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Biology, Fishery and Stock Status of Shortfin Mako Sharks (*Isurus oxyrinchus*) in Atlantic Canadian Waters

Biologie, pêche et état des stocks du requin-taupe bleu (*Isurus oxyrinchus*) dans les eaux du Canada atlantique

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Abstract

Shortfin makos are a high-value bycatch of pelagic longline fisheries off the eastern coast of Canada. Annual catches in Canadian waters average 60-80t per year. Both Canadian and U.S. tagging studies indicate that makos are highly migratory, seasonal residents of Canadian waters, representing the northern extension of a North Atlantic-wide population centred at more southerly latitudes. Therefore, Canadian catches represent but a small part of that estimated for the population as a whole.

The two indices of population abundance examined in this analysis did not provide a consistent 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.

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. Published results suggest that makos are somewhat more productive than many other sharks. However, this conclusion was based in part on growth studies which have recently been discredited; the results presented here and elsewhere indicate that makos grow more slowly than was previously reported. 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 (which are severely overexploited in Canadian waters).

In summary, shortfin makos in Atlantic Canadian waters represent the margins of the distribution of the population, and are fished most heavily outside of the Canadian EEZ. Given the bycatch nature of the fishery in Canada, it appears unlikely that current exploitation rates in Canada are having an appreciable impact on the population. Nevertheless, there are some signs that the population is declining in abundance, implying that continued monitoring is warranted.

Résumé

Le requin taupe bleu constitue une prise accessoire de grande valeur dans le cadre des pêches pélagiques à la palangre au large de la côte est du Canada. En moyenne, entre 60 et 80 tonnes de requins taupes bleus sont pêchées chaque année dans les eaux canadiennes. Des études de marquage effectuées au Canada et aux États-Unis indiquent que le requin taupe bleu migre beaucoup et que les eaux canadiennes ne constituent qu'un prolongement saisonnier vers le nord de l'aire de répartition de la population de l'Atlantique Nord. Ainsi, les prises canadiennes ne représentent qu'une petite partie des requins taupes bleus capturés dans l'Atlantique Nord.

Les deux indices d'abondance de la population examinés dans cette analyse n'ont pas permis d'avoir une idée précise de l'état de la population de requins taupes bleus. Un indice normalisé du taux de capture lors de l'importante pêche pélagique commerciale suggère une abondance stable depuis 1988. L'analyse n'était cependant pas d'une efficacité statistique suffisante pour détecter autre chose qu'une chute marquée de l'abondance. En comparaison, la taille médiane des requins taupes bleus capturés dans le cadre de la pêche commerciale a diminué depuis 1998, ce qui suggère une réduction du nombre de grands requins de cette espèce.

Il est bien connu que les élasmobranches sont peu productifs par rapport aux téléostéens, principalement en raison de leur faible fécondité et du fait qu'ils atteignent la maturité sexuelle à un âge avancé. Des résultats d'autres études suggèrent que le requin taupe bleu est un peu plus productif que de nombreuses autres espèces de requins. Cette conclusion est cependant fondée en partie sur des études de croissance qui ont récemment été discréditées. Les résultats présentés dans ce rapport et ailleurs indiquent que le requin taupe bleu croît plus lentement que ne le suggèrent les études antérieures. Néanmoins, le requin taupe bleu devrait être plus résistant à l'exploitation que le requin taupe commun (qui fait l'objet d'une surexploitation marquée dans les eaux canadiennes) compte tenu de sa croissance plus rapide et de sa plus grande fécondité.

En résumé, les eaux du Canada atlantique sont situées en périphérie de l'aire de répartition du requin taupe bleu dans l'Atlantique Nord. Cette espèce est davantage pêchée à l'extérieur de la zone économiquement exclusive du Canada. Compte tenu du fait que le requin taupe bleu fait l'objet d'une pêche accessoire au Canada, il est peu probable que les taux de capture actuels au pays aient une incidence notable sur la population. Certains indices laissent néanmoins croire que l'effectif de la population est en baisse, ce qui signifie qu'une surveillance continue est nécessaire.

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 Indian oceans. In Canadian waters the shortfin mako shark is most closely associated with warm waters such as in and around 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). In Canadian waters these sharks are not abundant, due to their preference for warm waters, but neither are they uncommon. 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 their range, and most of their population is believed to reside in more temperate waters.

The status of the mako shark population has never been assessed in Canadian waters. Non-restrictive catch guidelines of 250t have been in place since 1995, but these guidelines were not based on any scientific advice. O'Boyle et al. (1996) provided a brief summary of catches. Based on an analysis of U.S. pelagic longline logbooks fishing outside of Canadian waters, 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 objective of the current analysis was to provide a detailed view of shortfin mako distribution, migration patterns, biology, fisheries and size composition in Atlantic Canadian waters. Also included is an index of abundance based on a standardized catch rate model.

Biology

Morphometry

Various measures of mako shark size have been used in the past: fork length (FL) and total length (TL) have been reported both as straight line lengths and measured over the curve of the body, shark tournaments record either the round or dressed weight, and the fishing industry sometimes records inter-dorsal length. To convert all of these measurements into a common currency, a series of inter-conversion factors were developed through matched measurements made by scientific staff on freshly-caught mako sharks on board commercial vessels or at shark fishing tournaments. The resulting length-length and length-weight relationships are shown in Fig. 1. The standard measure reported in this paper is that of fork length measured over the curve of the body.

Stock Structure

All available evidence suggests that there is a single population of shortfin makos in the North Atlantic. A total of 110 tags were applied to makos in a Canadian tagging program carried out between 1961-1982 (Burnett et al. 1987). With only 5 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 (Fig. 2). A far more extensive shark tagging program was put in place by the U.S. National Marine Fisheries Service between 1962-1993 (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 (Fig. 3). Although most of the recaptures were made in U.S. waters, where fishing effort on makos is highest, it was clear that many of the makos migrated over long distances. 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).

Both the tagging and the genetic studies were consistent with the view that mako sharks are highly migratory, with no evidence of extended residency in Canadian waters.

Reproduction and Diet

Female shortfin makos usually become sexually mature at a length of 2.7-3.0 m TL, while males mature at 2.0-2.2 m TL (Pratt and Casey 1983; Mollet et al. 2000). Developing embryos have no placental connection during development (ovoviviparous) and 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. It has been suggested that females may rest for 18 months after birth before the next batch of eggs are fertilized (Mollet et al. 2000).

The shortfin mako feeds mainly upon squid and bony fishes including mackerels, tunas, bonitos and swordfish. Larger sharks may also eat sharks, porpoises, other marine mammals and sea turtles.

Age, Growth and Longevity

Although growth models exist for makos in the Pacific Ocean, the only 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 (Campana et al. 2002c). As a result, the growth rates of Pratt and Casey (1983) are probably about twice as high as they should be.

A preliminary growth model of makos in the NW Atlantic is presented in Fig. 4. Ages were based on growth bands 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 yr. There was no evidence of sexually dimorphic growth for the first 13 yr of life. All males between the age of 8-15 yr (FL > 199 cm) were mature, as was a female with a FL of 330 cm. Females between the age of 7-18 yr (FL up to 272 cm) were immature.

Temperature and Depth Associations

Although most observed makos were caught at depths of less than 400 m, water depth was not well correlated with mako catch (Fig. 5A). 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 13^0 C (at the depth of the gear) (Fig. 5B), with the overall mean being closer to 18^0 C. These findings are consistent with the overall distribution 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 $7\text{-}10^0$ 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.

Fisheries Management

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 shark 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).

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.

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. 2004). 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 (Table 4).

The Scotia-Fundy Observer Program (SFOP) has maintained 100% coverage of foreign fisheries in the Canadian zone since 1987, thus allowing accurate determinations 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 1990-1999 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. 6). 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. 7). 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 (Fig. 8).

An analysis of SFOP-observed sets between 1990-2003 indicates that makos typically comprise less than 2-3% of the catch (Table 5). The fisheries for swordfish and yellowfin tuna contain the highest proportions of makos, consistent with their being warm-water fisheries.

Length Composition

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.

A total of 2748 makos were measured, ranging in length between 50-330 cm (Fig. 9). 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 70-80 cm FL were presumably that 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 (NAFO Divisions 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 (Figs. 10-12). However, 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 (Fig. 13). This pattern is consistent with that seen in blue sharks, whereby recreational fishers appeared capable of targeting (or retaining) larger sharks (Campana et al. 2004). The largest mako caught at a shark derby (330 cm) 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. 14). However, the trend in the Canadian fishery between 1998 and 2003 has been declining. 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 or a real change in trend. However, the recent decline in the median size in the Canadian fishery is a negative sign, suggesting a decline in abundance of larger makos.

Commercial Catch Rates

Calculations of mako catch rate (kg/hook) were based on directed 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 CFV, area fished (around Newfoundland; eastern Scotian Shelf (NAFO Division 4VW); and the southern region (NAFO Division 4X, 5Z)), season (quarter), and species sought (bigeye tuna, swordfish, bluefin tuna, yellowfin tuna, porbeagle). 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 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 unreported sets. 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. In the case of the Japanese fishery, the trips included were those targeting bigeye tuna in the 4^{th} quarter on the Scotian Shelf between 1987-1999. Canadian data were restricted to trips targeting swordfish between July and September on the Scotian Shelf between 1996-2003. For both countries, only vessels which fished more than one year were included in the model.

The final (and accepted) 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. 15). However, the confidence intervals around the year estimates were large, thus limiting the statistical power of the model.

COSEWIC Criteria

Population Structure

The ESU for shortfin mako is represented by a single highly-migratory population inhabiting the North Atlantic Ocean.

Declining Total Population

There are no definitive indicators of mako population size in Canadian waters. The standardized commercial catch rate index suggested no net change in abundance between 1988-2003. However, the analysis was of low statistical power, and would have been unable to detect anything other 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.

If there has been a decline in mako abundance, it is highly likely that fishing mortality is the only appreciable cause of the decline.

Small Distribution and Decline or Fluctuation

The current extent of occurrence in Canadian waters varies seasonally due to seasonal migrations. Summing across the annual distributional range (Gulf of Maine, Scotian Shelf, southern Newfoundland, Gulf of St. Lawrence) gives a total area of about 1,200,000 km^2. The current area of occupancy, represented by frequent sightings or captures, is probably less than 800,000 km^2.

There is no suggestion of a change in extent of occupancy or occurrence since 1989. There is no evidence suggesting a fragmentation of the population, nor would one be expected given the scale of the population.

The proportion of the population that resides in Canadian waters is unknown, but based on the fact that this is a North Atlantic-wide population, is probably < 5%. There are no known breeding areas in Canadian waters.

Small Total Population Size

There are no reliable estimates of the number of mature makos in Canadian waters. Our analysis did not have the statistical power necessary to identify any decline in mature numbers, if it existed.

There are no reliable population-level stock assessments available for shortfin makos anywhere in the North Atlantic. However, the catch rate analysis by Baum et al. (2003) for NW Atlantic makos suggested a 40% decline in the population since 1986. The tentative conclusion of ICCAT (2004) was that there may have been a population decline of uncertain magnitude.

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. 2004), most of the mako catch is retained. Annual catches in Canadian waters average 60-80t per year. These catches represent but a small part of that estimated for the population as a whole (ICCAT 2004).

Both Canadian and U.S. tagging studies indicate that makos are highly migratory, moving freely between Canadian and U.S. waters, and between coastal waters and the central Atlantic. There appears to be only a single population in the North Atlantic. As fast and active swimmers with a preference for temperatures of at least 18^0 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.

The two indices of population abundance examined in this analysis did not provide a consistent 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. In light of the bycatch nature of the mako fishery 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 20% 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 and did not include them afterwards. However, 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 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 have now been discredited; the results presented here and elsewhere (Campana et al. 2002c) indicate that makos grow more slowly than 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 the population, and are fished most heavily outside of the Canadian EEZ. Given the bycatch nature of the fishery in Canada, it appears unlikely that current exploitation rates in Canada are having an appreciable impact on the population. Nevertheless, there are some signs that the population is declining in abundance, implying that continued monitoring is warranted.

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Table 1. Reported mako shark landings (mt) by country.

	Canadian Atlantic (NAFO Areas 2 - 5)					Northwest Atlantic				North Atlantic
Year	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					

Notes: Canada is from DFO Zonal Statistics File, except for 2003 which is from MARFIS
Japan, Faroes, other countries in Canadian Atlantic are from Scotia-Fundy & NF IOP (excludes discards)
NW Atlantic landings from countries other than Japan are from ICCAT statistics for area 92
Japan in NW Atlantic represents nominal catch of unspecified sharks and rays from FAO Statistics (2001)
North Atlantic landings from ICCAT statistics for Atlantic Shark Stock (1978-2002)

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

* from ZIF, not MARFIS as in Table 1

Table 3. Mako shark catches (mt) by country in Canadian waters as observed by the Observer Program. Catches include both landings and discards. The percentage of the catch that was discarded is also shown.

CATCH

Year	Canada	Faroe Is	Japan	Foreign Total
1979			0	
1980		2	0	2
1981			1	1
1982			0	0
1983			6	6
1984			2	2
1985				0
1986			2	2
1987			14	14
1988		0	21	21
1989	0	1	17	18
1990	2	5	10	15
1991	1	2	14	16
1992	7	2	30	32
1993	12	0	17	17
1994	10		23	23
1995	5		4	4
1996	3		5	5
1997	7		2	2
1998	6		1	1
1999	4		6	6
2000	4			0
2001	14			0
2002	14			0
2003	4			0

DISCARD PERCENTAGE

Year	Canada	Faroes	Japan
1979			
1980			
1981			
1982			33
1983			18
1984			40
1985			
1986			30
1987			28
1988			17
1989	54		26
1990			19
1991			4
1992		11	4
1993	38		5
1994	4		8
1995	5		2
1996	7		3
1997	2		1
1998	26		11
1999	11		68
2000	23		
2001	15		
2002	11		
2003	19		

Notes: Based on data from Maritimes IOP (1978-2003) and Newfoundland IOP (1980-1998)

Table 4. Canadian landings (mt) of mako shark by fishing gear, area and year.

Year	Region	Longline	Handline	Gillnet	Otter trawl	Other	Derby	Subarea total	Annual total
1993	Scotia-Fundy			0.3				0	4
	NF	1.1		2.3		0.1		4	
	Quebec							0	
	Gulf							0	
1994	Scotia-Fundy	117.6	2.3	9.5	1.7	0.1		131	142
	NF	6.5		4.5				11	
	Quebec		0.2					0	
	Gulf							0	
1995	Scotia-Fundy	88.0	0.2	13.4	0.7	0.5		103	111
	NF	5.9		2.4				8	
	Quebec							0	
	Gulf	0.1						0	
1996	Scotia-Fundy	50.5	0.3	7.8	1.0			60	68
	NF	5.6		2.3				8	
	Quebec						0.0	0	
	Gulf							0	
1997	Scotia-Fundy	90.2	0.2	9.3	1.5			101	110
	NF	4.0		4.0	0.1			8	
	Quebec							0	
	Gulf	0.2						0	
1998	Scotia-Fundy	46.2	0.2	8.0	2.2	0.6		57	71
	NF	9.5		4.0				14	
	Quebec							0	
	Gulf	0.2						0	
1999	Scotia-Fundy	45.8		4.8	1.8	0.7		53	70
	NF	7.8	0.1	9.2	0.1			17	
	Quebec	0.0						0	
	Gulf	0.1						0	
2000	Scotia-Fundy	48.2	0.1	5.3	0.4	0.8		55	80
	NF	10.7		12.9	0.1	0.5		24	
	Quebec	0.0					0.3	0	
	Gulf	0.1					0.2	0	
2001	Scotia-Fundy	51.2	0.2	5.2	0.2	0.4		57	70
	NF	8.6		3.6	0.1			12	
	Quebec	0.0	0.1	0.2		0.0		0	
	Gulf	0.0				0.1		0	
2002	Scotia-Fundy	54.3	0.3	9.8	0.8	1.3		67	79
	NF	6.4	0.1	4.5				11	
	Quebec			0.1				0	
	Gulf	0.8		0.2		0.1	0.7	2	
2003*	Scotia-Fundy	44.9	0.2	6.1	0.5	1.4		53	60
	NF	5.8		0.9		0.1		7	
	Quebec	0.0						0	
	Gulf							0	

* from ZIF, not MARFIS as in Table 1

Table 5. Observed shark bycatch associated with directed fisheries between 1990-2003.

DIRECTED SPECIES	PERCENTAGE OF TOTAL CATCH																						
	Porbeagle Shark		Sword fish		Bigeye Tuna		Bluefin Tuna		Yellowfin Tuna		Albacore Tuna		Marlins		Blue Shark		Mako Shark		Unspecified Shark		Ground fish		OBSERVED CATCH (mt)
	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	
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

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

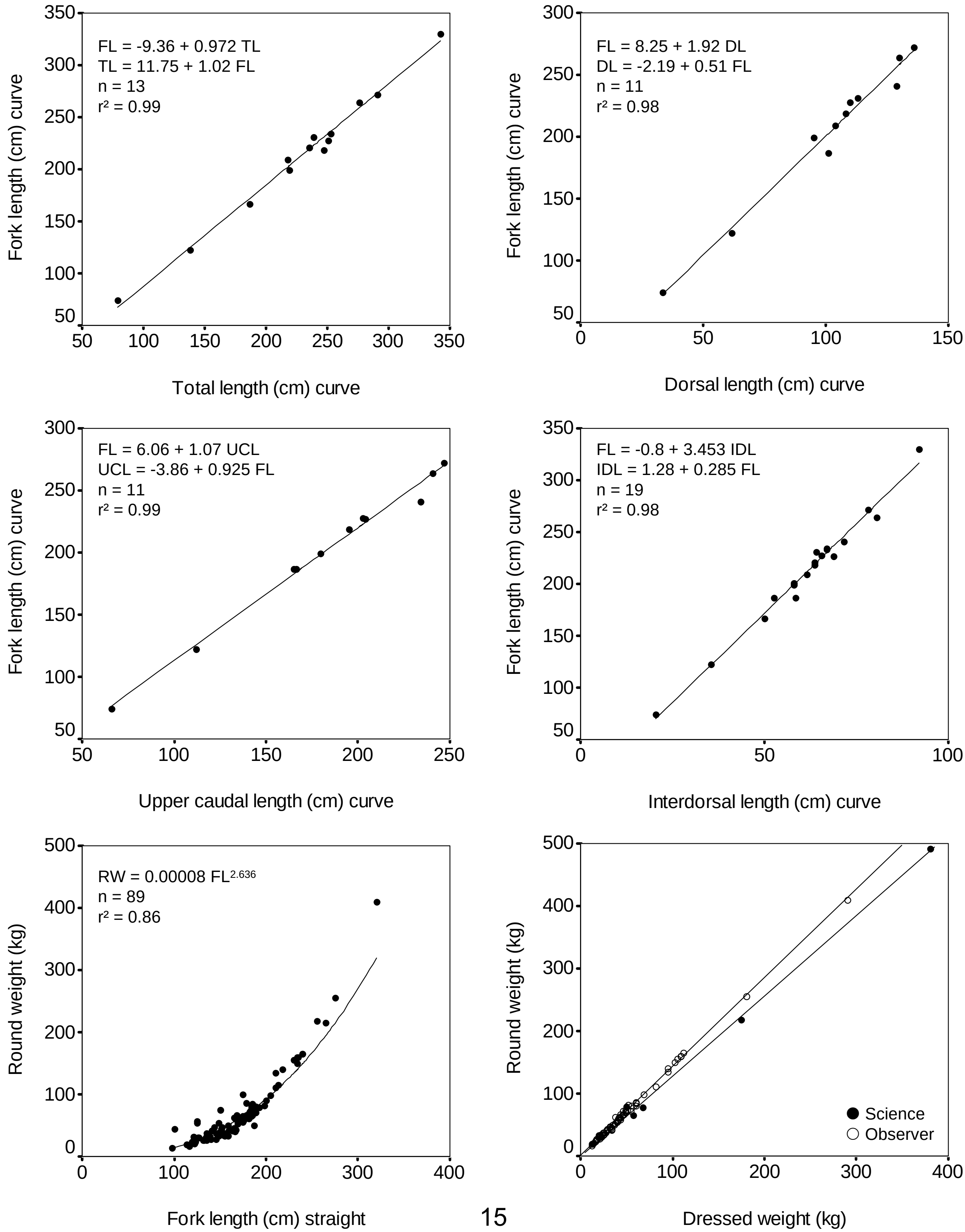


Fig. 2. Mako sharks tagged between 1961-1982 in the Canadian tagging program.

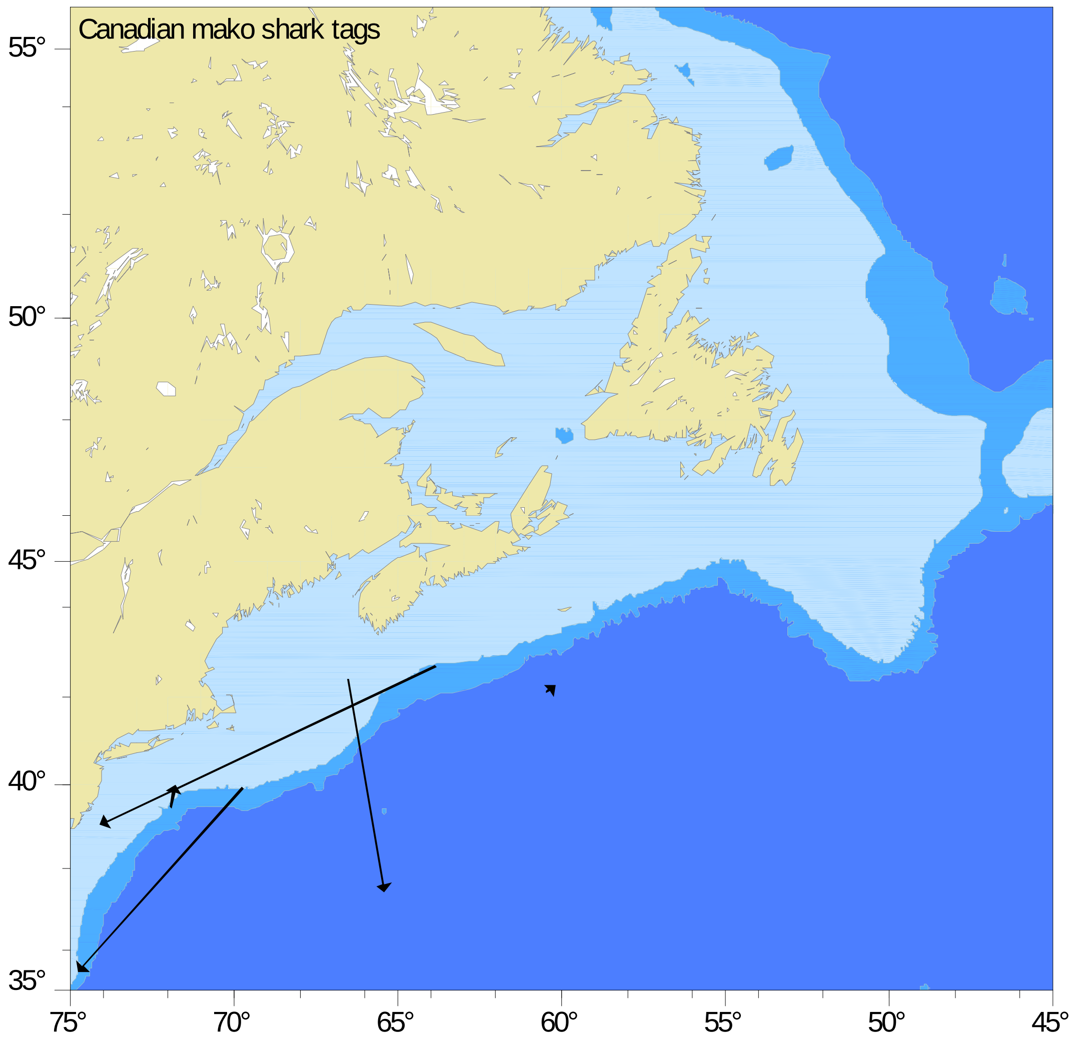


Fig. 3. Recaptures of shortfin makos tagged by the NMFS Shark Tagging Program. Figure adapted from Fig. 38 of Kohler et al. (Mar. Fish. Rev. 60:1-87 (1998)).

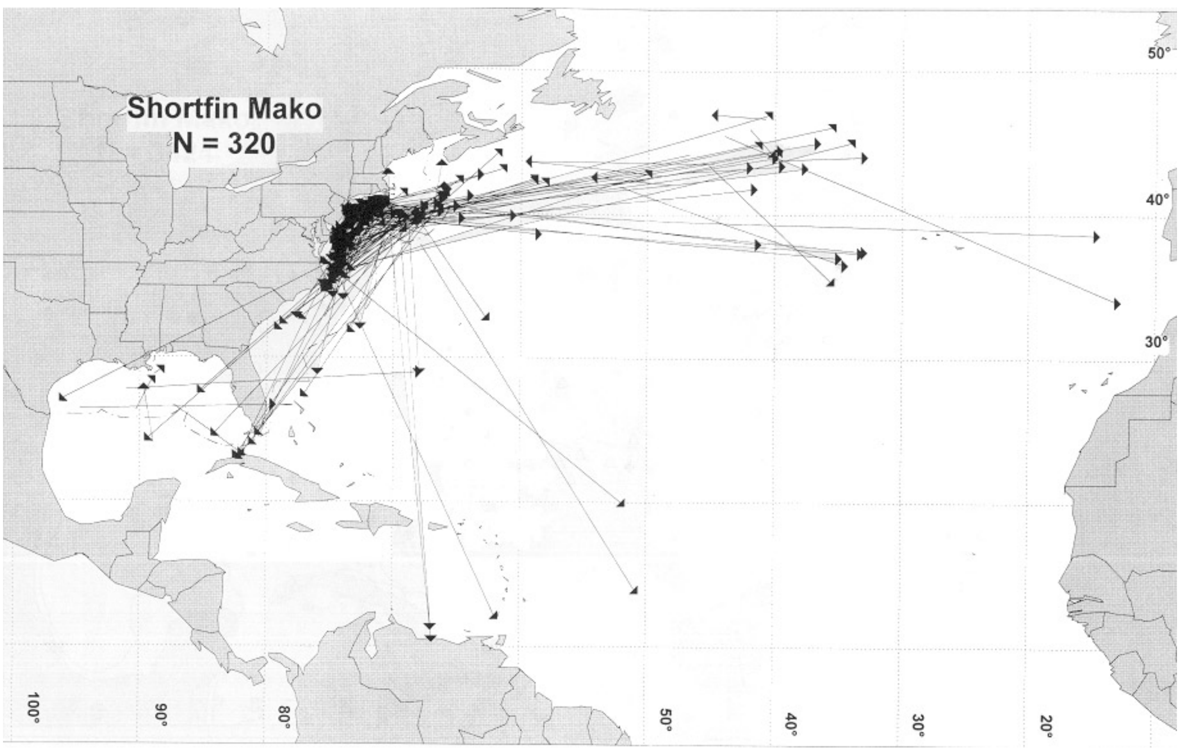


Fig. 4. Growth curve for makos caught in Canadian waters.
Female=closed circle; male=closed square; Birth size=open symbol.

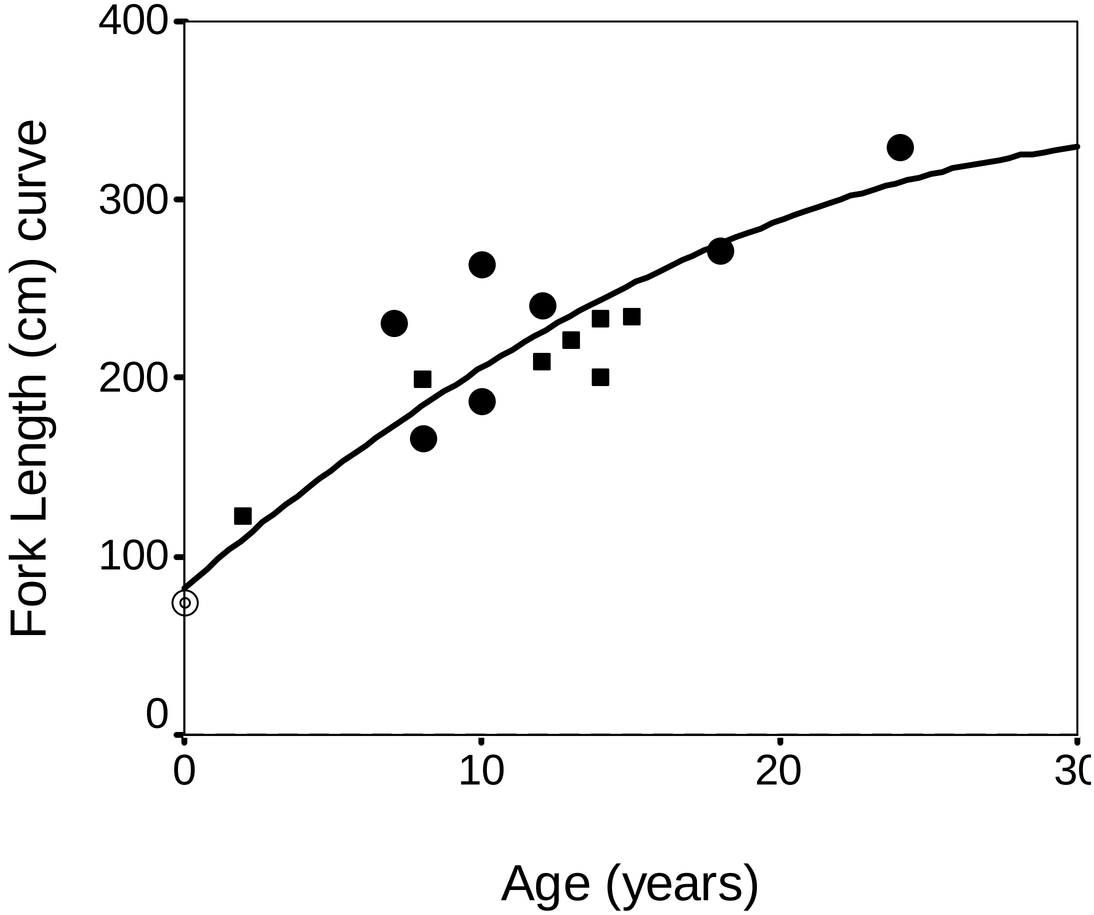
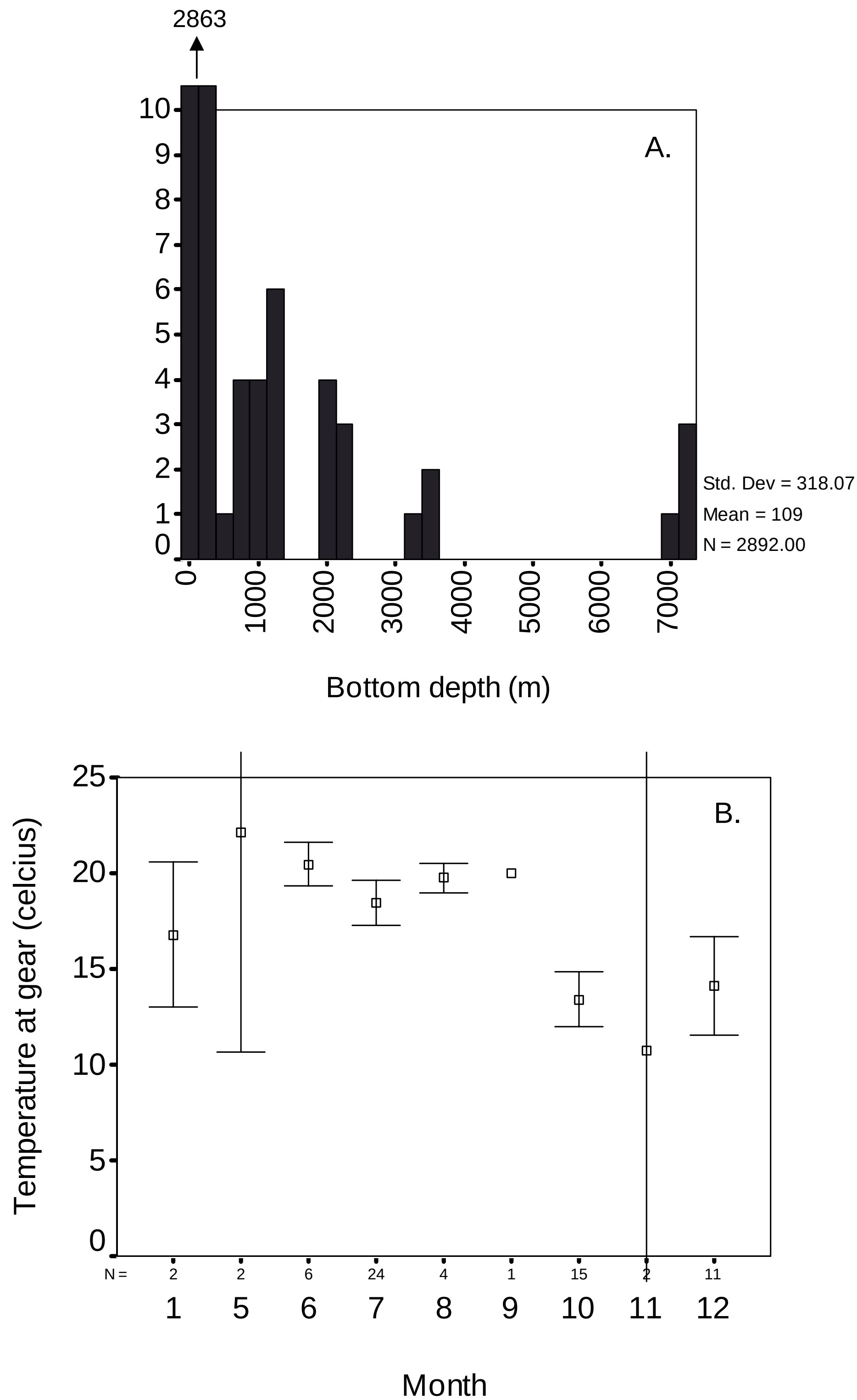


Fig. 5. Frequency histogram of bottom depths associated with mako shark catches (A) and month by month error bar plot of gear temperatures associated with catch (B).



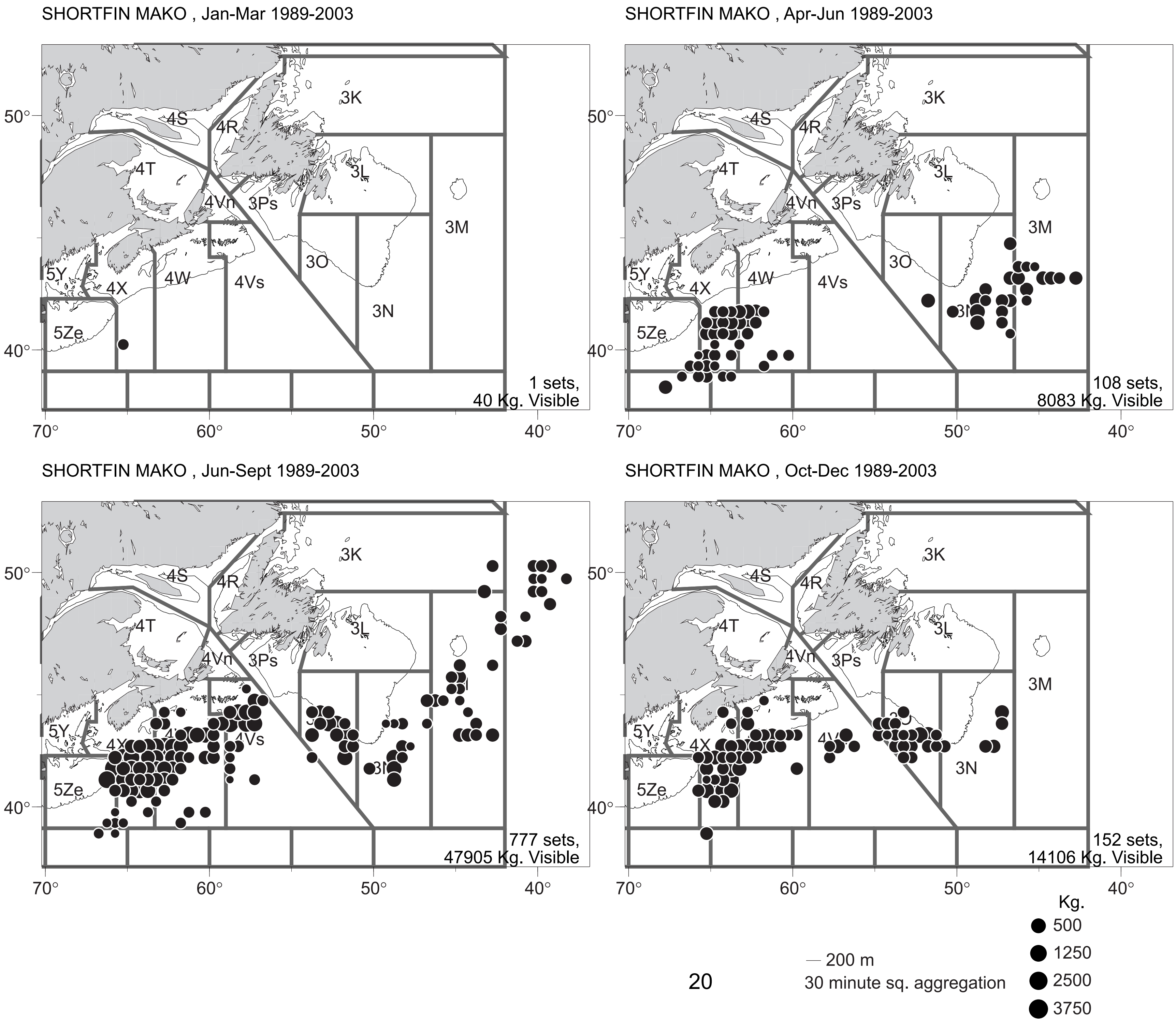
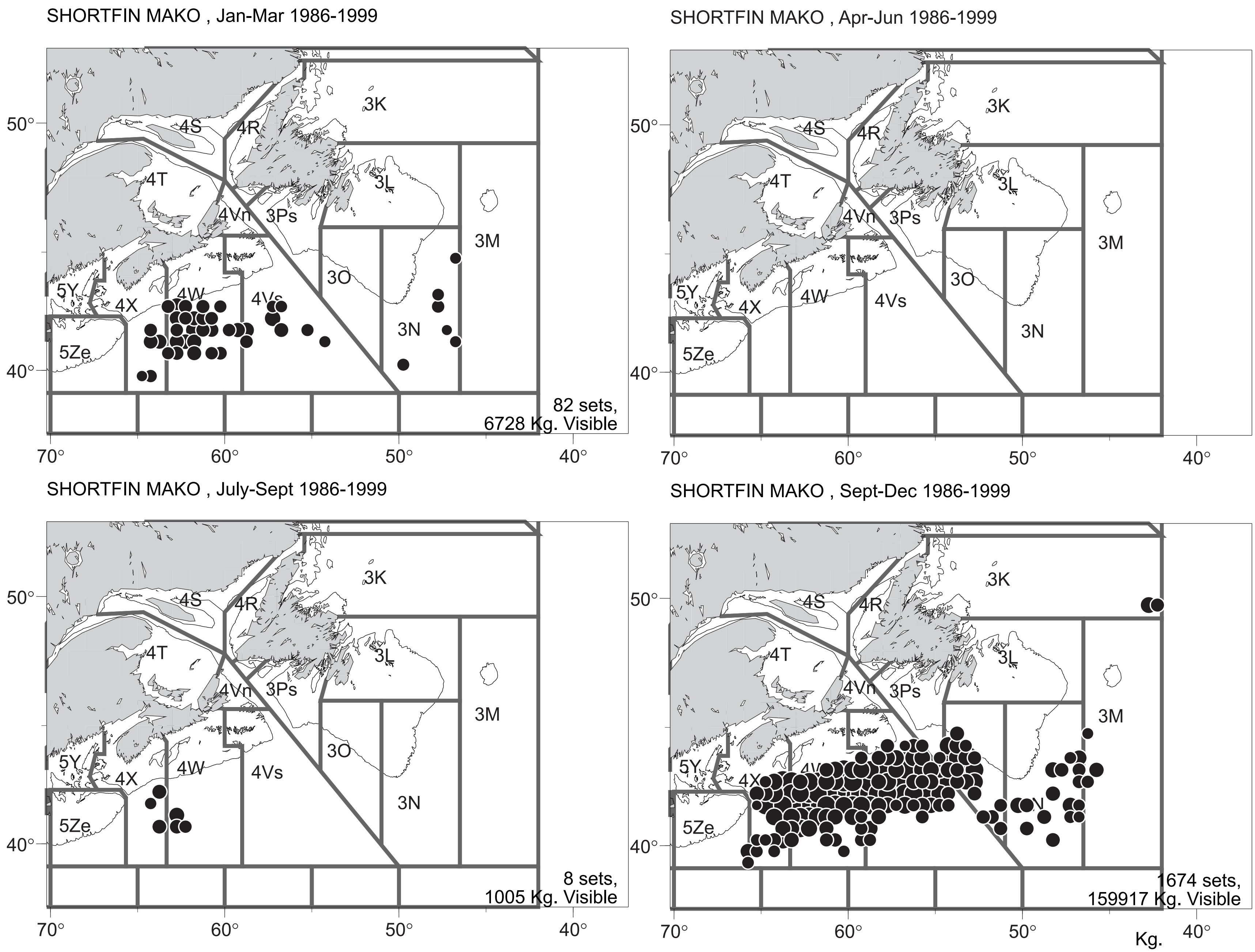


Fig. 6. Mako shark catch location by season observed by SFOP on Canadian vessels fishing swordfish or tuna betweeen 1989-2003.



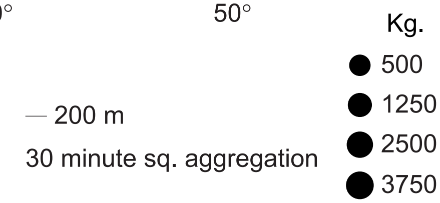


Fig. 7. Mako shark catch location by season observed by SFOP on Japanese vessels fishing swordfish or tuna between 1986-1999.

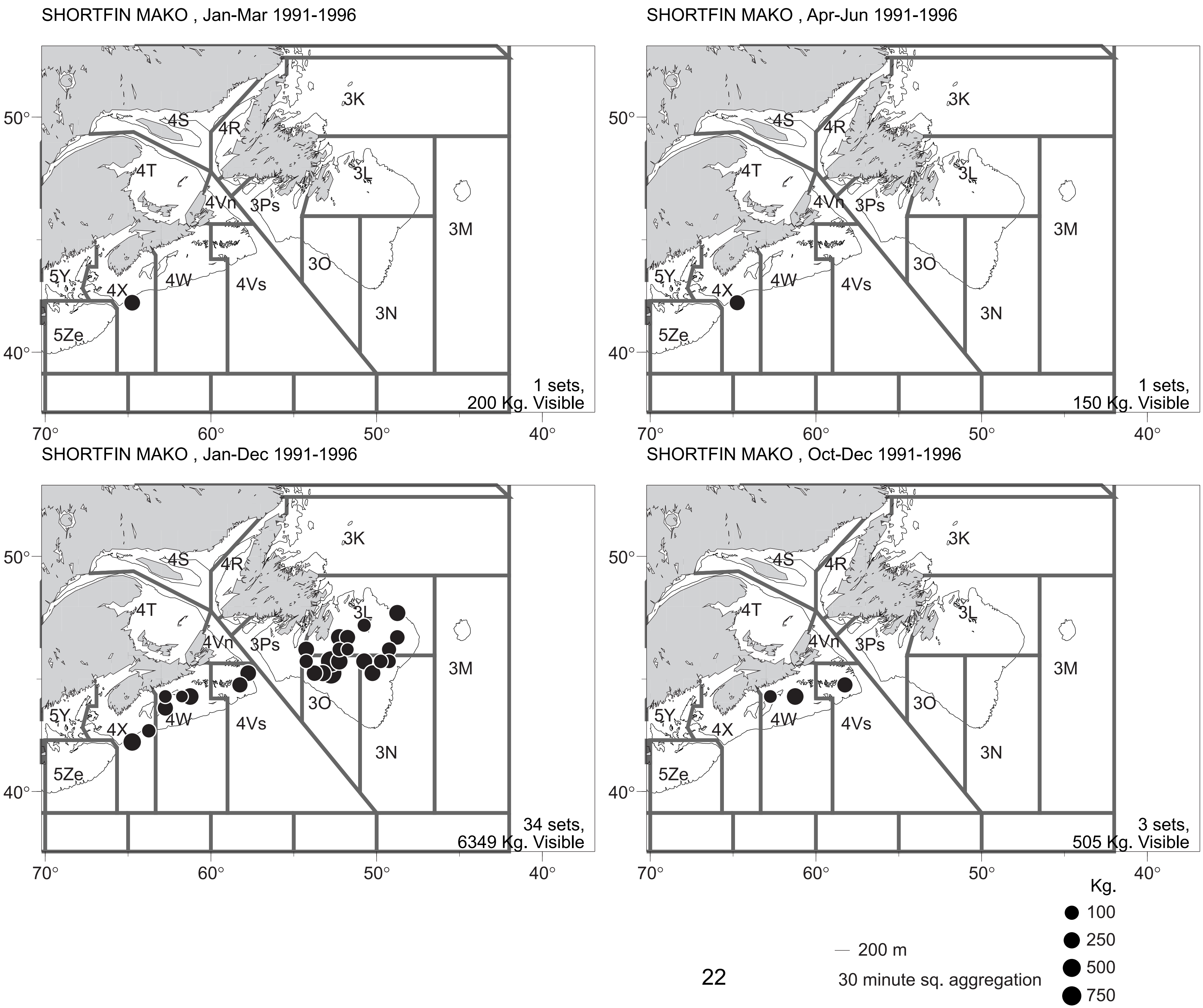
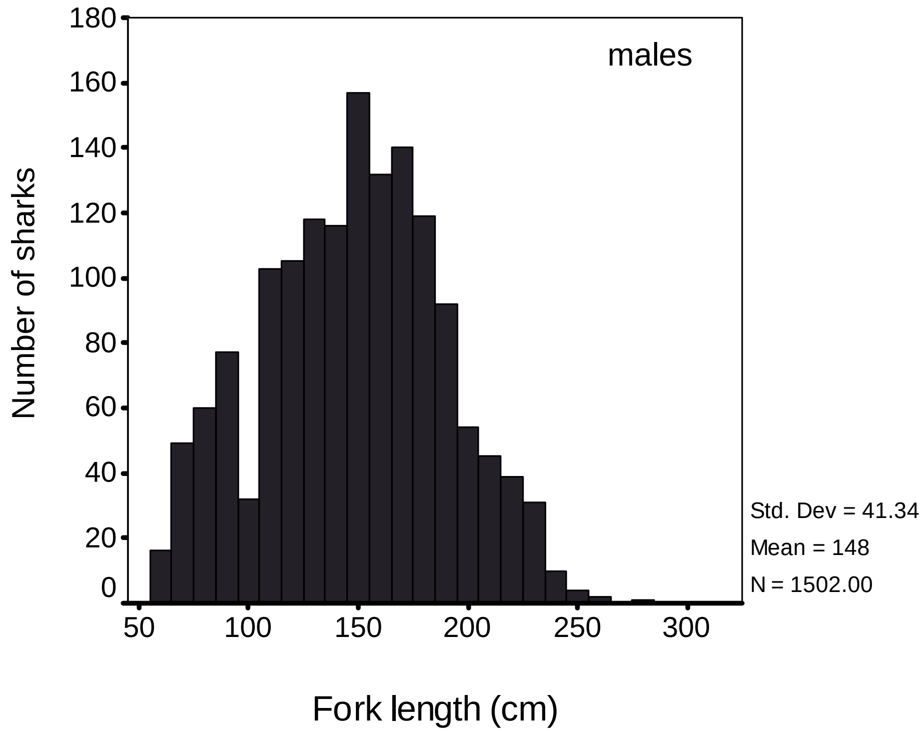


Fig. 8. Mako shark catch location by season observed by SFOP on Canadian and Faroese vessels fishing porbeagle shark between 1991-1996.

Fig. 9. Length frequency histograms of male and female mako sharks (year, area and season combined) from Observer data.



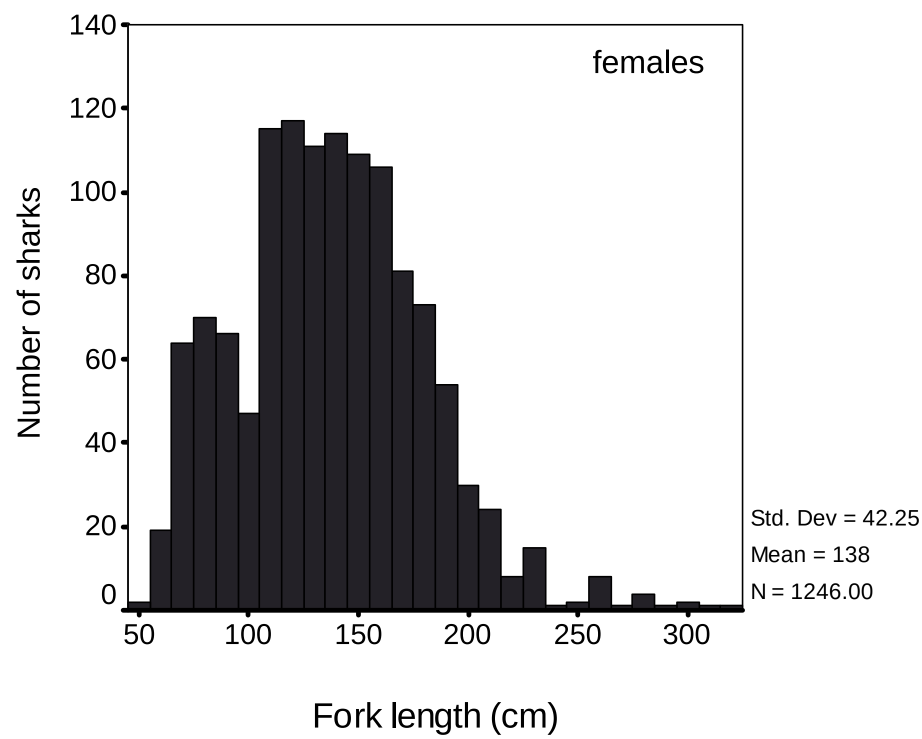


Fig. 10. Length frequency histograms of mako sharks caught off of Newfoundland, aggregated by quarter and range of years.

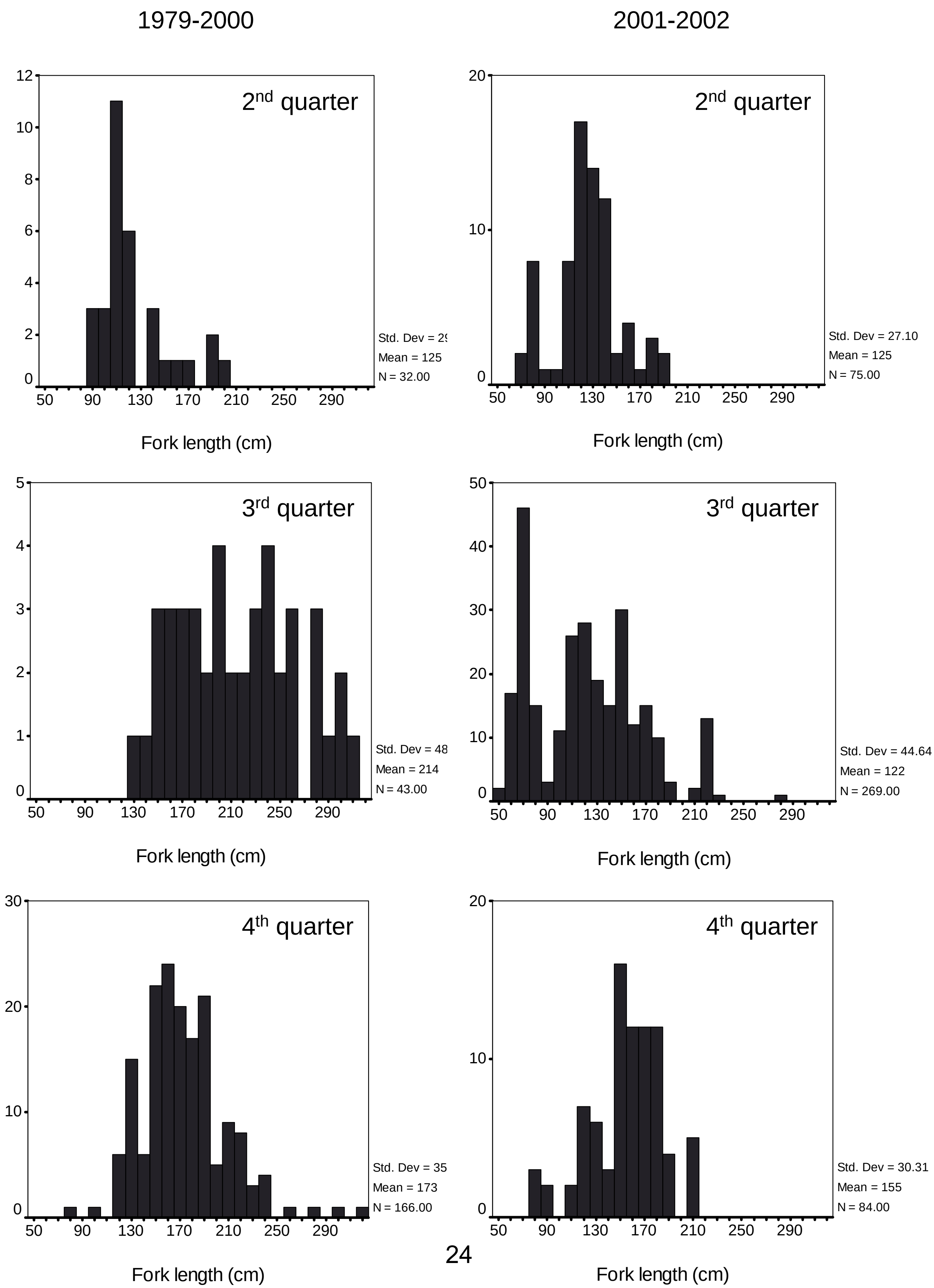
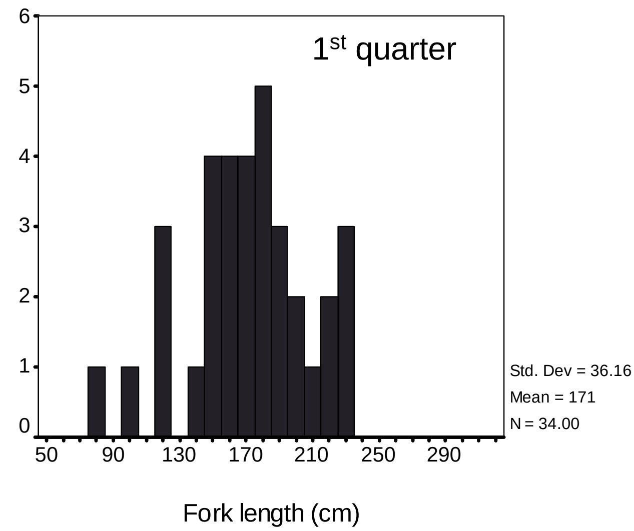
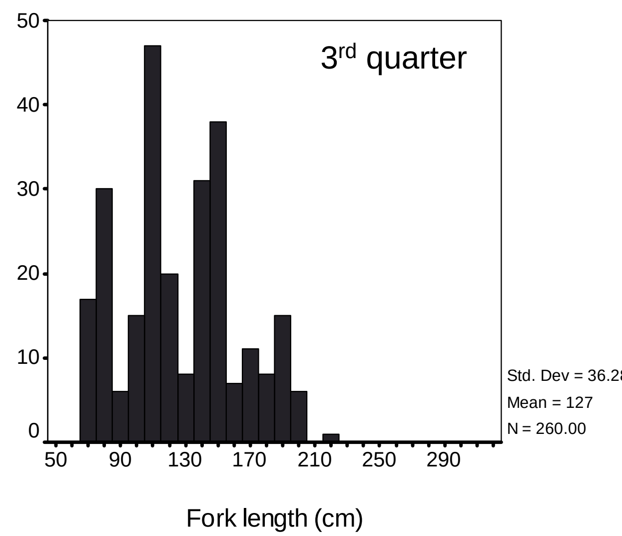
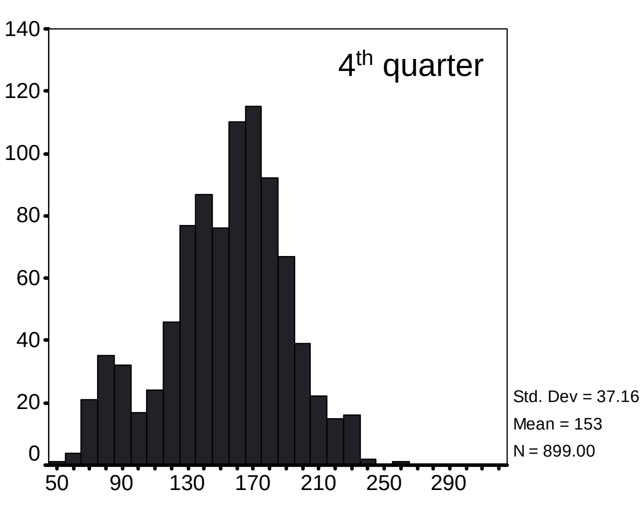


Fig. 11. Length frequency histograms of mako sharks caught on the Scotian Shelf, aggregated by quarter and range of years.

1979-2000 | 2001-2002







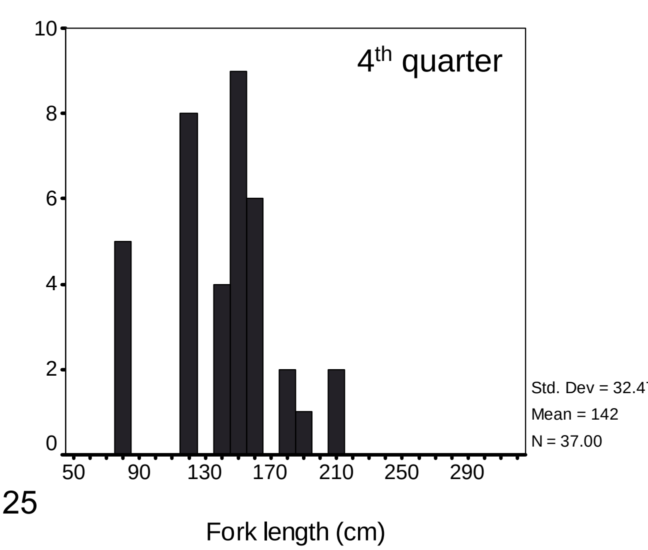
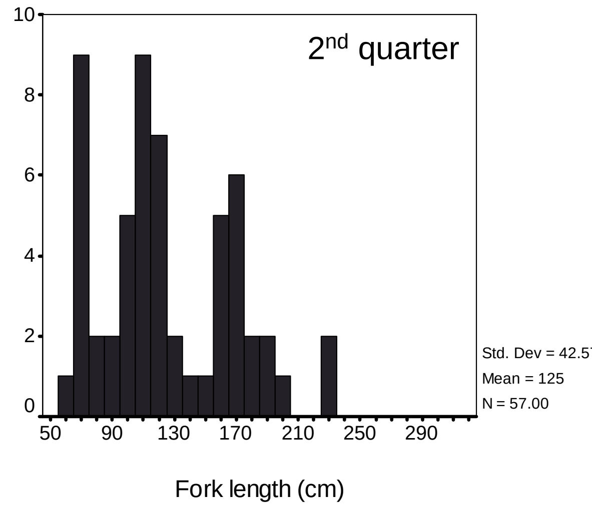
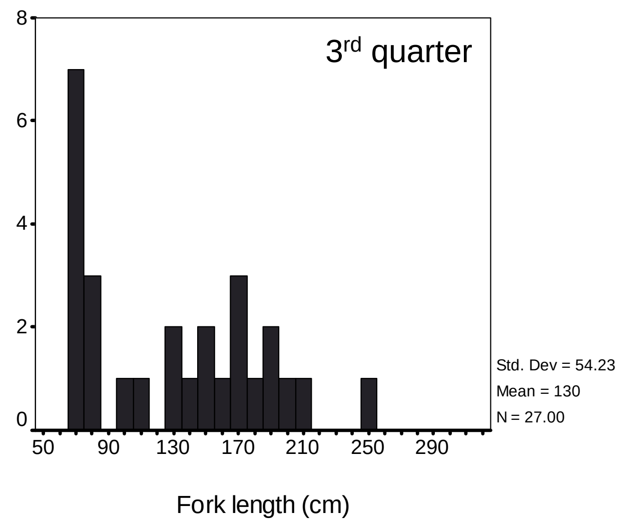


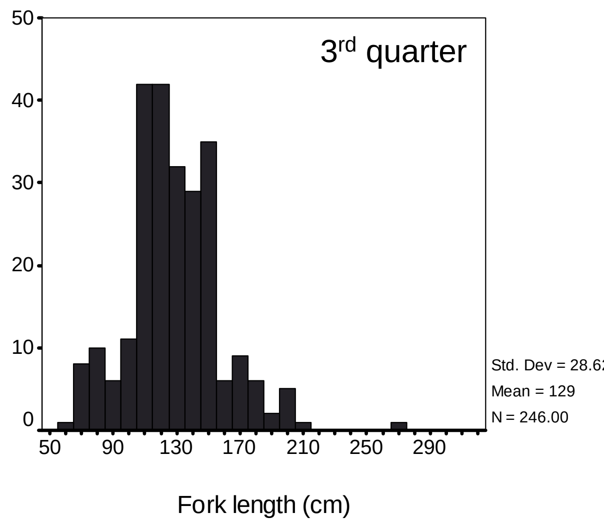
Fig. 12. Length frequency histograms of mako sharks caught south of Nova Scotia (4X and 5Z), aggregated by quarter and range of years.

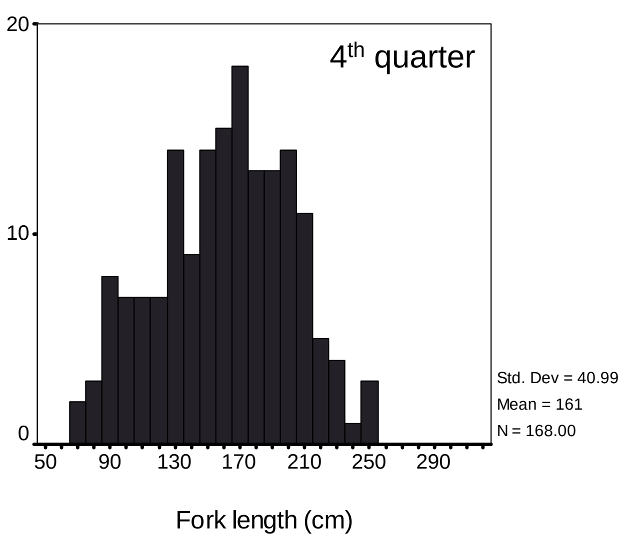
1979-2000

2001-2002









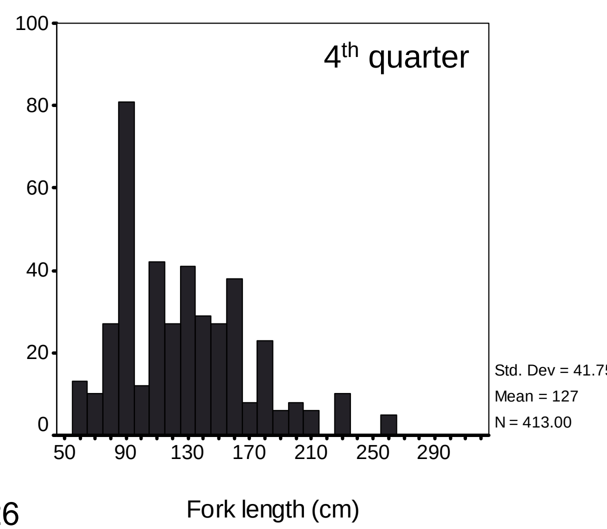


Fig. 13. Length frequency histogram of male and female mako sharks (sexes combined) caught at shark derbies between 1998-2004.

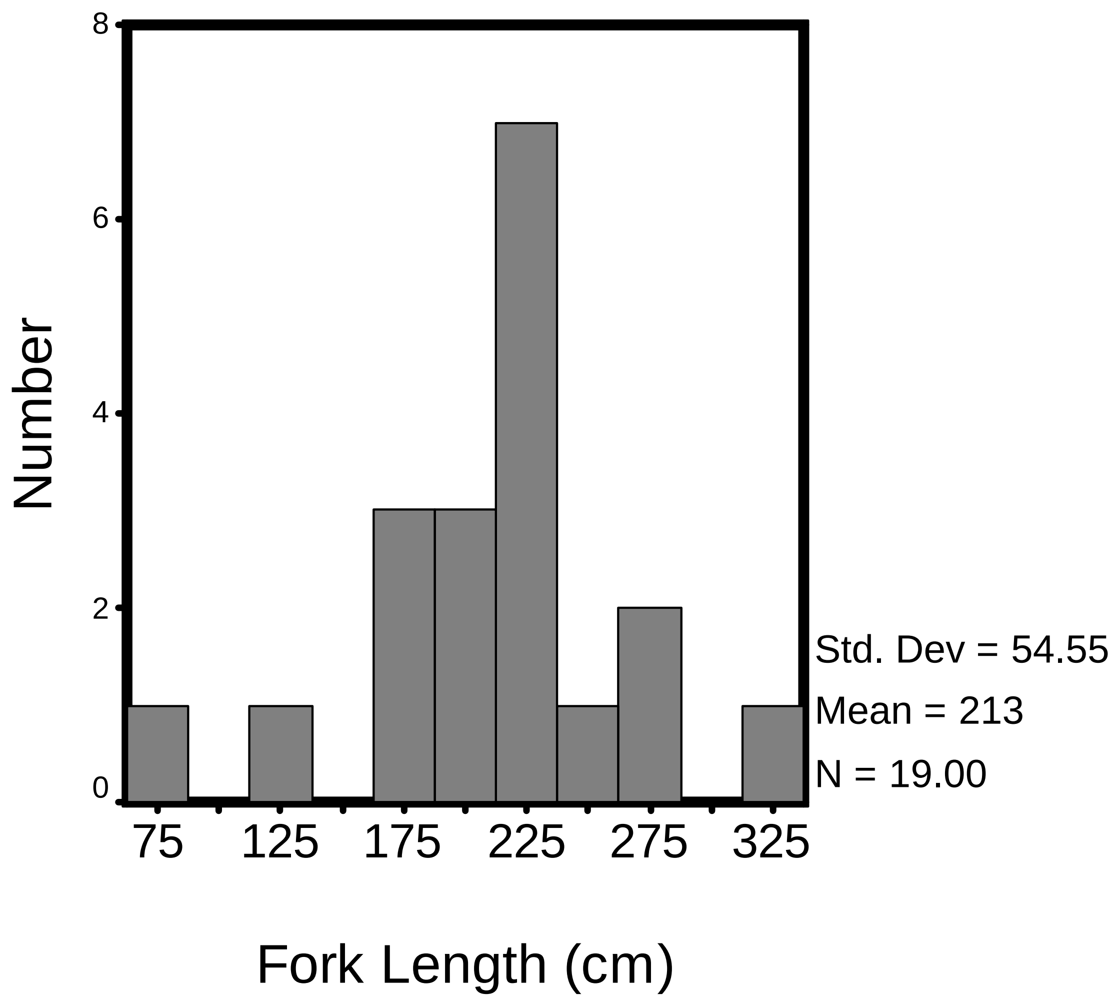


Fig. 14. Long-term changes in the median fork length of makos caught by Japanese (solid squares) and Canadian (open circles) pelagic longliners. LOESS curves have been fit to the trends.

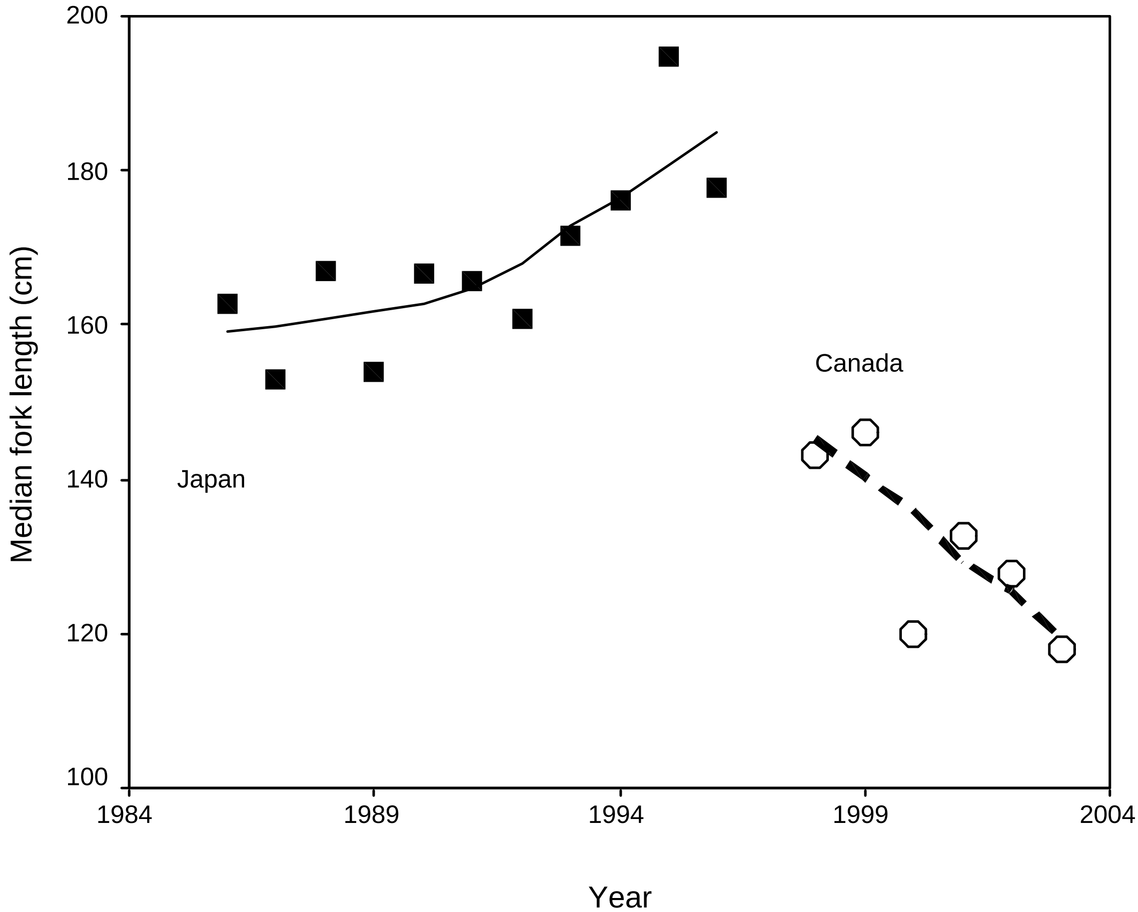


Fig. 15. Standardized trip-level catch rate of the weight of mako sharks caught by pelagic longliners on the Scotian Shelf between 1988 and 2003. Data were restricted to Japanese longliners targeting bigeye tuna between Oct-Dec of 1987-99 and Canadian longliners targeting swordfish between July-Sept of 1996-2003. The GLM model was fit to non-zero trips using a gamma error distribution and with Year and Vessel CFV as factors. Error bars represent 1 SE around the mean. There was no evidence of a trend in catch rate through time.