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Influence of Recreational and Commercial Fishing on the Blue Shark (*Prionace Glauca*) Population in Atlantic Canadian Waters

Incidence de la pêche récréative et commerciale sur la population de requin bleu (*Prionace glauca*) des eaux canadiennes de l'Atlantique

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Abstract

The nominal catch of blue sharks in the Canadian Atlantic grossly underestimates the actual catch mortality. Based on new estimates of bycatch mortality, the sum of landed catch and bycatch mortality in the Canadian Atlantic has averaged about 1000 mt annually since 1986.

Most of the tagged blue sharks recaptured in our waters were tagged in U.S. waters. In contrast, most of the tags applied in Canadian waters were later recaptured in the central and eastern Atlantic, 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.

The weight of sharks landed at recreational shark tournaments has increased from around 4 mt in 1993 to around 20 mt in recent years. Blue sharks accounted for 99% of all sharks landed. The recreational catch and release fishery catches another 13 mt annually. Mature females were not present in the catches due to their absence from Canadian waters. However, the size composition at the derbies was not representative of the population: small sharks were poorly represented (due to derby catch restrictions) and large males were over-represented (due to their being targeted by derby participants).

Some members of the public have expressed concern that recreational shark fishing tournaments are having an adverse effect on the blue shark population. The results of this analysis indicate that shark tournaments only account for about 3% of the fishing mortality in Canadian waters, and thus are having a negligible effect on population abundance and overall mortality. The ethical questions surrounding shark tournaments were not addressed by this analysis.

Several indices of population health suggest that blue shark abundance has declined, and mortality has increased, in the past decade. Median size in the catch has declined, as have standardized catch rates from both commercial longline fisheries and recreational shark tournaments. These declines are consistent with an unpublished analysis of U.S. logbooks, but of smaller magnitude than that reported in a widely-reported article in Science.

Catch curve analysis suggests a very high fishing mortality on the population as a whole. However, Petersen analysis of tag recaptures indicates that the exploitation rate in Canadian waters was < 1%.

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 mt and catch mortalities of between 26,000 and 37,000 mt. As first approximations, they probably provide conservative estimates of actual blue shark catch mortality in the North Atlantic. As such, the Canadian contribution to overall population mortality is very low.

Blue sharks have low commercial value and are discarded in great numbers by commercial pelagic fisheries. Life table analysis indicates that blue shark populations are both productive and resilient compared to other shark species, a fact which may help explain their persistence in the face of a high overall catch mortality and a decline in relative abundance. Nevertheless, careful monitoring of population status appears to be warranted.

Résumé

Les prises nominales de requin bleu dans les eaux canadiennes de l'Atlantique sous-estiment nettement le niveau de mortalité réel par capture. D'après de nouvelles estimations du niveau de mortalité par capture, le total des prises débarquées et des prises accessoires rejetées à l'eau dans le Canada atlantique se situe en moyenne à quelque 1 000 tm par an depuis 1986.

La plupart des requins recapturés dans nos eaux avaient été étiquetés dans des eaux américaines. Des individus étiquetés dans les eaux canadiennes, la plupart ont été recapturés dans l'Atlantique Centre et l'Atlantique Est, aussi loin qu'en Afrique. En général, les résultats des études d'étiquetage correspondent à l'observation à l'effet que le requin bleu est hautement migratoire, rien ne prouvant qu'il reste longtemps dans les eaux canadiennes.

Le volume de requins capturé lors des tournois de pêche récréative a augmenté, passant d'environ 4 tm en 1993 à environ 20 tm dans les dernières années. Le requin bleu comptait pour 99 % des prises. Viennent s'y ajouter les prises de la pêche récréative avec remise à l'eau, qui se chiffrent à 13 tm par an. Des femelles d'âge mûr n'ont pas été capturées parce qu'elles n'entrent pas dans les eaux canadiennes. Toutefois, la composition par taille des prises des tournois de pêche n'est pas représentative de la population : les petits requins y sont mal représentés (à cause des restrictions sur les prises par les tournois) et les gros mâles sont surreprésentés (étant la cible des participants).

Un certain nombre de particuliers s'inquiètent que les tournois de pêche récréative du requin aient un effet défavorable sur la population de requin bleu. Les résultats de cette analyse indiquent que ces tournois sont à l'origine d'environ 3 % seulement du taux de mortalité du requin par pêche dans les eaux canadiennes, et n'ont donc qu'un effet négligeable sur les effectifs de la population et le niveau de mortalité global. Les questions d'éthique que posent les tournois de pêche du requin ne sont pas abordées dans cette analyse.

Plusieurs indices de l'état de santé de la population suggèrent que l'abondance du requin bleu a diminué et que le niveau de mortalité a augmenté au cours de la dernière décennie. La taille médiane des prises a diminué, tout comme les taux de capture normalisés réalisés dans le cadre des pêches commerciales à la palangre et des tournois de pêche récréative. Ces déclins concordent aux résultats inédits d'une analyse des registres de pêcheurs américains, mais ils sont de moindre ampleur que ceux signalés dans un article de grande diffusion publié dans *Science*.

L'analyse d'une courbe des prises semble indiquer que la population dans l'ensemble est soumise à un niveau de mortalité par pêche très élevé. Par contre, une analyse Petersen du nombre de requins étiquetés qui ont été recapturés indique que le taux d'exploitation dans les eaux canadiennes est inférieur à 1 %.

Deux approximations indépendantes du niveau total de mortalité du requin bleu par capture dans l'Atlantique Nord, reposant sur les taux de prises accessoires et des estimations des niveaux de mortalité, laissent supposer des prises dans l'Atlantique Nord de plus de 100 000 tm et des niveaux de mortalité par capture de 26 000 à 37 000 tm. Étant de premières approximations, elles représentent probablement des estimations modérées du niveau de mortalité réel du requin bleu par capture dans l'Atlantique Nord. La contribution canadienne au niveau total de mortalité est donc très faible.

Le requin bleu ayant peu de valeur commerciale, il est rejeté à la mer en grand nombre lorsque pris dans le cadre des pêches pélagiques commerciales. Une analyse de la table de survie révèle que les populations de requin bleu sont très productives et résilientes en comparaison d'autres espèces de requin, un fait qui pourrait expliquer leur persistance en dépit du niveau élevé de mortalité par capture et du déclin de l'abondance relative. Malgré cela, une surveillance étroite de l'état de la population semble justifiée.

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, 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. FAO's recently released *International Plan of Action for the Conservation and Management of Sharks* (FAO 1998) concluded that many of the world's shark species are severely depleted. The issue was also highlighted in an American Fisheries Society policy statement, which 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 at sexual maturation. Although the blue shark is among the more productive of pelagic shark species (Cortés 2000), a sustainable catch level or fishing mortality has never been calculated for blue sharks in the North Atlantic. Our earlier paper provided first estimates of blue shark catch and bycatch in the Canadian Atlantic, concluding that unreported bycatch was about 20 times larger than reported catch (Campana et al. 2002). The first objective of the current analysis was to provide improved catch and bycatch estimates, estimates of discarding mortality, and several indices of exploitation rate and population status in the Canadian Atlantic for this shark species. A second objective was to provide an initial description of the recreational shark fishery in the Maritimes, along with an appraisal of its impact on blue shark population status.

Biology

Morphometry

Various measures of blue shark size have been used in the past: fork length and total length 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 blue 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.

Prior to 1996, length measurements at recreational shark tournaments were recorded as total length with the top lobe of the caudal fin depressed to the midline. Since this is a non-standard measurement, shark measurements at pre-1996 tournaments were estimated based on the conversion from dressed weight.

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. A total of 2017 tags were applied to blue sharks in a Canadian tagging program carried out between 1961-1980 (Burnett et al. 1987) (Table 15). Most of the tags 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 U.S. waters (Fig. 2).

A second tagging study was carried out by the National Marine Fisheries Service of the U.S., in cooperation with Canadian fishers. This study applied thousands of tags to blue sharks in U.S. and international waters, of which 916 tags were applied in Canadian waters between 1971-2002 (Table 16). With most of the tagging effort taking place after 1990, this study provides a view of recent migration patterns.

The NMFS tagging program resulted in 188 recaptures in Canadian waters between 1974-2002: 171 from foreign tagging and 17 from Canadian tagging. Most of the tagged sharks recaptured in our waters were tagged in the U.S., a pattern which would be expected given that most of the tagging effort was concentrated in the U.S. (Fig. 3 bottom). 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. 3 top). There was no obvious difference in migration pattern between males and females, or between small and large sharks.

Overall, the tagging studies were consistent with the view that blue sharks are highly migratory, with no evidence of extended residency in Canadian waters. The fact that few of the sharks tagged in Canada were later recaptured in the U.S. supported the hypothesis that many blue sharks migrate in a clockwise gyre across the North Atlantic.

Reproduction

Size at sexual maturity was assessed in examinations of more than 2000 blue sharks landed at shark tournaments. Males were considered to be sexually mature if sperm was present in the ampulla epididymis, if the claspers were calcified and could be freely rotated, and if the rhipidion could be opened and the terminal spur extruded. Females were considered to be mature if the uterus was enlarged or flaccid, or if embryos or ova were visible. Our results indicated that the length at maturity varied between 193-210 cm for males with a length at 50% maturity of 201 cm (Fig. 4). There has been no trend in length at male maturity since 1999 ($p > 0.1$). Mature females were seldom caught at shark tournaments, and 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). The blue shark is a viviparous species, with litters usually consisting of 25 to 50 pups after a gestation period of between 9 and 12 months. Newborn pups measure 40 to 51 cm in length. After copulation the females may retain and nourish the spermatozoa in the oviducal gland for months or years while awaiting ovulation.

Age and Growth

There are no well validated age and growth models for blue sharks. Skomal and Natanson (2003) used vertebral sections to estimate age, concluding that longevity was between 16 and 20 years. Growth based on recapture of tagged sharks was more rapid than that based on vertebral sections, but the two recaptures of tetracycline-tagged sharks were at liberty for too short a period to be able to reliably validate the vertebral sections. In contrast, growth estimated from examination of whole vertebrae suggested a growth rate similar to that of the recaptured sharks (MacNeil and Campana 2003). However, no validation was available for these age interpretations either. In neither study was there evidence of sexually dimorphic growth before sexual maturity, although Skomal and Natanson (2003) noted a slightly reduced growth rate for mature males.

Comparison of the two growth models indicates that there is little difference for blue sharks less than about 4 years of age, but that the lengths at age increasingly diverge after that point (Fig. 5). Accordingly, the two models were used to bracket the likely range of size at age estimates required for the catch curve estimates of total mortality presented later. Plots of the standard deviation versus the mean length at age suggested no relationship; therefore, standard deviation was assumed to be invariant with age, with a value of 12 for the Skomal and Natanson (2003) model and a value of 18 for the MacNeil and Campana (2003) model.

Fisheries Management

Since 1995, fisheries management plans for blue sharks in Atlantic Canada have maintained non-restrictive catch guidelines of 250 mt annually for blue sharks in the directed shark fishery. The non-restrictive catch guidelines approximated the reported landings of these species in Atlantic Canada in 1992 and 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 is 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. (2002).

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 the EEZ. Landings peaked at around 250 mt in 1994, declining thereafter to only 19 mt in 2003 (Table 1). Only Canadian, Japanese and Faroese vessels are known to have caught 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 mt in the 1990s. North Atlantic nominal catches are substantially larger, averaging over 30,000 mt 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 mt per year since 1990. Most of the landings are from longlines, although recreational shark fishing derbies averaging 10-20 mt annually have accounted for a growing proportion of the landings in recent years. 1986-2001 catch locations mapped by quarter indicate that most of the 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 (Fig. 6).

Minor differences between the Canadian catch reported in Table 1 and the corresponding table of Campana et al. (2002) are due to the more accurate derby landings reported here.

Shark Tournaments (Derbies)

The weight of sharks landed at recreational shark tournaments has increased from around 4 mt in 1993 (the first year of the derbies) to around 20 mt in recent years (Table 2). Although shortfin mako (*Isurus oxyrinchus*), thresher (*Alopias vulpinus*), and porbeagle (*Lamna nasus*) have all been caught at derbies, blue sharks account for 99% of all landings.

Shark derbies in Atlantic Canada are currently located all 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 shown in Table 3. Fishing locations are centred in the waters around Halifax and Lockeport, and in the southern Bay of Fundy (Fig. 7).

Recreational Shark Fishery (Catch and Release)

DFO regulations state that the recreational shark fishery is to be catch and release only, with the exception of shark derbies. Although the catch and release fishery is designed to return all sharks to the water while alive, some level of hooking mortality is inevitable. Therefore, we estimated the total recreational shark catch using two independent methods, then estimated catch mortality using assumptions of hooking mortality.

Phone Survey

A total of 1400-1800 recreational shark fishing licences were issued annually between 2001 and 2002. Since relatively few of these returned fishing logs, 201 recreational shark fishers were selected for over-the-phone interviews conducted between September and December 2002. A sample of 100 fishers were randomly selected, and then contacted, from the list of licences which were issued in 2002. Using the shark derby logs from the previous 6 years, an additional 100 ‘frequent’ shark fishers were identified based on names which appeared more than once in the logs. These samples sizes represent ~10% of the licencees. Considerable effort was expended contacting fishers who could not be contacted on first attempts. The survey questioned fishers about the number of shark fishing trips made in the two most recent fishing years, as well as their catches on each of those trips.

The results of the phone survey are shown in Table 4A. The percentage of licencees who actually fished for sharks in one of the two years was relatively small: 7% of the random sample, and 14-22% of the ‘frequent’ fishers. Of these, most fished 2-3 times per year, catching 4-12 sharks annually. The median annual catch/licence was <1.

There was no evidence that frequent fishers were any more successful than the random sample of fishers.

Shark Fishing Logs

Less than 2% of the recreational licencees returned fishing logs at the end of the fishing year (Table 4B). The average number of trips per year was very similar to that reported in the phone survey (excluding charter operators, which are shown separately). However, the median number of sharks caught per year was much less than that reported in the phone survey. Since the recreational fishing logs were returned voluntarily and prepared after more thought than the phone surveys, it is likely that they represent a more accurate indication of average catch than do the phone surveys.

Estimation of Total Annual Recreational Catch

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 (Table 4C). The mean weight of an individual shark in the recreational shark catch could not be determined directly from derby landings, since derby fishers discard large numbers of undersized sharks. According to derby logs since 1995, the number of discarded sharks was equal to 34% of the number retained; however, not all fishermen recorded discarding in their logs, so this number is an underestimate. Based on informal interviews with derby participants, the actual percentage discarded is considerably higher. Therefore the calculation of mean individual shark weight assumed that 50% of the sharks caught were undersized and therefore discarded.

Charter fishery catch rates were considerably higher than were those of individual fishers, so they were tabulated separately (Table 4C). The final estimate for annual recreational shark catch outside of derbies was 12.5 mt.

As an independent estimate of the recreational catch, the number of tags returned as part of fully-monitored shark derbies was compared to the number caught by Canadian recreational fishers throughout the year. Derby tag recaptures accounted for 4 out of the 6 recaptures. Although the sample size is relatively low, this ratio is almost identical to the ratio of 0.63 obtained from comparing the recreational shark catch calculated above to the derby catches. Therefore the recreational shark fishery was assumed to catch 0.66 of the derby catch for the years before 2001.

Bycatch

Observed Bycatch

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 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 (Table 5). Blue shark bycatch in fisheries other than that for large pelagics was much smaller, although the 1-2 mt observed on 4X groundfish longlines could add up to 20-60 mt annually when pro-rated across non-observed trips.

Observed catch and bycatch between 1990-1999 averaged about 250 mt annually, with most of that coming from Japanese vessels. In most years, virtually all of the blue shark catch was discarded (Table 5). Since 1999, virtually all observed catch and bycatch has been by Canadian vessels. Catch locations mapped by quarter over the period 1986-2001 indicate that most of the Canadian bycatch occurred in deep waters off the continental shelves of Nova Scotia and Newfoundland, increasing in quantity through the year (Fig. 8). 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. 9). 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 (Fig. 10).

Estimation of Unobserved Blue Shark Bycatch

To determine the magnitude of the blue shark bycatch in the various large pelagic fisheries, bycatch was estimated by country, fishery, quarter and year from Scotia-Fundy Observer Program (SFOP) observations made between 1986-2000, 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, since they accounted for more than 99% of the blue shark catch. Bycatch in the foreign fisheries was fully observed, so estimation was used more to calculate bycatch proportion than bycatch weight. Total pelagic catch for each cell was determined from ZIF for Canadian vessels, and from

SFOP for foreign vessels. Full details on the estimation protocol are presented in Campana et al. (2002).

For the 6 large pelagic fisheries (3 Japanese, 3 Canadian) other than porbeagle, mean blue shark bycatch accounted for 26-152% of the total large pelagic catch, with an overall mean of 34%. Blue shark bycatch in the porbeagle fishery was substantially less, averaging 7%. Since there were no consistent trends across years, the weighted mean proportion (weighted by number of observed sets) across years was used to estimate the Canadian bycatch. Therefore, each quarter and fishery was characterized by a unique bycatch proportion, but this proportion was maintained for all years. This method of calculation is considered to be less susceptible to sampling variability than was the year by year method of Campana et al. (2002). In addition, the sum of the large pelagic catches was updated and revised from those of Campana et al. (2002).

Anecdotal reports on observer catch estimation methods highlight the difficulty of estimating, or even recording, the component of the catch which is not brought onto deck before discarding. Since some Canadian vessels routinely remove blue sharks (or cut off the leader) before they reach the deck, it is likely that the estimated bycatch proportions calculated above represent the minimum actual Canadian bycatch. In order to estimate the extent of any such underreporting, we prepared a second set of analyses based only on those sets which reported at least one blue shark. This second set of bycatch proportions assumes that blue sharks were caught in all sets, but reported only in some; thus it sets an upper limit to the bycatch estimate. We have termed this a maximum estimate. Campana et al. (2002) concluded that blue shark bycatch on Canadian vessels fishing swordfish or other tunas was underreported by some observers, and that actual bycatch lies somewhere in the range defined by our minimum and maximum bycatch estimates. For the current analysis, we have assumed that the mean of the minimum and maximum bycatch estimates represents the most probable bycatch for these fisheries. Minimum bycatch estimates appear to be valid for the Japanese, bluefin tuna and porbeagle fisheries, although bycatch for both domestic and foreign fleets may have been higher than that shown for the period prior to 1994, due to the prevalence of finning at the time. Minimum, maximum and most probable estimates for each fishery are all shown in Tables 6-9.

Blue shark bycatch and proportions for each year and quarter in the Canadian bluefin tuna, swordfish, and other tuna (albacore, yellowfin, and bigeye) fisheries are presented in Tables 6-9. Bycatch proportions often exceeded 100%. Annual bycatch estimates averaged less than 100 mt for the bluefin tuna fishery, less than 500 mt for other tuna, and around 2000 mt in the swordfish fishery.

Blue shark proportions in the porbeagle fishery tended to be small in both the Canadian and Faroese longline fisheries, averaging 7% (Table 9). Annual bycatch estimates averaged about 50 mt.

Hooking Mortality

A confounding issue in the interpretation of blue shark bycatch concerns the survival or mortality of the discarded sharks. Virtually all blue sharks are discarded after capture. Prior to 1994, all shark bycatch was killed by finning. In principle, sharks discarded alive and in good health after 1994 should not be included in any calculations of fishing mortality or nominal catch. However, many 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.

Table 10 provides a summary of 3 sets of studies made on blue sharks caught as part of both commercial and recreational shark fisheries. The percentage of blue sharks which 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. Since 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.

There is no objective method for determining what percentage of the injured sharks of Table 10 would subsequently die. However, the detailed post-capture examinations of the injured sharks in the scientific study of Table 10 indicates that most were gut hooked. Since gut hooked sharks would appear to be at the highest risk of death, due to potential for damage of internal organs and interference with feeding and/or digestion, we arbitrarily assumed a 50% mortality rate for gut hooked sharks. It is worth noting that many of the gut hooked sharks looked healthy from the outside, which may explain the high variance between the percentage of healthy and injured sharks in the Observer study.

The bottom of Table 10 shows the survival estimates accepted for use in the current analysis. Given that the scientific study is most reliable, and assuming a 50% mortality rate for injured 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%. Note that most discards were finned prior to June 1994; thus those discards were assumed to be 100% dead.

Total Catch Mortality

Total estimated annual blue shark catches and discards in Canadian waters are shown in Table 11. 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 mt per year over the time series (Table 11; Fig. 11). The proportion of catch mortality contributed by tournament fishing was negligible, averaging 3% of the total catch mortality in recent years.

Length Composition

Measurements by scientific staff at shark derbies have provided accurate measurements of blue shark fork length by sex since 1993. These measurements highlight a striking difference between the length compositions of the males and females: mature females are virtually absent from the derby catches (Fig. 12). In addition, the bimodality evident in the male length composition is consistent with targeted fishing for the largest males.

To determine if the length composition in the derby catches is 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 (Fig. 13). The absence of small sharks in the derby catches was almost certainly due to regulations which specify a 6’ (183 cm TL) minimum size limit. In addition, although the length frequencies of the females were similar between commercial and derby catches, large males (>200 cm) were over-represented 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 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 (Fig. 13c). 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.

In summary then, comparison of derby length frequencies with those of the charter and commercial fleets indicated that the size composition at the derbies was not representative of the population: small sharks were poorly represented (due to derby catch restrictions) and large males were over-represented (due to their being targeted by derby participants).

Commercial and Recreational Catch Rates

Commercial Catch Rate

Calculations of commercial catch rate (ln-transformed kg/hook) 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 Scotia-Fundy Observer Program (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 (Newfoundland, eastern Scotian Shelf (NAFO Division 4VWX), and the southern region (NAFO Division 4X, Georges Bank)), season, and species sought (bigeye tuna, swordfish and bluefin tuna). 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. Catch rate trends for these groupings are shown in Fig. 14.

In general, the catch rates of Fig. 14 indicate that catch rates increased after 1994 – this is an artifact of the introduction of the ban on finning in 1994, since blue sharks were often not counted by SFOP unless they were brought up on deck. This practice was changed after 1994 so as to count and estimate the weight of all sharks, whether brought on deck or not. For this reason, the final catch rate analysis was restricted to the period after 1994. Catch rates from 1995 onwards tended to decrease or remain stable, depending on the fishery and season.

The overall trend in catch rate was analyzed using a general linear model with year, region, season, species sought and vessel (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 aliased (confounded the interpretation of) the analysis. Therefore, only vessels which fished at least 10 sets in at least 2 years were included. As discussed earlier, the analysis was also restricted to fall and winter, and the regions Newfoundland and Scotian Shelf, for the period after 1994. GLM trends for swordfish and bigeye tuna were similar, so were left together in the same analysis; the different trend for bluefin tuna necessitated a separate analysis.

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 12). The marginal catch rate based on the signficant factors indicated that catch rates have declined significantly since 1995 (Fig. 15). Although this GLM accounted for most of the data, there was some aliasing between the early Japanese and later Canadian data. Nevertheless, when the model was re-run using Canadian vessels only, the predicted trend was very similar to that of Fig. 15.

The GLM based on bluefin tuna fisheries was significant with respect to all factors (Table 13). However, the significant interaction terms necessitated that the marginal trends be plotted separately by region (Fig. 16). The trend based on the Scotian Shelf fishery showed a significant decline since 1995, but with relative stability in recent years. The trend based on the Newfoundland fishery suggested a modest increase since 1995, although there were few significant differences among years. In light of the aliasing between the Canadian and Japanese fisheries, the model was re-run using only Canadian data. The resulting marginal trend was very similar to that of the Scotian Shelf trend (modest decline).

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.

Tournament Catch Rates

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. A coarser approximation of fishing success (percentage of fishers catching sharks) at each derby suggests that catch rates across derbies within a year are often synchronous (Fig. 17). In addition, there is some suggestion of a slight decline in catch rate between 1998 and 2003.

Examination of SST (sea surface temperature) in relation to catch rate suggests a relationship with temperature, since the year with the highest catch rate (1999) was also among the warmest, while the year with the poorest catch rate (2001) was among the coldest. Although a rigorous statistical analysis was not carried out, anecdotal comments by fishers also supported the view that there was a correspondence between warm water conditions and higher catch rates for blue sharks. Records maintained by a charter operator indicate that blue sharks were caught at temperatures between 51-68 ^{0}F (10-20 ^{0}C); however, most were caught between 58-65 ^{0}F (14-18 ^{0}C).

A standardized catch rate was prepared using a binomial dependent variable (successful/unsuccessful) and derby location as a fixed factor in a GLM. The model was not statistically significant; nevertheless, the standardized catch rate resembled the averaged trajectories of Fig. 17.

A final GLM was based on the overall fishing success at the 5 shark fishing derbies carried out annually since 1998. Individual catch rates were not available, so an index based on the percentage of fishers successful in catching a shark at each derby was used. This model was less than ideal, since the derbies represented fixed factors, and thus year X derby interaction terms could not be assessed. With these deficiencies in mind, the model suggested a significant decline since 1999 (Table 14; Fig. 18). When scaled to the same scale as the standardized bigeye/swordfish model, the trend across years was similar in the two models (Fig. 18 bottom). 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.

Published Indices of Abundance

Although the data were not available for re-analysis here, Baum (2002) provided area-specific CPUE trends for blue sharks based on U.S. commercial logbook data. These trends were not shown in her widely-cited paper on shark declines in the NW Atlantic (Baum et al. 2003). For the area surrounding the Grand Banks and immediately adjacent to Canadian waters (Area 7: the largest region, and the one with the greatest blue shark catches and highest catch rates), blue shark CPUE increased between 1986-1993, declining thereafter (Fig. 19). The net decline between 1986-2000 was 9.6%.

Most of the remaining blue sharks reported by Baum (2002) were caught in Area 6 off of the northeast U.S. The decline in Area 6 was 63.8%.

The overall decline in blue shark CPUE reported by Baum et al (2003) showed a monotonic decline of 60% over the period 1986-2000 (Fig. 19 bottom). This modelled decline appears to have little in common with the observed CPUE series in the region containing most of the blue sharks (Fig. 19 top). Although Baum et al. (2003) acknowledge that the observed Area 7 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. Therefore it is interesting to note that the observed Area 7 time series was very similar to the GLM fit to the Canadian/Japanese Observer time series of Fig. 15.

A complicating factor in Baum's (2002, 2003) analysis is that only the logbooks from the pelagic longline fishery were considered. After 1994, shark-directed trips were recorded on a shark logbook and not on the pelagic longline logbook. As a result, shark-directed trips were included in Baum's analysis before 1994, but excluded afterwards. Thus the apparent decline in catch rate after 1994 may have been influenced by the exclusion of an unknown proportion of the shark data.

Exploitation Rate from Tag-Recaptures

The exploitation rate of blue sharks in Canadian waters was estimated through Petersen analysis of tag recaptures. Two sets of tagging studies were conducted. A total of 2017 tags were applied to blue sharks in a Canadian tagging program carried out between 1961-1980 (Burnett et al. 1987). Most of the tags were applied before 1972, which makes this study an index of exploitation rate in the early years of the longline fishery. A second tagging study was carried out by the National Marine Fisheries Service of the U.S., in cooperation with Canadian fishers. This study applied 916 tags to blue sharks in Canadian waters between 1971-2002. With most of the tagging effort taking place after 1990, this study provides an index of recent exploitation rate. Details of both studies, including recapture locations, were described earlier.

Despite the relatively high tagging effort in the Canadian study, there were relatively few recaptures in the 1960s and 1970s (Table 15). Annual exploitation rates never exceeded 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.

Analysis of the NMFS tagging data provided several relative indices of exploitation rate in Canada (Table 16). Mean exploitation rate in the tagging year, weighted by tagging effort, was 0.78% between 1992-2002. 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 (Table 16b). Since 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% with 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) and recaptured inshore during shark fishing derbies in the same year, 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 0.1-7%.

It is important to note that the estimates of exploitation rate mentioned above reflect only Canadian exploitation, not that on the population as a whole.

As a final index of Canadian exploitation rate, we compared the proportion of tags recaptured in Canadian waters versus those recaptured anywhere in the Atlantic (Table 16a). This comparison suggested that roughly 1/3 of the total fishing mortality occurred in Canada. However, this calculation assumes that the reporting rate is similar between Canada and elsewhere, whereas Canadian fishers (particularly the recreational fishers) are much more likely to report any recaptures. Thus the proportion of fishing mortality due to the Canadian fishery is likely to be much lower than 1/3.

As an overall comparison of recent and historic blue shark exploitation rate, we compared the overall recaptures/tag in the period 1961-1972 (Table 15) with that of 1992-2002 (Table 16). The recapture rate increased from a mean of 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 2 periods. Confirmation would require data on blue shark fishing effort in the two periods, but such data are not available.

Trends in Length Composition

A biological indicator of increased exploitation rate is a long-term decline in length in the catch. We examined two such indices. In the first index, measurements by scientific staff at shark derbies provided accurate measurements of fork length by sex. In neither sex was there evidence of a consistent decline in either mean or median fork length since 1993 (Fig. 20). However, comparison of derby length frequencies with those of the charter and commercial fleets indicated that the size composition at the derbies was not representative of the population: small sharks were poorly represented (due to derby catch restrictions) and large males were over-represented (due to their being targeted by derby participants). While a declining trend in the derby index would suggest a declining trend in the overall population, the same cannot be assumed for a constant index.

A second index of length trends in the blue shark population was based on measurements of blue sharks by Observers on board commercial longlining vessels. To minimize seasonal differences, the analysis was restricted to the fall and winter seasons. There has been a significant decline in mean blue shark length in the catch since the late 1980s (Fig. 21). Significant differences were also observed in the length composition between the Canadian and Japanese fleets, but these are almost certainly due to differences in depths fished (Campana et al. 2002).

Demographic Analysis

Natural Mortality

The instantaneous natural mortality rate (M) has never been directly estimated in blue sharks. Therefore, various studies have inferred M in blue sharks using meta-analysis of observed relationships between growth rate, mortality rate, and/or longevity (Table 17). The range of inferred values for M ranges from 0.07 to 0.48, with an overall mean of 0.23. Since M would be expected to vary inversely with growth rate, the importance of an accurate growth model is clear.

Life Table Analysis

Life table analysis uses age-structured estimates of survival rate, sexual maturation and fecundity to project population growth under various scenarios. It is well suited for use in sharks given their well-defined reproductive cycle and high rates of survival (Cortés 1998).

Table 18 presents the life table analysis for blue sharks. Values for fecundity, age at sexual maturation, and longevity were drawn from the literature, while the value of M was the mean value discussed in the previous section. The results indicated that the intrinsic rate of population growth, *r*, in an unfished population would be about 0.36. This translates into a 43% annual rate of increase in the absence of fishing. By comparison with other shark species, this is quite productive. F_{msy} 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. Given that few mature females are caught in the NW Atlantic, the assumption of full availability is unrealistic. Making the more realistic assumption that only immature females are vulnerable, F=0.41 results 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 (Cortés 1998; Smith et al. 1998; Frisk et al. 2001).

Mortality from Catch Curves

The instantaneous total mortality rate, *Z*, was estimated using catch curve analysis. Since Z = F + M, and since an estimate of M was presented in a previous section, F can be estimated if Z is known. To derive an age frequency representative of the population, length frequency samples were converted to age frequencies using mixture separation methods based on alternate growth models. Mature females are essentially absent from the fishery: therefore, the catch curve analysis was restricted to males, for which the entire size range is available. Samples were drawn from the observed commercial fishery, for which no size selectivity was evident.

An overall length frequency for the blue shark population was not available. Therefore, 3 sets of length frequencies from areas and regions believed to be representative were used in the calculations:

a) Oct-Nov, 1991-94, NAFO Division 4W; Japan n=1224

b) Dec, 1995-96, 4VW, Japan n=196

c) Aug-Oct 2003, 4X, Canada n=105

Subsequent analysis indicated that the sample sizes for samples (b) and (c) were too small to provide meaningful results. Therefore, the analysis was restricted to sample (a).

Conversion of a length frequency to an age frequency requires estimates of the mean length at each age, along with the corresponding variances. Since a range of published growth models are available, we bracketed the most likely range by calculating two sets of catch curves: one using the slow-growth model of Skomal and Natanson (2003), and the other using the fast-growth model of MacNeil and Campana (2003). Mean length at age values came from the von Bertalanffy fit for the fast growth model, and a quadratic fit for the slow-growth model. In both cases, there was no relationship between the mean and the variance. Therefore, variance was held constant at 190 over ages 0-12 for the slow-growth model, and at 312 over ages 0-8 for the fast-growth model. These age ranges cover a comparable length range. Conversion to age frequency was through a maximum likelihood-based normal mixture separation method.

The proportions at age were well estimated for both growth models up until age 4. After age 6, the standard errors (SE) for each proportion at age were greater than 1 under the slow growth model, although they never exceeded 0.07 under the fast growth model. Nevertheless, there was one age group under each growth model for which the proportion was zero. Since a missing age group in a continuous age frequency is highly unlikely, we assumed that that one age group was due to a slight misalignment of observed and predicted lengths at age, and mistakenly assigned to adjacent age groups. Simulations under which the missing age group was interpolated using adjacent age groups (which were in turn depleted by the appropriate amount) demonstrated that the catch curve was little affected by the interpolation procedure (since the missing age group was near the centre of the age frequency). The interpolated proportion at age was well within the bounds defined by the SE. Therefore, the catch curve analysis was completed using the interpolation for the missing age group. The original catch proportions at age, along with corresponding SE's, are shown below:

SLOW GROWTH			FAST GROWTH	
AGE	Prop.	SE	Prop.	SE
0	.000	.014	.000	.027
1	.038	.008	.036	.007
2	.036	.011	.055	.013
3	.153	.029	.564	.031
4	.452	.073	.174	.040
5	.000	.207	.138	.053
6	.193	.710	.000	.069
7	.047	>1	.028	.066
8	.019	>1	.004	.029
9	.022	>1		
10	.015	>1		
11	.008	>1		
12	.004	>1		
13	.003	>1		
14	.002	>1		
15	.003	>1		
16	.004	>1		

Decomposition of the length frequency into alternate age frequencies is shown in Fig. 22. Total instantaneous mortality rates (Z) based on the slope of the descending limb of the catch curve indicate that average Z in the early 1990s ranged between 0.52 to 0.89, depending on which growth model was used. Assuming that M=0.23 (as per Table 17), F was 0.29-0.66. These values are F are considered high for most elasmobranchs, but are consistent with theoretical predictions that blue sharks are relatively resistant to fishing pressure (Smith et al. 1998; Cortés 2002; Cox et al. 2002; Schindler et al. 2002). Catch curves for each of the years 1991-1994 individually were more variable (as expected), but roughly similar to the catch curve based on pooled years.

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, the majority of 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.

While blue shark catch statistics in the North Atlantic are unreliable, the catch of the more valuable tuna and swordfish species is monitored much more closely by ICCAT. Even here, nominal catch is likely to underestimate actual catch, due to fishing by non-member countries. Nevertheless, the nominal catch of large pelagic species is likely to be a relatively good index of the actual large pelagic catch.

Given reliable large pelagic catch records in the North Atlantic, 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. To test this assumption, we reviewed the literature for estimates of blue shark catch rate throughout the North Atlantic (Table 19). The mean ± 95% CI overall blue shark catch rate was 18.4 ± 8.3 blue sharks/1000 hooks. Although differences among studies were noted, there were no consistent differences in blue shark catch rate between east and west Atlantic, nor 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.

Based on an analysis of 5787 observed sets for large pelagics in the Canadian Atlantic, the overall proportion of blue sharks in the large pelagic catch was 0.34 by weight. This estimate ignores differences among fisheries.

The total catch of large pelagics documented by ICCAT for the Atlantic in the year 2000 was 620,808 mt. 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 east and west tropics (assuming that one half of the tropics was from the northern tropics, and that blue shark abundance was less in tropical waters than temperate waters). The final large pelagic catch estimate for 2000 was 316,182 mt, which is likely to be a conservative estimate.

Our calculations for approximating blue shark catch in the North Atlantic are shown in Table 19. Total blue shark catch is estimated at more than 100,000 mt. This value is almost 4 times the nominal catch of Table 1. Assuming 40% hooking mortality in the longline fishery (Table 10) and an arbitrary 20% mortality in the purse seine fishery, the catch mortality of blue sharks in the year 2000 was about 37,000 mt. This value is considerably more than the nominal catch, but is still likely to be an underestimate due to non-reported large pelagic catch and the fact that large pelagic CPUE is somewhat higher in the Canadian Atlantic than elsewhere (a high large pelagic CPUE would result in a lower blue shark: large pelagic catch ratio). In addition, our estimate of blue shark catch mortality does not take into account any mortalities due to finning in unregulated, unobserved international waters.

A totally independent calculation of North Atlantic blue shark catch mortality is possible using the exploitation rate calculated from tagging and the fishing mortality estimated from the catch curve analysis. The Canadian exploitation rate from Table 16 was 0.0078, corresponding to an observed catch in Canadian waters of 321 mt. Given the population-level F of 0.66 (=exploitation rate of 0.48) from the fast-growth catch curve (Fig. 22), and assuming a 75% tag reporting rate from the observed catch, the North Atlantic catch mortality would be 26,338 mt (this value would be lower if the slow-growth catch curve F was used).

In summary, two independent approximations of total North Atlantic blue shark catch mortality provide values of 37,000 mt and 26,000 mt. Although these two estimates are not particularly close to each other, nor are they grossly divergent. As first approximations, they probably provide conservative estimates of actual blue shark catch mortality.

Discussion

Several conclusions concerning blue shark bycatch and its impact on population status can be reached based on the analyses reported in this study:

The reported catch of blue sharks grossly underestimates both the actual catch (sum of landed catch and discards) and the catch mortality. In the Canadian Atlantic, nominal catch of blue sharks by both domestic and foreign longline fisheries typically accounted 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 mt annually since 1986, with most of this being the result of discard mortality.

Most of the tagged blue sharks recaptured in our waters were tagged in the U.S. In contrast, most of the tags applied in Canadian waters were later recaptured in the central and eastern Atlantic, 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.

The weight of sharks landed at recreational shark tournaments has increased from around 4 mt in 1993 to around 20 mt in recent years. Blue sharks account for 99% of all sharks landed. The recreational catch and release fishery catches about another 13 mt annually. Mature females were not present in the catches due to their absence from Canadian waters. However, the size composition at the derbies was not representative of the population: small sharks were poorly represented (due to derby catch restrictions) and large males were over-represented (due to their being targeted by derby participants).

Some members of the public have expressed concern that recreational shark fishing tournaments are having an adverse effect on the blue shark population. The results of this analysis indicate that shark tournaments only account for about 3% of the fishing mortality in Canadian waters. Thus tournaments are having 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 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 since 1995. Similarly, the median size of blue sharks in the commercial catch has declined since 1987, suggesting an increase in mortality rate. Neither of these indices provides a reliable estimate of the magnitude of the population decline – merely that relative abundance has declined.

In the only published overview of the status of North Atlantic blue sharks, Baum et al. (2003) used a model of CPUE from the logbooks of U.S. fishers to conclude that the population had declined monotonically by 60% over the period 1986-2000. However, this conclusion was at odds with the 9.6% decline, characterized by increasing, then decreasing abundance, for the area of highest blue shark abundance. 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 questionable if the unregulated fishermen's logbooks used by Baum (2002, 2003) could be considered more accurate than the Observer records reported here. Nevertheless, it is interesting to note that the observed Atlantic Canada time series of Baum (2002) was very similar to the GLM fit to the Canadian/Japanese Observer time series of Fig. 15. Based on this correspondence, it seems likely that the relative abundance of blue sharks has declined since the 1990s.

Consistent with the decline in abundance is the high estimated mortality rate for the population as a whole, as indicated by the catch curve analysis. The catch curve analysis indicated a high mortality rate no matter which growth curve was used. Of course, catch curve analysis assumes a random sample of the population and constant recruitment over the period analysed. The assumption of constant recruitment seems likely for an elasmobranch over a short period of time, but given the migratory habits of blue sharks which vary by size, it is not possible to confirm that the samples used for the catch curve analysis were random. Nevertheless, the fact that they were taken from adjacent years, used males only, and that large males were present in the length frequency, gives some credibility to the analysis.

Despite a high overall exploitation rate, 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.

The life table analysis reported here is consistent with the results of other studies (Smith et al. 1998; Frisk et al. 2001; Cortés 2002) which suggest that blue shark populations are both productive and resilient compared to other shark species. 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).

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 mt and catch mortalities of between 26,000 and 37,000 mt. As first approximations, they probably provide conservative estimates of actual blue shark catch mortality in the North Atlantic. As such, the Canadian contribution to overall population mortality is very low.

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. Continued and careful monitoring would appear to be warranted.

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Table 1. Reported blue 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			4		4					
1980				13	13					4
1981			1		1					12
1982			2		2					9
1983			1		1					8
1984					0					14
1985					0					39
1986			13		13		1			51
1987			38		38		360			593
1988			5		5		241			512
1989			10		10		232			561
1990	8		13		21	140	394			2261
1991	31	16	5		52	198	375			3217
1992	101	30	30		161	345				2045
1993	24	44	47		115	553	17			7208
1994	138		116		254	450	1		4	8196
1995	152		73		225	397	347	3		8403
1996	23		173		196	238	169	1	160	8398
1997	19		36		55	99	89	1	6	35951
1998	14		17		31	115	3	1		34298
1999	67		11		78	170	2	9	31	34722
2000	34		0		34	83				32297
2001	8		0		8	116				29942
2002	25		0		25					29583
2003	19		0		19					

Notes: Canada is from DFO Zonal Statistics File and shark derby statistics
Japan, Faroes, other countries in Canadian Atlantic are from Scotia-Fundy & NF Observer programs (excludes discards)
NW Atlantic landings from countries other than Japan are from ICCAT statistics for area 92 until 1999
Japan in NW Atlantic represents nominal catch of unspecified sharks and rays from FAO Statistics (2001)
North Atlantic (plus Mediterranean) landings from ICCAT (5 Mar 2004)

Table 2. Species of shark landed at shark derbies between 1993-2003. Weights are live equivalent weights

	Blue shark		Mako		Porbeagle		Thresher shark		TOTAL	
Year	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)
1993	93	3636	0	0	1	6	0	0	94	3642
1994	117	5048	0	0	0	0	0	0	117	5048
1995	122	6464	0	0	0	0	0	0	122	6464
1996	114	4967	1	46	0	0	0	0	115	5013
1997	273	10315	0	0	0	0	0	0	273	10315
1998	269	10406	0	0	0	0	0	0	269	10406
1999	300	14598	0	0	0	0	0	0	300	14598
2000	235	15488	3	489	0	0	0	0	238	15977
2001	162	7594	0	0	1	57	1	84	164	7735
2002	327	19324	4	674	1	27	0	0	332	20026
2003	342	12017	3	399	1	132	0	0	346	12548

Table 3. Number of participants, and number and weight of sharks landed at shark derbies, between 1993-2003

Year	Derby	# days/derby	Number landed	Weight landed (kg)	# boats	# participants
1993	Halifax	2	94	3642		94*
1994	Halifax	2	65	2133		65*
	Lockeport	2	15	565		15*
	Split Crow	1	37	2350		37*
1995	Halifax	2	80	4659		62*
	Split Crow	1	10	795		18*
	Dartmouth	1	32	1010		32*
1996	Lockeport	2	17	716		61*
	Split Crow	1	17	1318		17*
	Dartmouth	1	29	1093	15	34*
	Eastern Passage	2	52	1886	17	26*
1997	Halifax	2	95	3158	25	91*
	Lockeport	2	15	541		14*
	Split Crow	1	51	2263	21	77*
	Eastern Passage	1	112	4353	32	134*
1998	Lockeport	2	53	2114	12	160
	Split Crow	1	9	330		108
	Dartmouth	1	68	3183	28	181
	Eastern Passage	1	123	4280	35	210
	Yarmouth	2	16	499	16	74
1999	Dartmouth	1	89	3209	34	180
	Lockeport	2	74	2939	11	100
	Split Crow	1	31	2094	25	117
	Yarmouth	2	106	6356	30	180
2000	Dartmouth	1	32	1886	21	140
	Lockeport	2	100	5627	13	84*
	Yarmouth	2	77	5961	49	312
	Split Crow	1	29	2503	24	120
2001	Eastern Passage	1	25	1186	31	176
	Lockeport	2	13	575	35	140
	Yarmouth	2	76	3737	60	349
	Brooklyn	2	37	1404	26	185
	Halifax	1	13	834	15	71
2002	Eastern Passage	1	37	1470	35	188
	Riverport	2	17	594	5	35
	Lockeport	2	123	6781	20	108*
	Yarmouth	2	103	6886	51	318
	Brooklyn	2	43	3545		330
	Halifax	1	9	750	22	91
2003	Eastern Passage	1	53	1787	37	199
	Riverport	2	32	1303	20	76
	Lockeport	2	64	2113	30	221
	Yarmouth	2	84	3669	50	348
	Brooklyn	2	111	3581	83	307
	Halifax	1	2	95	12	50

* minimum number of participants, based on logs submitted

Table 4. Estimation of recreational shark catch (outside of derbies):

A) Comprehensive phone interviews.

Proportion of licences interviewed	2001 n	2001 %	2002 n	2002 %
Number of recreational shark licences (Scotia Fundy)	1427		1775	
Number interviewed	162	11.4%	162	9.2%

Sample of 'frequent' (> 1 derby) shark fishers
(n=72; includes some from random sample)

	2001 n	2001 %	2002 n	2002 %
Number who fished outside of derbies	10	14%	16	22%
Average # trips/person (not including derbies) by those who fished	1.7		2.6	
Average number caught/person during year by those who fished	6.3		7.7	
Median number caught/person during year by those who fished	4.0		7.0	

Random sample of shark licenses (n=95)

	2001 n	2001 %	2002 n	2002 %
Number who fished outside of derbies	7	7%	7	7%
Average # trips/person (not including derbies) by those who fished	3.7		3.0	
Average number caught/person during year by those who fished	21.0		12.3	
Median number caught/person during year by those who fished	7.0		12.0	

	2001	2002
Average annual catch/license (n=95)	1.55±1.84	0.91±0.82
Median annual catch/license (n=95)	0.52	0.88

B) Recreational shark fishing logs

Number of reported trips outside of derbies (1995-2003)	247
Average # trips/person/year (excluding charter shark fishers)	3.1
Average # trips/person/year by charter shark fishers	32
Average number caught/person/year (excluding charter shark fishers)	2.4
Average number caught/person/year by charter shark fishers	162

C) Estimation of total annual recreational catch

Average number of licencees who fished (7%)	112
Annual catch (numbers) by licensees who fished*	269
Annual catch (numbers) by charters	162
Estimated number of sharks caught outside of derbies	431
Mean weight of blue shark from recreational fishery (kg)**	29
Estimated weight of sharks caught outside of derbies (kg)**	12,500

* based on average annual catch from recreational shark fishing logs
** based on mean weight in charter catch, which includes undersized sharks
*** this figure is believed to be most applicable to the period 2001-2003

Table 5. Blue shark catches and discards (mt) by country in Canadian waters as observed by the Scotia-Fundy and Newfoundland Observer programs. The percentage of the catch that was discarded is also shown.

CATCH

Year	Canada	Faroe Is	Japan	USSR	Other	Total
1978	0		0			0
1979	0		4			4
1980		0	0	13	3	16
1981		0	1		1	2
1982			2			2
1983			1			1
1984			0			0
1985	0		0			0
1986			13	0		13
1987		0	38			38
1988		0	5		1	6
1989	0	0	10			10
1990	1	0	13	0		14
1991	4	6	5	0		15
1992	0	30	30		0	60
1993	1	62	47			110
1994	16		116		0	132
1995	15		73			88
1996	2		173			175
1997	1		36			37
1998	1		17			18
1999	1		11			12
2000	1		0			1
2001	0		0			0
2002	1		0		0	1
2003	0		0			0

DISCARDS

Year	Canada	Faroe Is	Japan	USSR	Other	Total
1978	1		8			9
1979	10		8			18
1980		3	6	0	3	12
1981		1	12		1	14
1982			52			52
1983			25			25
1984			14			14
1985	1		0			1
1986			31	1		32
1987		2	121			123
1988		16	129		1	146
1989	42	8	164			214
1990	7	22	102	1		132
1991	20	59	129	19		227
1992	2	82	202		1	287
1993	14	19	186			219
1994	48		207		3	258
1995	107		100			207
1996	37		61			98
1997	30		0			30
1998	210		17			227
1999	185		282			467
2000	70		3			73
2001	179		0			179
2002	228		0		4	232
2003	85		0			85

DISCARD PERCENTAGE

Year	Canada	Faroes	Japan
1978	.	.	100
1979	100	.	22
1980	.	.	100
1981	.	100	73
1982	.	.	100
1983	.	.	96
1984	.	.	96
1985			
1986	.	.	80
1987	.	100	76
1988	.	100	96
1989	100	100	96
1990	100	100	92
1991	98	90	96
1992	.	73	97
1993	100	23	79
1994	78	.	64
1995	88	.	59
1996	89	.	26
1997	98	.	.
1998	100	.	45
1999	100	.	96
2000	100	.	100
2001	100	.	.
2002	100		
2003	100		

Notes: Based on data from Scotia-Fundy (1978-2003) and Newfoundland Observer programs (1980-1995)

TABLE 6. BLUE SHARK BYCATCH AND PROPORTIONS IN CANADIAN BLUEFIN TUNA FISHERY.

CANADA

QUARTILE		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
I	tunas, SF, porbeagle catch (mt)				35	77	8		8		27									
	blue shark proportion (minimum)				0.48	0.48	0.48		0.48		0.48									
	blue shark catch (mt) (minimum)				17	37	4		4		13									
	blue shark proportion (maximum)				0.48	0.48	0.48		0.48		0.48									
	blue shark catch (mt) (maximum)				17	37	4		4		13									

QUARTILE		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
II	tunas, SF, porbeagle catch (mt)						3	0	0				2			6				
	blue shark proportion (minimum)						4.85	4.85	4.85				4.85			4.85				
	blue shark catch (mt) (minimum)						14	1	2				9			31				
	blue shark proportion (maximum)						4.85	4.85	4.85				4.85			4.85				
	blue shark catch (mt) (maximum)						14	1	2				9			31				

QUARTILE		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
III	tunas, SF, porbeagle catch (mt)				275	381	350	273	319	247	263	326	317	265	357	280	155	265	351	234
	blue shark proportion (minimum)				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	blue shark catch (mt) (minimum)				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	blue shark proportion (maximum)				0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	blue shark catch (mt) (maximum)				49	69	63	49	57	44	47	59	57	48	64	50	28	48	63	42

QUARTILE		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
IV	tunas, SF, porbeagle catch (mt)				90	74	66	168	69	125	3	136	159	123	141	57	118	79	4	
	blue shark proportion (minimum)				0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	
	blue shark catch (mt) (minimum)				55	45	40	102	42	76	2	83	97	75	86	35	72	48	3	
	blue shark proportion (maximum)				1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	
	blue shark catch (mt) (maximum)				103	84	75	191	79	143	4	155	181	140	161	65	134	91	5	

TOTAL		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
	blue shark catch (mt) (minimum)*				72	82	58	104	48	76	15	83	106	75	86	66	72	48	3	0
	blue shark catch (mt) (maximum)				169	190	156	242	142	187	64	214	247	188	225	146	162	138	68	42

* most probable catch
Tuna, swordfish, and porbeagle shark catch from ZIF for LL, troller lines, rod & reel, handline
DATABASE FOR CATCH: BFTmainspc_TunaSFPORcatch gearselected.sav
Blue shark proportions, minimum and maxinum, represent weighted means from all sets, or only those with blue shark catch, respectively from Campana et al (2002).

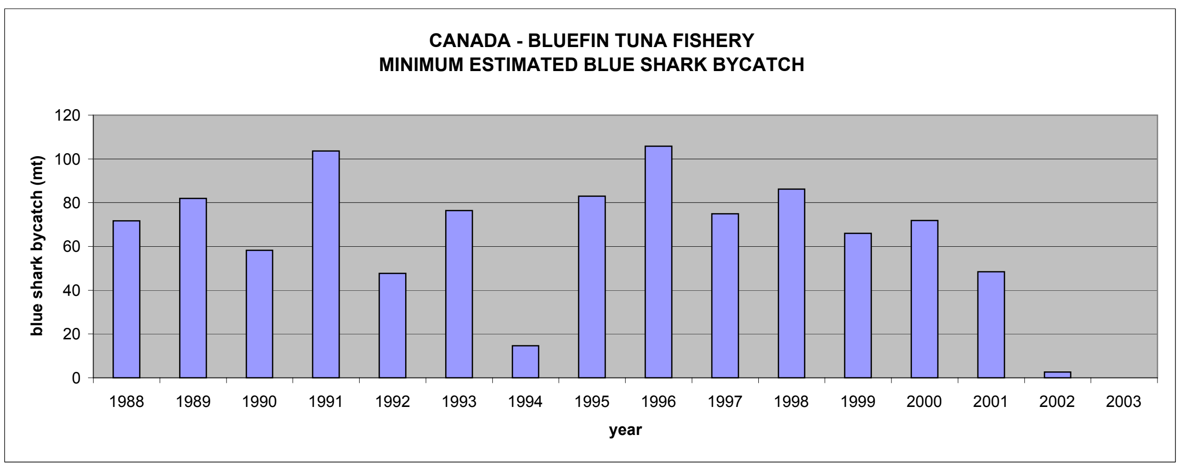


TABLE 7. BLUE SHARK BYCATCH AND PROPORTIONS IN CANADIAN SWORDFISH FISHERY.

CANADA

QUARTILE		YEAR 1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
I	tunas, SF, porbeagle catch (mt)							1			29									
	blue shark proportion																			
	blue shark catch (mt)																			

QUARTILE		YEAR 1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
II	tunas, SF, porbeagle catch (mt)				2		1	48	87	74	42	32	8	29	26	139	62	25	41	22
	blue shark proportion (minimum)				0.55		0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	blue shark catch (mt) (minimum)				1		1	26	48	41	23	18	5	16	14	77	34	14	23	12
	blue shark proportion (maximum)				3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70
	blue shark catch (mt) (maximum)				6	0	4	177	323	275	154	119	31	107	97	515	230	94	152	82

QUARTILE		YEAR 1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
III	tunas, SF, porbeagle catch (mt)		321	193	665	800	635	764	1103	1666	1167	1015	540	831	802	1029	790	915	820	804
	blue shark proportion (minimum)		0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
	blue shark catch (mt) (minimum)		173	104	359	432	343	413	596	900	630	548	291	449	433	556	426	494	443	434
	blue shark proportion (maximum)		1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
	blue shark catch (mt) (maximum)		366	220	758	912	724	871	1257	1899	1331	1157	615	947	915	1173	900	1043	935	917

QUARTILE		YEAR 1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
IV	tunas, SF, porbeagle catch (mt)		95	37	246	300	189	171	298	422	328	393	85	150	82	3	2	0	150	
	blue shark proportion (minimum)		4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63	
	blue shark catch (mt) (minimum)		440	169	1141	1388	876	790	1381	1955	1517	1819	393	696	380	13	11	0	697	
	blue shark proportion (maximum)		6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	
	blue shark catch (mt) (maximum)		624	240	1618	1970	1244	1120	1959	2774	2152	2581	557	988	539	19	16	0	989	

TOTAL		YEAR 1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
	blue shark catch (mt) (minimum)		613	273	1500	1820	1220	1229	2024	2896	2170	2384	689	1161	828	645	472	508	1162	446
	blue shark catch (mt) (maximum)		990	460	2382	2882	1971	2169	3540	4948	3637	3857	1203	2042	1551	1707	1146	1137	2075	998
	blue shark catch (mt) (most probable)*		801	367	1941	2351	1595	1699	2782	3922	2903	3120	946	1601	1189	1176	809	823	1619	722

* most probable catch calculated as mean of minimum and maximum
Tuna, swordfish, and porbeagle shark catch from ZIF for LL, troller lines, rod & reel, handline
DATABASE FOR CATCH: Sfmainspc_TunaSFPORcatch gearselected.sav
Blue shark proportions, minimum and maxinum, represent weighted means from all sets, or only those with blue shark catch, respectively from Campana et al (2002).

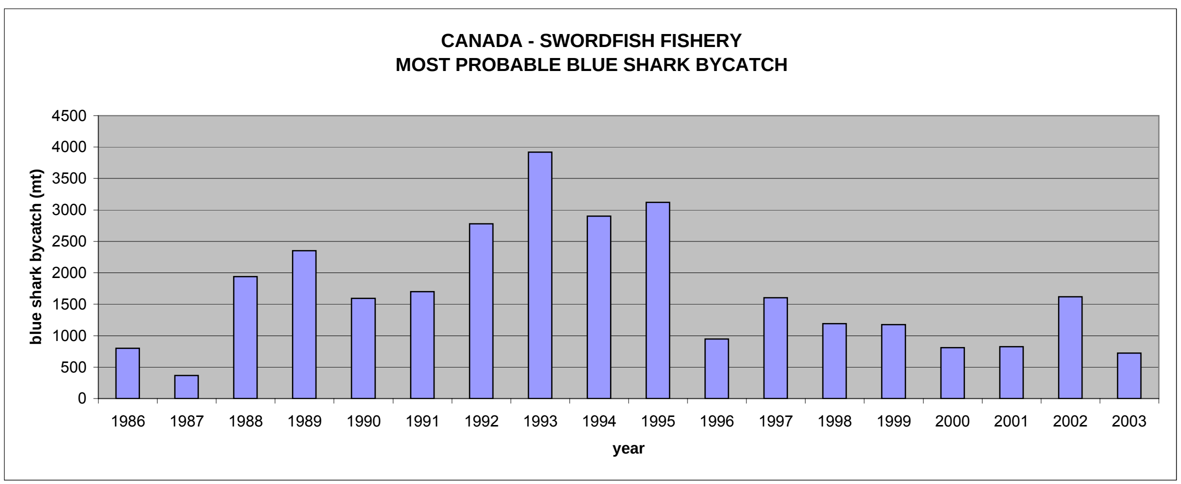


TABLE 8. BLUE SHARK BYCATCH AND PROPORTIONS IN CANADIAN OTHER TUNA FISHERY.

CANADA

QUARTILE		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
I	tunas, SF, porbeagle catch (mt)				8	113	7	2	0		2									
	blue shark proportion																			
	blue shark catch (mt)																			
II	tunas, SF, porbeagle catch (mt)						3	1		13	27	41	51	47	43	82	180	232	23	27
	blue shark proportion (minimum)						1.42	1.42		1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42
	blue shark catch (mt) (minimum)						5	1		18	38	58	73	66	60	116	255	329	33	38
	blue shark proportion (maximum)						1.41	1.41		1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41
	blue shark catch (mt) (maximum)						5	1		18	38	58	72	66	60	115	253	327	33	38
III	tunas, SF, porbeagle catch (mt)				0	1	4	26	31	89	97	269	273	184	93	97	336	152	283	86
	blue shark proportion (minimum)				0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	blue shark catch (mt) (minimum)				0	0	2	9	11	31	34	94	96	64	33	34	118	53	99	30
	blue shark proportion (maximum)				0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77
	blue shark catch (mt) (maximum)				0	1	3	20	24	68	75	207	210	142	72	75	259	117	218	66
IV	tunas, SF, porbeagle catch (mt)				127	4	6	0	1	11	5	4	4	29	20	52	37	43	65	
	blue shark proportion (minimum)				2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	
	blue shark catch (mt) (minimum)				314	9	15	1	1	27	12	10	10	73	48	129	92	107	162	
	blue shark proportion (maximum)				3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	
	blue shark catch (mt) (maximum)				502	15	24	1	2	43	20	16	16	117	77	206	147	171	259	
TOTAL	blue shark catch (mt) (minimum)				314	10	21	11	12	76	85	162	178	204	141	279	465	490	294	68
	blue shark catch (mt) (maximum)				502	16	32	22	26	129	133	281	299	324	209	396	659	615	509	104
	blue shark catch (mt) (most probable)*				408	13	27	16	19	103	109	222	238	264	175	338	562	552	402	86

* most probable catch calculated as mean of minimum and maximum
Tuna, swordfish, and porbeagle shark catch from ZIF for LL, troller lines, rod & reel, handline
DATABASE FOR CATCH: OtherTunamainspc_TunaSFPORcatch gearselected.sav
Blue shark proportions, minimum and maxinum, represent weighted means from all sets, or only those with blue shark catch, respectively from Campana et al (2002).

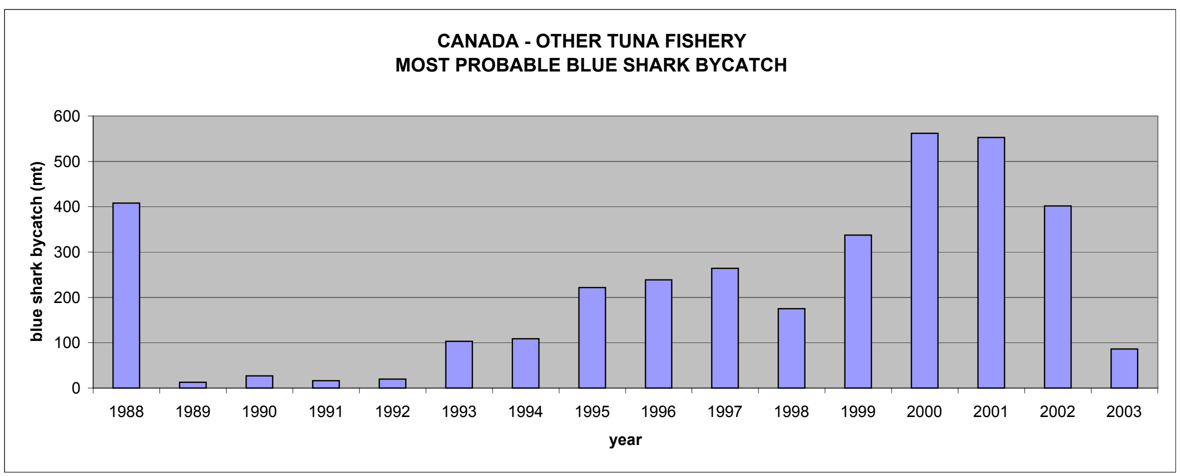


TABLE 9. BLUE SHARK BYCATCH AND PROPORTIONS IN CANADIAN PORBEAGLE SHARK FISHERY

CANADA

QUARTILE		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
I	tunas, SF, porbeagle catch (mt)								75		49	89	184	237	143	253	168	20	0.41	
	blue shark proportion (minimum)								0.07		0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	
	blue shark catch (mt) (minimum)								5		3	6	13	17	10	18	12	1	0	
	blue shark proportion (maximum)								0.14		0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	
	blue shark catch (mt) (maximum)								11		7	13	26	33	20	35	23	3	0	

QUARTILE		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
II	tunas, SF, porbeagle catch (mt)								233	319	766	525	379	565	554	520	558	457	146	86
	blue shark proportion (minimum)								0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	blue shark catch (mt) (minimum)								5	6	15	11	8	11	11	10	11			
	blue shark proportion (maximum)								0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	blue shark catch (mt) (maximum)								14	19	46	32	23	34	33	31	33	27	9	5

QUARTILE		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
III	tunas, SF, porbeagle catch (mt)							126	306	298	228	208	135	210	172	13	3	6	20	11
	blue shark proportion (minimum)							0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	blue shark catch (mt) (minimum)							30	73	72	55	50	32	50	41	3	1	1	5	3
	blue shark proportion (maximum)							0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
	blue shark catch (mt) (maximum)							35	86	84	64	58	38	59	48	4	1	2	6	3

QUARTILE		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
IV	tunas, SF, porbeagle catch (mt)							202	190	276	445	335	221	197	118	133	128	0	28	
	blue shark proportion (minimum)							0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	
	blue shark catch (mt) (minimum)							8	8	11	18	13	9	8	5	5	5	0	1	
	blue shark proportion (maximum)							0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	
	blue shark catch (mt) (maximum)							24	23	33	53	40	26	24	14	16	15	0	3	

TOTAL		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
	blue shark catch (mt) (minimum)*							38	91	89	91	80	62	86	67	37	29	3	6	3
	blue shark catch (mt) (maximum)							60	133	136	170	143	113	149	116	86	73	32	18	8

* most probable catch

Tuna, swordfish, and porbeagle shark catch from ZIF for LL, troller lines, rod & reel, handline

DATABASE FOR CATCH: Porbeagle catch selected.sav

Blue shark proportions, minimum and maxinum, represent weighted means from all sets, or only those with blue shark catch, respectively from Campana et al (2002).

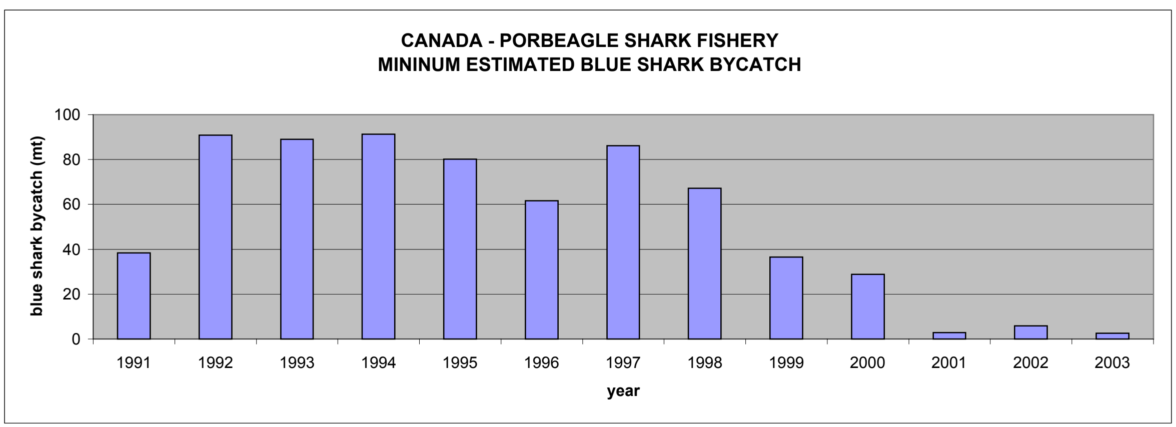


Table 10. Estimates of blue shark hooking mortality in the commercial and recreational fisheries

Scientific Study on Commercial Vessel (Sept 2003)

Year	Fishery	n	% healthy	% injured[1]	% dead
2003	Blue shark	105	**38**	**44**	**18**

Scotia-Fundy Observer Program

Year	Fishery	n	% healthy	% injured	% dead
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)

Year	Fishery	n	% healthy	% injured[1]	% dead[2]
2002	Blue shark	111	**63**	**37**	**0**

[1] Gut hooked; unable to tell if was fatal injury
[2] 9% were in poor condition upon release, and presumably would have died

Survival estimates used:
Using the results of the scientific study, and assuming 50% mortality of gut-hooked sharks, **60% of blue sharks would survive capture in commercial fishery**. The IOP results are believed to underestimate injury rates due to the difficulty of seeing internal injuries.

Assuming 50% mortality of gut-hooked sharks, **81% of blue sharks would survive capture and release in the recreational fishery.**

Table 11. Total blue shark catch (mt) in Atlantic Canada by source.

Year	Derbies	Recreational[1]	Landed commercial[2]	Observed foreign catch[3]	Observed foreign discards‡	Observed Canadian discards†	Estimated catch and discards from Canadian fishery*	TOTAL ESTIMATED CATCH MORTALITY**
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	16	11	19	0	3	70	1471	627
2001	8	13	0.4	0	0	179	1426	581
2002	19	13	5	0	4	228	2029	840
2003	19	13	0.1	0	0	85	811	346

[1] catch and release fishery, excluding derbies; 2001-2003 estimated from rec logs and phone survey;
other years assumed to be 0.66 of derby catches based on tag recaptures and 2002-2003 ratios
[2] Canadian landings only
[3] Scotia-Fundy Observer Program measurements of all foreign kept catch
‡ Scotia-Fundy Observer Program measurements of all foreign discarded catch
† Scotia-Fundy Observer Program measurements of Canadian discards; coverage was about 5% of fleet
* from Tables 3-6; sum of most probable bycatches from porbeagle, bluefin tuna, swordfish and other tuna fisheries
** Sum of landed catches, plus hooking mortality probabilities of Table 7 applied to recreational, foreign discards and estimated catch from Canadian fishery;
foreign discards prior to 1994 assumed to be dead due to finning

Table 12. Results of the catch rate standardization model relating the catch rate (ln-transformed kg/hook) of blue shark in bigeye tuna and swordfish fisheries to region, season, CFV and year.

Dependent Variable: LNCPUE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
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			

a. R Squared = .510 (Adjusted R Squared = .434)

Table 13. Results of the catch rate standardization model relating the catch rate (ln-transformed kg/hook) of blue shark in bluefin tuna fisheries to region, season, CFV and year.

Dependent Variable: LNCPUE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	232.336	28	8.298	5.712	0.000
Intercept	9.623	1	9.623	6.624	0.011
CFV	28.439	6	4.740	3.263	0.005
YR	25.944	6	4.324	2.977	0.009
CFV * YR	0.000	0	.	.	.
SEASON	6.249	1	6.249	4.302	0.040
REGION	22.168	1	22.168	15.260	0.000
CFV * SEASON	0.000	0	.	.	.
CFV * REGION	14.103	2	7.051	4.854	0.009
YR * SEASON	0.000	0	.	.	.
YR * REGION	18.409	2	9.204	6.336	0.002
SEASON * REGION	0.000	0	.	.	.
Error	191.753	132	1.453		
Total	806.185	161			
Corrected Total	424.089	160			

a. R Squared = .548 (Adjusted R Squared = .452)

Table 14. Results of the catch rate standardization model relating the derby catch rate (blue sharks/fisher) to derby and year. Interaction terms could not be tested.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.548	11	0.050	3.598	0.010
Intercept	2.361	1	2.361	170.327	0.000
YEAR	0.330	5	0.066	4.755	0.007
DERBY	0.234	6	0.039	2.816	0.046
Error	0.222	16	0.014		
Total	3.107	28			
Corrected Total	0.770	27			

a. R Squared = .712 (Adjusted R Squared = .514)

Table 15. Tag recaptures and calculated exploitation rates for blue sharks tagged by Canadian tagging program.

Year	Tagged	Recaps anywhere	prop. recap anywhere*
1961	8	0	0.000
1962	61	1	0.016
1963	18	0	0.000
1964	83	0	0.000
1965	174	1	0.006
1966	8	0	0.000
1967	302	4	0.013
1968	223	3	0.013
1969	301	3	0.010
1970	6	0	0.000
1971	86	0	0.000
1972	609	5	0.008
1973	0	0	
1974	0	0	
1975	31	0	0.000
1976	0	0	
1977	0	0	
1978	0	0	
1979	31	0	0.000
1980	76	0	0.000

* not really an exploitation rate, since recaptures are spread across all years

Table 16. Tag recaptures and calculated exploitation rates for blue sharks in Canadian waters, as recorded by NMFS. a) all fleets

Year	n Canada regardless of nation	Recaps of Can tags anywhere	prop. recap anywhere	Recaps of Can tags in Canada	prop. recap in Canada	Ratio Can:anywhere	Can recap of Can tags in tagging yr	Can exploitation rate in tagging yr*	Total observed catch in Canada (mt)**
1971	1								
1974	55	1	0.02	0	0.00	0.00			
1976	27								
1977	36								
1978	6								
1979	9								
1980	18								
1981	17								
1982	41								
1983	14								
1984	1								
1985	14								
1987	1								
1988	3								
1991	24								
1992	51	1	0.02	1	0.02	1.00	0	0.00	448
1993	60	7	0.12	4	0.07	0.57	0	0.00	338
1994	42	4	0.10	1	0.02	0.25	0	0.00	520
1995	22	0	0.00	0	0.00				434
1996	1	0	0.00	0	0.00				297
1997	202	25	0.12	2	0.01	0.08	0	0.00	90
1998	61	4	0.07	1	0.02	0.25	0	0.00	265
1999	51	8	0.16	5	0.10	0.63	0	0.00	556
2000	17	6	0.35	1	0.06	0.17	0	0.00	119
2001	20	1	0.05	0	0.00	0.00	0	0.00	200
2002	122	2	0.02	2	0.02	1.00	2	0.04	269
								Mean (1992-2002) weighted by effort = 0.0078	Mean observed catch (1992-2002) =321 mt

b) recreational fishery

Year	Tagged in Canada by rec fishery	Derby recaps of Can rec tags in tagging yr	Derby exploitation rate in tagging yr*	95% confidence interval for exploitation rate	Derby catch (numbers)
1993	7	0	0		93
1994					117
1995	1	0	0		122
1996					114
1997	14	0	0		273
1998	6	0	0		269
1999	45	0	0	0-0.08	300
2000	12	0	0		235
2001	10	0	0		162
2002	117	1	0.017	0.01-0.07	327
			Mean weighted by effort = 0.0094		

* recap/tags in tagging year, multiplied by 2 to adjust for mid-season tagging effort

** sum of catches from derbies, recreational fishery, landed commercial, foreign catch and discards, observed Canadian discards

Table 17. Estimates of the instantaneous natural mortality rate (M) of blue sharks from the literature.

Reference	Population	Mortality source	M
Hoenig (1983)	All	Estimated from longevity*	0.21 - 0.28
Kleiber et al (2001)	North Pacific	Multifan-Cl analysis	0.22 - 0.27
Cortes (2001)	All	Average of 4 published methods	0.16 - 0.27
Smith et al (1998)	Pacific	Hoenig (1983)	0.223
Schindler et al (2002)	Central Pacific	Regression of Pauly (1980)	0.18
Cox et al (2002)	Central Pacific	Regression of Pauly (1980)**	0.12 - 0.40
Fisk et al (2001)	All	Meta-analysis using fast growth model [1]	0.24 - 0.48
Fisk et al (2001)	All	Meta-analysis using slow growth model [2]	0.07 - 0.14
			Overall mean M = 0.23

* based on Skomal and Natanson longevity of 16 yr (observed) or 21 yr (inferred)
** calculated separately for small and large sharks
[1] using MacNeil and Campana (2003) growth model
[2] using Skomal and Natanson (2003) growth model

Table 18. Life history analysis for the blue shark. The intrinsic rate of increase (r) is calculated from Euler's equation, and is shown at the bottom.
Upper calculations show the result of fishing immature females to a zero rate of population growth.

Input parameters:		Fecundity	Female Age	Fecundity*maturit	Fec/4 (allows for females and biennial repro cycle)
		37	0	0	0.000
Select Area (1-3)=	3		1	0	0.000
F=	0.410		2	0	0.000
Mo = (first year)	0.460		3	0	0.000
Mi = (immature)	0.230		4	9.25	2.313
Mm= (mature)	0.230		5	18.5	4.625
Tmat=	5		6	27.75	6.938
Tmax=	20		7	37	9.250
Fec (mx) > age 18=	9.250	(see table)	8	37	9.250

After the input parameters are entered, click on cell F82, go to Tools menu, select Solver, click on Solve Button, click OK; this gives an accurate r value in cell F82

Age **Age (x)**	**Area Shelf**	**Area NF**	**Area combined**	Selected Area	Survivorship **Si**	# Survivors **lx**	Fecundity **mx**	Survivors x Offsprin **lx.mx**	Needed for G **lx.mx.x**	Stationary Age **Lx**	Life-Span **Tx**	Life Expectation **ex**
0			1	1.000	0.419	1.000	0.000	0.000	0.000	0.709	1.430	1.430
1			1	1.000	0.527	0.419	0.000	0.000	0.000	0.320	0.721	1.721
2			1	1.000	0.527	0.221	0.000	0.000	0.000	0.169	0.401	1.815
3			1	1.000	0.527	0.116	0.000	0.000	0.000	0.089	0.232	1.993
4			1	1.000	0.527	0.061	2.313	0.142	0.568	0.047	0.143	2.332
5			1	1.000	0.527	0.032	4.625	0.150	0.749	0.025	0.096	2.974
6			0	0.000	0.795	0.017	6.938	0.118	0.711	0.015	0.072	4.192
7			0	0.000	0.795	0.014	9.250	0.126	0.879	0.012	0.056	4.147
8			0	0.000	0.795	0.011	9.250	0.100	0.798	0.010	0.044	4.091
9			0	0.000	0.795	0.009	9.250	0.079	0.713	0.008	0.034	4.019
10			0	0.000	0.795	0.007	9.250	0.063	0.630	0.006	0.027	3.929
11			0	0.000	0.795	0.005	9.250	0.050	0.550	0.005	0.021	3.816
12			0	0.000	0.795	0.004	9.250	0.040	0.477	0.004	0.016	3.673
13			0	0.000	0.795	0.003	9.250	0.032	0.410	0.003	0.012	3.494
14			0	0.000	0.795	0.003	9.250	0.025	0.351	0.002	0.009	3.268
15			0	0.000	0.795	0.002	9.250	0.020	0.299	0.002	0.006	2.984
16			0	0.000	0.795	0.002	9.250	0.016	0.253	0.002	0.004	2.627
17			0	0.000	0.795	0.001	9.250	0.013	0.214	0.001	0.003	2.177
18			0	0.000	0.795	0.001	9.250	0.010	0.180	0.001	0.002	1.610
19			0	0.000	0.795	0.001	9.250	0.008	0.151	0.001	0.001	0.897
20			0	0.000	0.795	0.001	9.250	0.006	0.126			
								0.997	8.059			

Output parameters:

Net Repro. Rate **Ro**	Generation Tim **G**	Intrinsic Rate of Increase **r**	Finite Rate of Pop. Increase **e^r**
0.997	8.085	**0.000**	1.000

Calculation of r from Euler's equation

With initial r=		-0.000403			After trial values of r ending in convergence:		
				r=	0.3592573	Fmsy=	0.180
						e^r =	1.432

Table 19. Blue shark catch rates in other areas of the North Atlantic. Estimates of North Atlantic blue shark catch assume that the proportion of blue sharks in the large pelagic catch is similar to that in the NW Atlantic

Study	Area	Number of blue sharks/1000 hooks
Casey (1982)	U.S.	19.0
Casey and Postuszak (1984)	U.S.	15.3
Mejuto (1985)	NE Atlantic	13.9
Buencuerpo et al. (1998)	NE Atlantic	19.6
Stone and Dixon (2001)	Georges Bank	5.1
Baum (2002)	NW Atlantic	20-40
This study (bluefin tuna)	NW Atlantic	15.4
This study (swordfish)	NW Atlantic	40.0
This study (other tunas)	NW Atlantic	7.3

Conclusion: The density of blue sharks is roughly similar wherever large pelagics are fished in the North Atlantic

Calculation of blue shark catch in the entire North Atlantic

Total large pelagic catch in the North Atlantic[1]:	316,182 mt
Proportion of blue sharks in catch[2]:	0.34
Estimated catch of blue sharks:	107,502 mt (28% of which is by purse seines)
Assumed hooking mortality:	40% (20% from purse seines)
Estimated catch mortality of blue sharks:	**36,980 mt**

[1] from ICCAT for the year 2000

[2] overall mean from Scotia-Fundy Observer Program measurements on Japanese and Canadian large pelagic vessels, 1986-2000

Fig. 1. Morphometric conversions between various length and weight measures for blue sharks measured at shark derbies. FL = fork length.

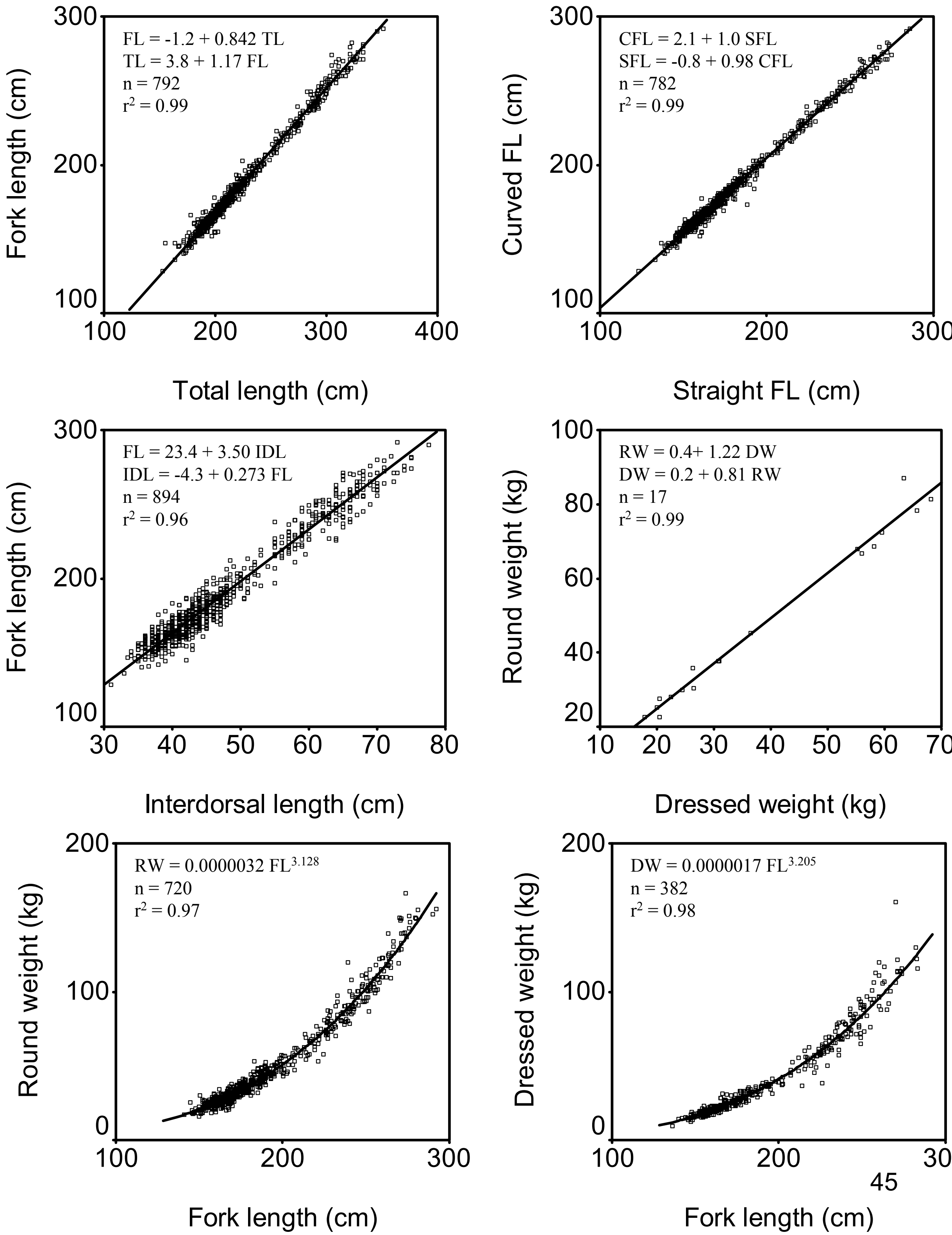


Fig. 2. Blue sharks recaptured between 1961-1972 from Canadian tagging program.

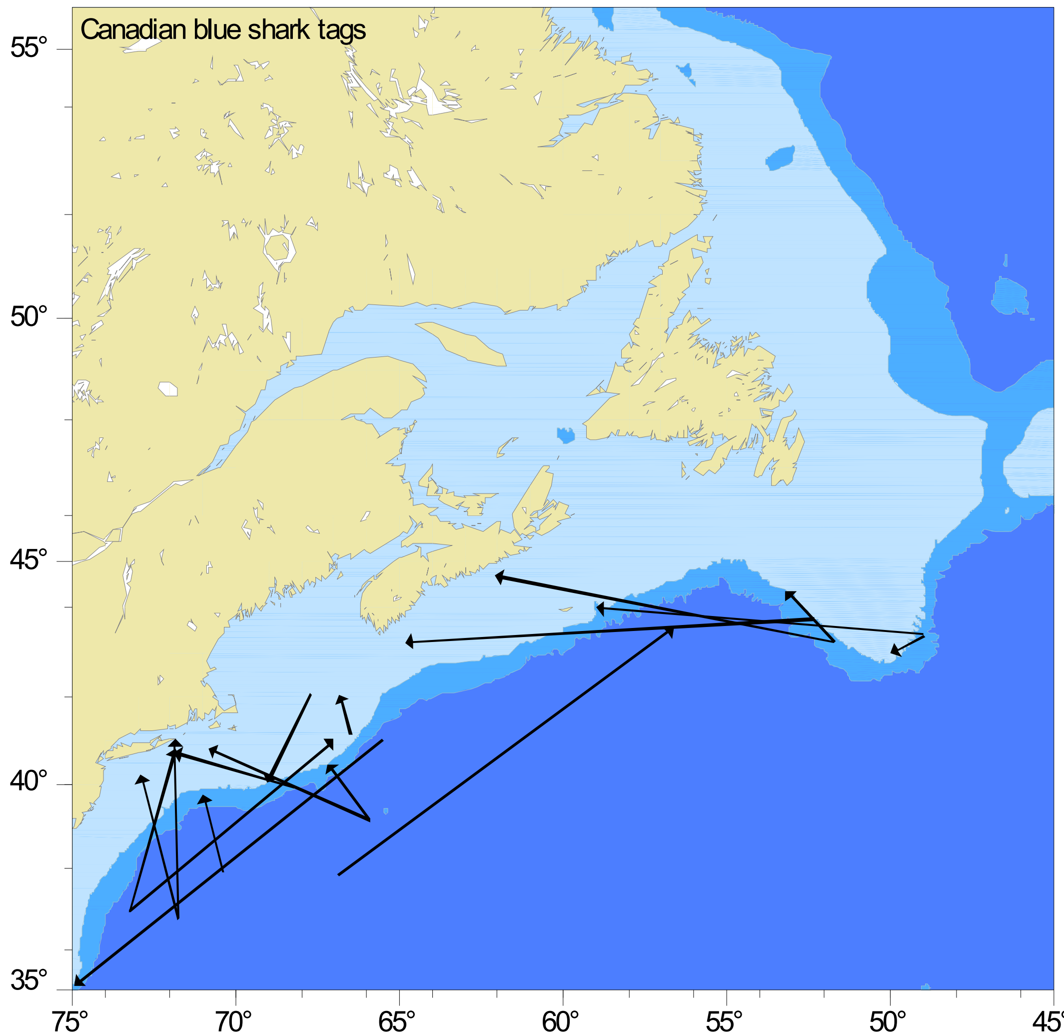
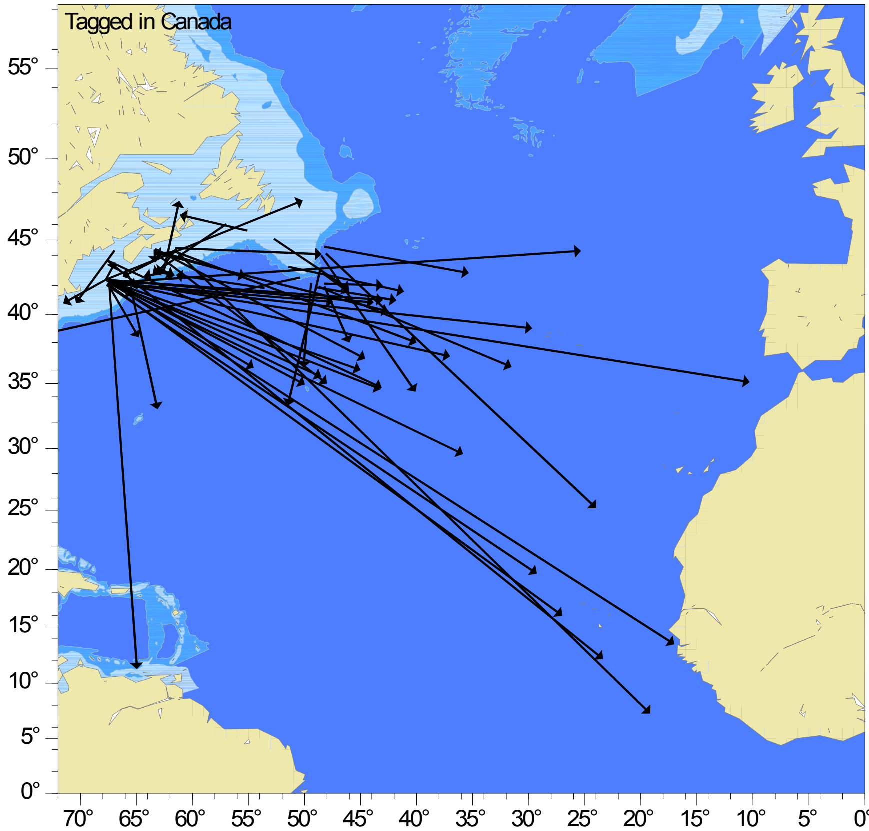


Fig. 3. Blue sharks tagged or recaptured between 1971-2002 in Canadian waters under the NMFS tagging program.



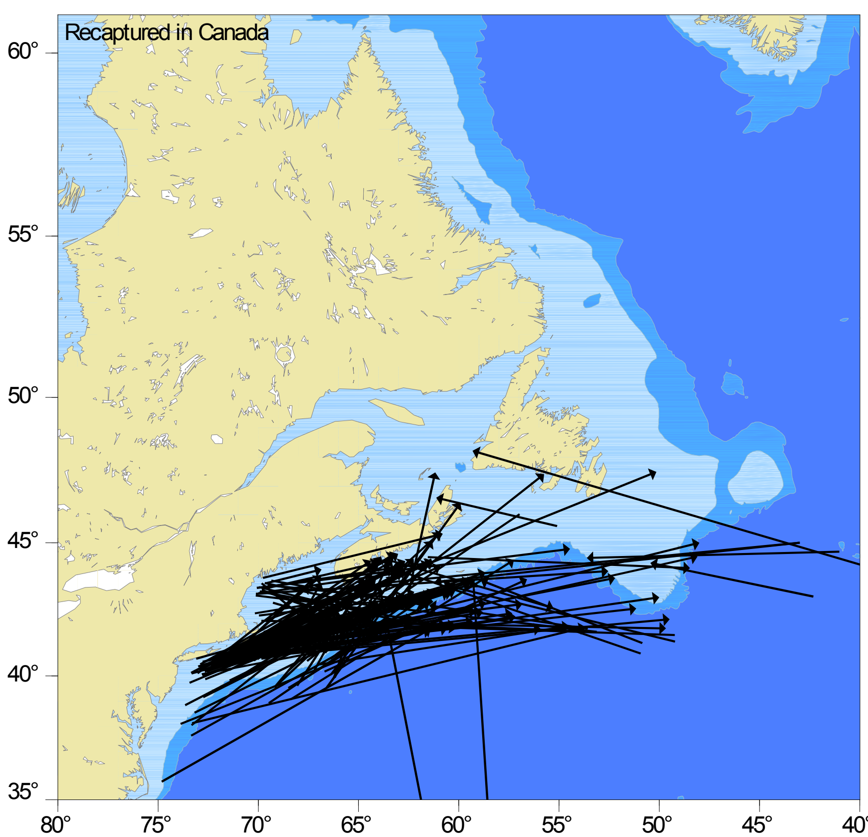


Fig. 4. Maturity ogives for blue sharks examined at shark derbies. Length at 50% maturity was well estimated for males, but could not be estimated for females because of the scarcity of females > 200 cm fork length.

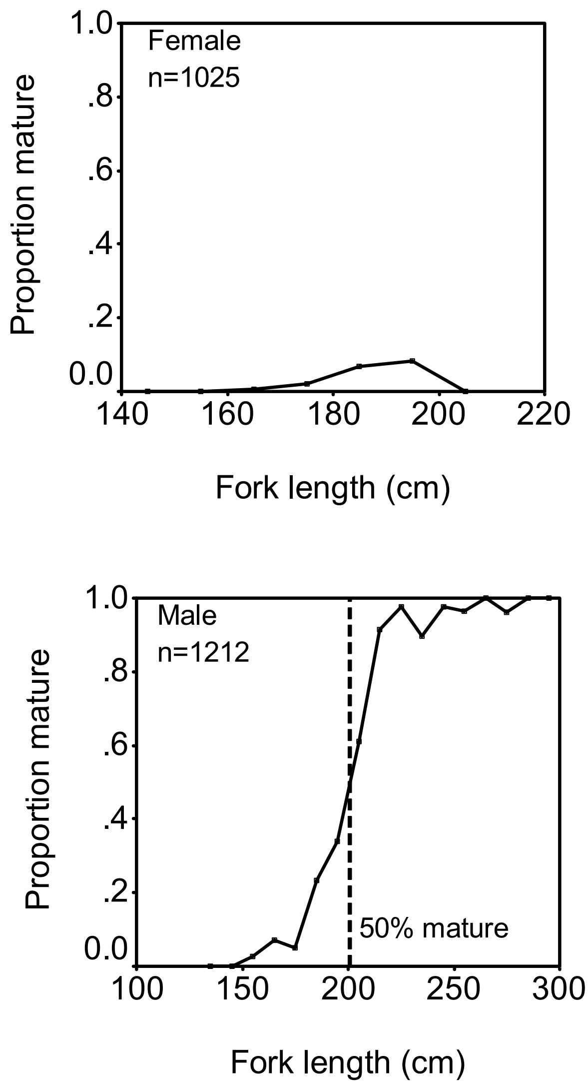
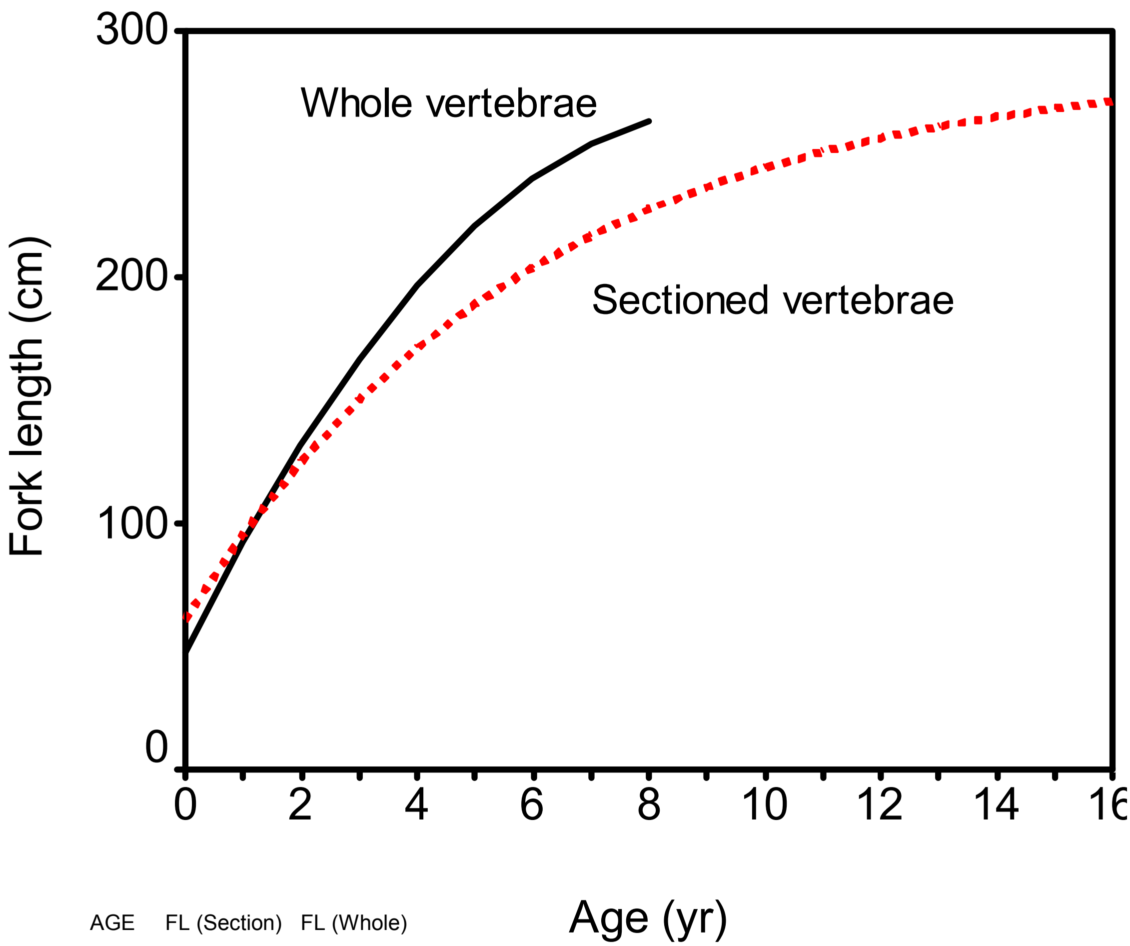


Fig. 5. Alternative growth models for blue sharks in the northwest Atlantic. Growth estimated from whole vertebrae (MacNeil and Campana 2003) predicts faster growth than does growth estimated from sectioned vertebrae (Skomal and Natanson 2003). Both models were used to bracket growth for predicting age composition. FL = fork length.



AGE	FL (Section)	FL (Whole)
0	61.0	47.5
1	95.8	92.3
2	125.2	132.1
3	150.1	166.7
4	171.2	196.3
5	189.0	220.7
6	204.1	240.1
7	216.8	254.3
8	227.6	263.5
9	236.7	
10	244.4	
11	251.0	
12	256.5	
13	261.1	
14	265.1	
15	268.4	
16	271.3	

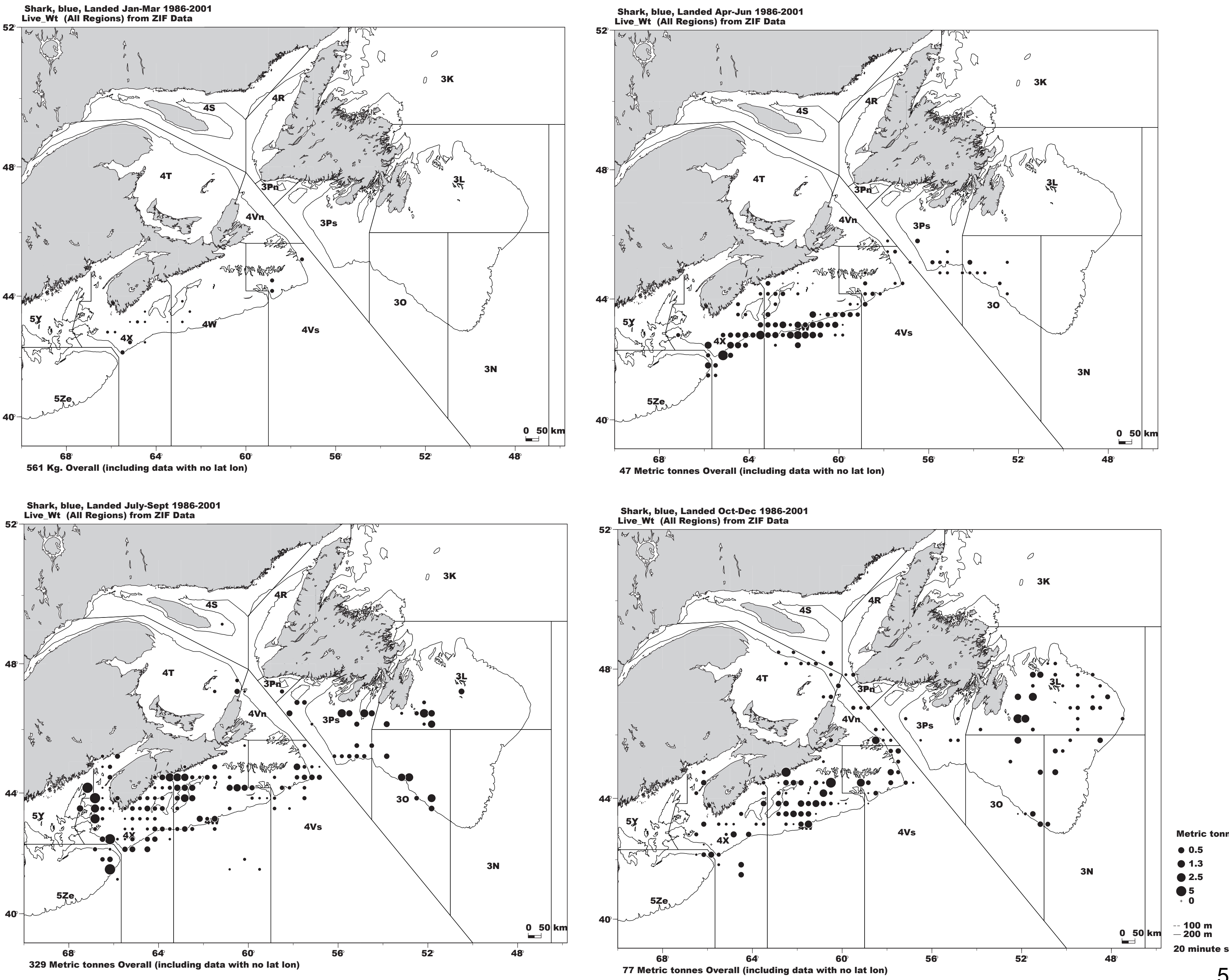
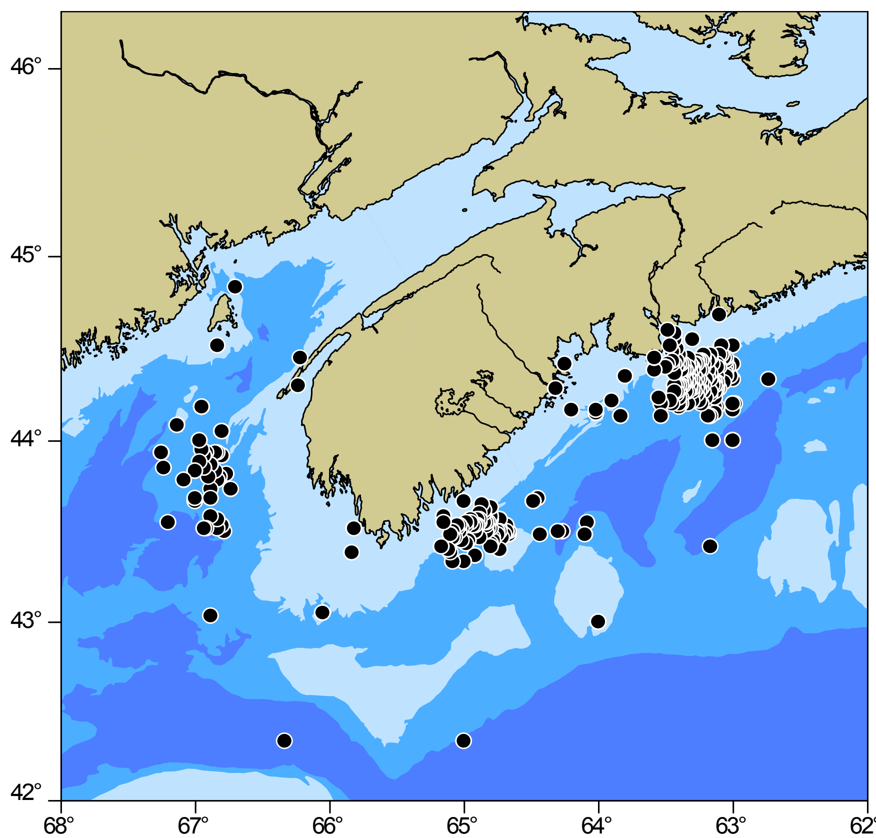


Fig 6. Catch location by season for blue sharks landed by commercial vessels between 1986-2001.

Fig. 7. Location of sharks caught at shark derbies off of Nova Scotia (1996-2002).



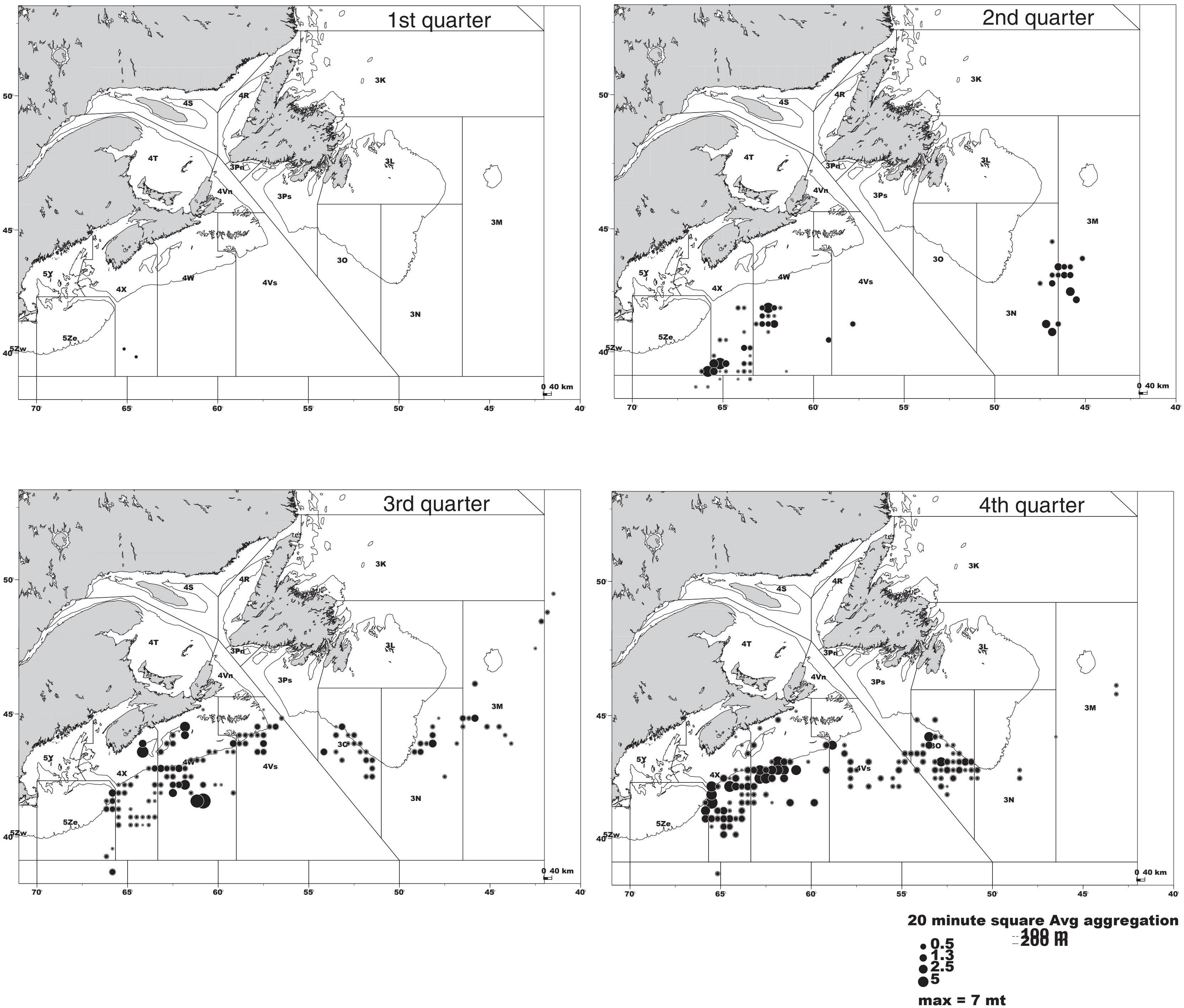
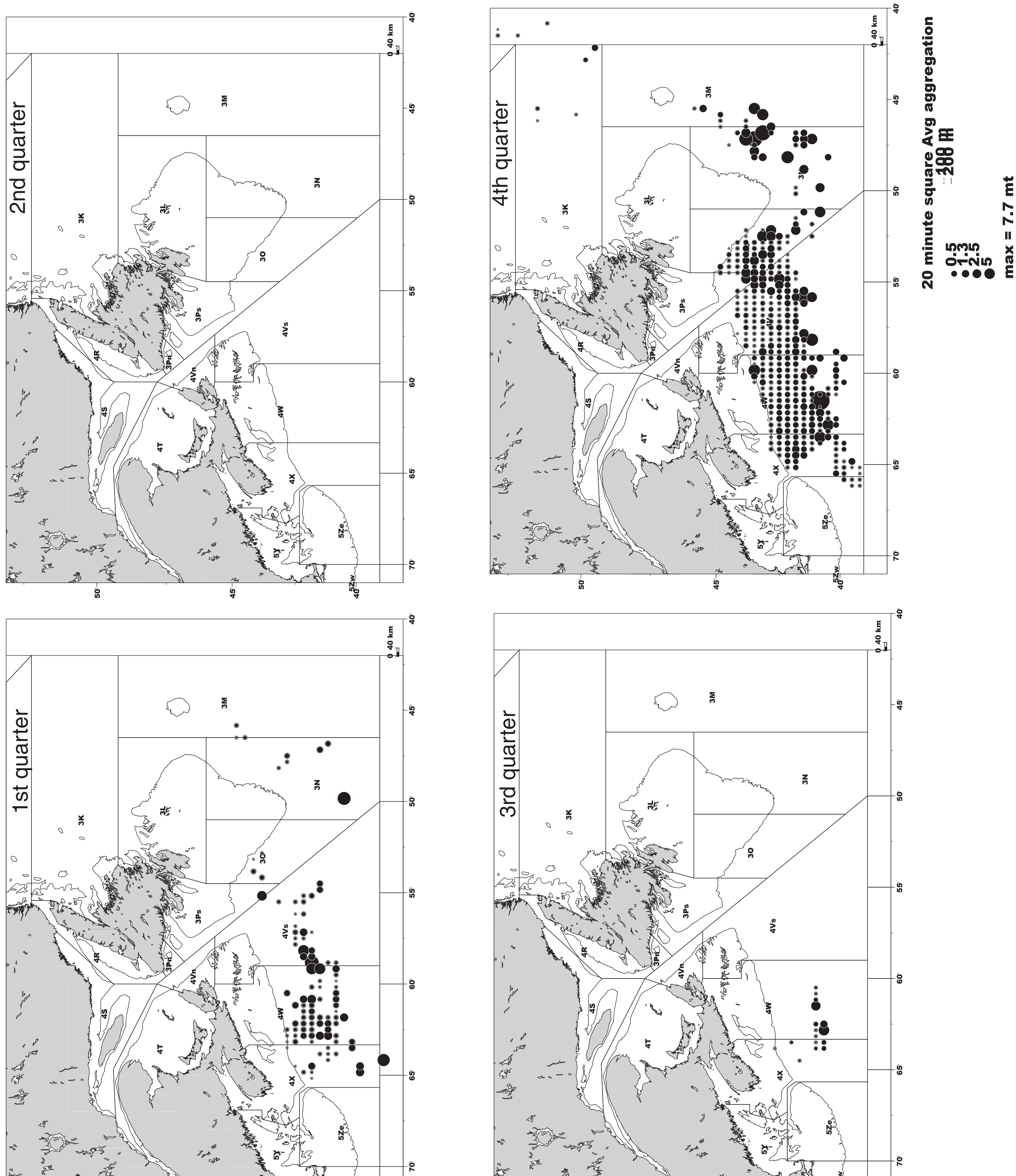


Fig. 8. Blue shark catch location by season observed by SFOP on Canadian vessels fishing swordfish or tuna between 1986-2001.

Fig. 9. Blue shark catch location by season observed by SFOP on Japanese vessels fishing swordfish or tuna between 1986-2001.



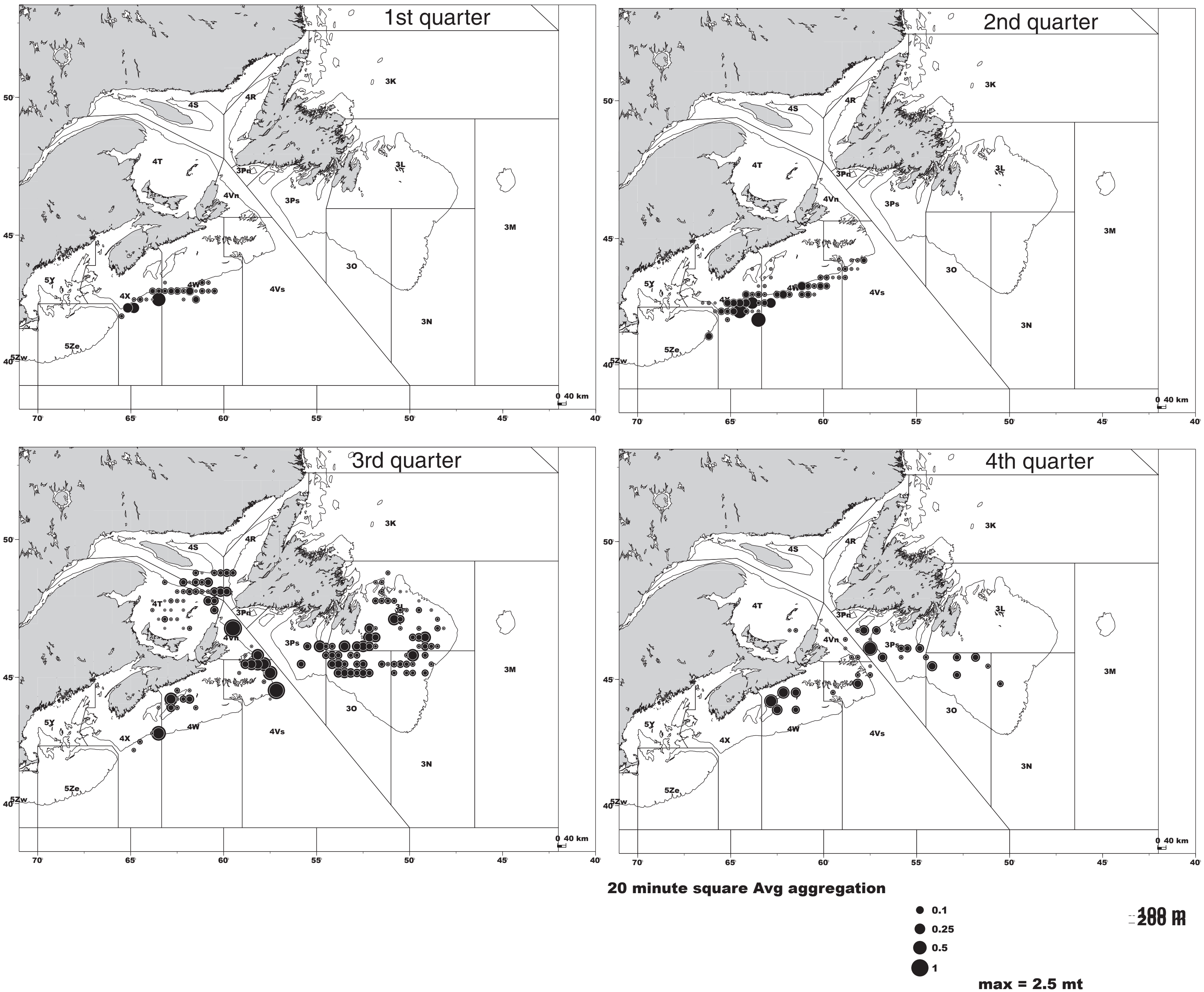


Fig. 10. Blue shark catch location by season observed by SFOP on Canadian and Faroese vessels fishing porbeagle shark between 1986-2001.

Fig. 11. Total catch mortality by source for blue sharks caught in Atlantic Canadian waters.

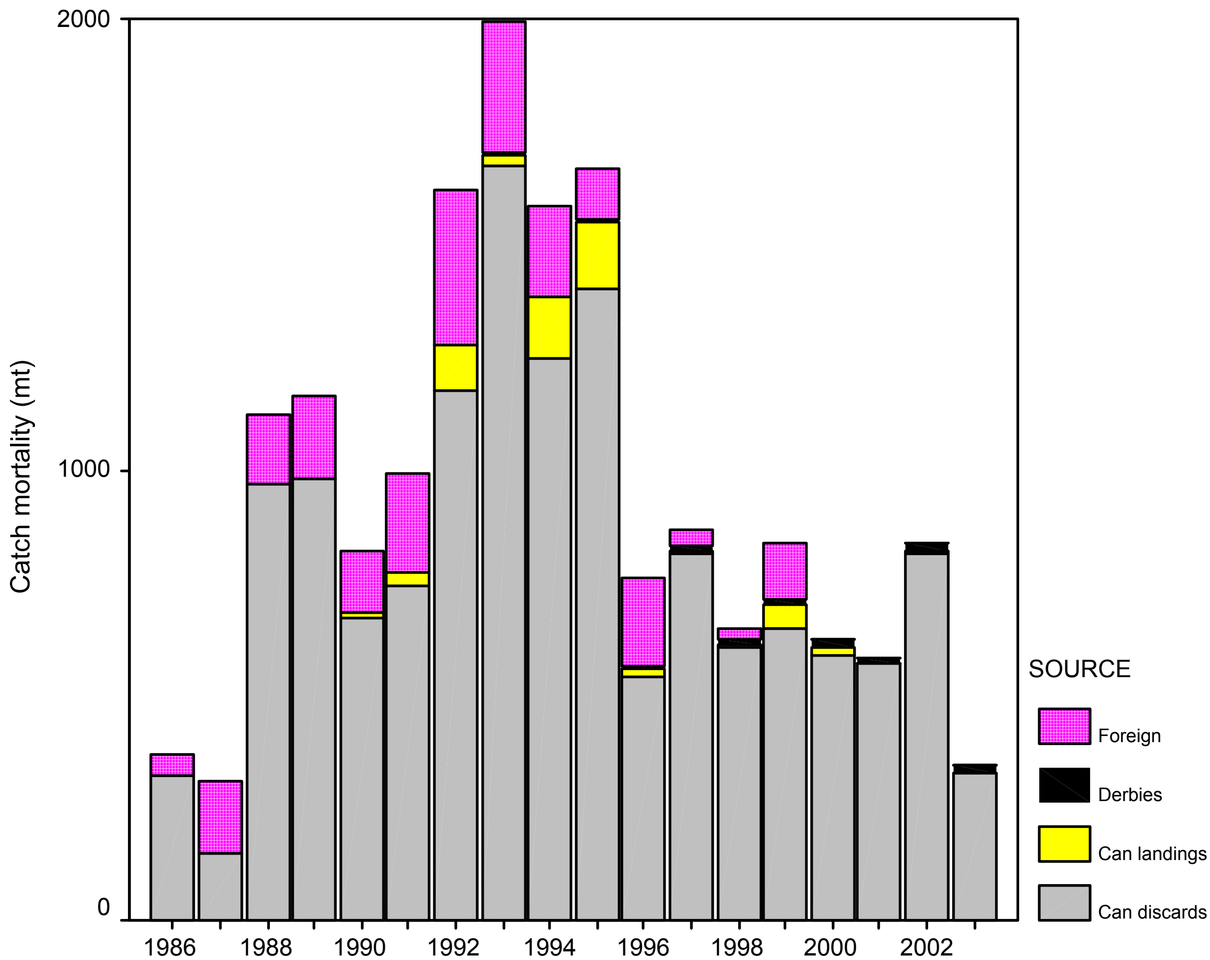


Fig. 12. Length frequency by sex for blue sharks examined at shark derbies. Large mature males made up more than half of the catch of males, while large mature females were almost completely absent.

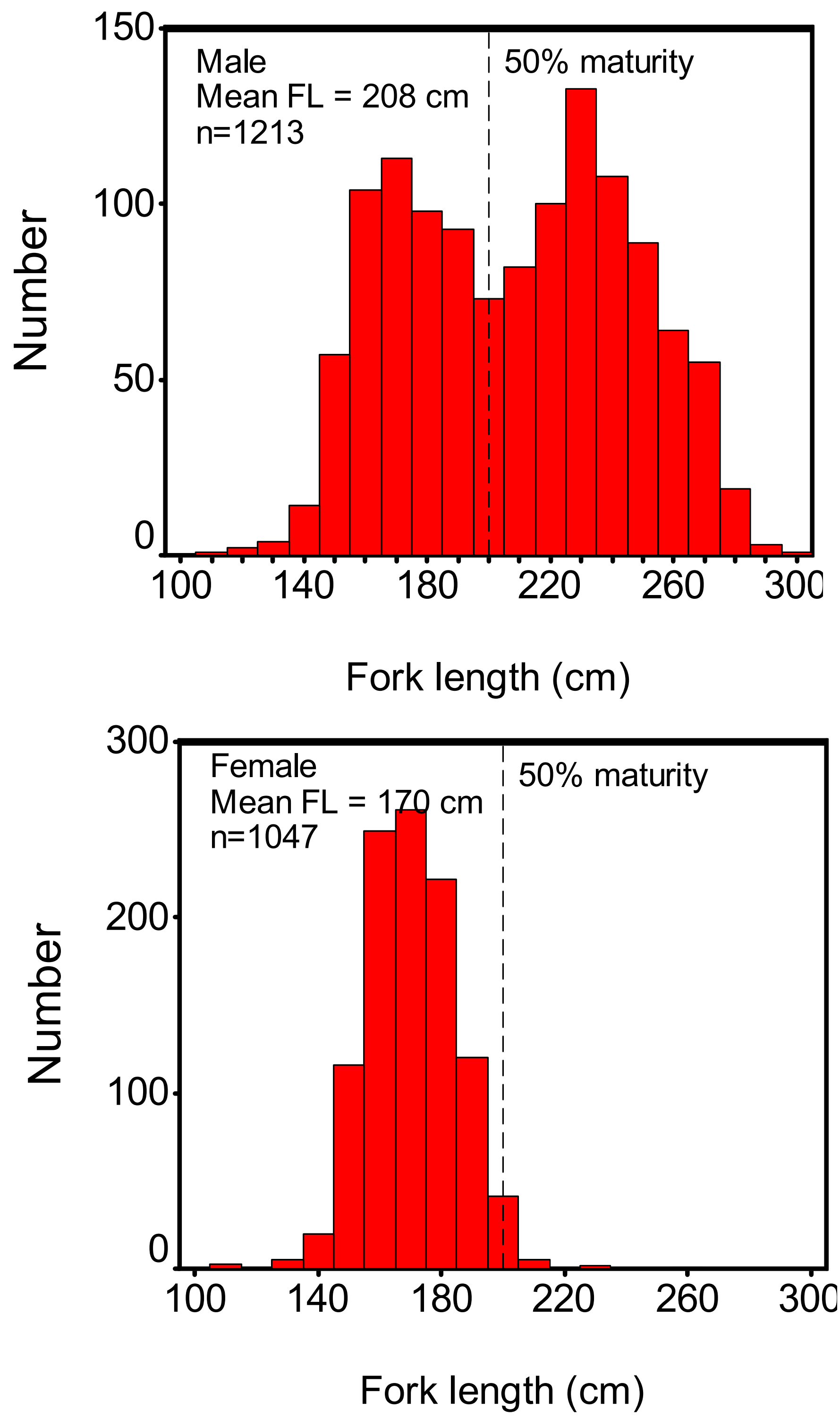


Fig. 13A. Comparison of length frequencies between blue sharks caught at shark derbies and those measured by Observers in the commercial catch on the Scotian Shelf over the same range of months and years.

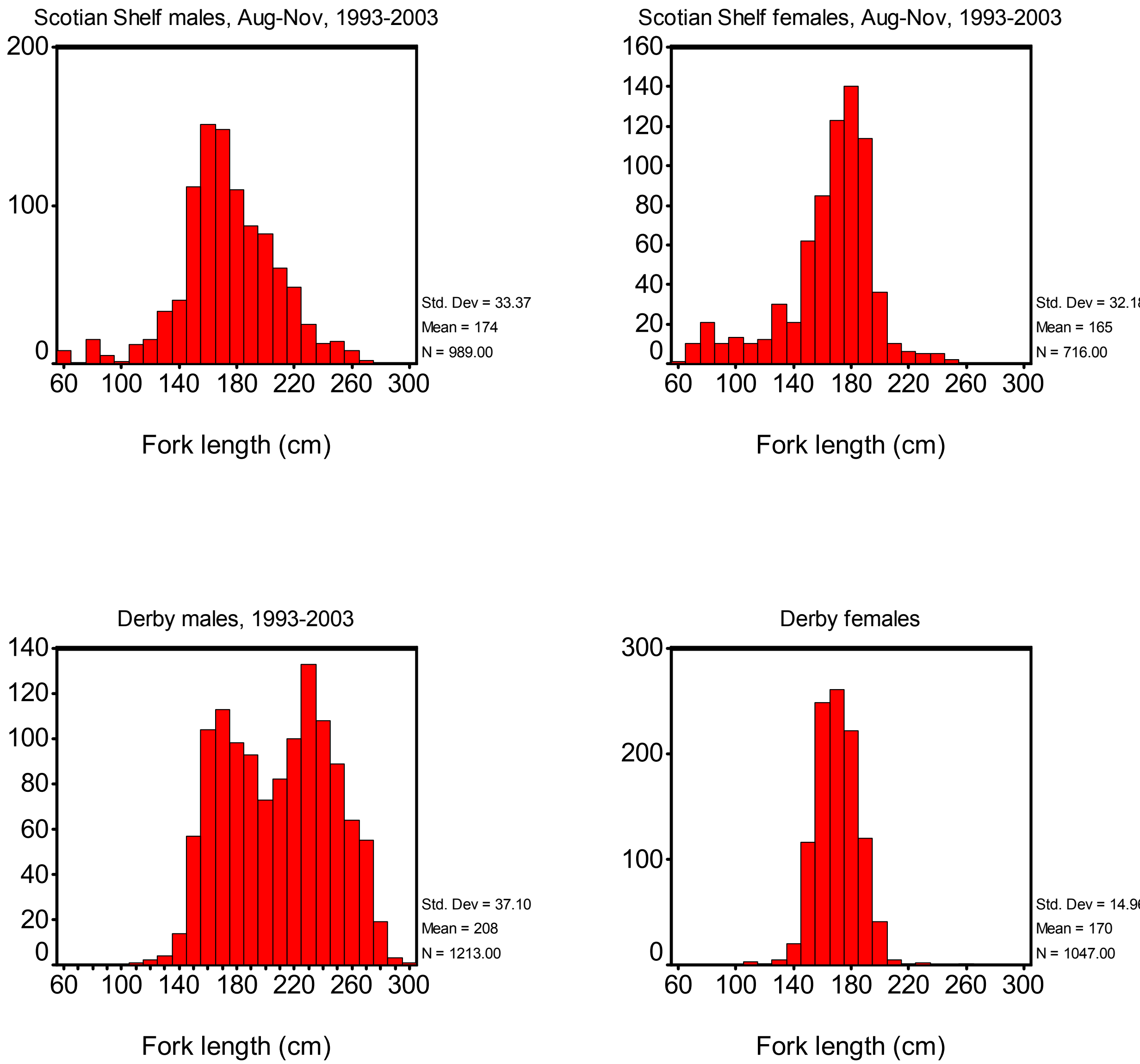


Fig. 13B. Comparison of length frequencies between blue sharks caught at shark derbies and those measured by Observers in the commercial catch in southern Nova Scotia.

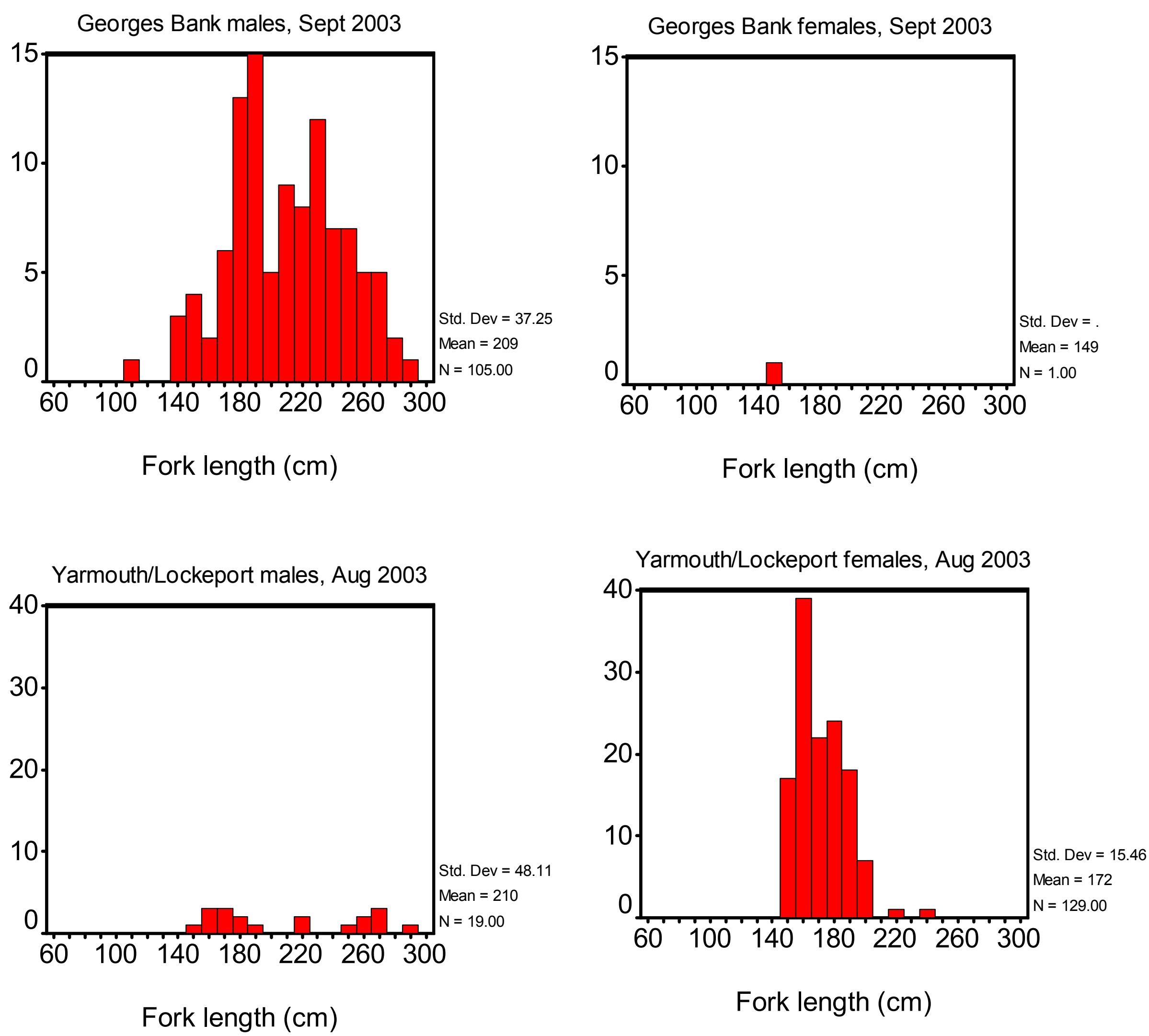


Fig. 13C. Comparison of length frequencies between blue sharks caught at shark derbies and those measured by Observers in the commercial catch off of central Nova Scotia.

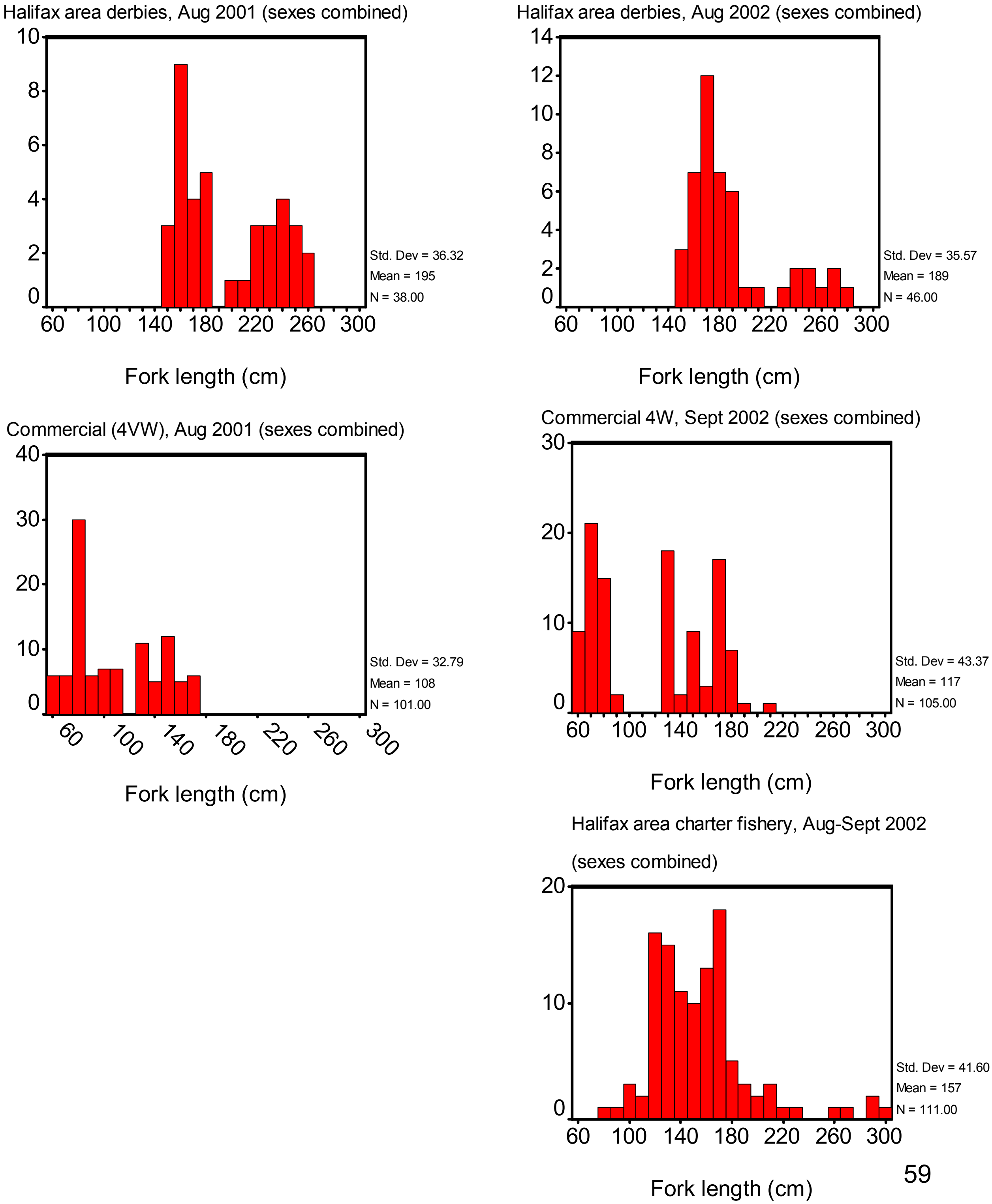


Fig. 14. Commercial catch rates (mean ± 1 SE) of blue shark by season in Japanese and Canadian large pelagic fisheries targeting other species. A vertical line marks the year after shark finning was banned.

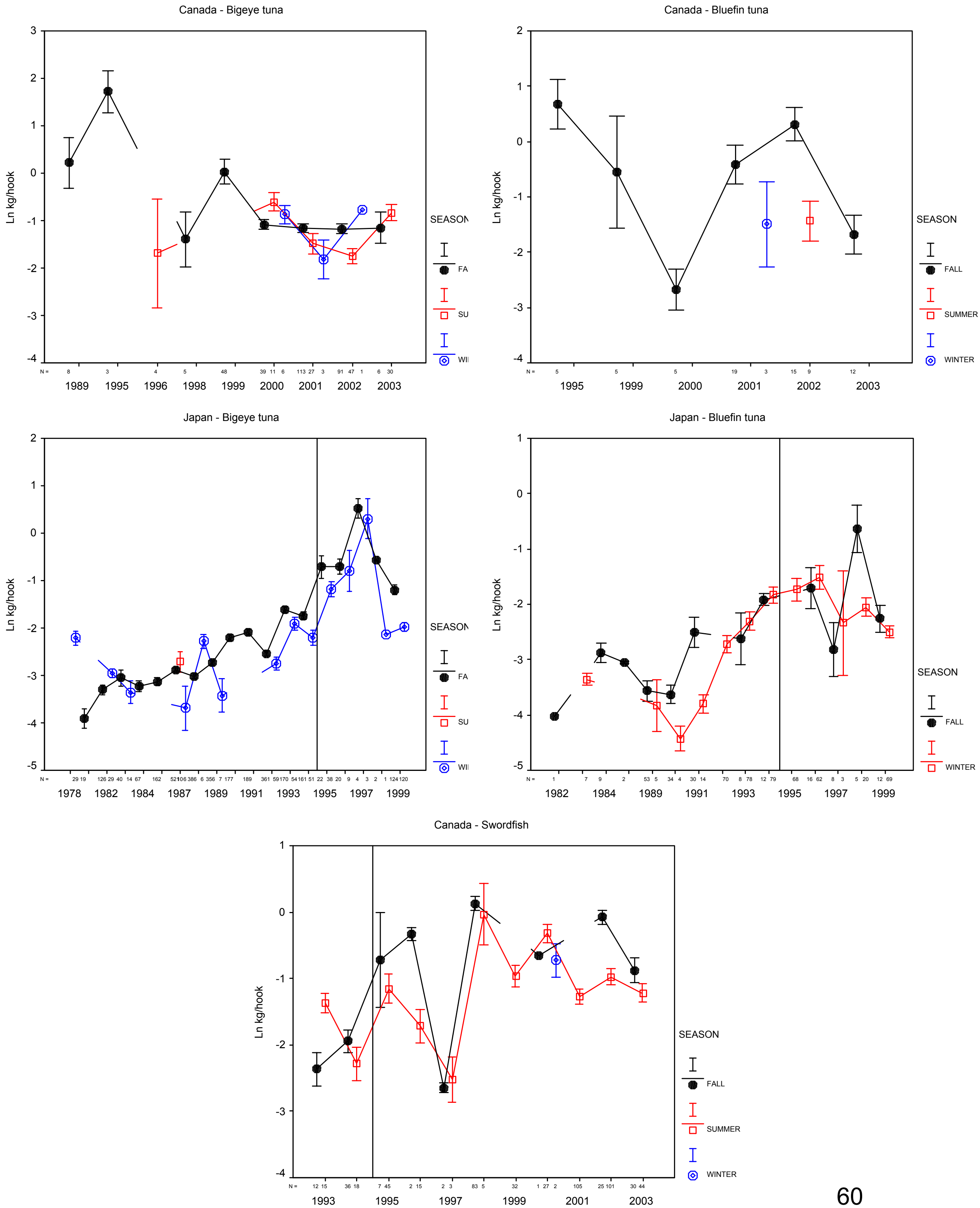


Fig. 15. Standardized commercial catch rate (ln-transformed kg/hook ± 95% CI) of blue shark in Canadian and Japanese large pelagic fisheries targeting bigeye tuna and swordfish.

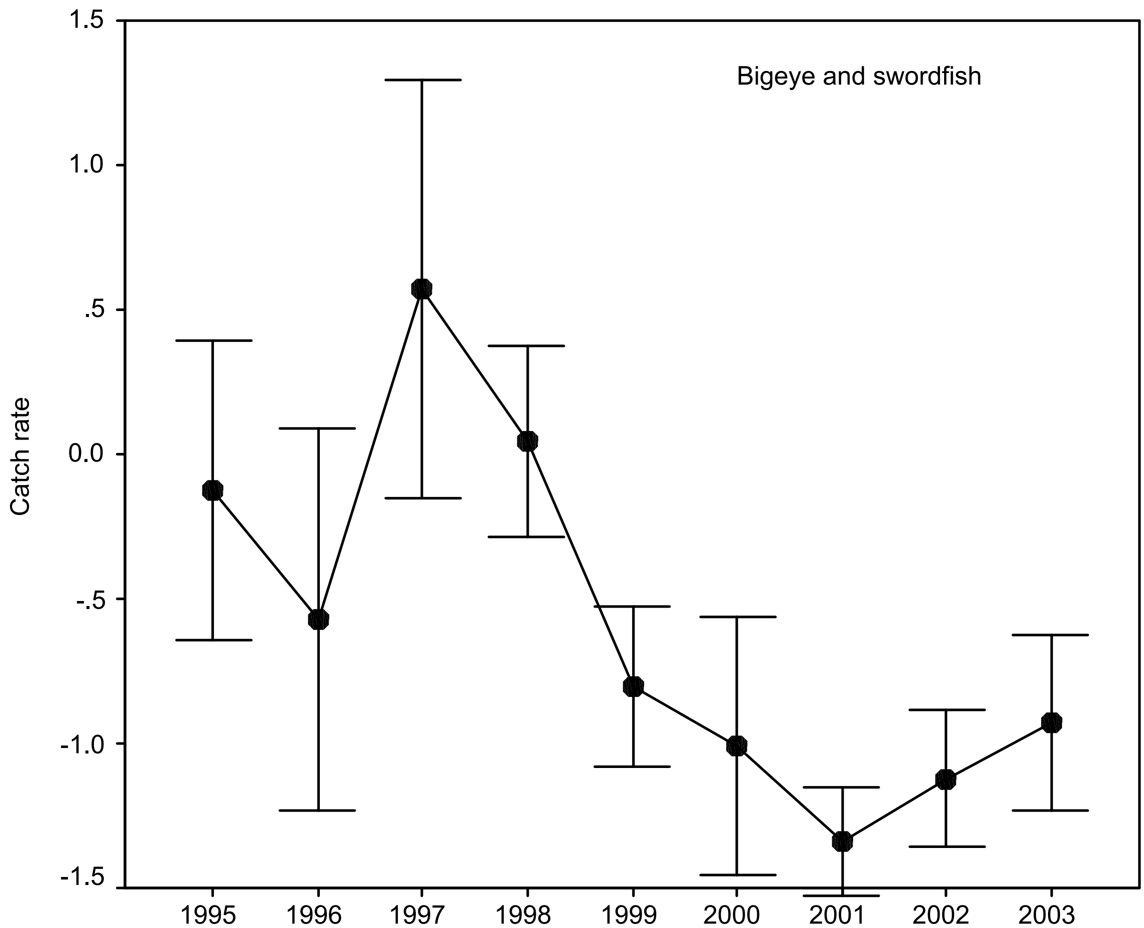


Fig. 16. Standardized commercial catch rate (ln-transformed kg/hook ± 95% CI) of blue shark by region in Canadian and Japanese large pelagic fisheries targeting bluefin tuna.

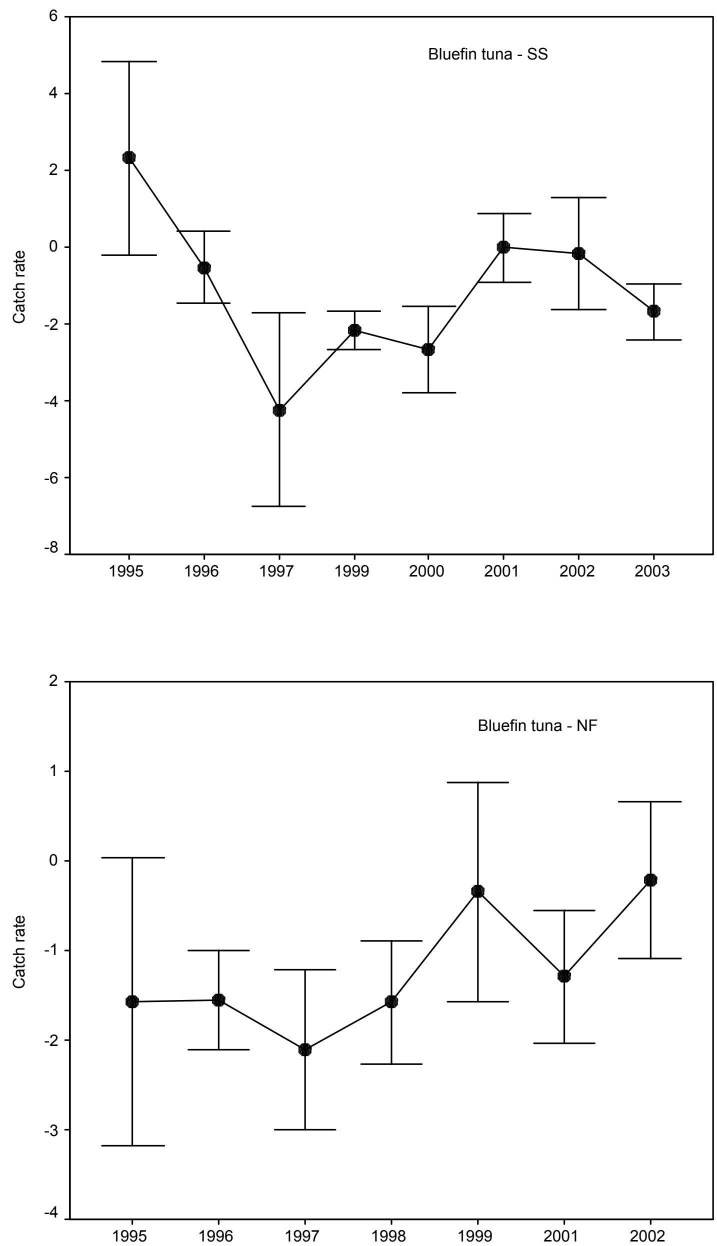


Fig. 17. Percentage of fishers who caught sharks between 1998-2003 at shark derbies off of Nova Scotia.

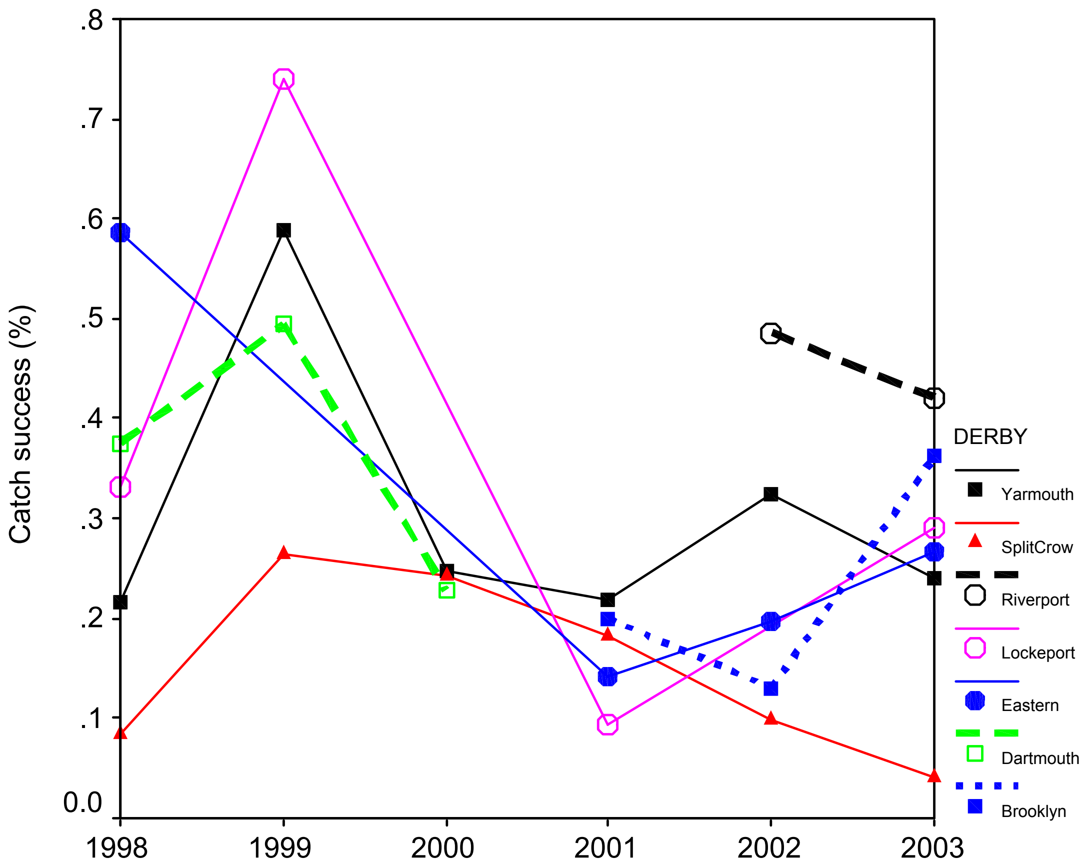
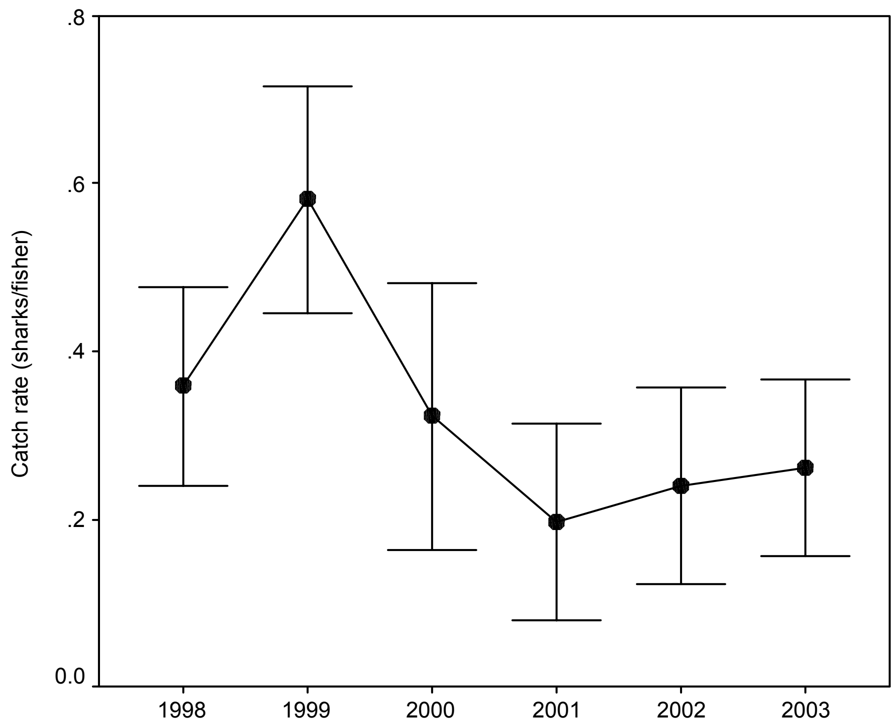


Fig. 18. (Top) Standardized catch rate (sharks/fisher, ± 95% CI) of blue sharks at recreational shark derbies; (Bottom) Standardized catch rates of blue sharks at recreational shark derbies compared to those of standardized commercial offshore fisheries for bigeye tuna and swordfish.



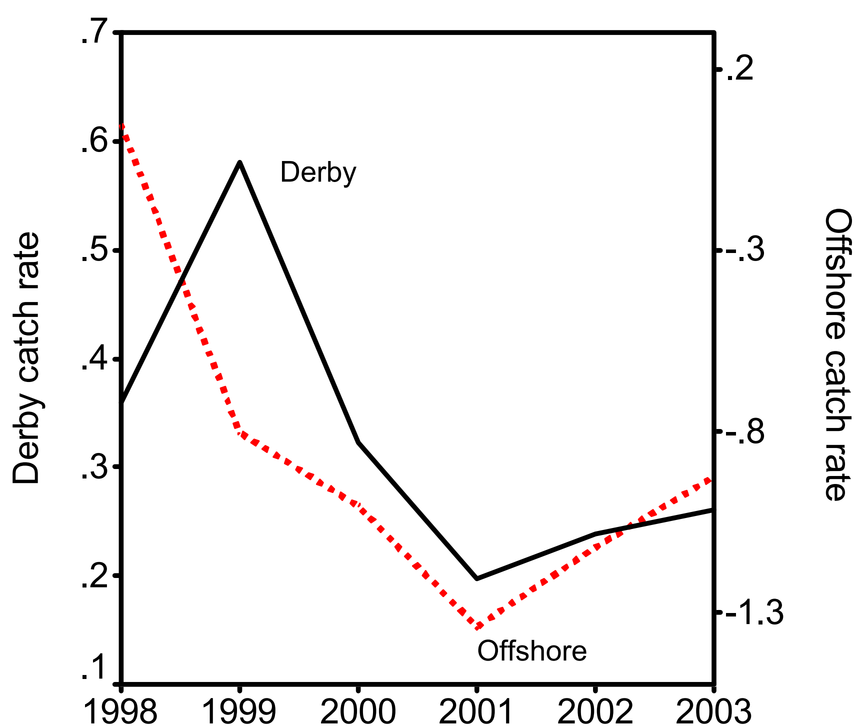


Fig. 19. Relative abundance of blue sharks indicated by an analysis of U.S. commercial longline fishery logbooks by Baum (2002). (Top) Mean (circles) and median (line) number of blue sharks caught per 1000 hooks in non-zero sets east of N.S. in international waters. (Bottom) Estimated trend in the entire west Atlantic .

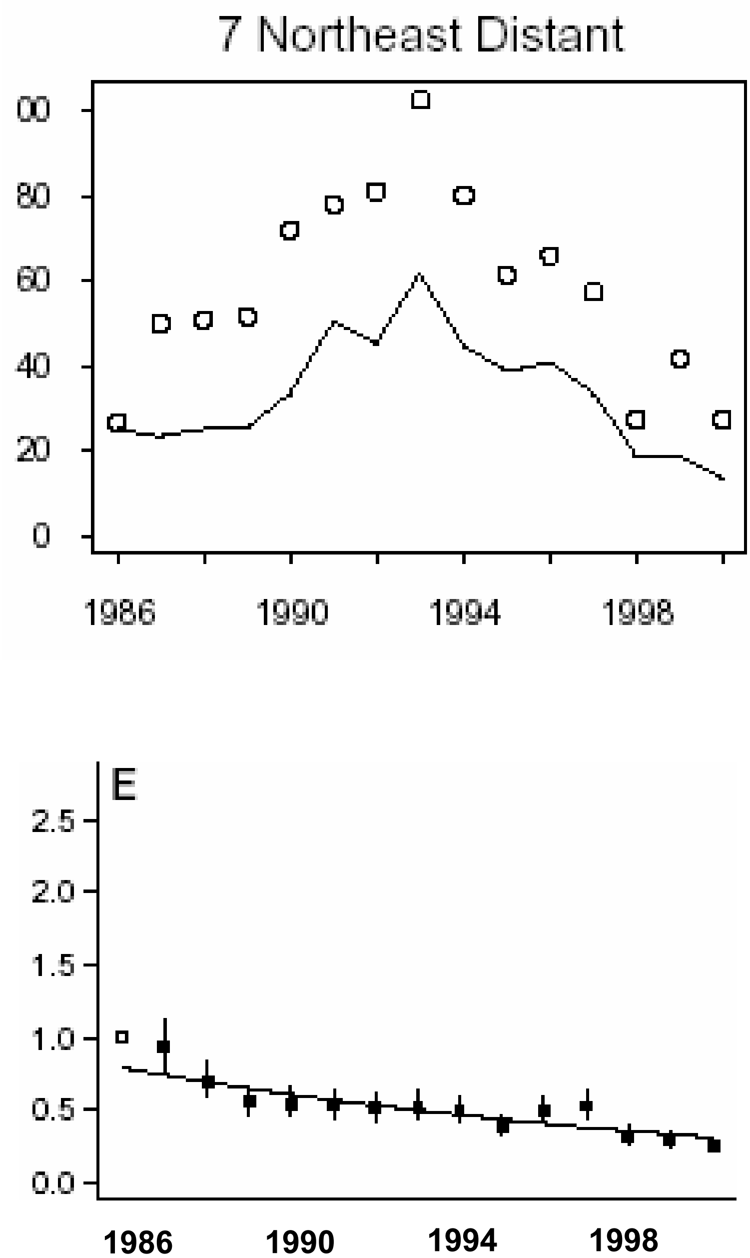
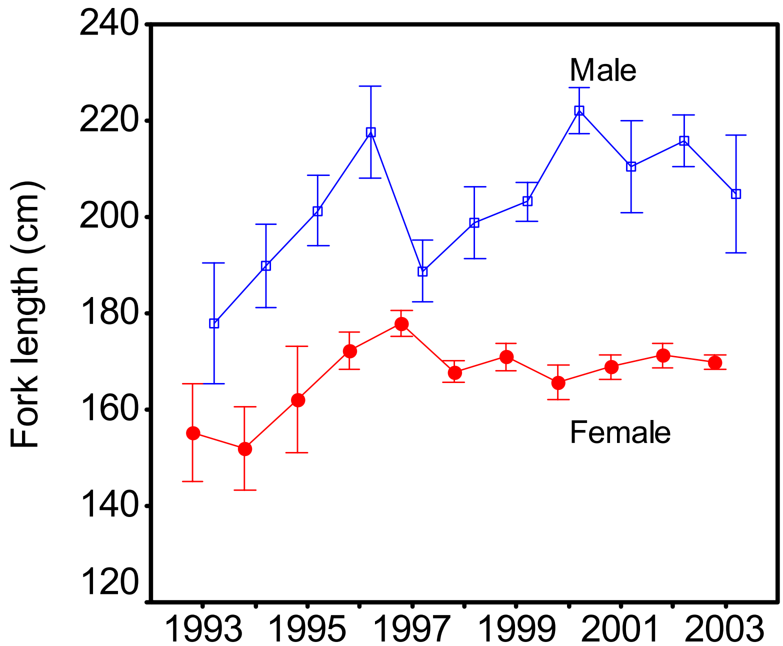


Fig. 20. Trends in mean and median fork length by sex for blue sharks caught at shark derbies since 1993.



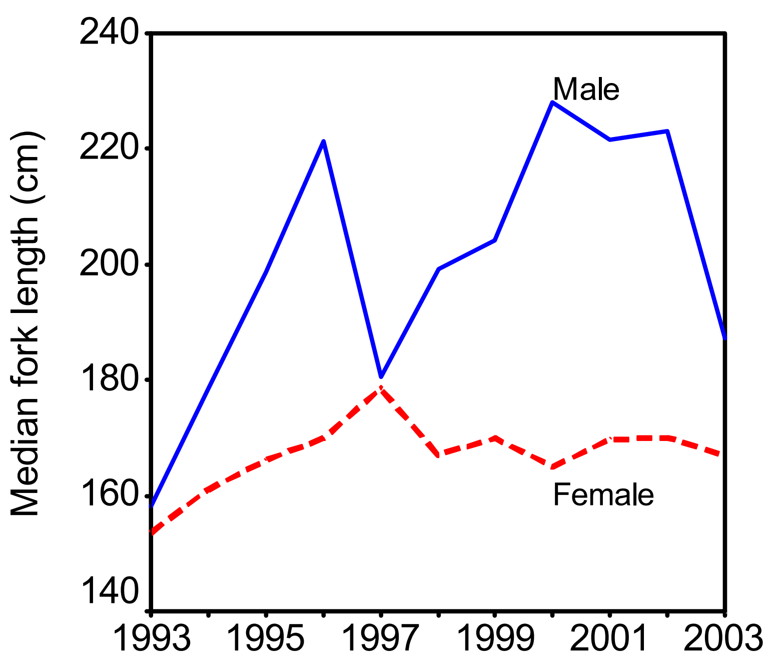


Fig. 21. Trend in mean fork length (± 95% CI) of blue sharks caught in fall and winter in Japanese (open square) and Canadian (closed circle) pelagic longline fisheries, as observed by the Scotia-Fundy Observer Program.

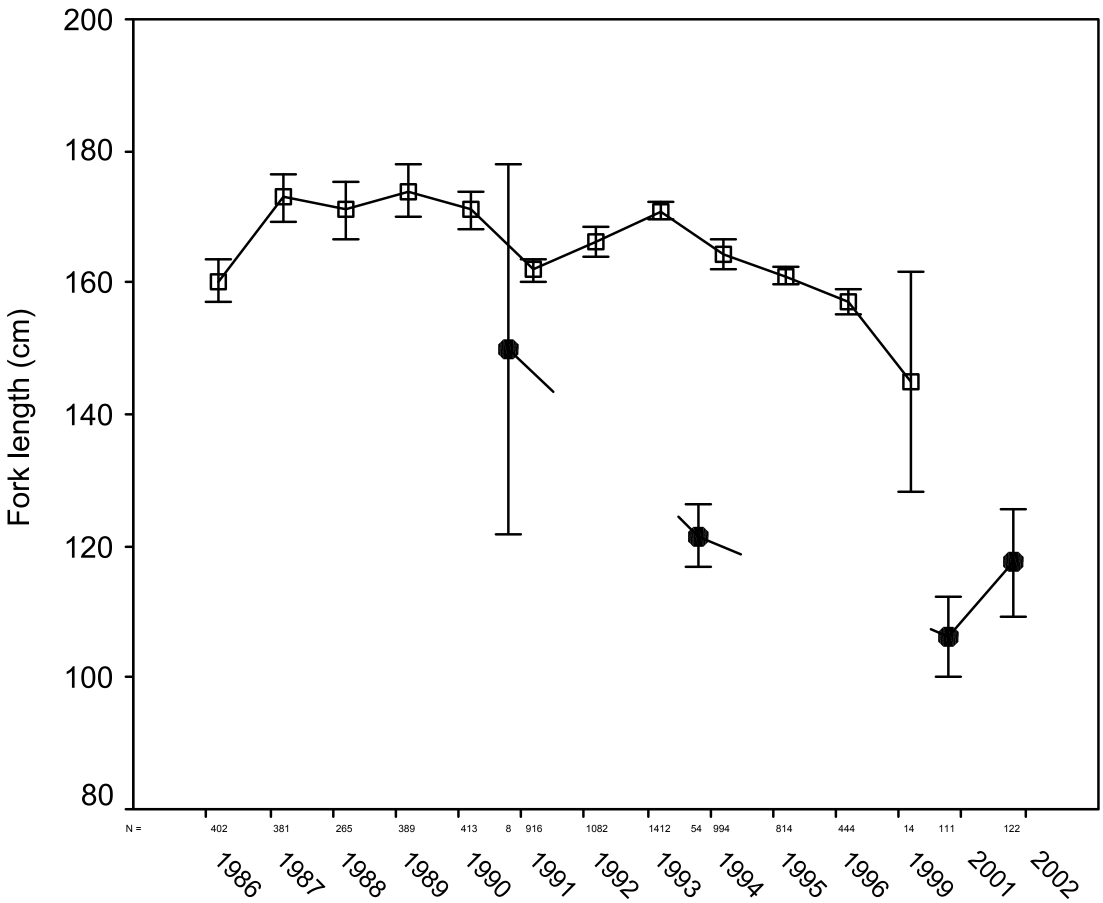


Fig. 22. Estimation of total instantaneous mortality rate (z) using catch curves generated from the alternative growth models of Skomal and Natanson (2003) and MacNeil and Campana (2003).