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The biology and fishery of shortfin mako sharks (*Isurus oxyrinchus*) in Atlantic Canadian waters

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Abstract

Shortfin mako sharks are a high-value bycatch of pelagic longline fisheries off the eastern coast of Canada. Tagging studies indicate that they are highly migratory, seasonal residents of Canadian waters, representing the northern extension of a North Atlantic-wide population centred at more southerly latitudes. Annual catches in Canadian waters average 60–80 mt per year, which represents but a small part of that estimated for the population as a whole. New ageing results indicate that the species grows more slowly than was reported previously, thus making the population less productive and more susceptible to overexploitation than has been reported. Two indices of population abundance did not provide a definitive view of mako shark population status. A standardized catch rate index from the commercial large pelagic fishery suggested stable abundance since 1988. However, the analysis did not have the statistical power to detect anything less than a severe decline. In contrast, the median size of mako sharks in the commercial catch has declined since 1998, suggesting a loss of larger sharks. These results are broadly consistent with a previous report of population decline, although it appears unlikely that current exploitation rates in Canada are having an appreciable impact on the population.

Keywords: Abundance; Distribution; Growth; Shortfin mako; *Isurus oxyrinchus*; Shark

1. Introduction

The shortfin mako shark (*Isurus oxyrinchus*) is a large temperate and tropical pelagic shark species of the family Lamnidae that occurs in the Atlantic, Pacific and southern oceans (Compagno, 2001). In Canadian waters the shortfin mako shark is most closely associated with the warm waters of the Gulf Stream. It has been recorded from Georges and Browns Bank, along the continental shelf of Nova Scotia, the Grand Banks and even into the Gulf of St. Lawrence (Templeman, 1963). The species is highly migratory, with tagging results suggesting that there is a single well-mixed population in the North Atlantic (Casey and Kohler, 1992). Atlantic Canada represents the northern extension of the species range, and most of the population is believed to reside in more southerly waters. Although these sharks are not abun-

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dant in Canadian waters, neither are they uncommon.

Little is known of the biology or fishery for this shark anywhere in the world, in part reflecting the difficulty of capturing or studying a large, fast-swimming marine predator. Dietary studies confirm that this is an apex predator, feeding mainly upon large teleosts such as tunas and swordfish, as well as other sharks, marine mammals and sea turtles (Stillwell and Kohler, 1982; Compagno, 2001). Females become sexually mature at a length of 2.7–3.0 m total length (TL), while males mature at 2.0–2.2 m TL (Pratt and Casey, 1983; Mollet et al., 2000). Developing embryos feed on unfertilized eggs in the uterus during the gestation period of 15–18 months. The 4–25 surviving young are born as free-swimming sharks in the late winter and early spring at a length of about 70 cm TL, and have no placental connection during development. Females may rest for 18 months after birth before the next batch of eggs is fertilized (Mollet et al., 2000). The combination of low fecundity and late age at sexual maturation results in the shortfin mako having low productivity compared to teleosts. This low productivity is typical of elasmobranch species and has prompted many authors to question the sustainability of intensive shark fisheries (Cortés, 1998; Walker, 1998; Musick, 1999; Stevens et al., 2000).

Recent years have seen an increasing number of countries discuss legislation to protect endangered elasmobranch stocks, highlighted by the Food and Agriculture Organization (FAO) (1998) recently-released International Plan of Action for the Conservation and Management of Sharks. The latter is based on the conclusion that many of the world's shark species are severely depleted (FAO, 1998). However, the health of shortfin mako populations has never been properly assessed. Based on an analysis of U.S. pelagic longline logbook information from vessels fishing in the NW Atlantic, Baum et al. (2003) suggested that the North Atlantic population had declined since 1986. An initial attempt to prepare a North Atlantic-wide stock assessment of shortfin makos also suggested that the population may have declined, but the assessment was hampered by poor data quality, and the conclusion was considered to be very provisional (ICCAT, 2004). The status of the mako shark population and fishery in Canadian waters has never been evaluated (O'Boyle et al., 1996).

Since 1995, fisheries management plans in Atlantic Canada have maintained non-restrictive catch guidelines of 250 mt annually for mako sharks in the directed shark fishery. The non-restrictive catch guidelines were not based upon estimates of stock abundance. Fishing gears to be used in the directed fishery were limited to longline, handline or rod and reel gear for commercial licenses and to rod and reel only for recreational licenses. The recreational fishery was restricted to hook and release only. No catch restrictions were put on sharks caught as bycatch in large pelagic fisheries. A ban on "finning" sharks (the removal of the fins and at-sea disposal of the finless carcass) was implemented in June 1994. Full details of the Canadian shark management plan are presented in Campana et al. (2002a).

The objective of the current analysis was to provide a detailed view of shortfin mako distribution, biology, fisheries and size composition in Atlantic Canadian waters. Also included is an index of abundance based on a standardized catch rate model, and a perspective on the relationship of the Canadian mako fishery to that of the North Atlantic population.

2. Material and methods

2.1. Biological data

Data on mako size and sex were available from both scientific and observer sources. The Observer Program (OP) placed scientifically-trained observers on board randomly selected fishing vessels to accurately and independently record catch and fishing practices. Observers monitored the size composition of the catch on randomly selected fishing vessels prior to 1987, and on all foreign vessels from 1987 onwards, recording either total length (Scotia-Fundy OP) or fork length (Newfoundland OP). Shark tournaments recorded either the round or the dressed weight, and the fishing industry often recorded the inter-dorsal length. To convert all of these measurements into a common size measurement, a series of inter-conversion factors were developed through matched measurements made by scientific staff or trained observers on freshly-caught mako sharks on board commercial vessels or at shark fishing tournaments (Fig. 1). The standard measure reported in this paper is fork length measured over the curve of the body. Sex and reproductive condition were observed and recorded for all sharks.

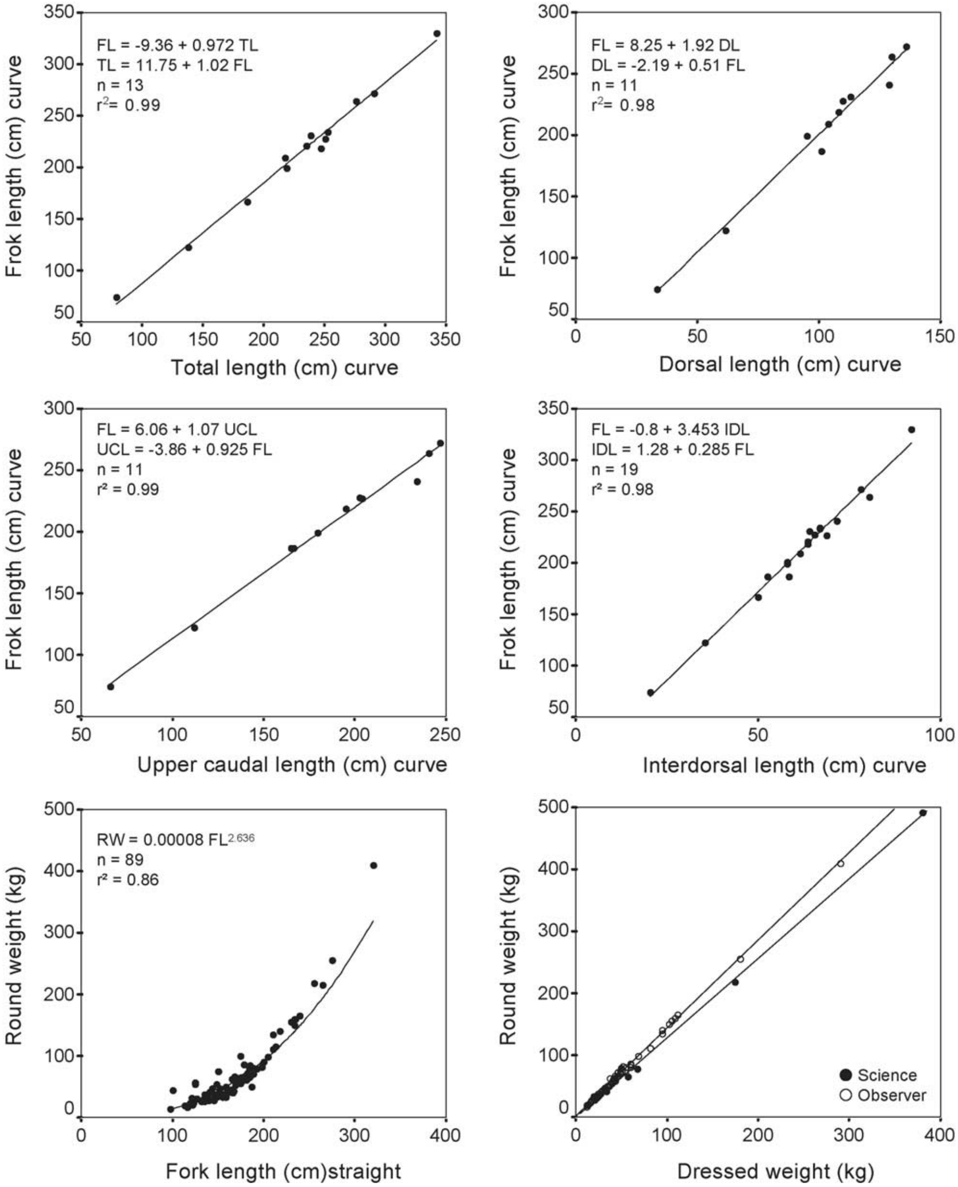

Fig. 1. Morphometric conversions between various length and weight measures, based on measurements taken by observers and scientific staff.

2.2. Commercial data

Commercial catch and effort statistics were available for the period 1979 to the present, with the landings from 1994 onwards considered to be very reliable. Canadian landings data were extracted from Department of Fisheries and Oceans (DFO) zonal statistics files (ZIF) from 1991 to 2002, and from DFO MARFIS statistics files for 2003. ZIF data alone were used for Table 2. Foreign catches (including discards) from 1979 onwards were available from the Scotia-Fundy (SFOP) and Newfoundland Observer Program (NFOP). Landings data for the northwest Atlantic (not including Japanese vessels) are from ICCAT statistics for area 92 (ICCAT, 2004), while those for Japanese vessels were derived from FAO statistics of the nominal catch of unspecified sharks and rays (and thus were not restricted to makos) (FAO, 2001). North Atlantic landings are derived from the International Commission for the Conservation of Atlantic Tunas (ICCAT) statistics for the Atlantic shark stock (ICCAT, 2004).

Calculations of mako catch rate (kg/hook) were based on directed pelagic longline catches for large pelagic species, which account for most of the mako sharks caught in Canada. All foreign data came from the Scotia-Fundy Observer Program (SFOP) and are thus considered accurate. All Canadian data came from pelagic longline logbook data cross-matched to landings; for the period examined (>1996), these data are also considered to be relatively accurate. Initial examination of the catch rate data indicated that the major data sources could be categorized by country (Japan, Canada, Faroes), vessel identity number (CFV), area fished (around Newfoundland; eastern Scotian Shelf (North Atlantic Fisheries Organization (NAFO) Division 4VW); and the southern region (NAFO Division 4X, 5Z)), season (quarter), and species sought (bigeye tuna (*Thunnus obesus*), swordfish (*Xiphias gladius*), bluefin tuna (*Thunnus thynnus*), yellowfin tuna (*Thunnus albacares*), porbeagle (*Lamna nasus*)). The distribution of the set by set data was highly skewed, with many zero sets. Since previous analyses of blue shark had demonstrated that the shark reporting rate prior to 1994 was inconsistent due to finning (Campana et al., 2002a), it was likely that some of the zero sets were actually sets where sharks were not reported. Accordingly, the data were first analyzed at a trip level; all trips which reported at least one mako shark were assumed to have been accurately reported, and thus all sets of that trip (including zero sets) were used in the analysis. Trips with no makos reported were not used. The catch rate of makos in porbeagle-directed trips was very low, so this category of data was not used.

The overall trend in catch rate was first analyzed at the set by set level using a general linear model (GLM) with a negative binomial error distribution, using year, region, season, species sought and vessel (CFV) as factors. However, the frequency of zero sets and missing cells confounded the analysis. Therefore, the data were aggregated to the trip level, and then restricted to the factor levels with the most data. This resulted in a trip-level GLM using year and CFV as factors. A gamma error distribution suited the trip-level data well. In the case of the Japanese fishery, the trips included were those targeting bigeye tuna in the fourth quarter on the Scotian Shelf between 1987 and 1999. Canadian data were restricted to trips targeting swordfish between July and September on the Scotian Shelf between 1996 and 2003. For both countries, only vessels which fished more than 1 year were included in the model.

The length composition of the commercial catch was determined from observer measurements from both the Scotia-Fundy and Newfoundland Observer Programs. The total length measurements of SFOP was first converted to fork length (as per Fig. 1) to make it comparable with the other measurements. Trends through time were analyzed through use of median lengths (rather than means), since many of the length distributions were non-normally distributed. Locally-weighted least square regressions (LOESS) were used to display trends.

2.3. Age determination

Vertebral samples were obtained, and fork length and reproductive condition were recorded, from shortfin makos obtained between 2000 and 2004 at Canadian shark fishing tournaments and on board commercial vessels. Multiple vertebrae were removed from the area just above the branchial chamber wherever possible. Vertebrae were then stored frozen until processing.

One vertebra from each sample was removed for processing. The centrum was sectioned through the middle along the sagittal plane using an Isomet saw with two diamond blades separated by a 0.6 mm spacer. The resulting “bow-tie” sections were stored individually in capsules in 70% ETOH. Each section was digitally photographed at a magnification of 4× to 12.5×. Growth increments (consisting of paired opaque and translucent bands) were counted from digitally-enhanced images using the ageing criteria of Natanson et al. (2002). These ageing criteria have been validated as providing accurate ages over a broad age range for porbeagle (Natanson et al., 2002), as well as a single shortfin mako with an age of 21 years (Campana et al., 2002c).

2.4. Depth and temperature data

Bottom depth and vertical temperature profiles were collected by many of the Japanese vessels and several of the Canadian vessels as part of routine longlining operations. For each set, bottom depth was determined from acoustic soundings, while temperature profiles were collected using XBTs. Temperature at depth was estimated based on assumed gear depth. These data were then made available to onboard observers and recorded with the associated catch.

3. Results

3.1. Age, growth and longevity

A preliminary growth model of makos in the northwest Atlantic is presented in Fig. 2. Ages were based on growth increments visible in digitally-enhanced vertebral cross-sections, using the criteria for annuli validated as being accurate in many porbeagles and one mako (Campana et al., 2002c). Although the sample size is relatively small, it appears that makos live for at least 24 years. There was no evidence of sexually dimorphic growth for the first 13 years of life. All males between the age of 8–15 years (FL > 199 cm) were mature, as was a female with a FL of 330 cm. Females between the age of 7–18 years (FL up to 272 cm) were immature.

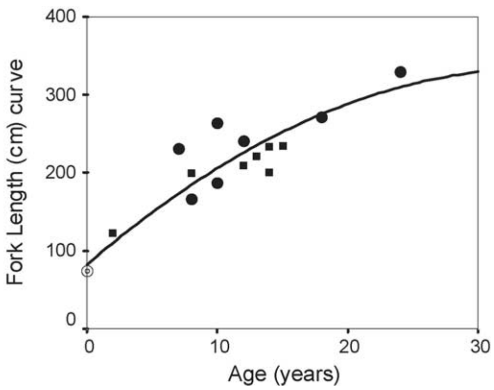

Fig. 2. Growth curve for makos caught in Canadian waters. Female: closed circle; male: closed square; birth size: open symbol.

3.2. Temperature and depth associations

Although most observed makos were caught at depths of less than 400 m, mako catch did not appear to be associated with any particular water depth (Fig. 3A). Indeed, many of the makos caught in the tuna and swordfish fisheries were caught in the open ocean, off the continental shelf.

Most observed mako catches were made at temperatures greater than 13 °C (at the depth of the gear) (Fig. 3B), with the overall mean being closer to 18 °C. These findings are consistent with the overall distribu-

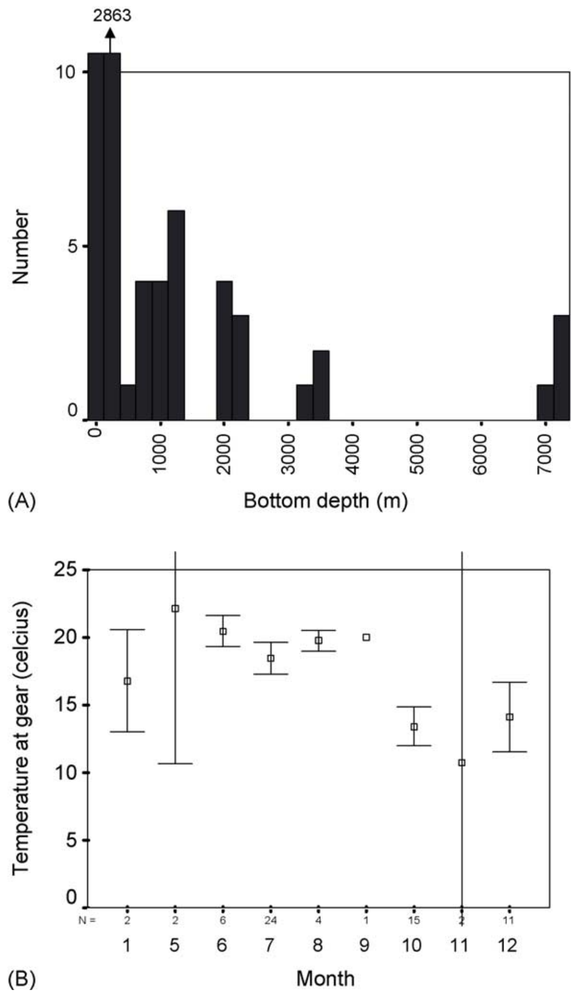

Fig. 3. Frequency histogram of bottom depths associated with mako shark catches (A) and month by month error bar plot of gear temperatures associated with catch (B).

Table 1
Reported mako shark landings (mt) by country

Year	Canadian Atlantic (NAFO areas 2–5)					Northwest Atlantic				North Atlantic
	Canada	Faroe Is	Japan	Other	Total	Japan	USA	Other	Unspecified pelagic sharks	
1979			0		0					
1980		2	0		2					
1981			1		1					
1982			0		0	226				
1983			5		5	85				
1984			1		1	213				
1985						214				
1986			2		2	231				
1987			10		10	232				
1988		0	17		18	168				
1989		1	13		14	176				
1990		5	8		13	140				193
1991		2	14		16	198				314
1992		2	29		31	345				246
1993	4	0	16		20	553	237			1094
1994	142		21		164	450	273			977
1995	111		4		115	397	253			1078
1996	67		5		72	238	181	1		1132
1997	110		2		111	99	213	1		3299
1998	71		1	0	72	107		2		2578
1999	70		2		72	123		2		2432
2000	79				79	83				1975
2001	70				70	116	160			1984
2002	79			1	79		153			2667
2003	66				66					

tion of the population in more southerly waters. Like other lamnids, makos have rete mirabile (vascular heat exchangers) with which they are able to maintain their body temperature and metabolic rate some 7–10 °C above that of the ambient water (Carey and Teal, 1969). In part, this explains their very fast swimming speed and their abilitty to leap out of the water when hooked.

3.3. Landings

Mako shark landings and/or nominal catch in the Canadian Atlantic (NAFO Areas 2–5) are recorded for Canadian vessels landing their catch, and for foreign vessels operating under 100% observer coverage within the EEZ. Reported landings peaked at around 160 mt in 1994, declining thereafter to only 60 mt in 2003 (Table 1). However, it is possible that part of the mako catch reported prior to 1996 was actually porbeagle. Only Canadian, Japanese and Faroese vessels are known to have caught significant quantities of mako shark in Canadian waters. In the northwest Atlantic as a whole (north of Florida), mean reported catches are somewhat larger, averaging 400–800 mt in the 1990s. North Atlantic nominal catches are substantially larger, averaging about 2300 mt since 1998. It is likely that a significant portion of the mako catch in international waters goes unreported (ICCAT, 2004).

There is no directed fishery for mako, with most of it being bycatch in pelagic longline fisheries (Table 2). The swordfish fishery is the main source of mako catches. Bycatch in the groundfish gillnet fishery is also significant. Recreational catches are minor, accounting for only a few sharks landed each year (Campana et al., 2004a). A breakdown of the Canadian catch by region and gear type indicates that most of the catch is taken by longline in the Scotia-Fundy region.

The Scotia-Fundy Observer Program (SFOP) has maintained 100% coverage of foreign fisheries in the Canadian zone since 1987, thus allowing accurate de-

Table 2
Canadian mako shark landings (mt) by fishery

Year	Porbeagle fishery	Swordfish fishery	Tuna fishery	Unspecified pelagic fishery	Groundfish bycatch	Fishery not recorded	Mako total
1991	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0
1993	0	0	0	0	3	0	3
1994	0	63	5	49	14	11	141
1995	0	56	9	23	20	3	112
1996	1	33	7	13	10	3	67
1997	2	53	14	21	15	4	109
1998	0	40	5	7	18	0	70
1999	1	34	7	8	21	0	71
2000	0	30	15	10	24	0	79
2001	0	33	15	7	15	0	70
2002	0	32	13	11	22	0	78
2003	0	36	6	6	12	0	60

terminations of both nominal catch and bycatch. SFOP coverage of domestic longline vessels has been considerably less, probably on the order of 5%. Nevertheless, SFOP observations confirm that most of the mako caught by both foreign and domestic vessels is retained, and not discarded (Table 3). Observed catch between 1990 and 1999 averaged about 20 mt annually, with most of that coming from Japanese vessels. Since 1999, virtually all observed catch has been by Canadian vessels. Catch locations mapped by quarter over the period 1986–2003 indicate that most of the Canadian mako catch occurred in deep waters off the continental shelves of Nova Scotia and Newfoundland in the summer and fall (Fig. 4). Significant catches have also been observed in the deep basins of the Scotian Shelf. Catch locations of Japanese longliners occurred almost exclusively off the continental shelf (due in part to regulations which restrict the area and time of the fishery), primarily in the first and last quarters of the year (Fig. 5). The location of mako shark bycatch in the Canadian and Faroese porbeagle fishery was somewhat different, being more localized on the Scotian and Newfoundland shelves.

An analysis of SFOP-observed sets between 1990 and 2003 indicates that makos typically comprise less than 2–3% of the catch (Table 3). The fisheries for swordfish and yellowfin tuna contain the highest proportions of makos, consistent with their being warm-water fisheries.

3.4. *Length composition*

A total of 2748 makos were measured, ranging in length between 50 and 330 cm (Fig. 6). The mean length for males was 148 cm FL, while that for females was 138 cm FL. Most of the makos >250 cm FL were females. Prominent modes between 70 and 80 cm FL were presumably those of young-of-the-year.

To determine if the size composition varied by region or time of year, the length measurements were disaggregated by region (4X5Z; 4VW; 3NOP) and fishing quarter. The data were further disaggregated into recent samples (2001–2002) and those collected earlier (prior to 2001). There were no consistent patterns across regions or time periods (Campana et al., 2004b), although the Japanese fishery appeared to catch larger makos than did the Canadian fishery. In addition, the size composition of the makos tended to be somewhat larger in historic samples than in recent collections. There was also some tendency for larger makos to be found off of Newfoundland, rather than further south. Modes corresponding to young-of-the-year were apparent in all regions and quarters.

The size composition of 19 makos caught at shark derbies was somewhat larger than that typically seen in the commercial fishery. This pattern is consistent with that seen in blue sharks, whereby recreational fishers appeared capable of targeting (or retaining) larger sharks (Campana et al., 2004a). The largest mako caught at a shark derby (330 cm

Table 3
Observed shark bycatch associated with directed fisheries between 1990 and 2003

Directed species	Porbeagle Shark Kept	Porbeagle Shark Disc	Swordfish Kept	Swordfish Disc	Bigeye Tuna Kept	Bigeye Tuna Disc	Bluefin Tuna Kept	Bluefin Tuna Disc	Yellowfin Tuna Kept	Yellowfin Tuna Disc	Albacore Tuna Kept	Albacore Tuna Disc	Marlins Kept	Marlins Disc	Blue Shark Kept	Blue Shark Disc	Mako Shark Kept	Mako Shark Disc	Unspecified Shark Kept	Unspecified Shark Disc	Groundfish Kept	Groundfish Disc	Observed catch (mt)
	Percentage of total catch																						
Porbeagle	92.4	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.1	4.6	0.2	0.0	0.0	0.3	0.0	0.1	3979
Swordfish	0.6	0.8	48.0	1.7	3.7	0.1	0.1	1.5	2.2	0.1	0.7	0.1	0.2	0.1	0.3	36.9	2.3	0.3	0.1	0.3	0.0	0.0	1536
Bigeye	0.4	0.1	4.2	0.6	37.7	0.2	3.9	0.2	9.8	0.1	8.4	0.2	0.1	0.0	5.1	26.7	1.8	0.2	0.0	0.3	0.0	0.0	4503
Bluefin	1.2	1.3	4.3	0.2	7.9	0.0	46.8	0.3	0.5	0.0	7.3	0.1	0.0	0.0	7.4	21.2	1.0	0.1	0.0	0.3	0.0	0.0	1947
Yellowfin	0.1	0.1	2.3	0.4	24.7	0.2	6.8	0.2	19.5	0.3	10.7	0.2	0.3	0.0	19.9	11.3	2.5	0.1	0.1	0.2	0.0	0.0	424
Albacore	0.6	0.3	1.8	0.0	70.3	0.1	17.6	0.1	0.0	0.0	2.8	0.0	0.0	0.0	2.1	4.2	0.1	0.1	0.0	0.0	0.0	0.0	273
Groundfish LL	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3	3.8	91.6	3.8	12352
Groundfish GN	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	5.0	89.0	5.8	718

LL: longline; GN: gillnet.

FL) was equivalent to the largest recorded by observers.

A biological indicator of increased exploitation rate is a long-term decline in median size in the catch. A plot of median fork length against year of collection indicated a gradual increasing trend in the Japanese fishery until 1996 (Fig. 7). However, a linear regression of the trend in the Canadian fishery between 1998 and 2003 shows a significant decline ($p < 0.05$). Since there is no overlap in the time series of the two countries, it is difficult to determine if the disparate trends reflect targeting of different groups of mako, differences in gear selectivity or a real change in trend. Although a change in hook size, gear type or fishing area could result in a change in the size of mako caught, there was no evidence of any systematic changes in fishing area or gear type by Canadian vessels since 1998. Thus the recent decline in the median size in the Canadian fishery could be indicative of a decline in abundance of larger makos.

3.5. Commercial catch rates

The most appropriate catch rate model was a trip-level GLM with a gamma error distribution using year and CFV as factors. Models with CFV tended to outperform models using country (but not CFV) as a factor. Model results indicated that both year and CFV were significant factors. Since not all vessels fished all years, an interaction term could not be tested. There was no evidence of a trend in the standardized catch rate through time (Fig. 8). However, the confidence intervals around the year estimates were large, thus limiting the statistical power of the model.

4. Discussion

Shortfin makos are primarily a high-value bycatch of pelagic longline fisheries off the eastern coast of Canada. Unlike the situation with blue sharks, which are discarded in large numbers (Campana et al., 2004a), most of the mako catch is retained. Annual catches in Canadian waters average 60–80 t. These catches represent about 4% of that reported for the North Atlantic population (ICCAT, 2004), and probably represent an even smaller fraction of the actual North Atlantic catch.

All available evidence suggests that there is a single population of shortfin makos in the North Atlantic. A

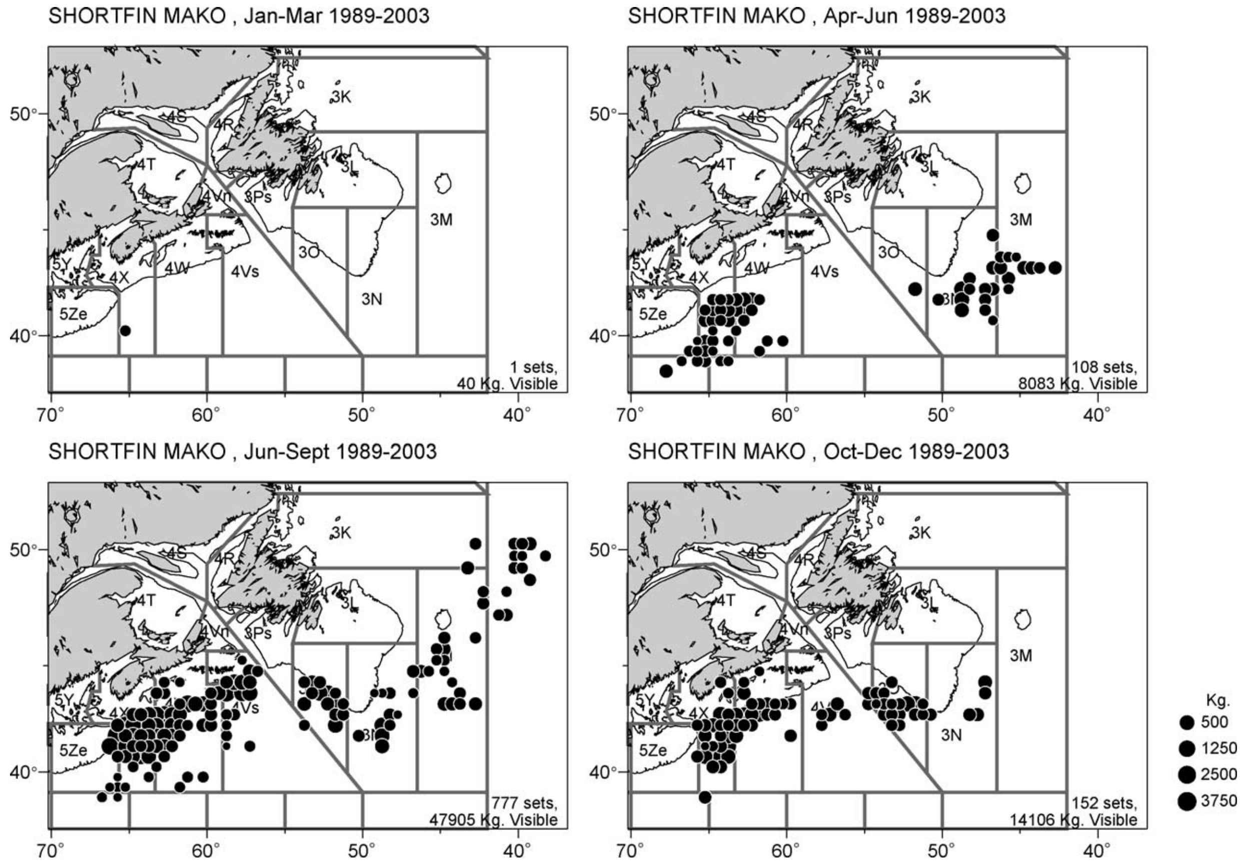

Fig. 4. Mako shark catch location by season observed by SFOP on Canadian vessels fishing swordfish or tuna betweeen 1989 and 2003. Data have been aggregated by 30 min squares. The 200 m contour is shown.

total of 110 tags were applied to makos in a Canadian tagging program carried out between 1961 and 1980 (Burnett et al., 1987). With only five recaptures from this study, it was difficult to draw many conclusions. However, it was clear that at least some of the sharks migrated freely between inshore and offshore waters, and between Canadian and U.S. waters (Campana et al., 2004b). A far more extensive shark tagging program was put in place by the U.S. National Marine Fisheries Service between 1962 and 1993 (Kohler et al., 1998). This study applied 3457 tags to mako sharks in U.S. and international waters, of which 320 tags were subsequently recovered. Although most of the recaptures were made in U.S. waters, where fishing effort on makos was highest, it was clear that many of the makos migrated over long distances, including across the Atlantic. Long-distance mixing was also consistent with a recent genetics analysis of microsatellite DNA, which found no differentiation within the Atlantic Ocean (Schrey and Heist, 2003). As fast and active swimmers with a preference for temperatures of at least 18 °C, it seems likely that makos are primarily seasonal residents of Canadian waters, and represent the northern extension of a population centred at more southerly latitudes.

Our results indicate that makos grow considerably more slowly than was previously reported. Although growth models exist for makos in the Pacific Ocean (Cailliet et al., 1983), the only previously existing growth model for Atlantic makos (Pratt and Casey, 1983) has recently been demonstrated to be incorrect. An age validation study using bomb radiocarbon demonstrated that Pratt and Casey (1983) mistakenly interpreted pairs of growth increments as one

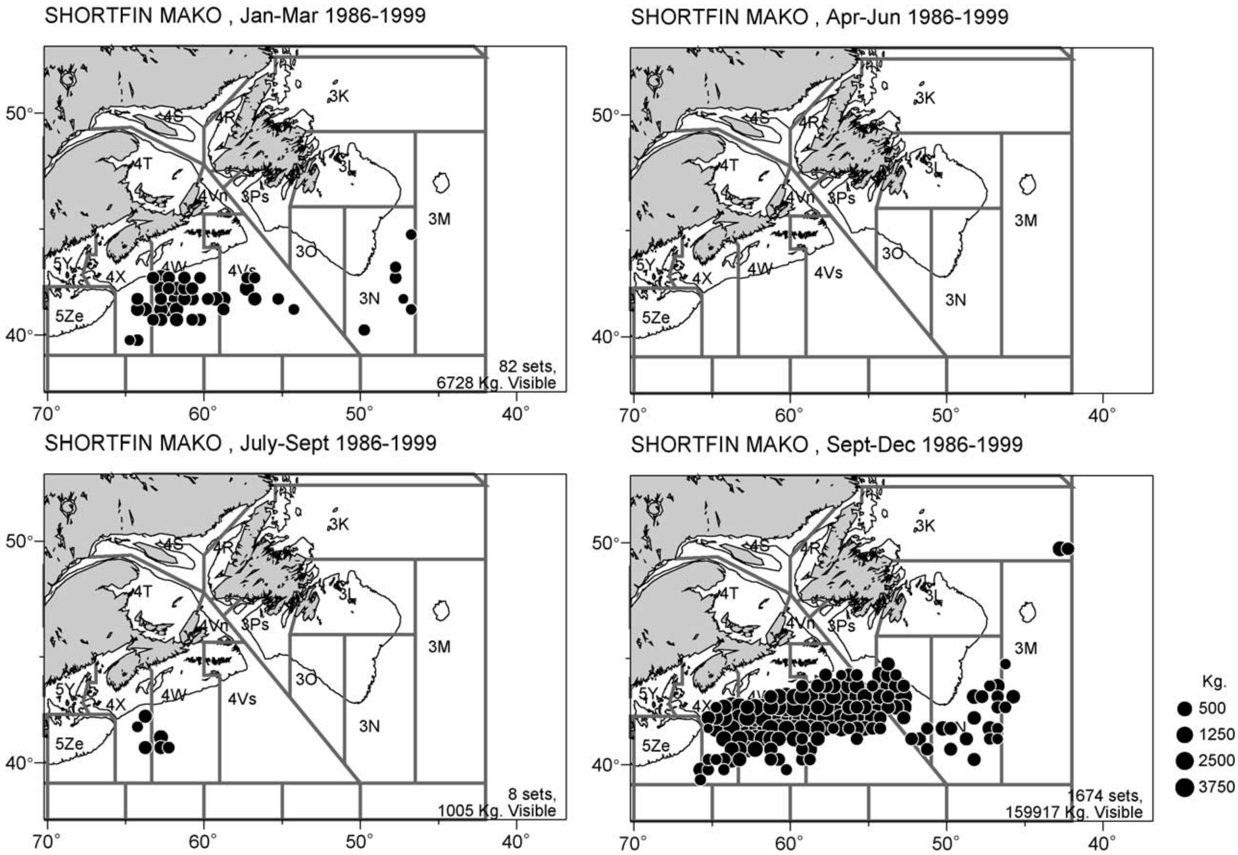

Fig. 5. Mako shark catch location by season observed by SFOP on Japanese vessels fishing swordfish or tuna between 1986 and 1999. Data have been aggregated by 30 min squares. The 200 m contour is shown.

(Campana et al., 2002c). As a result, the growth rates reported by Pratt and Casey (1983) are probably about twice as high as they should be. In contrast, the growth model for Pacific shortfin makos (Cailliet et al., 1983) produces length at age estimates that are very similar to those presented here.

The two indices of population abundance examined in this analysis did not provide a definitive view of mako shark population status. A standardized catch rate index from the commercial large pelagic fishery suggested stable abundance since 1988. Admittedly however, the analysis did not have the statistical power to detect anything less than a severe decline. In contrast, the median size of mako sharks in the commercial catch has declined since 1998, suggesting a loss of larger sharks due to growth overfishing. In light of the low catches and limited representation of the mako population in Canadian waters, there are no obvious alternative analyses which would provide superior results to those presented here.

In the only published overview of the status of North Atlantic mako sharks, Baum et al. (2003) used a model of CPUE from the logbooks of U.S. fishers to conclude that the population had declined by about 40% over the period 1986–2000. However, the confidence intervals around the mako trend line were broad, making precise estimation difficult. In addition, their analysis was restricted to pelagic longline logbooks which included shark-directed trips before 1994, but did not include shark-directed trips afterwards. Nevertheless, their analysis included a greater proportion of the mako fishery than was represented in the Canadian data presented here. An initial attempt to prepare a North Atlantic-wide stock assessment of shortfin makos also

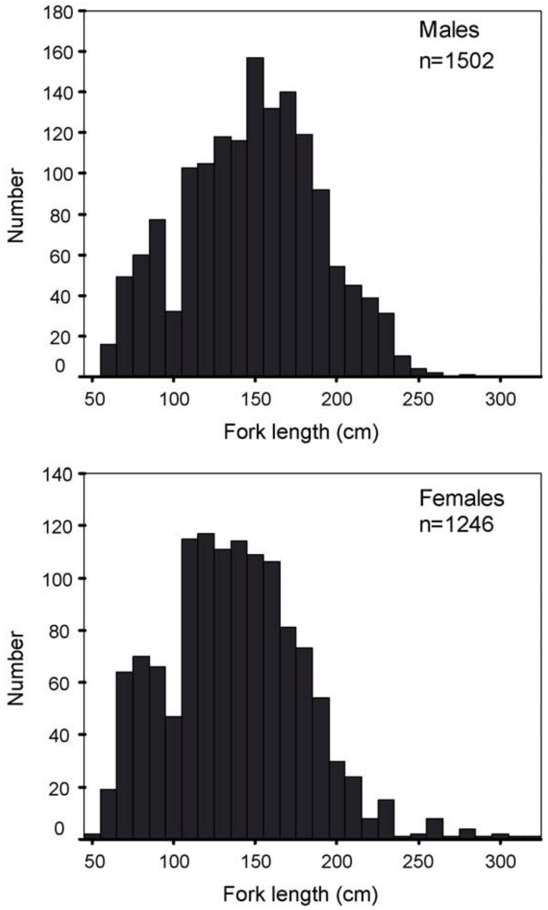

Fig. 6. Length frequency histograms of male and female mako sharks (year, area and season combined) from observer data.

suggested that the population may have declined, but the assessment was hampered by poor data quality, and the conclusion was considered to be very provisional (ICCAT, 2004).

It is widely recognized that elasmobranchs are unproductive compared with teleosts, largely as a result of their low fecundity and late age at sexual maturation (Cortés, 1998; Walker, 1998; Musick, 1999; Stevens et al., 2000). As a result, many of the world's shark species are now considered to be severely depleted (FAO, 1998). Published results suggest that makos are somewhat more productive than many other sharks (Smith et al., 1998). However, this conclusion was based in part on growth studies which are no longer accepted; the results presented here and elsewhere (Campana et al., 2002c) indicate that makos grow more slowly than

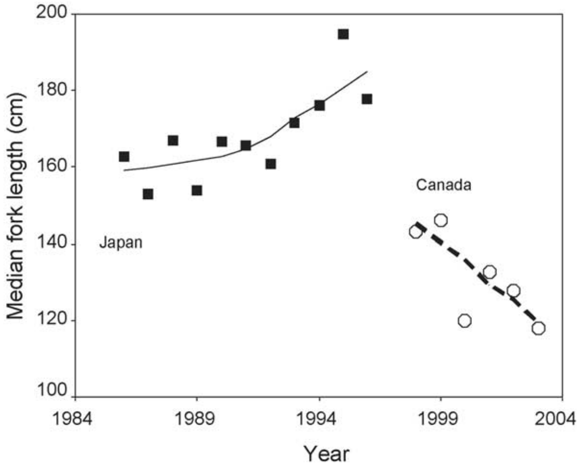

Fig. 7. Long-term changes in the median fork length of makos caught by Japanese (solid squares) and Canadian (open circles) pelagic longliners. LOESS curves have been fit to the trends.

was previously reported (Pratt and Casey, 1983). Nevertheless, the more rapid growth and greater fecundity of makos compared to porbeagles implies that makos should be somewhat more resilient to exploitation than are porbeagles. This fact is important, since porbeagles have been severely overexploited in Canadian waters (Campana et al., 2002b).

In summary, shortfin makos in Atlantic Canadian waters represent the margins of the distribution of

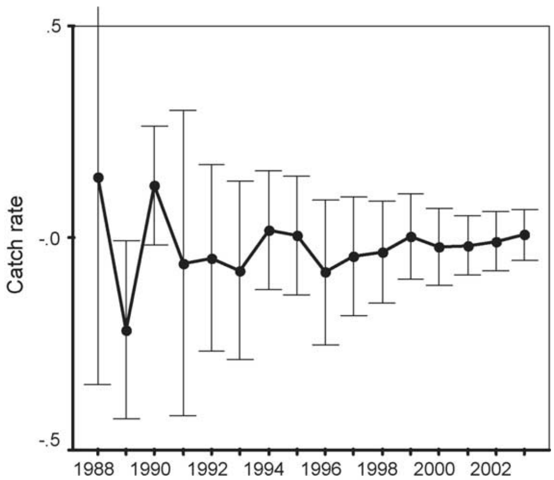

Fig. 8. Standardized trip-level catch rate of the weight of mako sharks caught by pelagic longliners on the Scotian Shelf between 1988 and 2003. Error bars represent 1 S.E. around the mean. The trend in catch rate is not significantly different than zero.

the population, and are fished most heavily outside of the Canadian EEZ. Given the low numbers of makos caught in Canadian waters, it appears unlikely that current exploitation rates in Canada are having an appreciable impact on the population. Nevertheless, if the population is declining in abundance (as suggested by outside reports), continued monitoring in Canadian waters would appear to be warranted.

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