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CATCH, BY-CATCH AND INDICES OF POPULATION STATUS OF BLUE SHARK *(PRIONACE GLAUCA)* IN THE CANADIAN ATLANTIC

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SUMMARY

The nominal catch of blue sharks in the Canadian Atlantic grossly underestimates the actual catch mortality; the sum of landed catch and by-catch mortality in the Canadian Atlantic has averaged about 1000 t annually since 1986. 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. Catch curve analysis suggests a very high fishing mortality on the population. 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 suggest North Atlantic catches of more than 100,000 t and catch mortalities of 26,000-37,000 t. 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, steps to reduce their mortality appear to be warranted.

RÉSUMÉ

La prise nominale du requin peau bleue dans l'Atlantique canadien sous-estime considérablement la mortalité par pêche réelle ; la somme des prises débarquées et de la mortalité des prises accessoires dans l'Atlantique canadien s'est élevée en moyenne à environ 1.000 t par an depuis 1986. Plusieurs indices de la santé de la population suggèrent que l'abondance du requin peau bleue a diminué, et que la mortalité a augmenté au cours de ces dix dernières années. La taille médiane de la capture a chuté, tout comme les taux de capture standardisés des pêcheries palangrières commerciales et des tournois de pêche récréative de requins. L'analyse de la courbe des prises suggère une mortalité par pêche de la population très élevée. Toutefois, l'analyse de Petersen des récupérations de marques indique que le taux d'exploitation dans les eaux canadiennes était inférieur à 1%. Deux approximations indépendantes de la mortalité par prise totale du requin peau bleue de l'Atlantique Nord suggèrent des captures nord-atlantiques supérieures à 100.000 t et des mortalités par pêche de 26.000-37.000 t. Les requins peaux bleues ont une faible valeur commerciale et sont rejetés en grands nombres par les pêcheries pélagiques commerciales. L'analyse de la table de survie indique que les populations de requins peaux bleues sont à la fois productives et résistantes par rapport à d'autres espèces de requins, ce qui pourrait expliquer leur persistance malgré une forte mortalité par prise globale et une chute de l'abondance relative. Néanmoins, des mesures visant à réduire leur mortalité semblent être justifiées.

RESUMEN

La captura nominal de la tintorera en el Atlántico canadiense subestima en gran medida la mortalidad real por captura; la suma de la captura desembarcada y la mortalidad por captura fortuita en el Atlántico canadiense se ha situado en un promedio de 1.000 t desde 1986. Varios índices del estado de la población sugieren que, durante la última década, ha descendido la abundancia de tintorera y se ha incrementado su mortalidad. La talla media de la captura ha descendido, y también se ha observado una disminución en las tasas de captura de las pesquerías de palangre comercial y de los torneos de pesca de recreo de tiburones. El análisis

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de la curva de captura sugiere un alto nivel de mortalidad por pesca de la población. Sin embargo, el análisis Petersen de las recuperaciones de marcas indica que la tasa de explotación en las aguas de Canadá era < 1%. Dos aproximaciones independientes de la mortalidad por captura total de tintorera en el Atlántico norte sugieren unas capturas en el Atlántico norte de más de 100.000 t y una mortalidad por captura que oscila entre 26.000 y 37.000 t. Las tintoreras tienen un bajo valor comercial y las pesquerías pelágicas comerciales descartan un gran número de tintoreras. Los análisis del ciclo vital indican que las poblaciones de tintorera son productivas y elásticas en comparación con otras especies de tiburones, un hecho que puede explicar su persistencia frente a una alta mortalidad global por captura y a un descenso en la abundancia relativa. Sin embargo, las medidas para reducir la mortalidad parecen estar justificadas.

KEYWORDS

Prionace glauca, Shark fisheries, Population dynamics, Catch/effort, Fishing mortality, Long lining

1. 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 by-catch in the Canadian Atlantic, concluding that unreported by-catch was about 20 times larger than reported catch (Campana *et al.* 2002). The objective of the current analysis was to provide improved catch and by-catch estimates, estimates of discarding mortality, and several indices of exploitation rate and population status in the Canadian Atlantic for this shark species.

2. Biology

2.1 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 **Figure 1**. The standard measure reported in this paper is that of fork length measured over the curve of the body.

2.2 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 snapped open. Females were considered to be mature if the uterus was enlarged or flaccid, or if embryos or large 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 (**Figure 2**). There has been no trend in length at male maturity since 1999. Mature females were seldom caught, 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.

2.3 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.

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 (**Figure 3**). 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.

3. Fisheries management

Since 1995, fisheries management plans for blue sharks in Atlantic Canada have maintained non-restrictive catch guidelines of 250 t 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, with the exception of tournaments. No catch restrictions were put on shark caught as by-catch in large pelagic fisheries. A ban on "finning" sharks (the removal of the fins and at-sea disposal of the finless carcass) was announced in June 1994. Full details of the Canadian shark management plan are presented in Campana *et al.* (2002).

4. 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 t in 1994, declining thereafter to only 19 t 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 t in the 1990s. North Atlantic nominal catches are substantially larger, averaging over 30,000 t since 1998. However, much of this reported catch is believed to have been caught in the northeast Atlantic.

Blue shark landings by Canadian vessels are very small, averaging 52 t per year since 1990. Most of the landings are from longlines, although recreational shark fishing derbies averaging 10-20 t annually have accounted for a growing proportion of the landings in recent years. 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 (**Figure 4**).

5. By-catch

5.1 Observed by-catch

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

Observed catch and by-catch between 1990-1999 averaged about 250 t annually, with most of that coming from Japanese vessels. In most years, virtually all of the blue shark catch was discarded (**Table 2**). Since 1999, virtually all observed catch and by-catch has been by Canadian vessels. Catch locations mapped by quarter over the period 1986-2001 indicate that most of the Canadian by-catch occurred in deep waters off the continental shelves of Nova Scotia and Newfoundland, increasing in quantity through the year (**Figure 5**). 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 (**Figure 6**). The location of blue shark by-catch 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 (**Figure 7**).

5.2 Estimation of Unobserved Blue Shark By-catch

To determine the magnitude of the blue shark by-catch in the various large pelagic fisheries, by-catch was estimated by country, fishery, quarter and year from Scotia-Fundy Observer Program (SFOP) observations made between 1986-2000, with by-catch 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. By-catch in the foreign fisheries was fully observed, so estimation was used more to calculate by-catch proportion than by-catch 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 by-catch accounted for 26-152% of the total large pelagic catch, with an overall mean of 34%. Blue shark by-catch 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 by-catch. Therefore, each quarter and fishery was characterized by a unique by-catch 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 cut off the leader of blue sharks before reaching deck, it is likely that the estimated by-catch proportions calculated above represent the minimum actual Canadian by-catch. 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 by-catch proportions assumes that blue sharks were caught in all sets, but reported only in some; thus it sets an upper limit to the by-catch estimate. We have termed this a maximum estimate. Campana *et al.* (2002) concluded that blue shark by-catch on Canadian vessels fishing swordfish or other tunas was underreported by some observers, and that actual by-catch lies somewhere in the range defined by our minimum and maximum by-catch estimates. For the current analysis, we have assumed that the mean of the minimum and maximum by-catch estimates represents the most probable by-catch for these fisheries. Minimum by-catch estimates appear to be valid for the Japanese, bluefin tuna and porbeagle fisheries, although by-catch 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 3-6**.

Blue shark by-catch 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 3-5**. By-catch proportions often exceeded 100%. Annual by-catch estimates averaged less than 100 t for the bluefin tuna fishery, less than 500 t for other tuna, and around 2000 t 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 6**). Annual by-catch estimates averaged about 50 t.

6. Hooking mortality

A confounding issue in the interpretation of blue shark by-catch concerns the survival or mortality of the discarded sharks. Virtually all blue sharks are discarded after capture. Prior to 1994, all shark by-catch 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. However, there do not appear to be any published studies of hooking (discarding) mortality in sharks.

Table 7 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 7** would subsequently die. However, the detailed post-capture examinations of the injured sharks in the scientific study of **Table 7** indicate 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 7** 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.

7. Total catch mortality

Total estimated annual blue shark catches and discards in Canadian waters are shown in **Table 8**. Discards from the Canadian large pelagic fisheries were responsible for the largest proportion of blue sharks caught in Canadian waters since 1986. However, total estimated catch mortalities, based on the discard rates and hooking mortalities presented earlier, are lower, averaging around 1000 t per year over the time series (**Table 8; Figure 8**). The proportion of catch mortality contributed by recreational and tournament fishing was negligible, averaging 3% of the total catch mortality in recent years.

8. Commercial catch rates

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 **Figure 9.**

In general, the catch rates of **Figure 9** 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 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 9**). The marginal catch rate based on the significant factors indicated that catch rates have decline significantly since 1995 (**Figure 10**). 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 **Figure 10.**

The GLM based on bluefin tuna fisheries was significant with respect to all factors (**Table 10**). However, the significant interaction terms necessitated that the marginal trends be plotted separately by region (**Figure 11**). 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.

A final GLM was based on the overall fishing success at 5 shark fishing tournaments (derbies) carried out annually since 1998 (Campana et al. 2004). 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 11**; **Figure 12**). When scaled to the same scale as the standardized bigeye/swordfish model, the trend across years was similar in the two models (**Figure 12** 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.

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 (**Figure 13**). 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 constant decline of 60% over the period 1986-2000 (**Figure 13** bottom). This modelled decline appears to have little in common with the observed CPUE series in the region containing most of the blue sharks (**Figure 13** 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 **Figure 10**.

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.

9. 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, are described in Campana *et al.* (2004).

Despite the relatively high tagging effort in the Canadian study, there were relatively few recaptures in the 1960s and 1970s (**Table 12**). 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 13**). 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 13b**). 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 13a**). 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 12**) with that of 1992-2002 (**Table 13**). 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.

10. 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 (**Figure 14**). 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) (Campana *et al.* 2004). 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 late1980s (**Figure 15**). 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).

11. Demographic analysis

11.1 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 14**). 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.

11.2 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 15 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, and 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).

12. 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 missing 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 **Figure 16**. 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 14**), 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.

13. 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 by-catch proportion calculated from observed fisheries. Blue shark by-catches 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 16**). 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. 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 t. 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 t, which is likely to be a conservative estimate.

Our calculations for approximating blue shark catch in the North Atlantic are shown in **Table 16**. Total blue shark catch is estimated at more than 100,000 t. This value is almost 4 times the nominal catch of **Table 1**. Assuming 40% hooking mortality in the longline fishery (**Table 7**) and an arbitrary 20% mortality in the purse seine fishery, the catch mortality of blue sharks in the year 2000 was almost 37,000 t. 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 13** was 0.0078, corresponding to an observed catch in Canadian waters of 321 t. Given the population-level F of 0.66 (=exploitation rate of 0.48) from the fast-growth catch curve (**Figure 16**), and assuming a 75% tag reporting rate from the observed catch, the North Atlantic catch mortality would be 26,338 t (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 t and 26,000 t. 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.

14. Discussion

Several conclusions concerning blue shark by-catch 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 by-catch mortality, the sum of nominal catch and by-catch mortality has averaged about 1000 t annually since 1986, with most of this being the result of discard mortality.

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 unlikely that 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 **Figure 10**. 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 by-catch ratios and mortality estimates, suggest North Atlantic catches of more than 100,000 t and catch mortalities of between 26,000 and 37,000 t. As first approximations, 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 by country.

	Canadian Atlantic (NAFO Areas 2 - 5)					Northwest Atlantic				North Atlantic
Year	Canada	Faroe Is	Japan	Other	Total	Japan	USA	Other	Unspecified pelagic	
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 IOP (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. Blue shark catches and discards (mt) by country in Canadian waters as observed by the International Observer Program. The percentage of the catch that was discarded is also shown.

CATCH							DISCARDS							DISCARD PERCENTAGE			
Year	Canada	Faroe Is	Japan	USSR	Other	Total	Year	Canada	Faroe Is	Japan	USSR	Other	Total	Year	Canada	Faroes	Japan
1978	0		0			0	1978	1		8			9	1978	.	.	100
1979	0		4			4	1979	10		8			18	1979	100	.	22
1980		0	0	13	3	16	1980		3	6	0	3	12	1980	.	.	100
1981		0	1		1	2	1981		1	12		1	14	1981	.	100	73
1982			2			2	1982			52			52	1982	.	.	100
1983			1			1	1983			25			25	1983	.	.	96
1984			0			0	1984			14			14	1984	.	.	96
1985	0		0			0	1985	1		0			1	1985			
1986			13	0		13	1986			31	1		32	1986	.	.	80
1987		0	38			38	1987		2	121			123	1987	.	100	76
1988		0	5		1	6	1988		16	129		1	146	1988	.	100	96
1989	0	0	10			10	1989	42	8	164			214	1989	100	100	96
1990	1	0	13	0		14	1990	7	22	102	1		132	1990	100	100	92
1991	4	6	5	0		15	1991	20	59	129	19		227	1991	98	90	96
1992	0	30	30		0	60	1992	2	82	202		1	287	1992	.	73	97
1993	1	62	47			110	1993	14	19	186			219	1993	100	23	79
1994	16		116		0	132	1994	48		207		3	258	1994	78	.	64
1995	15		73			88	1995	107		100			207	1995	88	.	59
1996	2		173			175	1996	37		61			98	1996	89	.	26
1997	1		36			37	1997	30		0			30	1997	98	.	.
1998	1		17			18	1998	210		17			227	1998	100	.	45
1999	1		11			12	1999	185		282			467	1999	100	.	96
2000	1		0			1	2000	70		3			73	2000	100	.	100
2001	0		0			0	2001	179		0			179	2001	100	.	.
2002	1		0		0	1	2002	228		0		4	232	2002	100		
2003	0		0			0	2003	85		0			85	2003	100		

Notes: Based on data from Maritimes IOP (1978-2003) and Newfoundland IOP (1980-1995)

Table 3. Blue shark bycatch and proportions in the Canadian bluefin tuna fishery.

Canada

QUARTILE I		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
	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 II		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
	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 III		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
	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 IV		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
	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 maximum, represent weighted means from all sets, or only those with blue shark catch, respectively from Campana et al (2002).

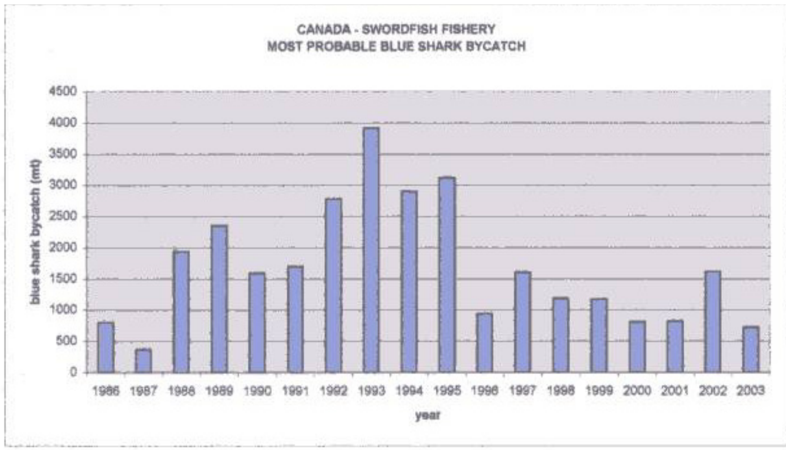


Table 4. Blue shark bycatch and proportions in the Canadian swordfish fishery.

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) (maximum)																			

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	3 7	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: BFTmainspc_TunaSFPORcatch gearselected.sav

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

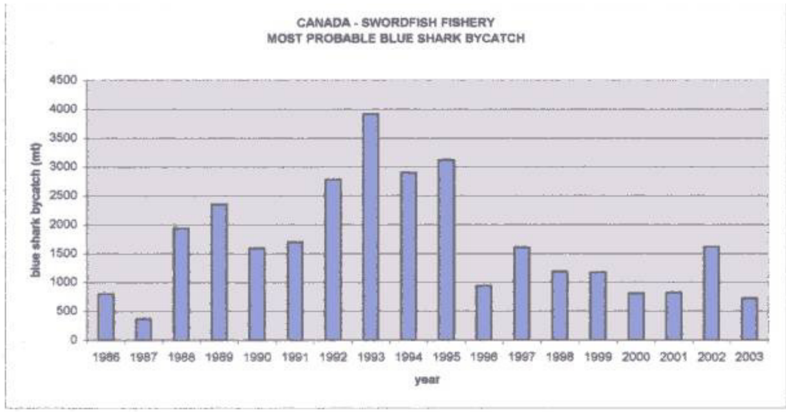


Table 5. Blue shark bycatch and proportions in the Canadian other tuna fishery.

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)				8	113	7	2	0		2									
	blue shark proportion																			
	blue shark catch (mt) (maximum)																			
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: BFTmainspc_TunaSFPORcatch gearselected.sav

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

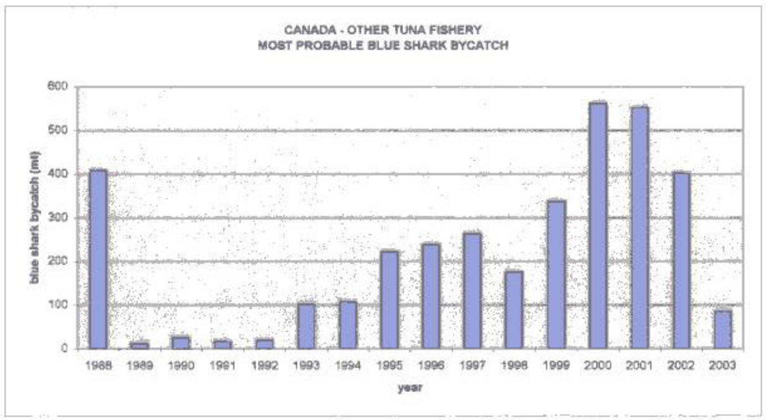


Table 6. Blue shark by-catch and proportions in the Canadian porbeagle shark fishery.

Canada

QUARTILE I	Year																		
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
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 II	Year																		
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
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 III	Year																		
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
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 IV	YEAR																		
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
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	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)*							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: BFTmainspc_TunaSFPORcatch gearselected.sav

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

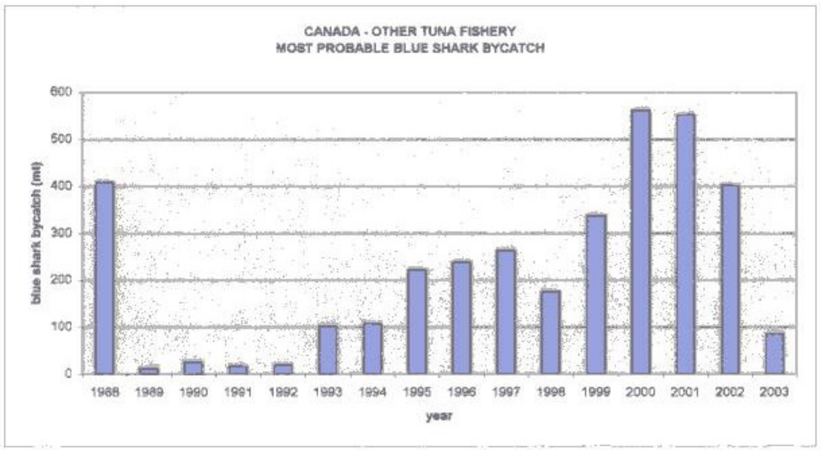


Table 7. Estimates of blue shark hooking mortality in the commercial and recreational fisheries.

Scientific Study on Commercial Vessel (Sept 2003)

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

International 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

.

Table 8. 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] International Observer Program measurements of all foreign kept catch
‡ International Observer Program measurements of all foreign discarded catch
† International Observer Program measurements of Canadian discards; coverage was about 5% of fleet
** Sum of landed catches, plus hooking mortality probabilities of Table 7 applied to recreational, foreign discards and estimated catch from Canadian fishery

Table 9. 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 10. 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 11. 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 12. 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 13a. Tag recaptures and calculated exploitation rates for blue sharks in Canadian waters, as recorded by NMFS. a) all fleets

Year	Tagged in 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**
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

Table 13b. Tag recaptures and calculated exploitation rates for blue sharks in Canadian waters, as recorded by NMFS. 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 14. 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

Table 15. 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*maturity	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				Selected	Survivor-ship	# Survivors	Fecun-dity	Survivors x Offspring	Needed for G	Stationary Age	Life-Span	Life Expectation
Age (x)	**Area Shelf**	**Area NF**	**Area combined**	Area	**Si**	**lx**	**mx**	**lx.mx**	**lx.mx.x**	**Lx**	**Tx**	**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			

Table 15, Continued

Output parameters:

Net Repro. Rate	Generation Time	Intrinsic Rate of Increase	Finite Rate of Pop. Increase
Ro	G	r	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= 0.359257

Fmsy= 0.180
e^r = 1.432

Table 16. 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 North Atlantic large pelagic catch is similar to that in the NW Atlantic.

	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 International Observer Program measurements on Japanese and Canadian large pelagic vessels, 1986-2000

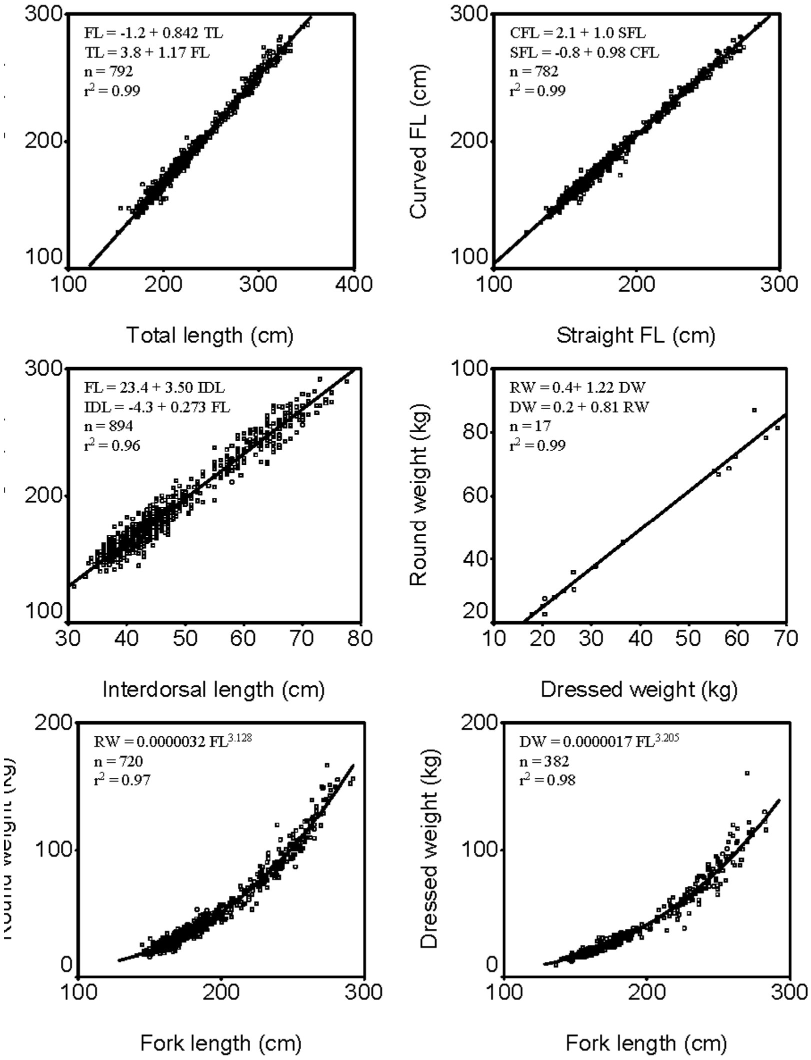


Figure 1. Morphometric conversions between various length and weight measures for blue sharks measured at shark derbies. FL = fork length.

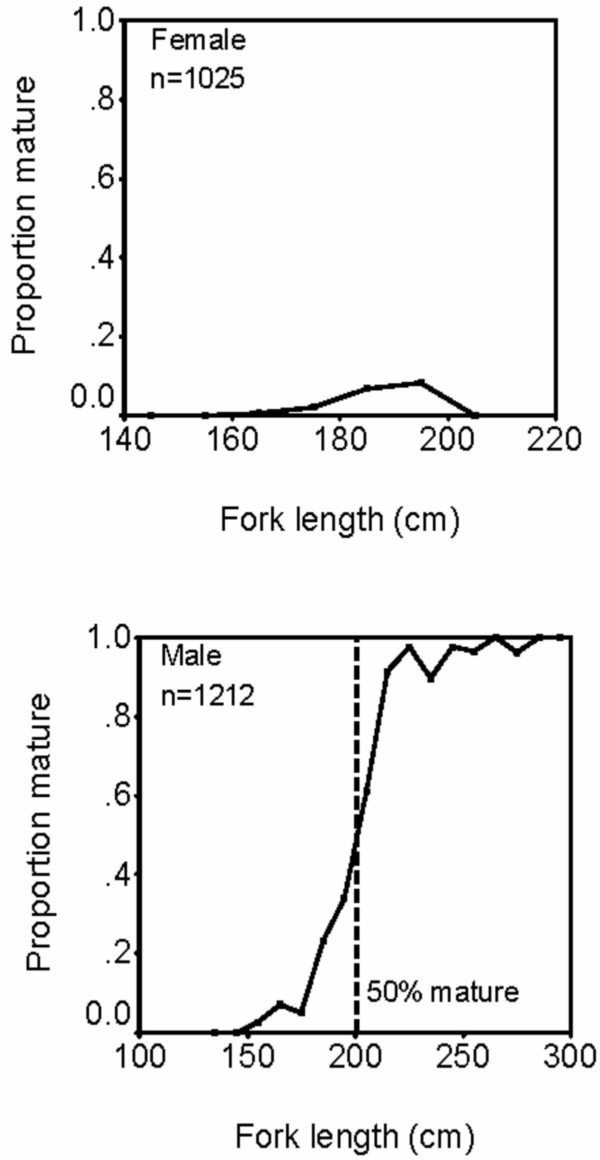


Figure 2. Maturity ogives for blue sharks examined at shark derbies. Length at 50% maturity was well estimated for males, but could not be estimated for females because of the scarcity of females > 200 cm fork length.

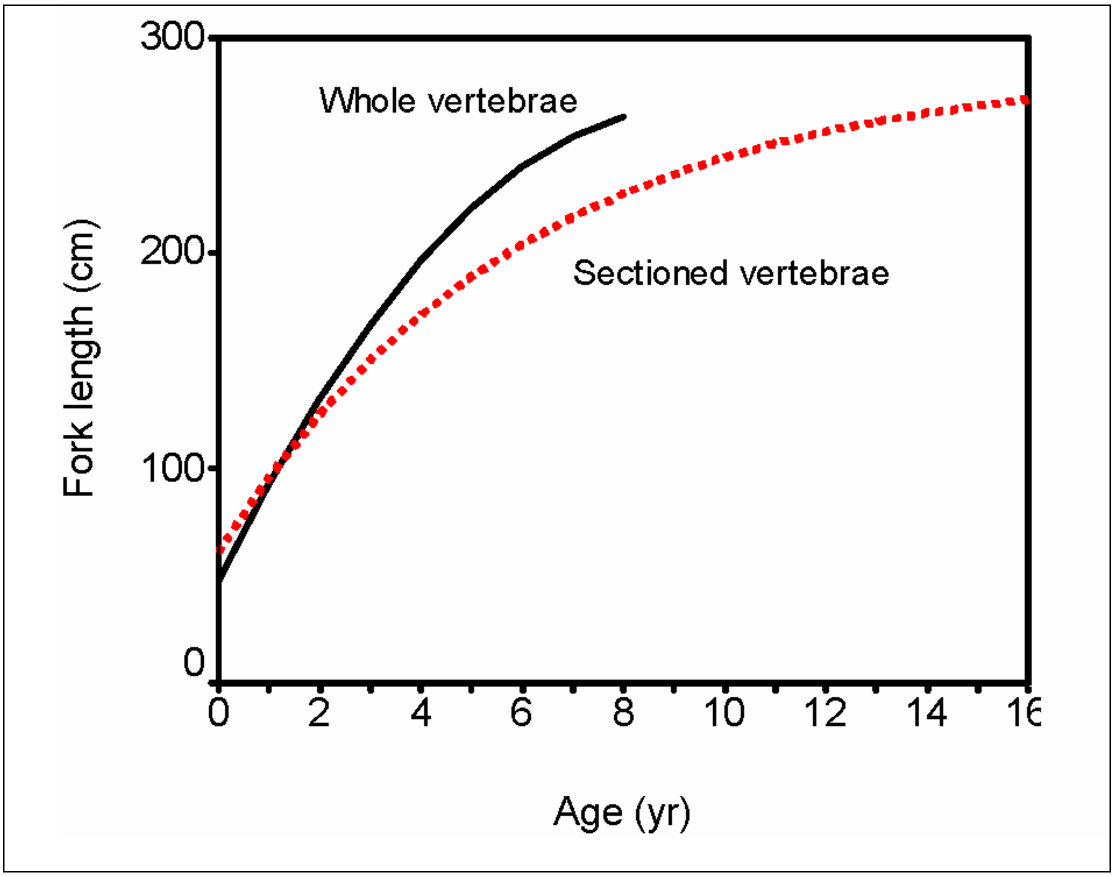
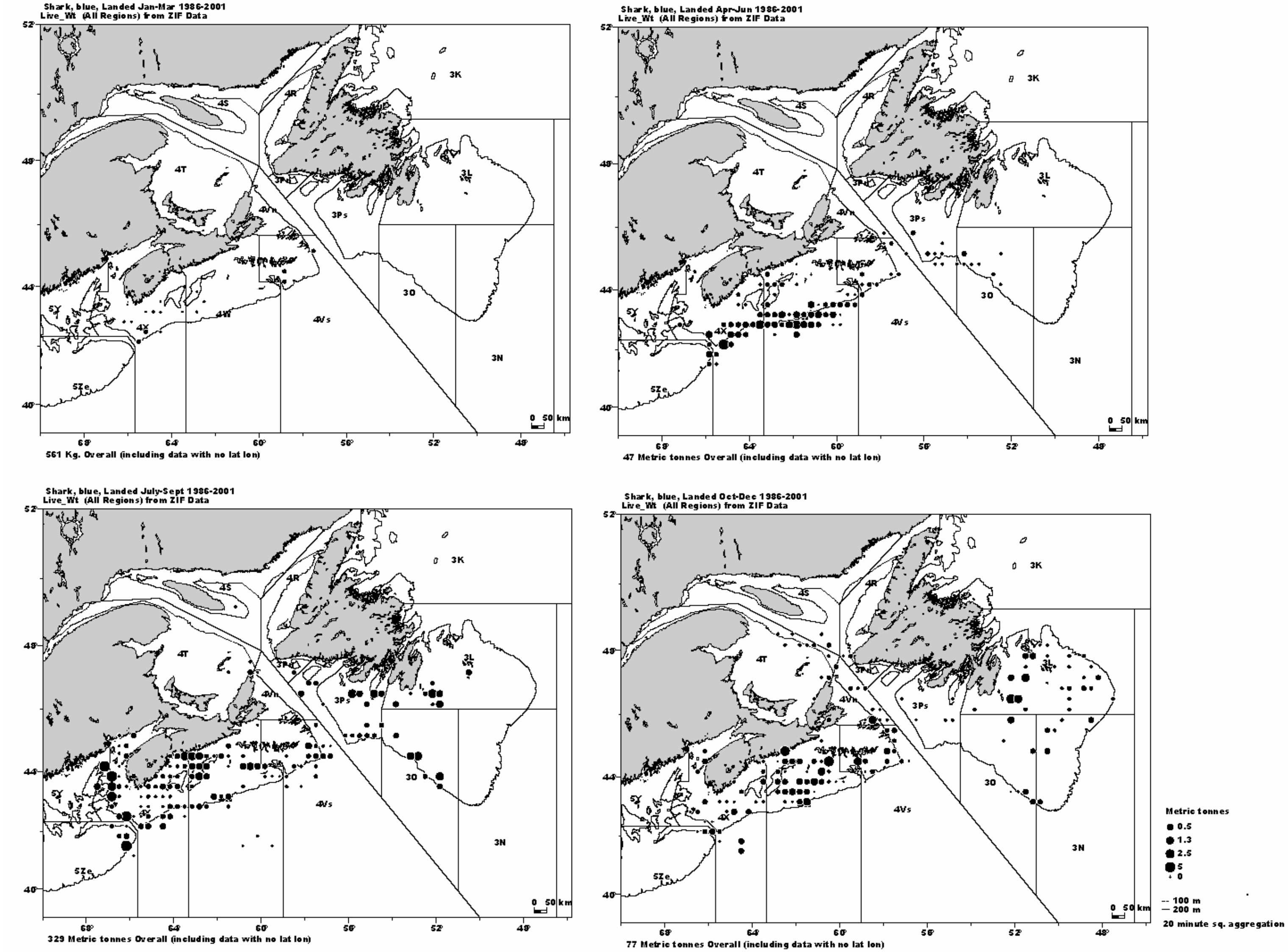


Figure 3. Alternative growth models for blue sharks in the northwest Atlantic. Growth estimated from whole vertebrae (MacNeil and Campana 2003) predicts faster growth that does growth estimated from sectioned vertebrae (Skomal and Natanson 2003). Both models were used to bracket growth for predicting age composition. FL = fork length.



.**Figure 4**. Catch location by season for blue sharks landed by commercial vessels between 1986 and 2001.

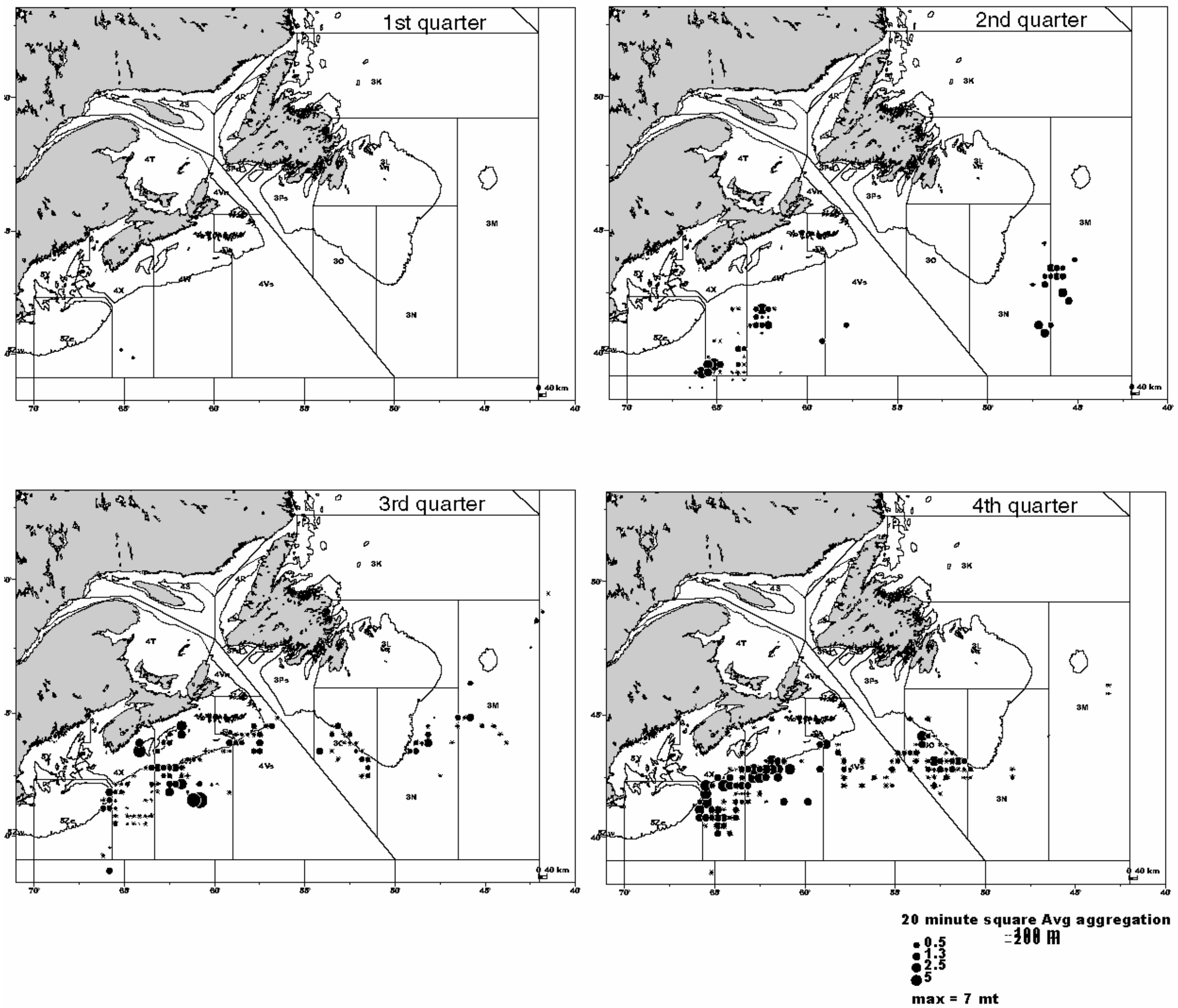


Figure 5. Blue shark catch location by season observed by IOP on Canadian vessels fishing swordfish or tuna between 1986-2001.

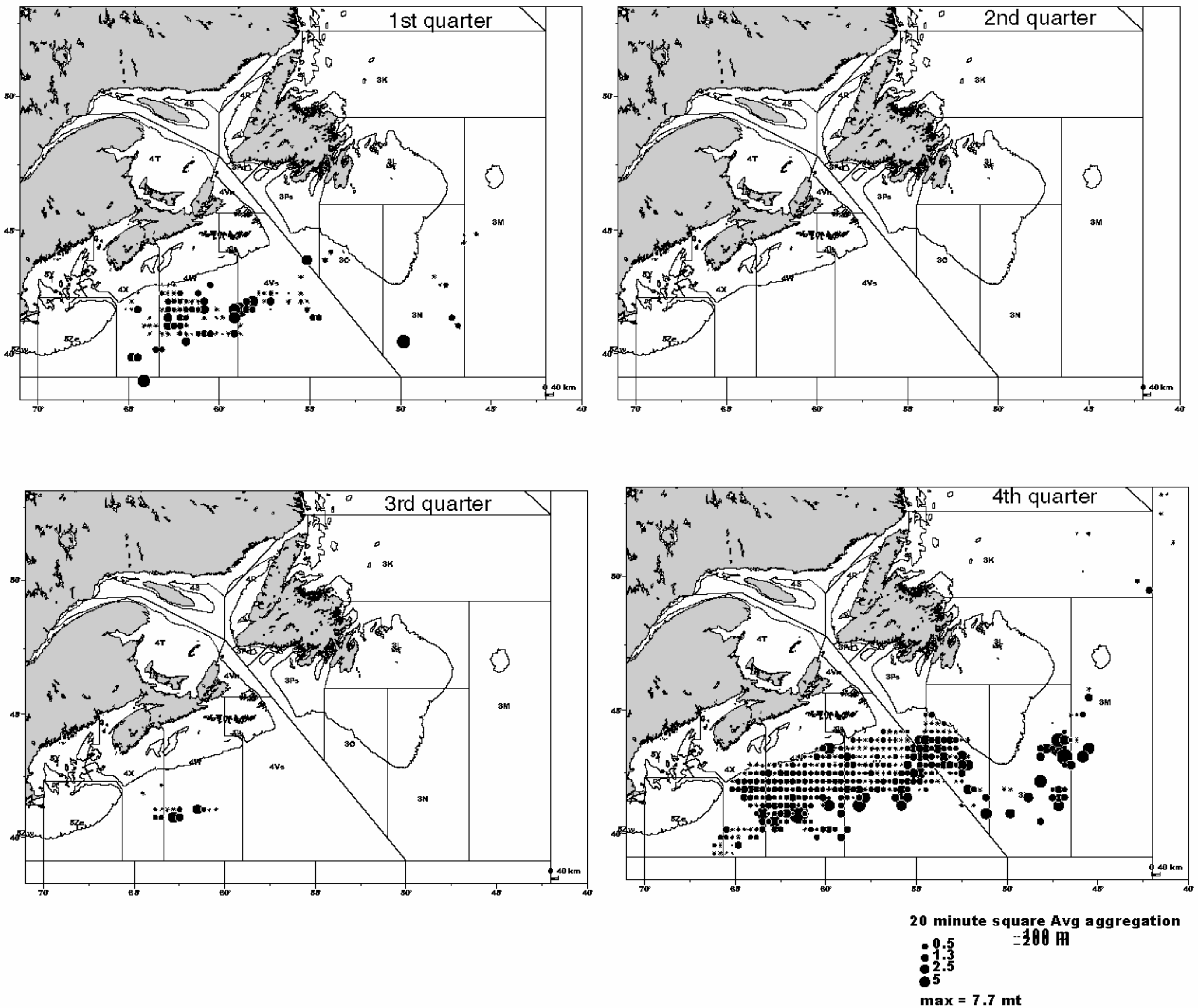


Figure 6. Blue shark catch location by season observed by IOP on Japanese vessels fishing swordfish or tuna between 1986-2001.

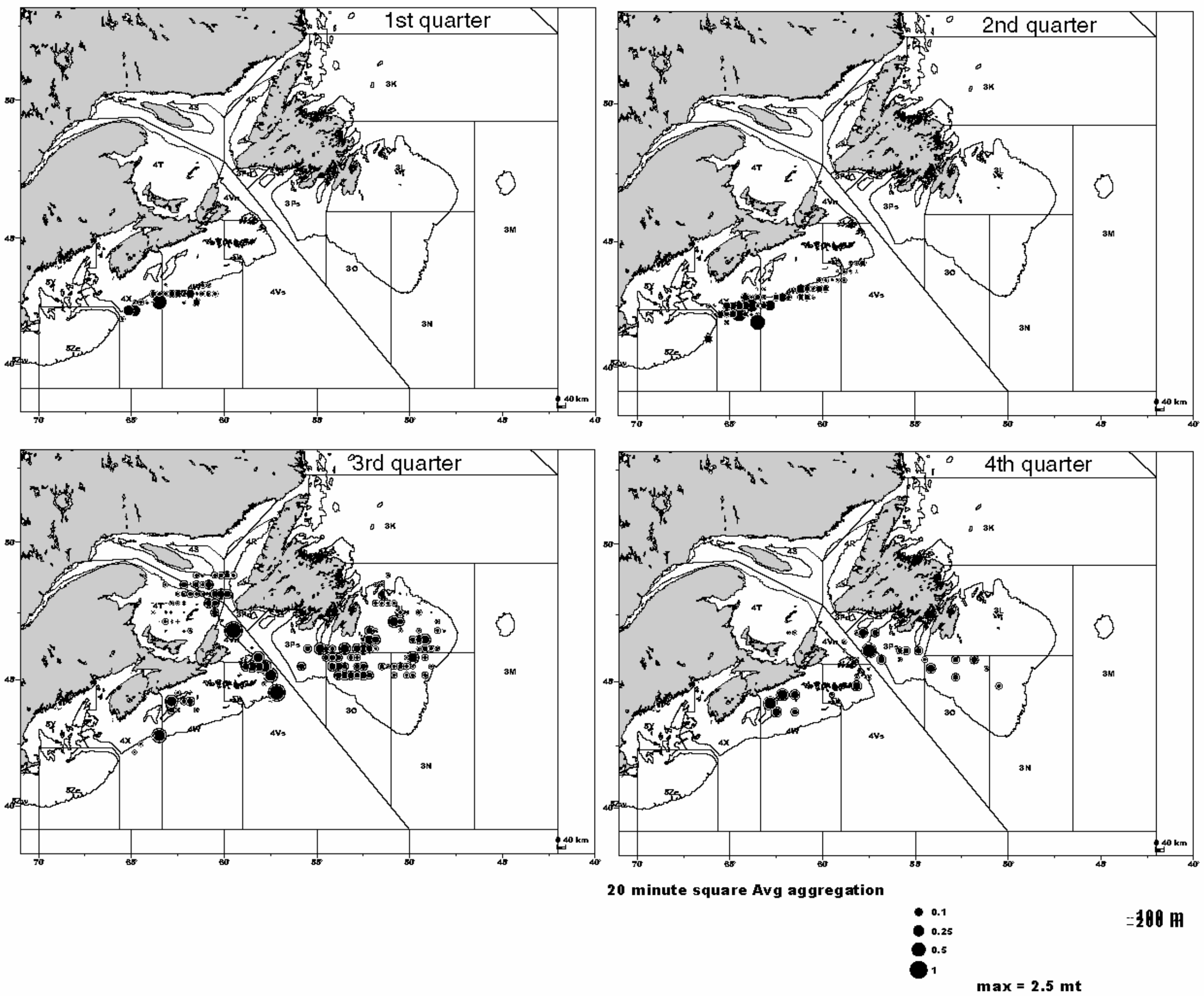


Figure 7. Blue shark catch location by season observed by IOP on Canadian and Faroese vessels fishing porbeagle shark between 1986-2001.

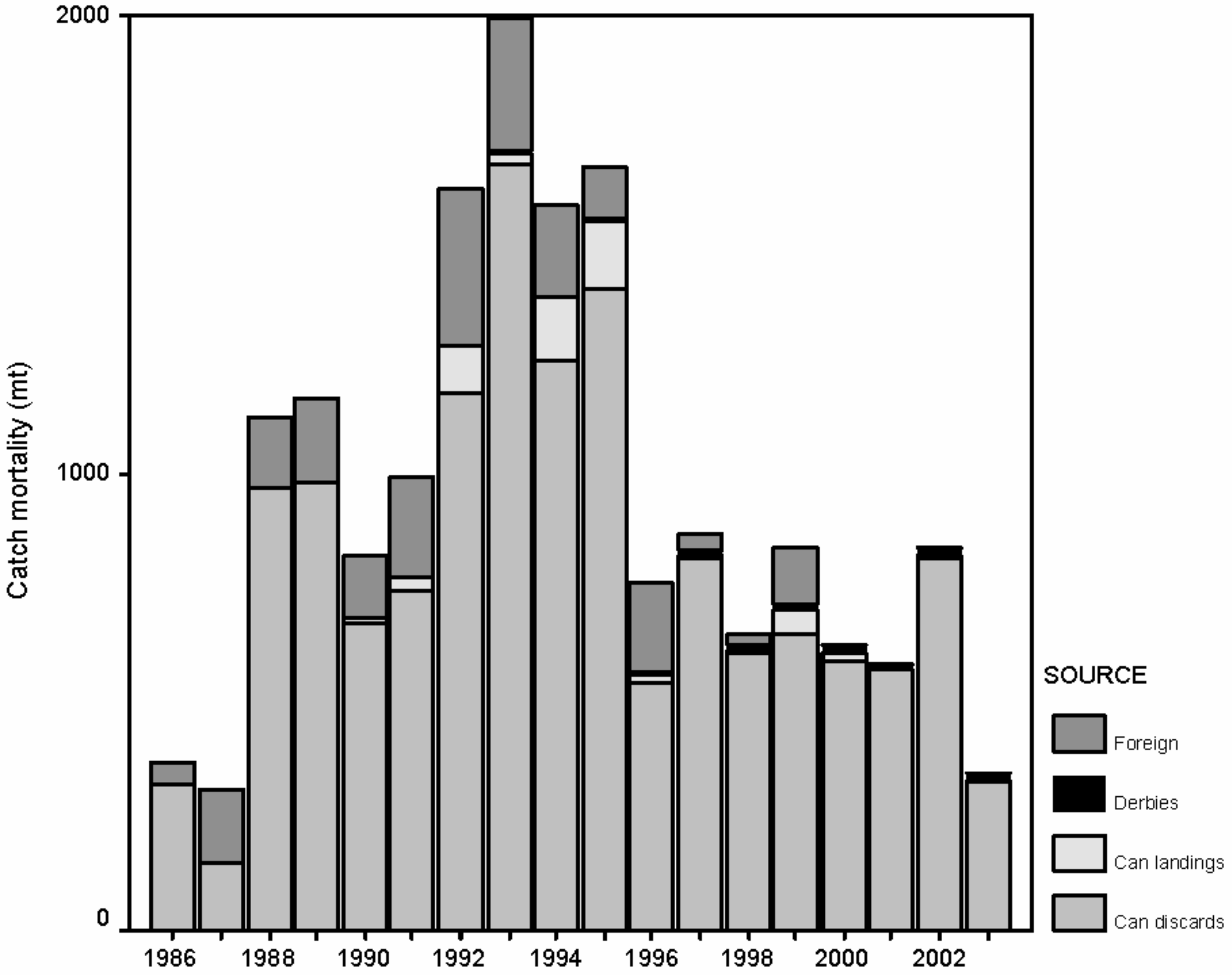


Figure 8. Total catch mortality by source for blue sharks caught in Atlantic Canadian waters.

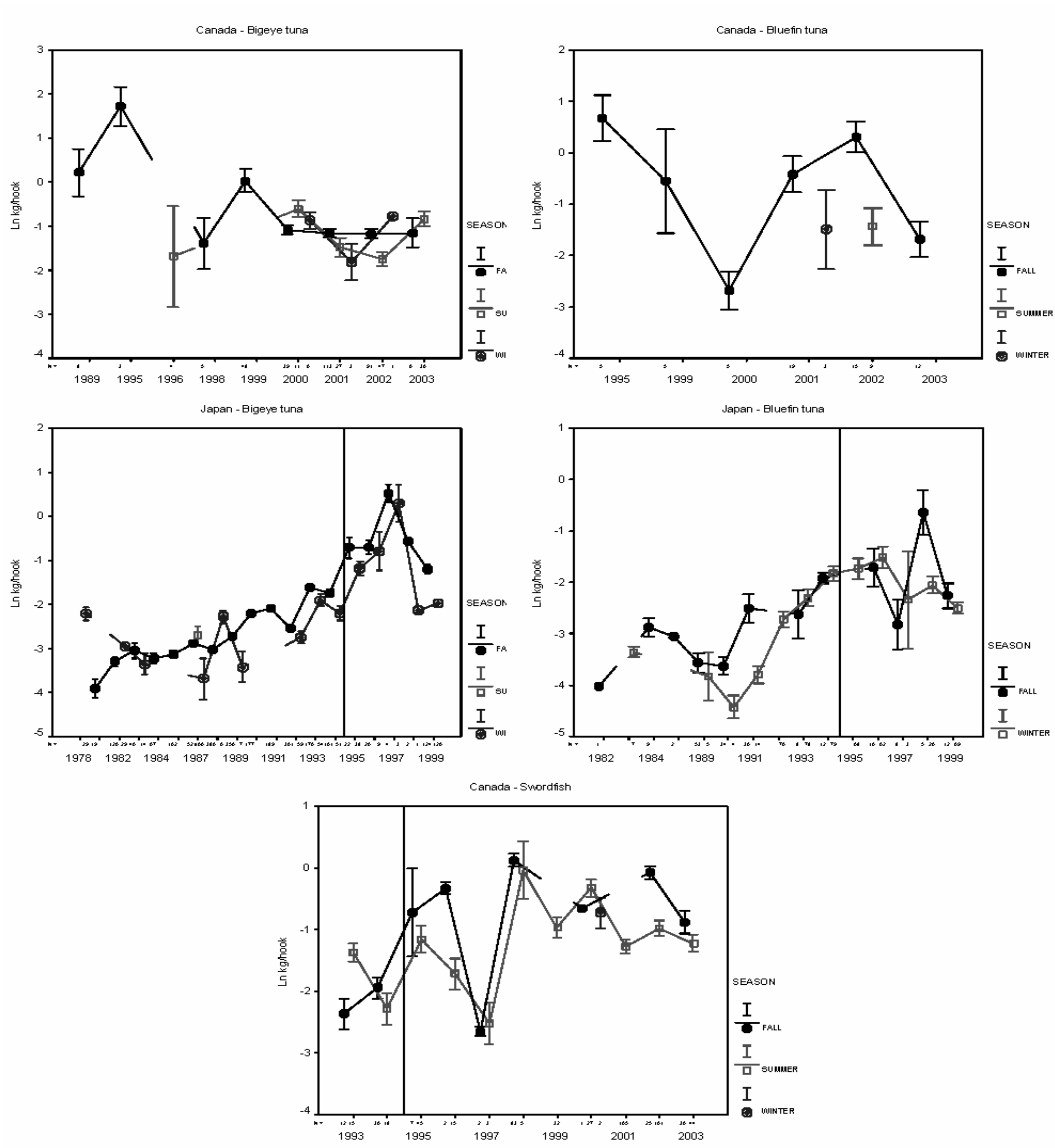


Figure 9. Commercial catch rates (mean ± 1 SE) of blue shark by season in Japanese and Canadian large pelagic fisheries targeting other species. A vertical line marks the year after shark finning was banned.

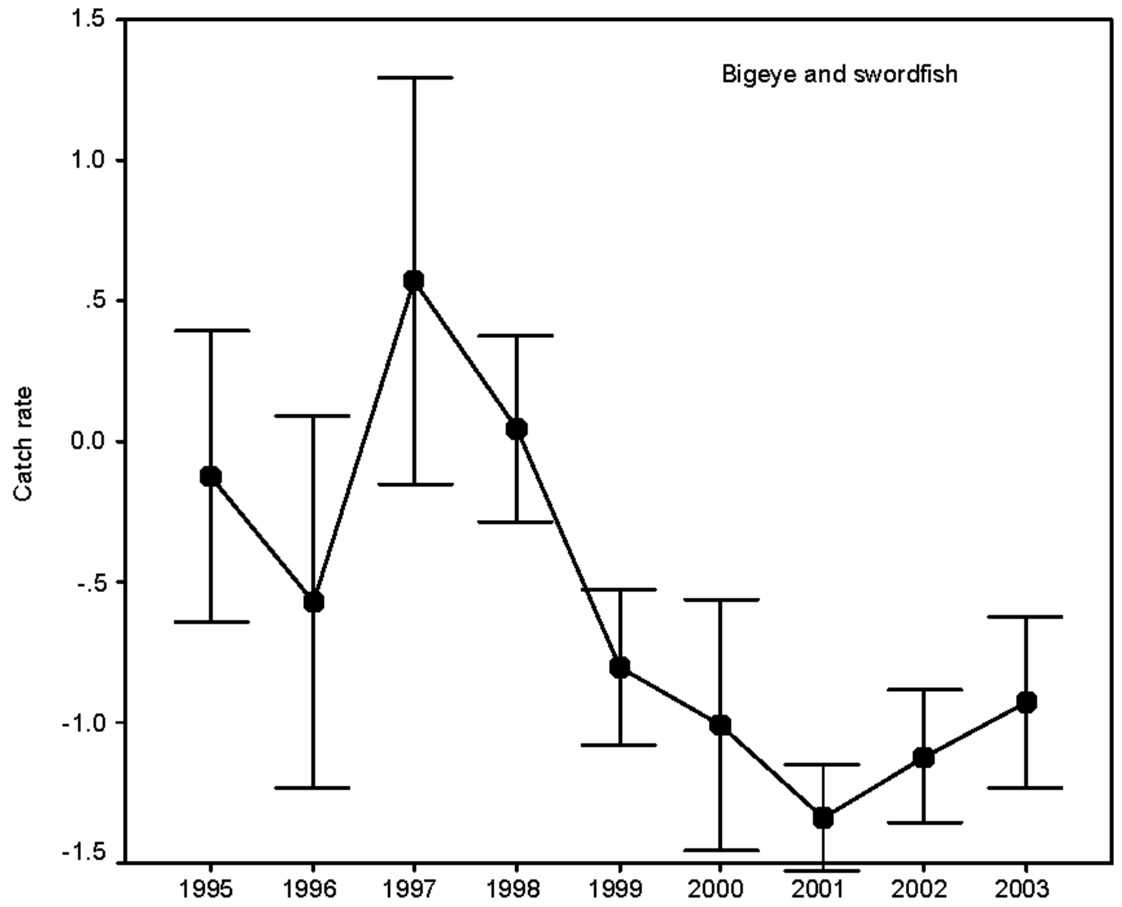


Figure 10. Standardized commercial catch rate (ln-transformed kg/hook ± 95% CI) of blue shark in Canadian and Japanese large pelagic fisheries targeting bigeye tuna and swordfish.

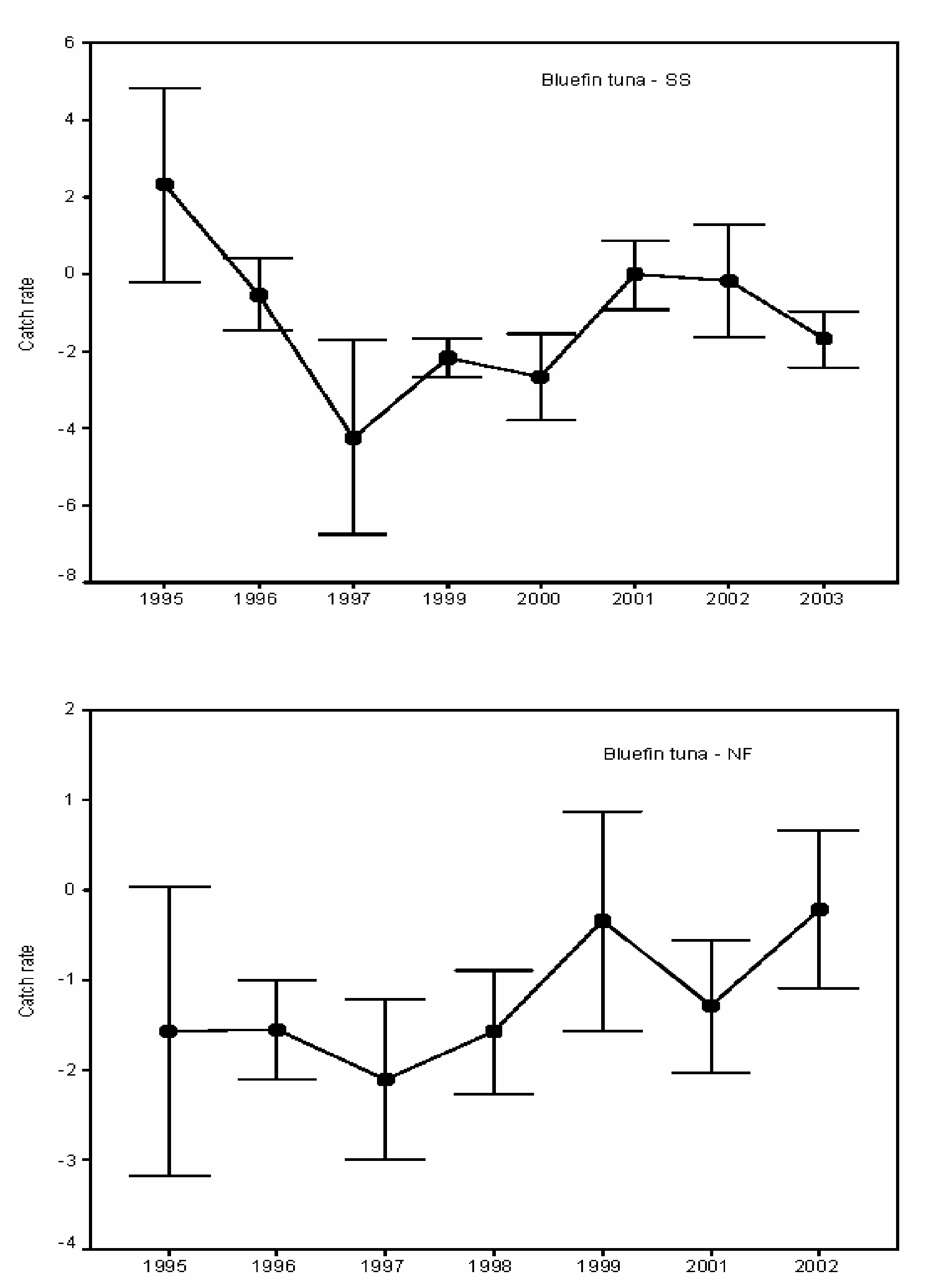


Figure 11. Standardized commercial catch rate (In-transformed kg/hook ± 95% CI) of blue shark in Canadian and Japanese large pelagic fisheries targeting bluefin tuna.

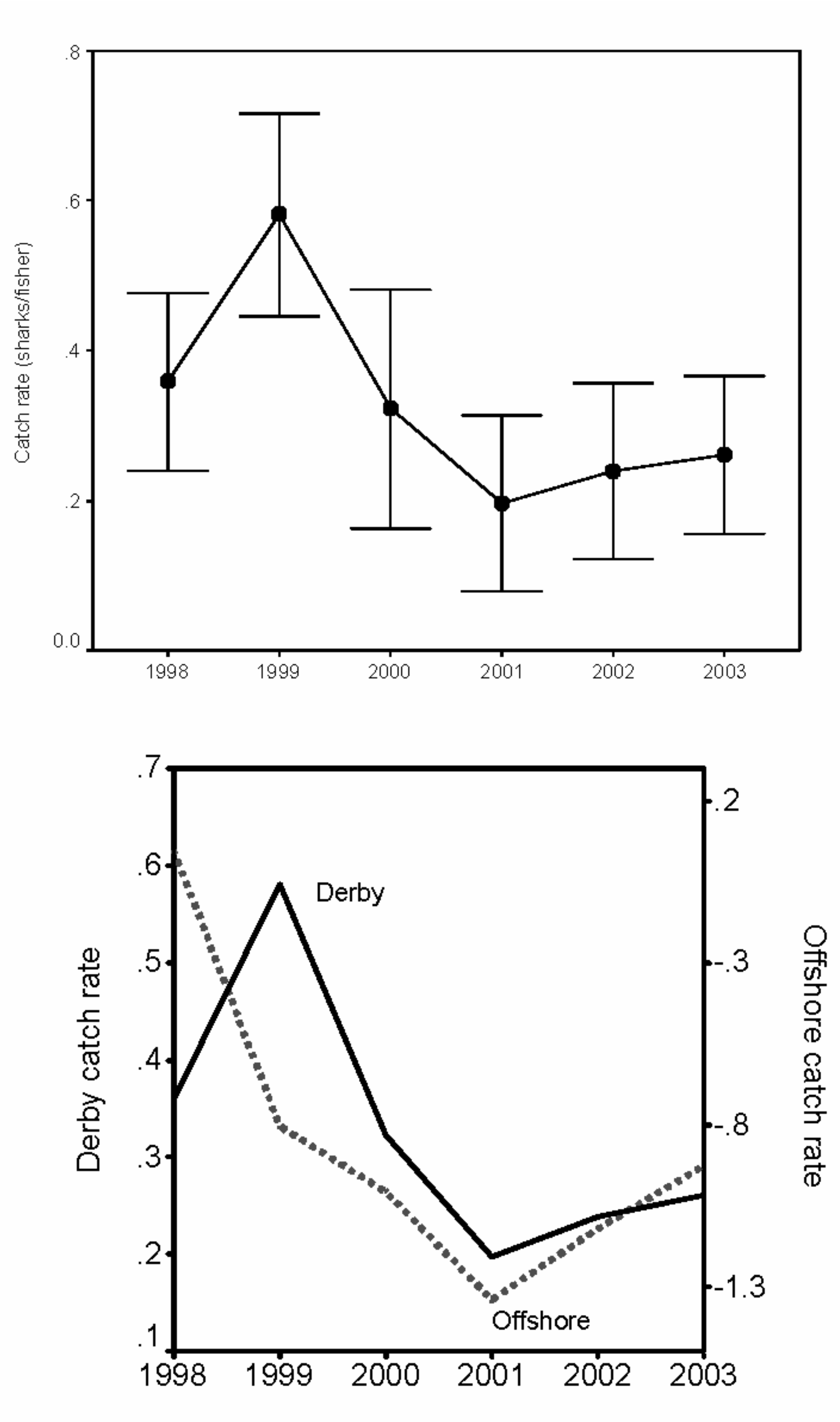


Figure 12. (Top) Standardized catch rate (sharks/fisher ± 95% CI) of blue sharks at recreational shark derbies; (Bottom) Standardized catch rates of blue sharks at recreational shark derbies compared to those of standardized commercial offshore fisheries for bigeye tuna and swordfish.

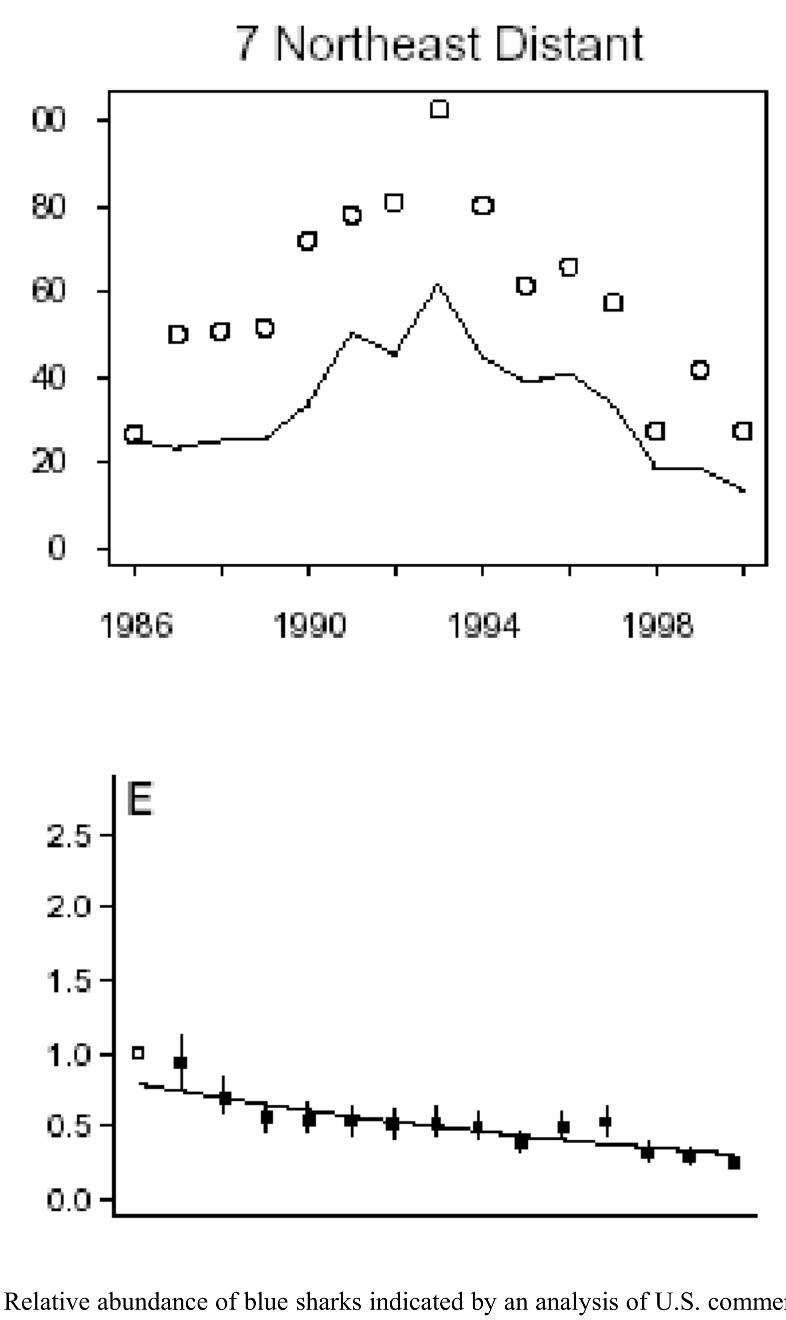


Figure 13. Relative abundance of blue sharks indicated by an analysis of U.S. commercial longline fishery logbooks by Baum (2002). (Top) Mean (circles) and median (line) number of blue sharks caught per 1000 hooks in non-zero sets east of N.S. in international waters. (Bottom) Estimated trend in the entire west Atlantic.

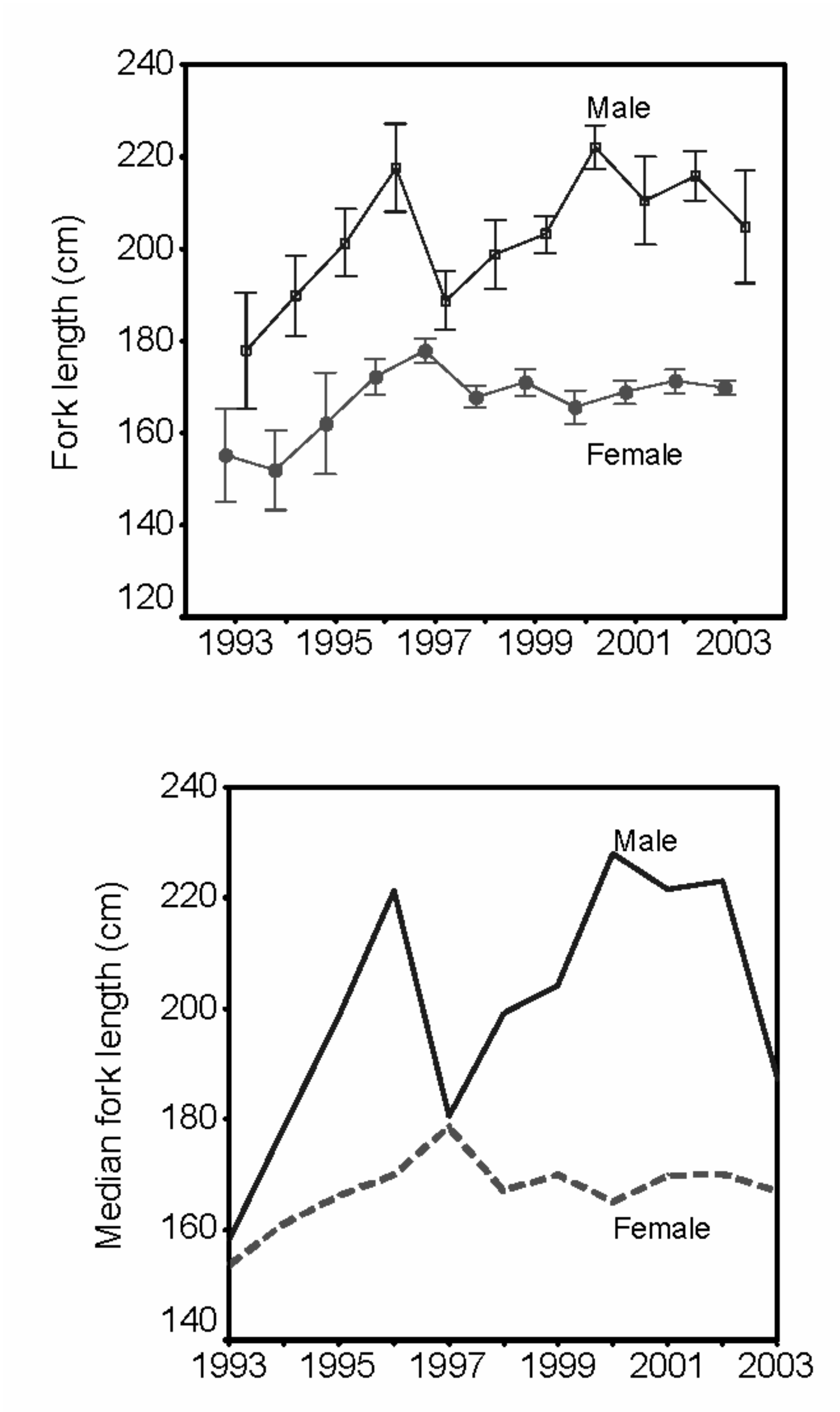


Figure 14. Trends in mean and median fork length by sex for blue sharks caught at shark derbies since 1993.

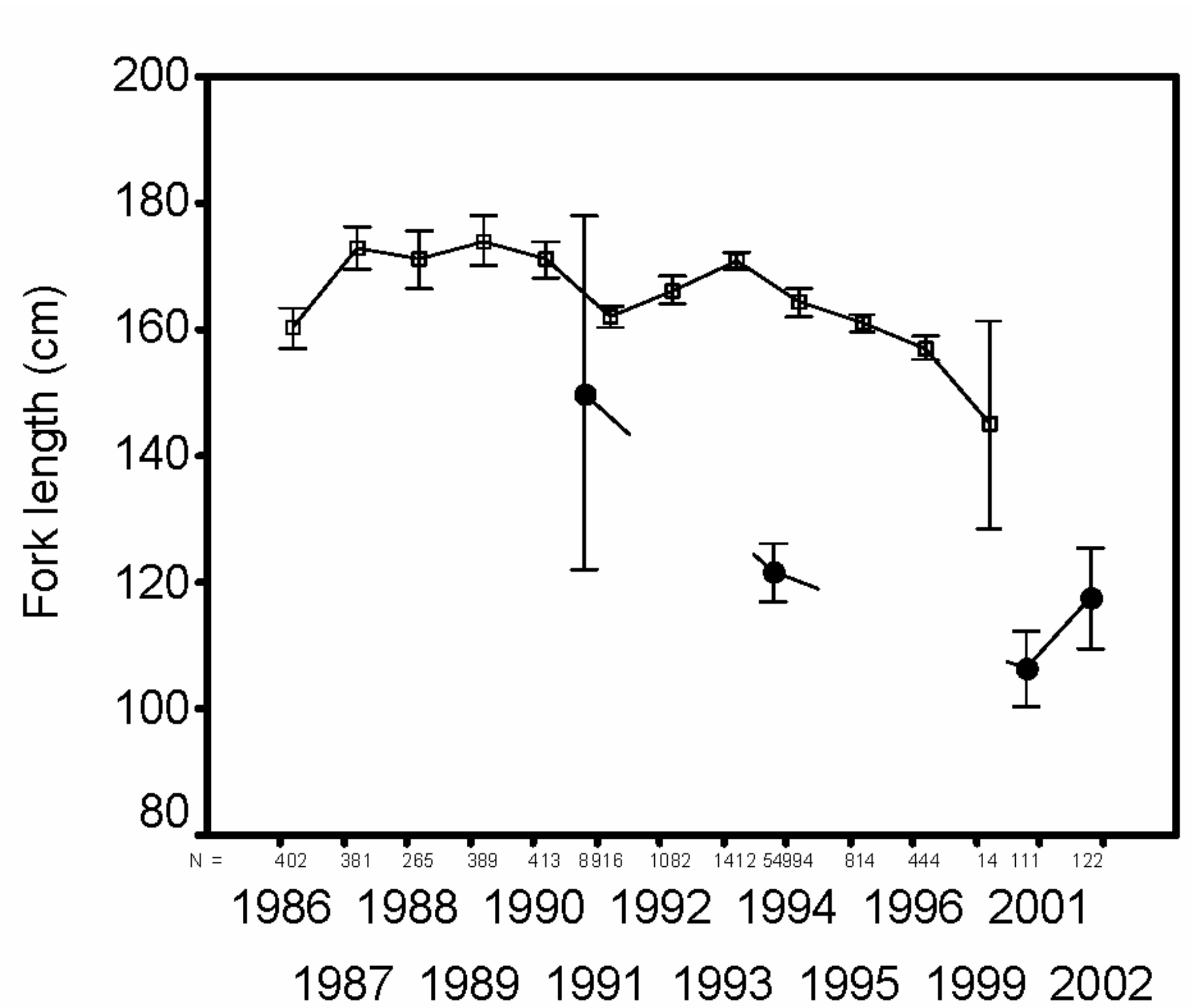


Figure 15. Trend in mean fork length (± 95% CI) of blue sharks caught in fall and winter in Japanese (open square) and Canadian (closed circle) pelagic longline fisheries, as observed by the International Observer Program.

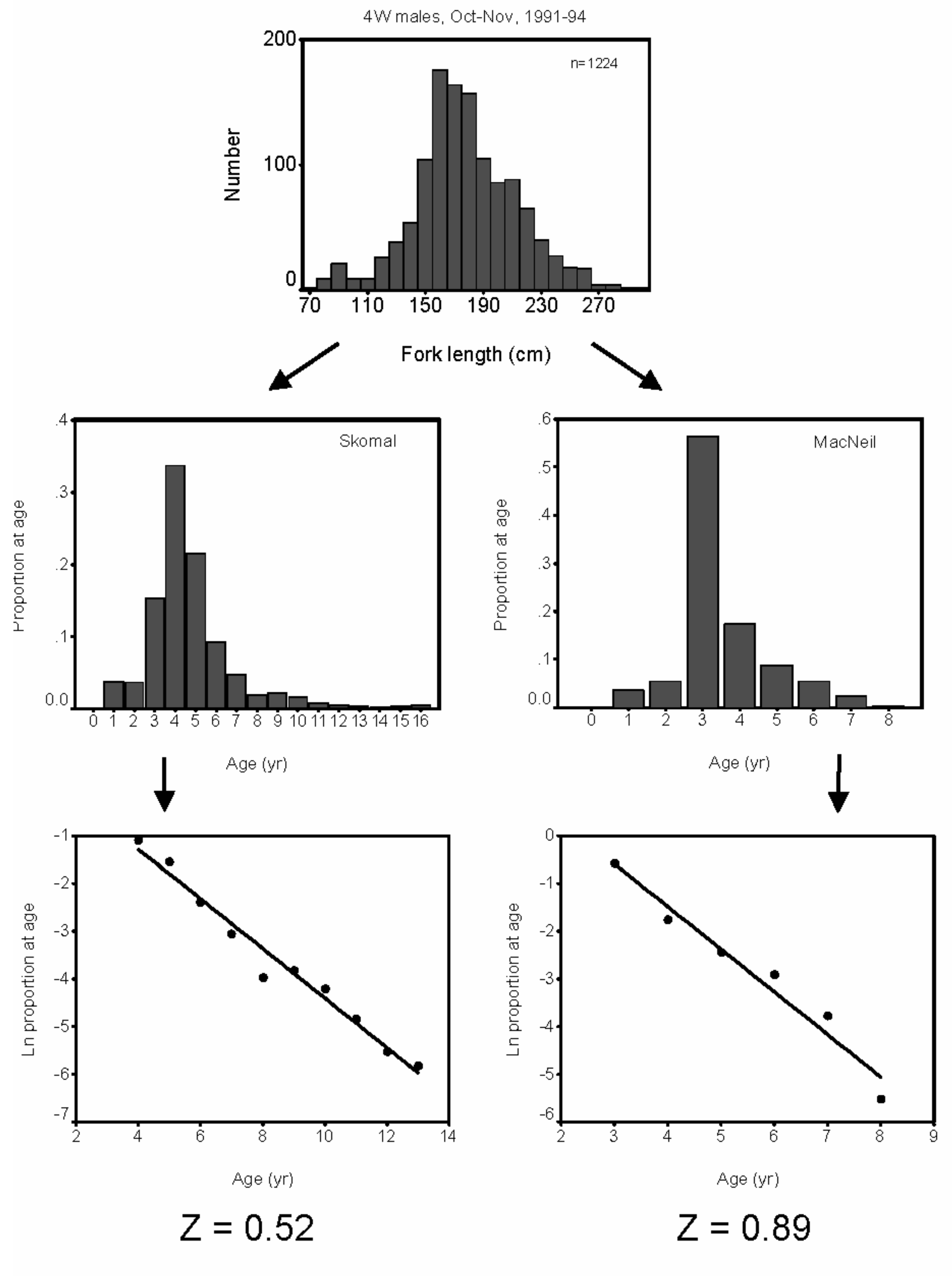


Figure 16. Estimation of total instantaneous mortality rate (z) using catch curves generated from the alternative growth models of Skomal and Natanson (2003) and MacNeil and Campana (2003).