Fisheries and Oceans Canada | Pêches et Océans Canada

Canadian Stock Assessment Secretariat
Research Document 99/158

Secrétariat canadien pour l'évaluation des stocks
Document de recherche 99/158

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An Analytical Assessment of the Porbeagle Shark (*Lamna nasus*) Population in the Northwest Atlantic

by

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ISSN 1480-4883
Ottawa, 1999

Abstract

A virgin population of porbeagle in the NW Atlantic was fished intensively at catch levels of about 4500t per year in the early 1960s before the fishery collapsed 6 years later. The fishery appeared sustainable during the 1970s and 1980s when annual landings averaged 350t. Catches of 1000-2000t throughout the 1990s appear to have reduced the population again, despite the introduction of a 1000t TAC between 1997-1999. In 1998, an intensive research program on porbeagle was initiated with the support and funding of the shark fishing industry, and in collaboration with the Apex Predator Program of NMFS. This research program led to the development of a confirmed growth model, established the presence of a single stock in the NW Atlantic, provided preliminary maturity ogives by length and age, and resulted in a credible estimate for natural mortality rate (=0.10). A standardized catch rate analysis indicated that the relative abundance of porbeagle in 1998 was about 50% of its 1991 level, while the standardized catch rate of mature porbeagle declined to 30% of its 1992 level. Based on Peterson analysis of tag recaptures, recent stock abundance is about 15-20% of the size of the virgin population that was present in the 1960s. Yield per recruit analysis produced an $F_{0.1}$ target fishing mortality of 0.083, but indicated that SSB is sensitive to even lower levels of F. The reference point at which the spawning population is maintained at 30% of its original level (a level at which the spawning population is more likely to be sustained) is $F_{30} = 0.067$. Independent measures of fishing mortality based on catch curve analysis, Peterson analysis and mean weight in the catch all suggest that F has been around 0.11 since 1996. Such a level of F is about 33% higher than $F_{0.1}$, and based on a mean annual catch of 1130t per year since 1996, suggests a $F_{0.1}$ yield on the order of 850t. An independent calculation of minimum replacement mortality rate estimated from life table analysis indicates that a fishing mortality of less than about 0.07 is required if the spawning numbers are to be maintained. Porbeagle have a low pup production rate and mature considerably after the age they first appear in the fishery. In light of the very low numbers of mature females now found in the population, it is important to protect them, possibly by restricting access to areas and/or seasons where large females are present.

Résumé

Une population vierge de maraîche du nord-ouest de l'Atlantique a fait l'objet d'une pêche intensive à des niveaux de capture annuels de 4 500 t environ au début des années 1960 avant de s'effondrer six ans plus tard. La pêche semblait durable au cours des années 1970 et 1980, période où les débarquements annuels moyens s'élevaient à 350 t. Des captures de 1 000 à 2 000 t au cours des années 1990 semblent avoir eu pour effet de réduire la population encore une fois, même si un TAC de 1 000 t a été imposé de 1997 à 1999. En 1998, un programme de recherche intensif sur le maraîche a été mis en œuvre avec l'appui et le financement de l'industrie de la pêche du requin, en collaboration avec le programme Apex Predator du NMFS. Ce programme de recherche a donné lieu à l'élaboration d'un modèle de croissance confirmé, permis d'établir la présence d'un seul stock dans le nord-ouest de l'Atlantique, donné des ogives préliminaires matures de longueurs et d'âges et fourni une estimation crédible de la mortalité naturelle (=0,10). Une analyse du taux de capture normalisé a montré que l'abondance relative de la maraîche en 1998 correspondait à 50 % environ de celle de 1991 et que le taux de capture normalisé de maraîches matures avait diminué à 30 % de sa valeur de 1992. Selon une analyse de Peterson des recaptures de poissons marqués, l'abondance actuelle du stock correspondrait à de 15 à 20 % environ de celle de la population vierge présente au cours des années 1960. L'analyse du rendement par recrue a donné un taux de mortalité par pêche cible au niveau $F_{0.1}$ de 0,083, mais a montré que la biomasse du stock reproducteur était sensible à des niveaux de F inférieurs. Le point de référence où la population de géniteurs est maintenue à 30 % de son niveau original (un niveau où cette population devrait normalement se maintenir) est de F_{30} = 0,067. Des mesures indépendantes de la mortalité par pêche fondées sur l'analyse de la courbe des captures, l'analyse de Peterson et le poids moyen au sein des captures portent toutes à croire que la valeur de F s'est maintenue aux environs de 0,11 depuis 1996. Un tel niveau est de 33 % environ plus élevé que celui du $F_{0.1}$ et si l'on se base sur une moyenne annuelle des captures de 1 130 t depuis 1996, ont obtient un rendement au niveau $F_{0.1}$ de l'ordre de 850 t. Un calcul indépendant du taux de mortalité au remplacement minimum estimé à partir d'une analyse de la table de survie indique que la mortalité par pêche devrait être inférieure à 0,07 environ pour assurer le maintien du nombre de géniteurs. Les maraîches ont un faible taux de reproduction et deviennent matures à un âge de beaucoup supérieur à celui où elles apparaissent dans les captures. Étant donné le très faible nombre de femelles matures de la population, il est important de les protéger, peut-être en limitant l'accès aux zones ou la pêche pendant les saisons où les grosses femelles sont présentes.

Introduction

The porbeagle shark (*Lamna nasus*) is a large cold-temperate pelagic shark species of the family Lamnidae that occurs in the North Atlantic, South Atlantic and South Pacific oceans. The species range extends from Newfoundland to New Jersey and possibly to South Carolina in the west Atlantic, and from Iceland and the western Barents Sea to Morocco and the Mediterranean in the east Atlantic. It is the only large shark species for which a commercial fishery exists in Canadian coastal waters.

Prior to 1994, DFO did not have an active program of research on sharks. Increasing interest by industry to exploit sharks - particularly porbeagle, blue and mako - stimulated the Marine Fish Division at the Bedford Institute of Oceanography (BIO) to initiate a modest research and assessment effort on sharks. The first status reports on each of these species was produced in 1995 (O'Boyle et al.1996). A subsequent RAP meeting in 1998 focused on porbeagle, and provided fuller documentation of the fishery and catch rate trends (O'Boyle et al. 1998). Because of the limited scientific information that was available at the time, abundance, mortality and yield calculations could not be made. Therefore, a provisional TAC of 1000t was set in place for the period 1997-1999, based largely on historic catches and the observation that recent catch rates had declined.

In 1998, an intensive research program on all aspects of porbeagle biology and population dynamics was initiated at the Bedford Institute of Oceanography. The research was carried out with the support and funding of the porbeagle shark fishing industry, who provided ship-board access to scientific staff, as well as length measurements of more than 75% of all sharks landed. In addition, a full scientific collaboration with the Apex Predators Program of the National Marine Fisheries Service (NMFS) in the U.S. provided a two-way access to both unpublished data and expertise, thereby enhancing the research capabilities at both sites. The combination of the BIO program, the industry support, and the NMFS collaboration considerably increased our understanding of porbeagle population dynamics, and allowed a comprehensive view of the resource that is seldom possible in other shark fisheries.

This report presents a detailed analysis of the past and present status of porbeagle stock dynamics in the northwest Atlantic. Included in the report are new results pertaining to porbeagle life history, stock structure, migration patterns, growth rate, reproduction, stock abundance, sustainable yield and mortality rates. The assessment concludes with an estimate of recent fishing mortality rates in relation to $F_{0.1}$ as well as alternative yields for the next Shark Management Plan. Issues requiring additional research to ensure the sustainability of the fishery are also identified.

Population Biology

Stock Structure and Migration Patterns

Several lines of evidence indicate that there is only one stock of porbeagle in the northwest Atlantic, and that there is no appreciable mixing of porbeagle from the northeast Atlantic with those in the northwest Atlantic. Month to month shifts in the location of the fishery suggest that porbeagle carry out extensive annual migrations up and down the east coast of Canada, with no indication of the presence of separate stocks (Fig. 1). Porbeagle first appear in the Gulf of Maine, Georges Bank and southern Scotian Shelf in Jan-Feb, move northeast along the Scotian Shelf through the spring, and then appear off the south coast of NF and in the Gulf of St. Lawrence in the summer and fall. Catches in the late fall suggest a return movement to the southwest. This pattern is reproduceable from year to year.

Analyses of unpublished Norwegian, Canadian and US tagging data carried out since the 1960s also suggested the presence of a single stock undergoing extensive annual migrations (Fig. 2). All three studies provided similar results, despite the fact that the Norwegian study[1] was carried out in the 1960s (542 tagged; 53 recaptures), the US tagging[2] was done almost every year between 1980-99 (1034 tagged; 119 recaptures), and the Canadian tagging was carried out between 1994-96 (256 tagged; 25 recaptures). Fig. 2 pools all tagging studies into one presentation, broken down by the quarter of the year in which the tags were applied, and showing only those sharks which were at liberty more than a year after tagging. Tags applied in the first half of the year tended to be recaptured at more easterly and northerly locations, while the reverse was seen for tags applied in the summer and fall. Many porbeagle were recaptured 500-1000 km from the point of tagging, and movement between the Grand Banks, the Scotian Shelf and the Gulf of Maine was not uncommon. Seasonal shifts in fishing effort cannot fully account for the large-scale migration pattern, since sharks tagged at the same time of year as their recapture also showed substantial movements, although perhaps not of the same scale (Fig. 2 – bottom panel). None of the tagged porbeagle were recaptured on the east side of the Atlantic, and none of the porbeagle tagged in the eastern Atlantic were recaptured off the North American coast.

Observations on many shark species suggest that there is segregation by sex and size (Pratt and Casey 1990). In some cases, after mating, the pregnant females move to another area during gestation and pupping. The females may remain separated from males and juveniles until the next breeding season. O’Boyle et al. (1998) examined the sex ratio of 1032 observed fishing sets and concluded that mature female porbeagle segregated from the main body of the population in the winter and early spring. This would account for the relative absence of mature females from the Scotian Shelf fishery in the spring. They also concluded that many of the migratory movements were sex-specific, and in some cases, segregated by size. Aasen (1963) also noted that one or the other sex predominated in some catches, and suggested that larger sharks tended to migrate further to the north and east than smaller sharks. There is no reason to dispute these conclusions. However, non-feeding behaviour by pregnant females could also account for the apparent absence from the longline catch. Therefore, the hypothesis that mature females are segregated from other sharks requires a more direct form of confirmation.

[1] unpublished Norwegian data courtesy of S. Myklevoll, Institute of Marine Research, Bergen, Norway
[2] unpublished U.S. data courtesy of N. Kohler and L. Natanson, NMFS, Narranganset, RI

Morphometry

Various measures of porbeagle size have been used in the past: Aasen (1963) used dorsal length and a non-standard measure of total length, the Scotia-Fundy IOP uses total length, the NF IOP uses fork length, and the fishing industry uses inter-dorsal length. Altogether, close to 122,000 porbeagle measurements were collated from a variety of sources for this assessment (Table 9). To convert all of these measurements into a common currency, it was necessary to develop a series of inter-conversion factors. Therefore a pre-determined array of measurements were taken from 361 porbeagles shortly after capture, and where possible, weighed round (before bleeding) and again when dressed. Some of the resulting length-length and length-weight relationships are shown in Fig. 3. The various length measures are defined as follows:

Total length = tip of snout to tip of upper lobe of tail
Fork length = tip of snout to fork in tail
Upper caudal length = tip of snout to upper caudal pit
Dorsal length = Origin of first dorsal fin to upper caudal pit
Inter-dorsal length = Posterior base of first dorsal fin to origin of second dorsal fin

Not shown in Fig. 3 are the following two relationships:

Frozen dressed weight in kg = 0.992 * (Fresh dressed weight in kg) – 1.02 (r^2=0.995)
Fork length straight measure = Fork length measured along the curve (r^2=0.998)

The conversion ratio between whole weight and frozen dressed weight varies slightly with fork length, being somewhat higher for small sharks. However, the mean ratio is 1.76 ∀ 0.02 for sharks > 130 cm FL (excluding fins), significantly higher than the ratio of 1.5 that is now applied to landed catches. In future, DFO will have to use a more appropriate conversion factor between landed dressed weight and live equivalent weight.

Since many of the length measurements available from the 1998 and 1999 fishery are derived from inter-dorsal length measurements made by industry (Table 9), several analyses were carried out to ensure that they were comparable among companies and were consistent with independent IOP measurements. There were no noticeable differences in the month-by-month size compositions of the two offshore vessels in the spring of 1999, suggesting that the crew-derived measurements were comparable. Comparisons between the crew-measured inter-dorsal lengths and IOP-measured fork lengths on observed trips made in 1995, 1996 and 1997 indicated that there was a small but significant bias towards larger lengths on the part of the crew. The extent of the bias ranged from a mean of 2-5 cm per trip. Therefore, all conversions of crew-measured inter-dorsal lengths to fork length were based on a 1995 trip in which paired fork length and inter-dorsal length measurements were made by the crew. The resulting regression is:

FL in cm = 26.3 + 2.755*IDL

and predicts fork lengths which are about 2 cm shorter than with the research relationship.

Many of the measurements available for 1996 and 1997 were based on individual frozen dressed weights made dock-side as part of Large Pelagic Receiving Tallies (LPRT). The paired length-weight measurements among these were used to develop the following seasonal inter-conversion factors:

Jan-June: IDL in cm = 10.686*(Dressed wt in lbs)$^{0.356}$
July-Sep: IDL in cm = 11.2*(Dressed wt in lbs)$^{0.35}$
Oct-Dec: IDL in cm = 10.22*(Dressed wt in lbs)$^{0.359}$

Age, Growth and Longevity

Age determinations are an important component of a stock assessment, since ages form the basis for both growth and mortality rates. Largely through the efforts of L. Natanson and J. Mello of the Apex Predator Program of NMFS, 315 porbeagle were aged using counts of growth bands visible in vertebral cross-sections (Fig. 4). The porbeagle aged were collected at various times of the year in the 1980s and 1990s, although the majority were collected after 1993. Each vertebral section was read multiple times by 2-3 independent readers. After appropriate inter-calibrations, no appreciable bias remained and the CV of age 1+ sharks fluctuated around 15% (Fig. 4). This level of precision is somewhat higher than is normally seen in otolith-based ages, but is considered unavoidable in vertebra-based age determinations.

The accuracy of the vertebra-based age determinations was confirmed in 4 ways (Fig. 4; Fig. 5). Further detail on the age validation methods will be discussed elsewhere. Nevertheless, it is important to note that the age determinations reported here are firmly based and unlikely to differ substantially from reality for sharks less than age 10. Older sharks remain unvalidated, but are assumed to be aged correctly based on the similar interpretation of their vertebral growth bands.

The relationship between fork length and vertebral age is shown in the left panel of Fig. 6. Also shown are the parameters of the fitted von Bertalanffy growth model. The model was fitted to age 1+ sharks only (not age 0) in order to minimize distortions due to seasonality and partial recruitment of the age 0 fish to the fishery. In the right-hand panel is a comparison of the fitted model with that obtained from an analysis of the tag-recapture length increments, the known-age and OTC-injected fish, the mean length at age determined from the modal progression analysis of the 0-group and 1-group fish, and Aasen's (1963) growth curve. All of the curves are very similar, with the exception of the 0-group. Since the von Bertalanffy fit is unreliable for the youngest age group, mean length at age 0 for all subsequent analyses was based on the modal progression value. There were no detectable differences in growth rate between the sexes.

The only previously published information on the growth of porbeagles was that of Aasen (1963), who generated growth curves based on vertebral readings and analyses of length frequencies. While he concluded that males and females had similar growth rates, he was unable to provide any independent confirmation of the accuracy of the age estimates. More recently, Francis and Stevens (1999) used length frequency analysis to estimate the growth rate of age 0-5 porbeagle in the south Pacific. Their estimated growth rates were similar to ours, but included an additional mode at the first age group. Of course, it is of questionable value to compare growth rates from such widely separated stocks.

The maximum age observed in our collection of 315 porbeagles was 22. This is unlikely to be a valid indicator of longevity, given the fishing history. Taylor (1958) defined the life span of a teleost species as the time required to attain 95% of the L_{inf}, which in the case of porbeagle would be 26 years. Using a wide range of species, Hoenig (1983) calculated the relationship between longevity, t_{max}, and the natural mortality rate, M, needed to attain one percent of initial abundance as

$$\ln (M) = 1.44 - 0.982 \ln (t_{max})$$

Given M=0.10 (as justified in a later section), this translates to a longevity of 45 years. However, a relationship based on other species need not be used. Assuming a constant instantaneous rate of mortality (M), the following equation applies:

$$\text{Ln (Proportion of fish that survive)} = -Mt_{max}$$

and produces a longevity estimate of 46 years at the 1% abundance level. Each of the above equations assumes that M is constant throughout the lifetime, whereas in fact, it probably increases in sexually mature or senescent fish. Any such increase would result in a lower estimate of longevity.

Porbeagle Reproduction

Porbeagles are ovoviviparous and oophageous, with an average litter size of around 4 pups (Francis and Stevens 1999). Mean embryo size at birth is 65-75 cm (Aasen 1963; Francis and Stevens 1999). Our preliminary results indicate that males mature between 160 - 190 cm in fork length (L_{50} ~ 175 cm; A_{50} ~ Age 7) while females mature between 205 - 240 cm (L_{50} ~ 212 cm; A_{50} ~ Age 14). These maturity ogives require more study, particularly for females. In the south Pacific, Francis and Stevens (1999) reported that pregnant females ranged between 170-200 cm FL .

The mating grounds of porbeagle are currently unknown, although O'Boyle et al. (1998) suggested the Grand Banks in early fall. Our preliminary results support that suggestion, although mating may also occur somewhat sooner (in the summer), and more broadly off southern NF than just the Grand Banks. On the other hand, our findings do not support their suggestion, or that of Aasen (1963), that birth occurs in late spring. In light of the 8-9 month gestation period (Aasen 1963; Francis and Stevens 1999), and assuming mating occurs in the summer and fall, a winter-spring birth period would be expected. Such a period is also consistent with the detailed reproductive study of Francis and Stevens (1999). However, intensive sampling on and off the Scotian Shelf throughout the period Feb-May uncovered no pregnant females. Clearly, further research is required here.

Management History

Efforts to develop a fisheries management plan for pelagic sharks in Atlantic Canada began in 1992. Pelagic sharks were not covered by fisheries regulations and amendments were required to the Fisheries Act. These amendments did not come into force until 1994. A ban on "finning" sharks (the removal of the dorsal fin and at-sea disposal of the finless carcass) was announced in June 1994 and a Management Plan for porbeagle, shortfin mako and blue sharks was announced in July 1994. However, there were problems implementing the Plan due to interpretation of the clause that determined eligibility for a license, and thus no licenses were issued in 1994. Further dedicated industry consultation (outside of ALPAC) was conducted in March 1995 and recreational interests were included at that time. Industry consensus was reached on the need to strengthen the control of the commercial fishery but no consensus was reached on how to regulate the recreational fishery. A revised but interim Management Plan was announced in July 1995.

The 1995 Fisheries Management Plan for pelagic sharks in Atlantic Canada established non-restrictive catch guidelines for porbeagle (1500t), shortfin mako (250t) and blue (250t) sharks in the directed shark fishery, limited the number of licenses by defining eligibility criteria, specified that licenses would be exploratory (one year duration), prohibited "finning", restricted fishing gears, established seasons, restricted fishing area, limited by-catch of other species in the directed shark fishery, restricted the recreational fishery to hook and release only, and specified scientific data requirements. 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. License eligibility criteria required active participation in the directed fishery in four of the five previous years, as documented by sales records. In addition, a limited number of licenses could be issued in areas of Atlantic Canada where there had been no previous fishing effort directed at these species. Fins could only be sold in proportion to a maximum of five percent of dressed carcass weight aboard a vessel and could not remain aboard the vessel after the associated carcasses were removed. 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 Plan included provision for restricting fishing seasons although there were no restrictions imposed in 1995. Vessels less than 65' in length were restricted to home areas by the Sector Management Policy of the Department of Fisheries and Oceans, and specific time/area closures were implemented for all vessels to limit by-catches of bluefin tuna and small swordfish, where these were known to be a problem. Recreational licenses were limited to hook and release. The Management Plan made provision for the collection of catch and effort data, through completion and submission of logbooks, and for collection of sampling data (species, sex, length, weight) for each shark landed, through a dockside monitoring program (DMP).

The Management Plan was rolled over into 1996, with minor modifications, to provide time for the development of the more comprehensive plan. The latter was finally released as the Canadian Atlantic Pelagic Shark Management Plan 1997-99 (Anon 1997). This plan was designed to govern the exploitation of all large pelagic shark species through the maintenance of a biologically sustainable resource and a self-reliant fishery.

Conservation was not to be compromised and a precautionary approach was to guide decision making. All licenses issued under the plan were to be considered exploratory while scientific information was collected and the sustainability of the resource was evaluated. Further details of the shark management plan, and of the porbeagle management history, are presented in O'Boyle et al. (1998).

The Fishery

Landings

The fishery for porbeagle sharks in the Northwest Atlantic (NAFO areas 3 - 6) started in 1961 when Norwegian vessels began exploratory fishing on what was then a virgin population (Fig. 7). These vessels had previously fished for porbeagle in the Northeast Atlantic. They were joined by vessels from the Faroe Islands during the next few years. Reported landings in the northwest Atlantic rose from 1,924t in 1961 to 9,281t in 1964 and then fell to less than 1,000t in 1970 as a result of a collapse of the fishery (Table 1). Although the fishery was unrestricted, reported landings were less than 500t until 1989. Reported landings rose to 1,917t in 1992, due to increased effort by Faroese vessels and also due to the entry of Canadian interests into this fishery. Faroese participation was phased out of the directed fishery by 1994, at which time total landings by three Canadian offshore pelagic longline vessels and a number of inshore vessels was 1615t. Since that time, the fishery has been almost exclusively Canadian, with landings declining gradually to 1008t in 1998. Landings in the first half of 1999 reached nearly 800t, and were voluntarily restricted over the summer in order to reserve quota for the fall. Since 1996, approximately 2/3 of the directed catch has been made by the 2 remaining offshore vessels, one of whom (the *Bakur*) switched from rope to monofilament gear in 1999 (making its gear comparable to that of the *Hamilton Banker*). The other 1/3 of the catch was made by a fleet of inshore vessels (Fig. 8). Both the inshore and offshore fleets are based in Nova Scotia, although the offshore vessels occasionally land their catch in Newfoundland (Table 3).

Porbeagle sharks are taken almost exclusively by a Canadian directed longline fishery. By-catch in the Canadian swordfish longline fishery, the Japanese tuna longline fishery, and various inshore fisheries is minimal, seldom exceeding 40t in recent years (Table 2). While the reported catches of mako and unspecified shark prior to 1996 are likely to have been mainly porbeagle, the effect on the overall catch trend is minimal. The International Observer Program (IOP) has maintained 100% coverage of foreign catches in the Canadian zone since 1987, thus ensuring the accuracy of the foreign catches since that time. There is almost no recreational fishery for porbeagle sharks.

All of the landings statistics presented in this document were extracted afresh in order to deal with some of the concerns and errors identified by O'Boyle et al. (1998). As a result, the catch history presented here is not necessarily the same as that reported in the O'Boyle et al. (1998) document, although most differences are relatively minor. One of the primary sources of error in the catch statistics proved to be the conversion factor applied by DFO to convert landed dressed weight to live equivalent (round) weight. Most, but not all, of the directed catch has been landed in Nova Scotia since 1991 (Table 4). While incidental catches have been treated differently, all directed catch is dressed as 'gutted, head and tail off'. Most, but not all, of this catch has been coded correctly by Statistics Branch, and the mean conversion factor applied has usually been close to the factor that has long been in use

(=1.47 lbs dressed-kg round, or equivalently, 1.50 kg dressed-kg round). Such has not been the case for some of the NF landings, where conversion factors have varied by a factor of two for catches landed in identical condition. In some years (eg-1998), the conversion error artificially reduced actual landings by 30t, although the discrepancy in most years was somewhat less (Table 4). This source of error was eliminated by applying a standardized conversion factor of 1.50 (kg-kg) to all landings used in catch rate calculations. However, the landings statistics themselves (Tables 1-3 and 5-7) were left unadjusted.

It will be difficult to correct historic landings using a biologically appropriate conversion factor between dressed weight and live equivalent weight. Directed inshore landings have always been dressed with the J cut (swordfish cut). However, one of the two offshore vessels has traditionally removed the collarbone, while the other has left it in. As of the beginning of 1999, both offshore vessels are leaving the collarbone in. Thus the biological conversion factor of 1.76 (kg dressed to kg round, excluding fins) discussed in the Morphometry section applies to 1999 and onwards.

A second source of error was identified just prior to the tabling of this document. One trip landed in NF in October 1997 was miscoded by DFO Statistics and assigned an additional 28t. All landings tables have been corrected since, but there was insufficient time to correct the catch rate calculations. Once this error has been corrected, it will reduce the catch rate calculation for one of the offshore vessels fishing in 3LNO in Oct 1997.

Location and Size Composition of the Catch

The overall pattern of catch location and size composition since 1998 is shown in Figs. 9-11. Both the inshore and offshore fleets fished the Scotian Shelf in the spring of 1998 (Fig. 9) and 1999 (Fig. 11), although the offshore fleet tended to fish off the edge of the continental slope while the inshore fleet fished well onto the shelf. Size compositions of both fleets were roughly similar, although the inshore fleet caught significantly more large (>180 cm) sharks than did the offshore fleet in 1999. In May, the offshore fleet moved into the waters off of southern NF. Fishing by both fleets was minimal during the summer months. In the fall, the small amount of catch taken by the inshore fleet was all from the Scotian Shelf, while the much larger offshore catches were made in the Gulf of St. Lawrence, off southern NF, and on the Grand Banks (Fig. 10). A detailed breakdown of landings by fleet, month and area for the years 1991-99 is presented in Tables 5-7.

A more detailed comparison of the size composition of the 1998 and 1999 catch by the inshore and offshore fleets is presented in Fig. 12. The range of lengths taken by both fleets in any given area and month tended to be similar. In most areas and months however, the inshore fleet caught a mode of large (>180 cm) sharks that was not caught by the offshore fleet.

Resource Status

Trends in Length Composition

A biological indicator of increased exploitation rate is a long-term decline in median length in the catch. Year-by-year length composition histograms are presented for those areas and months where sampling was sufficient (Table 9; Fig. 13). The length compositions for the years where fishing pressure was light (1961 and 1980) contain a relatively high proportion of large sharks compared to subsequent years. Plots of median fork length against year of collection showed a long-term decline in length composition on the Grand Banks (3LNO), the presumed mating ground (Fig. 14). The increases and decreases evident in 4W and 4X are not as likely to be biologically significant, since most of the sharks in that region during the spring are small and immature. In addition, the length composition of the spring catches is sensitive to the timing of the fishery as the porbeagle migrate up the shelf.

Commercial Catch Rates

Calculations of catch rate were based on directed longline catches, which account for virtually all historical catches. Most of the directed effort has traditionally come from the offshore fleet, both foreign and Canadian (Table 8). However, effort from the inshore fleet became substantial in 1996, the same year that one of the 3 offshore vessels was removed from the fishery. Effort trends and the balance between inshore and offshore have been relatively stable since then (Table 8; Fig. 8).

Two measures of catch rate were examined: catch weight per hook (ln-transformed kg/hook) and the catch rate of numbers of sharks greater than 200 cm FL (ln-transformed numbers/hook). A fork length equal to 200 cm is approximately midway between the lengths corresponding to 50% maturity in males and females, and is therefore a proxy for sexually mature porbeagles.

The catch rate of sexually mature sharks by the offshore fleet declined in almost every area/season combination (Fig. 15). For the most part, both offshore vessels experienced the same trend in catch rate. The catch rates for all sharks also declined, but much less so than was the case for the mature sharks (Fig. 16). Catch rates based on weight per hook were reasonably stable since 1996.

The catch rate of sexually mature sharks by the inshore fleet did not appear to vary consistently since 1996, although recent catch rates tended to be lower than those in 1996 and 1997 (Fig. 17). No trends were evident in the catch rates based on weight per hook (Fig. 18). Note that the time series of inshore catch rates consists of only 4 years.

The overall trend in catch rate was analyzed using a linear model with subarea, month, data source, CFV and year as factors. All factors were significant in the model predicting the catch rate of sexually mature porbeagles (Table 10). Several interaction terms were also significant, but their inclusion did not change the overall trend in catch rate, which is shown in Fig. 19. The standardized catch rate of mature porbeagles increased significantly between 1987 and 1992, but declined sharply afterwards as effort increased and the abundance of the large sharks declined. The 1998 point is about the lowest in the time series, and is 30% of the 1992 value. The standardized catch rate model based on weight per hook was also highly significant (Table 11), and also showed a significant decline since the early 1990s (Fig. 20). The most recent point is about 50% of the 1991 point. However, the catch rate has remained roughly stable since 1996, consistent with the fleet-specific catch rates shown in Figs. 16 and 18.

Mortality from Catch Curves

The annual length composition of the porbeagle population was reconstructed using samples stratified by year, fleet, subarea and season. The resulting length composition was then weighted by the ratio of the annual catch to the sampled catch to produce the annual catch at length (Fig. 21). The year 1994 was excluded from the reconstruction due to inadequate sampling across all strata (Table 9).

Catch at length was converted to catch at age using our fitted growth model (Fig. 6) and cohort slicing of the population length frequency. Attempts to decompose the length at age matrix using mixture analysis (MIX) was unsuccessful due to the large number of age groups (>20) involved. Cohort slicing is too coarse a procedure to provide an accurate catch at any given age, but provides acceptable results for cross-age analyses (such as catch curves).

Trends in annual ln-transformed catch at age (catch curves) are shown in Fig. 22. Recent years show a much-reduced ascending limb to the catch curve, suggesting an increasingly young age at recruitment to the fishery. Note that the 1961 sample (representative of the virgin population) is based on a fall fishery, while all other years extend through a greater portion of the year.

Total instantaneous mortality rates based on the slope of the descending limb of the catch curve indicate that recent mortality rates have been considerably higher than those of 1961 (Fig. 23). In general, mortality rates for immature sharks (ages 3-14) were lower than those of mature (age 15-25) sharks. The best indication of total mortality was that based on the most fully-recruited age (maximum abundance) to age 22 (Fig. 23-lower panel). Since the 1961 sample was essentially from a virgin population, the FR-Age 22 mortality estimate for that year is an estimate of natural mortality, which is around 0.1. The mortality rate for 1981 was very high, presumably a remnant of the very high fishing mortalities in the mid 1960s, which cascaded down the catch curve over the following 15-20 years. Since the high mortality rate was still evident 15 years after the fishery collapsed, this suggests that stock recovery in porbeagle is a very extended process.

Catch curves based on July-Dec catches are more comparable to the 1961 catch than are annual catch curves. The July-Dec catch curves show much the same pattern as the annual curves in recent years, but in earlier years, show an age of full recruitment between 9-14 years (Fig. 24). Since most of the fall fishery takes place on the Grand Banks, off southern NF and in the Gulf of St. Lawrence, these results suggest that immature animals are absent (in a relative sense) and that the area serves as a mating ground.

The trend in total mortality rate from the July-Dec catch curves is reasonably similar to that of the annual catch curves (Fig. 25). Total mortality appears to have declined slightly since the 1980s, with the rate for the past 5 years being on the order of 0.17-0.25. By subtracting the rate of natural mortality (=0.1), recent fishing mortality is estimated as being 0.07-0.15. Since mortality rates based on catch curves tend to integrate across several years, it is likely that the estimates for the past 5 years actually extend across a greater range of years.

Peterson Calculations of Abundance and Exploitation Rate

The stock abundance of both the virgin population of the 1960s and that of the fished population in the 1990s was estimated through Peterson analysis of tag recaptures (Table 12). Details of the tagging programs were described in the section *Stock Structure and Migration Patterns*. The independent tagging studies of the US and Canada provided similar estimates of population biomass between 1994 and 1997. These population estimates were about 15-20% of the size of the virgin population tagged by the Norwegians (Fig. 26).

While the Peterson calculations are straight forward (Table 12-bottom) (Ricker 1975), certain assumptions must be made concerning rates of tag loss, tag-induced mortality and the probability of non-reporting. Published estimates for these rates in sharks were not available, so approximate values based on teleosts were used. The probability of non-reporting is thought to be very low through the 1990s, given the few vessels in the fishery and the high level of motivation to tag and recapture. Similar high levels of reporting are believed to apply to the first 1-2 years of the Norwegian study, but the number of Norwegian fishing vessels increased substantially in the subsequent few years, so reporting rate may have dropped. The adjustment for dilution due to recruitment between the time of tagging and recapture was based on the mean of the annual biomass at age distributions, and is believed to be reasonably accurate. To check the validity of these and the other time-dependent assumptions, biomass estimates for a given tagging year were compared across recapture years. No trend was evident, suggesting that the assumptions were reasonable.

The exploitation rate of both the virgin population of the 1960s and that of the fished population in the 1990s was also estimated from from the Peterson calculations. The independent tagging studies of the U.S. and Canada provided similar estimates of exploitation rate since 1994, varying between 3-10%, with a mean of about 7% (Table 12; Fig. 26). This mean estimate is only slightly lower than that observed during the intensive fishing of the mid 1960s, just prior to the collapse of the fishery.

Since the catchability of the inshore and offshore fleet is probably different, it was inappropriate to examine the relationship between exploitation rate and fishing effort before the inshore:offshore balance stabilized in 1996. There has been no significant relationship since that time, although there is also very little contrast in the effort data.

Yield per Recruit

Yield per recruit was calculated on the basis of the fitted growth model (Fig. 6) , an empirical length-weight relationship (Fig. 3), the estimate of M=0.1 determined from the catch curve analysis (Fig. 23) and an assumed selectivity curve. The estimated $F_{0.1}$ value was 0.083 while F_{max} was estimated to be 0.17 (Table 13). Because the age of first capture occurs well before the age of sexual maturity, spawning stock numbers would be expected to be susceptible to even modest fishing mortalities (<0.05), as is shown in the figure panel of Table 13. The sharp decline in spawning stock numbers evident in Table 13 is reminiscent of the decline in the observed catch rate of sexually mature porbeagle (Fig. 19). An alternate reference point is one at which the spawning population is maintained at 30% of its original level: F_{30} = 0.067. A biomass equivalent to 30% of the virgin biomass is often viewed as the minimum level required to sustain a spawning population. Note however that this level is below that of $F_{0.1.}$

An independent calculation of minimum replacement mortality rate estimated from life table analysis indicates that a fishing mortality of less than about 0.07 is required if the spawning numbers are to be maintained. Brander (1981) presented the following equation for calculating minimum replacement mortality rate:

$$Z_m = E/2 * \exp(-Z_i * t_m)$$

where Z_m is the total mortality rate on mature sharks, t_m is the age at maturity for females and E is the expected annual birth rate. Using parameters suited to porbeagle:

$$\begin{aligned} Z_m &= 4/2 * \exp(-0.18 * 14) \\ &= 0.16 \\ &= M + 0.06 \end{aligned}$$

indicating that the mature population can sustain an F of no more than 0.06 if the immature population is fished at F=0.08. If M=0.10 is an underestimate of the actual value, the sustainable fishing mortality is even less:

Assuming that M=0.12: $$\begin{aligned} Z_m &= 0.12 \\ &= M + 0.02 \end{aligned}$$

These calculations need to be carried out more rigorously using life table analysis. However, they indicate that an $F_{0.1}$ yield is not sustainable unless the F on the mature population is considerably less than $F_{0.1}$.

Recent Fishing Mortality

One measure of relative fishing mortality is the time series of observed weight in the catch compared to that expected of fishing at $F_{0.1}$ or F_{max} (Fig. 27). This time series indicates that fishing mortality was less than $F_{0.1}$ during the 1980s, but that it increased to somewhere between $F_{0.1}$ and F_{max} during the 1990s.

This assessment contains several independent measures of recent fishing mortality. Fishing mortalities estimated from catch curves, Peterson exploitation rates and the mean weight in the catch all indicate that fishing mortalities between 1996-1998 were between that of $F_{0.1}$ and F_{max}, with a mean F of about 0.11 (Fig. 28). Since both fishing effort and quotas were stable between 1996-1998, these results suggest that the recent level of F has been about 33% higher than the $F_{0.1}$ value of 0.08.

Sources of Uncertainty

There are several sources of uncertainty in this assessment. There are large gaps in our understanding of porbeagle reproduction, including uncertainty in the size and age of female sexual maturity, and the location of the pupping grounds. Mature sharks are seldom seen in the winter and spring, and their overwintering grounds remain unknown. This uncertainty affects the estimation of spawning stock size, and could also influence yield projections through effects on availability. Yield modelling based on life history tables could provide more insight.

Other sources of uncertainty include some of the assumptions of the Peterson tag analysis, specifically those dealing with tag-induced mortality and tag loss rates. The age determination of old sharks (>10 yr) remains unvalidated, and could affect the accuracy of the catch curve calculations. In any event, further age determinations are required to more accurately reconstruct age composition from length composition.

Outlook

Porbeagle sharks produce few offspring and mature at a late age compared to the age of first capture. This combination of life history characteristics makes porbeagle highly susceptible to over-exploitation. Average catches of about 4500t per year in the early 1960s resulted in a fishery which collapsed after only 6 years, and which did not fully recover for another 20 years. However, the fishery appeared sustainable during the 1970s and 1980s when landings averaged 350t annually. Catches of 1000-2000t throughout the 1990s appear to have impacted the population, producing lower catch rates and markedly lower numbers of mature females.

The provisional TAC of 1000t introduced in 1996 was based on very limited scientific information, and did not include any estimates of yield, mortality or stock abundance. Nevertheless, it has apparently been effective in reducing overall mortality closer to a sustainable level. Recent catches averaging 1130t per year (1996-1998) have resulted in fishing mortality rates which exceed $F_{0.1}$ by 33%. However, the life history characteristics of porbeagle suggest that a sustainable spawning stock will require an overall fishing mortality which is somewhat less than $F_{0.1}$. Alternatively, a fishing mortality equal to $F_{0.1}$ on the immature population may be sustainable if the mature population is protected.

The life history characteristics of porbeagle indicate that the diminishing population of mature females needs to be protected. In light of the size segregation by season and location, reduced mortality of mature females may be achieved by restricting access to areas and/or seasons where large females are present.

Industry funding and support for the scientific study of this stock improved the accuracy and precision of the stock assessment, and should help ensure the sustainability of the fishery.

Acknowledgements

We thank Clearwater Fine Foods, Karlsen Shipping and the Atlantic Shark Association for providing access to their fishing vessels and unpublished data in support of the porbeagle research program. Lisa Natanson, Nancy Kohler, Wes Pratt, Chris Jensen and Joe Mello of the National Marine Fisheries Service provided invaluable data and advice, particularly with respect to age determinations and tagging. Sigmund Myklevoll of the Institute of Marine Research kindly provided unpublished data from the Norwegian fishery. We also thank Jerry Black, Bob Mohn and Steve Smith for analytical advice, the BIO Assessment Working Group for a critical review and advice, and Tom Hurlbut for his review of the completed document.

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Table 1. Reported porbeagle landings (mt) by country.

	Northwest Atlantic (NAFO Areas 2 - 6)										Northeast Atlantic
Year	Canada	Faroe Is	France	Iceland	Japan	Norway	Spain	USSR	USA	Total	Total
1961	0	100				1824				1924	1600
1962	0	800				2216				3016	500
1963	0	800				5763				6563	300
1964	0	1214		7		8060				9281	400
1965	28	1078				4045				5151	500
1966	0	741				1373				2114	500
1967	0	589			36					625	600
1968	0	662			137	269				1068	1000
1969	0	865			208					1073	1000
1970	0	205			674					879	4300
1971	0	231			221					452	4400
1972	0	260				87				347	3500
1973	0	269								269	400
1974	0									0	343
1975	0	80								80	577
1976	0	307								307	497
1977	0	295								295	374
1978	1	121								122	3120
1979	2	299								301	1295
1980	1	425								426	1172
1981	0	344			3					347	1031
1982	1	259			1					261	341
1983	9	256			0					265	886
1984	20	126			1	17				164	556
1985	26	210			0					236	440
1986	24	270			5			1		300	425
1987	59	381			16			0	12	468	404
1988	83	373			9			3	32	500	523
1989	73	477			9			3	4	566	444
1990	78	550			8			9	19	664	684
1991	329	1189			20			12	17	1567	450
1992	740	1149			7			8	13	1917	643
1993	919	465			6			2	39	1431	839
1994	1549				2				3	1554	1023
1995	1379				4				5	1388	730
1996	1024		39		9				8	1080	418
1997	1304				2				2	1308	375
1998	1008				0				12	1020	
*1999	789									789	

Notes: Northeast Atlantic Data is from FAO Statistics (1997)
Northwest Atlantic Data for 1950 - 60 is from FAO (ICCAT Report of Shark Working Group, Miami, 26 - 28 February 1996)
Canada for 1961 - 90 is from NAFO
Canada for 1991 - 99 is from DFO Zonal Statistics File
Faroe Is for 1961 - 63 is from FAO (ICCAT Report of Shark Working Group, Miami, 26 - 28 February 1996)
Norway from 1961-86 is from NAFO
Northwest Atlantic Data for 1964 - 86 is from NAFO
Northwest Atlantic Data for 1987-99 is from Scotia-Fundy & NF IOP (includes landings and discards)
Japan and USSR for 1981-99 is from Scotia-Fundy & NF IOP (includes landings and discards)
Northwest Atlantic Data (US/ 1961 - 94) is from FAO (ICCAT Report of Shark Working Group, Miami, 26 - 28 February 1996)

* 1999 Canadian catch reported to 31 July only

Table 2. Canadian porbeagle, mako and unspecified shark landings (mt) by fishery.

Year	Directed longline	Swordfish bycatch	Tuna bycatch	Other bycatch	Reported as mako	Reported as unspecified shark	TOTAL	TAC
1991	329	0	0	0	0	185	514	NA
1992	737	0	0	4	0	171	912	NA
1993	913	0	0	5	4	174	1096	NA
1994	1533	7	2	7	142	121	1812	NA
1995	1352	19	0	8	111	40	1530	1500
1996	997	6	1	20	67	20	1111	1500
1997	1263	5	0	36	86	43	1433	1000
1998	979	7	0	22	71	37	1116	1000
1999	782	0	0	7	17	3	809	1000

* 1999 catches are to 31 July only

Table 3. Canadian porbeagle catches (mt) by province of landing.

Year	NS	NB	PEI	QUE	NFL
91	328.9				
92	740.5				
93	918.8				
94	1544.5			4	0.5
95	1304.8			1.1	72.9
96	1021.7		0.2	0.1	1.6
97	1223.6	0.8			79.6
98	917.1	0.5	3.9		86.6
99	789.4				

* 1999 catches are to 31 July only

Table 4. Reported yearly directed porbeagle landings, converted from landed weight (lbs) to round weight (kg) using province-specific conversion factors. Corrected round weights (using a consistent conversion factor of 1.47) were used in all calculations of commercial catch rate.

Province	Year	Directed reported catch converted to round weight (mt)			
		Round	Gutted head on	Gutted head off	Gutted head and tail off
NS	91			329	
	92			733	
	93			912	
	94	3		1524	
	95		2	1276	
	96		18	978	
	97			1182	
	98		5	891	
	99		1	778	
NFL	95				69
	97				79
	98	82			

		Conversion factor used: dressed lb to round kg			
		Round	Gutted head on	Gutted head off	Gutted head and tail off
NS	91			1.47	
	92			1.59	
	93			1.47	
	94	2.23		1.51	
	95		2.01	1.48	
	96		2.01	1.51	
	97			1.52	
	98		2.01	1.48	
	99		2.01	1.48	
NFL	95				0.67
	97				1.47
	98	2.09			

		Conversion factor used: dressed kg to round kg			
		Round	Gutted head on	Gutted head off	Gutted head and tail off
NS	91			1.50	
	92			1.39	
	93			1.49	
	94	0.99		1.46	
	95		1.09	1.49	
	96		1.10	1.46	
	97			1.45	
	98		1.10	1.50	
	99		1.10	1.48	
NFL	95				3.30
	97				1.50
	98	1.05			

	Round weight (mt)	
All	Reported	Corrected
91	329	329
92	733	805
93	912	912
94	1528	1547
95	1347	1313
96	996	1014
97	1263	1272
98	979	1019
99	780	784

Table 5. Directed landings (mt) of porbeagle shark by Canadian vessels >= 100'.

Year	Subarea	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Subarea total	Annual total
1991	2-3	.	.	.	.	.	.	.	.	.	41.7	106.2	13.8	161.7	
	4RST	.	.	.	.	.	.	.	.	38.7	24	.	.	62.6	
	4VW	.	.	.	.	.	.	19	41.6	26.8	7.4	.	0.4	95.3	
	4X5Y	.	.	.	.	.	.	.	0.3	.	.	6.6	1.3	8.2	
	5Z	.	.	.	.	.	.	.	.	.	.	.	1	1	328.8
1992	2-3	.	.	.	4.1	.	0.3	.	59.1	124.7	41.1	0.2	.	229.6	
	4RST	.	.	.	.	.	.	6.7	.	6.8	69.2	45.7	.	128.4	
	4VW	.	.	21.5	27.8	22	15.3	21.5	0.5	0.3	5.2	8.5	0.6	123.1	
	4X5Y	0.1	.	0.7	1.8	25.5	4.7	74.2	.	.	0.2	0.1	.	107.3	
	5Z	50.7	.	2.5	.	82.1	10.9	.	.	.	.	.	.	146.2	734.6
1993	2-3	0.3	.	.	.	.	15.7	18.9	67.1	68.3	91.6	42.9	34.2	339	
	4RST	.	.	.	.	.	8.6	49.5	0.3	44.6	44.5	.	.	147.5	
	4VW	.	0.1	0.3	67.2	51.3	16	6.1	0.8	0.4	9.9	47.7	6.8	206.5	
	4X5Y	0.2	0.2	.	80.2	77.4	7.2	47.6	.	.	.	0.4	5.5	218.6	
	5Z	0.5	1.2	.	3	.	0	.	.	.	.	.	.	4.7	916.3
1994	2-3	.	.	.	.	.	35	17.4	30.5	70.3	131.4	5.7	.	290.3	
	4RST	.	.	.	.	.	.	31.7	.	30.3	10	.	.	72	
	4VW	1.6	0.1	33.7	265.3	211.2	173.5	36.9	.	1.7	21.3	112.6	74.7	932.8	
	4X5Y	.	.	15.5	36.9	2	28.4	1.5	.	.	.	51.8	11.1	147.3	
	5Z	.	.	.	6	8.3	.	.	.	.	.	.	0.6	14.9	1457.3
1995	2-3	.	.	.	.	8.4	102.6	60.1	15.3	128.5	149.1	65.3	.	529.3	
	4RST	.	.	.	.	.	.	6.3	.	.	.	12.3	.	18.5	
	4VW	.	.	68.8	115.3	152.4	41.3	12.6	.	.	.	49.6	60.8	500.9	
	4X5Y	.	.	21.6	66.4	14.2	.	4	.	.	.	6.8	1.9	114.9	
	5Z	.	.	.	23.1	2	.	.	.	.	.	.	.	25.1	1188.7
1996	2-3	.	0.1	.	.	.	37.5	14.6	.	85.5	90.3	69.9	.	297.9	
	4RST	.	.	.	.	.	.	.	.	.	.	5.5	.	5.5	
	4VW	11.1	.	32.1	3.8	42.4	7.9	27.6	.	.	.	22.6	16.2	163.7	
	4X5Y	1.3	.	54.9	100.3	80.7	28.3	0.1	.	.	.	.	1.1	266.6	
	5Z	.	.	0.7	.	.	0.7	.	.	.	.	.	0.2	1.5	735.2
1997	2-3	.	.	0.2	.	.	3.2	8.4	30.4	104.9	142.6	46.8	.	336.4	
	4RST	.	.	.	.	.	.	1	6.7	30.1	9.5	.	.	47.2	
	4VW	0.7	0.1	63.6	95.1	122.3	92.3	7.2	.	6.1	11.3	.	.	398.7	
	4X5Y	.	.	81.3	20.8	48.1	.	.	.	.	0.1	.	.	150.4	
	5Z	.	.	.	.	10.2	.	.	.	.	.	.	.	10.2	942.9
1998	2-3	.	.	0.8	0	37.6	13.7	0.8	50.2	51.2	99.4	.	.	253.7	
	4RST	.	.	.	.	.	.	.	.	33.2	15.1	.	.	48.2	
	4VW	.	.	92.5	60.6	61.3	18	0.3	.	2.9	2.2	.	.	237.8	
	4X5Y	0.2	4.4	16.9	48	75.7	7.4	.	.	.	.	0.2	.	152.8	
	5Z	.	.	0.8	32.2	20.8	.	.	.	.	.	.	.	53.8	746.3
1999	2-3	.	.	.	1.1	57.1	9.3	.	.	.	.	.	.	67.5	
	4VW	.	0	2.8	113.6	125.9	96.3	12.9	.	.	.	.	.	351.5	
	4X5Y	.	2.9	9.3	12	3	0.1	.	.	.	.	.	.	27.3	
	5Z	.	.	0.7	.	.	0.1	.	.	.	.	.	.	0.8	447.1

* 1999 until 31 July

Table 6. Directed landings (mt) of porbeagle shark by Canadian vessels < 100'.

Year	Subarea	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Subarea total	Annual total
1991	4X5Y	0.1	.	.	.	.	.	.	.	.	.	.	.	0.1	0.1
1992	4VW	.	.	.	.	0.1	0.5	0	.	0.3	0.1	0.1	0.1	1.3	
	4X5Y	.	.	.	.	.	0.1	0.1	0.7	1.2	0.2	0.1	.	2.3	
	5Z	.	.	.	.	.	2.2	.	.	0.1	.	.	.	2.3	5.9
1993	4VW	.	.	.	0.1	.	.	0.7	0.2	0.2	0.1	.	.	1.2	
	4X5Y	.	.	.	0.1	0.5	0.1	0.2	0.2	0	.	.	.	1.1	
	5Z	.	.	0	.	.	.	.	.	.	.	.	.	0	2.3
1994	2-3	0.1	.	.	0.1	0.1	.	0.1	0.3	.	0.5	.	.	1.1	
	4RST	.	.	.	.	.	.	0.1	3	0.8	.	.	.	4	
	4VW	.	.	.	0.9	3.3	0	8.9	10.2	15.3	22.5	2.2	0.1	63.3	
	4X5Y	.	.	.	.	0.2	4.2	2.5	3.7	6.3	4.1	1.9	0.1	23	
	5Z	.	.	.	.	.	0.1	0.2	.	.	.	.	.	0.2	91.6
1995	2-3	.	.	0.2	0	0	.	.	0.8	1.1	1.9	0.1	.	4.1	
	4RST	.	.	.	.	.	.	0.4	0.4	0.4	.	.	.	1.1	
	4VW	0.4	9.1	1.6	20	9.3	31.2	10	1.7	10.1	5.2	0.1	.	98.6	
	4X5Y	0.2	3.2	12.8	0.6	43.1	11	0.5	10.1	3.5	0.5	0.1	0.4	85.9	
	5Z	.	.	.	.	.	.	.	0.1	0.3	.	.	.	0.4	190.1
1996	2-3	.	.	.	.	0.5	0.1	0	1.2	0.4	0.7	0	.	2.8	
	4RST	.	.	.	.	.	.	0.4	.	2.3	2.4	7.6	.	12.6	
	4VW	9.7	13.9	52.1	16.5	31.7	13.8	6.3	8.6	4.4	10.3	5.6	24.5	197.4	
	4X5Y	.	.	2	26.3	16.5	8	1.6	1.1	0.5	1.1	0.4	0.3	57.8	
	5Z	.	14.9	0.8	0.7	0.2	.	.	.	.	0.1	0.3	0.6	17.7	288.3
1997	2-3	.	.	.	.	.	.	0.6	0.3	0.1	.	.	.	0.9	
	4RST	.	.	.	.	.	.	0.7	9.5	4	9	.	.	23.2	
	4VW	36.1	26.8	6	31.2	25.2	53	12.9	5.9	7.9	5.4	.	.	210.4	
	4X5Y	.	1	2.4	36.5	34.5	25.5	3.2	0.8	1.1	13.4	0.2	.	118.6	
	5Z	.	8.4	16.7	.	.	1.2	1	0	0.2	.	.	.	27.6	380.7
1998	2-3	.	.	.	.	.	.	.	0	.	0.2	.	0	0.2	
	4RST	.	.	.	.	.	.	0.7	0.2	4.5	0.1	.	.	5.4	
	4VW	3.8	0.3	0.3	33.4	58.7	37.6	3.3	7.2	5.9	9.2	0.9	.	160.6	
	4X5Y	4.7	1	2.6	24.4	19.3	12.7	2.7	2.1	3	2.3	1.7	0.4	76.9	
	5Z	11.2	3.5	0	1.2	0.9	0	0.1	0.5	.	0.8	0.3	0.2	18.7	261.8
1999	2-3	0	.	0.2	.	.	.	.	.	.	.	.	.	0.2	
	4VW	26.7	10.4	46.5	29.3	60.2	6.4	1.6	.	.	.	.	.	181.1	
	4X5Y	1.1	0.1	3.5	30.9	50.8	3.7	0.3	.	.	.	.	.	90.4	
	5Z	.	2.6	39.4	13.4	13.8	1.3	.	.	.	.	.	.	70.5	342.2

* 1999 until 31 July

Table 7. Undirected landings (mt) of porbeagle shark by Canadian vessels.

Year	Subarea	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Subarea total	Annual total
1991	4X5Y	0.1	.	.	.	.	.	.	.	.	.	.	.	0.1	0.1
1992	4VW	.	.	.	.		0.1	0.5	.	.	0.3	0.1	0.3	0.4	1.8	
	4X5Y	.	.	.	.	.	0.1	0.1	0.7	1.1	0.2	.	.	2.1	3.9
1993	2-3	0.3	.	.	.	.	.	.	.	.	.	.	.	0.3	
	4VW	.	0.1	0.3	0.3	.	.	0.7	0.2	.	0.1	.	.	1.6	
	4X5Y	0.2	0.2	.	0.1	0.5	0.1	0.2	0.2	0	.	.	.	1.5	
	5Z	0.5	1.2	0	0.1	.	.	.	.	.	.	.	.	1.8	5.2
1994	2-3	0.1	.	.	0.1	0.1	.	0.1	0.3	.	0.5	.	.	1.1	
	4RST	.	.	.	.	.	.	0.1	3	0.8	.	.	.	4	
	4VW	1.6	0.1	.	0.2	.	0	1.3	0.7	0.8	2.5	1.2	0.1	8.4	
	4X5Y	.	.	.	.	0.1	0.3	0.3	0.4	0.1	0.5	0.5	0.1	2.2	
	5Z	.	.	.	.	.	0.1	0.2	.	.	.	.	.	0.2	15.9
1995	2-3	.	.	0.2	0	0	.	.	0.8	1.1	1.9	0.1	.	4.1	
	4RST	.	.	.	.	.	.	0.4	0.4	0.4	.	.	.	1.1	
	4VW	0.4	.	0.4	0.8	0	0.5	2.6	0.7	6.6	4.2	0.1	.	16.4	
	4X5Y	0.2	.	.	0.4	1	0.5	0.3	0.1	1.5	0.5	0.1	0.4	4.9	
	5Z	.	.	.	.	.	.	.	0.1	0.3	.	.	.	0.4	26.9
1996	2-3	.	0.1	.	.	.	0.1	0	0.5	0.4	0.7	0	.	1.8	
	4RST	.	.	.	.	.	.	0.4	.	2.3	2.4	7.6	.	12.6	
	4VW	0.1	0	0.2	0.1	.	0.3	0.4	1.9	1.8	0.2	.	0.2	5.3	
	4X5Y	.	.	0.1	0.3	1.3	0.3	1.1	0.4	0.5	0.9	0.3	0.3	5.5	
	5Z	.	.	.	.	.	.	.	.	.	0.1	0.3	0.7	1.2	26.4
1997	2-3	.	.	0.2	.	.	.	0.6	0.3	.	.	.	.	1	
	4RST	.	.	.	.	.	.	0.7	9.5	4	9	.	.	23.2	
	4VW	0.9	0.1	0.1	0.4	.	0.3	0.3	1.1	2.8	0.2	.	.	6.2	
	4X5Y	.	0.6	0.2	0.2	0.5	1.4	0.7	0.8	1.1	2	0.2	.	7.7	
	5Z	.	.	.	.	.	1.2	1	0	0.2	.	.	.	2.5	40.6
1998	2-3	.	.	.	0	.	.	.	0	4.3	0.2	.	0	4.5	
	4RST	.	.	.	.	.	.	0.7	0.2	4.5	0.1	.	.	5.4	
	4VW	0.2	.	0.1	0.1	0.2	0.2	0.8	2.2	3.9	0.5	0.1	.	8.3	
	4X5Y	0.3	0.3	.	0.3	0.3	0.3	1.6	1	1.9	1.6	1	0.3	8.8	
	5Z	.	.	.	.	.	0	0.1	0.5	.	0.8	0.3	0.2	1.8	28.8
1999	2-3	0	.	0.2	.	.	.	.	.	.	.	.	.	0.2	
	4VW	0.2	0	0.1	0.4	0.5	0.2	0.2	.	.	.	.	.	1.7	
	4X5Y	0.2	0.1	0.3	0.7	1.5	0.8	0.3	.	.	.	.	.	3.9	
	5Z	.	.	.	.	.	1.4	.	.	.	.	.	.	1.4	7.2

* 1999 until 31 July

Table 8. Directed effort and associated catch by all countries.

	Number of hooks			Directed catch (mt)	
Year	Inshore	Offshore	TOTAL	Inshore	Offshore
1981		133154	133154		184
1987		173756	173756		377
1988		192162	192162		373
1989		161888	161888		477
1990		214840	214840		539
1991		107004	107004		329
1992		268869	268869		805
1993		402576	402576		899
1994	21320	652423	673743	35	1453
1995	14468	637619	652087	9	1149
1996	128182	413698	541880	203	740
1997	142742	443182	585924	288	942
1998	142828	458412	601240	211	775
1999	184015	274653	458668	329	446

Table 9. Number of porbeagle fork length measurements available from each data source.

YEAR	SOURCE						
	Norway[1]	*Industry*[2]	*LPRT*[3]	*NF IOP*	*SF IOP*	*Research*[4]	*Total*
61	1810						1810
79				17			17
80				810			810
81				1984			1984
86					33		33
87				1521	359		1880
88				1541	5512		7053
89				2132	58		2190
90				1705	8552		10257
91				26	16475		16501
92				13	14619		14632
93				886	9175		10061
94				116	2764		2880
95		3640		3409	3006		10055
96		2057	4092	5	3824		9978
97		1228	4643	3	1483		7357
98		9597		21	17		9635
99		14507				358	14865
TOTAL	1810	31029	8735	14189	65877	358	121998

1-From Aasen (1963)
2-DMP and QMP measurements of interdorsal length
3-Individual carcass weights associated with Large Pelagic Research Tally sheets
4-On-board scientific technician

Table 10. Results of the catch rate standardization model relating the catch rate (ln-transformed number/hook) of mature porbeagle (>200 cm FL) to area, month, data source, CFV and year.

```
LNCE200 ~ SUBAREA + MON + SOURCE + CFV + YR, data = xlnce200.majorcfv)

Residual standard error: 1.14 on 4553 degrees of freedom
Multiple R-Squared: 0.2872
F-statistic: 38.21 on 48 and 4553 degrees of freedom, the p-value is 0

Analysis of Variance Table           Response: LNCE200

Terms added sequentially (first to last)
            Df Sum of Sq  Mean Sq  F Value      Pr(F)
  SUBAREA    3  1157.299 385.7662 296.6789 0.00000000
      MON   11   212.501  19.3182  14.8570 0.00000000
   SOURCE    2     8.114   4.0569   3.1200 0.04425188
      CFV   19   388.801  20.4632  15.7375 0.00000000
       YR   13   618.359  47.5661  36.5814 0.00000000
Residuals 4553  5920.184   1.3003
Coefficients:
                 Value Std. Error  t value Pr(>|t|)
  (Intercept)  -3.2569   0.2846   -11.4440   0.0000
SUBAREAESHELF  -0.8381   0.0856    -9.7896   0.0000
    SUBAREANF   0.3196   0.0716     4.4659   0.0000
SUBAREASSHELF  -0.8112   0.0943    -8.6063   0.0000
         MON2  -0.2471   0.2070    -1.1937   0.2327
         MON3  -0.6977   0.1624    -4.2966   0.0000
         MON4  -0.5970   0.1583    -3.7705   0.0002
         MON5  -0.1977   0.1583    -1.2485   0.2119
         MON6  -0.5410   0.1626    -3.3277   0.0009
         MON7  -0.5589   0.1770    -3.1572   0.0016
         MON8  -0.9891   0.1804    -5.4815   0.0000
         MON9  -0.5150   0.1723    -2.9892   0.0028
        MON10  -0.3665   0.1717    -2.1339   0.0329
        MON11  -0.3455   0.1757    -1.9671   0.0492
        MON12  -0.4309   0.1923    -2.2408   0.0251
     SOURCESF  -0.0033   0.0747    -0.0448   0.9643
    SOURCEZIF  -0.1305   0.0916    -1.4240   0.1545
         CFVa  -0.3067   0.2645    -1.1593   0.2464
         CFVb  -1.2013   0.2485    -4.8331   0.0000
         CFVc  -1.4575   0.2869    -5.0805   0.0000
         CFVd  -1.3638   0.3342    -4.0803   0.0000
         CFVe  -1.1250   0.2988    -3.7649   0.0002
         CFVf  -0.8404   0.3711    -2.2644   0.0236
         CFVg  -0.4433   0.1599    -2.7722   0.0056
         CFVh  -1.6154   0.1420   -11.3733   0.0000
         CFVi  -0.4629   0.2207    -2.0974   0.0360
         CFVj  -1.3256   0.1968    -6.7345   0.0000
         CFVk  -0.6501   0.2844    -2.2858   0.0223
         CFVl  -1.3719   0.1557    -8.8109   0.0000
         CFVm  -0.8070   0.2088    -3.8649   0.0001
         CFVn  -1.3268   0.1642    -8.0812   0.0000
         CFVo  -0.2144   0.2174    -0.9860   0.3242
         CFVp  -1.3283   0.1396    -9.5128   0.0000
         CFVq  -1.4792   0.4001    -3.6974   0.0002
         CFVr  -1.7638   0.1745   -10.1069   0.0000
         CFVs  -2.1110   0.1716   -12.3021   0.0000
         YR87  -0.7049   0.1920    -3.6716   0.0002
         YR88  -1.1316   0.1758    -6.4369   0.0000
         YR89  -0.3179   0.2109    -1.5076   0.1317
         YR90  -0.1949   0.1714    -1.1374   0.2554
         YR91   0.0689   0.1673     0.4122   0.6802
         YR92   0.2931   0.1693     1.7310   0.0835
         YR93  -0.2176   0.1731    -1.2572   0.2087
         YR94  -0.3216   0.1845    -1.7429   0.0814
         YR95  -0.1439   0.1809    -0.7954   0.4264
         YR96  -0.3123   0.1873    -1.6680   0.0954
         YR97  -0.5571   0.1872    -2.9753   0.0029
         YR98  -0.9944   0.1875    -5.3038   0.0000
         YR99  -1.5078   0.1924    -7.8386   0.0000
```

Table 11. Results of the catch rate standardization model relating the catch rate (ln-transformed kg/hook) to area, month, data source, CFV and year.

```
LNWT.TOW ~ SUBAREA + MON + SOURCE + CFV + YR, data = xlncpue.majorcfv)

Residual standard error: 1.002 on 5044 degrees of freedom
Multiple R-Squared: 0.1034
F-statistic: 12.12 on 48 and 5044 degrees of freedom, the p-value is 0

Analysis of Variance Table           Response: LNWT.TOW
Terms added sequentially (first to last)
            Df Sum of Sq  Mean Sq  F Value        Pr(F)
  SUBAREA    3    18.168  6.05589  6.03608 0.0004239328
      MON   11   109.924  9.99310  9.96042 0.0000000000
   SOURCE    2    35.718 17.85912 17.80070 0.0000000198
      CFV   19   248.881 13.09899 13.05614 0.0000000000
       YR   13   170.900 13.14616 13.10315 0.0000000000
Residuals 5044  5060.553  1.00328

Coefficients:
                Value Std. Error t value Pr(>|t|)
  (Intercept)  0.2831  0.2376     1.1916  0.2335
SUBAREAESHELF -0.1731  0.0677    -2.5578  0.0106
    SUBAREANF -0.0014  0.0589    -0.0243  0.9806
SUBAREASSHELF -0.1709  0.0741    -2.3066  0.0211
         MON2 -0.2144  0.1726    -1.2422  0.2142
         MON3  0.0298  0.1315     0.2269  0.8205
         MON4  0.2014  0.1280     1.5731  0.1158
         MON5  0.1414  0.1278     1.1064  0.2686
         MON6 -0.2384  0.1315    -1.8133  0.0699
         MON7 -0.3600  0.1423    -2.5291  0.0115
         MON8 -0.6026  0.1472    -4.0940  0.0000
         MON9 -0.2865  0.1391    -2.0588  0.0396
        MON10 -0.1162  0.1385    -0.8393  0.4014
        MON11 -0.1302  0.1404    -0.9276  0.3536
        MON12 -0.2977  0.1569    -1.8979  0.0578
     SOURCESF  0.2048  0.0607     3.3719  0.0008
    SOURCEZIF -0.0148  0.0751    -0.1971  0.8438
         CFVa  0.2231  0.2318     0.9627  0.3357
         CFVb -0.0866  0.2178    -0.3974  0.6911
         CFVc -0.5790  0.2517    -2.2998  0.0215
         CFVd -0.8395  0.2848    -2.9479  0.0032
         CFVe -0.1669  0.2621    -0.6366  0.5244
         CFVf  0.0099  0.2861     0.0347  0.9723
         CFVg  0.0558  0.1393     0.4007  0.6887
         CFVh -0.2399  0.1241    -1.9339  0.0532
         CFVi -0.1842  0.1938    -0.9504  0.3420
         CFVj  0.0501  0.1727     0.2899  0.7719
         CFVk -0.1978  0.2496    -0.7923  0.4282
         CFVl  0.1102  0.1334     0.8265  0.4086
         CFVm  0.0206  0.1832     0.1125  0.9104
         CFVn -0.3063  0.1434    -2.1359  0.0327
         CFVo  0.3087  0.1892     1.6316  0.1028
         CFVp  0.0004  0.1219     0.0030  0.9976
         CFVq -0.8645  0.3078    -2.8087  0.0050
         CFVr -0.3764  0.1511    -2.4909  0.0128
         CFVs -0.7148  0.1485    -4.8119  0.0000
         YR87  0.5100  0.1510     3.3778  0.0007
         YR88  0.3242  0.1468     2.2082  0.0273
         YR89  0.6759  0.1508     4.4834  0.0000
         YR90  0.5891  0.1444     4.0792  0.0000
         YR91  0.8539  0.1399     6.1016  0.0000
         YR92  0.6344  0.1411     4.4955  0.0000
         YR93  0.4020  0.1445     2.7825  0.0054
         YR94  0.4903  0.1500     3.2689  0.0011
         YR95  0.1675  0.1513     1.1071  0.2683
         YR96 -0.0181  0.1561    -0.1157  0.9079
         YR97  0.3248  0.1559     2.0834  0.0373
         YR98 -0.0390  0.1560    -0.2497  0.8029
         YR99  0.0196  0.1606     0.1220  0.9029
```

Table 12. Peterson calculations of population biomass (mt) and exploitation rate based on tag recapture analysis.

Study	Year of tagging	Interval (yr)	# tagged	# recaptured	Catch (mt)	Biomass	95% CI	Exploitation	Recruits (mt) during interval
Norwegian	1961	2	92	2	6563	107558	117495	0.04	722
Norwegian	1962	1	209	11	6563	71276	39719	0.08	328
Norwegian	1962	2	209	11	9283	85522	50629	0.09	1021
Norwegian	1962	3	209	3	5161	117579	127450	0.03	981
Norwegian	1963	1	227	8	9283	145906	94108	0.05	464
Canadian	1994	1	40	1	1375	17687	20672	0.04	69
Canadian	1994	3	40	3	1338	6057	6050	0.14	254
Canadian	1995	1	180	5	1015	19026	14706	0.04	51
Canadian	1995	2	180	3	1338	31913	31417	0.03	147
Canadian	1995	3	180	7	1003	9864	7744	0.07	191
Canadian	1995	4	180	5	800	8568	8528	0.06	216
Canadian	1996	3	36	1	800	6556	8857	0.05	152
U.S.	1997	1	142	1	1003	44598	53568	0.01	50
U.S.	1997	2	142	2	800	20132	22171	0.02	88
U.S.	1996	1	62	3	1338	13164	11762	0.07	67
U.S.	1996	2	62	2	1003	11185	12036	0.05	110
U.S.	1996	3	62	1	800	11056	15267	0.03	152
U.S.	1995	1	126	6	1015	11457	8132	0.07	51
U.S.	1995	2	126	3	1338	22429	21898	0.04	147
U.S.	1995	4	126	3	800	9040	10680	0.05	216
U.S.	1994	1	136	9	1375	11713	6982	0.1	69
U.S.	1994	2	136	7	1015	9176	6499	0.09	112
U.S.	1994	3	136	6	1338	11397	9437	0.08	254
U.S.	1994	4	136	4	1003	9772	10481	0.06	271
U.S.	1993	1	132	4	1614	26696	22240	0.05	81
U.S.	1993	4	132	5	1338	10544	10374	0.08	361
U.S.	1988	6	55	3	1550	5027	7148	0.14	667
U.S.	1987	3	83	3	648	5952	6253	0.07	123
U.S.	1987	8	83	3	1375	3741	7919	0.11	839
combined	1994	1	176	10	1375	13745	7914	0.09	69
combined	1994	3	176	9	1338	10292	7219	0.1	254
combined	1995	1	306	11	1015	16116	9069	0.06	51
combined	1995	2	306	6	1338	30882	23993	0.03	147
combined	1995	3	306	7	1003	16697	13347	0.04	191
combined	1995	4	306	8	800	9665	8066	0.05	216

Peterson equation:
Biomass = (Tags remaining + 1) * (Catch + 1 - Recruitment) / # recaptures
and
Exploitation rate = # recaptures / tags remaining
where
Tags remaining = (# tagged) * exp[(-Pr loss) * interval] * (1 - (Pr tagging mortality) * Pr reporting
and
Pr loss = 0.1 per year
Pr tagging mortality = 0.2 in first year only
Pr reporting = 0.9

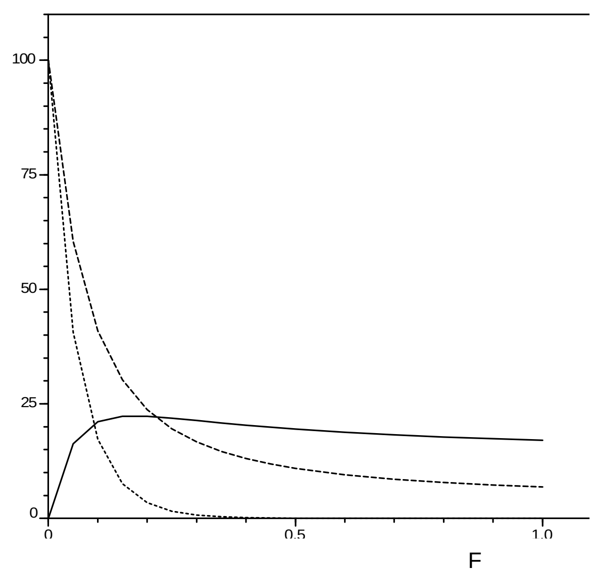
Note: Biomass is calculated for year of tagging, while Exploitation is calculated for year of recapture

Table 13. Yield per recruit analysis. Weights used are live round weights calculated with a biological length-weight conversion factor.

Age	FL (cm)	Wt (kg)	PR	M
0	95.6	11.8	0.05	0.1
1	110.1	17.3	0.80	0.1
2	123.3	23.5	0.90	0.1
3	135.3	30.3	1.00	0.1
4	146.2	37.4	1.00	0.1
5	156.1	44.6	1.00	0.1
6	165.0	51.9	1.00	0.1
7	173.2	59.1	1.00	0.1
8	180.5	66.2	1.00	0.1
9	187.2	73.1	1.00	0.1
10	193.3	79.7	1.00	0.1
11	198.8	86.1	1.00	0.1
12	203.8	92.1	1.00	0.1
13	208.4	97.7	1.00	0.1
14	212.5	103.1	1.00	0.1
15	216.3	108.1	1.00	0.1
16	219.6	112.7	1.00	0.1
17	222.7	117.1	1.00	0.1
18	225.5	121.1	1.00	0.1
19	228.1	124.9	1.00	0.1
20	230.4	128.3	1.00	0.1
21	232.5	131.5	1.00	0.1
22	234.4	134.4	1.00	0.1
23	236.1	137.1	1.00	0.1
24	237.7	139.6	1.00	0.1
25	239.1	141.9	1.00	0.1
26	240.4	144.0	1.00	0.1
27	241.5	145.9	1.00	0.1
28	242.6	147.6	1.00	0.1
29	243.5	149.2	1.00	0.1

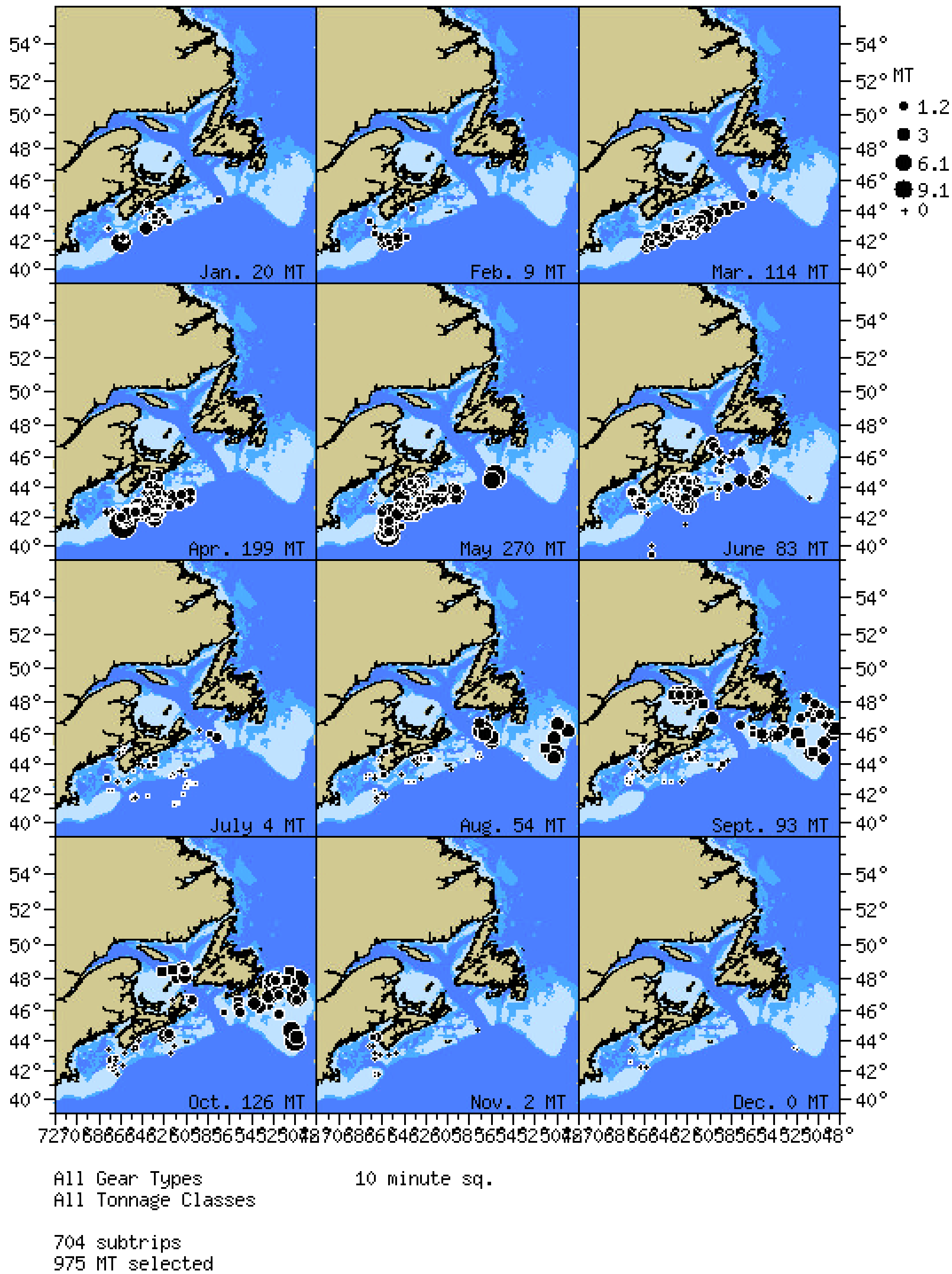
Reference	F	Average wt	Yield
	0.05	55.98	16.30
F0.1	0.08	50.23	20.09
	0.10	47.74	21.09
Fmax	0.17	39.57	22.35
	0.20	37.60	22.26
	0.30	31.99	21.35
	0.40	28.52	20.33
	0.50	26.18	19.48
	0.60	24.51	18.78
	0.70	23.26	18.22
	0.80	22.29	17.76
	0.90	21.52	17.38
	1.00	20.89	17.06

Yield, percent biomass and percent spawning numbers vs F



Pop biomass as percentage of maximum = upper dashed line
Spawning stock numbers as percentage
of maximum = lower dashed line
Yield per recruit = solid line

Fig. 1. Overview of porbeagle shark distribution and seasonal migration pattern based on monthly catch locations in the 1998 fishery.



704 subtrips
975 MT

Fig. 2. Annual migration of porbeagle based on Norwegian, American and Canadian tagging studies. Unpublished data courtesy of N. Kohler and L. Natanson (NMFS) and S. Myklevoll (IMR, Norway).

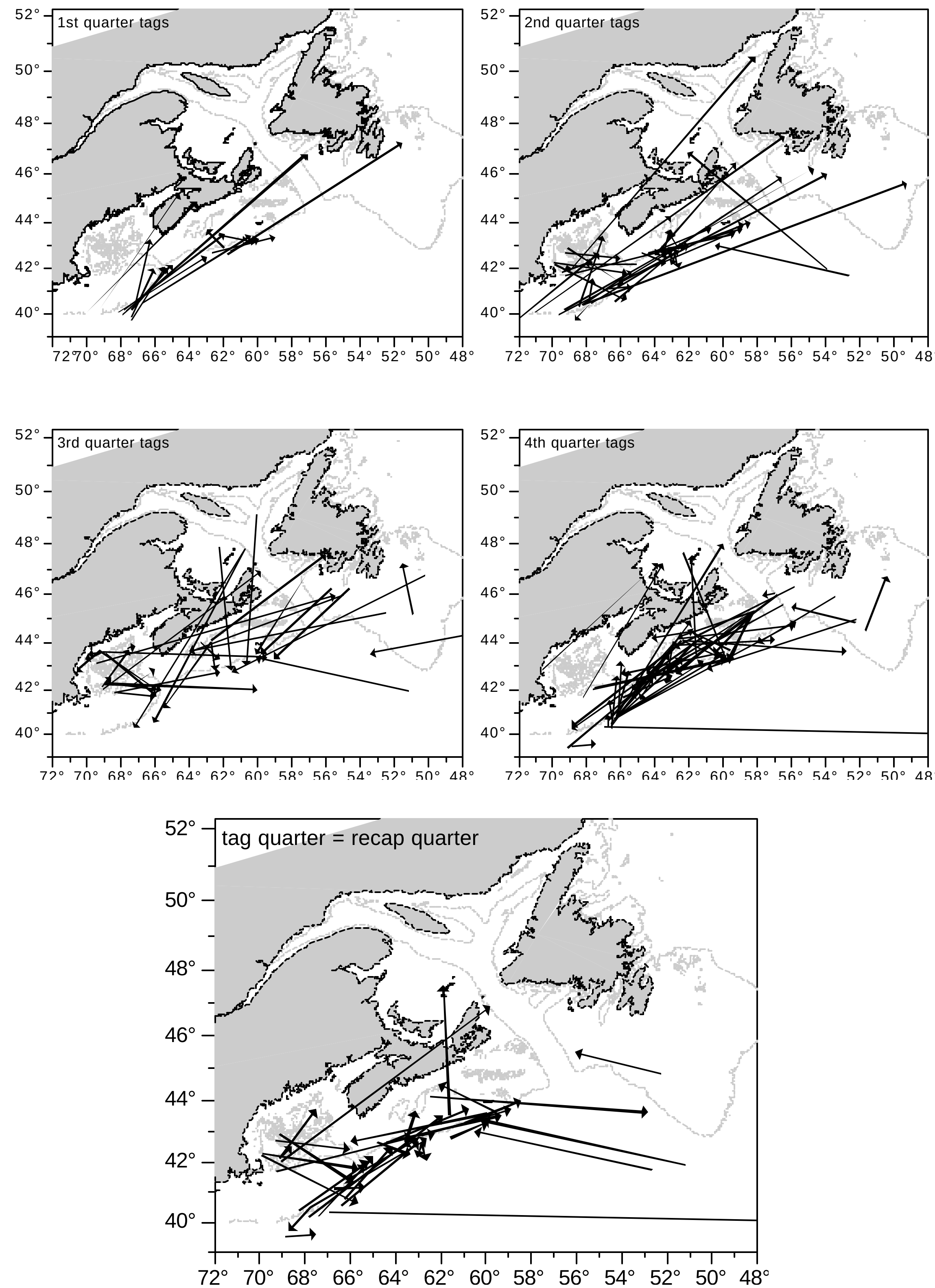


Fig 3. Morphometric conversions between various length and weight measures, based on at-sea measurements for all but frozen dressed weights. All measurements were made in the spring.

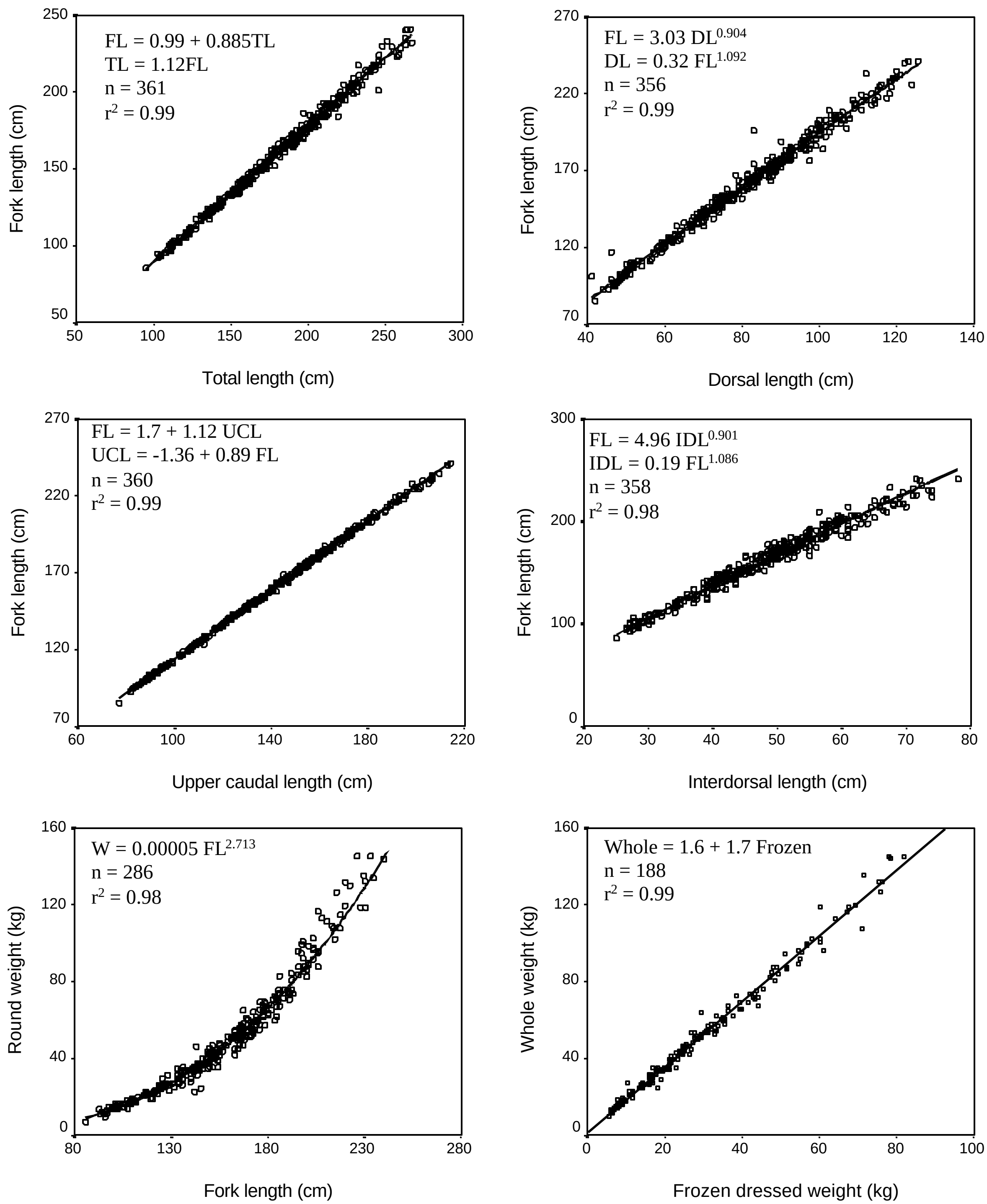
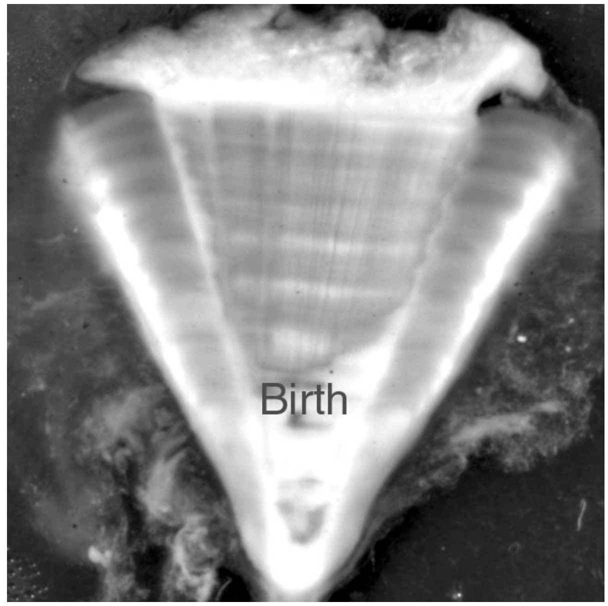


Fig. 4. Basis for age determination and calculation of growth rates in porbeagle sharks. Unpublished age data courtesy of L. Natanson and J. Mello, NMFS.

- Ages determined from growth bands in vertebral cross sections; the example shown in the photo to the right appears to be from a 8-yr old shark
- 315 sharks were aged
- All sharks were aged independently by 3 age readers, with no reader bias and acceptable precision
- The validity of the growth bands as accurate age indicators was confirmed through a variety of age validation studies (see below)



<u>Evidence Confirming the Validity of the Vertebral Ages</u>

1. Progression of length frequency modes from monthly observer samples of the Scotian Shelf fishery (see Fig. 10). These results confirmed the size at age and growth rate of ages 0 and 1.
2. Recaptures of porbeagle (n=4) tagged as YOY and recaptured 4-6 years later. In each case, the vertebral band counts matched those expected based on time at liberty.
3. Recaptures of porbeagle (n=2) injected with tetracycline and recaptured 1.5-2.5 years later. In both cases, the expected number of growth bands was deposited on the vertebrae between the date of injection and the date of recapture. One of the injected sharks was a large adult, confirming annulus formation in a 10-year old individual.
4. Analysis of growth rates in tagged porbeagle (n=48) at liberty 1-6 years, measured at both tagging and recapture. The size-specific growth rate determined from this analysis was very similar to that based on the vertebrae.

Age bias graph

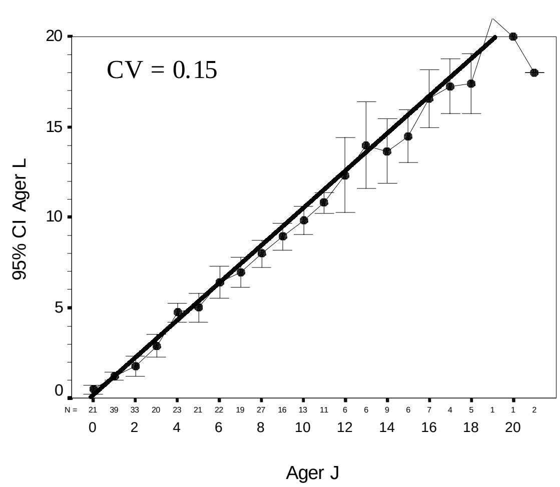
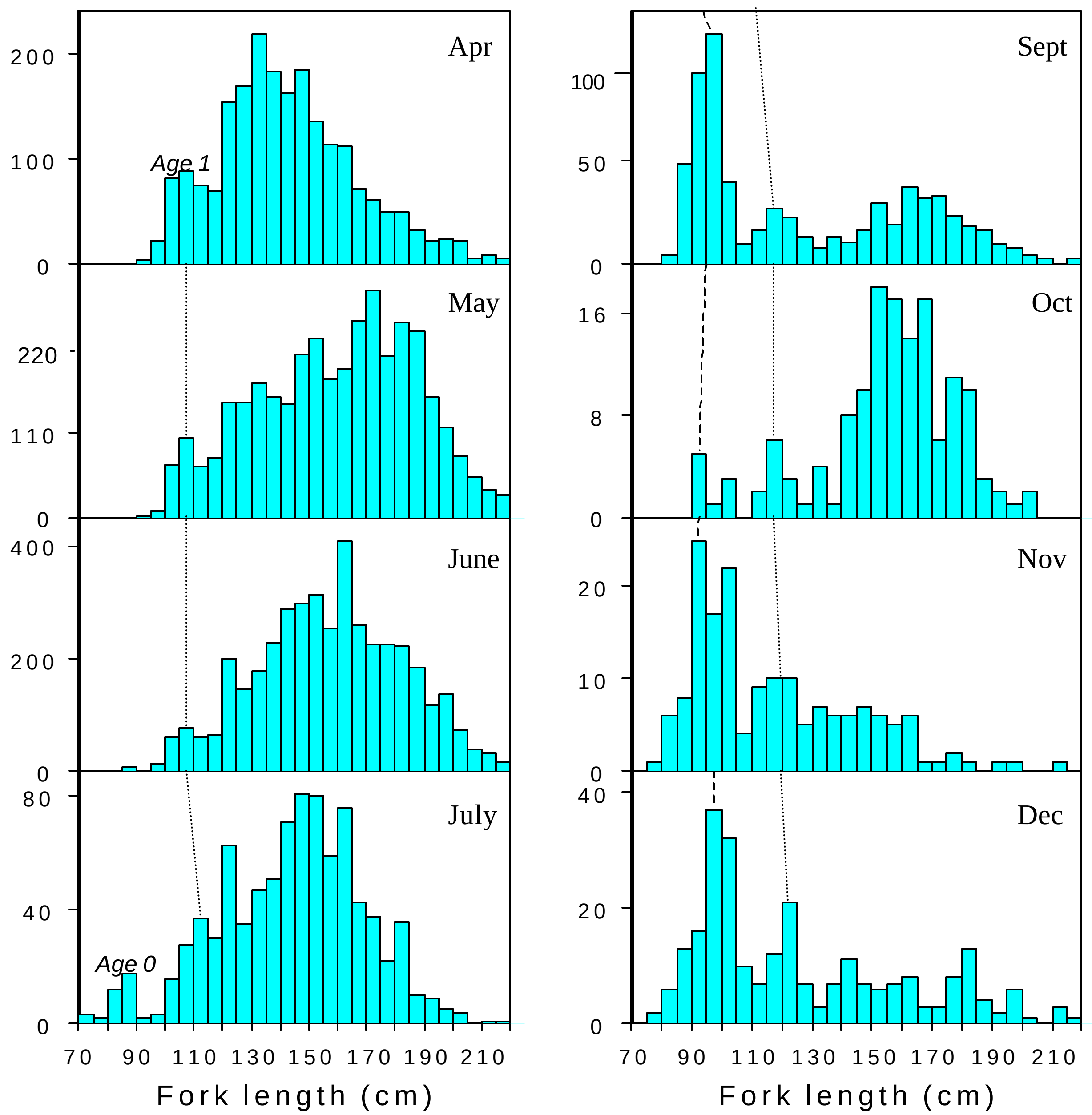
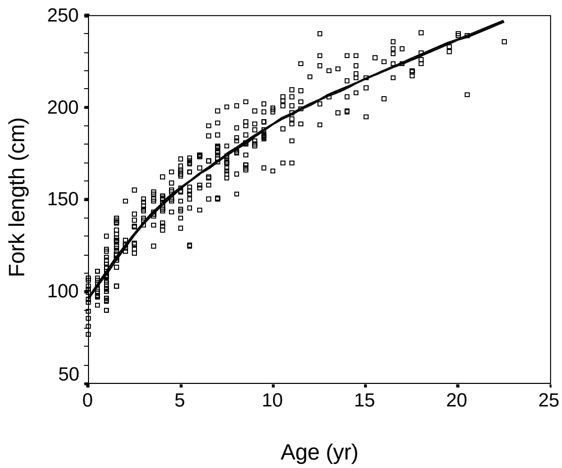


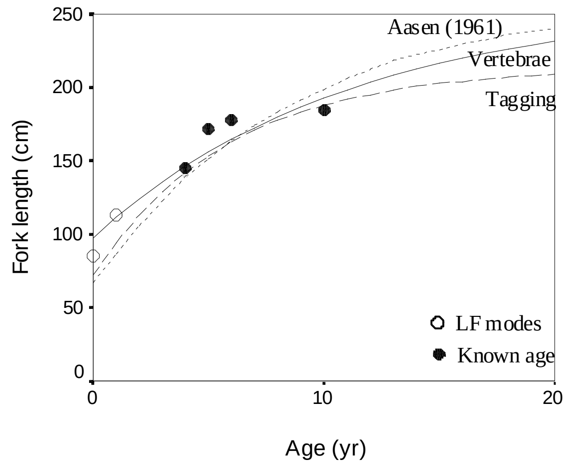
Fig. 5. Calculations of mean fork length (cm) and annual growth rate (cm/yr) on the basis of monthly progressions of length frequency modes collected by Observers in the 1991 Scotian Shelf fishery.



	Mean length in Apr	Mean length in July	Mean length in Dec	Annual G (cm/yr)
Age 0	-	85	98	31.2
Age 1	106	113	123	25.5

Fig. 6. (Left) Porbeagle growth curve based on vertebral ring counts, fitted with a Loess curve. There was no significant difference between the sexes. (Right) Comparison of von Bertalanffy growth curve fit to growth curves based on independent data. Unpublished age data courtesy of L. Natanson and J. Mello, NMFS.





Fitted von Bertalanffy growth model:

Residual sum of squares : 40402.66
parameters:

Linf	k	t0
253.0	0.097	-4.89

formula: FL ~ Linf * (1 - exp(- k * (AGE - t0)))
308 observations

Fig. 7. Reported landings of porbeagle in the NW Atlantic by country.

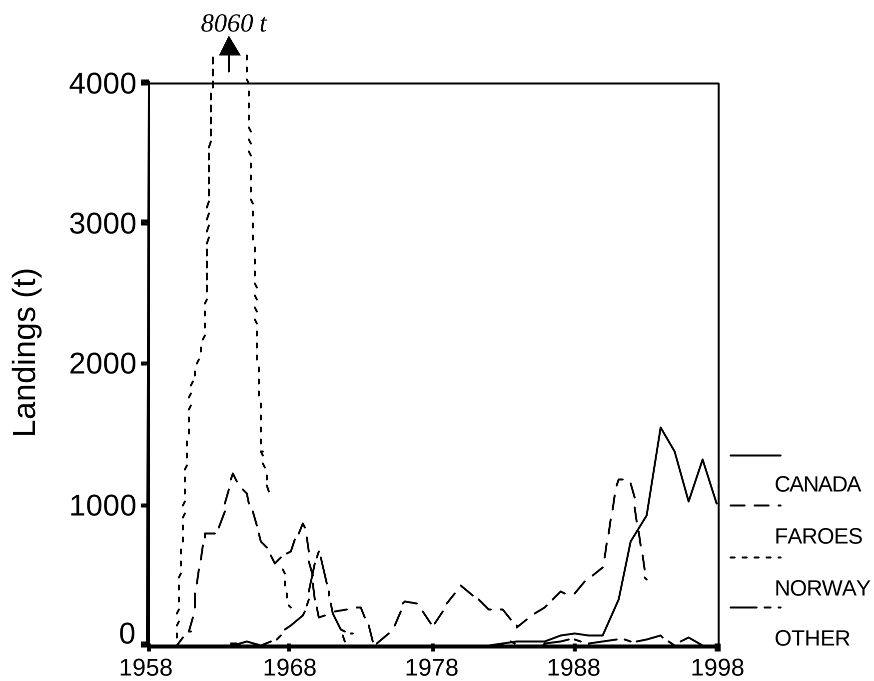


Fig 8. Canadian catches by the inshore (< 100') and offshore (> 100') fleet since 1991.

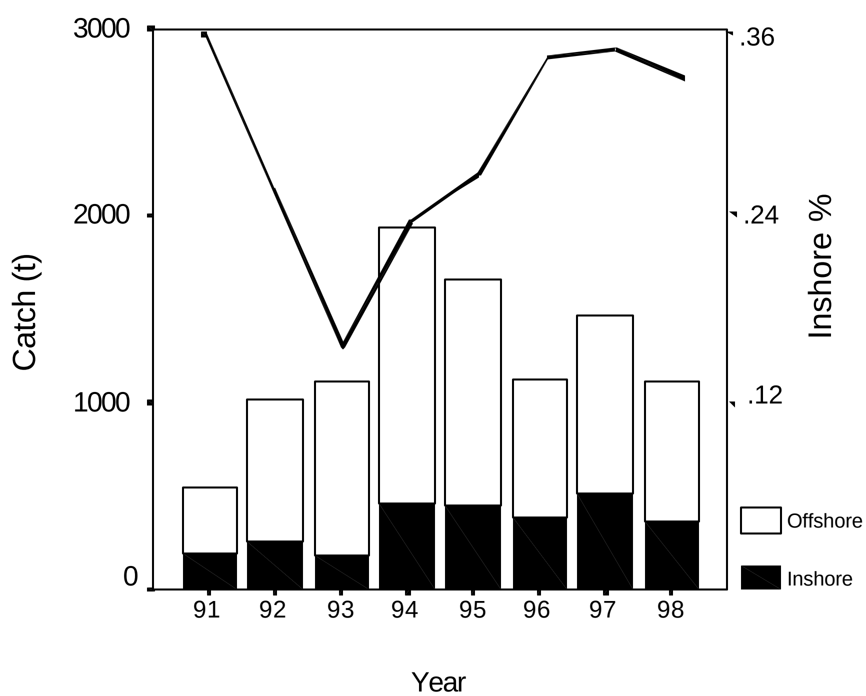


Fig. 9. Location and size composition of commercial porbeagle catches by the inshore (TC1-3) and offshore (TC 4-5) fleet in the spring of 1998.

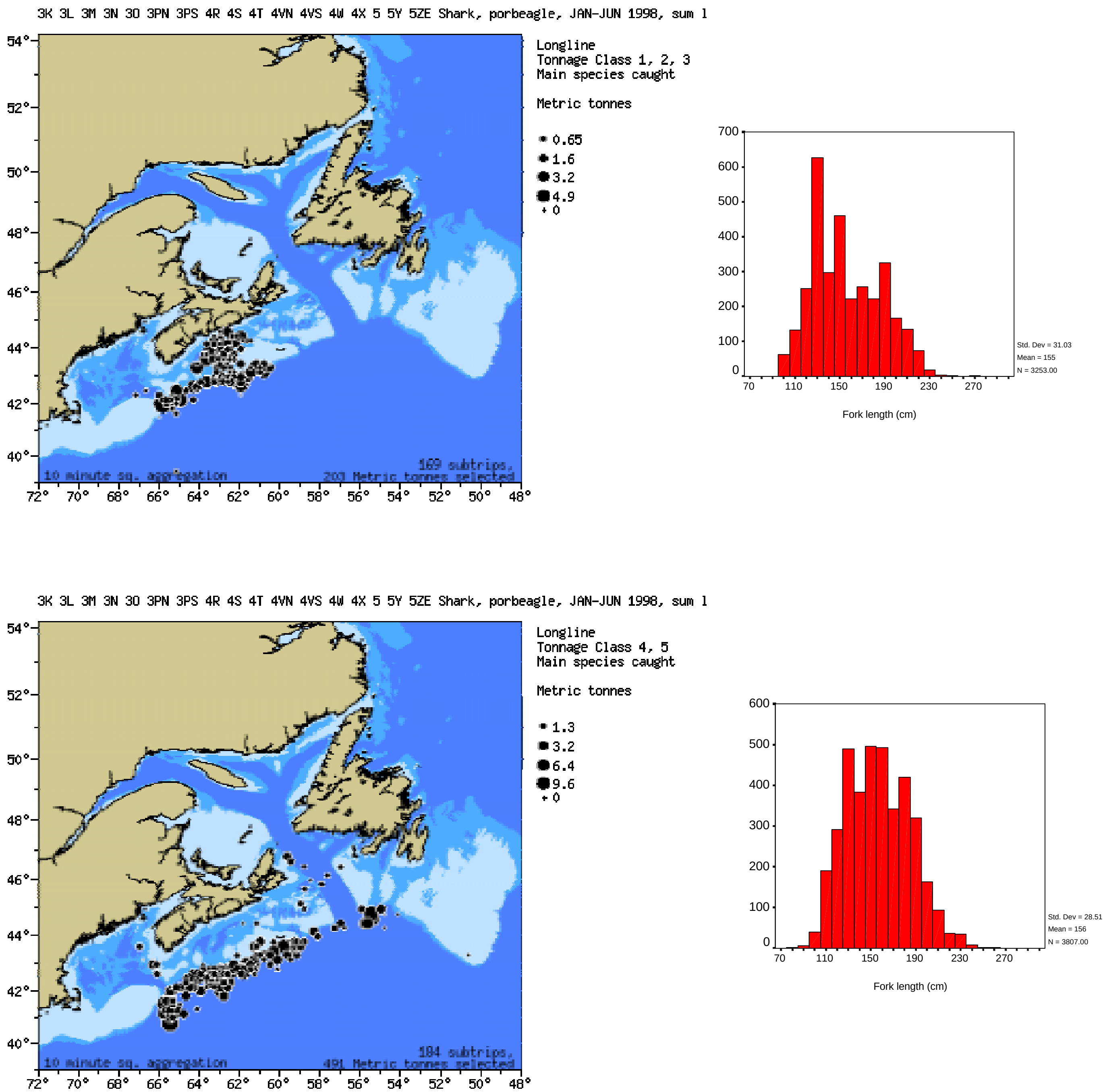


Fig. 10. Location and size composition of commercial porbeagle catches by the inshore (TC1-3) and offshore (TC 4-5) fleet in the fall of 1998.

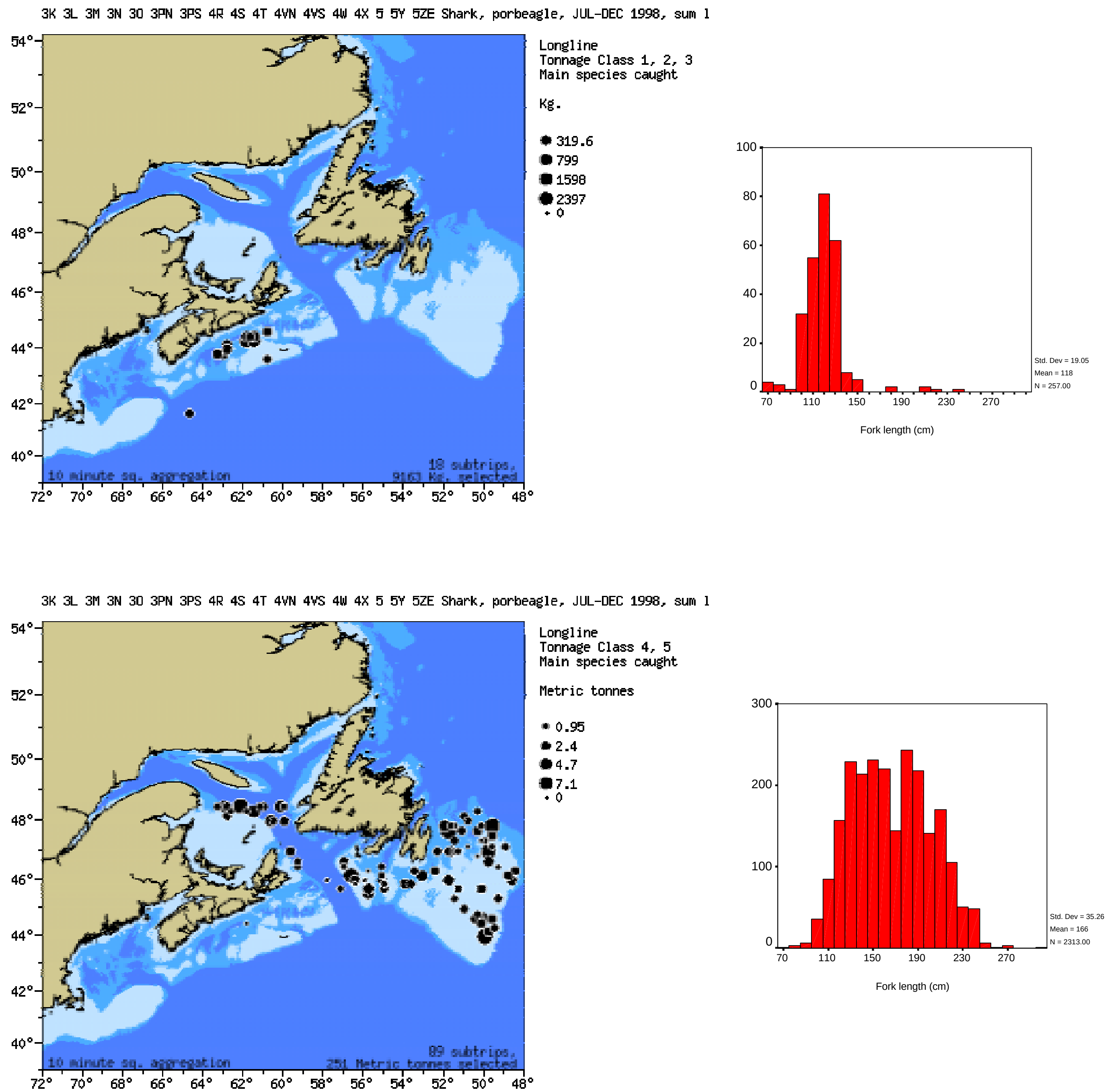


Fig. 11. Location and size composition of commercial porbeagle catches by the inshore (TC1-3) and offshore (TC 4-5) fleet in the spring of 1999.

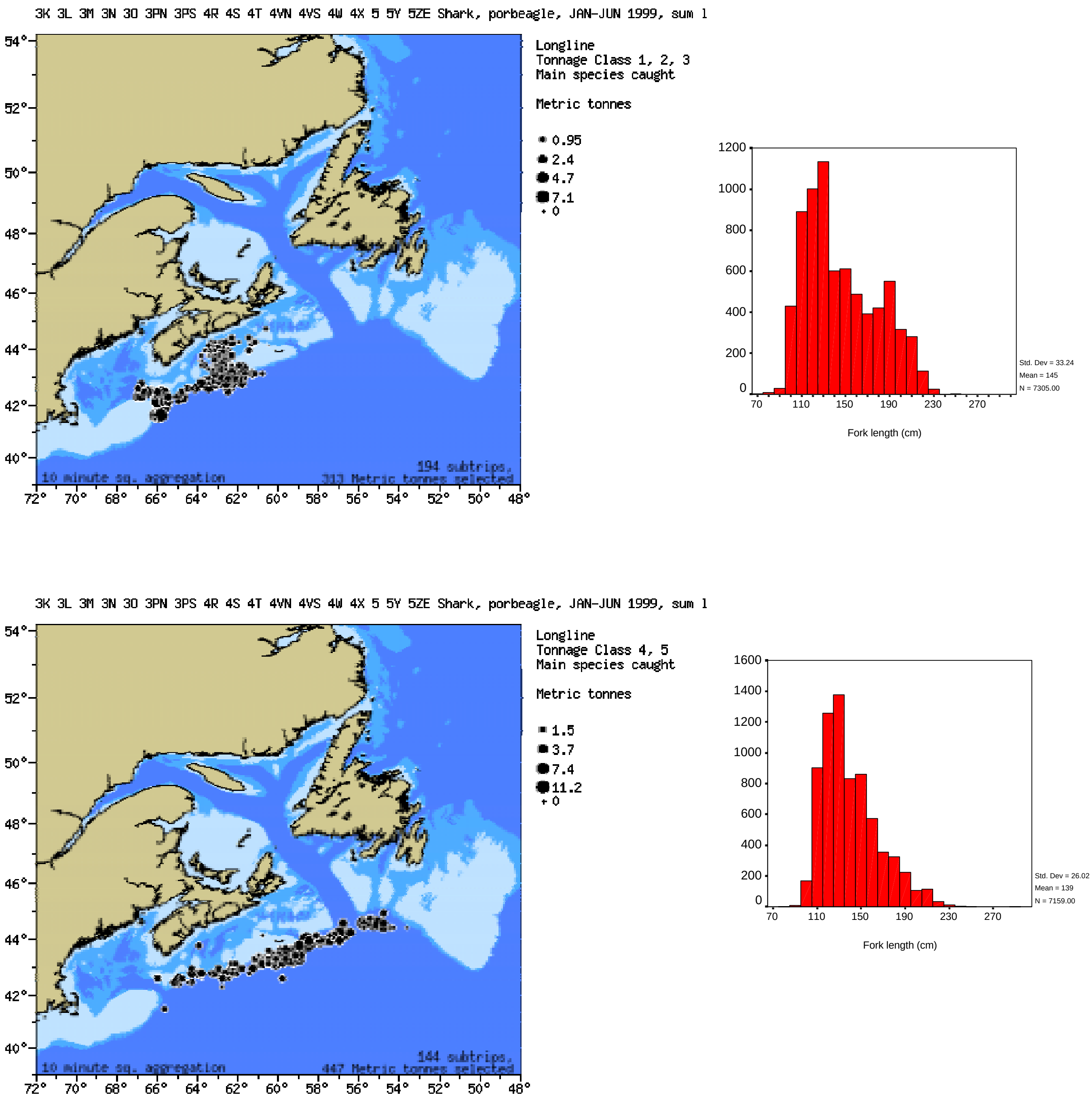


Fig. 12a. Comparison of length composition of 1998-99 Scotian Shelf catches by the inshore and offshore fleet.

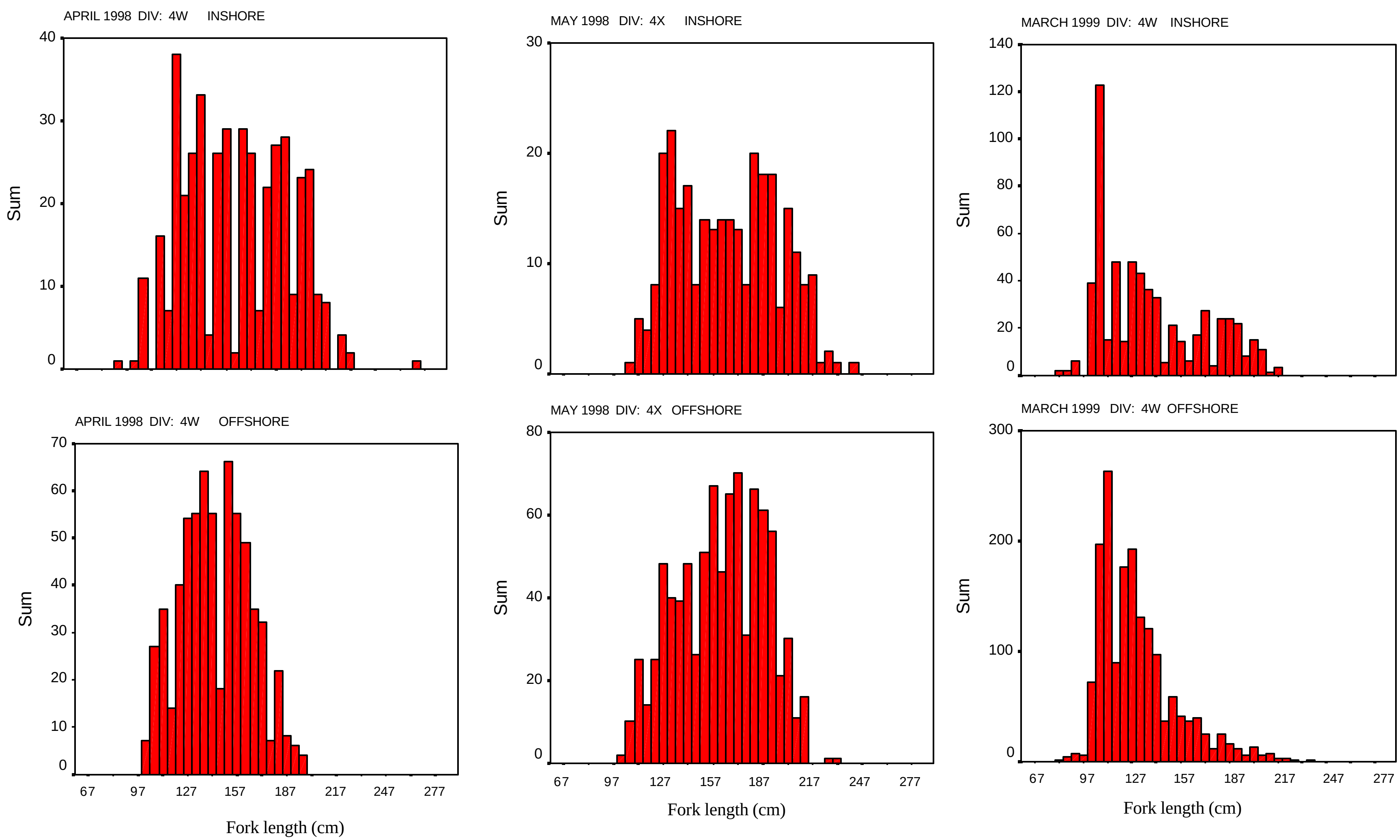


Fig. 12b. Comparison of length composition of 1998-99 Scotian Shelf catches by the inshore and offshore fleet.

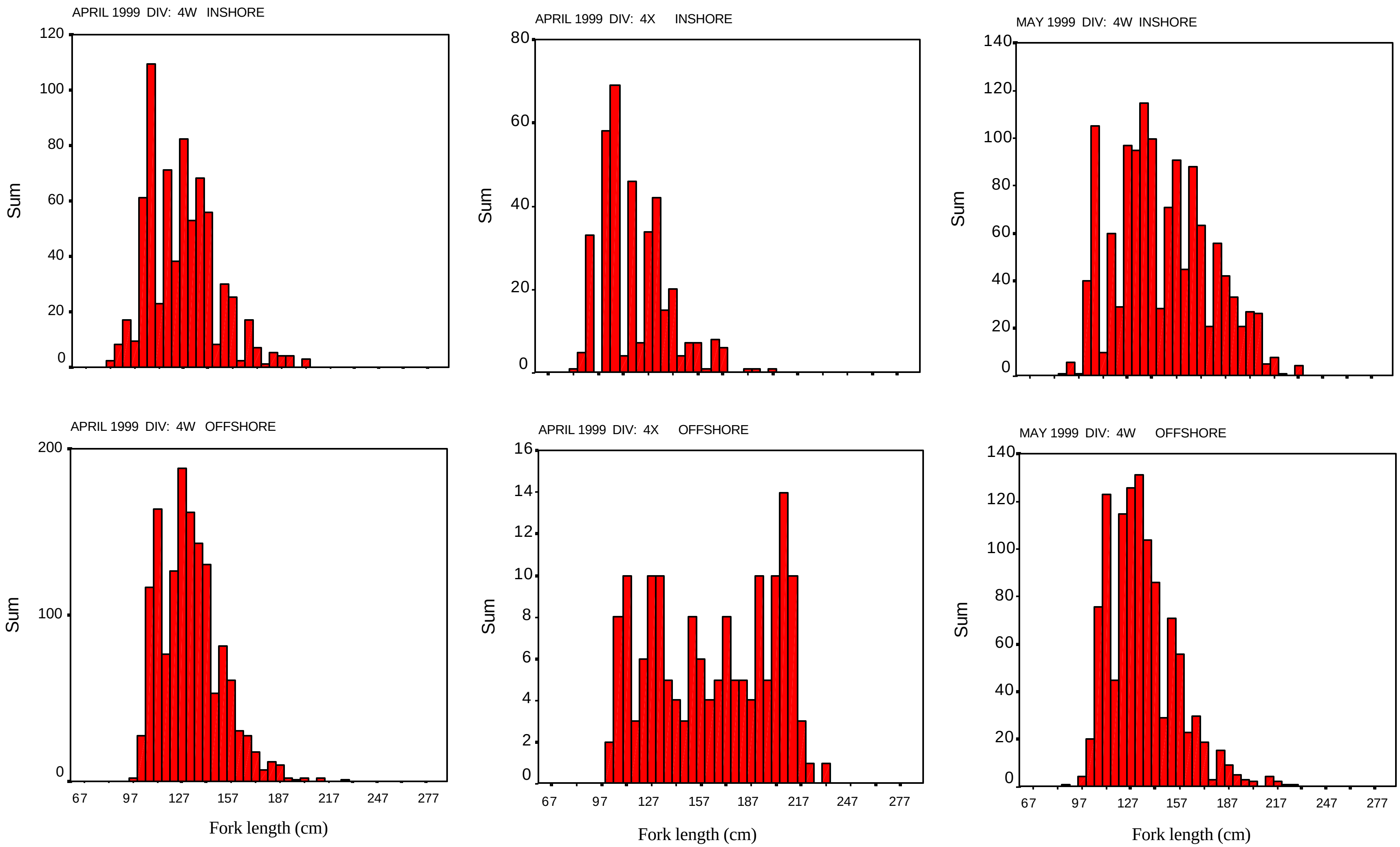


Fig. 13. Year to year trends in area-specific porbeagle length frequencies.

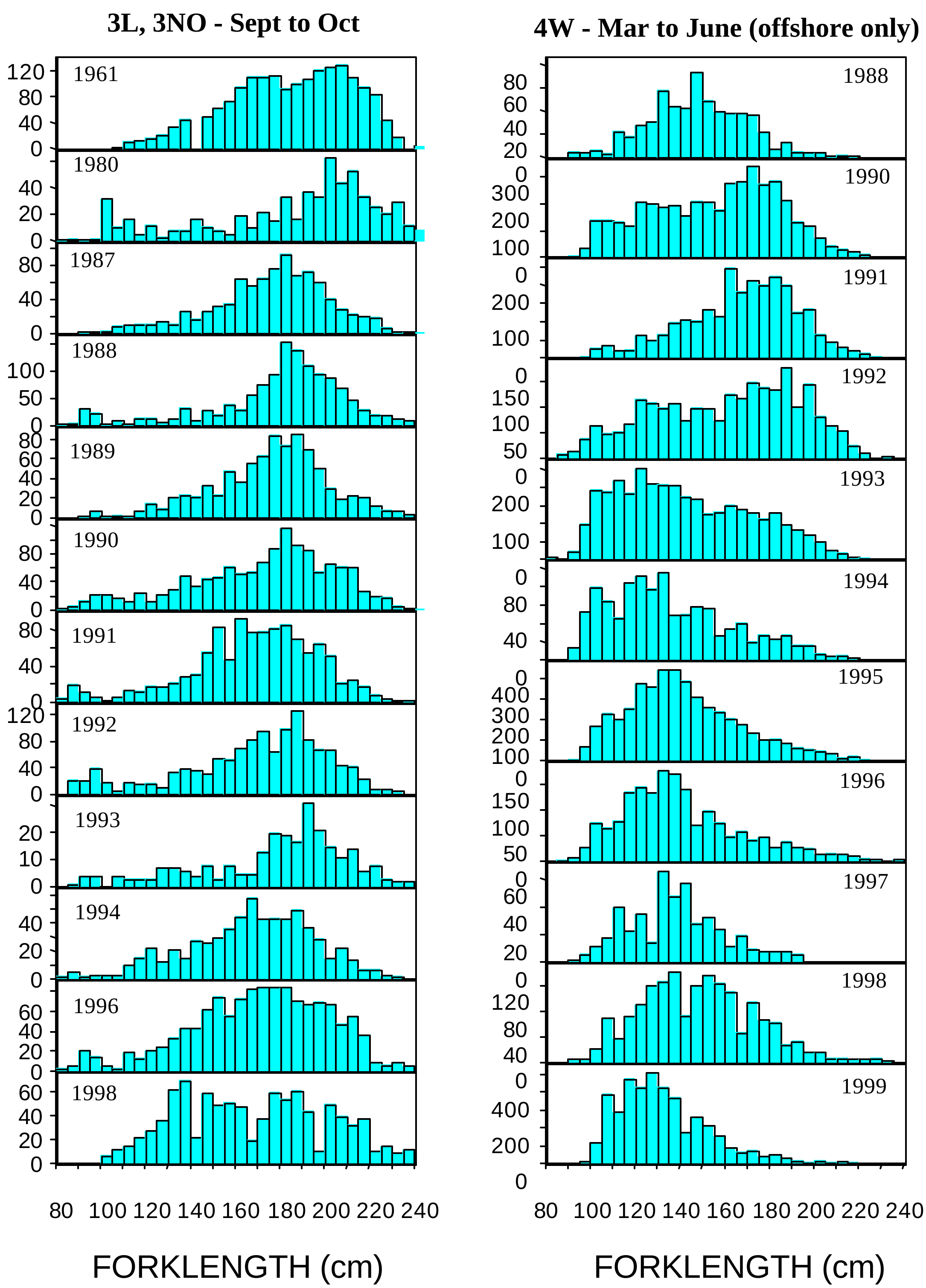
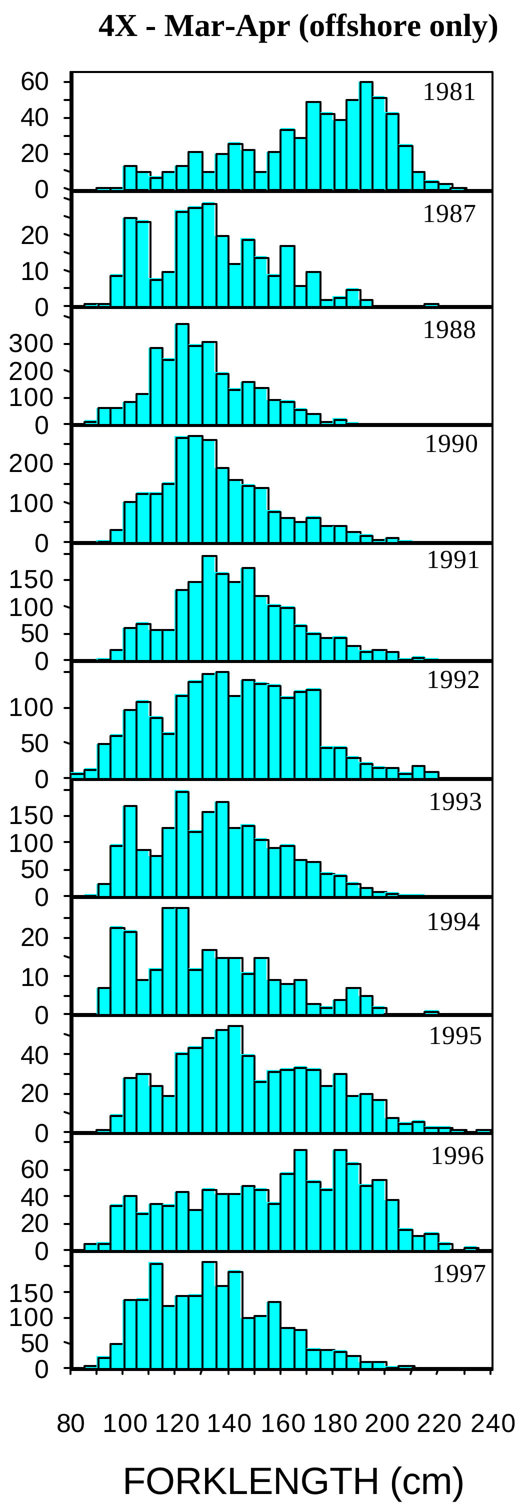


Fig. 13 - Cont'd



4X - Mar-Apr (offshore only)
1981
1987
1988
1990
1991
1992
1993
1994
1995
1996
1997
60
40
20
0
20
10
0
300
200
100
0
200
100
0
150
100
50
0
100
50
0
150
100
50
0
20
10
0
40
20
0
60
40
20
0
150
100
50
0
80 100 120 140 160 180 200 220 240
FORKLENGTH (cm)

Fig. 14. Long term changes in the median size of porbeagle in the commercial catch by the offshore fleet. Changes in the timing of the spring fishery probably explain some of the recent trends on the Scotian Shelf. However the decline in the abundance of the large sharks (3L, 3NO; early 1990s in 4W) appears to be biologically significant.

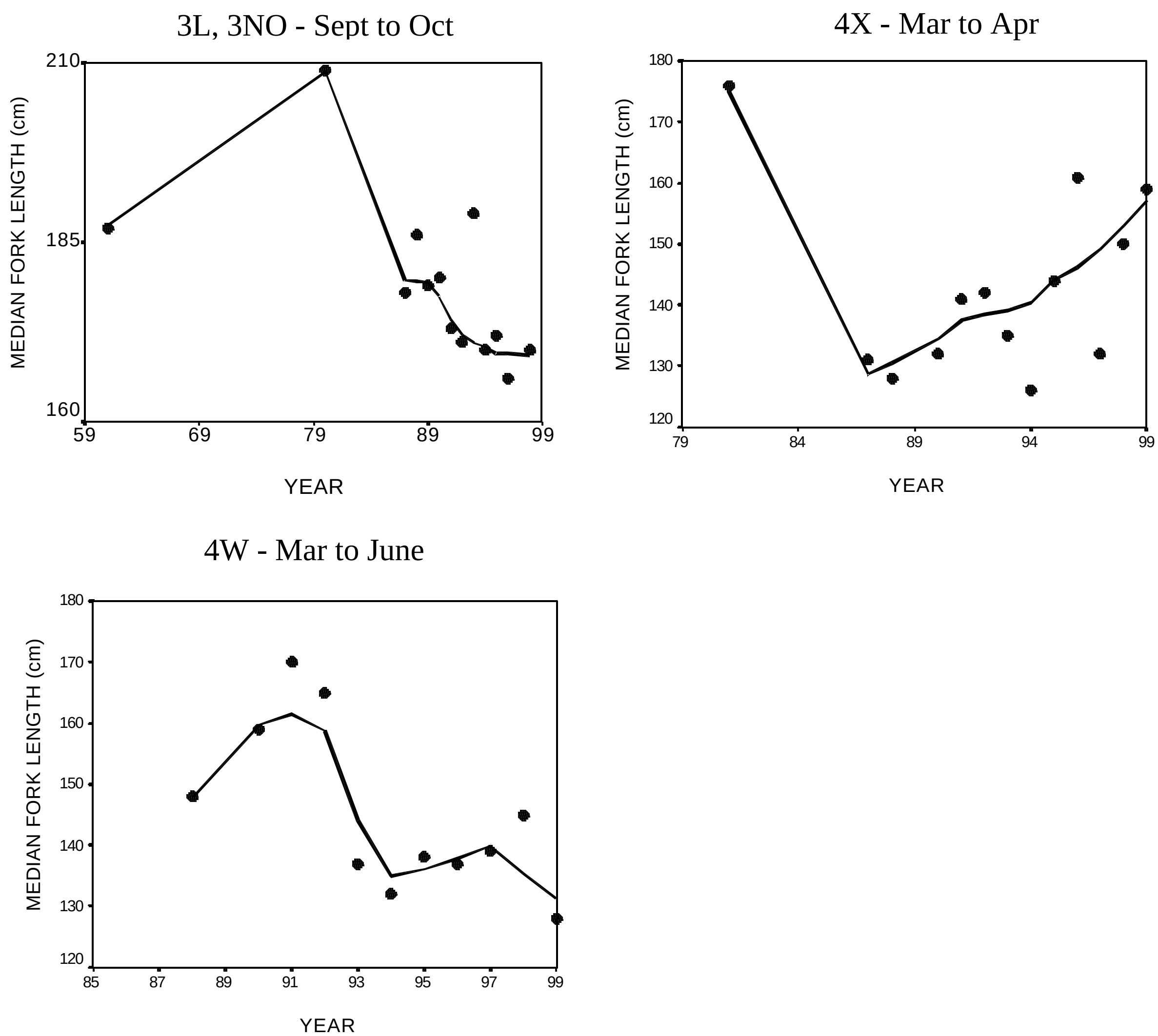


Fig. 15. Commercial catch rates of sexually mature porbeagle (ln-transformed number larger than 200 cm FL per hook) based on size composition and logbook records of two offshore vessels.

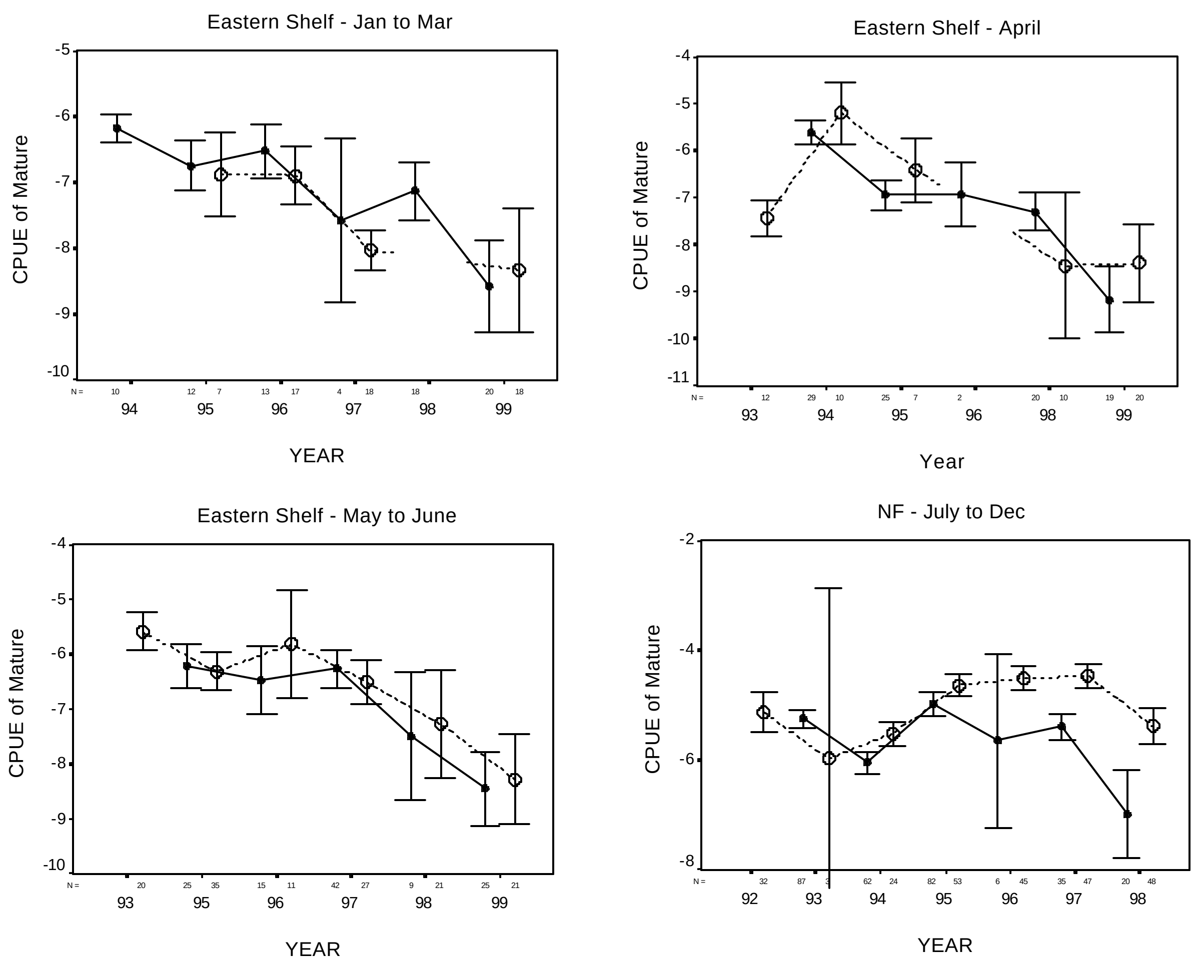


Fig. 16. Commercial catch rates (ln-transformed weight per hook) based on logbook records of two offshore vessels.

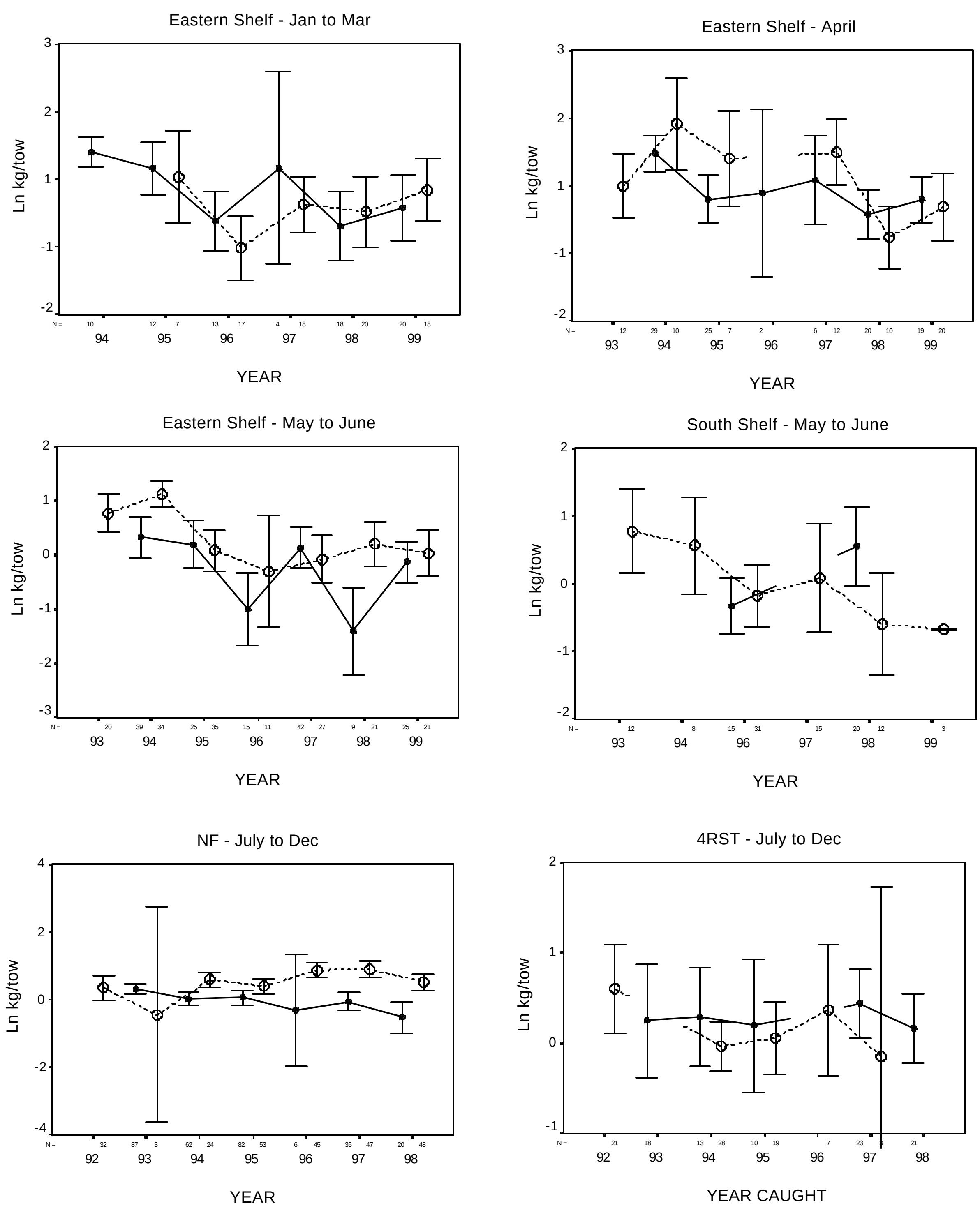


Fig. 17. Commercial catch rates of sexually mature porbeagle (ln-transformed number larger than 200 cm FL per hook) based on size composition and logbook records of inshore vessels. Differences among years are not statistically significant unless marked with *.

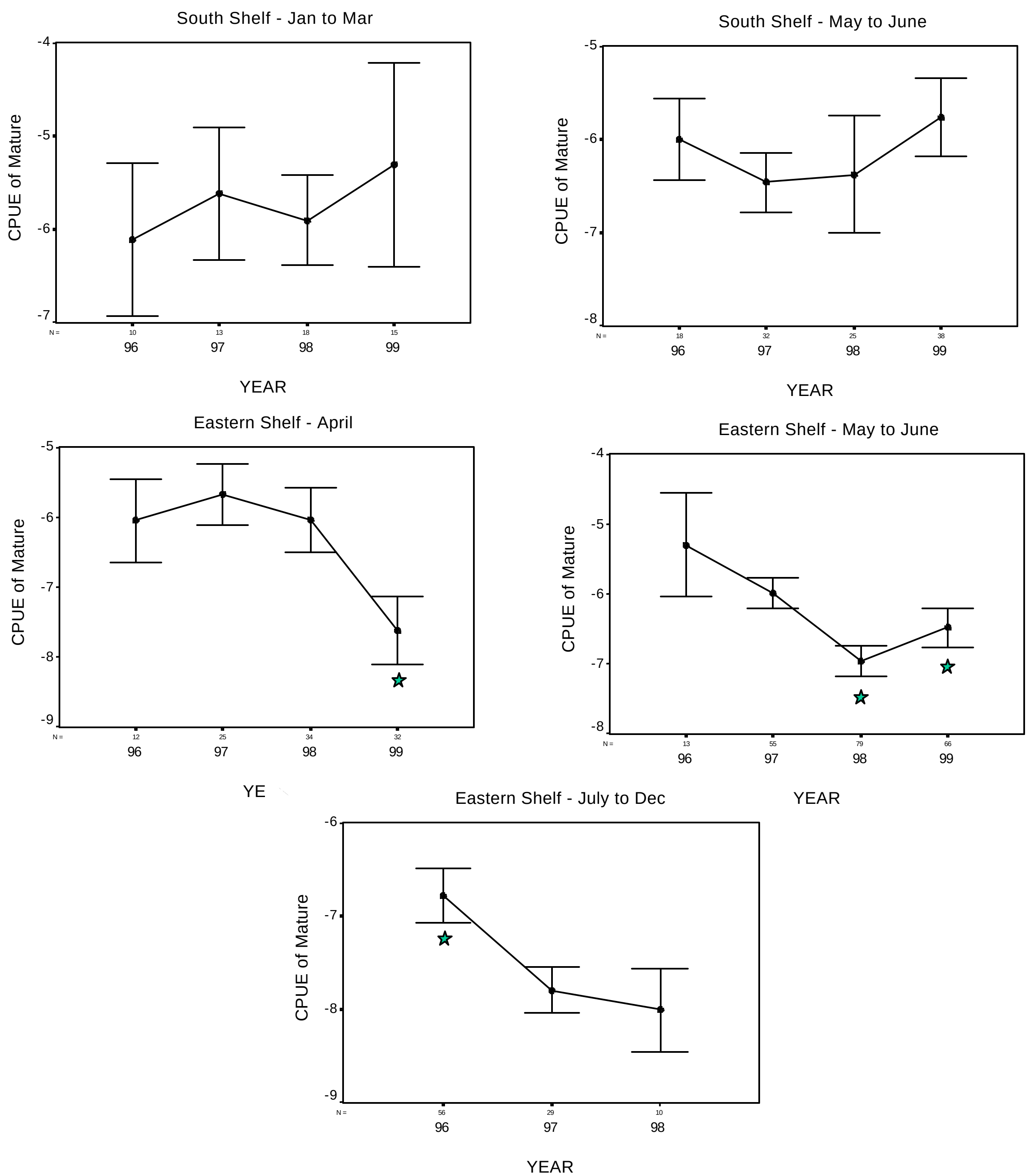


Fig. 18. Commercial catch rates (ln-transformed weight per hook) based on logbook records of inshore vessels. Differences among years are not statistically significant unless marked with *.

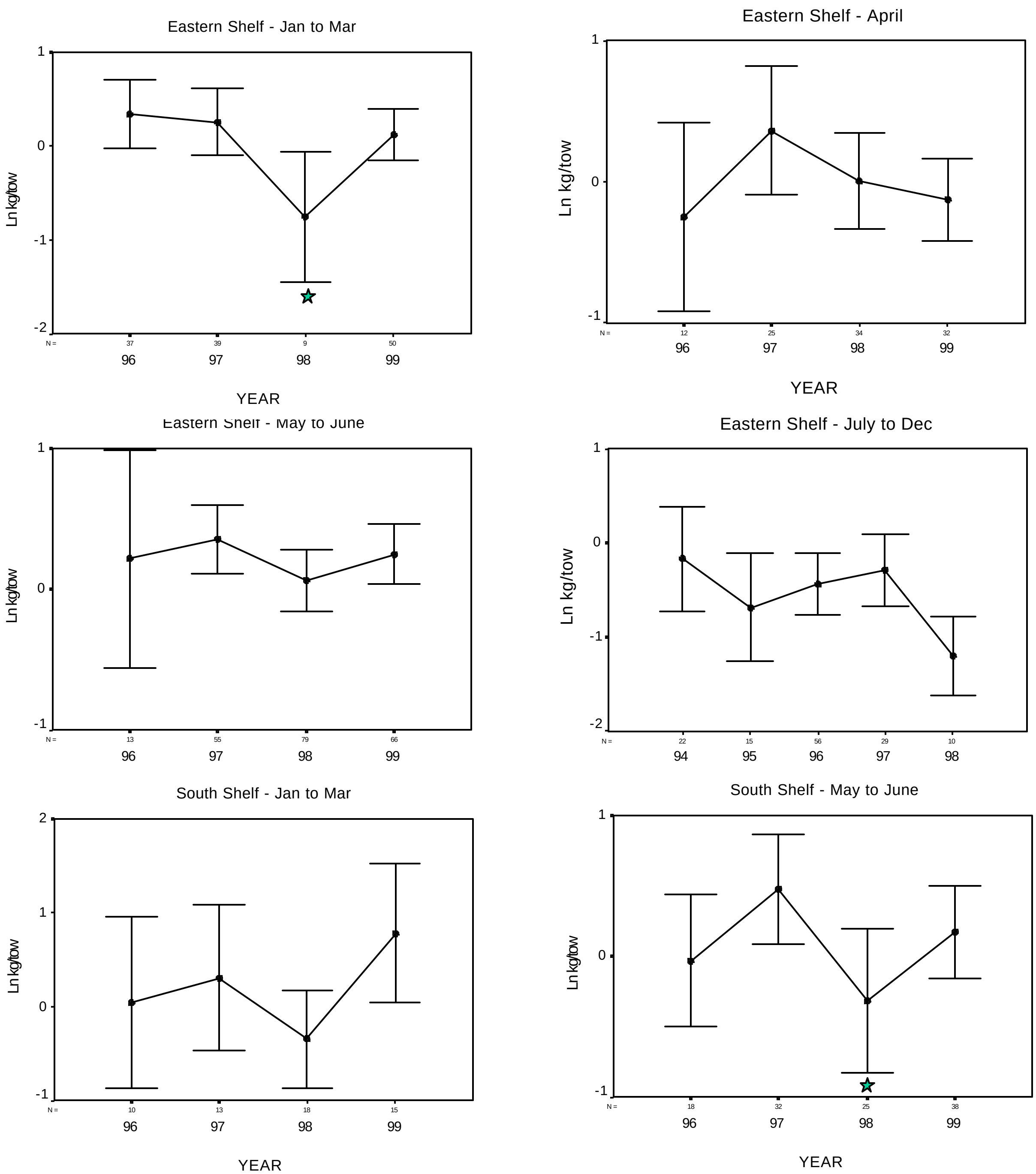


Fig. 19. Standardized catch rate (number/hook) of sexually mature porbeagle shark (> 200 cm FL). Factors in the catch rate analysis included year, month, area, CFV and data source.

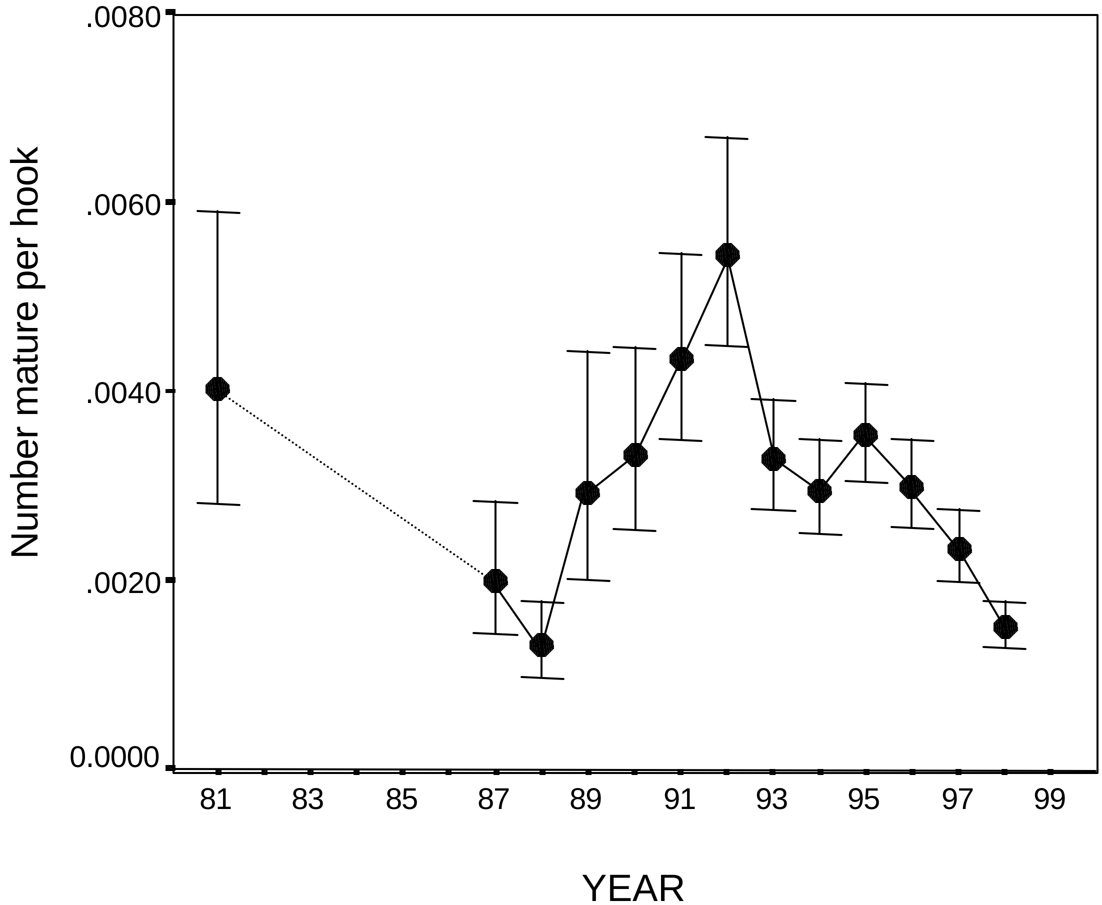


Fig. 20. Standardized catch rate (kg/hook) of porbeagle shark. Factors in the catch rate analysis included year, month, area, CFV and data source.

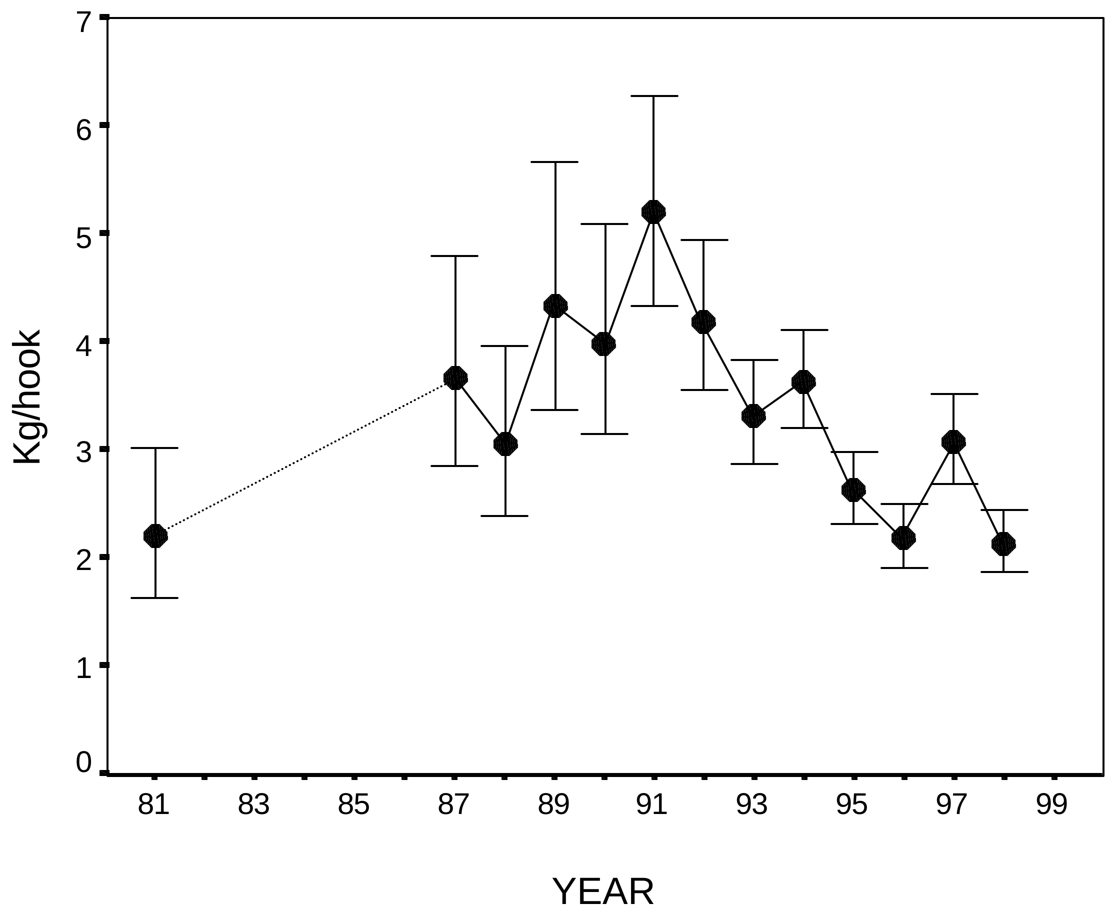


Fig. 21. Annual length frequencies for porbeagle over the entire stock area for those years where sampling was adequate. All lengths are in terms of fork length (cm). The 1961 sample is adapted from Aasen (1963).

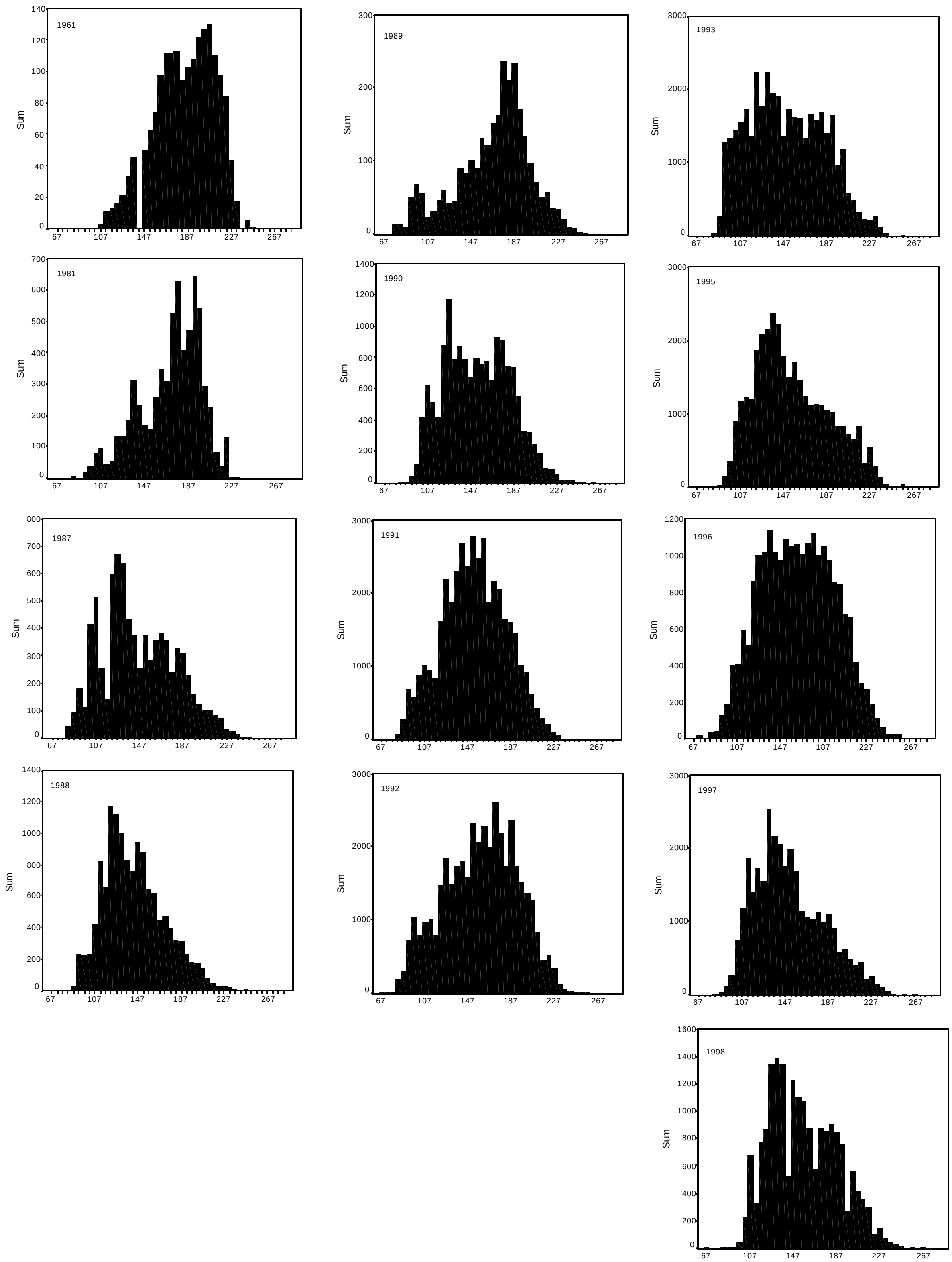


Fig. 22. Annual catch curves (ln-transformed numbers at age) based on cohort slicing and the growth curve presented in Fig. 6.

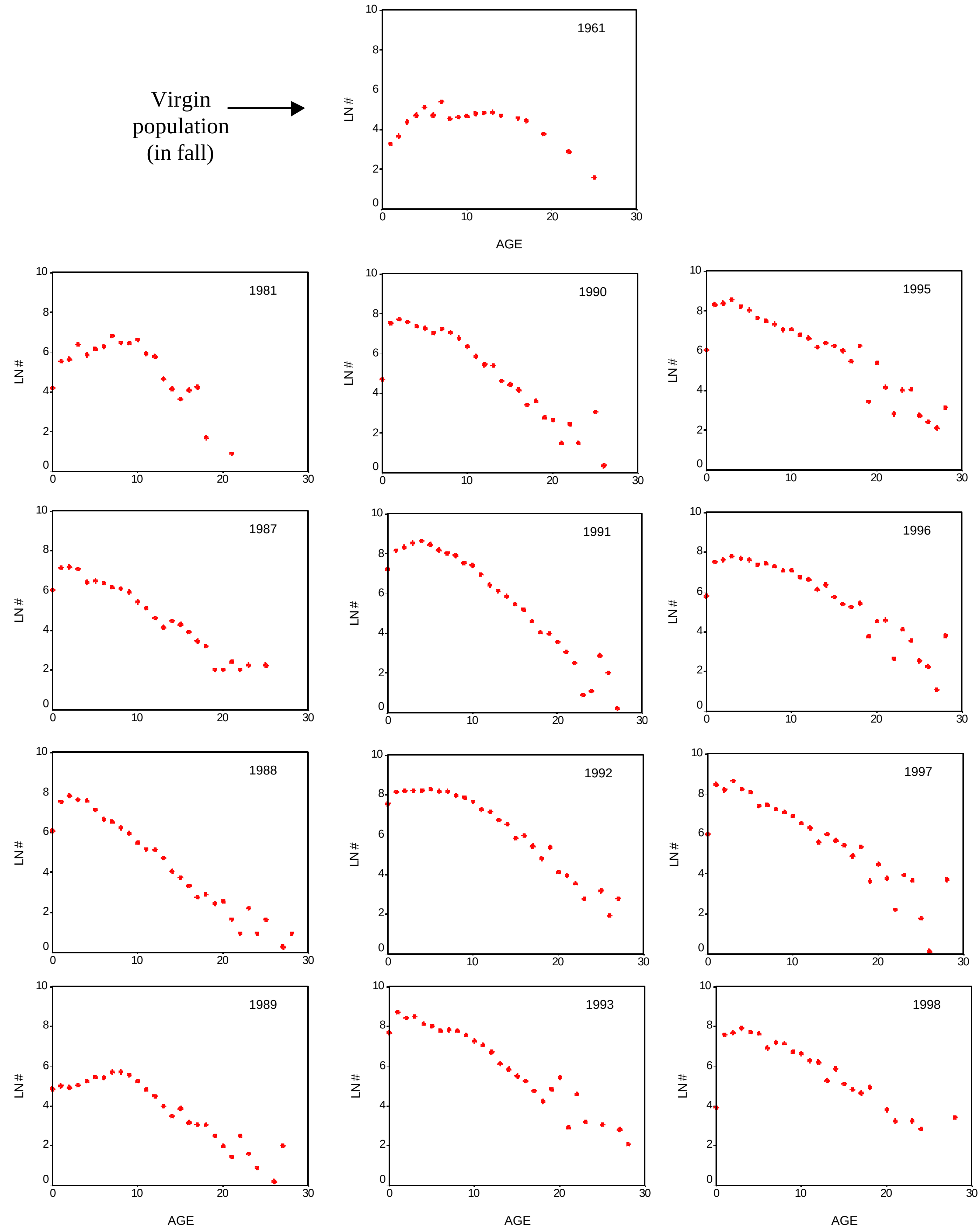


Fig. 23. Trends in total instantaneous mortality (Z) based on annual catch curves. The fitted line is a LOESS curve. FR=fully recruited.

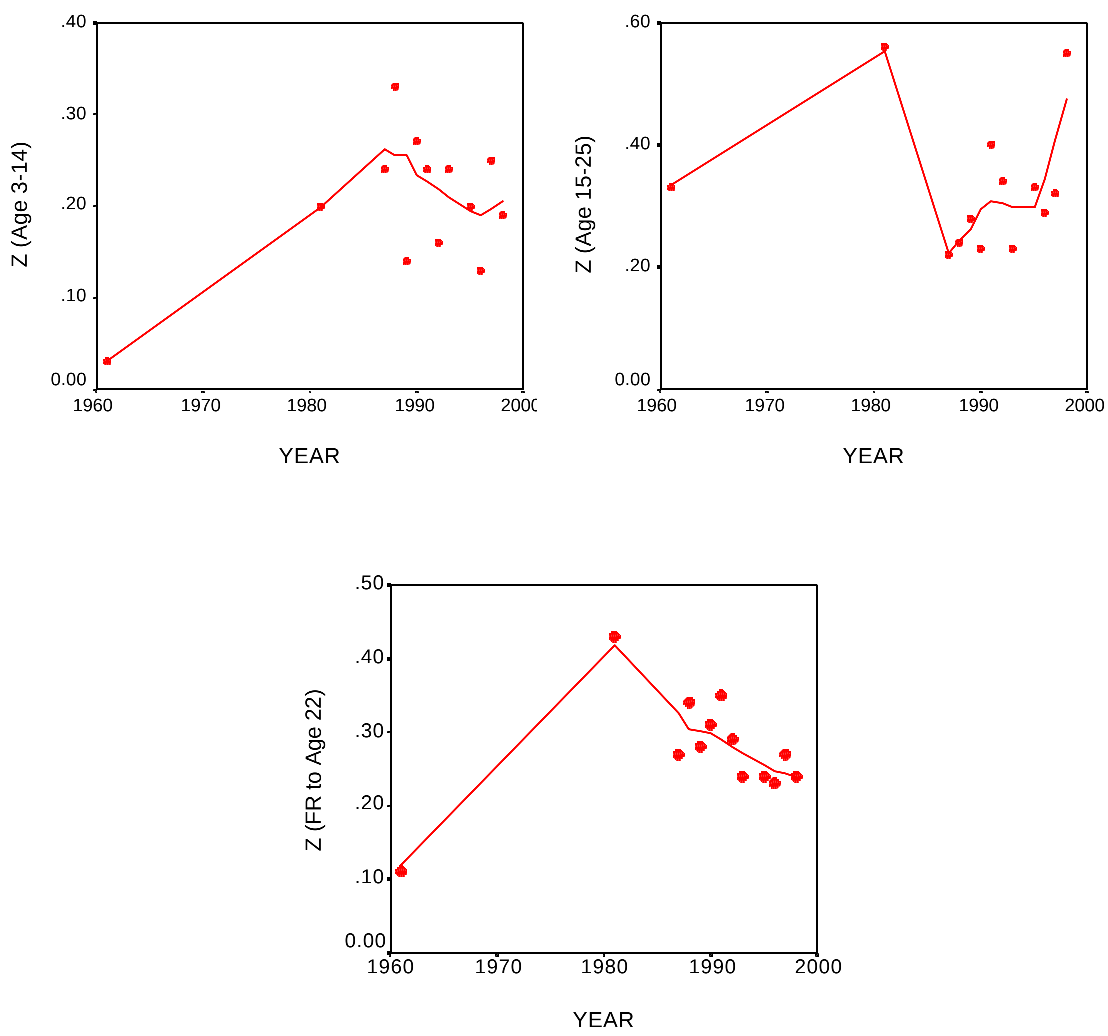


Fig. 24. Catch curves (ln-transformed numbers at age) in the fall (July-Dec) based on cohort slicing and the growth curve presented in Fig. 6.

Virgin population

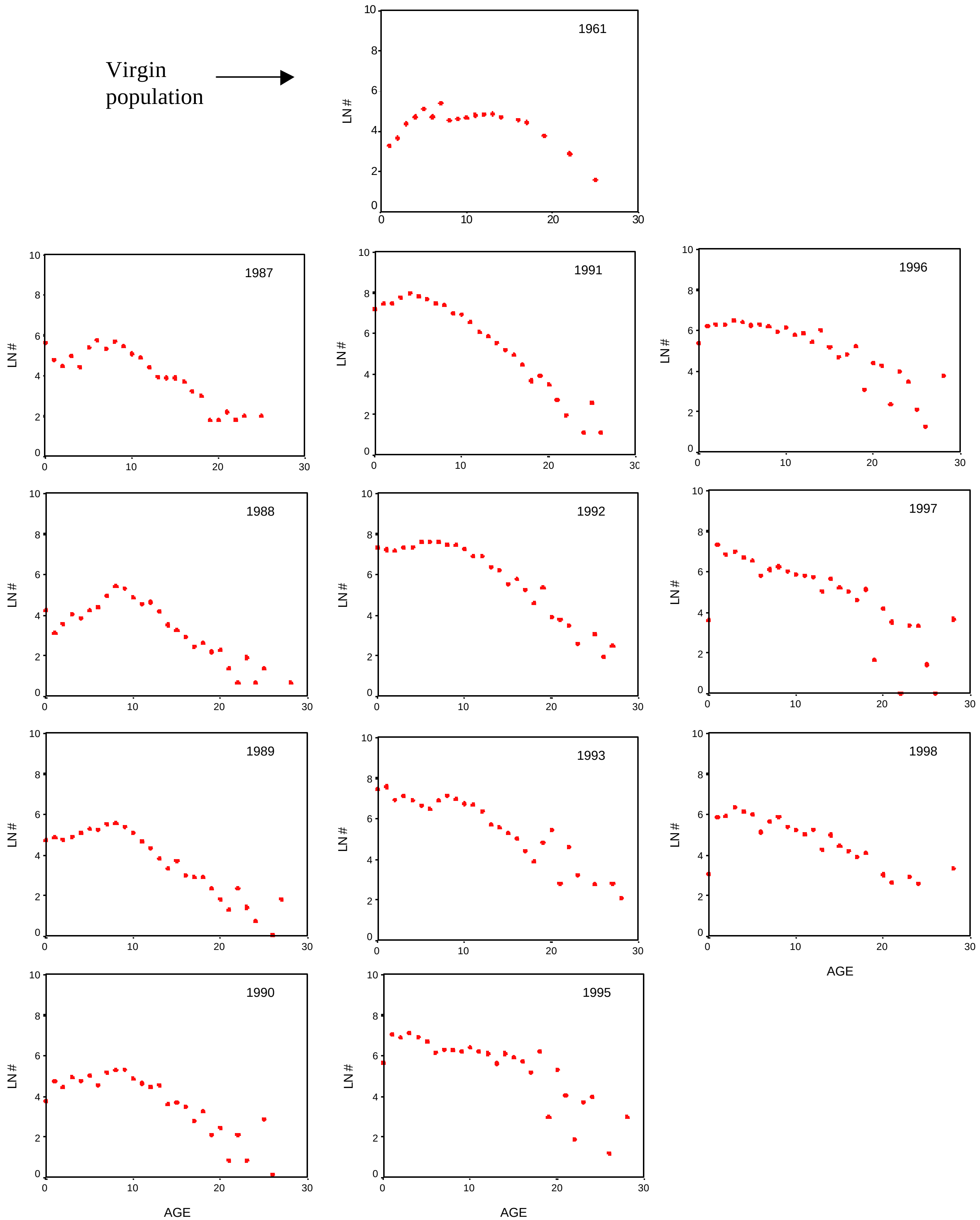


Fig. 25. Trends in total instantaneous mortality (Z) based on July-Dec catch curves. The fitted line is a LOESS curve. FR=fully recruited.

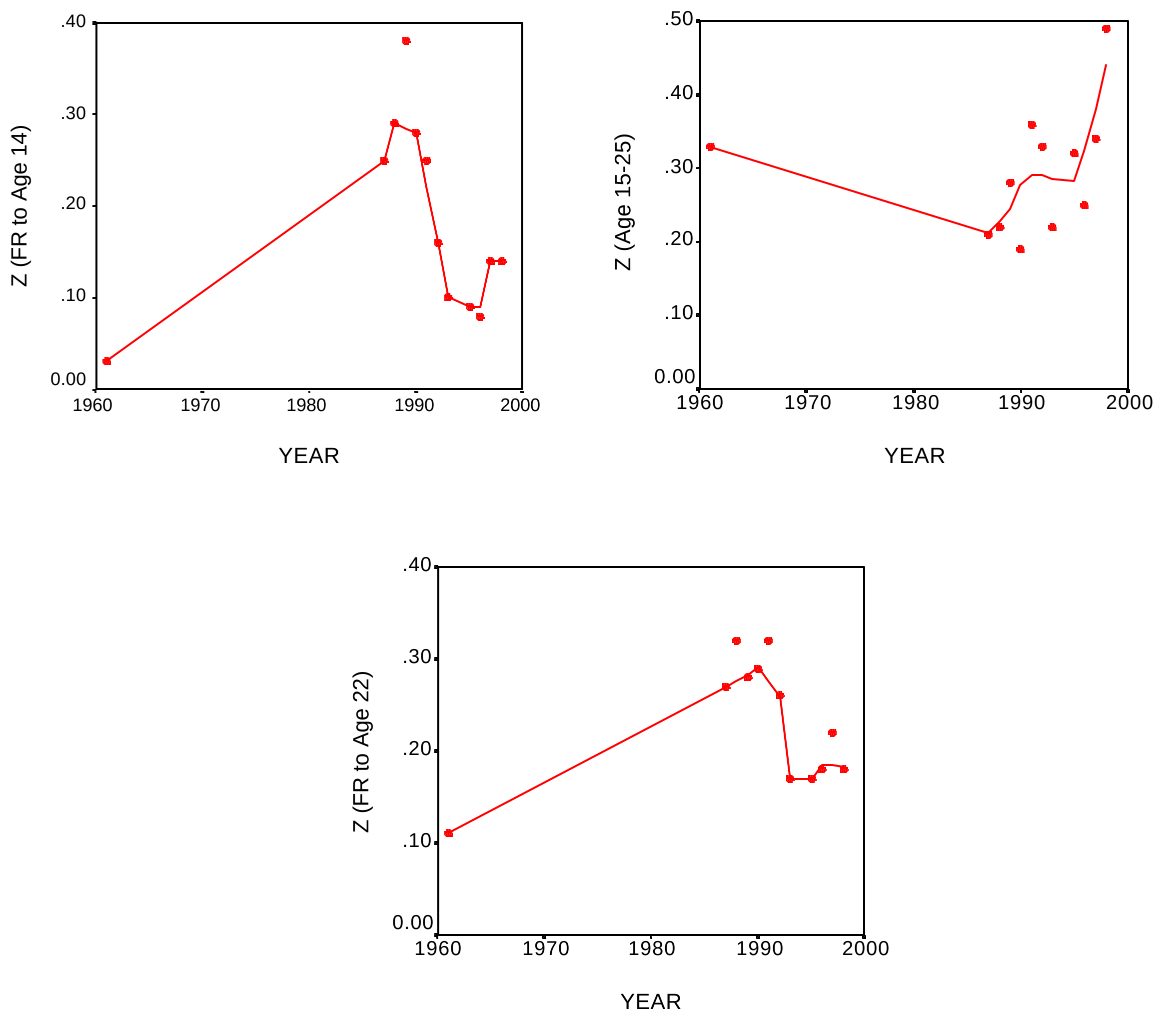


Fig. 26. Estimates of population biomass (mt) and exploitation rate based on Peterson analysis of tag recaptures from Canadian, American and Norwegian tagging studies. The basis for the analysis is shown in Table 9. Only years with more than 4 recaptures from a given tagging year are shown.

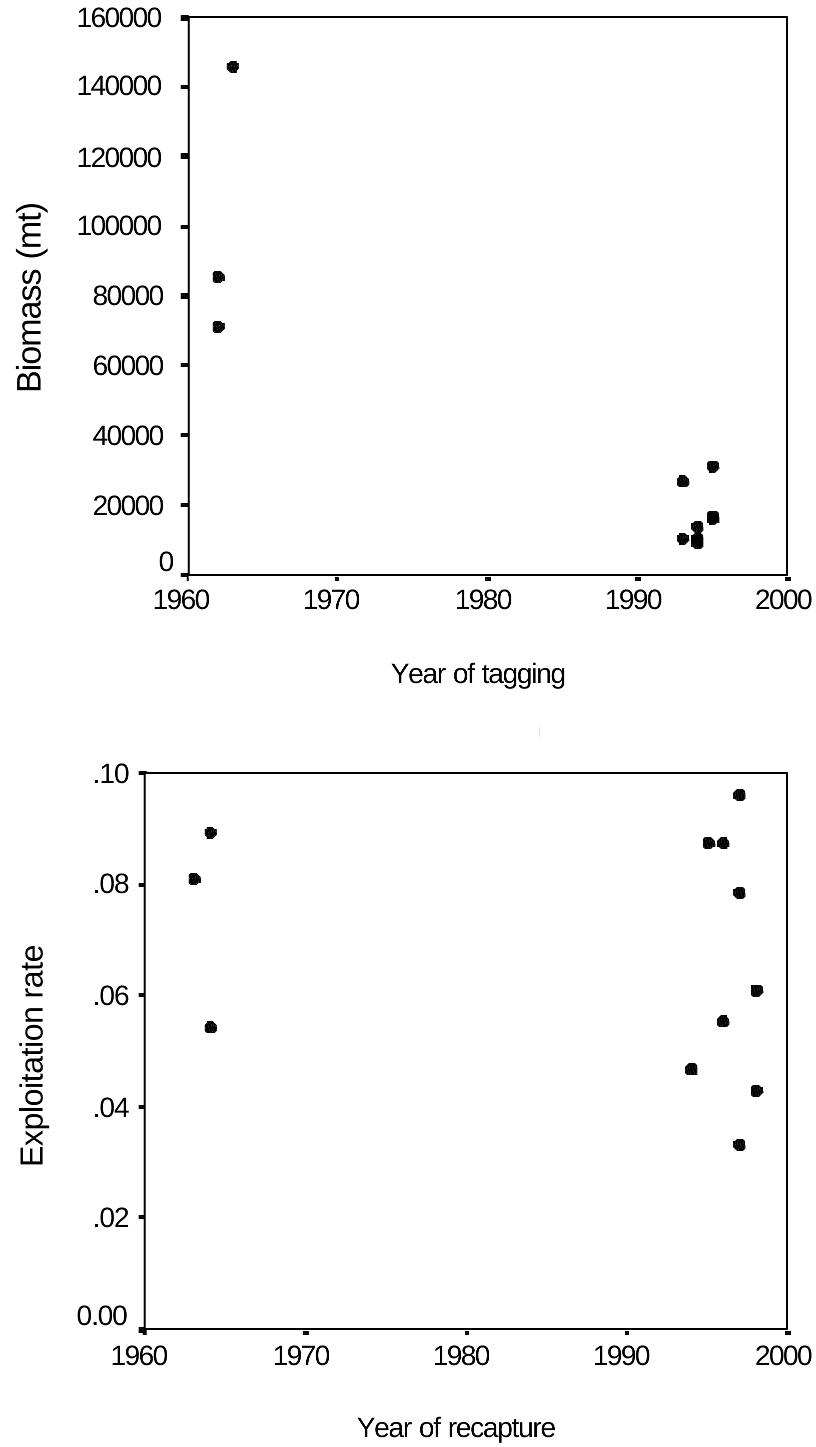


Fig. 27. Mean observed weight of porbeagle in the catch compared to that expected of fishing at $F_{0.1}$ and F_{max}.

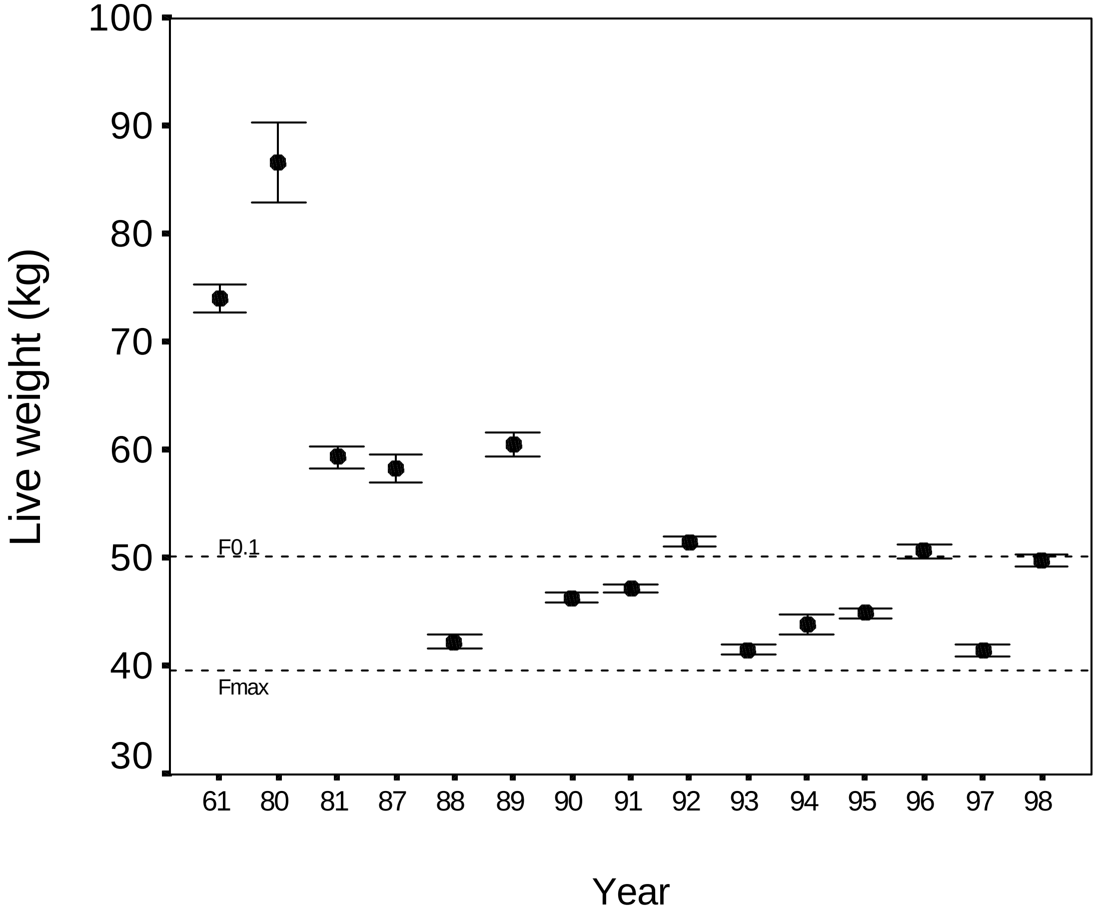


Fig. 28. Summary of recent fishing mortality estimates (F) derived from independent analyses. All estimates are drawn from analysis of the years 1996 to 1998 inclusive (1995-1998 in the case of the tagging), during which catches and fishing effort have been relatively constant.