 (168–4883)														565 (0–1695)	
	3OPs offshore					10 (0–30)	104 (23–210)	93 (0–273)			50 (0–148)	109 378 (N/A)	36 693 (N/A)	64 055 (N/A)			
	4R											450 (N/A)	290 (N/A)				
Deepsea catshark	2GHJ3K											205 (0–572)					
	3OPs offshore											570 (N/A)					
Portuguese shark	2GHJ3K											114 (0–301)	70 (0–214)				
Spiny dogfish	2GHJ3K											104 (0–301)	650 (86–1385)				
	3LN												393 (N/A)				
	South coast nearshore	3701 (978–6880)	42 752 (5442–109 606)	14 149 (2183–31 521)	115 (0–349)									952 (N/A)	39 860 (N/A)	7421 (1689–16 474)	252 (N/A)
	3OPs offshore	10 (N/A)	7 (0–22)	39 (N/A)		48 (7–117)	1639 (11–4670)	19 (0–55)	226 (N/A)	525 (274–821)	59 (9–129)						
Greenland shark	0A/B												5 (N/A)				
	2GHJ3K											50 (0–131)	59 (0–162)				
	3LN												43 (N/A)				
	3OPs offshore					1 (0–3)	8 (1–19)		1 (N/A)			5 (N/A)	4 (N/A)				
Basking shark	2GHJ3K												53 (0–136)				
	3OPs offshore		5 (0–15)				6 (0–15)	9 (0–25)				4 (N/A)					
Blue shark	South coast nearshore		177 (0–540)														
	3OPs offshore		22 (4–46)	4 (N/A)		4 (0–11)	7 (1–16)	18 (0–46)		2 (0–6)							
Porbeagle	South coast nearshore	137 (0–410)	119 (0–359)												276 (N/A)	34 (0–94)	
	3OPs offshore	68 (N/A)	6 (0–17)	11 (N/A)		14 (0–39)	22 (2–50)	20 (4–42)						20 (N/A)			
Shortfin mako	South coast nearshore		128 (0–360)	309 (0–902)										1 (N/A)			29 (N/A)
	3OPs offshore		4 (0–13)	42 (N/A)		9 (0–21)	11 (0–25)	18 (2–37)									

Table 5. Incidental catch estimates of number of sharks in Newfoundland nearshore gillnet fisheries, 2001 to 2003, based on bycatch collector records. Where available, 95% confidence intervals are included in brackets. 'N/A' indicates that insufficient data were available to perform resampling analyses

Species	Area	Target species: Cod 2001	Cod 2002	Cod 2003	Greenland halibut 2002
Porbeagle	South coast nearshore			115 (0–289)	
Blue shark	South coast nearshore	309 (0–919)		35 (0–105)	
Basking shark	Northeast coast nearshore	428 (64–941)			
Spiny dogfish	Northeast coast nearshore	511 (N/A)			
	South coast nearshore	303 (0–720)	5575 (0–16 641)	789 (158–1629)	12 (0–41)
	West coast nearshore		676 (0–1797)		

weight of 750 kg (Froese & Pauly 2006; Table 4). Actual numbers caught are likely to be higher, given levels of estimated catches (e.g. >80 t in 2002).

DISCUSSION

Impacts of fishing on sharks

The results from this study provide insight into the potential impact of incidental catches of different shark species in gillnet fisheries in Newfoundland and Labrador. The frequency of reported incidental catches of sharks varied widely and depended on both the fishery and shark species in question. Large sharks were typically reported as individuals, while black and spiny dogfish were generally recorded in schools (especially in offshore fisheries targeting Greenland halibut and cod, respectively). Most entrapments occurred during summer months, a reflection of both heightened fishing activity and increased numbers of many shark species in the area.

There were clear geographical differences in catches of different shark species. The most diverse assemblage of shark species (over the 3 yr period) was encountered in the offshore waters of the southern Grand Banks (the 3OPs offshore area), as both large pelagic species such as porbeagle, blue, and shortfin mako, as well as deepwater species such as black dogfish and Greenland shark, were found here. From 2001 to 2003, no fishery was reported to have caught all 9 species reported here, but the largest number of species (7) was reported through the fishery observer program on board vessels targeting monkfish and skates (on the southwestern shelf edge of the Grand Banks, included in area 3OPs; Fig. 1). This included all species except the Portuguese shark and deepwater catshark. No data on catch depth of individual sets were available, but it is likely that some degree of spatial segregation by depth occurs given the various species' divergent habitat preferences (e.g. Scott & Scott 1988, Campana et al. 2004, 2005a, 2008, Kulka 2006). It should be noted that when all fishery observer reports from both inshore and offshore fisheries for Greenland halibut throughout the Newfoundland and Labrador area are combined, a total of 8 species have been reported from this fishery, excluding only the blue shark. As this fishery is active in a large proportion of Newfoundland waters, it represents a potentially widespread risk for many shark species.

Black dogfish is the most commonly captured species in Newfoundland gillnet fisheries but occurs almost exclusively in nets fishing for Greenland halibut in deep waters of 2GHJ3K and 3OPs. The latter area includes the Laurentian Channel, where the species is considered to aggregate for reproduction (Kulka 2006). The species is thought to be vulnerable to overexploitation because of its expected low metabolism and reproductive rate (Kiraly et al. 2003). Although incidental catches appear substantial (an estimated average of 68 t yr^{-1} from 1998 to 2005 in numerous deepwater fisheries [including gillnet fisheries], equating to 57 000 individuals), survey indices indicate that the population has remained stable in recent years. Specifically, number of individuals tow^{-1} from demersal trawl surveys on the Grand Banks did not change appreciably (from 0.02 to 0.06) between 1995 and 2005 (Kulka 2006; note that the surveys upon which these indices are based do not cover the whole range of this species).

Spiny dogfish are caught in most fisheries along the south coast of Newfoundland but are especially common in nets targeting cod and redfish. Occasional catches have been reported further north, along the northeast coast of Newfoundland as well as offshore areas (Table 2). Catches are highly variable, likely owing to the species' habit of travelling in large, age- and sex-segregated schools, and Newfoundland's position on the northern edge of the species' range (Kulka 2006, Campana et al. 2007). Because of small sample sizes in some of the contributing data sets, no overall confidence interval for the incidental catch estimate could be calculated, but it is likely to be large.

Spiny dogfish captured in Atlantic Canadian waters have traditionally been considered part of a single greater northwest Atlantic population, but this has recently been questioned. There is now increasing evidence that dogfish in this area form a metapopulation of reasonably well defined groups that remain largely separate but can interact periodically through migration (Castro et al. 1999, NEFSC 2003, Fordham 2004, Kulka 2006, Campana et al. 2007, DFO 2007a). Directed catch levels are presently low, and the stock is not thought to be overfished. However, concerns remain regarding the effects of historic, high levels of fishing effort targeting mature females and the potential for affecting particular groups within the metapopulation (Kulka 2006, Sosebee & Rago 2006, DFO 2007a,b).

Total catch estimates of the various large, pelagic sharks during the 2001 to 2003 period are typically low, with an estimated average annual catch in the tens to low hundreds for these species. It is unknown how such catches may affect populations of these sharks. However, all species are considered vulnerable to overfishing (e.g. Campana et al. 2003, 2004, 2005a,b, 2006, COSEWIC 2004). Porbeagle, blue shark, and shortfin mako were reported only from waters south of Newfoundland, in nets fishing for cod and redfish inshore and on top of the Grand Banks, and in nets targeting monkfish, skates, white hake, and Greenland halibut on the southwestern shelf edge (within the 3OPs offshore area). This area is known to be a breeding ground for porbeagle, and consequently seasonal closures have been put in place for the directed porbeagle fishery in this area (DFO 2002a). Although the reproductive status of reported incidentally caught sharks is unknown, continued incidental catches in this area may have a negative effect on the eventual recovery of porbeagle in Atlantic Canadian waters. The northwest Atlantic stock of porbeagle, the only species for which abundance estimates are available, is thought to have declined by 90 % since exploitation began in the 1960's (COSEWIC 2004). As such, even low levels of incidental catch may negatively affect the recovery of porbeagle.

On the basis of various indices of population health, both shortfin mako and blue sharks also appear to be overexploited in Canadian waters; they are not thought to breed here (Campana et al. 2005a,b). On the basis of their life histories, these species may be somewhat more resilient to fisheries-related mortality (including incidental catch) than porbeagle. Nonetheless, shortfin makos have been classified as 'Threatened' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), while blue sharks have been classified as species of 'Special Concern' (COSEWIC 2006a,b). It should be noted that Atlantic Canadian waters form only a small part of the range of these species, and most catches occur outside Canadian waters.

Confidence intervals for incidental catch estimates are wide, indicating substantial uncertainty, but estimates are at least indicative of continuing mortality of these species and should be incorporated into future stock assessments. A Canadian Atlantic pelagic shark Integrated Fisheries Management Plan has been implemented by the Department of Fisheries and Oceans to ensure that large shark stocks recover (DFO 2002a, 2005).

The total number of basking sharks estimated to have been captured was small, and the effect of incidental catches on their population is unknown (Campana et al. 2008). Catches were reported mainly in offshore fisheries along the south coast of Newfoundland, although there were also reports from along the northeast coast and further offshore. Basking sharks in Atlantic Canadian waters are considered to be part of a single western Atlantic population; however, there is recent evidence of trans-Atlantic movement by individual sharks, which may indicate stronger links between 'populations' at opposite ends of the north Atlantic basin that were previously considered distinct (Campana et al. 2008, Gore et al. 2008).

The impact of incidental catch in gillnets on populations of Greenland shark is unknown. Catches were reported in deepwater fisheries along the entire shelf edge off Newfoundland and Labrador from area 0A/B down to the edge of the Grand Banks in area 3OPs offshore. Data on age at maturity, reproduction, and longevity are unavailable, and stock structure of the species in the northwest Atlantic is unclear. However, the species is thought to be sensitive to overfishing (Castro et al. 1999). In addition to catches reported here, high catch levels have been recorded in the offshore trawl fishery for Greenland halibut in NAFO area 0A/B (Davis Strait; DFO unpubl. data).

There is no information on stock size of deepsea catshark and Portuguese shark in Canadian waters. Catches were reported exclusively in the offshore fishery for Greenland halibut, in areas 2GHJ3K and 3OPs offshore (only deepsea catshark in the latter area). Catch levels appear relatively low (in the low hundreds annually), but concern may be warranted given their likelihood of low reproductive rates (Scott & Scott 1988).

The present results indicate the potential impact of incidental catch in a wide range of Newfoundland and Labrador gillnet fisheries on sharks in the wider northwestern Atlantic marine environment. Most of the species reported here have very wide distributions, and individuals may readily move hundreds, if not thousands of kilometers, making effective management challenging. Future management strategies will need to take into account a wide range of pressures, including incidental mortality in a diverse suite of fisheries, throughout the distribution of these species.

It is important to note that catches of large pelagic sharks have been reported from fisheries where current effort is relatively low when compared to historical levels (particularly the cod fishery). Although such catch levels might be relatively low at present, there is a concern about the potential additional risk to these species once target stocks recover and effort levels subsequently increase. Similar problems might occur in fisheries that are currently spatially limited (particularly the fishery for monkfish and skate, but also that for white hake and redfish) but which may face calls for expansion in the future. The potential impact of such changes to fisheries needs to be considered as part of a comprehensive shark management plan, where incidental mortality in as many fisheries as possible is taken into account.

Data issues

Although some data exist on relative biomass, abundance, and distribution of shark species in Newfoundland and Labrador waters, there are difficulties when attempting to relate the results of the present study to these data. Most of these data were collected through annual demersal trawl surveys for cod and other groundfish species, yielding minimum estimates of relative biomass and abundance for all species involved (described by Kulka 2006). However, such surveys are by design unlikely to properly estimate the abundance of large, pelagic sharks (e.g. blue shark, porbeagle, basking shark), as their catchability in demersal trawls is likely to be very low. These surveys could in theory provide a better measure of abundance of several demersal shark species (e.g. spiny dogfish, black dogfish, and other deepwater species). However, for these species, the surveys described by Kulka (2006) did not cover the entire range of their distribution (with a considerable proportion of their populations occurring in unsurveyed waters), did not occur at the same time as the commercial fisheries described here, and did not sample the same age classes. This complicates attempts at assessing the relative impact of incidental catch in gillnet fisheries in Newfoundland and Labrador.

Bycatch collectors received identification sheets to help facilitate their identifications, but large pelagic sharks (particularly porbeagle and shortfin mako) may have been misidentified, with some recorded as 'large sharks'. Fishery observers received detailed information on the distinguishing characteristics of different shark species during the course of their training and were considered familiar with most species in the area. The only species that observers may have had trouble differentiating were Greenland shark and basking shark (also identified as an issue by Campana et al. 2008). Interviewing observers indicated that this had been a problem in the past but was much less so in the period under study.

Traditionally, the focus of fishery observer training has been on providing data on catches of teleost species, which are typically caught in large quantities and reported by weight rather than by number, for practical reasons. As a result, information on approximate numbers of individuals of larger species (including sharks) is often not recorded as part of standard protocols. Because of the workload of individual fishery observers (including e. g. estimating catches, measuring lengths of subsamples of species, recording details of the fishing gear, performing surveillance duties), it is not realistic to expect fishery observers to record amounts of caught teleost fish in numbers. However, it is recommended that fishery observers record the approximate number of individuals involved in incidental catch events, such as those involving sharks.

Management measures

From the results described above it is clear that incidental catch of sharks occurs with some frequency in many Newfoundland and Labrador gillnet fisheries. It is clear that the estimates reported here likely represent underestimates, given the lack of accurate information on numbers of sharks involved; there is also concern that landings of sharks may be underreported in many fisheries, given the current uncertainty surrounding their conservation status in Canadian waters (COSEWIC 2004, 2006a,b). At present, it is unclear what the impact of this continued incidental mortality might be. Mortality of many shark species (whether directed or incidental) in Canadian waters is likely to be considerably lower than the estimated mortality in the open ocean outside territorial waters (e.g. Campana et al. 2003, 2005a, 2006, 2008). Nonetheless, there is concern that insufficient management action may negatively affect management actions undertaken in other parts of some species' range (e.g. Gore et al. 2008). Canada has developed a National Plan of Action for the Conservation and Management of Sharks in a move towards more holistic management of all marine resources in Canadian waters (DFO 2005, 2007b). Additional research is required in the seasonal abundance, distribution, movements, life history, and population structure of most species discussed here, particularly for deepwater species such as the Greenland shark and black dogfish. Expansion of fishery observer coverage, and continued long-term contact with inshore fishermen (in fisheries where putting observers on small boats is impractical), would improve our knowledge of incidental catches of sharks in gillnet fisheries. Mortality of incidentally caught sharks could also be reduced by ensuring that such sharks are handled in a way that minimises further injury and released as quickly as possible, similar to what is already mandated for other species (e.g. various species of wolffish; Kulka et al. 2007).

Additional management measures may be required for certain species (e.g. basking shark, porbeagle) that have shown a recent significant decline or that appear to be naturally uncommon. These could include temporary regional closures to fisheries to avoid capture of migratory species such as sharks, gear modifications, the introduction of incidental catch quotas, or possibly financial incentives. Such recommendations are compatible with the precautionary approach to marine management as promoted under Canada's Oceans Strategy, and similar to those suggested under COSEWIC's recommendation to list several species of sharks under Canada's Species at Risk Act (DFO 2002b, COSEWIC 2004, 2006a,b).

CONCLUSIONS

Incidental mortality of sharks has been quantified for the first time in various gillnet fisheries in Newfoundland and Labrador, for the years 2001, 2002, and 2003. On the basis of the data reported here, spiny dogfish were most often captured off the south coast in nearshore fisheries for cod and redfish and offshore fisheries for monkfish and skate. Catches of pelagic sharks such as porbeagle, blue shark, shortfin mako, and basking shark occurred regularly in a variety of fisheries, with estimates ranging from several tens to low hundreds yr^{-1}. Catches of Greenland shark and black dogfish were largely confined to the offshore fishery for Greenland halibut, occurring together with small numbers of several other, lesser-known deep-water species.

For almost all species, lack of adequate abundance and stock structure data mean that the impact of this incidental mortality cannot be evaluated. However, concern is warranted given the low resilience of most shark species to overfishing, and widespread lack of understanding of these species' basic biological characteristics and roles in the marine ecosystem. Incidental mortality of sharks in Canadian fisheries needs to be better monitored and, where possible, reduced or eliminated in order to facilitate recovery. For most shark species discussed here, many aspects of their biology, including life history, growth rates, age at maturation, reproductive rates, longevity, distribution, and stock structure, remain poorly known. Further efforts to collect these data are required to better inform the management of these species in Canadian waters.

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