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Analytical Assessment of the Porbeagle Shark (*Lamna nasus*) Population in the Northwest Atlantic, with Estimates of Long-term Sustainable Yield

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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, and the population slowly recovered.. Catches of 1000-2000t throughout the 1990s appear to have once again reduced population abundance, resulting in very low catch rates and disturbingly low numbers of mature females. 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. Research to date has led to the development of a confirmed growth model, established the presence of a single stock in the NW Atlantic, suggested size- and sex-specific migration patterns, determined fecundity and maturity ogives by length and age, revealed highly specific temperature and depth associations, determined diet, and resulted in credible estimates for natural mortality rate (=0.10) which increase after sexual maturity (to 0.2 in females). The TAC of 850t introduced in 1999, based on scientific information available to that point, resulted in preliminary estimates of $F_{0.1}$ yield, mortality and stock abundance. Nevertheless, it was acknowledged at the time that the $F_{0.1}$ yield was probably not sustainable. The current assessment confirms the unsustainability of fishing at $F_{0.1}$ for porbeagle, and indicates that a fishing mortality above 0.08 will cause the population to decline. A fishing mortality of 0.04-0.05 is required if the population is to be allowed to recover. Independent estimates of recent fishing mortality based on Petersen analysis of tag recaptures, Paloheimo Zs, and an age- and sex-structured population model all suggest that F is now about 0.20. A standardized catch rate analysis indicated that the relative abundance of young porbeagle in 2000 was 30% of its 1991 level, while the standardized catch rate of mature porbeagle declined to 10% of its 1992 level. Current population size appears to be at 10-20% of virgin levels. The 850t TAC of the past two years is close to the MSY of a healthy population. However, the current population is seriously depleted and will require a greatly reduced fishing mortality if recovery is to occur.

Résumé

Au début des années 60, une population vierge de requin-taupe commun de l'Atlantique nord-ouest a été exploitée intensivement à des niveaux de prises d'environ 4 500 t par année jusqu'à ce que la pêche s'effondre 6 ans plus tard. Dans les années 70 et 80, la pêche semblait viable, les débarquements annuels se chiffrant en moyenne à 350 t, ce qui a permis à la population de se rétablir lentement. Des prises se situant entre 1 000 et 2 000 t tout au long des années 90 semblent à nouveau avoir réduit l'abondance de cette population, résultant en de très faibles taux de capture et un faible nombre inquiétant de femelles adultes. En 1998, un programme de recherche intensive sur le requin-taupe commun a été mis en œuvre avec l'appui et le financement de l'industrie de la pêche du requin et en collaboration avec le Apex Predator Program du NMFS. Les recherches réalisées jusqu'à maintenant ont permis d'élaborer un modèle confirmé de la croissance de l'espèce, ainsi que d'établir le régime alimentaire et des ogives de la fécondité et de la maturité selon la longueur et l'âge. En plus de révéler l'existence d'un seul stock dans l'Atlantique nord-ouest et des régimes de migration différents selon la taille et le sexe, elles ont permis d'établir la présence de l'espèce à des températures et des profondeurs très précises. Elles ont en outre donné des estimations plausibles du taux de mortalité naturelle (= 0,10), qui augmente après la maturité sexuelle (à 0,2 chez les femelles). Le TAC de 850 t introduit en 1999, basé sur les données scientifiques disponibles à ce moment-là, a donné des estimations préliminaires du rendement à F0,1, de la mortalité et de l'abondance. On a toutefois reconnu, lorsque ce TAC a été fixé, que le rendement à F0,1 n'était probablement pas durable. La présente évaluation confirme la non viabilité de la pêche du requin-taupe commun à F0,1 et établit qu'une mortalité par pêche supérieure à 0,08 mènera au déclin de la population. La mortalité par pêche doit se situer entre 0,04 et 0,05 si l'on veut que la population se rétablisse. Des estimations indépendantes des récents taux de mortalité par pêche basées sur une analyse Petersen des étiquettes récupérées, la méthode de Paloheimo et un modèle de population structuré par âge et par sexe suggèrent que F se situe à environ 0,20 en ce moment. Une analyse normalisée des taux de capture indique que l'abondance relative de jeunes requins-taupes communs en 2000 se chiffrait à 30 % du niveau en 1991, tandis que le taux de capture normalisé d'adultes a chuté à 10 % du niveau en 1992. La taille actuelle de la population semble se situer entre 10 et 20 % des niveaux de la population vierge. Le TAC de 850 t fixé pour les deux dernières années se rapproche du RMS d'une population en bonne santé. La population actuelle étant toutefois très appauvrie, son rétablissement nécessitera une forte réduction du taux de mortalité par pêche.

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 biology and population dynamics (Campana et al. 2001; Jensen et al. 2001; Natanson et al. 2001), and led to the first analytical stock assessment of porbeagle (Campana et al. 1999). Based on that assessment, the Shark Management Plan for 2000-2001 set a TAC of 850t, with the intention of reviewing stock status again in the spring of 2001 once the research program had collected more information.

Intensive cooperative research since the time of the last assessment has continued to improve our understanding of porbeagle stock dynamics, making possible a more refined and accurate review of stock status. Included in this report are new results pertaining to porbeagle life history, migration patterns, growth rate, longevity, reproduction, temperature preferences, diet, stock abundance and mortality rates. The assessment concludes with estimates of recent fishing mortality rate and long-term sustainable yield, as well as biological options for the next Shark Management Plan. Some of the steps required to ensure the sustainability of the fishery are also identified.

Population Biology

Stock Structure

Evidence presented at the last porbeagle stock assessment indicates 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 (Campana et al. 1999). 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. 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 (areas are shown in Fig. 1). Catches in the late fall suggest a return movement to the southwest. This pattern is reproduceable from year to year. The results of tagging studies carried out by Norway, Canada and the US also document extensive annual migrations (Campana et al. 1999). 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.

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, dockside monitors have sometimes used dressed carcass weight, and the fishing industry uses inter-dorsal length. Altogether, more than 142,000 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. These conversion factors were developed through matched measurements made by scientific staff as part of the porbeagle research program, and as presented in Campana et al. (1999).

At the time of the last assessment, an accurate conversion factor relating Aasen's nonstandard measure of total length to curved fork length (the standard measure) was not available. This has since been developed and was used to convert Aasen's total length to curved fork length. The equation is:

$$FL = 3.64 + 0.95 * AasenTL \quad r^2=0.99$$

where FL and AasenTL are in cm.

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. Campana et al. (1999) presented a preliminary growth model for porbeagle based on counts of growth bands visible in vertebral cross-sections. A total of 576 porbeagle have now been aged and validated to an age of at least 11 years (Natanson et al. 2001). The revised growth model is not substantially different than what was first presented, but shows more detail and the first evidence of sexually dimorphic growth in this species (Fig. 2). In both sexes, growth rate appears to decrease slightly at the onset of sexual maturity. Since females mature at an older age than do males, females grow to a larger size. Fig. 2 presents the von

Bertalanffy growth parameters by sex, as well as that of the combined sexes. Predicted lengths and weights at each age are also shown, although observed sizes at age 0 and 1 were used to to minimize distortions due to seasonality and partial recruitment of the young fish to the fishery.

It is possible that the ages of very old porbeagle (>15 yr) are underestimated by vertebral band counts. If true, the growth rate of old porbeagle is somewhat slower than that suggested by the von Bertalanffy growth parameters. The fact that the L_{inf} of the females is considerably larger than the largest porbeagles normally observed suggests that growth overestimation of the oldest fish (and only the oldest fish) is a possibility. For this reason, the combined growth curve has been used in most analyses.

The maximum age observed in our collection of 576 porbeagles was 25 yr. 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 40 years. Assuming a constant instantaneous rate of mortality (M) = 0.1, 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. Based on preliminary results suggesting an increase in female natural mortality rate (to 0.20) at the age of sexual maturity, longevity would be estimated at 29 yr.

Porbeagle Reproduction

Porbeagles are ovoviviparous and oophagous, 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). Based on examination of 393 males and 382 females (Jensen et al. 2001), we have found that males mature between 160 - 190 cm in fork length (L_{50} ~ 174 cm; A_{50} ~ Age 8) while females mature between 205 - 230 cm (L_{50} ~ 217 cm; A_{50} ~ Age 13) (Fig. 3). Mean litter size in the NW Atlantic is 3.9 pups.

Until recently, the mating grounds of porbeagle were unknown, although there have been suggestions that mating occurred on the Grand Banks (O'Boyle et al. 1998) or more broadly off southern NF (Campana et al. 1999). Our most recent research indicates that mating occurs in the late summer or early fall on the Grand Banks, off southern NF and at the entrance to the Gulf of St. Lawrence (Fig. 4). Most large females collected in these areas in the fall were pregnant. Late stage embryos have only been observed on the Scotian Shelf and in the Gulf of Maine, but it is not clear if that distribution is an artifact of nonexistent sampling off southern NF in the winter or a more southerly birthing location. Birth apparently occurs in late winter or spring after an 8-9 month gestation period (Aasen 1963; Francis and Stevens 1999; Jensen et al. 2001). There is no evidence of an extended latency period after birth, since virtually all sexually mature females are pregnant in the fall (Fig. 4). Therefore, the reproductive cycle is 1 yr.

Porbeagle Feeding and Diet

The stomachs of 1022 porbeagles were examined immediately after capture between Feb 1999 and Jan 2001. Half of all stomachs contained significant amounts of prey other than bait. Stomach fullness varied around a mean value of 7-10% throughout the year, but other than a suggestion of lower values in Feb and Mar, showed no obvious trend across months (Fig. 5). Stomach capacity increased exponentially with fork length, from about 0.5 litres in young of the year to 8 or more litres in large sharks (Fig. 5).

The diet of porbeagles of all sizes, and at all times of the year, was almost exclusively fish and cephalopods (Fig. 6). Pelagic fish made up most of the diet in spring, while groundfish were the largest component of the diet in the fall. This shift in diet was almost certainly a reflection of depth, since spring and fall porbeagle distributions were mainly in deep and shallow water, respectively. The relative contribution of groundfish increased with shark size, while the contribution of cephalopods decreased (Fig. 6). Other elasmobranchs were occasionally eaten by large porbeagles, but marine mammals and birds were never found in the stomachs. A more complete analysis of porbeagle diet is currently underway (Joyce et al., unpublished).

Temperature and Depth Associations

Porbeagle appear to occupy well defined temperatures throughout the year. On the basis of more than 400 XBT temperature profiles made at fishing stations by industry, we were able to determine the water temperature at mid-gear depth for many of the sets made between 1994-1999. Mid-gear depth was estimated to be 100 m in the spring and 34 m in the fall, based on temperature loggers attached to the gear in 1999 and 2000. Water depth was determined based on geographic location of the set. The water temperature at depth of the locations not being fished was determined by extraction of MEDS data for the corresponding month and year.

Water depth was not correlated with porbeagle catch in the spring; depth varied between 200-2800 m (Fig. 7a). In contrast, fall catches were made in much shallower waters, most often at depths of less than 150 m (Fig. 7b).

Porbeagle were caught at a mean temperature of 7.4 ^{0}C, with 50% being caught between 5-10 ^{0}C. The range of surface temperatures was similar. There was no significant seasonal pattern in temperature (Fig. 7c), suggesting that the porbeagle adjusted their location to occupy the preferred temperature range.

For much of the spring, porbeagle were caught most frequently in waters immediately adjacent to the frontal edge separating cool Shelf waters from warmer offshore waters (Fig. 8). Porbeagle were not associated with fronts in the fall fishery, although the temperature occupied was similar to that observed in the spring (5-10 ^{0}C). A more complete analysis of temperature and depth associations is currently underway.

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; O’Boyle et al. 1998). 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. Based on a preliminary stock assessment (O’Boyle et al.

1998), the TAC was set at 1000t per year. However, the scientific information available at the time was too limited to determine if the TAC was sustainable.

The Canadian Atlantic Pelagic Shark Management Plan 2000-2001 (Anon 2000) was the first to be based on an analytical assessment for porbeagles (Campana et al. 1999), although it was not known if the advised 850t quota was sustainable over the long term. Therefore, the porbeagle TAC was set at a total of 1700t over the 2-year period, with no one year to exceed 1000t, while additional research in support of an improved stock assessment was carried out. In addition, the fall fishery on the southern NF mating grounds was restricted to 100t, in order to help protect the spawning stock. The precautionary TACs for mako and blue shark remained unchanged from previous management plans.

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. 9). 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 about 1,900t in 1961 to over 9,000t 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 about 2,000t 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 about 1600t. Since that time, the fishery has been almost exclusively Canadian, with landings declining gradually to 1066t in 1998. Landings from 1998 onwards have been restricted by quota control. Landings in the first half of 1999 and 2000 exceeded 700t each year, and the industry voluntarily restricted fishing 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, although the proportion taken by the inshore vessels increased to above 40% in 1999 and 2000 (Fig. 10). 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.

In contrast with many other pelagic and groundfish fisheries, the directed fishery for porbeagle is highly species-specific. Table 4a summarizes an analysis of IOP-observed, porbeagle-directed sets between 1990-2000, demonstrating that 92% of the catch was porbeagle. Most of the 8% bycatch was blue shark, and <1% was large pelagic species other than sharks. Both Canadian and Faroese vessels experienced similarly low levels of bycatch in the porbeagle fishery (Table 4b). Anecdotal comments by scientific technicians onboard shark fishing vessels since 1999 confirm the very low level of bycatch. Of 112 sets observed by the technician, blue shark was the only species common to most sets, while spiny dogfish and lancetfish were observed in about 25% of sets. No other species were observed more than a half dozen times.

The last assessment document identified inconsistencies in the conversion factor applied by DFO to convert landed dressed weight to live equivalent (round) weight (Campana et al. 1999). While incidental catches have been treated differently, most directed catch has been coded correctly by Statistics Branch as 'gutted, head and tail off', using the conversion 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. This source of error was eliminated by applying a standardized conversion factor of 1.50 (kg-kg) to all landing statistics and catches used in catch rate calculations.

Location and Size Composition of the Catch, with Inferences on Migration

The overall pattern of catch location and size composition since 1999 is shown in Fig. 11. Both the inshore and offshore fleets fished the Scotian Shelf in the spring of 1999 and 2000, although the offshore fleet tended to fish near the edge of the continental slope while the inshore fleet fished well onto the shelf. The size composition of the catch of both fleets was very similar. 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 mainly 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. 11). Large sharks were more common in the fall catch off of southern NF. A detailed breakdown of landings by fleet, month and area for the years 1991-2000 is presented in Tables 5-7.

A more detailed comparison of the size composition of the 2000 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 contrast to previous years however (Campana et al. 1999), the offshore fleet caught a larger proportion of large sharks in the spring than did the inshore fleet. Catches in the NF-Gulf area have traditionally been dominated by larger sharks, and although the same overall pattern was evident in 2000, the relative contribution of large sharks to the fall catch was less (Fig. 12).

Closer examination of the month to month shifts in length frequency in Fig. 12 suggests a seasonal migration of the larger sharks (>180 cm FL) along the Scotian Shelf towards NF in the spring. This pattern is evident in both the inshore and offshore length frequencies, whereby the relative abundance of the mode for larger sharks on the Shelf decreases substantially between March and May, appearing off NF in May. The change in the mode was most apparent in the offshore fishery along the edge of the Shelf, suggesting that the migration route might occur along the Shelf edge. To test this suggestion, we examined the sex ratios in the 1998-2000 catch, broken down by month and area. All years showed similar patterns. The sex ratio of immature sharks did not vary appreciably from month to month, either on the Shelf or in NF-Gulf (Fig. 13). However, the sex ratio of sharks of mature size on the Shelf clearly showed a significant increase in the proportion of females between Feb and May, reaching about 50% off NF in May. Examination of the month to month length frequencies by sex indicated that the proportion of mature males decreased more quickly than that of mature females, although the abundance of mature animals of both sexes declined. Such a pattern strongly suggests a springward migration of mature sharks, particularly males, along the Shelf towards the NF mating grounds. If true, this would suggest that the Scotian Shelf serves as the residence for mainly immature sharks, characterized by more limited migratory movements. Analysis of tagging data confirms that small sharks are less likely to move long distances than are larger sharks (Fig. 14).

Resource Status

Trends in Length Composition

A biological indicator of increased exploitation rate is a long-term decline in fork length in the catch. A plot of median fork length against year of collection showed a long-term decline in length composition on the NF-Gulf mating ground in early fall (Fig. 15). The median lengths for the years prior to 1980 are most representative of the length composition of a lightly fished population. In contrast, 1999 and 2000 were characterized by very low median sizes, indicating the loss of many sharks of mature size.

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 when exploratory licences first became available, and 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. 10).

Catch rate measures were disaggregated into those for immature and those for mature sharks; both were calculated in terms of ln-transformed numbers per 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. To calculate catch rate at length, length composition was determined for each of 3 subareas (south Shelf, east Shelf and NF-Gulf) in each of 3 seasons (Jan-Mar, Apr-June, July-Dec) for each year based on available measurements (Table 9). Set by set catch rates in terms of weight were converted to numbers based on the mean weight of the length composition of the subarea-season-year cell, then apportioned according to the length frequency. Numbers above 200 cm FL were pooled within a set to form the index for mature sharks, while the remainder were pooled to form the index for immature sharks.

A traditional measure of catch rate, kg per hook, is the one most visible to the fisher. Catch rates (kg per hook) by the offshore fleet on the Scotian Shelf have declined steadily since 1991, reaching their lowest level in 2000 (Fig. 16). Inshore catch rates paralleled those of the offshore initially, but have increased slightly since 1998. The divergent catch rates by the inshore and offshore on the Shelf are probably due to the different size compositions in the catch brought about by fishing in different locations (Fig. 11), highlighting the importance of a size-structured catch rate. Catch rates by the offshore in NF-Gulf have been variable, but have declined markedly since 1996 (Fig. 16).

The catch rate of sexually mature sharks (numbers per hook) by both the offshore and the inshore fleets has declined markedly since 1996 on both the Shelf and NF-Gulf (Fig. 17). The offshore catch rate for immature sharks has also declined, but less so than was the case for the mature sharks. In contrast, the inshore catch rate of immature sharks has increased since 1996. Closer comparison of the inshore and offshore catch rates of immature sharks on the Shelf indicates that both trends are roughly stable and similar between 1996-1999; divergence in the trends is limited to the year 2000 and appears to be due to differences in area fished (Fig. 17).

The overall trend in catch rate was analyzed using a linear model with subarea, month, CFV and year as factors. All factors were significant in the model predicting the catch rate of 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. 18. The standardized catch rate of mature porbeagles increased significantly between 1989 and 1992, but declined sharply afterwards as effort increased and the abundance of the large sharks declined. The 2000 point is the second lowest in the time series, and is 10% of the 1992 value. The standardized catch rate model for immature porbeagles was also highly significant (Table 11), and also showed a significant decline since the early 1990s (Fig. 18). The 2000 point is about 30% of the 1991 point. However, the catch rate has remained roughly stable since 1996 (ignoring the 1997 value, which is anomalously low in the mature CPUE series), consistent with the fleet-specific catch rates shown in Fig. 17. Overall, these catch rates suggest a monotonic and disturbing decline in the abundance of mature sharks, with a low but stable rate for immature sharks.

Natural and Total Mortality from Catch Curves

The length composition by sex of the porbeagle population was reconstructed using samples stratified by year, subarea and season, as described under *Commercial Catch Rates*, scaled to the ratio of the catch to the sampled catch in that aggregation cell. Lengths were aggregated into 5-cm categories, corresponding to measurement precision in the early years. Catch at length in each cell was converted to catch at age (excluding age 0) using maximum likelihood estimators (the probability distribution functions) characteristic of the fitted sex-specific growth models (Fig. 2). Normal variability and a constant SD of length at age (SD~12) were assumed based on the aged sharks. This approach would be expected to yield estimates of proportion at age which are considerably more accurate than the cohort slicing which was used in the last assessment, particularly for ages<15 yr. However, uncertainty in the validity of the ageing and growth curve for old females led us to develop a second catch at age matrix based on the sex-combined growth curve, which leads to slower growth after the age of sexual maturity for the females. We present both scenarios for contrast in the catch curves, but otherwise use the combined growth curve in all analyses as a more realistic description of growth for old females. The annual catch at age matrix aggregated across all subareas and sexes is presented in Table 12.

Trends in ln-transformed catch at age (catch curves) are shown in Fig. 19. The upper 4 panels show the catch curves of the 1961 (virgin) population, while the remainder show the catch curves for each of the last 3 years. Total instantaneous mortality rates (Z) based on the slope of the descending limb of the catch curve indicate that recent mortality rates have usually been higher than those of 1961 (Fig. 19). However, the exact mortality rate in recent years may be underestimated by the reduced abundance of young sharks in recent years. This effect is shown by a much-reduced ascending limb to the catch curve, indicating an increasingly young age at recruitment to the fishery, and probably explains the apparently low total mortality rate of mature females in the recent NF-Gulf fishery.

The estimates of Z from the catch curves for the lightly-fished 1961 population are also estimates of natural mortality (M). Campana et al. (1999) estimated M as 0.1 based on preliminary catch curves. Based on the refined catch curves presented here, M for maturing males on the Shelf indeed appears to be around 0.1 (Fig. 19). However, it appeared to be slightly higher (0.15) for fully mature males on the NF mating grounds. M could not be estimated for immature females in 1961. However, M for mature females on the mating grounds was estimated as 0.20 on the basis of the combined growth curve. For reasons presented earlier, female M based on the sex-specific growth curve is considered suspect and would result (implausibly) in a mature M of 0.44.

There is no reason to expect sex-specific differences in M prior to sexual maturity. Therefore, M was estimated for the combined length frequencies on the Shelf between 1998-2000 for ages before maturity (3-8). The mean Z was 0.21. On the basis of exploitation rate estimated from tag returns (see *Petersen Analysis*, where recent F~0.09), recent M for immature porbeagles would be 0.12.

It will be necessary to confirm the ages of very old porbeagle (>20 yr) before we can estimate M with any more precision. At this point however, an M of 0.1 for immature porbeagles of both sexes is consistent with both the samples from the virgin population and recent catch curves. M for mature males was also well estimated at 0.15. M for mature females definitely appears to be higher than that of males, and based on the combined growth curve, would be around 0.20. An increased natural mortality in mature animals, particularly females, is consistent with both the observed age composition and life history theory (Roff 1984), since mortality would be expected to increase in females carrying large embryos over an extended gestation period. Nevertheless, it appears that this is the first demonstration of this effect in sharks, probably because of the scarcity of reliable age determinations.

Recent Mortality Rates based on Paloheimo Z's

Total mortality rate in the most recent years was estimated through use of Paloheimo Z's. The catch at age for the two major fishing grounds was first standardized to a common fishing effort, then the total instantaneous mortality rate (Z) along cohorts between adjacent years was calculated (Table 13). Five of the six mortality estimates ranged between 0.27-0.37, with a mean of 0.32. The Z estimates for mature sharks on the NF mating grounds was not signficantly different than that for immature sharks on the Shelf.

The Z estimate of –0.04 for young sharks on the Shelf between 1998-99 was not considered reliable; April 1998 was the first month in which detailed length measurements were collected as part of the science-industry collaboration, and thus the month with the highest proportion of small sharks (March) was not represented in the catch at age. The absence of small sharks would be expected to distort the catch at age and artifactually produce a low estimate of Z.

With a mean Z = 0.32 for ages 3-9 on the Shelf (Table 13), and given an immature M = 0.10, recent fishing mortality on immature Shelf porbeagles would be 0.22. This estimate would be slightly inflated if older but immature females were less available on the Shelf in the spring. In the NF-Gulf area in fall, mean Z for ages 9-13 was estimated as 0.33. Assuming an M = 0.15 intermediate to that of immature and mature sharks, F would be estimated at 0.18.

Petersen Calculations of Recent Exploitation Rate

Recent exploitation rate of the fished population in the 1990s was estimated through Petersen analysis of tag recaptures. Details of the tagging programs were described in Campana et al. (1999). However, unlike the analysis presented in the last assessment, the current analysis was restricted to porbeagle tagged at age 0 or 1 (<125 cm), since this accounted for most of the Canadian and US tagging (Fig. 20). The total number of releases at size was not available for the Norwegian tagging program, and thus could not be included in the analysis. The reporting rate for Canadian tags dropped sharply in 1999, and even further in 2000, requiring adjustment of the reporting rate used in the Petersen calculations (Fig. 21). However, if a 100% reporting rate is assumed for all years, calculated exploitation rate decreases by only 10% of the mean.

The unadjusted exploitation rate based on the Petersen calculations ranged between 4-12%, with a mean of 8%. No trend was apparent across recent years, and the independent tagging studies of the U.S. and Canada provided similar estimates of exploitation rate since 1994. When adjusted for age-specific selectivity (Table 14), exploitation rate was estimated to lie between 5-20%, with a mean of about 11% (Fig. 21).

Yield per Recruit

Yield per recruit was calculated on the basis of the fitted growth model (Fig. 2), an empirical length-weight relationship (Campana et al. 1999), the estimates of immature and mature female natural mortality determined from the catch curve analysis (Fig. 19), and an area-specific selectivity curve based on the shape of recent catch curves and the fitted population model presented later. The estimated $F_{0.1}$ and yield values were not unduly affected by the selection of natural mortality schedules (Table 14). However, the choice of selectivity vectors was quite influential. Yield in the NF-Gulf fishery was estimated to be higher, but at a lower $F_{0.1}$, than that on the Shelf. Based on a combined selectivity vector (effort-weighted 2:1 Shelf:NF), $F_{0.1}$ was estimated at 0.18. 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 (<0.1), as is shown in the figure panel of Table 14. The sharp decline in spawning stock numbers evident in Table 14 is reminiscent of the decline in the observed catch rate of sexually mature porbeagle (Fig. 18).

Campana et al. (1999) suggested that an $F_{0.1}$ yield would not be sustainable unless the F on the mature population was considerably less than $F_{0.1}$. As documented in the *Life Table Analysis* section, it is now clear that $F_{0.1}$ is not sustainable for porbeagle sharks.

Age- and Sex-Structured Population Model

A forward-projecting, age- and sex-structured population dynamics model was developed for NW Atlantic porbeagle in order to estimate current population status relative to that of earlier years. The model was fit to available catch at length and CPUE data between 1961-2000, using the growth model, natural mortality rates, maturity ogives, fecundity and area-season stratification described earlier. The steepness of the Beverton-Holt spawner-recruit model was defined *a priori* as 0.37 on the basis of the well-defined reproductive parameters of porbeagle. Model output included time trends in biomass, female spawner numbers and area-specific selectivity curves. AD Model Builder was used to prepare the model and fit the likelihood functions. Full model details are available in Harley (unpublished report).

The base model assumed a combined growth curve, a higher M in the first year of life, an increased M at the onset of sexual maturity, and a fixed selectivity. Both total biomass and spawning stock numbers were modelled as declining sharply after the onset of the 1961 fishery, recovering slightly through the 1970s and 1980s, then declining once more to a record low level (Figs. 22-23). Current biomass was estimated as being 11% of virgin biomass and fully recruited F in 2000 was estimated as 0.26 (Table 15). The time series of fishing mortality indicates that F has been very high since the mid 1990s (Fig. 24).

Four alternative model runs are presented in Table 15; all are similar to or more pessimistic than the base run. The most viable of the alternative runs (run 5) was one in which both selectivity and recruitment deviates were estimated, and there was no increase in M at maturation. The time trend in biomass was very similar to that of the base run (Figs. 25-26), with similar terminal F (=0.26) but a slightly higher terminal biomass (17% of virgin biomass).

The reference points from the model were similar in all runs. MSY was 1000-1000t at an F_{MSY} of 0.04-0.05 (Table 15).

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 16 presents the life table analysis for porbeagle. The values of M, maturity ogive and fecundity were as presented earlier. Fishing mortality was added to M to investigate various fishing strategies, subject to area-specific selectivities. A fishery in which all ages were fully selected was also investigated. The results indicated that the intrinsic rate of population growth (r) in an unfished population varied between 0.05-0.07 depending on the natural mortality assumptions which were made. Such values are very low compared to most fishes (Myers et al. 1999), and indicate that the porbeagle population is intrinsically unproductive and slow to recover from stock depletion. Fishing mortalities on the order of 0.18 resulted in population decline under all scenarios. A fishing scenario with F=0.08 resulted in population decline when the selectivity of the mature fish was high (eg- in NF-Gulf) and produced only marginal growth when mature selectivity was low (eg- on the Shelf). F=0.08 corresponded to zero population growth using the combined PR vector, and thus serves as the reference point for $F_{replacement}$. F_{msy} is half of $F_{replacement,}$ and thus equals 0.04. This value is very similar to that estimated from the population model.

Sources of Uncertainty

There are several sources of uncertainty in this assessment. Mature sharks are seldom seen in the winter and spring, and their overwintering and birthing grounds remain unknown. This uncertainty could influence yield projections through effects on availability. The age determination of old sharks (>15 yr) remains unvalidated, and has implications for the mortality rate calculations of mature females.

Some of the underlying assumptions of the population model are uncertain, particularly that of selectivity, which introduces uncertainty into the estimates of recent population status. If mature sharks are more fully recruited than estimated, the model output is optimistic. Another source of uncertainty includes some of the assumptions of the Peterson tag analysis, specifically those dealing with tag-induced mortality and tag loss and reporting rates.

Although all of the measures of recent fishing mortality shown here are considered valid, that derived from Paloheimo Zs is considered most reliable, followed by that of the Petersen analysis and then the population model.

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 recover for another 25 years. However, the fishery appeared sustainable during the 1970s and 1980s when landings averaged 350t annually, and the population slowly recovered. Catches of 1000-2000t throughout much of the 1990s appear to have once again reduced population abundance, resulting in lower catch rates and disturbingly low numbers of mature females.

The TAC of 850t introduced in 1999, based on preliminary scientific information and with excellent cooperation from industry, resulted in preliminary estimates of $F_{0.1}$ yield, mortality and stock abundance. Nevertheless, it was acknowledged at the time that the $F_{0.1}$ yield was probably not sustainable. The current assessment confirms the unsustainability of fishing at $F_{0.1}$ for porbeagle, and indicates that a fishing mortality above 0.08 will cause the population to decline. A fishing mortality of 0.04-0.05 corresponds to MSY, and is required if the population is to be allowed to recover. Several independent estimates of recent fishing mortality all suggest that recent catches averaging 1000t per year have resulted in an F of about 0.20 (Fig. 27). An annual catch of 200-250t would correspond to fishing at MSY and would allow population recovery. Annual catches of 400t would not allow any population growth, nor room for error in the estimates. Current population size appears to be at 10-20% of virgin levels.

The current porbeagle population is seriously depleted and will require a greatly reduced fishing mortality if recovery is to occur. Due to the low productivity of the species, recovery will not be rapid. However, annual catch levels of about 1000t will be sustainable over the long term once the population has recovered.

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Table 1. Reported porbeagle landings (mt) by country. Canadian reported landings have been converted to live equivalent weight, which differs in some cases from the live weight recorded in the statistics.

	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	814	1149			7			8	13	1991	643
1993	920	465			6			2	39	1432	840
1994	1573				2				3	1578	1023
1995	1348		7		4				5	1364	730
1996	1043		40		9				8	1100	411
1997	1317		13		2				2	1334	539
1998	1054		20		0				12	1086	465
1999	955				6					961	
2000	899				0					899	

Notes: Northeast Atlantic and France data is from FAO Statistics (1998)
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 - 2000 is from DFO Zonal Statistics File, corrected to appropriate live equivalent weight.
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 1987-2000 is from Scotia-Fundy & NF IOP (includes landings and discards)
Japan and USSR for 1981-2000 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)

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 SHARK	TAC
1991	329	0	0	0	0	185	514	NA
1992	805	0	0	9	0	171	985	NA
1993	912	0	0	8	4	174	1098	NA
1994	1552	9	2	18	142	121	1844	NA
1995	1313	21	0	15	111	40	1500	1500
1996	1024	6	1	24	67	20	1142	1500
1997	1295	6	0	40	86	43	1470	1000
1998	1020	8	0	28	71	37	1164	1000
1999	930	2	1	23	64	16	1036	1000
2000	888	2	1	8	62	13	974	850*

* The TAC for 2000 and 2001 combined has been set at 1700 mt

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

Year	NS	NB	PEI	QUE	NFL	TOTAL
1991	329					329
1992	814					814
1993	920					920
1994	1567			5	<1	1572
1995	1312			1	35	1348
1996	1041		<1	<1	2	1043
1997	1237	1			80	1318
1998	926	1	4		123	1054
1999	955	<1				955
2000	899	<1			<1	899

Table 4a. Observed bycatch associated with directed pelagic fisheries between 1990-2000.

DIRECTED SPECIES	CATCH (% total catch)																								TOTAL CATCH (mt)
	Porbeagle Shark		Sword fish		Bigeye Tuna		Bluefin Tuna		Yellowfin Tuna		Albacore Tuna		Ground fish		Marlins		Blue Shark		Mako Shark		Other Shark		Other		
	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Dis	Kept	Disc	Kept	Disc	Kept	Dis	Kept	Dis	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	
Porbeagle	92.0	0.12	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	4.7	0.2	0.0	0.0	0.305	0.4	0.1	3856
Swordfish	0.4	0.4	43.7	1.5	4.0	0.1	0.0	1.3	3.0	0.1	0.5	0.0	0.0	0.0	0.6	0.3	0.4	36.8	2.5	0.3	0.1	0.2	1.2	2.6	981
Bigeye	0.1	0.1	2.5	0.3	36.8	0.1	3.4	0.1	10.1	0.1	7.8	0.1	0.0	0.0	0.2	0.0	4.8	24.5	1.7	0.2	0.0	0.3	4.1	2.8	4100
Bluefin	1.2	1.4	3.3	0.1	7.1	0.0	50.5	0.4	0.4	0.0	7.0	0.0	0.0	0.0	0.0	0.0	6.1	18.3	1.0	0.1	0.0	0.1	1.1	2.0	1752
Yellowfin	0.1	0.1	1.7	0.3	24.1	0.2	7.0	0.2	17.9	0.3	10.5	0.2	0.0	0.0	0.4	0.0	20.0	10.1	2.5	0.1	0.0	0.1	2.2	2.0	415
Albacore	2.2	0.9	5.9	0.0	0.2	0.0	59.4	0.3	0.0	0.0	9.4	0.0	0.0	0.0	0.0	0.0	7.2	11.7	0.4	0.2	0.0	0.0	0.2	2.0	81
Silver hake	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	10.0	1.1	12502
Pollock *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	96.6	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.1	1.0	1557
Redfish *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	96.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.8	0.6	0.5	4614

* Based on catches between 1998-1999

Table 4b. Observed bycatch associated with directed porbeagle fisheries between 1981-1999.

COUNTRY	DIRECTED (mt)	BYCATCH (%)									
	Porbeagle Shark	Blue Shark	Mako Shark	Other Shark	Sword fish	Bluefin Tuna	Albacore Tuna	Bigeye Tuna	Yellowfin Tuna	Ground fish	Other
Canada	995	6.99	0.20	0.03	0.03	0.04	0.00	0.00	0.00	0.03	1.61
Faroes	3378	5.91	0.13	0.41	0.01	0.06	0.00	0.00	0.00	0.02	0.15
TOTAL	4373	6.15	0.14	0.32	0.01	0.05	0.00	0.00	0.00	0.03	0.48

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

Year	Subarea	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Subarea total	Annual total
1991	2-3	.	.	.	.	.	.	.	.	.	41.6	106.1	13.8	162	
	4RST	.	.	.	.	.	.	.	.	38.6	23.9	.	.	63	
	4VW	.	.	.	.	.	.	19.0	41.6	26.8	7.4	.	0.4	95	
	4X5YZ	.	.	.	.	.	.	.	0.3	.	.	6.6	2.3	9	329
1992	2-3	.	.	.	4.1	.	0.3	.	59.1	124.3	44.0	0.2	.	232	
	4RST	.	.	.	.	.	.	6.7	.	6.8	79.1	51.6	.	144	
	4VW	.	.	21.5	28.3	27.5	17.4	24.4	0.2	0.3	5.7	9.3	0.3	135	
	4X5YZ	50.8	.	3.2	1.8	134.4	19.0	84.0	.	.	0.2	.	.	293	804
1993	2-3	0.0	.	.	.	.	15.7	18.8	67.1	68.3	91.6	42.9	34.2	339	
	4RST	.	.	.	.	.	8.6	49.5	0.3	44.6	44.4	.	.	147	
	4VW	.	.	.	67.0	51.2	16.0	6.1	0.8	0.4	9.9	47.7	6.8	206	
	4X5YZ	.	.	.	83.0	77.3	5.8	47.5	.	.	.	0.4	5.5	220	911
1994	2-3	.	.	.	.	.	35.0	16.7	29.9	70.3	131.4	5.7	.	289	
	4RST	.	.	.	.	.	.	31.7	.	30.3	10.0	.	.	72	
	4VW	.	.	33.7	265.2	211.1	173.4	36.9	.	1.7	21.2	112.6	74.7	931	
	4X5YZ	.	.	15.5	42.8	10.3	28.4	1.5	.	.	.	51.8	11.7	162	1453
1995	2-3	.	.	.	.	8.4	102.5	60.1	14.9	102.9	136.9	65.2	.	491	
	4RST	.	.	.	.	.	.	6.2	.	.	.	12.3	.	19	
	4VW	.	.	68.8	115.2	152.3	41.3	12.6	.	.	.	49.6	60.8	501	
	4X5YZ	.	.	20.4	89.5	16.1	.	4.0	.	.	.	6.8	1.9	139	1149
1996	2-3	.	.	.	.	.	37.5	14.6	.	85.4	90.2	69.9	.	298	
	4RST	.	.	.	.	.	.	.	.	.	.	5.5	.	5	
	4VW	11.1	.	37.8	3.7	42.4	7.9	27.5	.	.	.	22.6	16.0	169	
	4X5YZ	1.3	.	56.3	100.0	80.7	28.9	0.1	.	.	.	.	1.1	268	741
1997	2-3	.	.	.	.	.	3.2	8.3	30.4	98.7	129.1	46.7	.	316	
	4RST	.	.	.	.	.	.	1.0	6.7	30.0	9.5	.	.	47	
	4VW	.	.	63.5	95.1	122.2	92.3	7.2	.	6.1	11.3	.	.	398	
	4X5YZ	.	.	81.2	20.8	58.3	.	.	.	.	.	.	.	160	922
1998	2-3	.	.	0.8	.	37.5	13.7	0.8	71.4	60.5	99.3	.	.	284	
	4RST	.	.	.	.	.	.	.	.	33.1	15.0	.	.	48	
	4VW	.	.	92.5	60.6	61.2	18.0	0.2	.	2.9	2.1	.	.	238	
	4X5YZ	.	4.4	17.7	80.1	96.4	7.4	.	.	.	.	.	.	206	776
1999	2-3	.	.	.	1.1	57.1	9.3	.	.	.	26.7	59.6	11.0	165	
	4RST	.	.	.	.	.	.	.	.	8.5	.	.	.	8	
	4VW	.	2.8	113.5	125.8	96.2	12.9	.	.	0.6	.	6.2	.	358	
	4X5YZ	.	2.9	10.0	11.9	3.0	.	.	.	.	.	.	.	28	559
2000	2-3	.	.	.	4.0	87.3	60.8	3.0	.	.	76.8	19.4	.	251	
	4RST													0	
	4VW	.	.	54.8	68.9	56.6	37.0	.	.	.	.	28.8	.	246	
	4X5YZ	.	.	50.0	10.5	0.4	.	.	.	.	.	.	.	61	558

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

Year	Subarea	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Subarea total	Annual total
1992	2-3													0	
	4RST													0	
	4VW													0	
	4X5YZ									0.1		0.1		0	0
1993	2-3													0	
	4RST													0	
	4VW	.	.	.	.	.	.	.	.	0.2	.	.	.	0	
	4X5YZ													0	0
1994	2-3	.	.	.	.	.	.	0.0	.	.	.	.	.	0	
	4RST	.	.	.	.	.	.	0.2	4.1	1.1	.	.	.	5	
	4VW	.	.	.	0.9	4.1	.	9.4	11.8	18.2	25.4	1.2	.	71	
	4X5YZ	.	.	.	.	0.2	4.9	.	3.4	6.9	7.4	1.7	.	24	101
1995	2-3	.	.	0.1	.	.	.	.	0.0	.	.	.	.	0	
	4RST	.	.	.	.	.	.	0.3	0.3	0.3	.	.	.	1	
	4VW	.	9.6	1.6	19.1	9.2	30.8	8.2	1.2	3.8	1.4	.	.	85	
	4X5YZ	.	3.9	12.8	0.3	42.0	10.6	.	11.4	1.6	.	.	.	83	168
1996	2-3	.	.	.	.	0.5	.	.	0.7	.	.	.	.	1	
	4RST	.	.	.	.	.	.	0.4	.	2.7	0.6	7.6	.	11	
	4VW	9.6	13.9	53.2	16.5	31.6	16.7	6.6	7.6	2.9	11.8	5.9	24.8	201	
	4X5YZ	.	14.9	2.7	26.9	17.9	7.7	0.6	0.2	.	0.2	0.1	.	71	285
1997	2-3													0	
	4RST	.	.	.	.	.	.	0.7	9.7	4.2	11.6	.	.	26	
	4VW	36.0	26.8	5.9	32.3	25.2	52.9	15.4	6.3	7.5	5.6	.	.	214	
	4X5YZ	.	8.7	19.0	36.5	34.0	24.0	2.6	0.0	0.0	13.1	.	.	138	378
1998	2-3													0	
	4RST	.	.	.	.	.	.	1.0	0.2	0.6	.	.	.	2	
	4VW	3.6	0.3	0.2	33.8	59.7	37.4	2.7	4.6	2.4	9.0	0.8	.	155	
	4X5YZ	15.7	4.3	3.3	26.8	19.9	12.3	1.1	1.2	1.3	0.9	1.3	0.1	88	245
1999	2-3	.	.	.	.	.	.	.	.	2.8	0.5	.	.	3	
	4RST													0	
	4VW	26.5	10.3	45.1	28.9	62.2	6.4	1.0	1.2	0.9	5.5	12.3	.	200	
	4X5YZ	0.9	2.6	42.7	43.7	62.8	3.2	.	0.3	0.0	.	11.7	.	168	371
2000	2-3	.	.	.	.	.	.	.	1.3	.	.	.	.	1	
	4RST										16.1			16	
	4VW	.	7.4	22.6	78.2	96.9	41.7	0.4	1.6	.	4.5	.	.	253	
	4X5YZ	.	10.3	23.2	8.5	1.8	15.1	0.2	.	.	0.4	.	.	59	330

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
1992	2-3	.	.	.	.	.	.	.	.	0.3	.	.	.	0	
	4RST													0	
	4VW	.	.	.	.	0.1	0.7	0.1	0.3	0.4	0.1	0.4	0.6	3	
	4X5YZ	.	.	.	.	.	2.8	0.4	0.9	1.5	0.2	0.1	.	6	9
1993	2-3	0.4	.	.	.	.	.	.	.	.	.	.	.	0	
	4RST													0	
	4VW	.	0.1	0.5	0.4	.	.	0.7	0.3	.	0.1	.	.	2	
	4X5YZ	0.9	1.9	0.1	0.1	0.5	1.6	0.2	0.3	0.0	.	.	.	6	8
1994	2-3	0.1	.	.	0.1	0.2	.	0.8	0.9	.	0.5	.	.	3	
	4RST													0	
	4VW	1.6	0.1	.	0.2	.	0.0	1.7	0.9	1.0	3.1	1.5	0.1	10	
	4X5YZ	.	.	.	.	0.1	0.5	3.5	1.3	1.4	0.7	0.6	0.1	8	21
1995	2-3	.	.	0.2	0.1	0.1	.	.	1.2	1.1	1.9	0.1	.	4	
	4RST													0	
	4VW	0.5	.	0.5	1.0	0.0	0.6	3.3	0.8	7.7	5.1	0.1	.	20	
	4X5YZ	0.2	.	1.2	0.4	1.2	0.6	0.5	2.1	3.0	0.6	0.1	0.5	11	35
1996	2-3	.	0.2	.	.	.	0.1	0.0	0.5	0.4	0.7	0.0	.	2	
	4RST	.	.	.	.	.	.	.	.	0.1	1.9	.	.	2	
	4VW	0.1	0.0	0.2	0.2	.	0.3	0.7	1.9	1.9	0.3	.	0.3	6	
	4X5YZ	.	.	0.1	0.3	1.5	0.4	1.4	1.2	0.6	1.3	0.7	1.4	9	19
1997	2-3	.	.	0.2	.	.	.	0.7	0.4	0.1	.	.	.	1	
	4RST	.	.	.	.	.	.	.	.	0.0	0.1	.	.	0	
	4VW	1.2	0.2	0.2	0.5	.	0.4	0.6	1.4	3.7	0.7	.	.	9	
	4X5YZ	.	0.8	0.2	0.2	0.7	3.3	2.1	1.1	1.5	2.3	0.3	.	13	23
1998	2-3	.	.	.	0.1	.	.	.	0.0	6.1	0.2	.	0.0	6	
	4RST	.	.	.	.	.	.	.	.	3.9	0.1	.	.	4	
	4VW	0.2	.	0.1	0.2	0.2	0.2	1.0	3.0	4.8	0.6	0.1	.	10	
	4X5YZ	0.4	0.4	.	0.3	0.4	0.4	2.1	1.8	2.4	2.8	1.6	0.6	13	34
1999	2-3	0.0	.	0.2	.	.	.	.	0.0	.	.	0.3	.	1	
	4RST	.	.	.	.	.	.	.	.	0.0	.	.	.	0	
	4VW	0.2	0.0	0.2	0.5	0.6	1.4	3.6	0.9	.	5.0	0.2	0.1	13	
	4X5YZ	0.3	0.1	0.3	0.8	2.3	2.8	0.5	1.9	1.0	1.1	0.5	.	12	25
2000	2-3	.	.	0.1	.	0.1	0.1	.	0.1	.	.	.	.	0	
	4RST													0	
	4VW	0.3	0.1	0.3	.	0.4	0.4	0.3	2.2	0.3	0.1	.	.	4	
	4X5YZ	0.1	0.5	1.1	.	0.3	0.4	0.3	1.0	0.7	0.8	.	.	5	10

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

	Number of hooks			Directed catch (mt) with effort		
Year	Inshore	Offshore	TOTAL	Inshore	Offshore	Total
1981		133154	133154		184	184
						0
1987	.	173756	173756		377	377
1988	.	192162	192162		373	373
1989	.	161888	161888		477	477
1990	.	214840	214840		539	539
1991	.	551270	551270		1504	1504
1992	.	832107	832107		1951	1951
1993	.	695656	695656		1354	1354
1994	21600	667003	688603	35	1453	1489
1995	30168	640617	670785	9	1149	1158
1996	130616	418930	549546	179	740	919
1997	147746	444032	591778	287	922	1209
1998	147728	471240	618968	211	775	986
1999	214755	408036	622791	360	559	919
2000	163485	428562	592047	300	557	857

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

YEAR	SOURCE						
	Norway	*Industry*	*LPRT*	*NF IOP*	*SF IOP*	*Research*	*TOTAL*
1961	1971						1971
1979				17			17
1980				810			810
1981				1984			1984
1986					33		33
1987				1521	359		1880
1988				1541	5512		7053
1989				2132	58		2190
1990				1705	8552		10257
1991				26	16474		16500
1992				13	14619		14632
1993				886	9175		10061
1994				116	2764		2880
1995		3640		3409	3006		10055
1996		2057	4092	5	3824		9978
1997		1228	4643	3	1483		7357
1998		10441		21	17		10479
1999		16989				735	17724
2000		15931				357	16288
TOTAL	1971	50286	8735	14189	65876	1092	142149

Norway - From Aasen (1963)
Industry - DMP and QMP measurements of interdorsal length
LPRT - Individual carcass weights associated with Large Pelagic Research Tally sheets
NF IOP - NF International Observer Program
SF-IOP - SF International Observer Program
Research - On-board scientific technician

Table 10. Results of the catch rate standardization model relating the catch rate (ln-transformed number per hook) of mature porbeagle (>200 cm FL) to area, month, CFV and year. See also Fig. 18.

Call: lm(formula = LNCE200 ~ SUBAREA + MON + CFV + YR, data = combined.directed.major.CFV.IOP.CPUE.cpue)

Residual standard error: 1.262 on 4583 degrees of freedom; Multiple R-Squared: 0.3152
F-statistic: 47.95 on 44 and 4583 degrees of freedom, the p-value is 0

Analysis of Variance Table Terms added sequentially (first to last)

	Df	SS	MS	F	Pr(F)
SUBAREA	2	1084.008	542.0038	340.5727	0.00E+00
MON	11	160.242	14.5675	9.1536	2.22E-16
CFV	20	773.94	38.697	24.3156	0.00E+00
YR	11	1339.642	121.7856	76.525	0.00E+00
Residuals	4583	7293.607	1.5914		

Coefficients	Value	SE	t value	Pr(>|t|)
(Intercept)	-4.32	0.3137	-13.7695	0
SUBAREANFGUL	1.1565	0.0686	16.8652	0
SUBAREASSHEL	0.0817	0.051	1.6014	0.1094
MON2	-0.0394	0.2231	-0.1765	0.8599
MON3	-0.4284	0.1812	-2.3641	0.0181
MON4	-0.3589	0.1763	-2.035	0.0419
MON5	-0.3821	0.176	-2.1712	0.03
MON6	-0.6465	0.1793	-3.6064	0.0003
MON7	-0.8554	0.193	-4.4329	0
MON8	-1.2498	0.2016	-6.1986	0
MON9	-0.7882	0.191	-4.1261	0
MON10	-0.6602	0.1875	-3.5215	0.0004
MON11	-0.4805	0.1911	-2.5149	0.0119
MON12	-0.5419	0.2187	-2.4782	0.0132
CFV	-0.7372	0.254	-2.9028	0.0037
CFV	-1.0954	0.1849	-5.9254	0
CFV	-1.4729	0.1664	-8.8495	0
CFV	-0.0986	0.1941	-0.5079	0.6116
CFV	1.0144	0.2947	3.4423	0.0006
CFV	-1.0166	0.4149	-2.45	0.0143
CFV	-0.1118	0.2669	-0.4189	0.6753
CFV	-1.2067	0.3167	-3.8097	0.0001
CFV	-1.487	0.3503	-4.2455	0
CFV	-0.0241	0.3356	-0.0719	0.9427
CFV	-0.6841	0.3471	-1.9707	0.0488
CFV	-0.2381	0.1838	-1.2957	0.1951
CFV	-0.4374	0.3762	-1.1626	0.2451
CFV	-1.7351	0.1669	-10.3934	0
CFV	-0.5771	0.2265	-2.5484	0.0109
CFV	-1.2414	0.2022	-6.1384	0
CFV	-0.5201	0.265	-1.9628	0.0497
CFV	-1.4861	0.181	-8.2122	0
CFV	-1.6606	0.1923	-8.6374	0
CFV	-2.0731	0.1902	-10.9003	0
YR1990	0.1353	0.1996	0.6778	0.4979
YR1991	0.3608	0.1905	1.8935	0.0584
YR1992	0.6043	0.1889	3.199	0.0014
YR1993	-0.0515	0.1974	-0.2609	0.7942
YR1994	0.0397	0.207	0.1918	0.8479
YR1995	0.0677	0.2096	0.3228	0.7468
YR1996	-0.2756	0.2156	-1.2779	0.2013
YR1997	-1.8281	0.2204	-8.295	0
YR1998	-0.9283	0.2142	-4.3335	0
YR1999	-1.468	0.2154	-6.8163	0
YR2000	-1.6495	0.2164	-7.6236	0

Table 11. Results of the catch rate standardization model relating the catch rate (ln-transformed number per hook) of immature porbeagle (<200 cm FL) to area, month, CFV and year. See also Fig. 18.

Call: lm(formula = LNCEIMM ~ SUBAREA + MON + CFV + YR, data = combined.directed.major.CFV.IOP.CPUE.cpue)

Residual standard error: 1.132 on 4583 degrees of freedom; Multiple R-Squared: 0.1667
F-statistic: 20.83 on 44 and 4583 degrees of freedom, the p-value is 0

Analysis of Variance Table Terms added sequentially (first to last)

	Df	SS	MS	F	Pr(F)
SUBAREA	2	175.315	87.65737	68.39225	0
MON	11	156.905	14.26411	11.12918	0
CFV	20	435.78	21.78898	17.00025	0
YR	11	406.693	36.97211	28.84647	0
Residuals	4583	5873.965	1.28169		

Coefficients:	Value	SE	t value	Pr(>|t|)
(Intercept)	-3.5669	0.2815	-12.6687	0
SUBAREANFGUL	-0.4757	0.0615	-7.7292	0
SUBAREASSHEL	-0.0373	0.0458	-0.8139	0.4157
MON2	-0.0826	0.2002	-0.4126	0.6799
MON3	0.5448	0.1626	3.3502	0.0008
MON4	0.5064	0.1582	3.2003	0.0014
MON5	0.4689	0.1579	2.9692	0.003
MON6	0.1263	0.1609	0.785	0.4325
MON7	0.1618	0.1732	0.9342	0.3502
MON8	-0.1608	0.1809	-0.8884	0.3744
MON9	0.215	0.1714	1.2542	0.2098
MON10	0.3439	0.1682	2.0443	0.041
MON11	0.328	0.1715	1.9126	0.0559
MON12	-0.2529	0.1962	-1.2887	0.1976
CFV	-0.5217	0.2279	-2.2889	0.0221
CFV	-0.3065	0.1659	-1.8476	0.0647
CFV	-0.0238	0.1494	-0.1593	0.8735
CFV	-0.1942	0.1742	-1.115	0.2649
CFV	-0.1583	0.2644	-0.5988	0.5494
CFV	0.4262	0.3724	1.1446	0.2524
CFV	-0.2335	0.2395	-0.9751	0.3296
CFV	-0.5914	0.2843	-2.0806	0.0375
CFV	-1.1174	0.3143	-3.5549	0.0004
CFV	-0.3896	0.3012	-1.2934	0.1959
CFV	-0.2583	0.3115	-0.8292	0.407
CFV	-0.0823	0.1649	-0.4989	0.6179
CFV	0.2174	0.3376	0.644	0.5196
CFV	-0.1949	0.1498	-1.3006	0.1934
CFV	-0.0583	0.2032	-0.2868	0.7743
CFV	0.2863	0.1815	1.5774	0.1148
CFV	-0.0574	0.2378	-0.2413	0.8094
CFV	0.109	0.1624	0.6715	0.502
CFV	-0.2267	0.1725	-1.3139	0.1889
CFV	-0.5497	0.1707	-3.2207	0.0013
YR1990	0.0857	0.1791	0.4784	0.6324
YR1991	0.5979	0.171	3.4968	0.0005
YR1992	0.2755	0.1695	1.6252	0.1042
YR1993	0.1036	0.1771	0.5851	0.5585
YR1994	0.2538	0.1858	1.3661	0.172
YR1995	-0.1962	0.1881	-1.0431	0.297
YR1996	-0.8578	0.1935	-4.4323	0
YR1997	-0.0555	0.1978	-0.2807	0.779
YR1998	-0.7263	0.1922	-3.7784	0.0002
YR1999	-0.4857	0.1933	-2.5132	0.012
YR2000	-0.5787	0.1942	-2.9803	0.0029

Table 12. Catch at age (in numbers) by year aggregated across subareas and sexes.

AGE	YEAR																
	1961	1980	1981	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	633	790	179	1770	1108	1180	1166	2488	3400	3739	5589	2932	2006	5757	1799	3654	3823
2	806	826	183	1594	1244	620	1303	2651	3035	3454	4737	3336	2098	5483	2291	3980	3844
3	1120	878	227	1537	1256	609	1325	3259	3293	3113	4190	3674	2242	5008	2406	3549	3260
4	1463	769	271	1359	1149	704	1225	3720	3613	2793	3671	3620	2207	4363	2267	2857	2589
5	1746	624	315	1143	989	754	1105	3772	3799	2550	3206	3208	2033	3538	2054	2211	1987
6	1973	572	380	979	805	735	1021	3498	3813	2362	2843	2693	1826	2664	1836	1726	1492
7	2101	590	449	852	639	696	957	3099	3669	2176	2551	2230	1622	1869	1602	1365	1120
8	2083	589	498	740	509	666	876	2673	3396	1968	2279	1864	1430	1246	1376	1101	881
9	1969	534	513	629	406	629	762	2240	3030	1728	1987	1577	1249	812	1171	912	743
10	1835	447	493	518	321	566	625	1813	2608	1460	1661	1337	1076	526	981	766	645
11	1707	361	442	413	249	478	487	1416	2169	1181	1318	1124	911	339	802	642	552
12	1574	294	371	321	190	380	366	1072	1747	920	996	934	757	215	642	531	459
13	1425	244	295	246	143	291	269	793	1369	695	723	767	618	134	505	434	371
14	1260	203	223	187	106	219	196	577	1049	515	510	622	498	83	392	349	293
15	1088	166	163	142	78	167	141	415	791	377	353	500	395	51	301	276	227
16	917	131	116	108	57	131	102	296	589	276	242	397	311	31	229	216	172
17	756	99	82	82	42	106	73	211	434	202	166	312	244	19	172	167	129
18	612	73	56	62	31	89	53	151	319	148	113	244	190	12	129	128	95
19	487	52	39	47	23	76	39	108	234	109	78	189	149	7	97	98	69
20	383	36	27	36	18	65	29	77	171	81	54	146	117	5	73	76	50
21	298	25	18	27	14	56	21	56	126	61	38	113	92	3	55	58	37
22	230	17	12	20	11	48	16	41	93	46	26	88	73	2	42	45	26
23	177	11	9	15	9	41	12	30	69	35	19	68	59	1	33	35	19
24	136	8	6	12	7	35	10	22	52	26	14	54	47	1	26	28	14
25	105	5	4	9	6	29	8	16	39	20	10	42	39	1	21	22	10
26	81	4	3	7	5	25	6	12	30	16	7	34	32	0	17	18	8
27	63	2	2	5	5	21	5	9	23	12	6	28	26	0	14	14	6
28	49	2	2	4	4	17	4	7	18	10	4	23	22	0	12	12	4
29	38	1	1	3	4	14	3	6	14	8	3	19	19	0	10	10	3
30	30	1	1	3	3	12	3	4	11	6	2	16	16	0	9	8	3
SUM	27146	8353	5381	12871	9431	9458	12208	34533	43000	30088	37397	32190	22404	32171	21361	25289	22932

Table 13. Recent mortality rates based on Paloheimo z's of the area-specific catch at age, standardized by effort (# hooks).

Shelf

Age	1998	1999	2000
1	1358	3293	3422
2	1771	3511	3298
3	1857	3048	2670
4	1706	2380	2047
5	1497	1775	1536
6	1300	1333	1129
7	1114	1019	827
8	951	803	632
9	815	658	516
10	688	552	433
11	564	462	359
12	449	380	287
13	348	306	223
14	265	241	168
15	198	185	123
16	145	140	89
17	106	104	63
18	76	76	45
19	55	55	31
20	39	40	22
# hooks	446118	466955	400666

Shelf-standardized

1998	1999	2000		
1220	2826	3422		
1591	3013	3298		
1667	2615	2670	Z98-99=-Ln ((4-6)/(3-5))=	-0.04
1532	2042	2047	Z99-00=-Ln ((4-6)/(3-5))=	0.27
1345	1523	1536		
1168	1144	1129		
1000	875	827	Z98-99=-Ln ((7-9)/(6-8))=	0.35
854	689	632	Z99-00=-Ln ((7-9)/(6-8))=	0.32
732	565	516		
618	474	433		
507	397	359		
403	326	287		
313	263	223		
238	207	168		
177	159	123		
131	120	89		
95	89	63		
68	65	45		
49	47	31		
35	34	22		

NFGulf

Age	1998	1999	2000
1	441	361	401
2	520	469	546
3	549	501	591
4	561	477	542
5	557	436	451
6	535	392	363
7	488	345	293
8	425	298	249
9	357	253	227
10	293	214	211
11	237	180	193
12	193	151	171
13	157	128	148
14	128	108	125
15	103	91	103
16	83	76	83
17	66	64	65
18	53	53	50
19	42	43	38
20	33	36	29
# hooks	172850	155836	191381

NFGulf-standardized

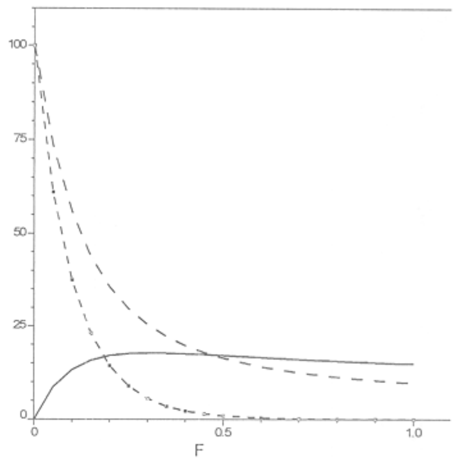
1998	1999	2000		
488	443	401		
576	576	546		
608	615	591		
621	586	542		
617	535	451		
593	482	363		
541	424	293		
470	366	249		
395	311	227	Z98-99=-Ln ((10-13)/(9-12))=	0.37
324	263	211	Z99-00=-Ln ((10-13)/(9-12))=	0.30
263	221	193		
213	185	171		
174	157	148		
141	132	125		
114	112	103		
92	94	83		
73	78	65		
58	65	50		
46	53	38		
37	44	29		

Table 14. **Yield per recruit analysis on the basis of area-specific partial recruitment (PR) vectors.**

Age	FL (cm)	Wt (kg)	PR-Shelf	PR-NF	PR-both	M
0	68	4.68	0.05	0.05	0.05	0.2
1	100	13.33	0.40	0.15	0.32	0.1
2	119	21.38	0.70	0.20	0.53	0.1
3	130	27.17	1.00	0.30	0.77	0.1
4	140	33.22	1.00	0.50	0.83	0.1
5	149	39.34	1.00	0.60	0.87	0.1
6	158	46.12	1.00	0.75	0.92	0.1
7	166	52.74	1.00	0.90	0.97	0.1
8	174	59.92	0.80	0.95	0.85	0.1
9	181	66.69	0.60	1.00	0.73	0.1
10	188	73.92	0.40	1.00	0.60	0.1
11	195	81.63	0.20	1.00	0.47	0.1
12	201	88.62	0.10	1.00	0.40	0.1
13	206	94.73	0.10	1.00	0.40	0.2
14	212	102.40	0.10	1.00	0.40	0.2
15	217	109.09	0.10	1.00	0.40	0.2
16	221	114.63	0.10	1.00	0.40	0.2
17	226	121.81	0.10	1.00	0.40	0.2
18	230	127.74	0.10	1.00	0.40	0.2
19	233	132.31	0.10	1.00	0.40	0.2
20	237	138.57	0.10	1.00	0.40	0.2
21	240	143.38	0.10	1.00	0.40	0.2
22	243	148.29	0.10	1.00	0.40	0.2
23	246	153.31	0.10	1.00	0.40	0.2
24	249	158.44	0.10	1.00	0.40	0.2
25	252	163.67	0.10	1.00	0.40	0.2
26	254	167.22	0.10	1.00	0.40	0.2
27	256	170.81	0.10	1.00	0.40	0.2
28	258	174.46	0.10	1.00	0.40	0.2
29	260	178.15	0.10	1.00	0.40	0.2

Reference	F	Average wt	Yield
	0.05	47.2	8.6
	0.10	43.5	13.3
	0.15	40.3	15.8
F0.1	0.18	38.7	16.6
	0.20	37.6	17.0
	0.25	35.3	17.6
	0.30	33.3	17.7
Fmax	0.31	32.9	17.7
	0.35	31.6	17.7
	0.40	30.1	17.5
	0.45	28.9	17.3
	0.50	27.7	17.0

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

Alternate Formulations

	F0.1	Yield
Original (M=.1, PR=1)	0.08	19.33
Increase M to .2	0.09	15.90
PR-Shelf	0.20	15.41
PR-NF	0.14	18.10
PR-both	0.18	16.67

Table 15. Age- and sex-structured population model for porbeagle, fit to catch at length and CPUE data by season/area.

Run	Details	Female spawners					Total biomass (000t)					Exploitation rates in 2000			
		1961	1991	2001	1991/1961	2001/1961	1961	1991	2001	1991/1961	2001/1961	Age 2	Age 5	Age 8	#NAME?
base	Base case: M increases at maturity; fixed selectivity; combined growth curve	63694	16618	6075	0.26	0.10	38967	13260	4409	0.34	0.11	0.16	0.25	0.26	-543
run2	As above but with no recruitment deviates	64710	18385	7500	0.28	0.12	39589	14357	4991	0.36	0.13	0.14	0.22	0.23	-405
run3	Estimating selectivity and recruitment deviates	69186	15048	2612	0.22	0.04	42327	12461	1572	0.29	0.04	0.41	0.64	0.80	-1005
run4	Estimating selectivity without recruitment deviates	69664	15273	2934	0.22	0.04	42619	12908	1928	0.30	0.05	0.35	0.52	0.65	-992
run5	Estimating selectivity and recruitment deviates with no increased mortality	100979	29606	13847	0.29	0.14	44317	16500	7695	0.37	0.17	0.14	0.21	0.26	-918

		B0	Fmsy	MSY/	MSY(t)	Bmsy/B0	Bmsy	B2001	B2001/Bmsy
base	Base case	38967	0.046	0.027	1069	0.63	24402	4409	0.18
run2	As above but with no recruitment deviates	39589	0.046	0.027	1086	0.63	24791	4991	0.20
run3	Estimating selectivity and recruitment deviates	42327	0.047	0.027	1138	0.62	26362	1572	0.06
run4	Estimating selectivity without recruitment deviates	42619	0.047	0.027	1143	0.62	26519	1928	0.07
run5	Estimating selectivity and recruitment deviates with no increased mortality	44317	0.063	0.024	1079	0.48	21275	7695	0.36

Table 16. Life table analysis of porbeagle shark, including simulations under various fishing strategies. The intrinsic rate of population growth (r) must be greater than 0 if the population is to grow.

Input parameters:

F=	0.00
Mo = (first year)	0.20
Mi = (immature)	0.10
Mm= (mature)	0.20
Tmat=	13
Tmax=	45
Fec (mx) > age 1	1.95

Age (x)	Fecundity	Fec/2	Selectivity Area Shelf	Selectivity Area NF	Combined
0	0	0	0.05	0.05	0.05
1	0	0	0.40	0.15	0.32
2	0	0	0.70	0.20	0.53
3	0	0	1.00	0.30	0.77
4	0	0	1.00	0.50	0.83
5	0	0	1.00	0.60	0.87
6	0	0	1.00	0.75	0.92
7	0	0	1.00	0.90	0.97
8	0	0	0.80	0.95	0.85
9	0	0	0.60	1.00	0.73
10	0	0	0.40	1.00	0.60
11	0.35	0.18	0.20	1.00	0.47
12	0.90	0.45	0.10	1.00	0.40
13	1.95	0.98	0.10	1.00	0.40
14	3.00	1.50	0.10	1.00	0.40
15	3.28	1.64	0.10	1.00	0.40
16	3.74	1.87	0.10	1.00	0.40
17	3.86	1.93	0.10	1.00	0.40
18	3.90	1.95	0.10	1.00	0.40
19	3.90	1.95	0.10	1.00	0.40
20	3.90	1.95	0.10	1.00	0.40

Life Table Analysis Model Output

Mo	Mi	Mm	F	Selectivity	r
0.2	0.1	0.1	0	0	0.071
		0.2			0.051
		$F_{replacement} =$	0.080	1	-0.028
				Shelf	0.012
				NF	-0.005
				Both	0
		$F_{msy} =$	0.04	1	0.013
				Shelf	0.031
				NF	0.024
				Both	0.029

Fig. 1. Map of the eastern coast of Canada, showing major fishing grounds and NAFO divisions. The 200-m contour is shown.

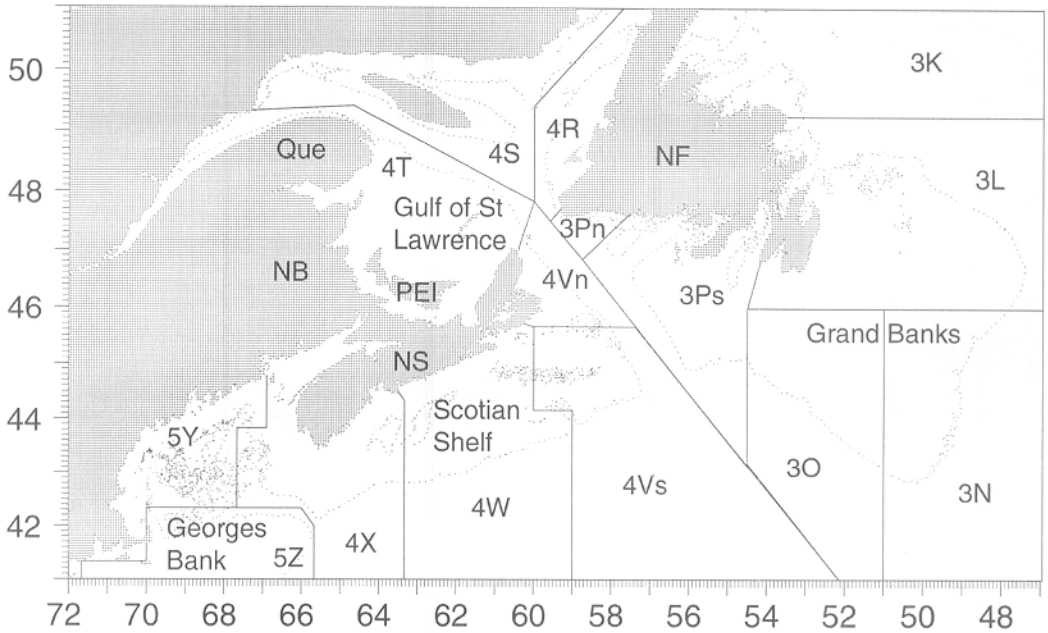
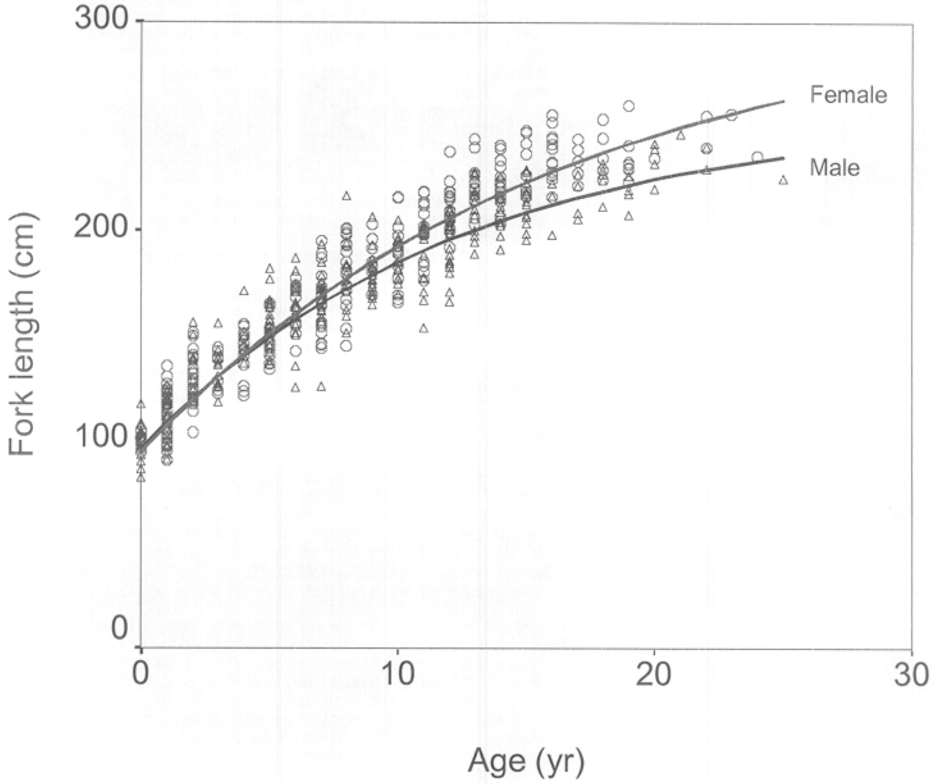


Fig. 2. von Bertalanffy growth curve for porbeagle shark, showing a reduction in growth rate for both sexes at the age of sexual maturity. The age-length table is based on the sex-combined growth model, substituting observed lengths for ages 0 and 1. Ages have been validated to age 11.



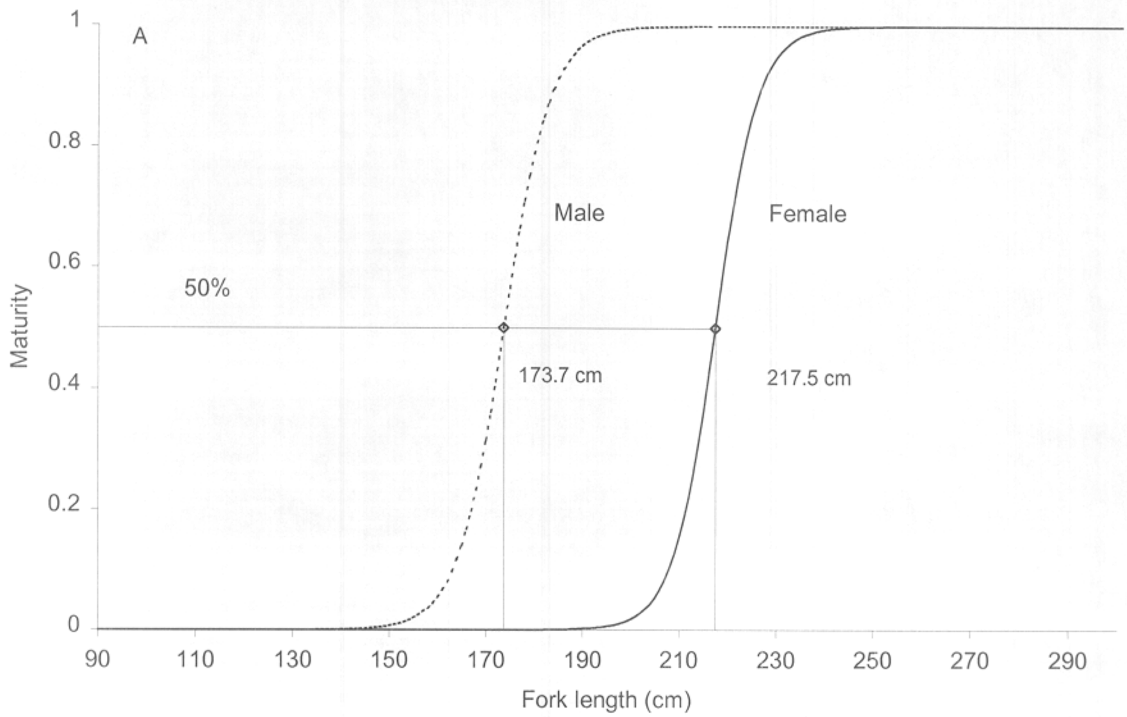
Age	FL (cm)	Wt. At age (kg)
0	68	4.68
1	100	13.33
2	119	21.38
3	130	27.17
4	140	33.22
5	149	39.34
6	158	46.12
7	166	52.74
8	174	59.92
9	181	66.69
10	188	73.92
11	195	81.63
12	201	88.62
13	206	94.73
14	212	102.40
15	217	109.09
16	221	114.63
17	226	121.81
18	230	127.74
19	233	132.31
20	237	138.57

Von Bertalanffy growth model

$$L_t = L_\infty \,(1-e^{-K(t-t_0)})$$

	L_∞	K	t_0	N
Combined	289.4	0.066	-6.06	576
Male	257.7	0.080	-5.78	283
Female	309.8	0.061	-5.90	291

Fig. 3. Maturity ogive for porbeagle shark, based on examination of 393 males and 382 females. Fitted lines are from logistic regression.



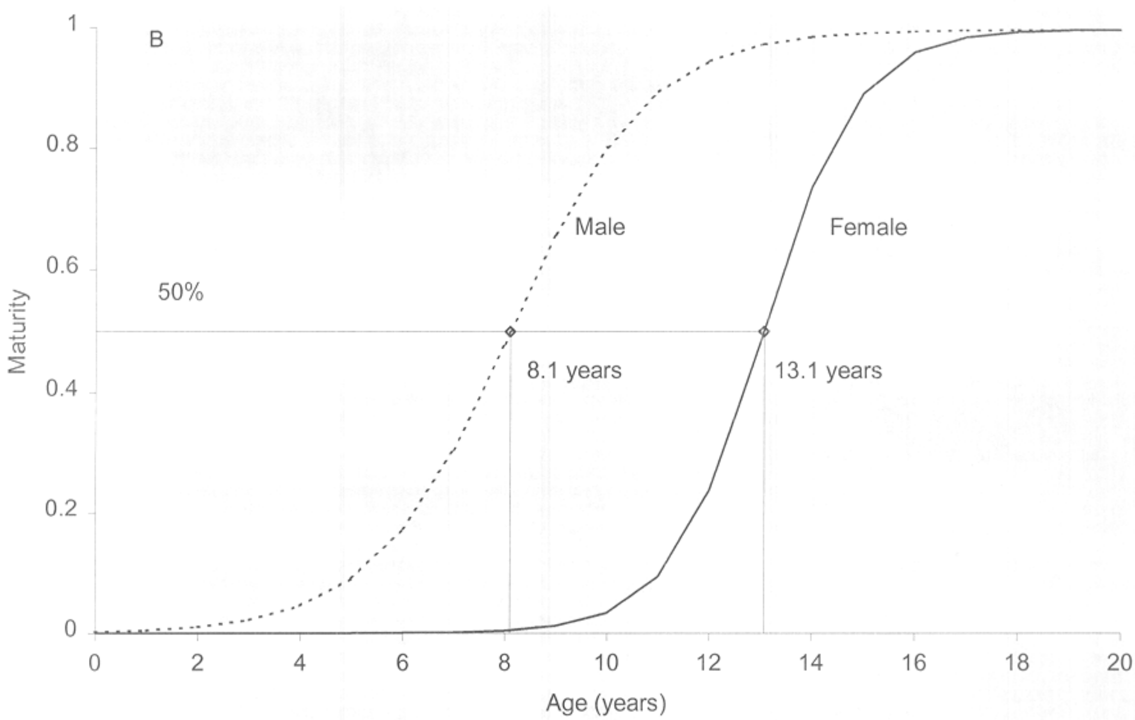
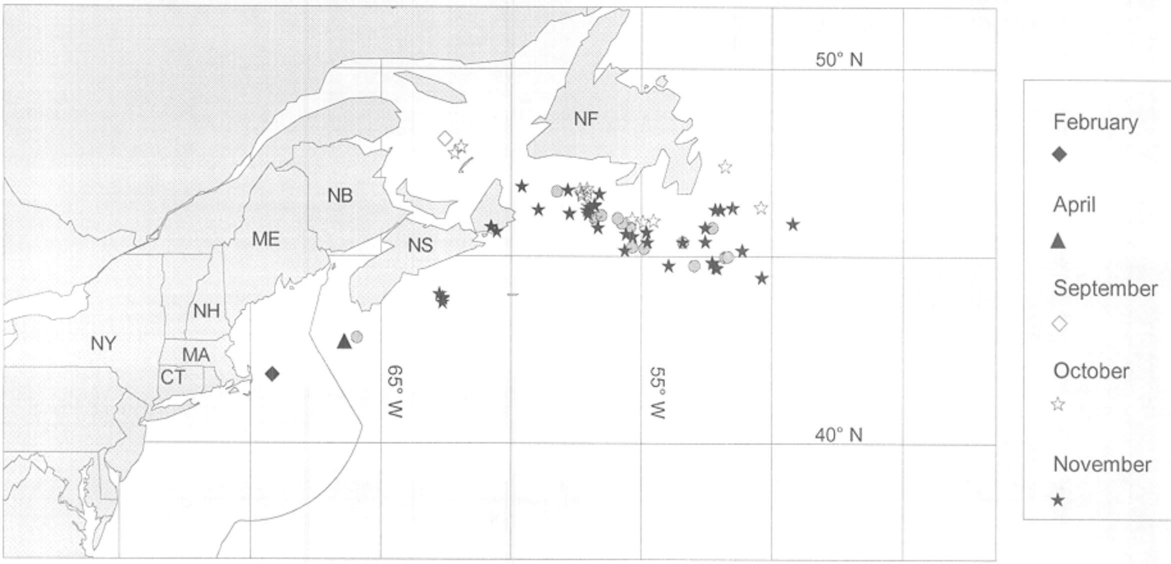


Fig. 4. (Top) Locations of pregnant female porbeagle sharks. Females give birth to an average of 3.9 pups in late winter or early spring. (Bottom) Monthly progression of pregnancy in females of mature size. The gestation period is 8-9 months while the reproductive cycle is 1 year.



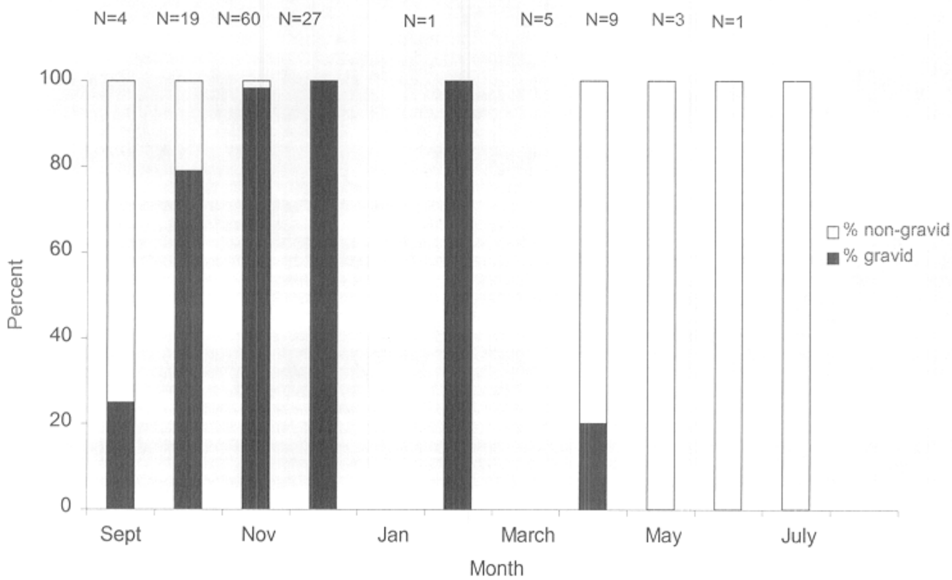


Fig. 5. Stomach fullness ratio by month (Top) and length-stomach volume relationship (Bottom) for porbeagle sharks.

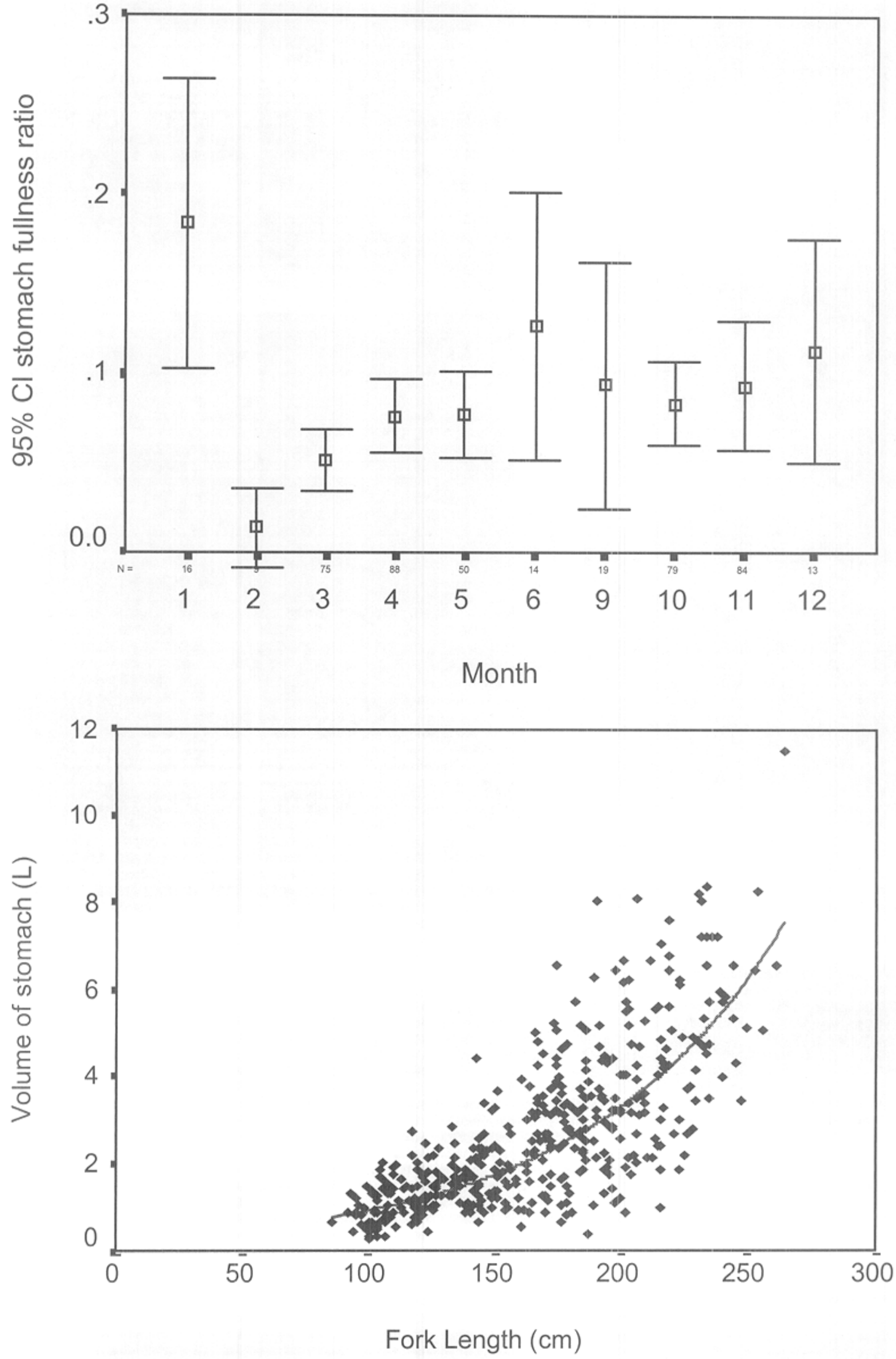


Fig. 6. Percentage by weight of major food categories in the porbeagle diet by size groupings and season.

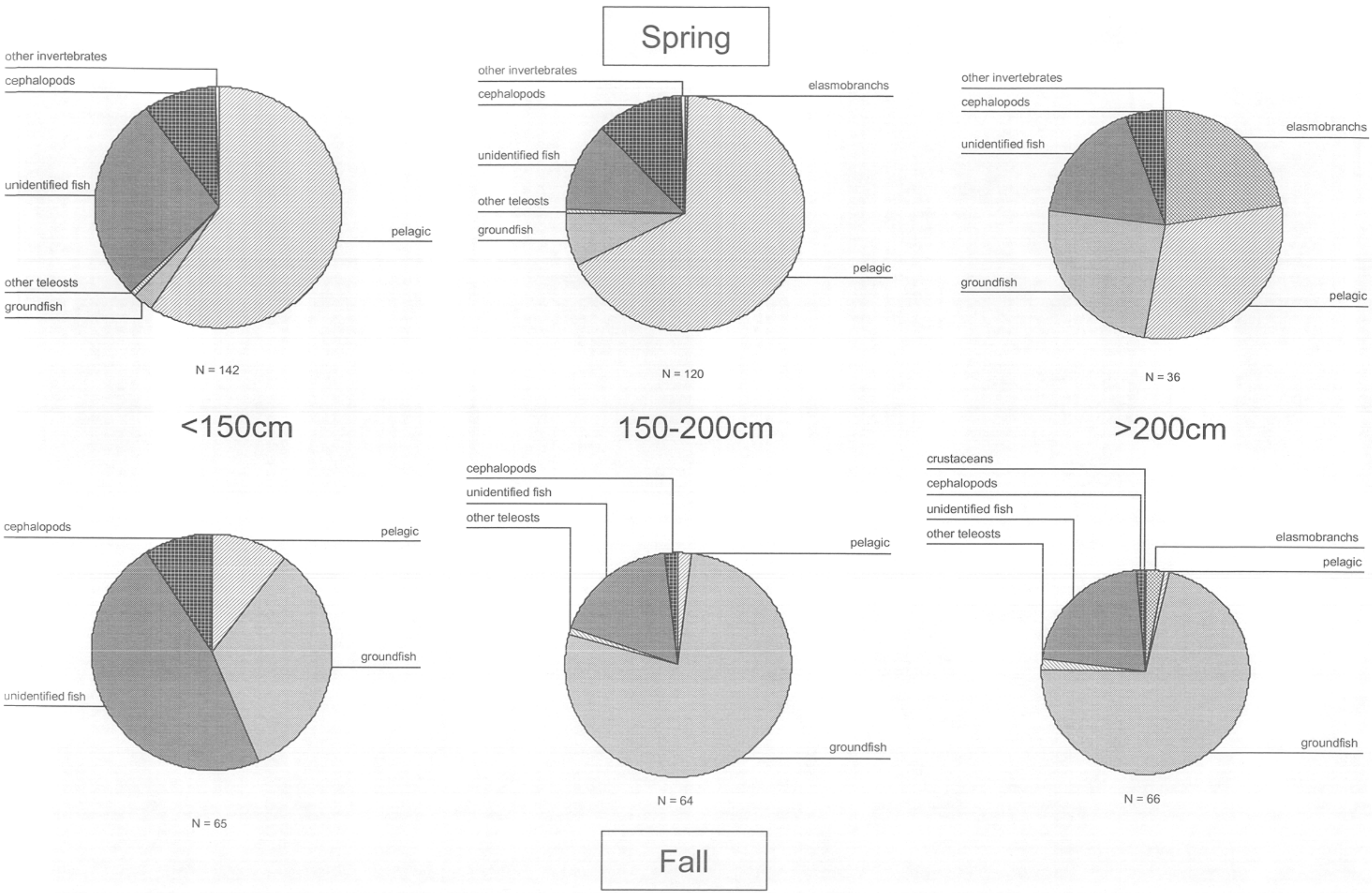


Fig. 7. Histograms of bottom depth for spring (A) and fall (B), and month by month error bar plot of temperatures associated with catch (C) for 1999.

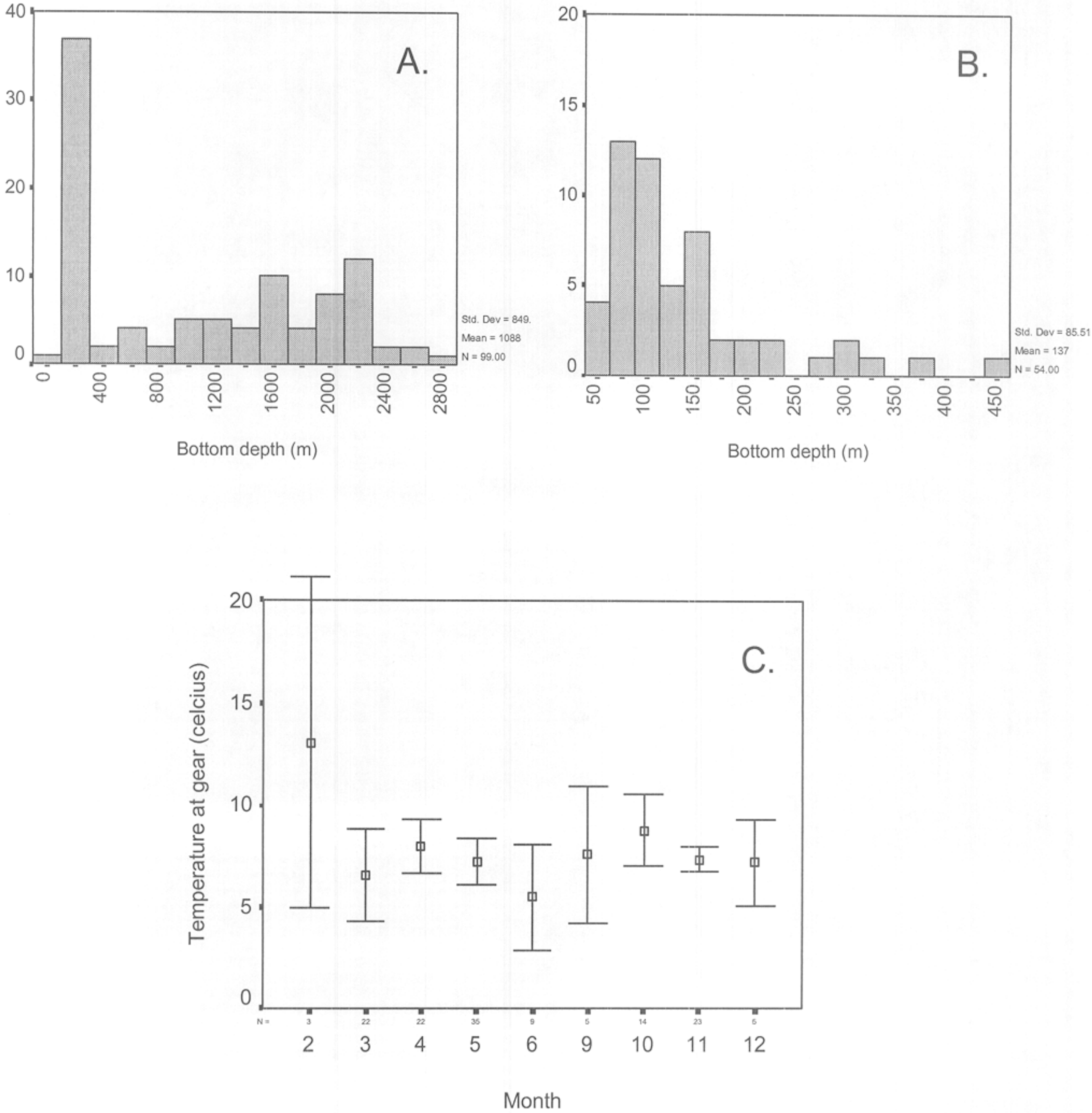


Fig. 8. Catch and associated temperature at mid-gear depth for 1999.

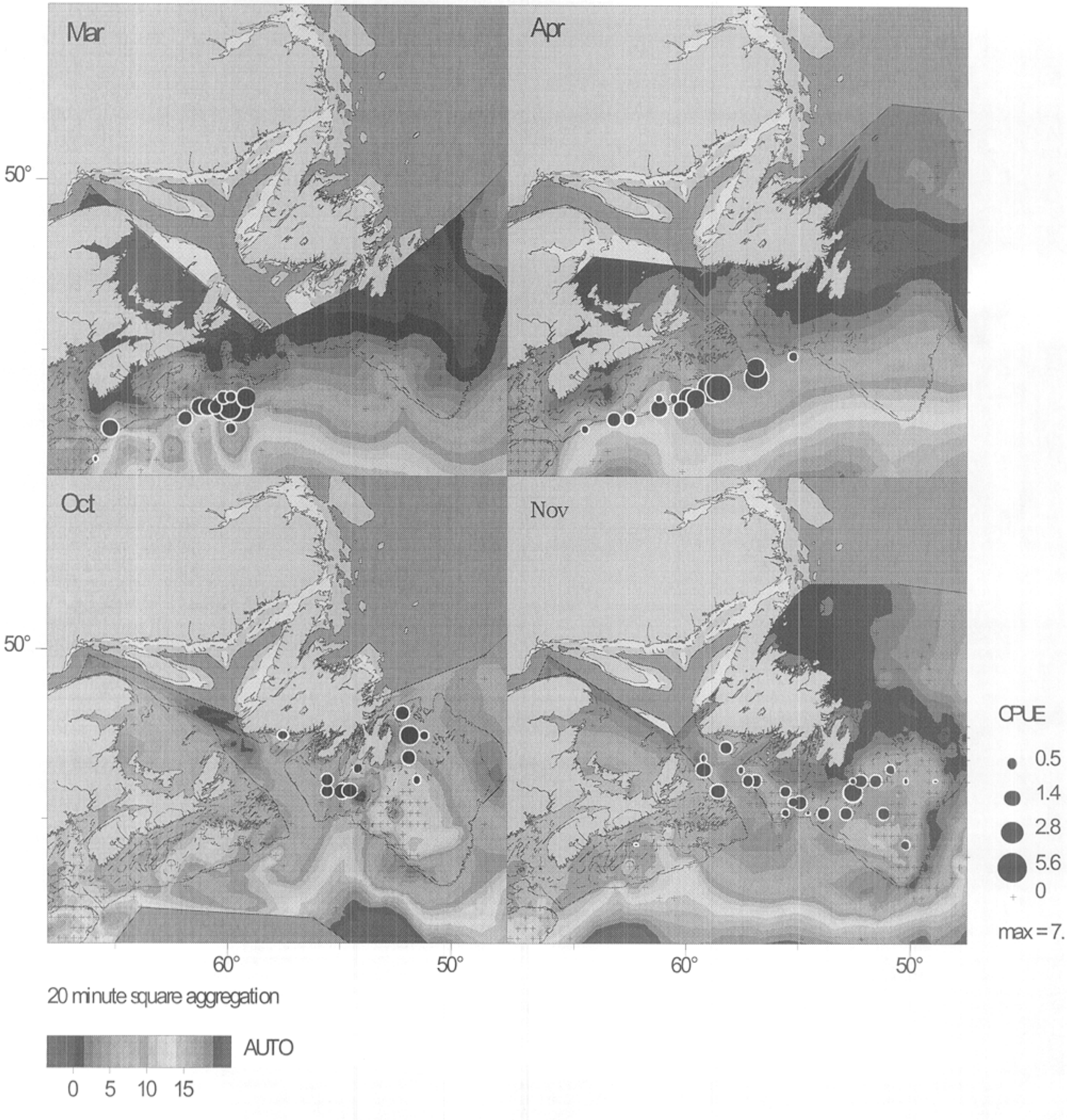


Fig. 9. Reported landings of porbeagle in the NW Atlantic by country.

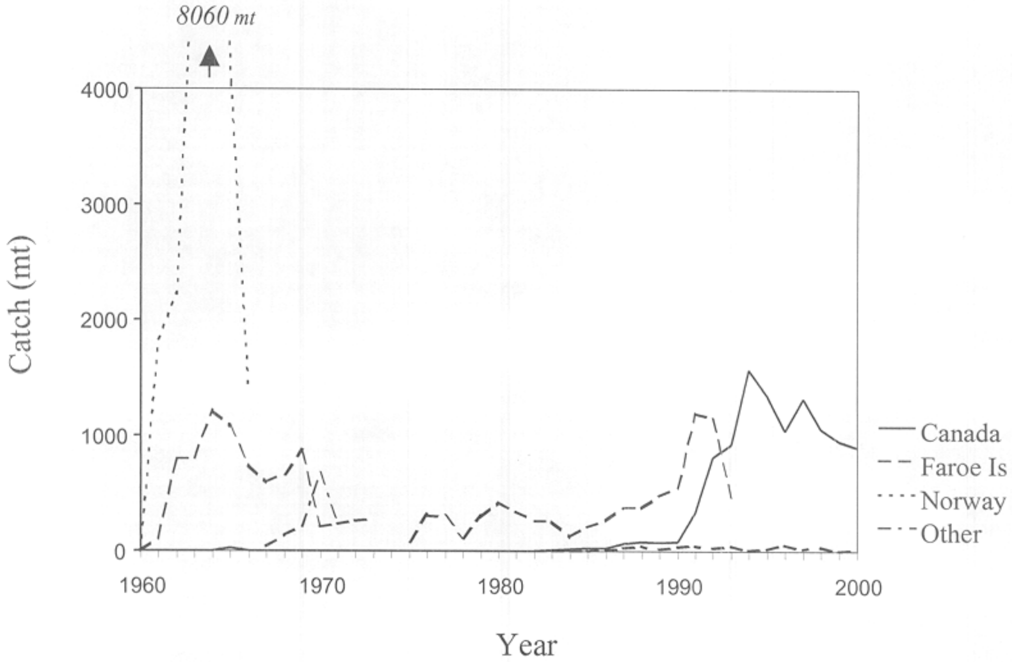


Fig. 10. Canadian landings by the inshore (<100') and offshore (>100') fleet since 1991.

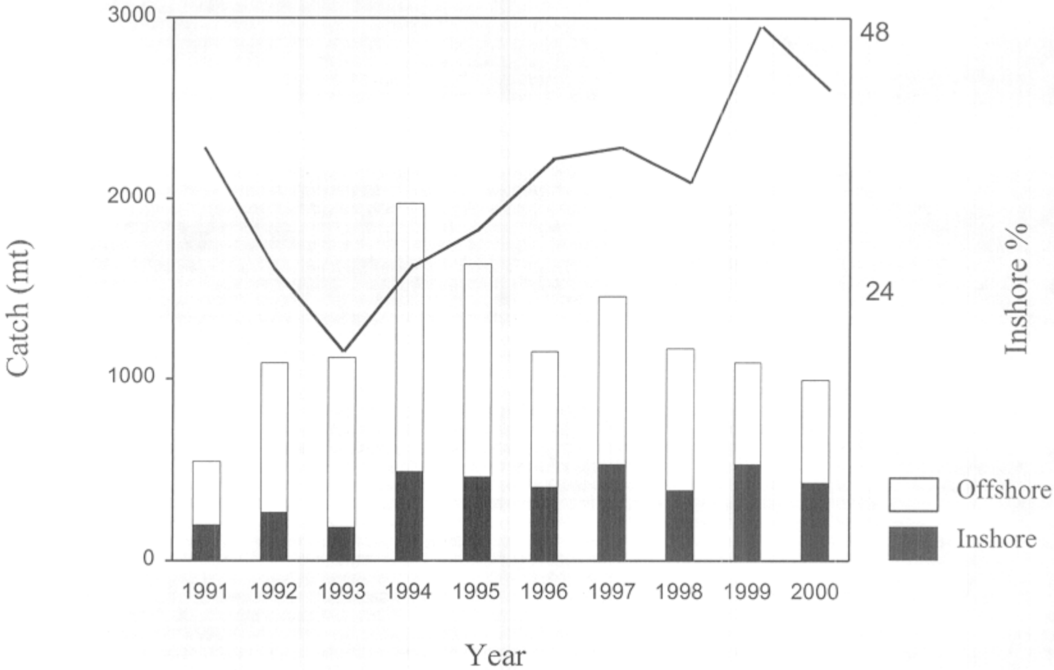


Fig. 11. Catch location and associated length composition for inshore and offshore vessels in spring (Jan.-Jun.) and fall (Jul.-Dec.) of 1999-2000.

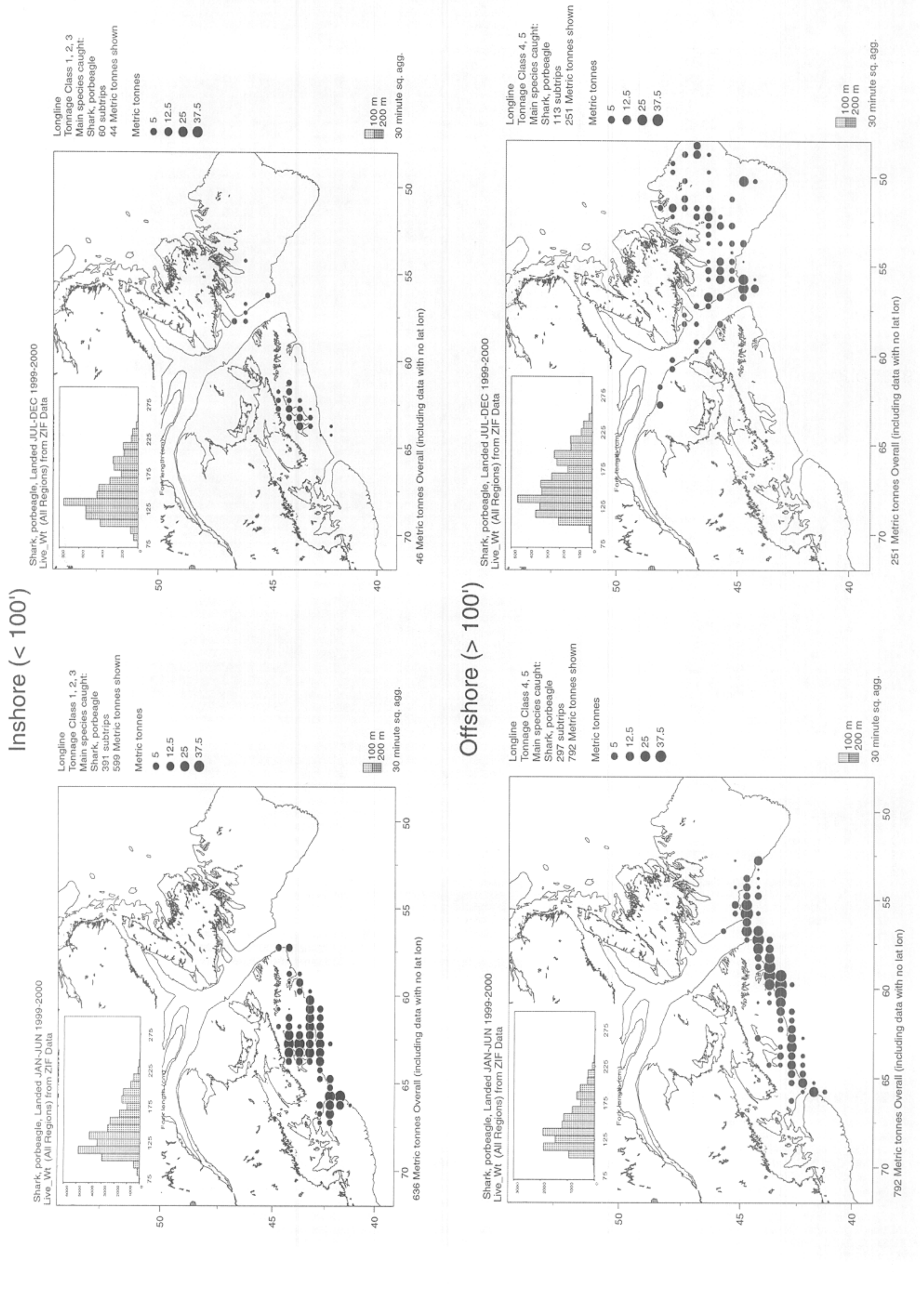


Fig. 12. Length composition of porbeagle catches in the 2000 spring and fall fishery.

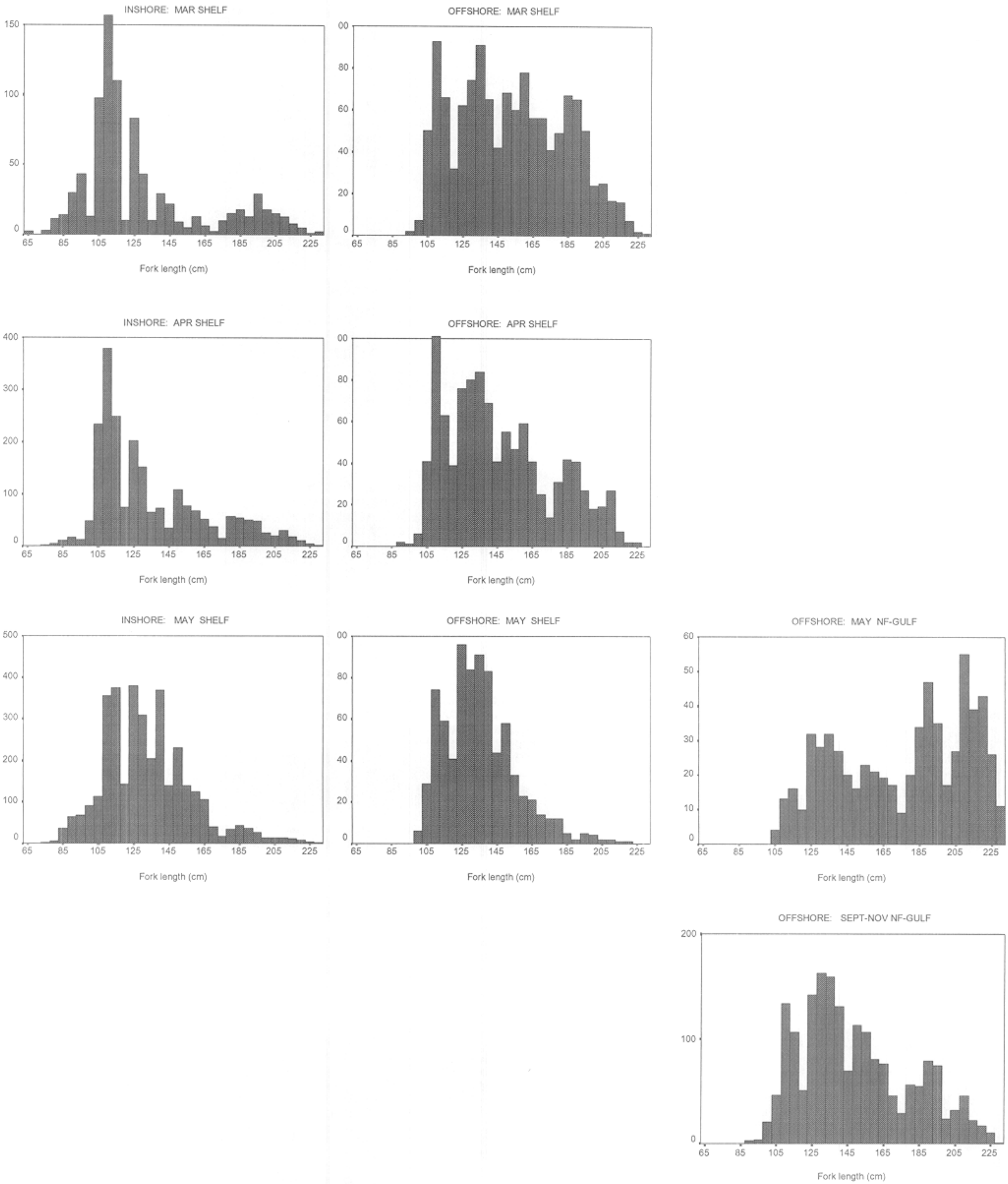


Figure 13. Percentage of females in the 1998-2000 commercial catch by month and area. There is no evidence of large scale segregation by sex among immature porbeagles. However, the along-shelf, sex-specific migration of the larger sharks in the spring is clearly evident. Average sample size ~ 400; minimum sample size > 20. Fitted lines are LOESS curves.

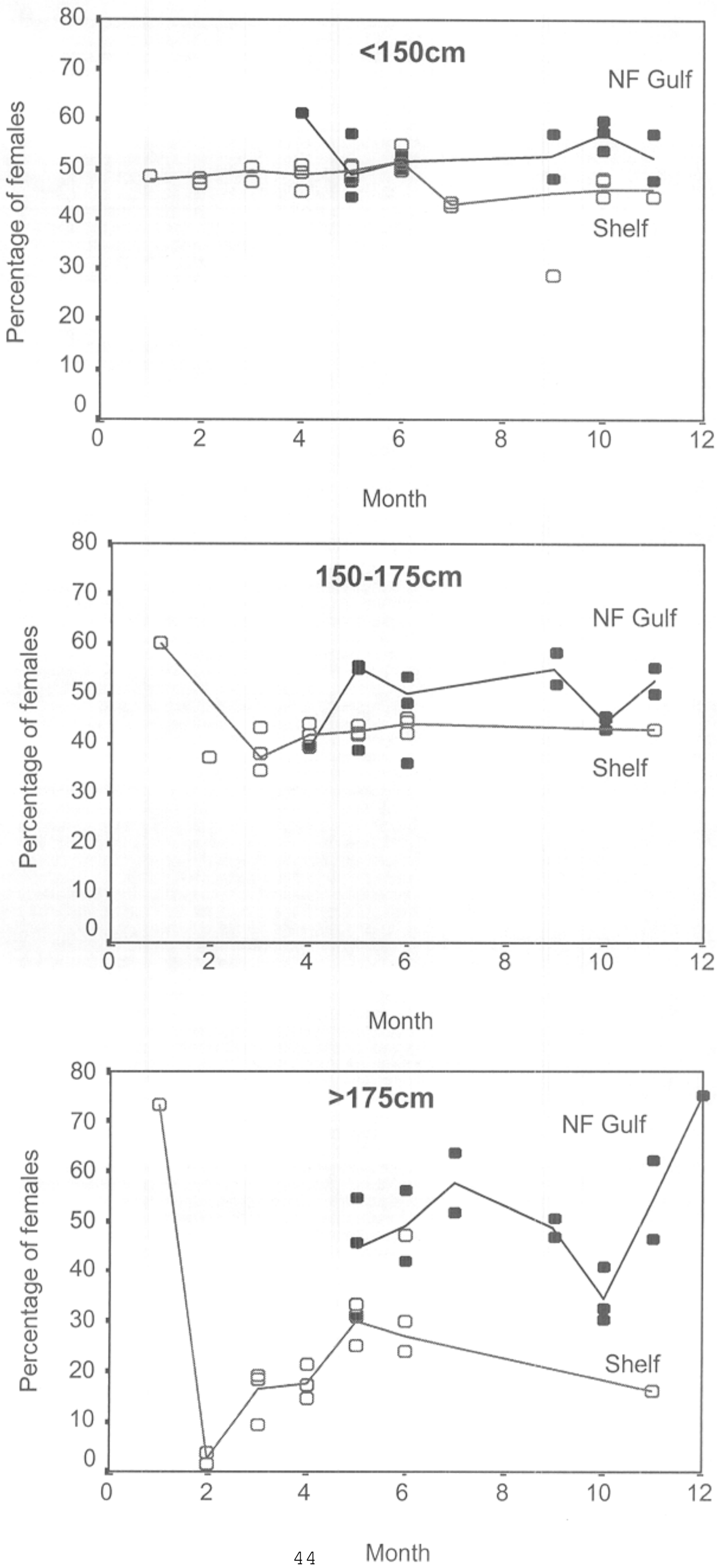


Fig. 14. Distance travelled versus forklength at recapture for tagged sharks at liberty > 1 yr. A LOESS curve has been fitted to the data. Larger sharks tend to travel further.

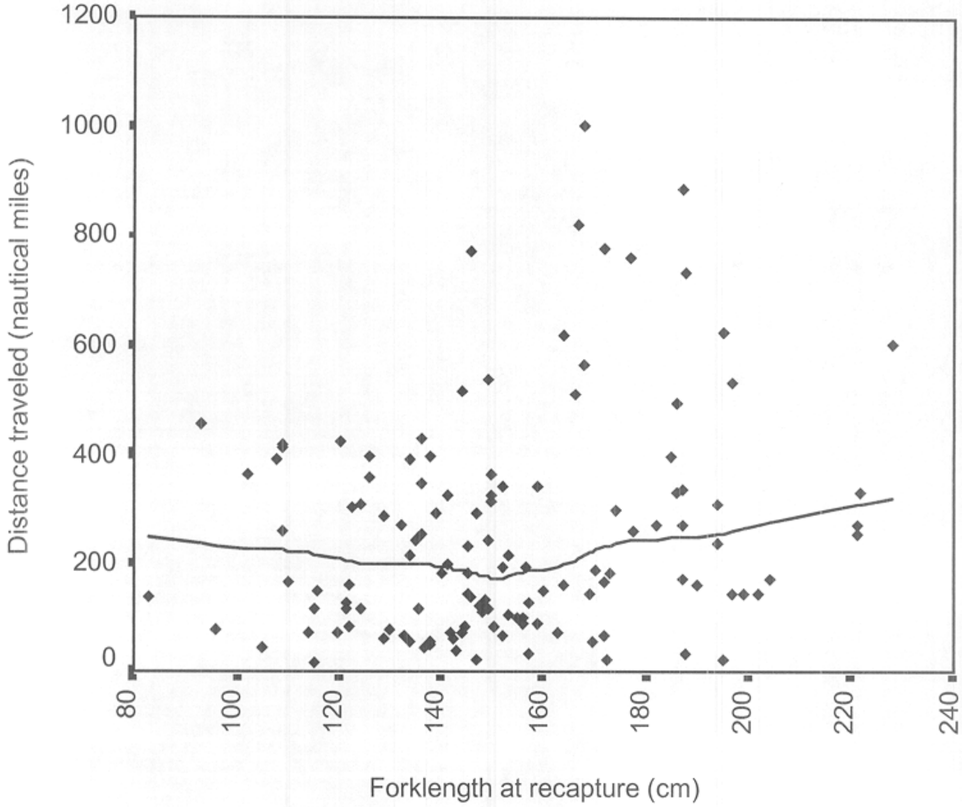


Fig. 15. Long term changes in the median fork length of porbeagle in the commercial catch by the offshore fleet on the mating grounds.

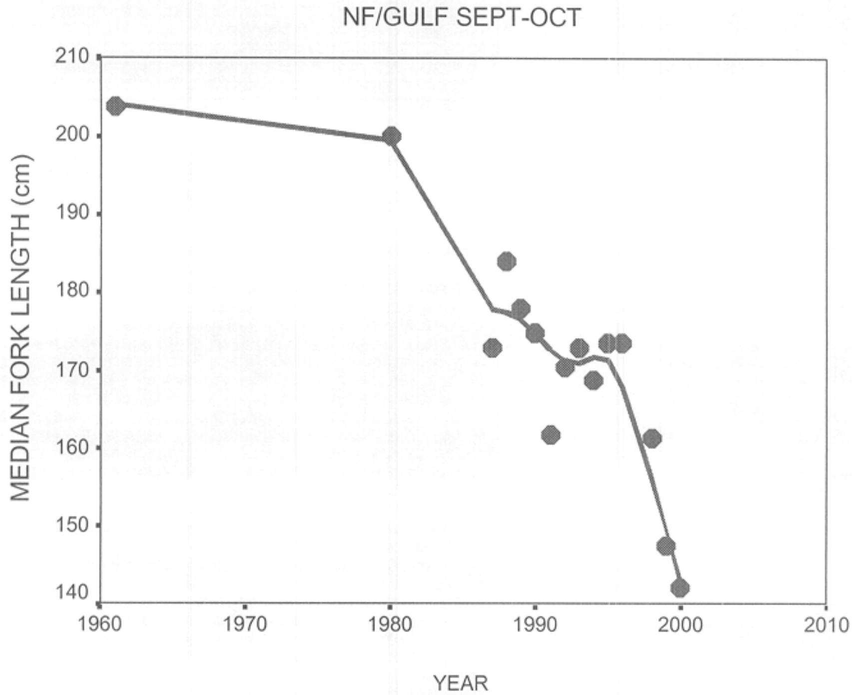
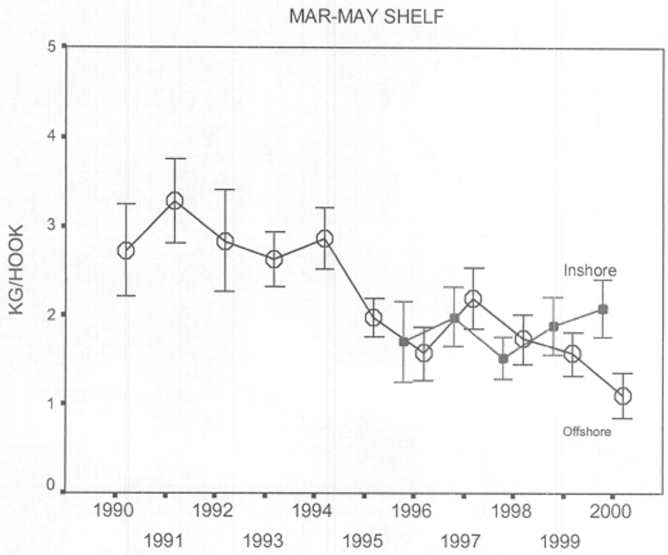


Fig. 16. Commercial catch rates (kg per hook) by the inshore and offshore fleets on the major fishing grounds, aggregated across all sizes of shark.



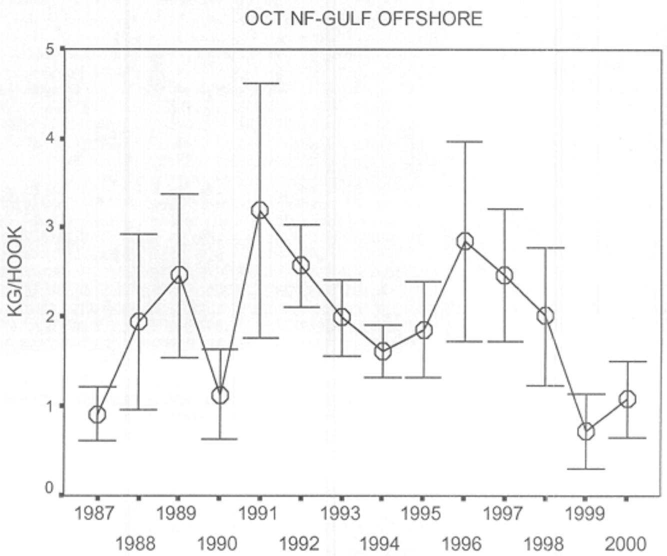


Fig. 17. Commercial catch rates (ln-transformed numbers per hook) by the inshore and offshore fleets on the major fishing grounds. Sharks > 200 cm FL were classified as mature, while those < 200 cm FL were classified as immature.

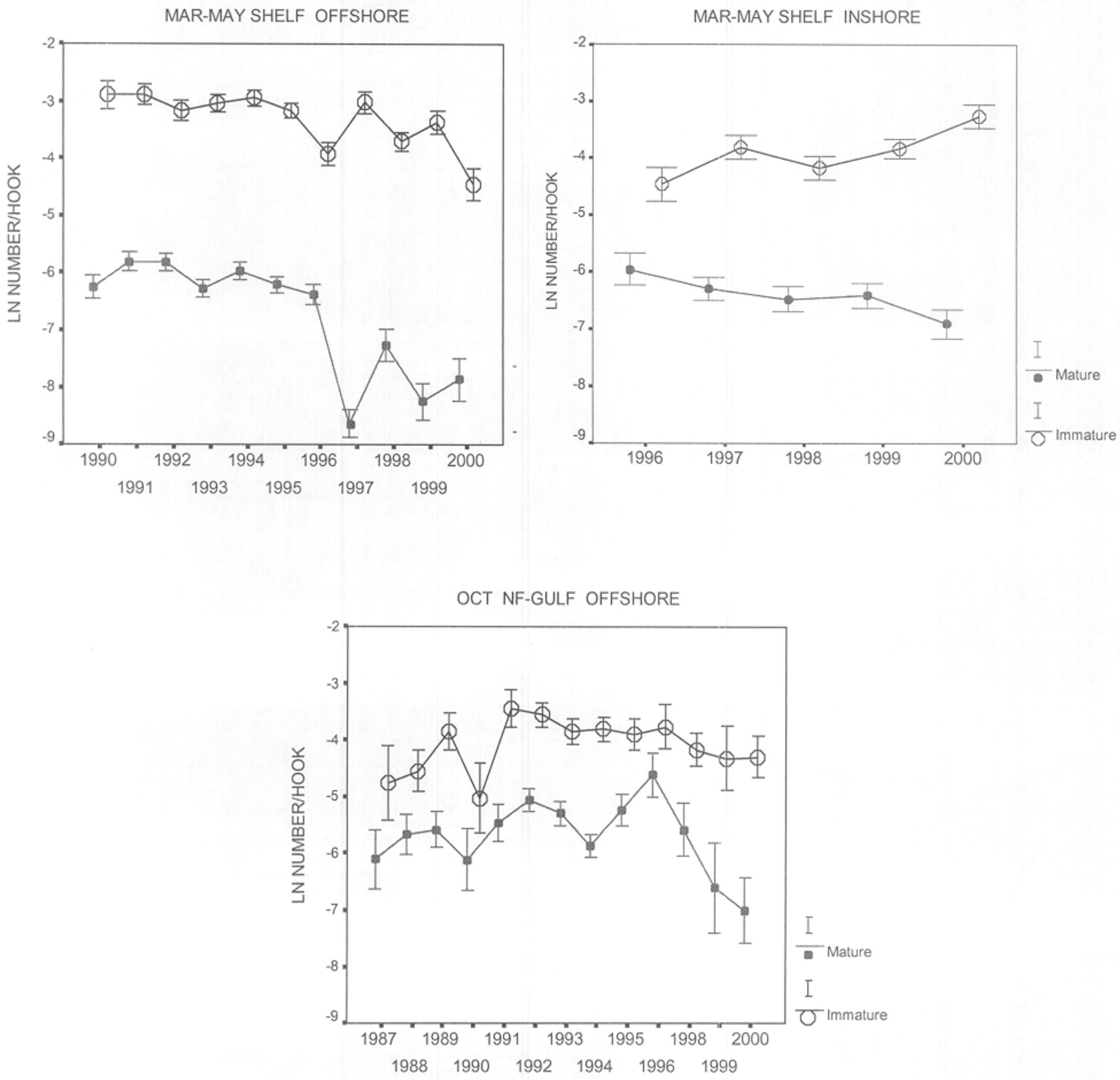


Fig. 18. Standardized catch rate (number/hook) of sexually mature (>200 cm FL) and immature porbeagle shark. Factors in the analysis included year, month, area and CFV. See Tables 10-11 for analysis results.

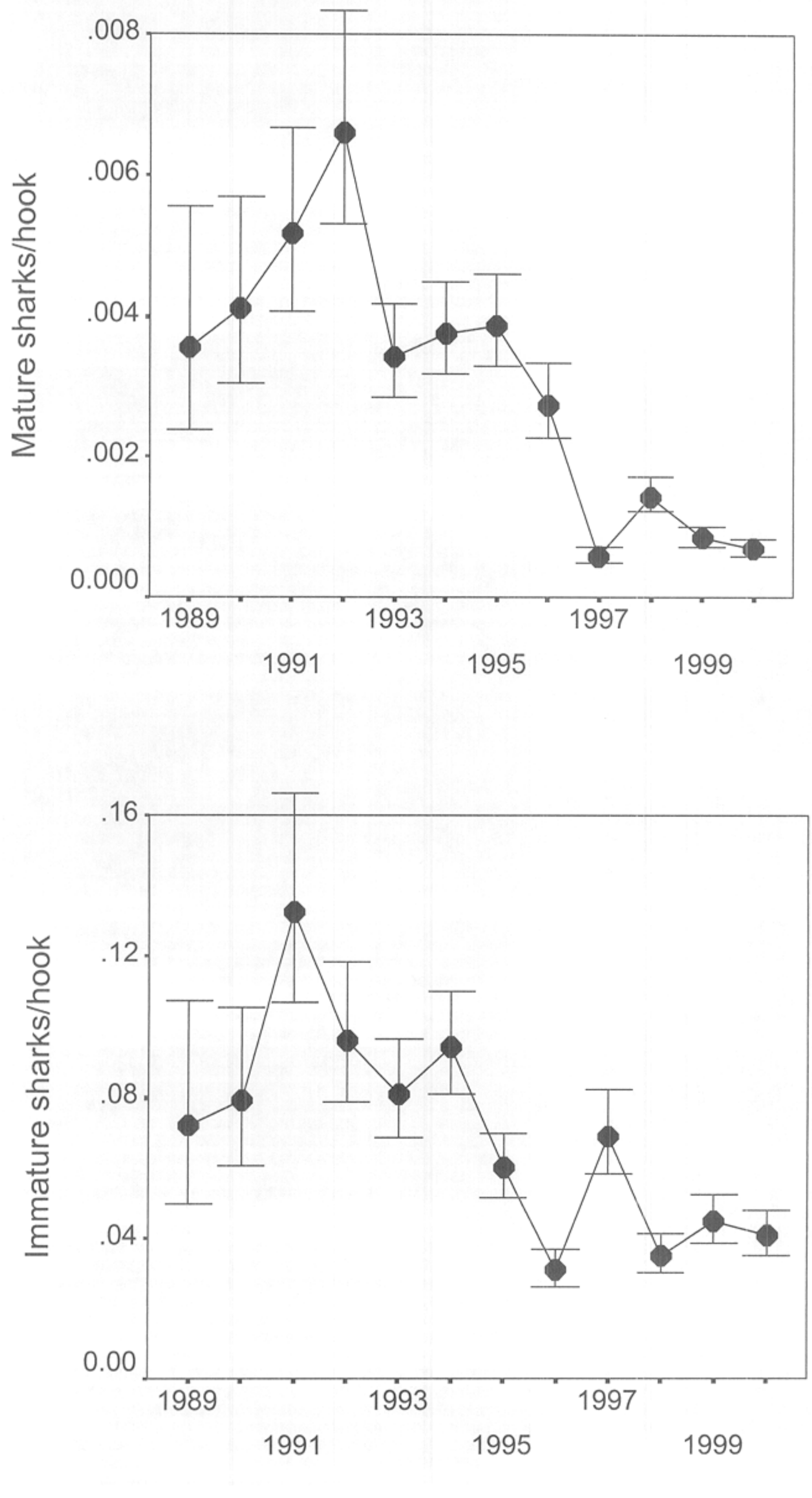


Fig. 19. Catch curves (ln-transformed numbers at age) by subarea used to calculate mortality rate (Z) over specified age ranges. The 1961 samples are from a virgin population, and thus Z=M. Decomposition of lengths to ages was based on the combined (across sexes) von Bertalanffy growth model except where indicated.

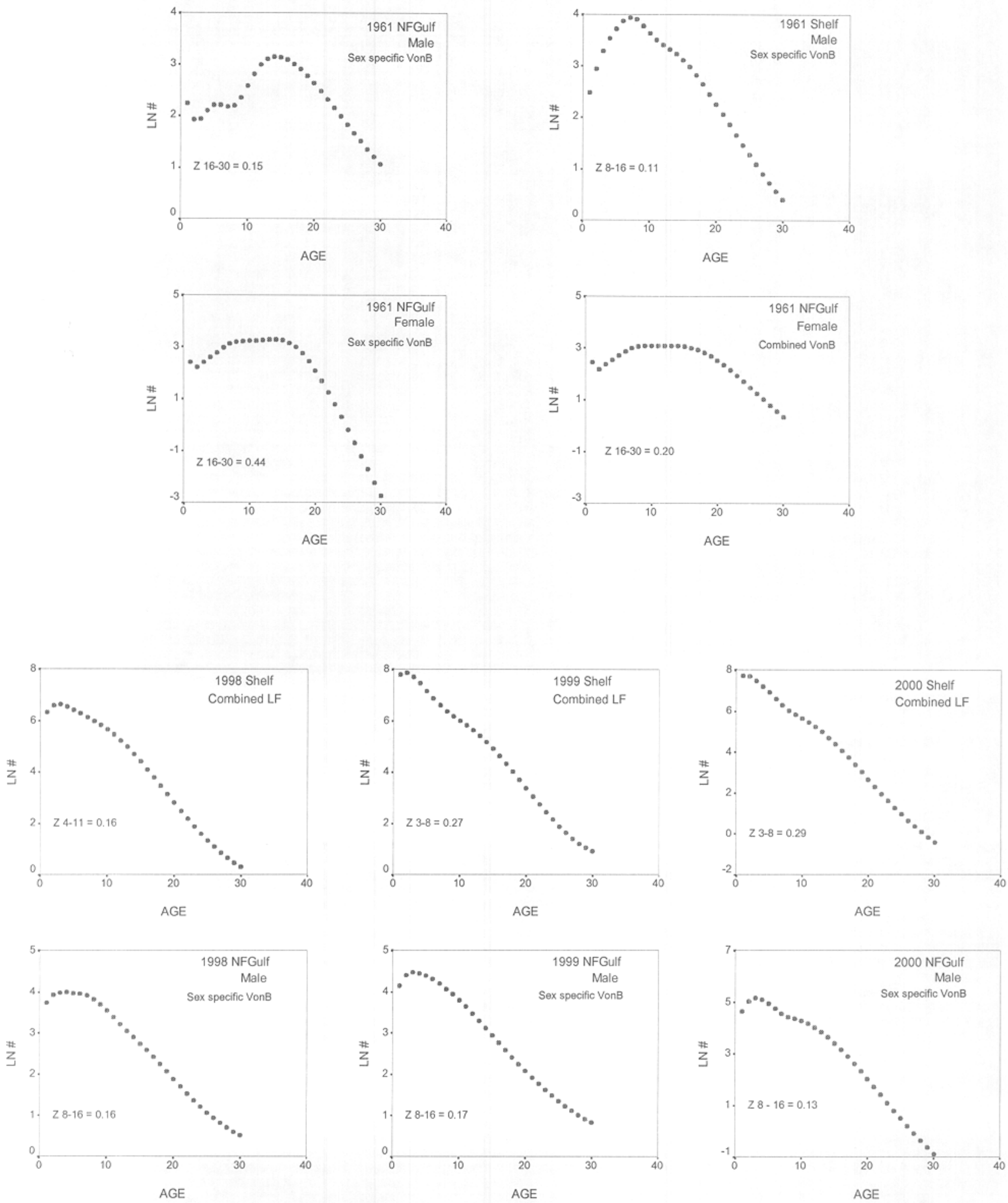


Fig. 19 cont'd.

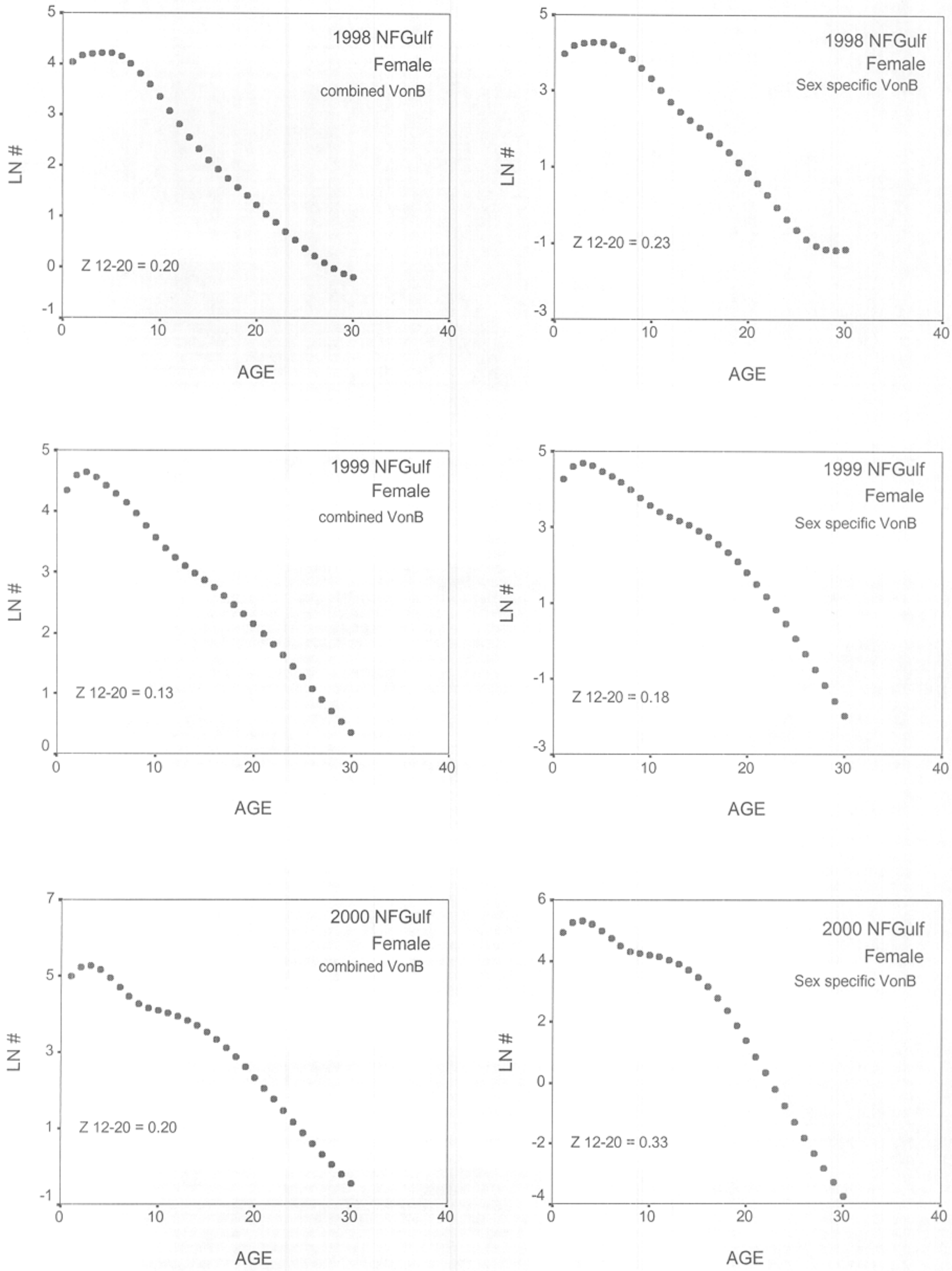

1998 NFGulf
Female
combined VonB
Z 12-20 = 0.20
1998 NFGulf
Female
Sex specific VonB
Z 12-20 = 0.23
1999 NFGulf
Female
combined VonB
Z 12-20 = 0.13
1999 NFGulf
Female
Sex specific VonB
Z 12-20 = 0.18
2000 NFGulf
Female
combined VonB
Z 12-20 = 0.20
2000 NFGulf
Female
Sex specific VonB
Z 12-20 = 0.33
LN #
AGE

Fig. 20. Frequency histograms of forklength at tagging. Most of the sharks tagged were <125 cm, corresponding to Ages 0-1.

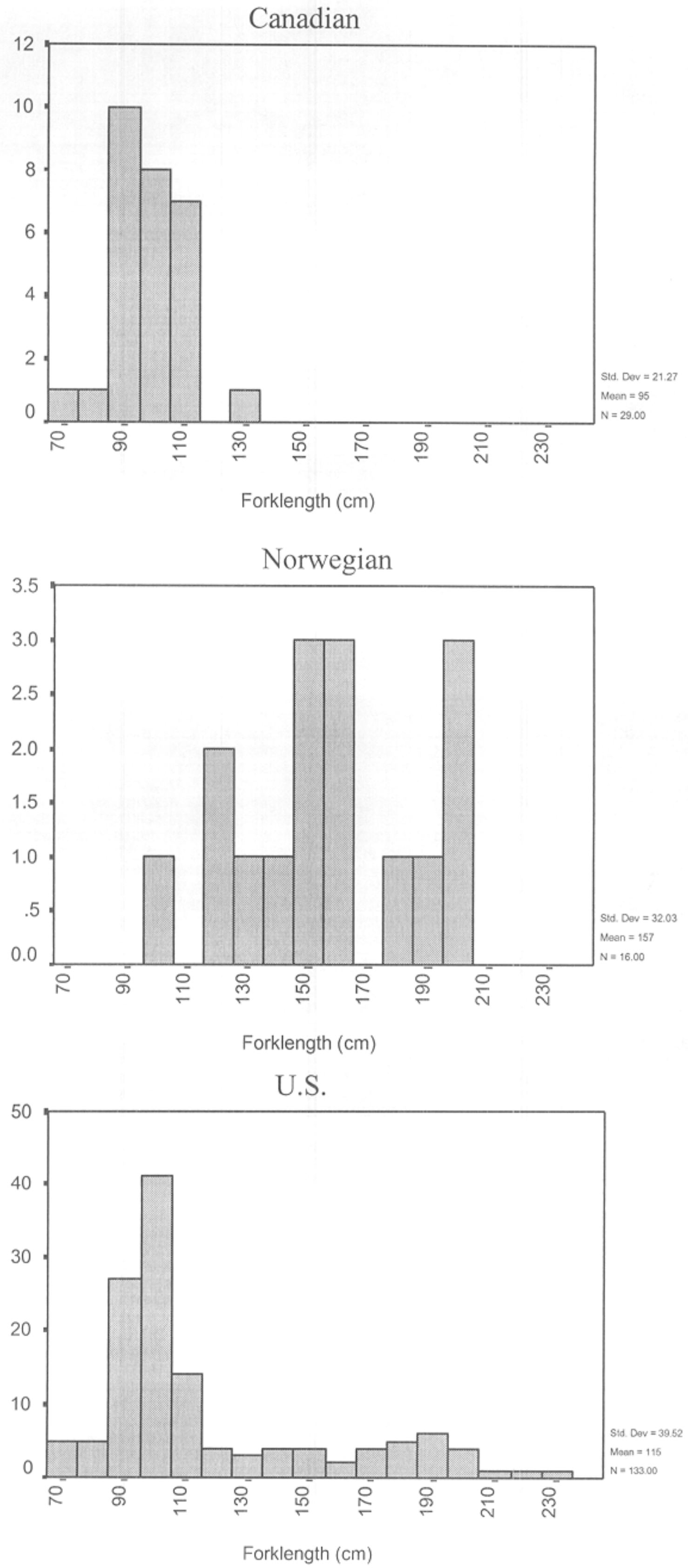
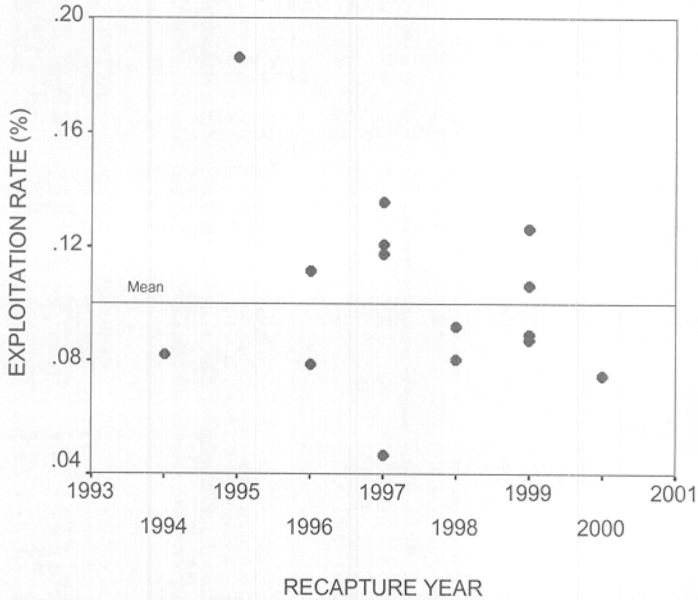


Fig. 21. Exploitation rate of porbeagle shark in recent years based on Petersen analysis of tag recaptures from Canadian and American tagging studies. The analysis was restricted to years with more than 3 recaptures and to sharks tagged at fork lengths < 125 cm; thus the exploitation rates are most applicable to the spring fishery on the Scotian Shelf. Exploitation rates have been divided by age-specific selectivity (Table 14) to calculate the fully-recruited exploitation rate.



STUDY	TAG_Y	INTE	TAGGED	RECAPYR	RECAP	PREV	LOSS	REPO	TAGM	EXPLOIT
US	1993	1	106	1994	3	0	.10	.90	.20	.08
US	1993	4	106	1997	5	6	.10	.90	.20	.12
US	1993	6	106	1999	3	13	.10	.90	.20	.09
Can/US	1994	1	171	1995	11	0	.10	.90	.20	.19
US	1994	2	131	1996	6	10	.10	.90	.20	.11
Can/US	1994	3	171	1997	9	17	.10	.90	.20	.14
US	1994	4	131	1998	4	22	.10	.90	.20	.09
US	1994	5	131	1999	5	26	.10	.90	.20	.13
Can/US	1995	1	295	1996	8	0	.10	.90	.20	.08
Can/US	1995	2	295	1997	6	9	.10	.90	.20	.05
Canadia	1995	3	179	1998	6	8	.10	.90	.20	.08
Can/US	1995	4	295	1999	10	21	.10	.75	.20	.11
Can/US	1996	1	74	1997	3	0	.10	.90	.20	.12
US	1997	2	99	1999	4	0	.10	.90	.20	.09
Can/US	1997	3	122	2000	3	4	.10	.70	.20	.07

Petersen equation:

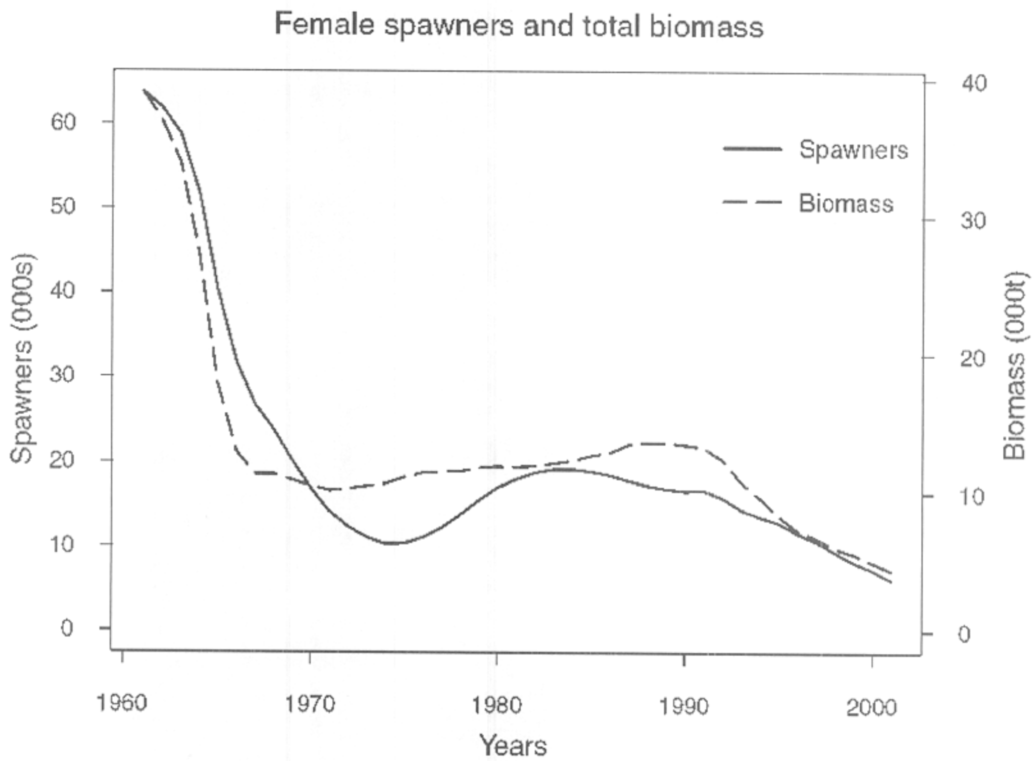
Exploitation rate = # recaptures / tags remaining

where

Tags remaining = (((# tagged) * (1 - (Pr tagmort)) - prev) * exp[(-Pr loss) * interval] * Pr reporting

Note: Exploitation is calculated for year of recapture and divided by age-specific selectivity

Fig. 22. Trends in biomass and spawner abundance (Top) and the spawner-recruit relationship (Bottom) for the base case model.



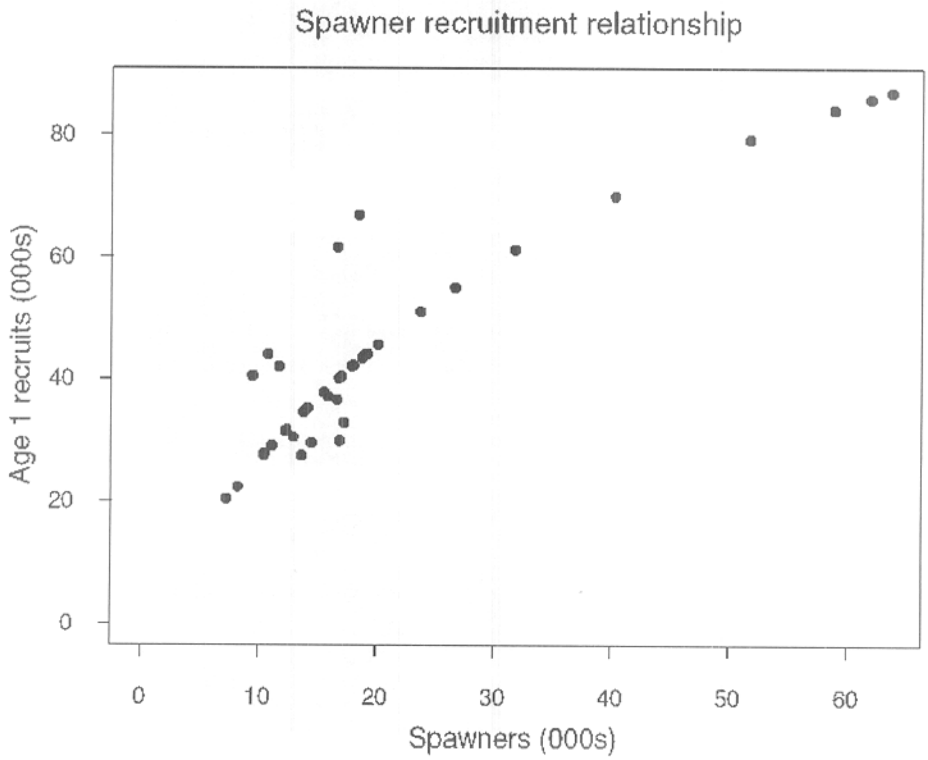


Fig. 23. Age- and sex-specific selectivity curves fixed in the base case model.

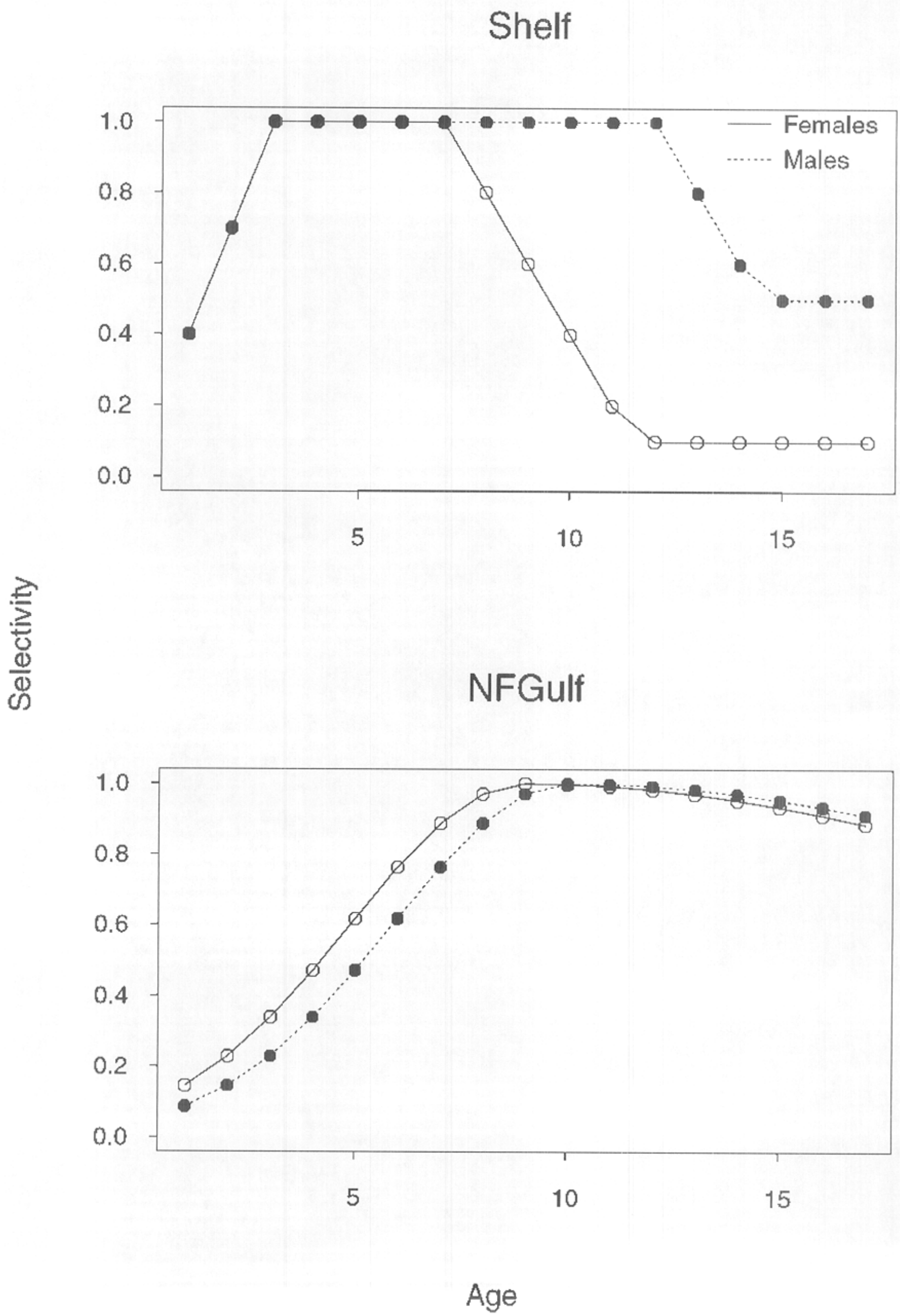


Fig. 24. Trend in fishing mortality (F) from the base case population model.

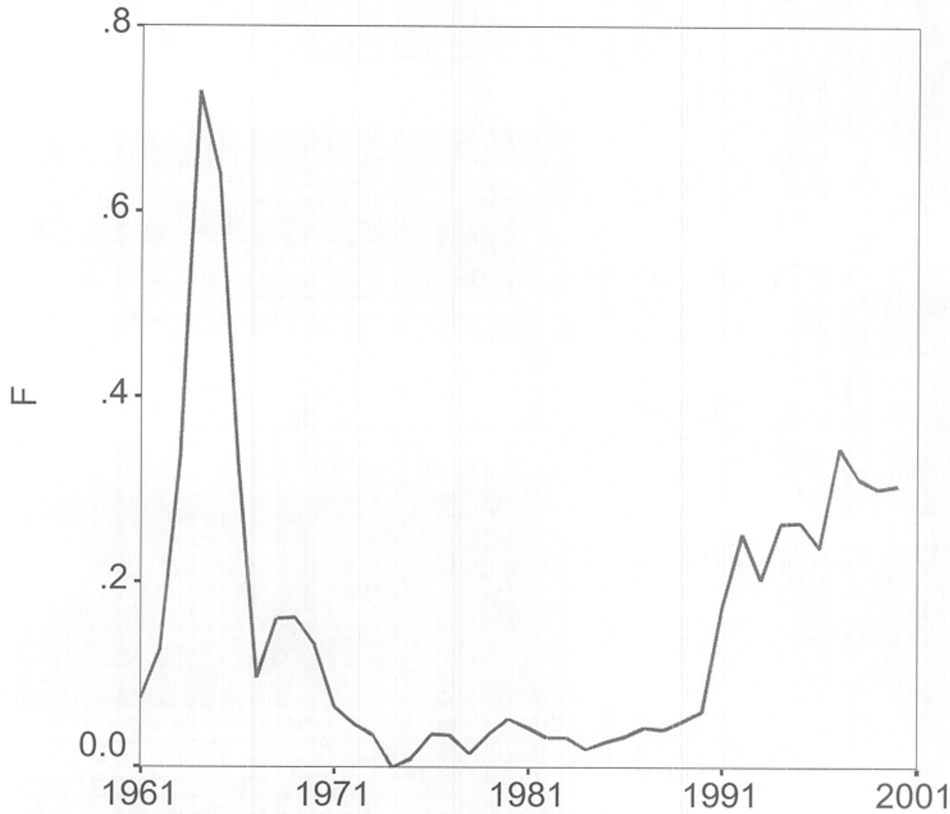
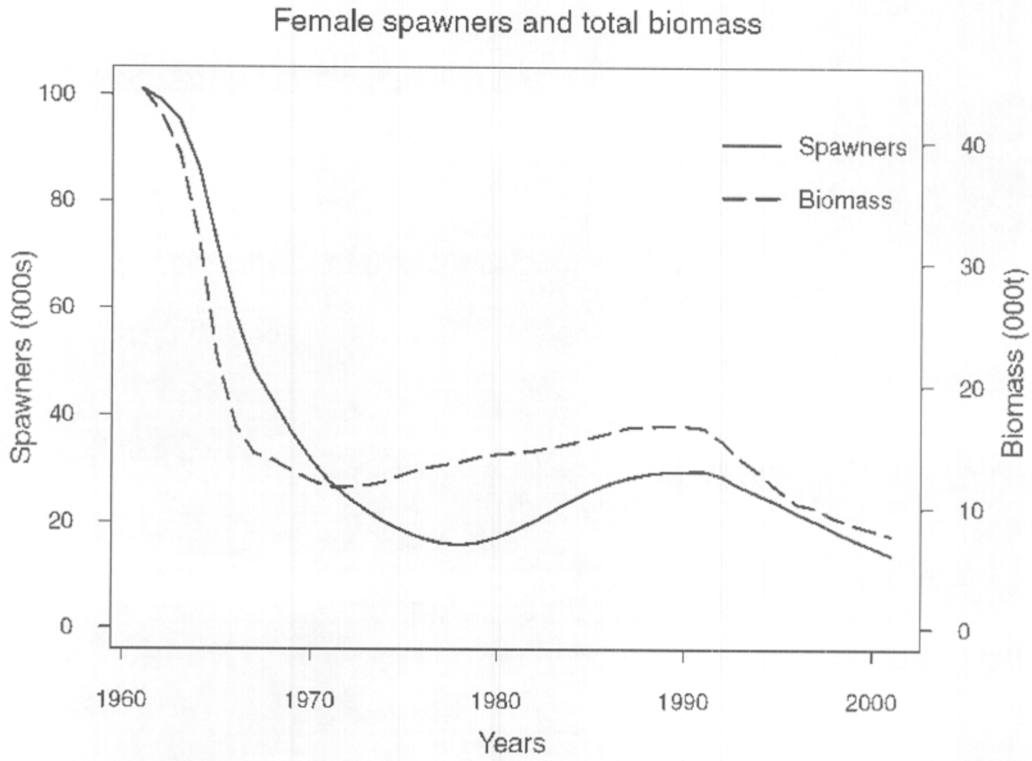


Fig. 25. Trends in biomass and spawner abundance (Top) and the spawner-recruit relationship (Bottom) for Run5 (no increased mortality).



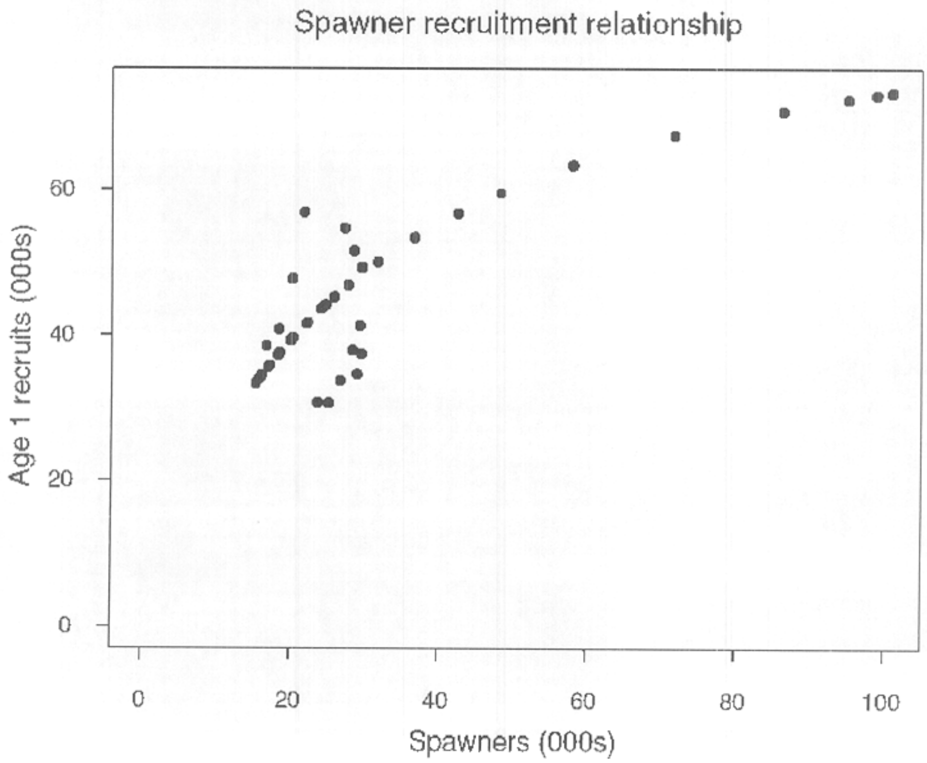


Fig. 26. Age- and sex-specific selectivity curves estimated for Run5 (no increased mortality).

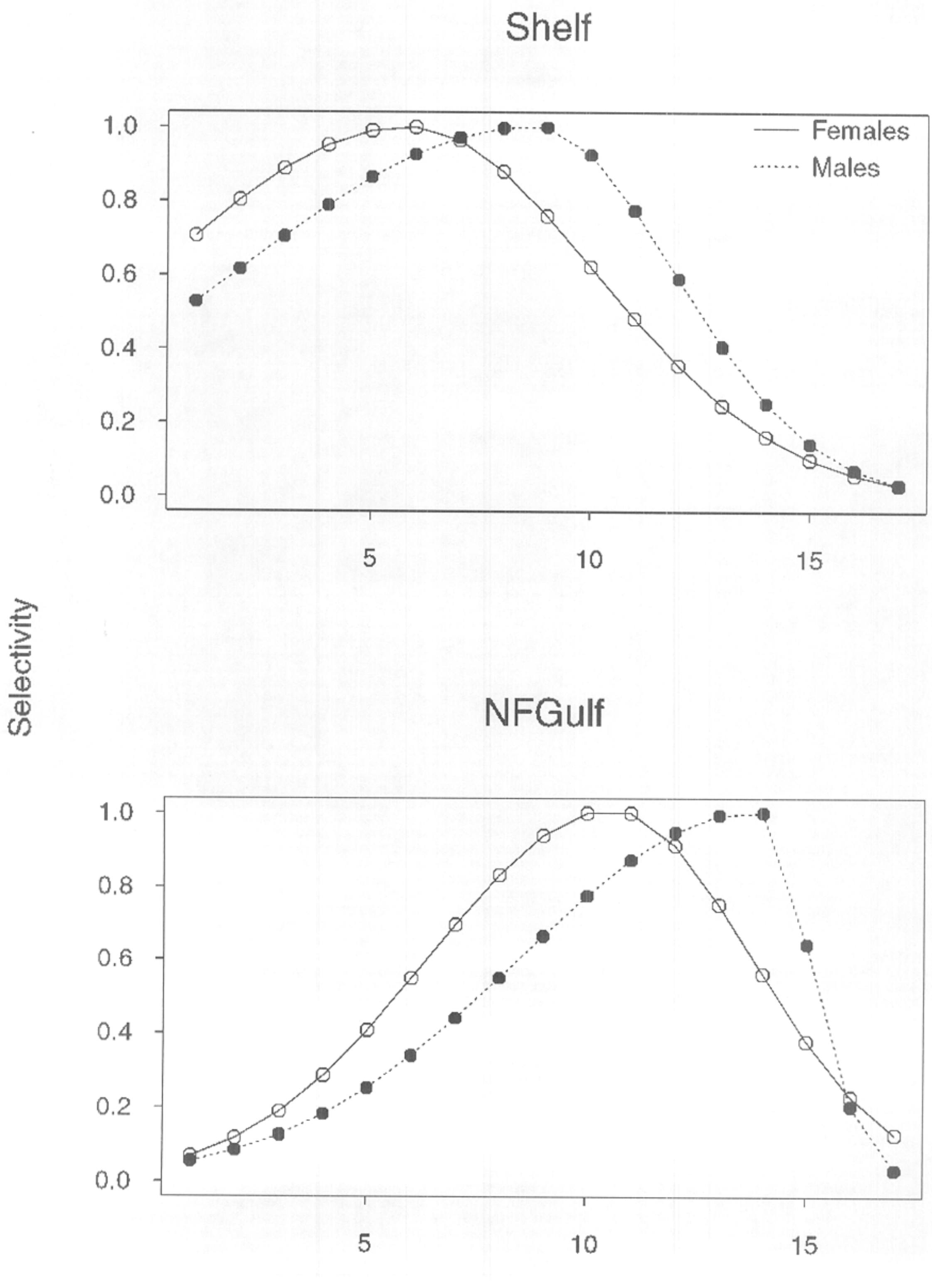


Fig. 27. Summary of recent fishing mortality (F) estimates derived from independent analyses. Estimates are drawn from analysis of the years 1994-2000 (tagging), 1998-2000 (Palohemo Z's), and 2000 (population model). The approximate range of uncertainty is indicated. All estimates of recent F are above a level which would allow population recovery (MSY) or maintain current population size (zero growth).