Effects of recreational and commercial fishing on blue sharks (*Prionace glauca*) in Atlantic Canada, with inferences on the North Atlantic population

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Abstract: The nominal catch of blue sharks (*Prionace glauca*) reported for the Canadian Atlantic grossly underestimates the annual catch mortality of about 1000 tonnes (t), making blue sharks the most frequently caught large shark in Canadian waters. Although blue sharks accounted for 99% of all sharks landed at recreational shark fishing tournaments, tournament catches accounted for only 3% of total fishing mortality. Standardized catch rate indices suggested a decline in blue shark abundance of about 5%–6%·year^{-1} since 1995. An increased mortality rate in recent years was suggested by a decline in the median size of blue sharks in the commercial catch. Two independent calculations suggest that North Atlantic catches exceeded 100 000 t, with catch mortalities ranging between 26 000 and 37 000 t. Because tagging studies indicated that blue sharks are highly migratory with a single population in the North Atlantic, the Canadian contribution to overall population mortality accounts for only 2% of the total. The fact that blue shark populations are relatively productive and resilient may help explain their persistence in the face of high international catch mortality and a decline in relative abundance.

Résumé : Les captures nominales de requins bleus (*Prionace glauca*) signalées dans l'Atlantique canadien sous-estiment considérablement la mortalité annuelle due à la pêche d'environ 1000 tonnes (t); il s'agit donc du grand requin le plus couramment capturé dans les eaux canadiennes. Bien que les requins bleus représentent 99 % de tous les requins débarqués lors des tournois récréatifs de pêche au requin, les captures lors des tournois ne représentent que 3 % de la mortalité totale due à la pêche. Les indices standardisés du taux de capture indiquent un déclin de l'abondance des requins bleus d'environ 5–6 %·an^{-1} depuis 1995. La diminution de la taille médiane des requins bleus dans les captures commerciales laisse croire à une augmentation du taux de mortalité au cours des années récentes. Deux calculs indépendants indiquent que les captures en Amérique du Nord dépassent 100 000 t et que les mortalités dues à la capture sont de l'ordre de 26 000 à 37 000 t. Comme des études de marquage indiquent que les requins bleus migrent beaucoup et qu'ils forment une seule population dans l'Atlantique Nord, la contribution canadienne à la mortalité globale de la population représente seulement 2 % du total. La persistance des requins bleus malgré une capture internationale importante et un déclin de leur abondance relative s'explique peut-être par la productivité relativement élevée et la résilience des populations.

[Traduit par la Rédaction]

Introduction

The blue shark (*Prionace glauca)* is a large temperate and tropical pelagic shark species of the family Carcharhinidae that occurs in the Atlantic, Pacific, and Indian oceans. The species is highly migratory, with tagging results suggesting that there is a single well-mixed population in the North Atlantic (Casey and Kohler 1991). In Canadian waters, the blue shark has been recorded off southeastern Newfoundland, the Grand Banks, the Gulf of St. Lawrence, and the Scotian Shelf, and in the Bay of Fundy. At certain times of the year, it is probably the most abundant large shark species in eastern Canadian waters (Templeman 1963).

The inherent vulnerability of sharks and other elasmobranchs to overfishing and stock collapse is well documented. The International Plan of Action for the Conservation and Management of Sharks (The Food and Agriculture Organization of the United Nations (FAO) 1998) concluded that many of the world's shark species are severely depleted. A recent policy statement by the American Fisheries Society noted that most elasmobranch populations decline more rapidly and recover less quickly than do other fish populations (Musick et al. 2000). Indeed, numerous authors have noted the low productivity of elasmobranchs compared with teleosts, which is largely a result of their low fecundity and late age of sexual maturation (Cortés 1998; Smith et al. 1998).

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Although the blue shark is probably the most frequently caught large shark in the world's oceans (Walker 1998; Stevens et al. 2000), the health of the blue shark population has never been properly assessed. Based on an analysis of US pelagic longline logbook information from vessels fishing in the Northwest Atlantic, Baum et al. (2003) suggested that the North Atlantic population had declined by 60% since 1986. In contrast, an initial attempt to prepare a North Atlantic wide stock assessment of blue sharks suggested that there had been no decline in population numbers since 1971, although the report noted that the assessment was hampered by poor data quality, making the conclusion very provisional (International Commission for the Conservation of Atlantic Tunas (ICCAT) 2005). In the Canadian Atlantic, the unreported bycatch of blue sharks is estimated to be about 100 times larger than the reported catch (Campana et al. 2002*a*). The status and health of the blue shark population and fishery in Canadian waters has never been evaluated, and the impact of the reported and unreported catches on the population is unknown.

Since 1995, fisheries management plans in Atlantic Canada have maintained nonrestrictive catch guidelines of 250 tonnes (t) annually (not based on estimates of stock abundance) for blue sharks in the directed shark fishery (Campana et al. 2002*a*). Fishing gears permitted in the directed commercial fishery are limited to longline, handline, or rod and reel gear. The recreational fishery is restricted to rod and reel (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.

Blue sharks in Atlantic Canada are incidentally caught in large numbers by commercial fishers and are increasingly being targeted by recreational shark fishers through fishing tournaments. The objective of this study is to provide an initial view of the impact of these fishing pressures on the status of the blue shark population, both within Canadian waters and in the North Atlantic as a whole. The analysis begins with a reconstruction of the total blue shark catch, including discards, in both the commercial and recreational fishery. Indices of abundance and exploitation rate were calculated from analyses of standardized catch rates, tag recaptures, and length composition. The Canadian catch mortality estimates were then put into the broader context of the entire North Atlantic population.

Materials and methods

Length and maturity data

Length and weight were measured and sexual maturity was assessed in examinations of more than 2000 blue sharks landed at shark tournaments. The standard length measure reported in this paper is that of fork length measured over the curve of the body. Alternate measures of length used by observers or the fishing industry were standardized to curved fork length using a series of interconversion factors developed through matched measurements made by scientific staff on freshly caught blue sharks (Campana et al. 2004). Length at maturity varied between 193 and 210 cm for males, with a length at 50% maturity of 201 cm (Campana et al. 2004). Mature females were seldom caught at shark tournaments, so length at maturity could not be estimated. However, reports from the literature indicate that females reach sexual maturity at lengths greater than 185 cm (Pratt 1979).

Length composition in the commercial catch was determined from observer measurements from both the Scotia–Fundy and Newfoundland Observer Programs. Trends in median length through time were plotted using locally weighted least square regressions (LOESS). To minimize seasonal differences, the analysis was restricted to the fall and winter seasons.

Tagging studies

The migration pattern and exploitation rate of blue sharks in Canadian waters were analyzed on the basis of tag recaptures from two sets of tagging studies. A total of 2017 tags were applied to blue sharks in a Canadian tagging program carried out between 1961 and 1980, 17 of which were recaptured (Burnett et al. 1987). A second tagging study was carried out by the US National Marine Fisheries Service (NMFS) in cooperation with Canadian fishers. This study applied thousands of tags to blue sharks in US and international waters, 916 of which were applied in Canadian waters between 1971 and 2002. A total of 59 of the Canadian-tagged sharks were subsequently recaptured, 17 of which were in Canadian waters. Both studies used steel dart tags inserted into the dorsal musculature behind the first dorsal fin. Recapture details are reported in Campana et al. (2004).

Commercial landings and observed bycatch

Commercial catch and effort statistics were available for the period of 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 1991–2002 and from DFO MARFIS statistics files for 2003. Foreign catches (including discards) from 1979 onwards were available from the Scotia–Fundy and Newfoundland Observer Programs (SFOP and NFOP, respectively). Landings data for the Northwest Atlantic (not including Japanese vessels) are from ICCAT statistics for area 92 (ICCAT 2005), and those for Japanese vessels were derived from FAO statistics of the nominal catch of unspecified sharks and rays (and thus were not restricted to blue sharks) (FAO 2001). North Atlantic landings are derived from ICCAT statistics for the Atlantic shark stock (ICCAT 2005).

Calculation of unobserved bycatch

To estimate the magnitude of unobserved blue shark bycatch in the various large pelagic fisheries, bycatch was estimated by country, fishery, quarter, and year from SFOP observations made between 1986 and 2000, with bycatch defined as the summed weight of the kept and discarded blue sharks relative to the summed large pelagic catch (tuna, swordfish, and porbeagle). The summed large pelagic catch accounted for virtually all of the catch, and its use in the estimation avoided problems associated with the species sought being unknown. The analysis was restricted to Canadian, Japanese, and Faroese vessels, as they accounted for more than 99% of the blue shark catch. Full details on the estimation protocol are presented in Campana et al. (2002*a*, 2004).

Hooking mortality

A confounding issue in the interpretation of blue shark bycatch concerns the survival or mortality of the discarded sharks. In principle, after 1994, sharks discarded alive and in good health should not be included in any calculations of fishing mortality or nominal catch. However, many pelagic shark species suffer a high hooking mortality because of their requirement for continued swimming to move water over their gills to breathe. Unfortunately, there do not appear to be any published studies of hooking (discarding) mortality in sharks.

There is no objective method for determining what percentage of the injured, discarded sharks would subsequently die. However, detailed postcapture examinations of 111 commercially caught, injured sharks indicate that most were gut-hooked. Gut-hooked sharks would appear to be at the highest risk of death because of the potential for damage of internal organs and interference with feeding and (or) digestion; therefore we arbitrarily assumed a 50% mortality rate for gut-hooked sharks.

Commercial catch rate

Calculations of commercial catch rate (ln-transformed kilograms per hook) used as an index of abundance were based on directed longline catches for large pelagic species, which account for most of the blue sharks caught in Canada. All data came from the SFOP and are thus considered accurate. Initial examination of the catch rate data indicated that the major data sources could be categorized by country (Japan, Canada), area fished (around Newfoundland, eastern Scotian Shelf (NAFO division 4VW), and the southern region (NAFO division 4X, Georges Bank)), season, and species sought (bigeye tuna (*Thunnus obesus*), swordfish (*Xiphias gladius*), and bluefin tuna (*Thunnus thynnus*)). Catch rate trends in the southern region tended to be quite different (and based on a much smaller sample size) than those off Newfoundland and the Scotian Shelf, so only the latter two regions were used. Before the introduction of the ban on finning in 1994, discarded sharks were not necessarily counted by SFOP; therefore, the final catch rate analysis was restricted to the period after 1994.

Estimation of catch from the recreational fishery

The Canadian recreational shark fishery is designated as catch and release only (with the exception of shark derbies). Logbook returns from this fishery were low in number, providing little information on the magnitude of the total recreational catch. Therefore, we estimated the total recreational shark catch using a phone survey, then estimated catch mortality using an assumed hooking mortality rate.

A total of 1400–1800 recreational shark fishing licences were issued annually between 2001 and 2002. Of these, 201 recreational shark fishers were selected for over-the-phone interviews conducted between September and December 2002. A sample of 100 fishers was randomly selected and then contacted from the list of licences that were issued in 2002. Using the shark derby logs from the previous six years, an additional 100 “frequent” shark fishers were identified based on names that appeared more than once in the logs. These samples sizes represent ~10% of the licensees. Considerable effort was expended in contacting fishers who could not be contacted on first attempts, resulting in 162 successful interviews. Details of the survey and its results are presented in Campana et al. (2004).

Total annual recreational catch (excluding derbies) was estimated based on the percentage of active fishers, the mean annual catch from the shark fishing logs, and the mean weight of blue sharks in the population. The mean weight of an individual shark in the recreational shark catch (29 kg) was based on charter catches, which include undersized sharks not landed at derbies. The recreational shark fishery was assumed to catch 0.66 of the derby catch for the years before 2001, based on the observed catch proportion in 2001–2002.

Catch rates from shark tournaments

Estimation of catch rates at shark tournaments should provide an index of shark abundance. However, estimation is complicated by the presence of multiple fishers per boat, discarding of undersized sharks, and difficulties in assigning catches to specific fishers on the boat. Therefore an index based on the percentage of fishers successful in catching a shark at each derby was used. The resulting general linear model (GLM) was based on the overall fishing success at the five shark fishing derbies carried out annually since 1998.

Results

Migration from tagging studies

The migration pattern of blue sharks in Canadian waters was analyzed on the basis of tag recaptures from two sets of tagging studies. Most of the 2017 tags applied in the Canadian tagging study were applied before 1972, which makes this study most applicable to the early years of the longline fishery. With only 17 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 US waters.

Most of the tagging effort in the NMFS program took place after 1990, thus providing a view of recent migration patterns. The NMFS program resulted in 188 recaptures in Canadian waters between 1974 and 2002: 171 from foreign tagging and 17 from Canadian tagging. Most of the tagged sharks recaptured in Canadian waters were tagged in the US, a pattern which would be expected given that most of the tagging effort was concentrated in the US (Fig. 1*b*). In contrast, most of the tags applied in Canadian waters were later recaptured in the central and eastern Atlantic, as far away as Africa (Fig. 1*a*). There was no obvious difference in migration pattern between males and females or between small and large sharks.

Commercial landings

Blue shark landings and (or) nominal catch in the Canadian Atlantic (NAFO areas 2–5) are known only for Canadian vessels landing their catch or for foreign vessels operating under 100% observer coverage within Canada’s 200-mile limit. Landings peaked at around 250 t in 1994, declining thereafter to only 19 t in 2003 (Table 1). Only Canadian, Japanese, and Faroese vessels are known to have caught

Fig. 1. Blue sharks (*Prionace glauca*) (*a*) tagged or (*b*) recaptured between 1971 and 2002 in Canadian waters under the US National Marine Fisheries Service tagging program. Bathymetric contour is 200 m.

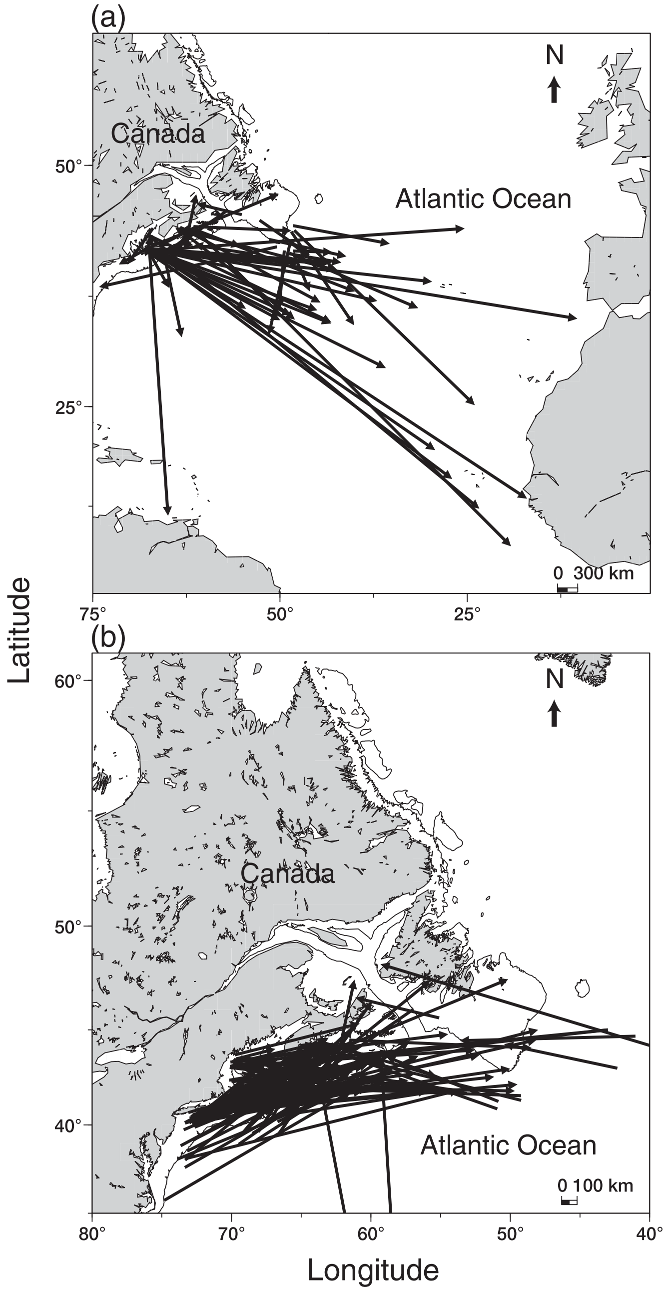
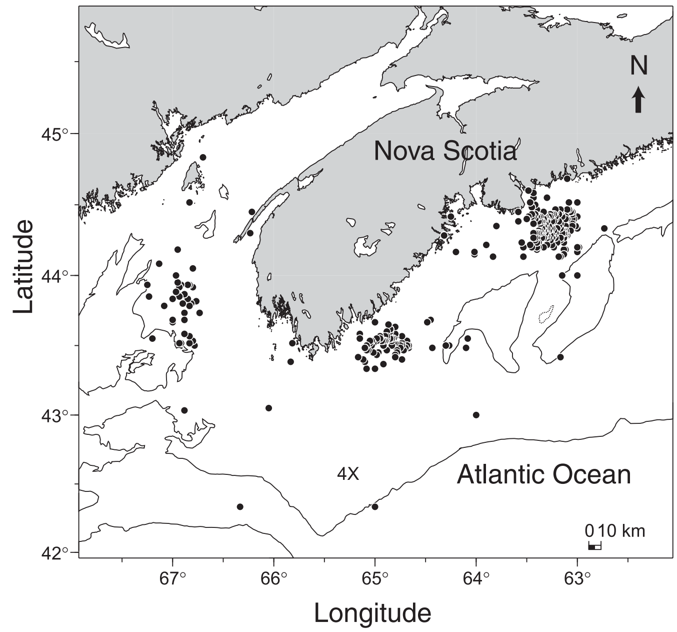


Fig. 2. Random subsample of fishing location of sharks caught at shark fishing tournaments off of Nova Scotia (1996–2002). Bathymetric contour is 200 m.



significant quantities of blue shark in Canadian waters. In the Northwest Atlantic as a whole (north of Florida), mean reported catches are somewhat larger, averaging 200–500 t in the 1990s. North Atlantic nominal catches are substantially larger, averaging over 30 000 t since 1998. However, much of this reported catch is believed to have been caught in the Northeast Atlantic.

Blue shark landings by Canadian vessels are very small, averaging 52 t·year^{-1} since 1990. Most of the landings are from longlines, although recreational shark fishing derbies averaging 10–20 t annually have accounted for a growing proportion of the landings in recent years. Most of the commercial catch is restricted to the Scotian Shelf in the first half of the year, extending northwards into the Gulf of St. Lawrence and the Newfoundland shelf between July and December.

Catch from shark tournaments (derbies)

The weight of sharks landed at recreational shark tournaments has increased from around 4 t in 1993 (the first year of the derbies) to around 15 t in recent years (Table 2). Although shortfin mako (*Isurus oxyrinchus*), thresher (*Alopias vulpinus*), and porbeagle (*Lamna nasus*) sharks have all been caught at derbies, blue sharks accounted for 99% of all landings.

Shark derbies in Atlantic Canada are all currently located in Nova Scotia. On average, there have been 5–6 derbies held each year between late July and mid-September. Fishing effort and catch at each derby is detailed in Campana et al. (2004). Fishing locations are centred in the waters around Halifax and Lockeport and in the southern Bay of Fundy (Fig. 2).

Catch from the recreational shark fishery

The percentage of recreational shark licensees who actually fished for sharks in 2001 or 2002 was relatively small: 7% of the random sample and 14%–22% of the “frequent” fishers. Of these, most fished two to three times per year, catching 4–12 sharks annually. The median annual catch per licence was 0.5 sharks in 2001 and 0.9 sharks in 2002. There was no evidence that frequent fishers were any more successful than the random sample of fishers.

Less than 2% of the recreational licensees returned fishing logs at the end of the fishing year. The average number of trips per year was very similar to that reported in the phone survey. However, the mean number of sharks caught per year

Table 1. Reported blue shark (*Prionace glauca*) landings (tonnes) by country.

	Canadian Atlantic (NAFO areas 2–5)					Northwest Atlantic					
Year	Canada	Faroe Islands	Japan	Other	Total	Japan	USA	Other	Unspecified pelagic sharks	Total	North Atlantic
1979			4		4					4	
1980				13	13					13	4
1981			1		1					1	12
1982			2		2					2	9
1983			1		1					1	8
1984					0					0	14
1985					0					0	39
1986			13		13		1			14	51
1987			38		38		360			398	593
1988			5		5		241			246	512
1989			10		10		232			242	561
1990	8		13		21	140	394			555	2 261
1991	31	16	5		52	198	375			625	3 217
1992	101	30	30		161	345				506	2 045
1993	24	44	47		115	553	17			685	7 208
1994	138		116		254	450	1		4	705	8 196
1995	152		73		225	397	347	3		972	8 403
1996	23		173		196	238	169	1	160	604	8 398
1997	19		36		55	99	89	1	6	244	35 951
1998	14		17		31	115	3	1		150	34 298
1999	67		11		78	170	2	9	31	259	34 722
2000	34		0		34	83				117	32 297
2001	8		0		8	116				124	29 942
2002	25		0		25					25	29 583
2003	19		0		19					19	

Table 2. Species of shark landed at shark derbies between 1993 and 2003.

	Blue shark		Mako		Porbeagle		Thresher shark		Total	
Year	No.	Weight	No.	Weight	No.	Weight	No.	Weight	No.	Weight
1993	93	3 636	0	0	1	10	0	0	94	3 646
1994	117	5 048	0	0	0	0	0	0	117	5 048
1995	122	6 464	0	0	0	0	0	0	122	6 464
1996	114	4 967	1	46	0	0	0	0	115	5 013
1997	273	10 315	0	0	0	0	0	0	273	10 315
1998	269	10 406	0	0	0	0	0	0	269	10 406
1999	300	14 598	0	0	0	0	0	0	300	14 598
2000	235	15 488	3	489	0	0	0	0	238	15 977
2001	162	7 594	0	0	1	57	1	84	164	7 735
2002	327	19 324	4	674	1	27	0	0	332	20 026
2003	342	12 017	3	399	1	132	0	0	346	12 548

Note: Weights are live equivalent weights (kg). Blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), porbeagle (*Lamna nasus*), thresher (*Alopias vulpinus*).

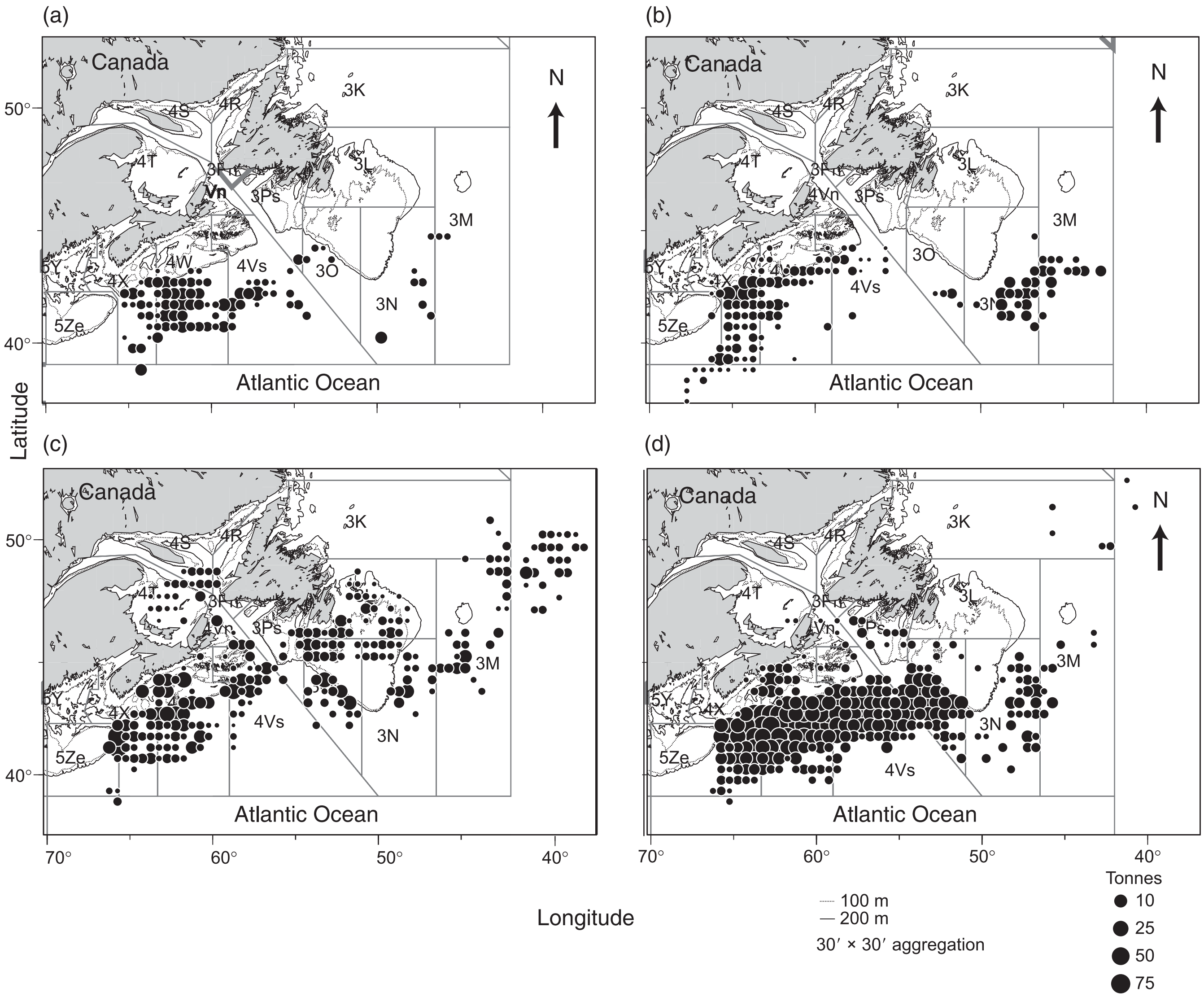
(2.4) was much less than that reported in the phone survey. Because the recreational fishing logs were returned voluntarily and prepared after more thought than the phone surveys, we assumed that their report of average catch was more accurate than those of the phone surveys. Charter fishery catches averaged 162 sharks annually spread across 32 trips.

Based on a 7% participation rate and the mean annual catch from fishing logs (with the charter fishery being treated separately), a total of 431 sharks weighing about 12.5 t were caught annually in the non-derby recreational shark fishery.

Observed commercial bycatch

The 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 ob-

Fig. 3. Blue shark (*Prionace glauca*) catch location by season as observed by the Scotia–Fundy Observer Program on Canadian, Japanese, and Faroese vessels fishing swordfish (*Xiphias gladius*), tuna (*Thunnus* spp.), or porbeagle sharks (*Lamna nasus*) between 1986 and 2004: (*a*) January–March; (*b*) April–June; (*c*) July–September; and (*d*) October–December. North Atlantic Fisheries Organization (NAFO) division boundaries are shown. Bathymetric contour is 200 m.



servations indicate that Canadian, Japanese, and (in earlier years) Faroese longliners caught substantially larger numbers of blue sharks than would otherwise be known from nominal catch statistics. Observed catch and bycatch between 1990 and 1999 averaged about 250 t annually, with most of that coming from Japanese vessels. In most years, virtually all of the blue shark catch was discarded. Since 1999, virtually all observed catch and bycatch has been by Canadian vessels. Observed catch locations mapped by quarter over the period 1986–2004 indicate that most of the Canadian and Japanese bycatch occurred in deep waters off the continental shelves of Nova Scotia and Newfoundland, increasing in quantity through the year (Fig. 3). 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, primarily in the first and last quarters of the year, in part because of regulations restricting the area and time of the fishery. The location of blue shark bycatch in the Canadian and Faroese porbeagle fishery was somewhat different, being more localized on the Scotian and Newfoundland shelves, as well as in the Gulf of St. Lawrence.

Unobserved blue shark bycatch estimates

For the six large pelagic fisheries (albacore, yellowfin, and bigeye for both Canada and Japan) other than porbeagle, mean blue shark bycatch accounted for 26%–152% of the total large pelagic catch, with an overall mean of 34% (n = 5787 sets). Bycatch proportions in individual sets often exceeded 100%. Annual bycatch estimates averaged less than 100 t for the bluefin tuna fishery, less than 500 t for other tuna, and around 2000 t for the swordfish fishery. Blue shark bycatch in the porbeagle fishery was substantially less, averaging 7% for an annual bycatch of about 50 t.

Table 3. Estimates of blue shark (*Prionace glauca*) hooking mortality in the commercial and recreational fisheries.

Year	Fishery	*n*	Percent healthy	Percent injured[a]	Percent dead[b]
Scientific study on commercial vessel (Sept. 2003)					
2003	Blue shark	105	38	44	18
Scotia–Fundy Observer Program					
2001	Swordfish	2035	78	5	17
	Tuna	2606	82	12	6
2002	Swordfish	2219	25	64	11
	Tuna	4265	75	18	7
2003	Swordfish	980	88	1	11
	Tuna	1518	83	10	7
	Porbeagle	116	59	16	23
Mean			70	18	12
Recreational fishery (Aug.–Oct. 2002)					
2002	Blue shark	111	63	37	0

[a]For 2002 and 2003 blue shark fishery, fish were gut-hooked, but observers were unable to tell if it was a fatal injury.
[b]For 2002 blue shark fishery, 9% were in poor condition upon release and presumably would have died.

Hooking mortality

Three sets of studies were made on blue sharks caught as part of both commercial and recreational shark fisheries (Table 3). The percentage of blue sharks that were dead upon retrieval was similar in both the scientific and observer studies: 10%–20%. These values are also consistent with the mortality values of 13.5% and 20% reported by Francis et al. (2000, 2001) for blue sharks caught in the New Zealand pelagic longline fishery. Because mortality is at least in part associated with the amount of time spent on the hook, the absence of dead sharks in the recreational fishery is understandable.

Based on the results of the scientific study and assuming a 50% mortality rate for injured (gut-hooked) sharks, 60% of the discarded sharks would be expected to survive capture in the commercial fishery. Survival in the recreational fishery would be expected to be higher at 81%. Many of the gut-hooked sharks looked healthy from the outside, which may explain the large variations in the percentages of healthy and injured sharks between the scientific and observer studies (Table 3). Because most discards were finned before June 1994, those discards were assumed to be 100% dead.

Total catch mortality

Total estimated annual blue shark catches and discards in Canadian waters are shown (Table 4). Discards from the Canadian large pelagic fisheries were responsible for the largest proportion of blue sharks caught in Canadian waters since 1986. However, total estimated catch mortalities, based on the discard rates and hooking mortalities presented earlier, are lower, averaging around 1000 t·year^{-1} over the time series (Table 4; Fig. 4). The proportion of catch mortality contributed by fishing at derbies was negligible, averaging 3% of the total catch mortality in recent years.

Length composition

Measurements by scientific staff at shark derbies since 1993 highlight a striking difference between the length compositions of the males and females: mature females were virtually absent from the derby catches, whereas mature males were caught more frequently than immature males (Fig. 5). Immature females were the category most represented in the catch.

To determine if the length composition in the derby catches was representative of the population sampled by the commercial fishery, a series of paired comparisons were made between the derby length frequencies and those from the commercial fishery (as measured by observers), matched for year, season, and area. In all cases, the presence of small sharks (<140 cm) seen in the commercial fishery was not well represented in the derby catches. The absence of small sharks in the derby catches was almost certainly the result of regulations, which specify a 6-foot (183 cm total length) minimum size limit. In addition, although the length frequencies of the females were similar between commercial and derby catches, large males (>200 cm) were overrepresented in the derbies. This overrepresentation is likely due both to specific targeting of large males by derby participants and by size-selective hooking of smaller sharks by commercial fishing gear. There may also have been some understandable reluctance by observers on board commercial fishing vessels to measure very large, live sharks.

Analysis of the size composition of the recreational charter fishery indicated that it was similar to that of the derbies, but with the addition of large numbers of sharks below 140 cm. Such a size composition is more consistent with that of the commercial fishery, supporting the view that the derbies and commercial fishery are actually sampling the same population but that selectivity has distorted the derby catch composition.

Catch rates

The overall trend in catch rate (used as a proxy for relative abundance) was analyzed at the set-by-set level using a GLM with year, region, season, species sought, and vessel identity (CFV) as factors. Models with CFV tended to outperform models using country (but not CFV) as a factor, but vessels fishing only a single year confounded the interpretation of the analysis. Therefore, only vessels that fished at least 10 sets in at least two years were included. Because of data availability, the analysis was restricted to the Newfoundland and Scotian Shelf regions in the fall and winter for the period after 1994. GLM trends for swordfish and bigeye tuna were similar and therefore were left together in the same analysis; the different trend for bluefin tuna necessitated a separate analysis, and because it was less informative, it was not presented here (Campana et al. 2004).

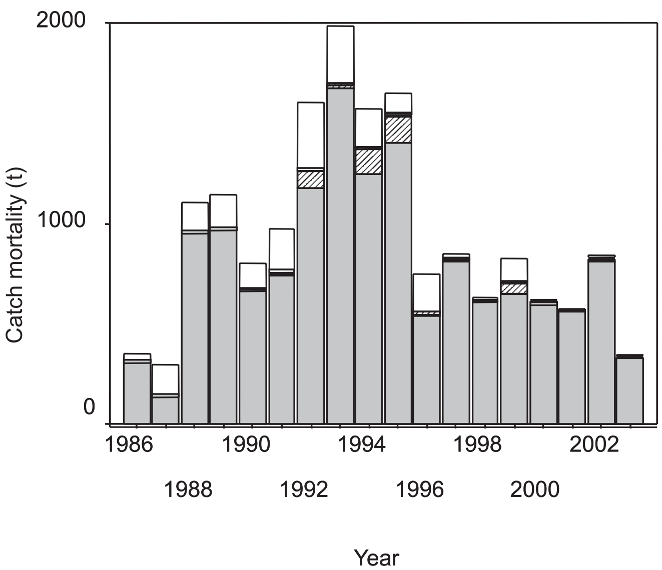
The GLM of blue shark catch rate based on the bigeye tuna and swordfish data indicated that all factors but season and species sought were significant (Table 5). The marginal catch rate based on the significant factors indicated that catch rates have declined significantly by 53% (6.6% per year) since 1995 (Fig. 6). Although this GLM used most of the data, there was some aliasing between the early Japanese and later Canadian data. Nevertheless, when the model was

Table 4. Total blue shark (*Prionace glauca*) catch (tonnes) in Atlantic Canada by source.

Year	Derbies	Recreational[a]	Landed commercial[b]	Observed foreign catch[c]	Observed foreign discards[d]	Observed Canadian discards[e]	Estimated catch and discards from Canadian fishery[f]	Total estimated catch mortality[g]
1986				13	32		801	365
1987				38	123		367	308
1988				6	146		2421	1120
1989				10	172	42	2446	1160
1990			8	13	125	7	1680	818
1991			31	11	207	20	1857	992
1992			101	60	285	2	2940	1622
1993	4	3	21	91	205	14	4190	1998
1994	5	3	133	116	210	53	3118	1586
1995	6	4	145	73	100	106	3505	1667
1996	5	3	18	173	61	37	1352	762
1997	10	7	9	36	0	28	2026	867
1998	10	7	4	17	17	210	1518	646
1999	15	10	53	11	282	185	1616	840
2000	15	11	19	0	3	70	1471	626
2001	8	13	0.4	0	0	179	1426	581
2002	19	13	5	0	4	228	2029	840
2003	12	13	6	0	0	85	811	345

[a]Catch and release fishery, excluding derbies; 2001–2003 estimated from recreational logbooks and phone survey; other years assumed to be 0.66 of derby catches based on tag recaptures and 2002–2003 ratios.
[b]Canadian landings only.
[c]Scotia–Fundy Observer Program measurements of all foreign-kept catch.
[d]Scotia–Fundy Observer Program measurements of all foreign-discarded catch.
[e]Scotia–Fundy Observer Program measurements of Canadian discards; coverage was about 5% of fleet.
[f]Sum of bycatches from porbeagle, bluefin tuna, swordfish, and other tuna fisheries.
[g]Sum of landed catches and hooking mortality applied to recreational, domestic commercial, and foreign discards; foreign discards before 1994 assumed to be dead as the result of finning.

Fig. 4. Total catch mortality (tonnes (t)) by source for blue sharks (*Prionace glauca*) caught in Atlantic Canadian waters: Canadian landings, hatched bars; tournament catches, solid bars; foreign catches, open bars; Canadian discards, shaded bars.



rerun using Canadian vessels only, the predicted trend was very similar to that presented in Fig. 6.

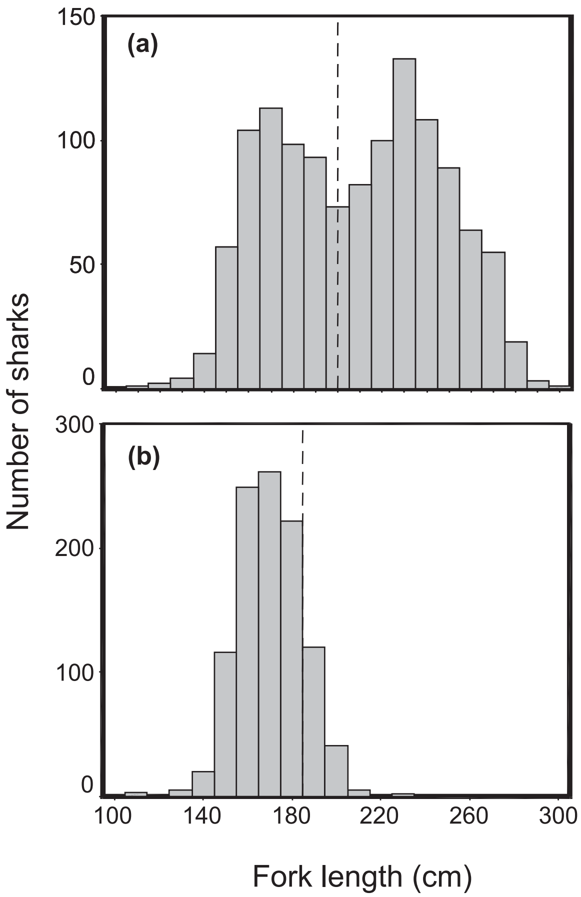
Additional models were run to assess the sensitivity of the results. Models using all vessels (rather than vessels fishing multiple years) produced marginally higher correlation coefficients but with fewer estimable years. Predicted trends were similar. In contrast, models using country rather than CFV explained much less of the variation. Therefore, the model presented in Table 5 was selected as the best available.

Fishing success at shark fishing tournaments suggested a significant decline of 27% (5.4% per year) in catch rates since 1998 (Fig. 7). A standardized catch rate prepared using a binomial dependent variable (successful/unsuccessful) and derby location as a fixed factor in a GLM was not statistically significant. Because individual catch rates were not available, an index based on the percentage of fishers successful in catching a shark at each derby was used. This model was less than ideal as the derbies represented fixed factors and thus year × derby interaction terms could not be assessed. Nevertheless, when scaled to the same scale as the standardized commercial catch rate model, the trend across years was similar. These results suggest that the derbies and the offshore commercial fishery are samples from the same population and that the catch rate in recent years has been less than that of earlier years.

Exploitation rate from tag recaptures

The exploitation rate of blue sharks in Canadian waters was estimated through Petersen analysis of tag recaptures (Ricker 1975). Despite the relatively high tagging effort in the Canadian study, there were only 17 recaptures in the 1960s and 1970s. Annual exploitation rates never exceeded

Fig. 5. Length frequency by sex for blue sharks (*Prionace glauca*) examined at shark fishing tournaments. Length at 50% maturity for each sex is shown by the broken vertical lines. (*a*) The mean fork length of males was 208 cm (n = 1213); (*b*) the mean fork length of females was 170 cm (n = 1047).



1%, and overall recapture rates (which will always overestimate exploitation rate) never exceeded 1.6% (mean of 0.4%). Although the tag-reporting rate for blue sharks was undoubtedly lower than that of more commercially valuable species, we suspect that the low recapture rate was due in part to the relatively low longline fishing effort of the period, as well as emigration out of the area.

Analysis of the US tagging data provided several relative indices of exploitation rate in Canada. Mean exploitation rate in the tagging year, weighted by tagging effort, was 0.78% between 1992 and 2002, corresponding to a mean annual observed catch of 321 t. Nonreporting of tags by the commercial fishery would result in this calculated exploitation rate being an underestimate.

To provide an estimate of exploitation rate which is unaffected by reporting rate, we repeated the calculation using a subset of the fishery — the recreational fishery — which is highly motivated to report any recovered tags. Because the recreational fishery is responsible for most of the recent tagging effort on blue sharks, it is safe to assume that the tag-reporting rate is close to 100% in this segment of the fishery. To calculate the recreational exploitation rate, we looked only at Canadian tags applied inshore in known recreational shark fishing grounds (and therefore assumed to represent tags applied by recreational fishers) (n = 212) and recaptured inshore during shark fishing derbies in the same year (n = 1), multiplied by 2 to allow for the fact that tags were applied throughout the recapture season. Mean weighted exploitation rate by the recreational fishery at scientifically monitored fishing tournaments was very small (0.94%). However, the confidence interval around the estimate was broad, ranging from 0.1% to 7%. The fact that the tagging area did not represent a closed population implies that exploitation rate would be underestimated, although it is likely that within-season emigration out of the area was low.

As an overall comparison of recent and historic blue shark exploitation rate, we compared the overall recaptures per tag in the period 1961–1972 with that of 1992–2002. The mean recapture rate increased from 0.009 to 0.089. Assuming comparable reporting rates in the two periods, this comparison suggests that fishing mortality on blue sharks increased 10-fold between the two periods. Longline fishing effort in the North Atlantic increased 8-fold between these two time periods (ICCAT 2005), which appears to explain much of the increased fishing mortality.

Trends in length composition

A biological indicator of increased exploitation rate is a long-term decline in length in the catch. There has been a significant decline in mean blue shark length in the observed longline catch since the late 1980s ($P < 0.05$; Fig. 8). Significant differences were also observed in the length composition between the Canadian and Japanese fleets ($P < 0.05$), but these are almost certainly due to differences in depths fished (Campana et al. 2002*a*). An index based on measurements made at the shark tournaments could not be used as the tournament length composition was not representative of the population.

Discussion

Our results indicate that the blue shark is the most frequently caught large shark in the Canadian Atlantic, despite negligible landings. The reported catch of blue sharks grossly underestimates both the actual catch (sum of landed catch and discards) and the catch mortality. The nominal catch of blue sharks by both domestic and foreign longline fisheries only accounts for about 5% of their actual catch. Based on reasonable estimates of bycatch mortality, the sum of nominal catch and bycatch mortality has averaged about 1000 t annually since 1986, with most of this being the result of discard mortality. This figure is larger than the annual average catch of porbeagle shark (*Lamna nasus*), for which there is a directed fishery (Campana et al. 2002*b*). The only shark species on the east coast of Canada that might be caught in larger numbers is the spiny dogfish (*Squalus acanthias*) (Rago et al. 1998).

Some members of the public have expressed concern that recreational shark fishing tournaments have had an adverse effect on the blue shark population. The weight of sharks landed at recreational shark tournaments has increased from around 4 t in 1993 to around 15 t in recent years. Blue sharks accounted for 99% of all sharks landed. The recreational catch-and-release fishery caught about another 13 t annually. However, these catch figures are very small com-

Table 5. Results of the catch rate standardization model relating the catch rate (ln-transformed kilograms per hook) of blue shark (*Prionace glauca*) in bigeye tuna (*Thunnus obesus*) and swordfish (*Xiphias gladius*) fisheries to region, season, vessel (CFV), species sought (SPECS), and year (YR).

Source	Type III sum of squares	df	Mean square	F	Significance (p)
Corrected model	286.034	62	4.613	6.741	0.000
Intercept	5.832	1	5.832	8.521	0.004
CFV	86.729	12	7.227	10.560	0.000
YR	39.565	7	5.652	8.258	0.000
CFV × YR	4.097	8	0.512	0.748	0.649
SEASON	0.011	1	0.011	0.017	0.898
REGION	2.737	1	2.737	3.999	0.046
CFV × SEASON	2.508	3	0.836	1.222	0.301
CFV × REGION	2.180	5	0.436	0.637	0.672
YR × SEASON	0.373	2	0.186	0.272	0.762
YR × REGION	7.204	4	1.801	2.631	0.034
SEASON × REGION	0.513	1	0.513	0.749	0.387
SPECS	0.259	1	0.259	0.379	0.539
CFV × SPECS	0.069	2	0.035	0.051	0.951
YR × SPECS	0.000	0			
SEASON × SPECS	0.000	0			
REGION × SPECS	0.000	0			
Error	275.135	402	0.684		
Total	996.625	465			
Corrected total	561.169	464			

Note: $R^2 = 0.51$ (adjusted $R^2 = 0.43$).

Fig. 6. Standardized commercial catch rate (ln-transformed kilograms per hook ± 95% confidence interval) of blue shark (*Prionace glauca*) in Canadian and Japanese large pelagic fisheries targeting bigeye tuna (*Thunnus obesus*) and swordfish (*Xiphias gladius*).

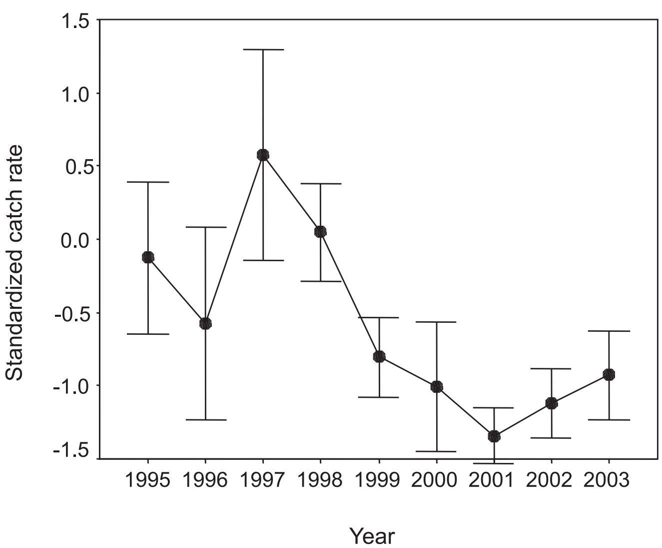
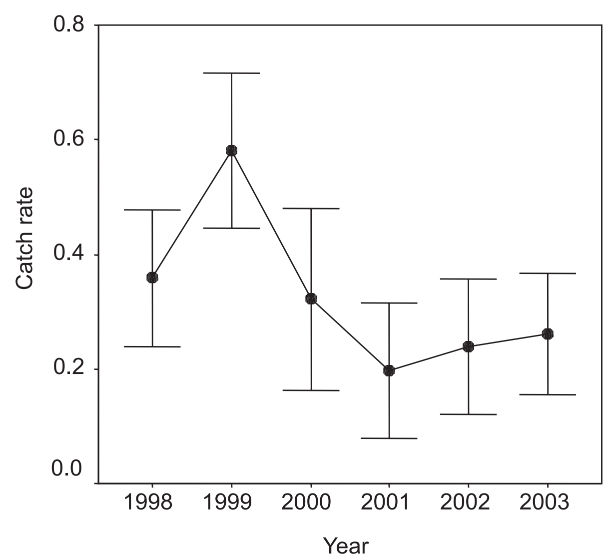


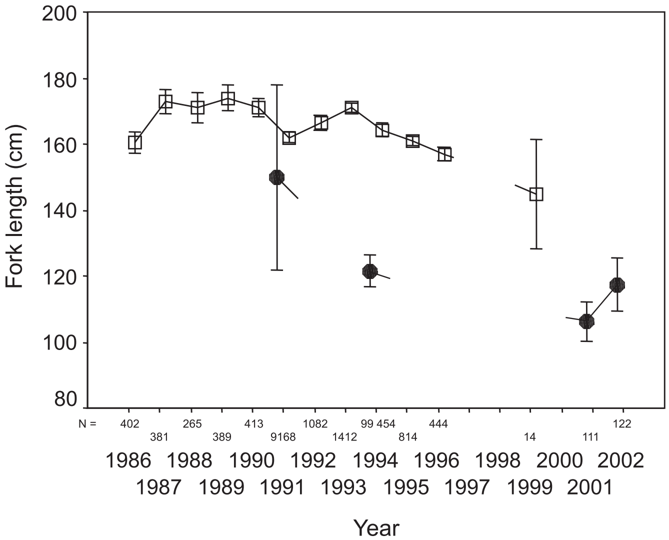
Fig. 7. Catch rate (sharks per fisher ± 95% confidence interval) of blue sharks (*Prionace glauca*) at recreational shark fishing tournaments.



pared with overall catch mortality in Canadian waters, accounting for about 3% of the total fishing mortality. Thus tournaments have had a negligible effect on population abundance and overall mortality. The ethical questions surrounding shark tournaments (which are essentially trophy tournaments) were not addressed by this analysis.

Two indices of population abundance suggest that blue shark abundance in the Canadian Atlantic has declined in the past decade. Standardized catch rate indices from both the commercial large pelagic fishery and recreational shark tournaments suggest a decline in blue shark abundance of about 5%–6%·year^{-1} since 1995. Similarly, the median size of blue sharks in the commercial catch has declined since 1987, suggesting an increase in mortality rate. In the only published

Fig. 8. Trend in mean fork length (±95% confidence interval) of blue sharks (*Prionace glauca*) caught in fall and winter in Japanese (□) and Canadian (●) pelagic longline fisheries.



overview of the status of Northwest Atlantic blue sharks, Baum et al. (2003) used a model of commercial catch rate from the logbooks of US fishers to conclude that the population had declined monotonically by 60% (4.3%·year^{-1}) over the period 1986–2000. However, this conclusion was at odds with the 9.6% decline, characterized by increasing and then decreasing abundance, for the area of highest blue shark abundance off of eastern Canada. Although Baum et al. (2003) acknowledged that the Atlantic Canada trend did not match the modelled overall trend, it is difficult to rationalize the very different trends between the overall model and the region with the greatest number of blue sharks. It is unlikely that the unregulated fishers' logbooks used by Baum (2002) and Baum et al. (2003) were as accurate as the observer records reported here. Nevertheless, their analysis covered a broader proportion of the blue shark geographic range than was represented in the Canadian data presented here. Therefore, it is interesting to note that the observed (as opposed to the modelled) Atlantic Canada time series of Baum (2002) was very similar to the GLM fit to the Canadian and Japanese observer time series of Fig. 7. Based on this correspondence and assuming that catch rate reflected relative abundance in the same way across the time series, it seems likely that the relative abundance of blue sharks has declined since the 1990s.

A perspective on the status of North Atlantic blue sharks

It is unlikely that the reported catch of blue shark in the North Atlantic is anywhere near the true catch: with a negligible commercial value, most blue sharks are discarded at sea with no record of having being caught. This point was highlighted in the Canadian Atlantic, where both the domestic and the foreign nominal catch grossly underestimated the catch mortality, let alone the catch.

Given reliable large pelagic catch records in the North Atlantic — the catch of valuable tuna and swordfish species is monitored closely by ICCAT — it should be possible to approximate the catch of blue shark in the large pelagic fisheries by applying a bycatch proportion calculated from observed fisheries. Blue shark bycatches by both foreign and domestic fisheries have been observed and recorded for 17 years in the Canadian Atlantic; therefore, the proportion of blue shark in the large pelagic catch is well known. A major assumption of this approach is that the proportion of blue shark in the large pelagic catch of the observed fishery is similar to that elsewhere in the North Atlantic. Campana et al. (2004) reviewed the literature for estimates of blue shark catch rate throughout the North Atlantic and reported that the overall blue shark catch rate (mean ± 95% confidence interval) was 18.4 ± 8.3 blue sharks per 1000 hooks. Although differences among studies were noted, there were no consistent differences in blue shark catch rate between eastern and western Atlantic, or between Canadian, American, and European fisheries. More importantly, the ratio of blue shark to the directed species appeared to be similar across locations. Thus, as a first approximation, it appeared reasonable to assume that relative blue shark abundance was similar in all North Atlantic large pelagic fisheries.

The total catch of large pelagics documented by ICCAT for the Atlantic in the year 2000 was 620 808 t (from ICCAT Task 1 online database, available at http://www.iccat.es/data/taski_excel.zip). To restrict the estimate to the North Atlantic, we excluded all catch entries from the South Atlantic and reduced by 75% the entries from the eastern and western tropics (assuming that one-half of the tropics was from the northern tropics and that blue shark abundance was less in tropical waters than in temperate waters). The final North Atlantic large pelagic catch estimate for 2000 was 316 182 t, which is likely to be a conservative estimate. Assuming a 34% bycatch of blue sharks (as calculated earlier), the total blue shark catch is estimated at more than 100 000 t. This value is almost four times the nominal catch listed in Table 1. Assuming a 40% hooking mortality in the longline fishery and an arbitrary 20% mortality in the purse seine fishery (as hook injury would not be a source of mortality in purse seines), the catch mortality of blue sharks in the year 2000 was estimated to be about 37 000 t. This value is considerably more than the nominal catch but is still likely to be an underestimate because of nonreported large pelagic catch and the fact that the large pelagic catch rate is somewhat higher in the Canadian Atlantic than elsewhere (a high large pelagic catch rate would result in a lower blue shark to large pelagic catch ratio). In addition, our estimate of blue shark catch mortality does not take into account any mortalities resulting from finning in unregulated, unobserved international waters.

An independent estimate of North Atlantic blue shark catch mortality is possible using the exploitation rate calculated from tagging and a previously reported fishing mortality estimated from the catch curve analysis of Campana et al. (2004). The Canadian exploitation rate from the US tagging study was 0.0078, corresponding to an observed catch in Canadian waters of 321 t. Given the population-level F of 0.66 (= exploitation rate of 0.48) from the fast-growth catch curve (Campana et al. 2004, their fig. 22) and assuming a 75% tag-reporting rate from the observed catch, the North Atlantic catch mortality would be 26 300 t.

These two independent approximations of total North Atlantic blue shark catch mortality, based on bycatch ratios and mortality estimates, suggest North Atlantic catches of more than 100 000 t and catch mortalities of between 26 000 and 37 000 t. As first approximations, these probably provide conservative estimates of actual blue shark catch mortality in the North Atlantic, although they are in line with the blue shark catches estimated by ICCAT (2005). Nevertheless, the Petersen analysis of tag recaptures indicated that the exploitation rate in Canadian waters appears to be but a small portion of the total. Similarly, the total Canadian catch mortality was only about 2% of the total estimated catch mortality for the entire North Atlantic. Therefore, the Canadian contribution to overall population mortality appears to be very low.

An obvious question to ask is to what extent do indices of blue shark abundance and mortality in Canadian waters reflect those for elsewhere in the Atlantic. The tagging studies indicated that most of the tagged blue sharks recaptured in our waters were tagged in the US. In contrast, most of the tags applied in Canadian waters were later recaptured in the central and eastern Atlantic, some as far away as Africa. Overall, the tagging studies were consistent with the view that blue sharks are highly migratory, with no evidence of extended residency in Canadian waters. These results are consistent with those of previous tagging studies, which show high flux rates among areas (Casey and Kohler 1991), and suggest that Canadian indices of blue shark population status may be a reasonable proxy for blue sharks elsewhere in the Northwest Atlantic. Nevertheless, it is clear that blue sharks are not randomly mixed in the Atlantic Ocean as a whole. Mature females were rare in both the tournament and commercial catches, presumably because of their absence from Canadian waters. They also appear to be rare along the eastern coast of the US (Pratt 1979) but somewhat more common in the Northeast Atlantic (Buencuerpo et al. 1998). Thus the North Atlantic population as a whole appears to be a heterogeneous mixture by size and sex.

So how does the blue shark population manage to survive in the face of such high catch mortalities? A life table analysis using demographic values drawn from the literature and a value for the instantaneous rate of natural mortality (M) of 0.23 indicates that the intrinsic rate of population growth (r) in an unfished population would be about 0.36 (Campana et al. 2004). This translates into a 43% annual rate of increase in the absence of fishing. F_{MSY} (instantaneous rate of fishing mortality at maximum sustainable yield) would be about 0.18. Assuming 100% availability of females of all ages to the fishing gear, an instantaneous fishing mortality (F) of 0.32 would result in zero population growth. Such values of F are high by shark standards but are consistent with published views that blue sharks are relatively resilient to moderate fishing pressure and are both productive and resilient compared with other shark species (Cortés 1998; Smith et al. 1998; Frisk et al. 2001). This may explain why blue sharks have been slow to decline in the face of what appears to be a very high overall catch mortality. An additional factor aiding their persistence is the fact that few mature females are caught either in Canadian or American waters (Pratt 1979; this study).

Blue sharks have low commercial value and are discarded in great numbers by commercial pelagic fisheries. Despite their persistence to this point, their decline in relative abundance, decline in median size, and their high overall exploitation rate are all indicators of excessive mortality. The presence of a highly migratory population in the international waters of the North Atlantic complicates any attempt at concerted management or conservation. Nevertheless, continued and careful monitoring appears to be warranted.

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