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**Observations on Porbeagle Shark (*Lamna nasus*)
in the North Atlantic**

by

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Abstract

There was a Norwegian directed fishery for porbeagle in the Northwest Atlantic during 1961- 66, which severely reduced the resource. Interest in porbeagle has recently grown again, with landings since 1991 being in excess of 1000t. In 1994 and 1995, the fishery was prosecuted almost solely by Canadian interests, with 1615t and 1309t being reported respectively. While a precautionary catch level of 1500t was established under a Shark Management Plan, the main components of the plan were not implemented until 1996. Information on the resource is very limited and thus a number of sources, both historical and recent were used to develop an evaluation of the population. The fishery appeared sustainable during the 1970s and 1980s when landings averaged 250t annually. Porbeagle is shown to have relatively low pup production rate and slow growth and is consequently very sensitive to over-exploitation. Given the uncertainty in the information base, and the sensitivity of the resource to overexploitation, it was recommended that the 1995 catch be used as a harvest ceiling and that the 1995 level of effort not be exceeded for several years.

Résumé

Une pêche dirigée norvégienne du requin-taupe commun a été effectuée dans l'Atlantique nord-ouest de 1961 à 1966. Cette pêche a fortement amenuisé la ressource. On a noté récemment un nouvel intérêt pour ce poisson dont les prises sont supérieures à 1000 t depuis 1991. La pêche de 1994 et 1995 a pratiquement toute été réalisée par des intérêts canadiens qui ont déclaré, pour chacune de ces années, des captures de, respectivement, 1615 t et 1309 t. Un niveau de capture prudent de 1 500 t a été fixé en vertu du plan de gestion du requin, mais les principaux éléments du plan n'ont pas été appliqués avant 1996. On dispose de très peu de renseignements sur cette ressource et des informations diverses, tant anciennes qu'actuelles, ont été utilisées pour évaluer la population. La pêche semblait durable au cours des années 1970 et 1980, lorsque les débarquements annuels moyens étaient de l'ordre de 250 t. Il est montré que le requin-taupe commun a un faible taux de reproduction et une croissance lente, ce qui le rend très vulnérable à la surpêche. Vu les incertitudes liées à la base d'information et la sensibilité de cette ressource à la surexploitation, il a été recommandé que le niveau des captures de 1995 serve de plafond et que l'effort de pêche exercé au cours de cette année ne soit pas dépassé pendant plusieurs années.

Introduction

The family Lamnidae is represented by three genera and four species in the North Atlantic (Compagno, 1984):

Porbeagle shark (Lamna nasus)
Shortfin mako shark (Isurus oxyrhincus)
Longfin mako shark (Isurus paucus)
Great white shark (Carcharodon carcharias)

The porbeagle shark is a cold-temperate species that occurs in the North Atlantic, South Atlantic and South Pacific areas. The species extends from Newfoundland to New Jersey and possibly to South Carolina in the West Atlantic and from Iceland and the Western Barents Sea to Madeira and Morocco and into the Mediterranean Sea in the East Atlantic. It is the only one for which a commercial fishery exists in Canadian coastal waters. The shortfin mako is a warm water species that only occasionally occurs in Canada. The longfin mako, first described in 1966, also a warm water species, has thus far not been reported in this area. Finally, the great white is a more solitary animal and rarely strays into Canadian Atlantic 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 these three species were produced in June 1995 (Anon.,1995). In the fall of 1995, it was decided to form an Elasmobranch Assessment team (Table 1) which would undertake producing the Research Documents and Stock Status Reports (SSRs) for porbeagle, blue and mako sharks as part of the Maritime Region's Regional Advisory Process (RAP). The team met formally three times during January - April 1996 to review prepared material and compile the reports.

This report summarizes the information compiled by the team on porbeagle sharks in the Northwest Atlantic. The information on the biology of this species is limited. Therefore, observations on porbeagle in the Northeast Atlantic have been used and assumed to apply to the Northwest Atlantic. Given that the research program was initiated recently, most analyses are preliminary and thus recommendations are made to further the research program. Notwithstanding the preliminary nature of the information, advice is provided to assist management decisions for the Canadian Zone. This Document and its associated Stock Status Report were tabled at the RAP Scotian Shelf Subcommittee during 15 - 19 April 1996.

The Fishery

Landings Trends in the North Atlantic

Prior to 1930, directed fishing for porbeagle in the North Atlantic was restricted to the Eastern North Sea (Gauld,1989). By 1930, fishing had extended into the Orkney-Shetland area and to the Faroe Islands. During 1930-65, Norway was the principle nation exploiting the resource. By the 1950's, fishing had spread to the waters off Ireland and fishing banks further offshore. In 1961, the Norwegian fleet began exploratory fishing, using pelagic longline gear, in the waters off New England and Newfoundland. They were joined by vessels from the Faeroe Islands during the next few years. Reported landings in the Northwest Atlantic rose from 1924t in 1961 to 9360t in 1964, and then fell to less than 1000t in 1967 (Table 2, Figure 1), the stock being fished down to unprofitable size during this period (Myklevoll, 1989). Subsequent effort levels remained low and reported landings were less than 600t until 1991. The fishery in the Northeast Atlantic, predominantly exploited by France, has remained below 1000t since 1982.

The Recent Fishery in the Northwest Atlantic

Several difficulties were encountered in trying to rationalize reported landings from different sources, with respect to both published records and current computerized data from which reports are generated. While there has been success in sorting out many discrepancies, especially as regards Canadian commercial landings, serious problems remain with the foreign landings. This has raised uncertainty as to whether or not the historical information reflects the landings of porbeagle and not those of other species. Hence this section represents the best estimate of the situation, and must be considered preliminary.

- **It is recommended that variation over time within NAFO and FAO reported shark landings be examined, and that discrepancies in reported landings between NAFO and FAO sources be resolved.**

In 1991, reported landings in the Northwest Atlantic rose to 1484t due to increased effort by Faroese vessels and entry of Canadian vessels into the fishery, and by 1992 reached a post-60's peak of 1790t (Figure 2, Table 3). Previously, the fishery had been concentrated in 4WX during the spring, but in 1991, the fall fishery in more northerly waters of the Gulf of St Lawrence and the Grand Banks of Newfoundland became more pronounced. The southerly spring and northerly fall fisheries have been very active ever since (Table 4, Figures 3 -5). Participation by Faroese vessels in the fishery within the Canadian 200 mile fishing zone was restricted in 1993 and total landings dropped to 1369t. Foreign participation was eliminated altogether from the directed fishery in 1994. Landings by three Canadian offshore pelagic vessels totaled about 1470t, while a number of inshore vessels took about 140t (total landings 1615t). There was a reduction in effort in 1995, with only two vessels still active after June, and landings dropped to 1309t.

In addition to the directed commercial fishery, porbeagle sharks are taken as bycatch in the Canadian swordfish longline fishery (15t reported in 1995) and the Japanese tuna longline fishery (catches in Canadian zone under 10t every year since 1992). Also, interest in angling for sharks has increased in Atlantic Canada over the last few years, based primarily on blue shark, but porbeagle sharks are taken occasionally. Removals by the developing recreational fishery have not been recorded.

Because Canadian interest in porbeagle sharks is recent, the processing of Canadian commercial landings data is not as advanced as in other fisheries. Only in the last few years has there been an attempt to ensure that shark landings are identified to species. There was 38t of unspecified sharks recorded in 1995, which is a marked improvement over 1994 (107t unspecified). As well, the Canadian effort information needs to be processed. The Fisheries Observer Program (FOP) has maintained 100% coverage of foreign catches in the Canadian zone since 1987. A zonal database for this program, incorporating the old Scotia/Fundy, Newfoundland, Gulf, and Quebec regions needs to be created.

- **It is recommended that the Fisheries Observer Program data for sharks in the Atlantic Zone be compiled into one dataset, and maintained as such on an annual basis.**

- **It is recommended that the historical logbook data for large pelagic fisheries be incorporated into the DFO statistical database.**

- **It is recommended that in future all Canadian porbeagle fishery effort data be entered into the DFO statistics database.**

Size Composition of the Landings

The only recent information on the size composition of the landings comes from the FOP. As stated above, only the data for the Scotia-Fundy program was available. Thus it was not possible to construct a table of size composition by fishery by year. Notwithstanding this, a summary of the Scotia-Fundy information is presented here.

There are about 56,000 sampling observations in the FOP database. Most of the information is for the directed Faeroe Is. fishery during 1987 - 93. Canadian information only exists for 1993-94. The mean size of the Faeroe Is. fishery varied between 163 - 180 cm for males and 156 - 179 cm for females (Table 5). In contrast, the landed sizes in the Canadian fishery during 1993-94 were substantially larger, being 180 - 190 cm for both males and females (Table 5 and Figure 6). It was shown earlier that the Canadian fishery exhibits relatively more effort in the fall in northerly waters than the foreign fishery, and the size difference between the two fisheries could be due to this. However, Aasen (1963) showed that the size of porbeagle caught in the 1961 Norwegian directed fishery in fact decreased from south to north (Table 6 and Figure 7). A similar analysis needs to be undertaken with the more recent Canadian information.

- **It is recommended that a complete analysis of the size composition of porbeagle in the recent directed fisheries be undertaken on the zonal FOP dataset.**

The information provided by Aasen (1963) indicates that historical data does exist that could be useful to the stock assessment of this resource. It is particularly noteworthy that the earlier information was collected from the harvesting of an almost virgin resource, at least in the Northwest Atlantic. The current fishery is composed of relatively smaller animals (Figure 8) which may be indicative of the long-term effects of exploitation on the resource. There are of course a number of confounding factors (season, area, gear, etc) that need to be accounted for before making valid comparisons.

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 May 1994. Between 1992 and 1994, a plan was developed through the Atlantic Large Pelagics Advisory Committee (ALPAC), the Committee that develops the Plans for the bluefin tuna and swordfish fisheries in Atlantic Canada. Following amendments to the Fisheries Act, 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 strength the control of the commercial fishery but no consensus was reached on how to regulate the recreational fishery. A revised Plan was announced in July 1995.

The 1995 Fisheries Management Plan for pelagic sharks in Atlantic Canada established precautionary catch levels 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 precautionary catch levels 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 previous five 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. Exploratory licenses are valid only for the year that they are issued with no obligation that they be re-issued in the future. 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 20m 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 until such time as suitable criteria were developed which might allow for the retention of sharks by recreational anglers. These criteria have not yet been developed. The 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.

Population Biology

Stock Structure and Movements

Observations on most shark species suggest that there is segregation by sex and size. In some cases, after mating, the pregnant females move to another area during gestation and pupping. The females appear to remain separated from males and juveniles until the next breeding season. Pups are seldom observed with juveniles or adults of either sex, suggesting the existence of discrete nursery areas. There are observations from commercial fisheries that support sex segregation in porbeagles. Gauld (1989), in his observations of the 1987-88 winter fishery off the Shetland Islands, noted a sex ratio (M/F) of 1:1.3. In the Spanish swordfish longline fishery off Spain and the Azores, the majority of porbeagle bycatch occurs in the winter with males outnumbering females two to one (Mejuto, 1985), suggesting a seasonal difference in distribution by sex. In the first year of commercial exploitation of this species in the northwest Atlantic, Aasen (1963) reported an overall sex ratio of 1:1, with some catches containing marked predominance of one or the other sex. He concluded shoaling by sex. In examining the July - September 1961 fishery, he also noted that the size of porbeagles increased from west to east and concluded that the migration was size specific.

About 56,000 observations made by Canadian fisheries observers during 1987-1994 on vessels directing for porbeagle sharks in Canadian Atlantic waters indicate an overall sex ratio of 1.2:1. The sex ratio is 1:1 up to approximately 145 cm, then is greater than one up to approximately 230 cm, and is less than one thereafter (Figure 9). The observer data has a wider geographic range and wider seasonal coverage than that of Aasen (1963). Thus the differences observed may be caused by seasonal and geographic differences in distribution by sex, supporting the observations of Aasen (1963). However, it could also be explained by differential growth, if it exists, or the long-term effects of exploitation and thus further analysis of these data are needed to confirm the existence of sex-related distributional patterns.

- **It is recommended that a comprehensive analysis of the Canadian Fisheries Observer data be undertaken to describe porbeagle spatial and temporal distribution patterns.**

Research programs on shark distributions rely mainly on tagging studies. In 1962, the United States National Marine Fisheries Service (NMFS) initiated a shark tagging program which relied heavily on the volunteer participation of sport and commercial fishers. Those program activities, although heavily concentrated in the northeastern US, have become international in scope and at the end of 1994, taggers from 31 countries were involved (Casey et al, 1995). In 1994 alone, participants in the program tagged 116 porbeagle sharks with 11 recoveries from the 1994 and earlier releases (Casey et al, 1995). As stated above, porbeagle sharks are thought to prefer cold temperate waters. Castro (1983) suggested that they preferred waters colder than 19°C, while Scott and Scott (1988) suggested that the preferred temperature is colder than 16°C. If true, this cold water temperature preference would largely restrict its distribution to the north temperate waters of the Canadian continental shelf. It would also limit the occurrence of this species off the eastern United States and explain the limited number of animals tagged by the US cooperative tagging program.

From 1961-84, Canada conducted a number of projects to tag large pelagic fishes, mainly swordfish and tunas; in a number of cases, sharks caught incidentally during these projects were also tagged (Burnett et al. 1987). Eight porbeagle were tagged; none have been recovered. In 1994, Canada initiated a shark tagging program in cooperation with sport and commercial fishers. Since the inception of the shark tagging program, 223 porbeagle sharks have been tagged. Only one recovery has been made, of a porbeagle tagged on the Scotian Shelf and recaptured in the same general area one year later.

Aasen (1963) reported that 92 porbeagle sharks had been tagged in the northwest Atlantic in 1961. He indicated that porbeagles tagged on Platts Bank in the Gulf of Maine had been recaptured on the Scotian Shelf, in the Gulf of St. Lawrence, and on the Grand Banks. Myklevoll (1989) indicated that a total of about 550 porbeagle sharks had been tagged in the northwest Atlantic and that 47 recaptures have been reported; however he reported no details of recapture locations.

Although tag recoveries have been made of porbeagle shark from these tagging programs, the number of recoveries are very limited. No hypotheses have been proposed related to the movements or migrations of this species. Therefore, it is not possible to state whether or not there is one or more stocks in the North Atlantic.

- **It is recommended that at a minimum the current Canadian tagging effort continue, to be enhanced if possible, within resource availability, and collaboration with other existing programs (US, Norway) be investigated.**

- **It is recommended that the possibility of using meristics, morphometrics and biochemical techniques for analysis of stock structure be investigated.**

Shark Reproduction

There are three types of reproduction in sharks, depending on the species - oviparity, ovoviviparity, and viviparity. These modes have markedly different implications for the life history strategy of the various species of sharks. Oviparity is the most primitive condition. Sharks, such as the catsharks, that are oviparous, lay large eggs that contain sufficient yolk to nourish the embryo throughout development and allow it to emerge fully developed. These eggs are enclosed in leathery cases that are deposited on the sea bottom, usually attached to plants and rocks. The pups of oviparous sharks are usually small, due to the limitation in yolk. Ovoviviparity (aplacental viviparity) is the most common mode of reproduction. The eggs develop into embryos within the uterus, and are nourished by yolk stored in the yolk sack, without forming a placental connection with the mother. In some ovoviviparous sharks, after the yolk is used up, the embryos will ingest unfertilized eggs that the mother continues to produce (oophagy). In a few species (e.g. sand tiger), intra-uterine cannibalism occurs and smaller embryos are also consumed. Finally, viviparity (placental viviparity) is the most advanced form. The embryos are initially nourished by yolk stored in the yolk sac. The yolk stalk elongates and the yolk sac becomes modified. In some species, the yolk sac comes into contact with the uterine wall and the embryo is nourished through a placental connection. In others, such as the blue shark, the yolk stalk becomes highly branched and the embryos obtain nourishment by absorbing nutritive secretions produced by the uterine lining of the mother.

Porbeagles are ovoviviparous and oophageous, with litter size ranging from 1 to 5 (Compagno, 1984). Males mature between 150 - 200 cm in total length while females mature between 200 - 250 cm (Aasen, 1961). This provides an age at first maturity of four and eight for males and females respectively (see below). Aasen (1963) observed no embryos in mature females during July - September, while large embryos were reported by fishermen on Flemish Cap in late May. Similar observations had been made in the Gulf of Maine in November and January (Bigelow and Schroeder, 1948). This suggests that parturition occurs in the spring (late May - early June), a time when porbeagle ascend from the deeper water into the surface water and feed intensively (Aasen , 1963). Aasen (1963) felt that porbeagle reproduce every year and that gestation (development of the embryo) lasts about 8 months. These observations and the presence of full sperm sacs in the female point to an autumn (September - October) mating, and suggest a gap between parturition and mating. Gauld (1989) reports that off the Shetlands, mating occurs later, in December - January, while parturition occurs in summer or autumn, rather than the spring. It may be that the reproductive cycle is later in the Northeast Atlantic.

Aasen's (1963) estimate of eight months for the length of gestation is at variance with estimates made by other authors. Based on the size frequency of embryos that he observed, Shann (1923) reported that gestation could take two years. Holden (1974) pointed out that, based on Aasen's (1963) data, growth in the first year of life was about 20cm/year. He pointed out that length at birth is around 66 - 75 cm (Aasen, 1963) with an L_0 of 72 cm. This is confirmed by Compagno (1984), who records a range of 60 - 75 cm. Holden (1974) considered that the production of such large young after only eight months would require an in-utero growth rate of 100 cm/year. He felt that this was unreasonable and indicated a longer gestation period. This issue remains unresolved.

Based on the above, it is suggested that mating in the Northwest Atlantic occurs in September - October. The embryos grow in the uterus and are born in either the following spring or one year after that. The mean number of embryos born per female observed by Aasen (1963) was 3.7, or about two per horn of the uterus.

If the 20 month gestation period is correct, maximum average pup production is four every two years, or two every year. If gestation is only 8 months long, maximum average pup production is four per year. The team recognized the importance of addressing this uncertainty and the need for further research.

- **It is recommended that studies be conducted to aid in resolving questions pertaining to the frequency of the reproductive cycle.**

It was noted that there are existing data collection activities, such as the DFO Fishery Observer Programs (FOP), that could be very valuable in acquiring new biological information.

- **It is recommended that every effort be made to provide programs such as FOP with the training necessary to collect biological information on the shark's life cycle.**

Growth and Natural Mortality

The only published information on the growth of porbeagles is that of Aasen (1963), who generated growth curves based on vertebral readings and analyses of length frequencies. He concluded that males and females have similar growth rates and calculated the following Von Bertalanffy growth equation (Figure 10):

$$Lt = 280(1 - EXP - 0.1155(t + 2.573))$$

The L_{inf} is thus 280 cm total length, the growth coefficient, K, is 0.1155, and t_0 is 2.573. As pointed out above, there is still uncertainty regarding the growth in-utero and thus this model may not be appropriate for this period of life. As well, the model is based upon the ageing of only 50 specimens and thus needs to be verified through further research. For instance, the team noted that the lack of differential growth by sex in porbeagles would be unlike other shark species. Both blues and makos in the North Atlantic exhibit differential growth by sex with the females typically having a higher L_{inf} than the males. It is possible that further observation and study will show differential growth in porbeagles.

- **It is recommended that age and growth studies be conducted to elucidate the growth of porbeagle in the Northwest Atlantic.**

Taylor (1958), in his work on cod, defines the life span of a teleost species as the time required to attain 95% of the L_{inf}, which is $t_0 + 2.996/K$ or, for porbeagle,

$$2.573+2.996/0.1155 = 28.5$$

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

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

which for porbeagle produces the value of 0.16. This compares to 0.18 calculated by Aasen (1963) using length frequency information. These calculations assume that Taylor's (1958) and Hoenig's (1983) definition of life span are equivalent. This would have to be confirmed through further study. While these calculations are very crude, and necessitated by data deficiencies, they indicate that the growth model is consistent with other generally observed life history relationships.

- **It is recommended that the applicability of teleost growth and life history models to sharks be determined and alternatives investigated.**

Resource Status

Uncertainties concerning the stock structure of porbeagle sharks and gaps in the knowledge of the biology of this species will need to be addressed before a conventional assessment of this resource can be conducted. For the present, a preliminary analysis of catch rates for the directed Canadian and Faroese porbeagle fisheries, was conducted using Analysis of Deviance, the data being derived from the Scotia/Fundy Region component of the Fisheries Observer Program. It is planned by 1997 to obtain the full Maritime Fisheries Observer Program dataset for porbeagle sharks, as well as effort data to go with the Canadian Commercial Landings data. None of the details of this analysis are presented here due to their preliminary nature.

- **It is recommended that analyses of porbeagle shark catch rates be conducted on an Atlantic zonal FOP database, and that use of general linear modeling be compared to the multiplicative method.**

An initial model, with five significant interactions which confounded relationships between main effects and catch rates, was overly complex. The Faroese spring (1987-93) and Canadian spring (1993-95) and fall (1991,1993-95) fisheries information was thus re-analyzed. Regardless of which fishery was considered, catch rates have declined in recent years. A steepening of this decline in catch rates is evident from the April/September catches through May/October catches to June/November catches. Different conclusions from catch rates for April (lesser rate of decline over the years) would be drawn than for June (greater rate of decline over the years). As both spring and fall fisheries experience a curvilinear increase, peak, and decrease in catch rate centred on May and October, especially for 4WX and the Grand Banks, much of the interaction can be attributed to this trend. Catch rates increase as the fishing effort moves north.

Only the Faroese spring fishery would be suitable for deriving standardized effort during 1987 - 93, but would be of limited value since the fishery terminated in 1993. A more complete catch/effort series for the Canadian fishery since 1991 is required before a valid interpretation of catch rates as indices of abundance can be made.

Outlook

There is very limited information for porbeagles on which to base harvest advice. Sequential Population Analysis (SPA) and Yield Per Recruit (YPR) models, as applied in the groundfish stock assessments, cannot be used here due to the lack of time series of age-based information on the commercial catch and population. However, some idea of the sensitivity of this resource to exploitation can be obtained from use of the equilibrium model of Brander (1981), which is a modification of that of Holden (1974).

For a stock to maintain its abundance, every mature female must on average produce one mature female during its life. Now the lifetime net fecundity (LNF) is simply a product of the annual net fecundity (ANF) and the years of spawning (YOS) or

$$LNF = ANF * YOS$$

For stock replacement, the LNF must equal one. Under this condition, the annual net fecundity can be calculated as

$$ANF = LNF/YOS = 1/YOS$$

If Z is the annual instantaneous rate of total mortality on mature fish, it can be shown that the YOS possible are 1/Z years (Brander, 1981). Thus, for replacement, the annual net fecundity must equal the instantaneous total mortality, or

$$ANF = Z$$

Brander (1981) expressed this relationship as

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

where

Z_m is the total mortality on the mature fish

Z_i is the total mortality on the immature fish

E is the annual litter size, which is divided by two to provide the estimate for females

t_m is the mean age of first maturity of a female

Thus, if we know the annual gross fecundity, E, and the mean age of first maturity, t_m, we can estimate the mortality at which the population will exactly replace itself. In addition, we can examine the ratio of the mortality on the immature and mature individuals to see what impact this has on the population.

Figure 11 shows the relationship between Z_i and Z_m, using E of 2 (assuming a litter every other year) and t_m of 8. All combinations of Z_i and Z_m to the right of the curve are unsustainable. Natural mortality is about 0.16 - 0.18. If the mortality of the immature individuals is about this level (0.18), which is reasonable given their size at birth, then the mortality on the adults could go as high as 0.24. If 0.18 of this has to account for natural mortality, this allows only 0.06 for fishing mortality - a very low rate of harvesting. These calculations are very sensitive to the estimates of E and t_m. If the reproductive cycle is annual, and not biannual, as assumed above, then E would be four and not two. The 'allowable' Z_m values roughly double. As well, increasing tm by two years to 10 decreases the replacement Z_m to 0.17, just below the natural mortality. Under this scenario, no fishery would be sustainable. The following table summarizes the replacement Z_m values for a range of E and t_m, under the assumption that Z_i equals the natural mortality, 0.18.

Mean Age of First Maturity t_m	**Gross Annual Fecundity, E**	
	2 (two year cycle)	**4 (one year cycle)**
6	0.34	0.68
8	0.24	0.47
10	0.17	0.33

It is evident that porbeagle sharks are long-lived, bear live young and produce comparatively low numbers of offspring. This combination of life history characteristics makes porbeagle sharks highly susceptible to over-exploitation. The porbeagle shark fishery appeared sustainable during the 1970s and 1980s when landings averaged 250t annually. The levels experienced in the early 1960s did not appear sustainable. The precautionary catch level of 1,500t in the 1994 Management Plan is not based upon estimates of stock abundance and may not be sustainable. Given the lack of knowledge of this resource and its sensitivity to over-exploitation, the 1995 level of fishing effort should not be exceeded for several years. As well, the 1995 catch level should be used as a harvest ceiling.

It is very important that the provisions of the Shark Management Plan be implemented to ensure orderly harvesting of the resource. This implies that the fishery must have a comprehensive scientific component to collect the information necessary to fill the identified knowledge gaps.

This species is part of a large pelagic species complex that includes tunas, swordfish, billfishes, and other species of large sharks. Management of the porbeagle shark fishery needs to consider interactions with other species in the complex. As well, the stock area of this species may extend beyond the Canadian zone. Management of this resource in the future could require bilateral or multilateral cooperation.

Summary of Research Recommendations

Throughout this document, recommendations have been made to fill knowledge gaps and thus lead to improved assessment in the long term. Here, these recommendations are prioritized to allow for a logical and coherent implementation of these recommendations.

The first four recommendations relate to the collection and processing of information from the historical and current fishery:

1 It is recommended that every effort be made to provide programs such as FOP with the training necessary to collect biological information on the shark's life cycle.

2. It is recommended that in future all effort data be entered into the DFO statistics database at the same time as the commercial landings of the Canadian porbeagle fishery.

3. It is recommended that the historical logbook data for large pelagic fisheries be incorporated into the DFO statistical database.

4. It is recommended that the Fisheries Observer Program data for sharks in the Atlantic Zone be compiled into one dataset, and maintained as such on an annual basis.

The next three recommendations relate to analyses of existing data to elucidate the trends in abundance:

5. It is recommended that analyses of porbeagle shark catch rates be conducted on an Atlantic zonal FOP database, and that use of general linear modeling be compared to the multiplicative method.

6. It is recommended that a complete analysis of the size composition of porbeagle in the recent directed fisheries be undertaken on the zonal FOP dataset.

7. It is recommended that a comprehensive analysis of the Canadian Fisheries Observer data be undertaken to describe spatial and temporal distribution patterns.

The next five recommendations relate to studies on the porbeagle's life history:

8. It is recommended that studies be conducted to aid in resolving questions pertaining to the reproductive cycle.

9. It is recommended that at a minimum the current Canadian tagging effort continue, to be enhanced if possible, within resource availability, and collaboration with other existing programs (US, Norway) be investigated.

10. It is recommended that age and growth studies be conducted to elucidate the growth of porbeagle in the Northwest Atlantic.

11. It is recommended that the applicability of teleost growth and life history models to sharks be determined and alternatives investigated.

12. It is recommended that the possibility of using meristics, morphometrics and biochemical techniques for analysis of stock structure be investigated.

The last recommendation is made to reduce confusion on the official landings statistics:

13. It is recommended that variation over time within NAFO and FAO reported shark landings be examined, and that discrepancies in reported landings between NAFO and FAO sources be resolved.

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Table 1. Members of the Maritimes Region RAP Elasmobranch Assessment Team

Member	Expertise	Affiliation	Telephone No.
Comeau, P.	Shark Catch Rates	MFD,BIO,DFO	902-426-4136
Crawford, R.	Shark Recreational Fishery	Dep of Fisheries, NS	902-424-0350
Fowler, M.	Shark Fishery Statistics and CPUE Analysis	MFD,BIO,DFO	902-426-3529
Frank ,K.	Elasmobranch Life History	MFD,BIO,DFO	902-426-3498
Hurlbut, T.	Spiny Dogfish Biology and Assessment	MFD, GFC, DFO	506-851-6216
Hurley, P.	Shark Reproduction and Biology	MFD,BIO,DFO	902-426-3520
Jones, C.	Shark Management	FMB, MC, DFO	902-426-1782
McRuer, J.	Spiny Dogfish Biology and Assessment	MFD,BIO,DFO	902-426-3585
O'Boyle (Chair), R.	Shark Population Models	MFD,BIO,DFO	902-426-4890
Porter, J.	Tuna and Swordfish Biology and Assessment	MFD, SABS, DFO	506-529-8854
Rodman, K.	Shark Recreational Fishery Management	FMB, MC, DFO	902-426-6074
Showell, M.	Observer Program Data Analysis	MFD,BIO,DFO	902-426-3501
Simon, J.	Skate Biology and Assessment	MFD,BIO,DFO	902-426-4136
Stobo, W.	Finfish Distribution and Tagging	MFD,BIO,DFO	902-426-3316

Table 2. Reported Landings (t) by Country of Porbeagle Shark in the North Atlantic

	Northwest Atlantic (NAFO Areas 0 - 6)					Northeast Atlantic											North Atlantic
Year	Canada	Faeroe Is	Norway	USA	Total	Denmark	Faeroe Is	France	Iceland	Norway	Portugal	Spain	Sweden	Channel Is	Germany	Total	Total
1950					0	1900				1300						3200	3200
1951					0	1600				800						2400	2400
1952					0	1600				600						2200	2200
1953					0	1100	100			700						1900	1900
1954					0	700	300			600						1600	1600
1955					0	600	100			900						1600	1600
1956					0	400				900						1300	1300
1957					0	600	100			1100						1800	1800
1958					0	900	300			1100						2300	2300
1959					0	600	600			900						2100	2100
1960					0	400	500			1500						2400	2400
1961		100	1824		1924	600				1000						1600	3524
1962		800	2216		3016	400				100						500	3516
1963		800	5763		6563	200				100						300	6863
1964		1300	8060		9360	300				100						400	9760
1965		1088	4045		5133	200				300						500	5633
1966		741	1373		2114	200				300						500	2614
1967		589			589	200				400						600	1189
1968		662	270		932	100				900						1000	1932
1969		865			865	100				900						1000	1865
1970		205		0	205	200				300		3800				4300	4505
1971		231		0	231	400				200		3800				4400	4631
1972		260		0	260	500				300		2700				3500	3760
1973		269		0	269	200				200						400	669
1974						170			2	165			3		3	343	343
1975		80		0	80	265			4	304			1		3	577	657
1976		307		0	307	233	1		3	259			1			497	804
1977		295		0	295	289	5		3	77						374	669
1978		121		0	121	112	9	833		76		2087	3			3120	3241
1979		299		0	299	71	25	1092	1	105			1			1295	1594
1980		425		0	425	175	8	896	1	84			8			1172	1597
1981		344		0	344	159	6	768		93			5			1031	1375
1982		259		0	259	85	17	198	1	34			6			341	600
1983		256		0	256	45	12	792		32			5			886	1142
1984		126	17	0	143	39		411	1	96			9			556	699
1985		210		0	210	72	12	254		80			10	12		440	650
1986		270		0	270	114	12	260		24			8	7		425	695
1987		258		12	270	55	33	280		25	3		5	3		404	674
1988		259		32	291	32	18	446		12	3		3	9		523	814
1989		456		3	459	33	14	351		26	2		3	15		444	903
1990		537		19	556	46	14	561		44	2		2	15		684	1240
1991	346	1122		16	1484	85	7	309		32	1		2	14		450	1934
1992	741	1036		13	1790	80	20	496	1	41			4			642	2432
1993	919	411		39	1369	91	76	643	3	23			3			839	2208
1994	1549	2		64	1615	94	48	790	4	25			2		22	985	2600
1995	1305	4			1309												

Notes: Northeast Atlantic Data is from FAO (ICCAT Report of Shark Working Group, Miami, 26 - 28 February 1996)
Northwest Atlantic Data for 1950 - 60 is from FAO (ICCAT Report of Shark Working Group, Miami, 26 - 28 February 1996)
Northwest Atlantic Data (Canada) for 1961 - 90 is from ICNAF/NAFO Statistical Bulletin
Northwest Atlantic Data (Canada) for 1991 is from DFO Zonal Statistics File (coded as mackerel shark)
Northwest Atlantic Data (Canada) for 1992 - 95 is from DFO Zonal Statistics File
Northwest Atlantic Data (Faeroe Is & Norway) for 1961 - 64 is from FAO (ICCAT Report of Shark Working Group, Miami, 26 - 28 February 1996)
Northwest Atlantic Data (Faeroe Is & Norway) for 1965 - 88 is from ICNAF/NAFO Statistical Bulletin
Northwest Atlantic Data (Faeroe Is & Norway) for 1989 - 92 is from NAFO Computer Files; Includes other minor foreign bycatch; 1991 includes 318t from DFO Commercial Data Division
Northwest Atlantic Data (Faeroe Is & Norway) for 1993 - 95 is from DFO FOP/Scotia-Fundy
Northwest Atlantic Data (US/ 1961 - 94) is from FAO (ICCAT Report of Shark Working Group, Miami, 26 - 28 February 1996)

Table 3. Reported Landings (t) by Gear Type of Porbeagle Shark in the Northwest Atlantic

	Canada					Foreign					Total
Year	Directed Longline	Bycatch Swordfish	Bycatch Tuna	Bycatch Other	Total	Directed Faeroe Is	Bycatch Tuna	Other Can Zone	US	Total	
1987						241	16	1	12	270	270
1988						246	9	4	32	291	291
1989						309	9	138	3	459	459
1990						406	8	123	19	556	556
1991	346			0	346	768	20	334	16	1138	1484
1992	733			8	741	993	9	34	13	1049	1790
1993	912			7	919	401	6	4	39	450	1369
1994	1532	7	2	8	1549		2	0	64	66	1615
1995	1277	15		13	1305		4	0		4	1309

Table 4. Reported Landings (t) by Season of Porbeagle Shark in the Canadian Zone

Year	Canada Jan-March	Canada April-June	Canada July-Sept	Canada Oct-Dec	Canada Total	Foreign Jan-March	Foreign April-June	Foreign July-Sept	Foreign Oct-Dec	Foreign Total
1987						27.82	213.63	6.27	9.96	257.68
1988						16.45	232.74	0.20	9.31	258.70
1989						0.00	313.25	0.03	8.49	321.77
1990						1.71	420.71	0.05	8.25	430.72
1991					346.00	1.60	545.25	235.17	22.04	804.05
1992	50.80	201.53	184.97	303.19	740.49	0.00	531.70	326.60	150.23	1008.53
1993	2.65	295.83	264.06	356.21	918.75	47.96	359.72	0.14	2.85	410.67
1994	1.76	740.95	355.38	450.86	1548.95	0.27	0.45	0.00	1.75	2.47
1995	26.13	650.65	294.86	332.86	1304.50	0.00	0.17	0.08	3.57	3.81

Table 5. Size Composition of Porbeagle Caught on Directed Porbeagle Trips (FOP Database)

			Male	Female
Faroes	1987	Mean	162.7	156.3
		n	610	478
	1989	Mean	180.2	170.7
		n	3496	2341
	1990	Mean	169.3	165.9
		n	4629	3879
	1991	Mean	176.7	175.5
		n	7173	6436
	1992	Mean	179.5	178.9
		n	7466	7117
	1993	Mean	164.7	159.2
		n	5132	3974
Canada	1993	Mean	180.9	180.9
		n	1438	989
	1994	Mean	183.9	187.7
		n	392	385

Table 6. Size Composition of Porbeagle Caught in Norwegian Directed Fishery during 1961 (from Aasen, 1963)

		Male	Female
Platts Bank	Mean	156.2	167.2
	n	50	81
Cashes Ledge	Mean	192.9	184.0
	n	228	138
Georges Bank	Mean	187.1	186.6
	n	279	304
Misaine Bank	Mean	198.1	202.5
	n	170	304
St Pierre Bank	Mean	213.6	207.3
	n	172	84

Figure 1. Reported Landings (t) of Porbeagle in the North Atlantic

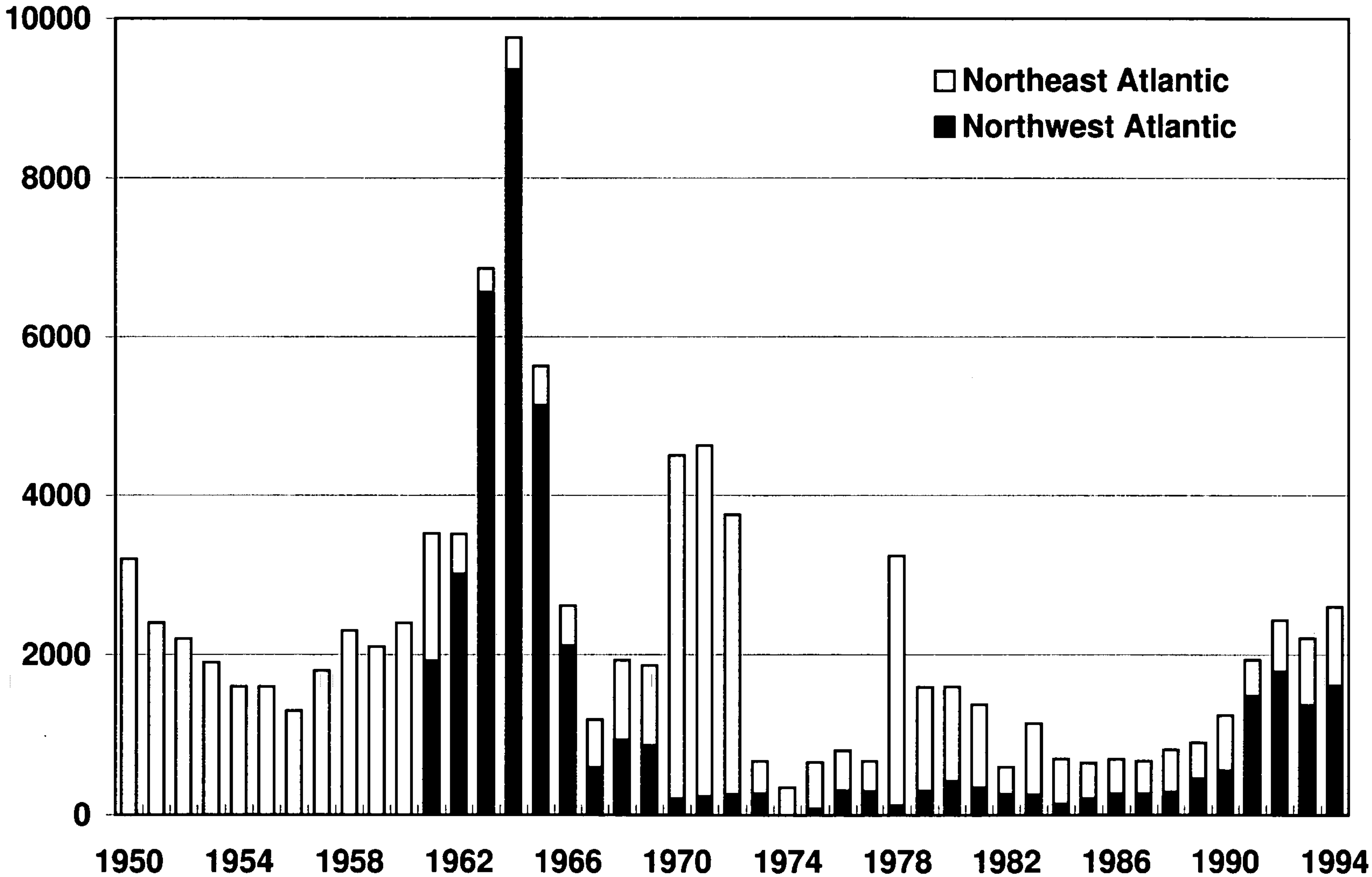
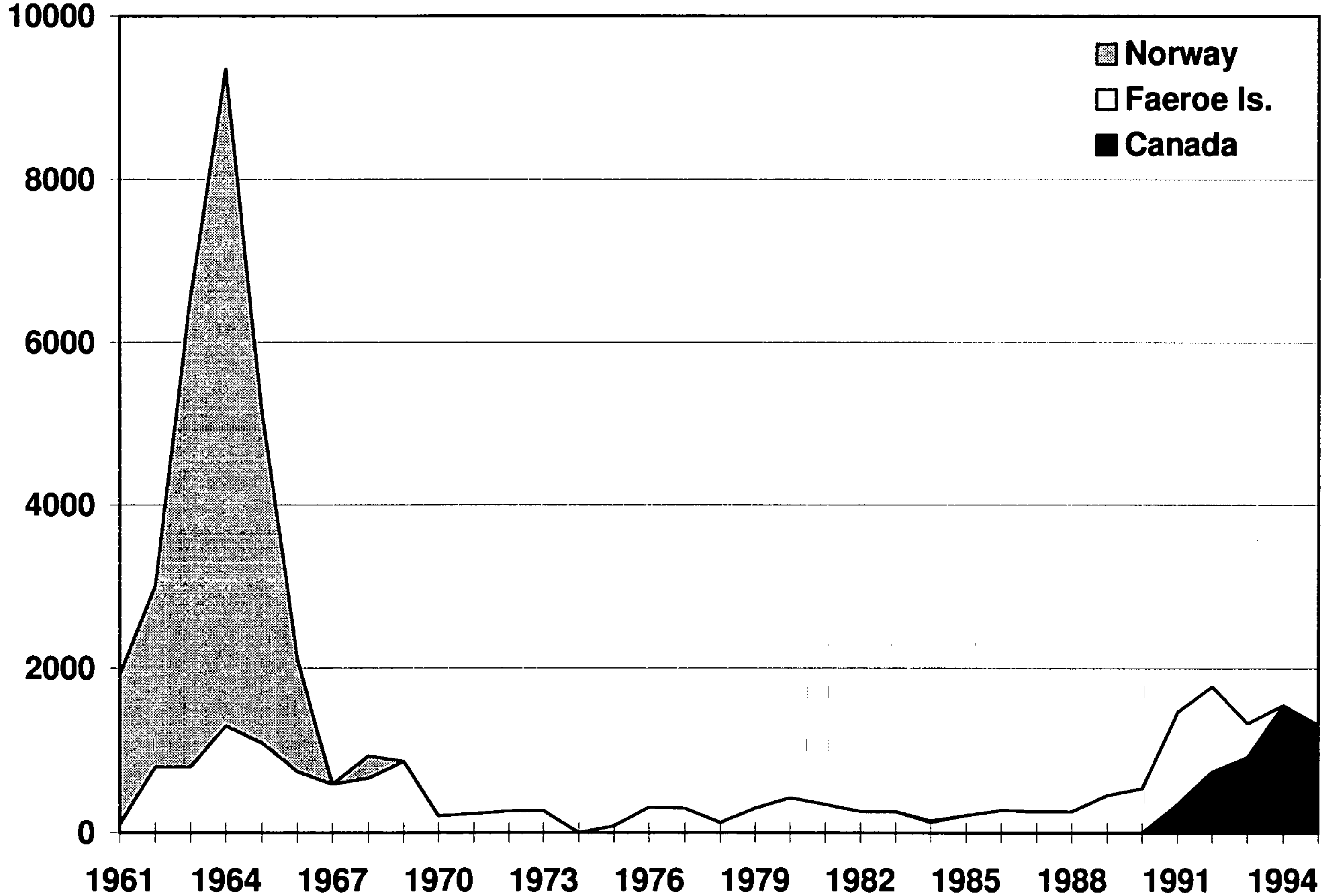


Figure 2. Reported Landings (t) by Country of Porbeagle in the Northwest Atlantic



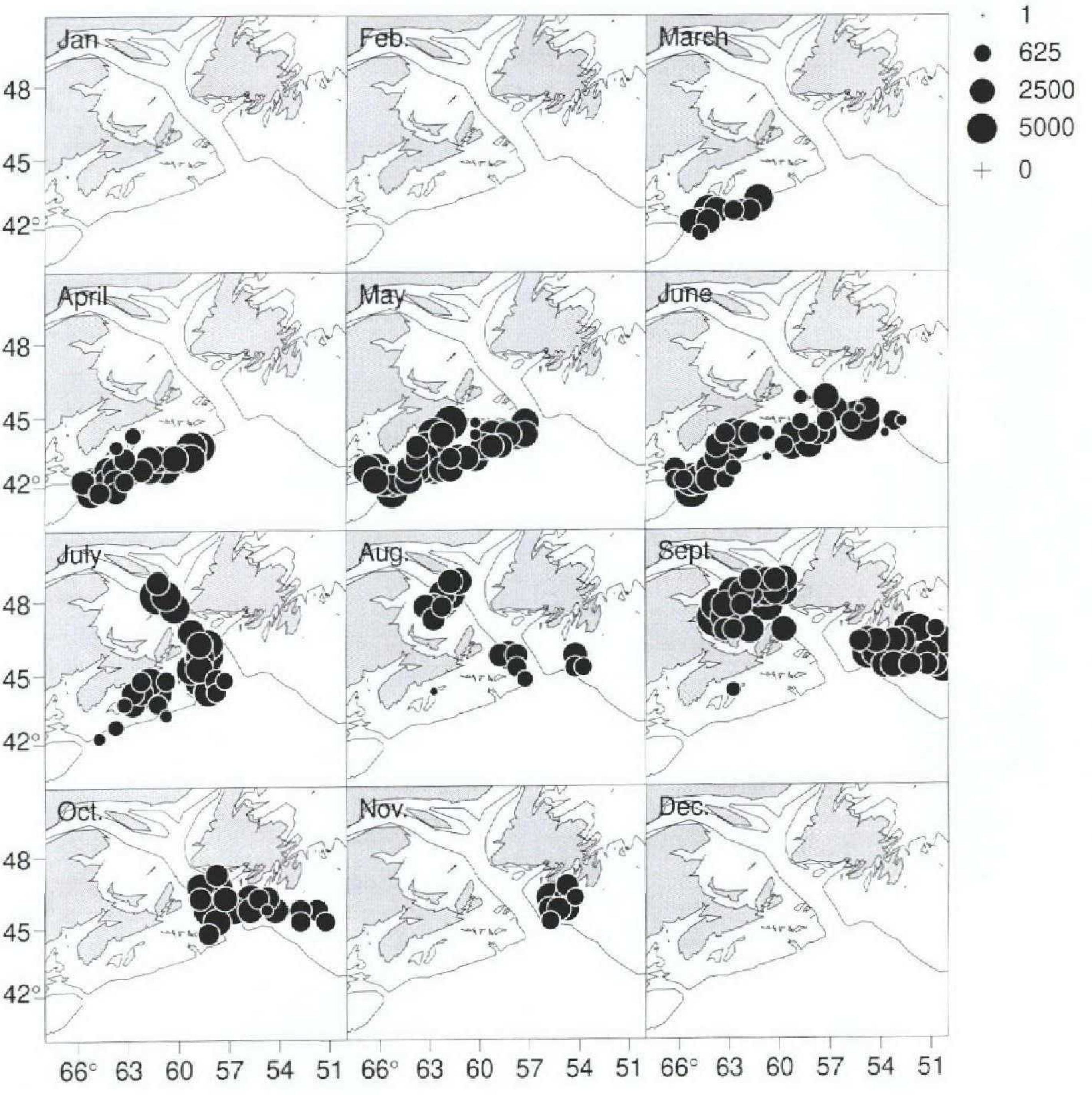


Figure 3a. Monthly distribution of porbeagle shark catches (kg) in the Faroes Is. longline fishery for porbeagle shark during 1978 - 1994.

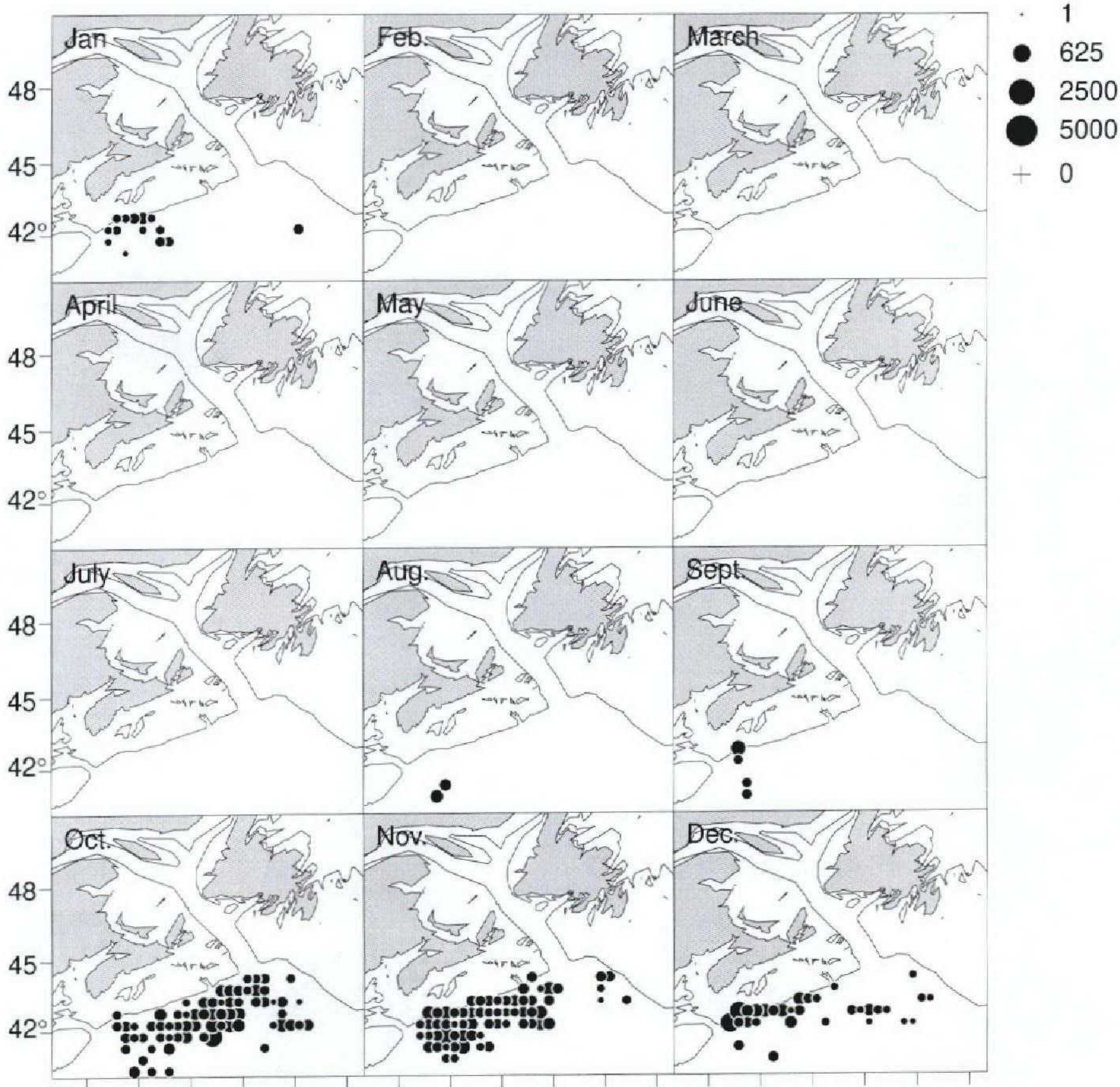


Figure 3b. Monthly distribution of porbeagle shark by-catch (kg) in the Japanese longline fishery for tuna during 1978 - 1994.

Figure 4. Reported Landings (t) by Season in Canadian Fishery

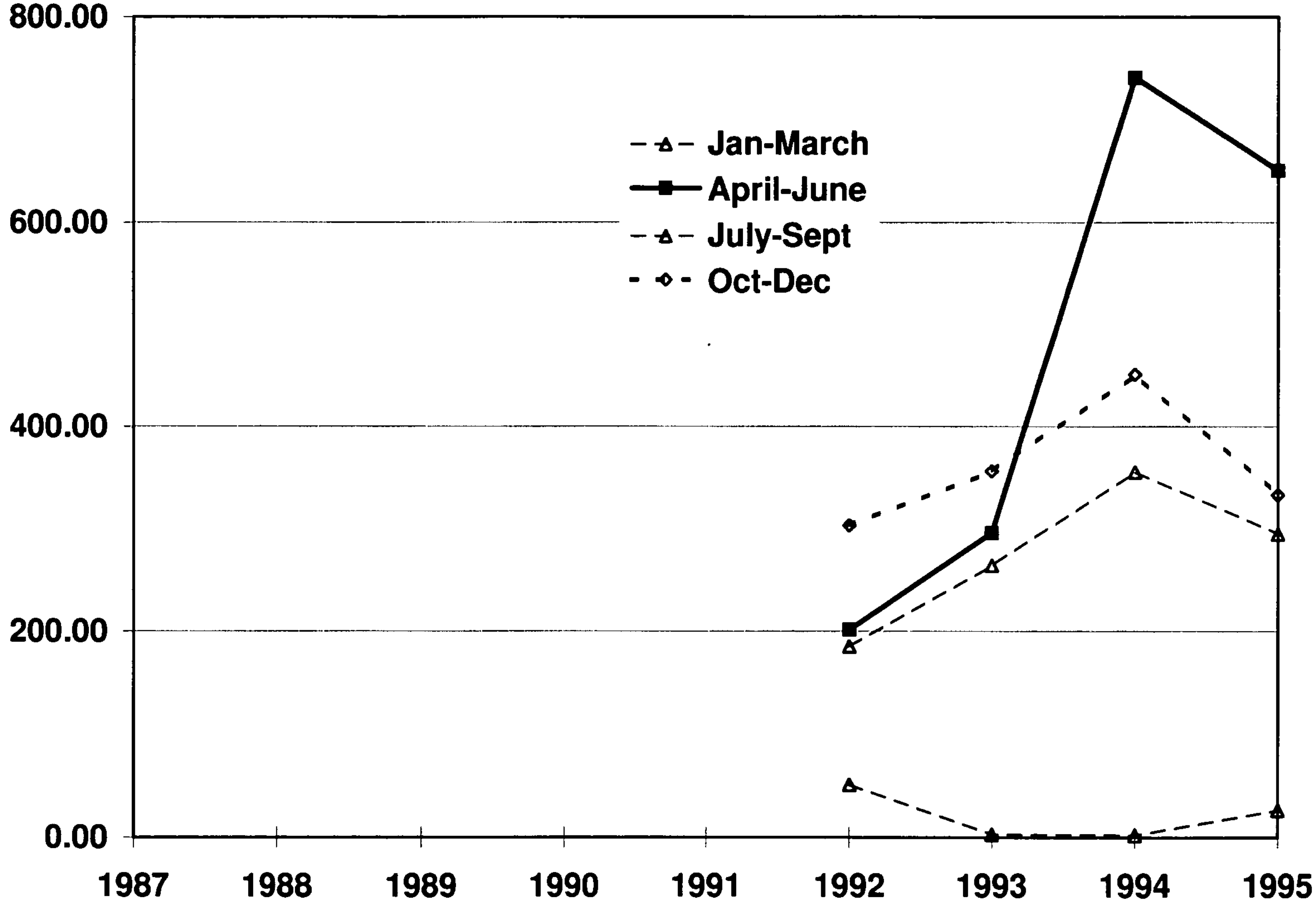
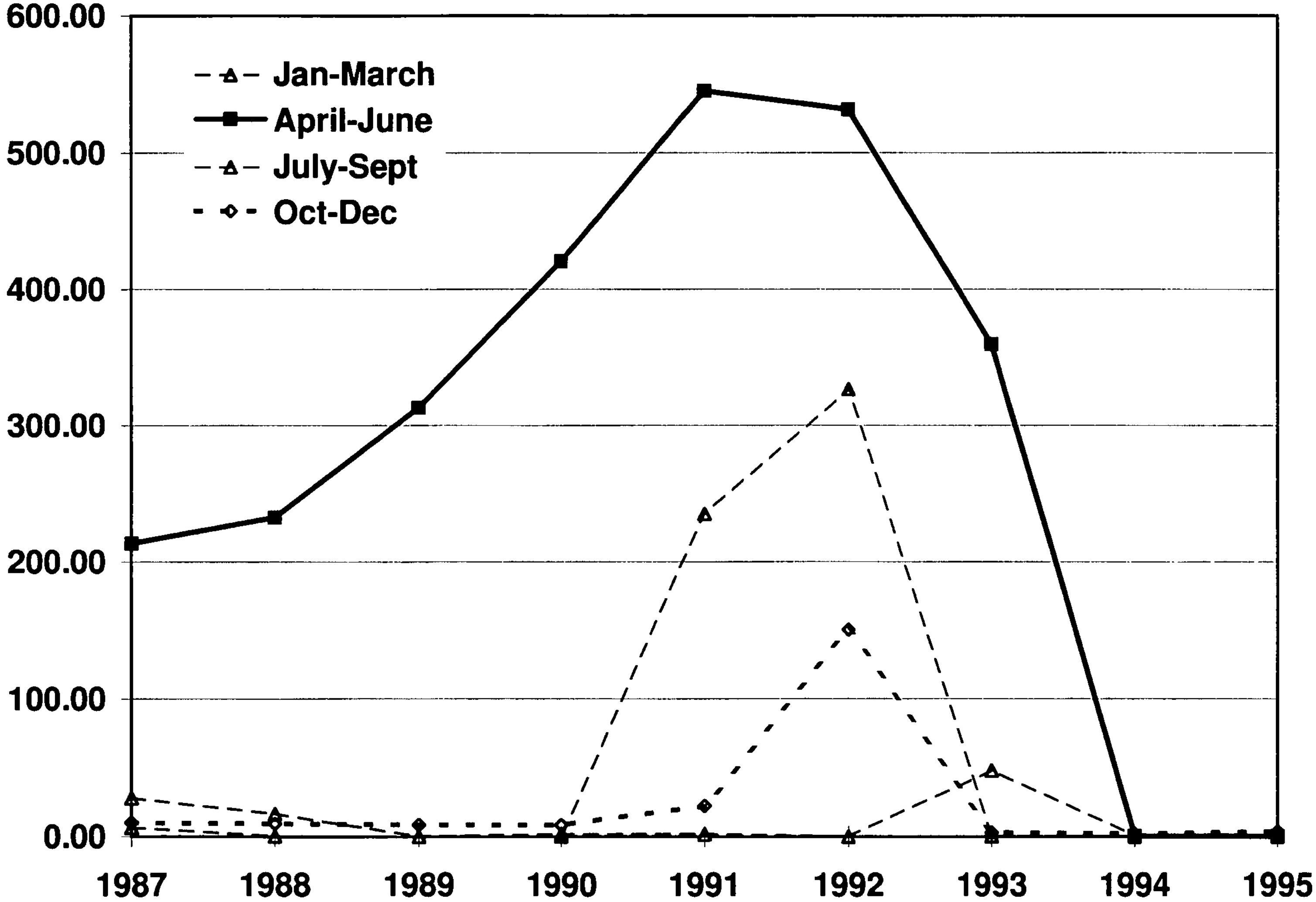


Figure 5. Reported Landings (t) by Season in Foreign Fishery



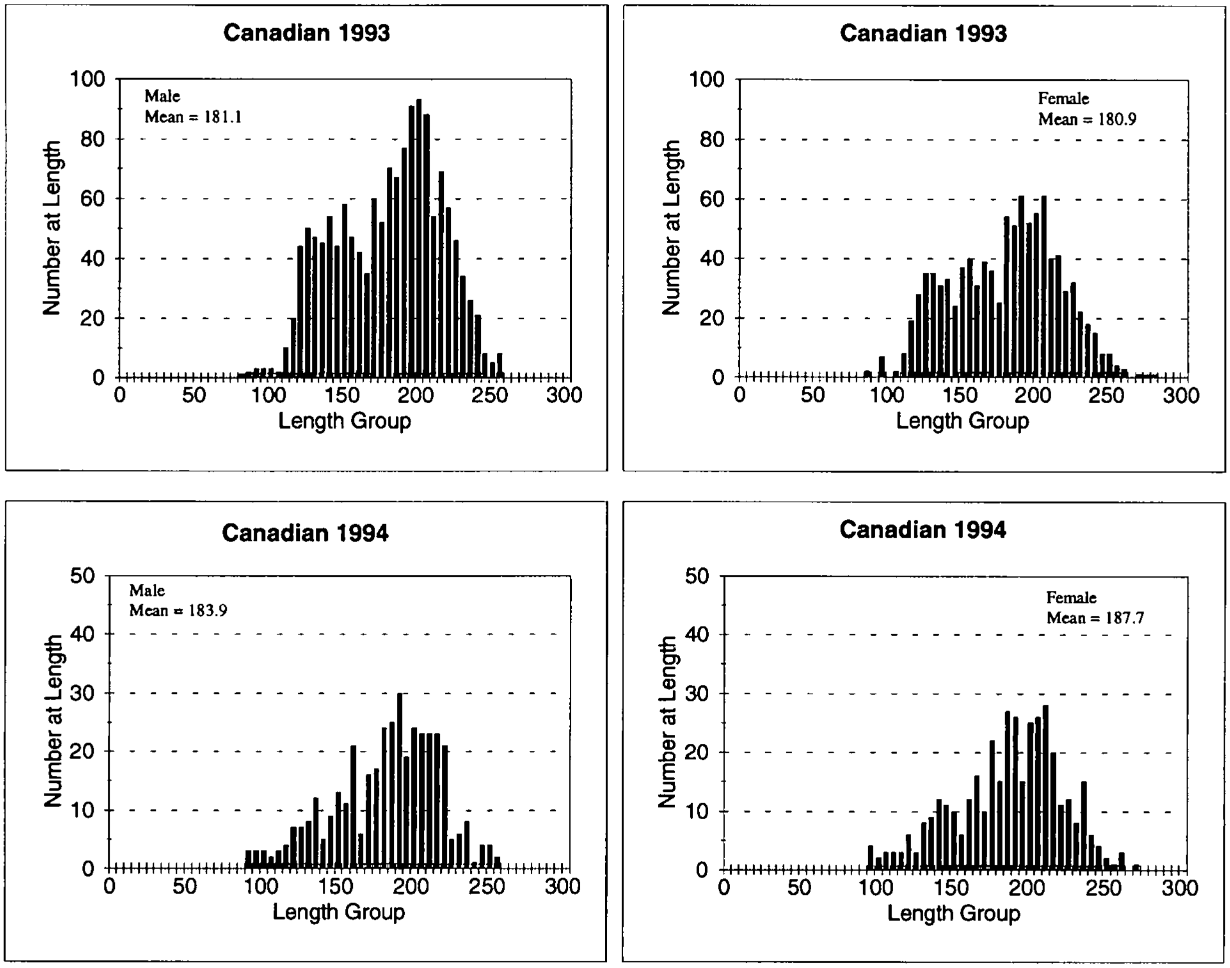


Figure 6. Size composition of porbeagle sharks (in 5cm intervals, by sex) caught in the Canadian directed fishery for porbeagle sharks in the northwest Atlantic in 1993 and 1994.

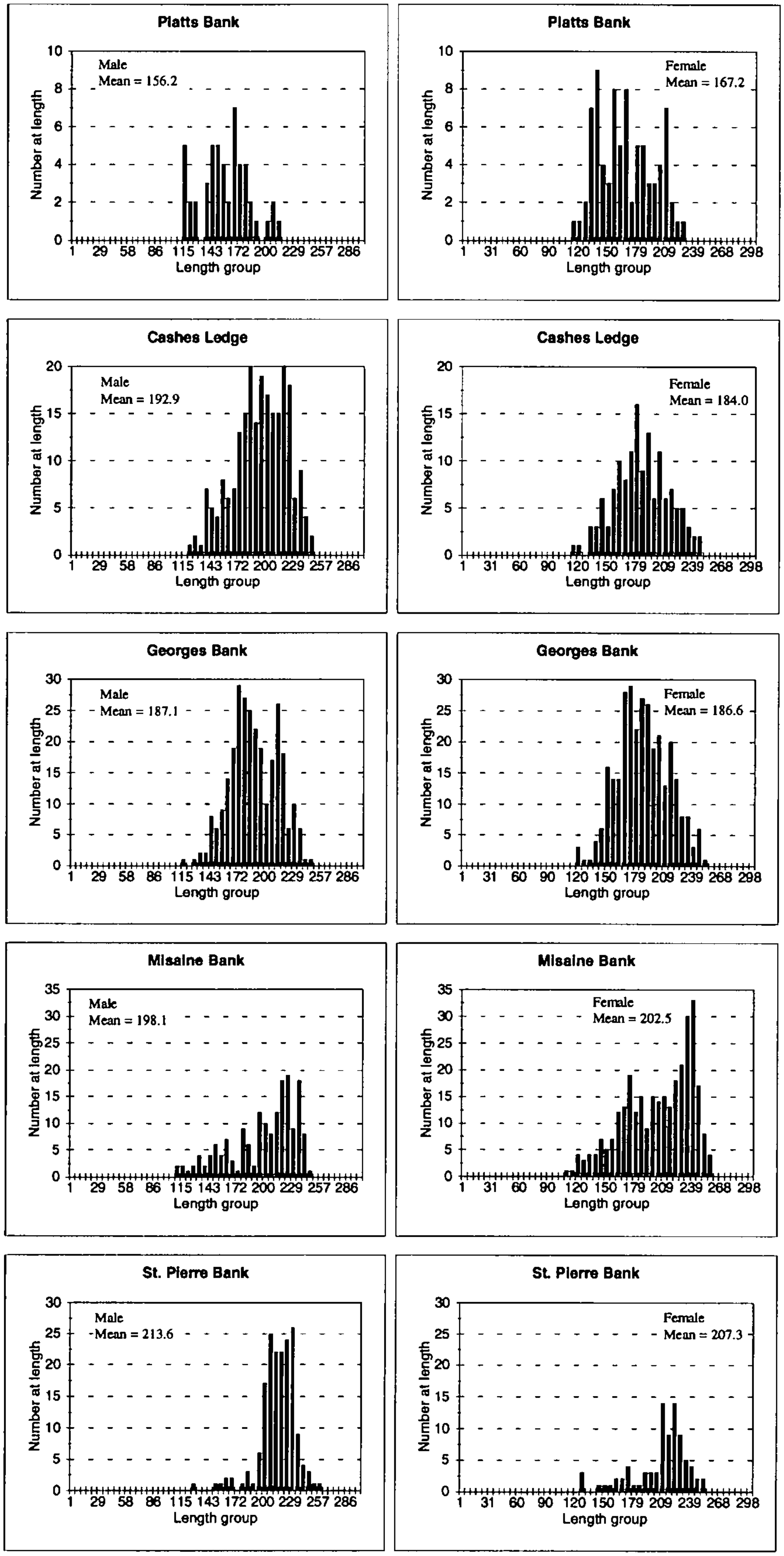


Figure 7. Size composition of porbeagle sharks (total length, in 6cm intervals, by sex, by area) caught in the Norwegian directed fishery for porbeagle sharks in the northwest Atlantic in 1961 (from Aasen 1963)

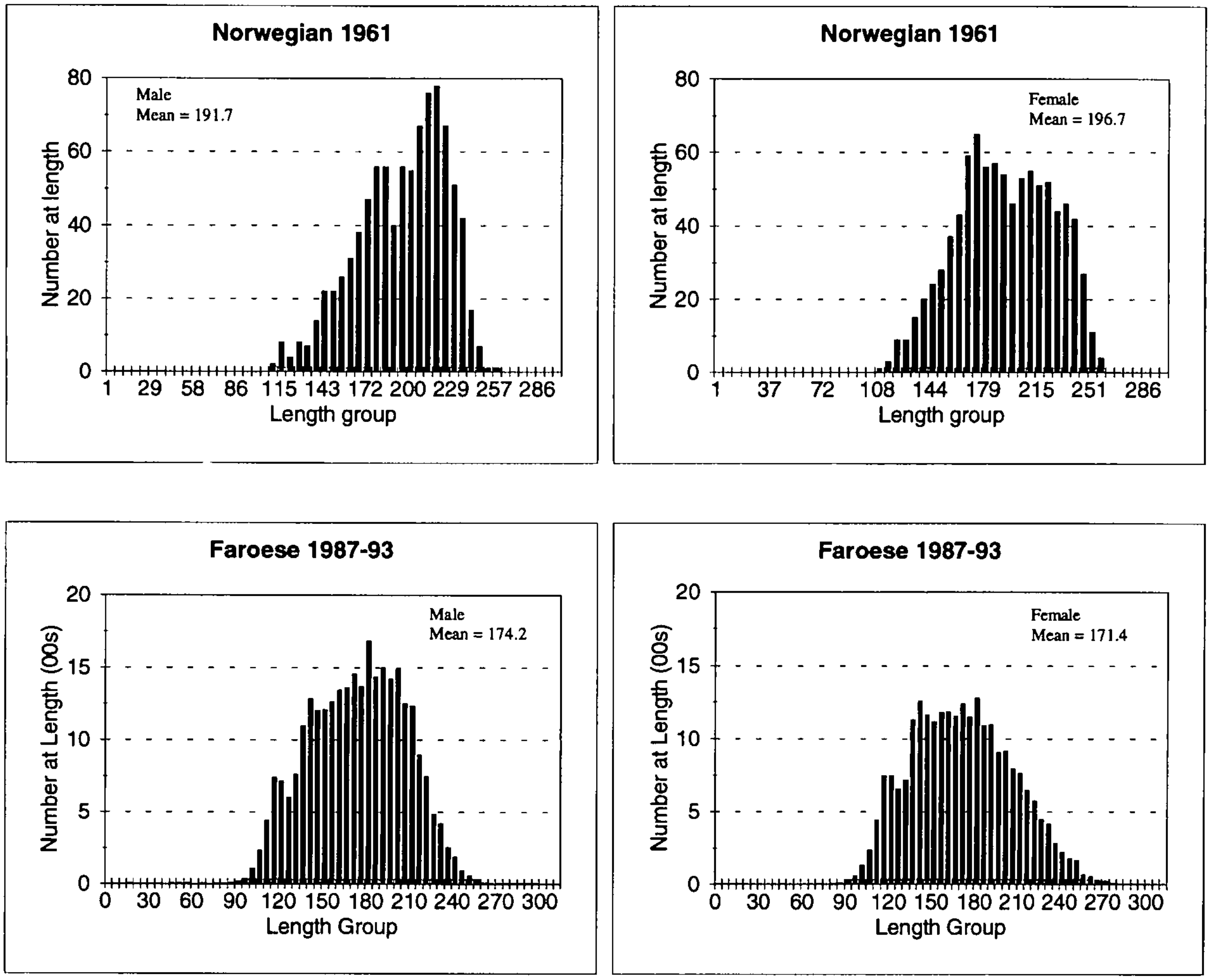


Figure 8. Size composition of porbeagle sharks (total length cm, by sex) caught in directed fisheries for porbeagle sharks in the northwest Atlantic in 1961 by Norwegian vessels (from Aasen 1963) and in 1987-93 by Faroese vessels.

Figure 9. Sex Ratio by Total Length of Porbeagle in the NW Atlantic

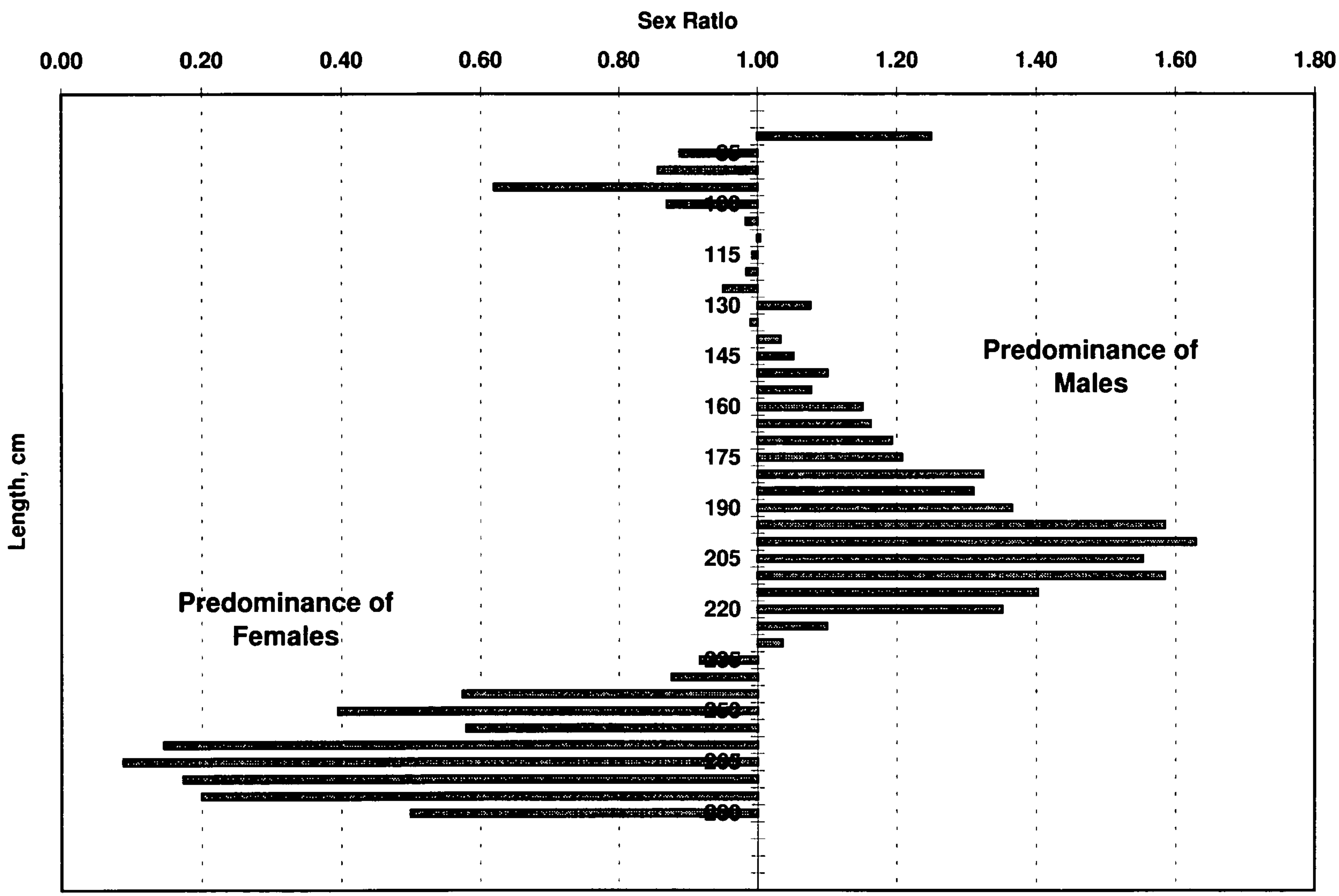


Figure 10. Von Bertalanffy Growth Curve for Porbeagle Shark (from Aasen, 1963)

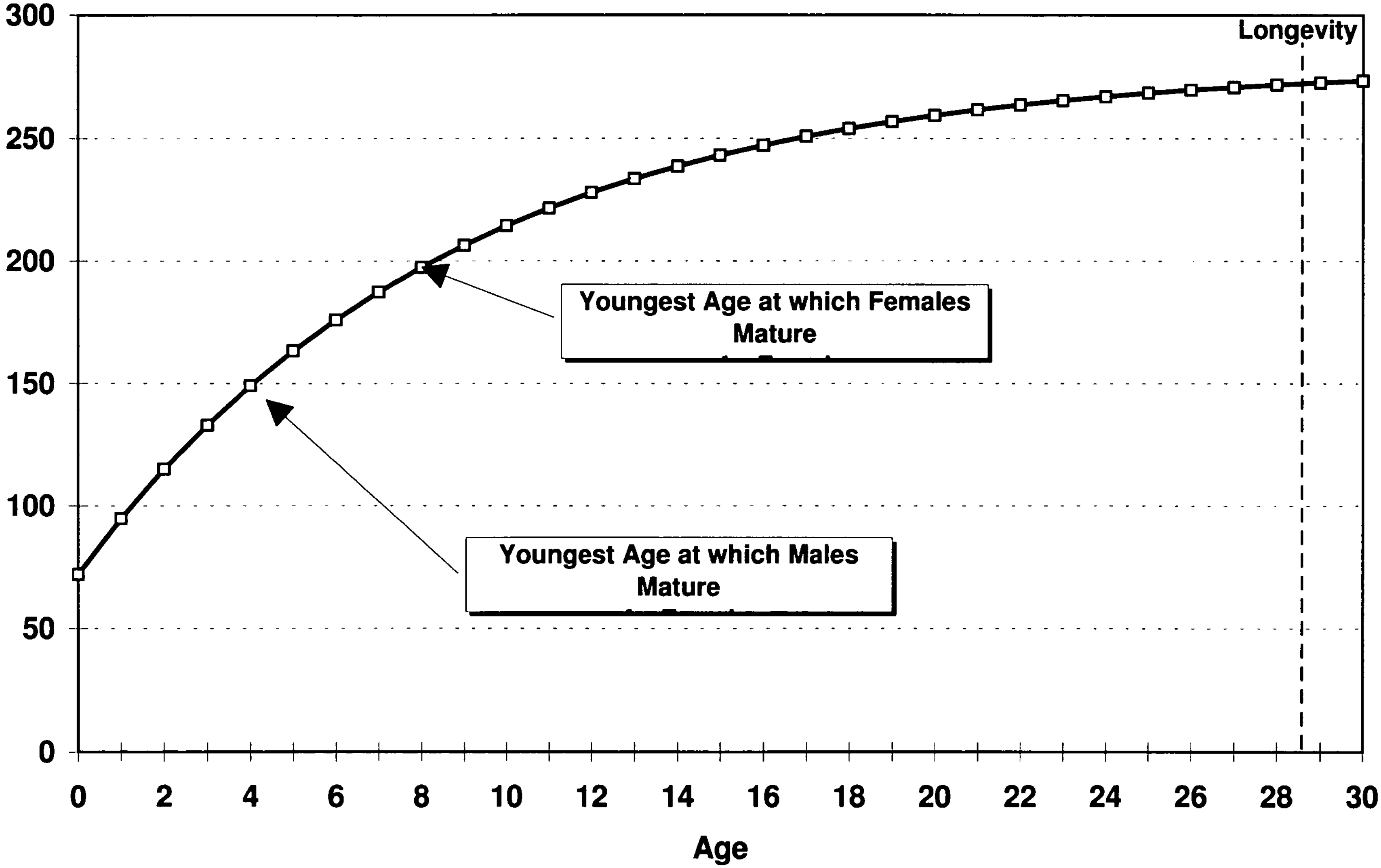


Figure 11. Z_i and Z_m for Equilibrium in a Porbeagle Population