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Observations on Blue Shark (*Prionace glauca*) in the North Atlantic

by

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Abstract

Blue shark has been caught primarily as a by-catch to other fisheries, although interest in directed fishing and particularly recreational fishing has grown in recent years. There is very little knowledge of either the catch or level of effort on this resource. Due to the lack of information, the Precautionary Catch Level of 250t in 1995 as outlined in the Shark Management Plan was not based on biological assessment. Compared to the other sharks, blue shark offers some potential for a sustainable fishery and perhaps a focus for recreational interests. However, the level of by-catch and incidental mortality in other fisheries needs to be determined. Therefore, commercial effort should not be expanded until there is better documentation of the by-catch in other fisheries.

Résumé

Le requin bleu est surtout capturé comme prise accessoire d'autres pêches, bien que l'intérêt pour la pêche dirigée de l'espèce, en particulier la pêche récréative, ait monté dans les dernières années. Comme peu de données sur les prises et le niveau d'effort sont disponibles pour cette espèce, le quota prudent de 250 t donné dans le Plan de gestion 1995 du requin n'était pas basé sur une évaluation biologique. Comparé aux autres requins, le requin bleu offre un certain potentiel pour une pêche durable et peut-être une pêche récréative. Toutefois, le taux des prises accessoires et de mortalité fortuite lors d'autres pêches doivent être déterminés. Par conséquent, il ne devrait pas y avoir d'augmentation de l'effort de pêche commerciale tant que de meilleures données sur les prises accessoires d'autres pêches ne soient disponibles.

Introduction

The blue shark is distributed worldwide. It is the most abundant of the large sharks in the North Atlantic (Skomal, 1990). 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 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 Maritimes 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 blue sharks in the Northwest Atlantic. Where necessary, observations are reported for blues in the Northeast Atlantic. Given that the research program was initiated recently, many of the analyses are preliminary and thus recommendations are made to further the research program. Notwithstanding the preliminary nature of the information, advice is provided to serve as the basis for management in the Canadian Zone. This document was externally reviewed as part of the RAP.

Reproductive Biology

There are three modes of reproduction in sharks - 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 in 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. bigeye thresher), 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.

Males mature between 150 to 200 cm FL (50% at 183cm), which spans ages 4 -6, while females first start maturing at 180 to 190 cm FL or about age five. Mature males appear to dominate in the NW Atlantic while mature females dominate in the NE Atlantic (Aasen, 1966; Casey, 1982; Connett, 1987; Pratt, 1979; Stevens, 1975, 1976). This separation, other than at the time of mating, may be an adaptation for females to avoid the dangers associated with male mating behaviour, as will be discussed below (Nakano, 1994).

Pratt (1979) has proposed the sexual cycle of the blue shark in the western North Atlantic. He suggests that age 4- and 5-yr-old females migrate inshore to the summer feeding/mating grounds of the continental shelf in late May and early June. Here they interact with males and receive dermal punctures and lacerations (tooth cuts). This is the reason why the female's skin is almost twice as thick as that of the male. The occurrence of fresh mating wounds could be used in future studies in the Canadian Zone to locate mating areas.

The 5-yr-old females and some 4 yr olds, copulate with the males of 180 cm and larger. This process continues until as late as November. Based on changing sex ratios, it appears that once a female is inseminated, it moves offshore, presumably to avoid aggressive males. Pratt (1979) proposed that the sperm is stored in the female until the following spring, during which the 6-yr-old females remain offshore and fertilize their eggs (May, June). This long storage of sperm needs to be confirmed through further observation.

Pratt (1979) documents the size of embryo by month for blue sharks observed in the North Atlantic. He observed that embryos reach full term in a gestation period of 9-12 months. Pupping follows in April to July. Pratt (1979) provides no estimate of litter size per female. However, Aasen (1966) observed 45 embryos per female, with a range of 32 - 67, although his sample size (12) was small. Nakano (1994) provides litter size estimates for blue sharks in the Pacific Ocean of one to 62, with an average of 26, based on 669 pregnant females. It is uncertain whether or not these litters are produced annually or biannually.

Pratt (1979) noted the lack of young-of-the -year and age two sharks in NW Atlantic waters and suggested offshore pupping but was unable to specify exactly where. Young-of-the-year are found in nursery areas in the NE Atlantic (Casey, 1982; Connett, 1987) while juveniles of both sexes are found throughout the North Atlantic, as are immature adults. Further, blue shark condition is at an annual low in the winter and spring. During this time, they use energy stores for extensive north-south and transatlantic migrations (Kohler, 1987). It is also noteworthy that in the North Pacific (Nakano, 1994), after mating in the lower latitudes, the females migrate into northern waters where the pups are born in nursery areas. A similar migration and parturition may occur in the North Atlantic. More information on these movements is given in a later section.

- **It is recommended that observations be made on the Canadian East Coast fisheries to clarify the life cycle of the blue shark in the Northwest Atlantic.**

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

Growth and Natural Mortality

A number of studies have been conducted on the growth of blue shark, both in the Atlantic and Pacific Oceans. Tanaka et al. (1990) reviewed the studies to date and concluded that, given age reader precision, inter-technique variability, and natural biological variability, real differences in growth parameters between sexes and among regions may not exist. While Nakano (1994) presents the most comprehensive information on blue shark growth (based on 29,161 individuals), his data pertains to the North Pacific; that of Skomal (1990) is for the Northwest Atlantic. It is thus reported on here.

According to Skomal (1990), fork length at birth appears to be just under 40 cm (Figure 1). This is consistent with most other studies. It should be pointed out that Tanaka et al. (1990) considered that a Von Bertalanffy growth model (VBGM)(Bertalanffy, 1938) fit the embryonic growth phase well.

The VBGM reported by Skomal (1990) for males is

$$Lt = 286*(1\text{-EXP} - 0.16*(t+0.89))$$

while that for females is

$$Lt = 313*(1\text{-EXP} - 0.15*(t+0.87))$$

The t_0 estimates of 0.87 to 0.89 reported here are in agreement with those of others (Tanaka et al, 1990; Nakano, 1994) and suggest a gestation period of 11 months, assuming embryonic growth as per these equations. This is in agreement with the observations of Pratt (1979). Note, however, that this is not necessarily inconsistent with a two year reproductive cycle, if Pratt's (1979) proposal of sperm storage is correct.

Skomal's (1990) estimates of the growth coefficient (K), ranging from 0.15 to 0.16, are high in relation to other studies and make blue sharks among the fastest growing elasmobranchs. Also, while the L_{inf} for males and females was 286 and 313 cm respectively, he felt that the females do not grow to this maximum due to high mortality in adulthood. However, Skomal (1990) did not observe many animals above five years old. Other authors (Tanaka et al., 1990; Nakano, 1994) have observed a smaller L_{inf} for females than for males.

According to Taylor's (1958) cod model, the male's life span can be estimated as $t_0 + 2.996/K$ or

$$0.89+2.996/0.16 = 20$$

For females, the life span would be

$$0.87+2.996/.15 = 21$$

These are considerably higher than Skomal's (1990) estimated maximum ages for males and females of 16 and 13 respectively, these being lower perhaps due to high adulthood mortality, as mentioned above.

Hoenig (1983) provides a relationship between his definition of longevity, t_{max}, (arbitrarily set at the age to which 0.01 of the population survives) and observed natural mortality rates (M), or

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

If t_{max} is assumed here to be equivalent to Taylor's (1958) estimate of life span, Hoenig's (1983) model would predict an M of 0.22 and 0.21 for males and females respectively. If Skomal's (1990) values of 16 and 13 are used, these estimates of M increase dramatically to 0.28 and 0.34 for males and females respectively. These estimates are higher than those calculated for other sharks (Hoenig and Gruber, 1990) and point to a possible inconsistency with the growth equation of Skomal (1990).

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

Stock Structure and Movements

The blue shark occurs throughout the tropical, sub-tropical and temperate waters of the Atlantic, Pacific and Indian Oceans, and is probably the most widely distributed of all shark species. The species range extends from Newfoundland to Argentina in the west Atlantic and from Norway to South Africa in the East Atlantic and includes the mid-Atlantic and the Mediterranean Sea areas.

In 1962, the United States National Marine Fisheries Service (NMFS) initiated a shark tagging program relying heavily on the volunteer participation of recreational anglers and commercial fishers. The 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). Since its inception, the program has tagged over 46 species of sharks and 20 species of other fishes (Casey and Kohler, 1991). In 1994 alone, participants in the program tagged 4448 blue sharks with recoveries 335 being made from 1994 and earlier releases (Casey et al, 1995).

The program has relied on two basic tags, a jumbo rototag (plastic cattle ear tag) which is inserted through the first dorsal fin and a dart tag (stainless steel dart with monofilament streamer and plexiglas capsule with reward message inside) (Casey, 1985). Dart tags are preferred because they can be applied in the dorsal musculature of the back without bringing the animal onboard the vessel, are applied with simple inexpensive equipment, are visible, and contain return instructions in several languages. The jumbo rototag requires that the animal is brought on board the vessel for attachment, thus causing greater stress to the animal and greater danger to the tagging personnel. A periodic newsletter keeps participants informed of releases, recoveries and other biological and management items related to sharks, along with the detailed information on recoveries and the names of the returnees.

From 1961 to 1984 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). During that program, 2003 blue sharks were tagged; 17 of the tagged blue sharks have been recovered. In 1994, Canada initiated a shark tagging program in cooperation with recreational anglers and commercial fishers. Since its inception, 49 blue sharks have been tagged, and 2 recovered.

- **It is recommended that the current Canadian tagging effort be continued and collaboration with other existing programs be investigated.**

- **It is recommended that historical and current Canadian shark tagging data sets be combined into a common database.**

This species has comprised the largest part of the sport fishing catch off the Northeast coast of the US and consequently has had the greatest tagging effort directed to it as well as the greatest number of recoveries (figure 2). The generally accepted hypothesis is that blue sharks are transatlantic in nature, but those found off the eastern seaboard of North America are part of a population restricted to the North Atlantic (Casey and Kohler, 1991). This stock definition is similar to that for the Pacific blue shark population in extent, trans-Pacific and restricted north of the equator (Nakano, 1994).

Blue sharks have been reported to have a wide (8-27° C) temperature tolerance (Castro, 1983; Scott and Scott, 1988). But Carey and Scharold (1990) have suggested that this range may be due to diurnal migration associated with sexual activity or exploration of the warm surface waters to increase body temperatures quickly after periods in the cold deeper waters . Casey (1985) reported that they are most commonly found in a restricted range from 13-18° C and suggested that this temperature preference determines the timing of their movements. In the Western Atlantic, the winter range of blue sharks is defined as eastward of the northern margin of the Gulf Stream, that is in the Gulf stream and the Sargasso Sea. In fact, blue sharks are found in these two areas throughout the year. Beginning in April and May, as the shelf waters warm, there is a movement onto the continental shelf off North Carolina; this shoreward movement extends progressively eastward to Newfoundland. Anectodal information from recreational anglers and examination of sharks landed during fishing tournaments in the coastal waters of Nova Scotia monitored by the Marine Fish Division in 1993-95 suggest that the seasonal migration of blue sharks into the nearshore areas of the Nova Scotia coast is similar to that described by Pratt (1979) and Casey (1985) where subadult females dominate the catches early in the season and large males dominate catches late in the season.

Observer records of blue shark bycatches in the longline fishery directed by Faeroese vessels for porbeagle sharks in Canadian Atlantic waters (figure 3) suggest that blue sharks first appear off the western Scotian Shelf in March-April, move onto the continental shelf and progressively eastward during the summer and leave the region by October. These observations do not take into account that the geographic area of the porbeagle fishery may not encompass the distribution of blue shark during this period. Observer records of blue shark bycatches by Japanese tuna longline vessels fishing in the Canadian Atlantic (figure 4) shows that the blue sharks range extensively along the edge of the continental shelf, and into the Gulf Stream, and indicates that the blue shark has a wider distribution than that implied by the Faeroese porbeagle fishery.

- **It is recommended that monthly distribution maps of blue shark bycatch be produced that also show the full geographic range of the porbeagle and tuna fisheries.**

Bycatches of blue sharks are also known to occur in longline fisheries conducted in the North Atlantic by Japan, Taiwan, Korea, Spain and the USA (Bonfil 1994).

- **It is recommended that bycatches of blue shark in other North Atlantic fisheries should be examined to assist in the determination of blue shark distribution and movements.**

Casey (1985) reported that most of the animals caught on the Continental Shelf of eastern North America are males and immature females; few pregnant or postpartum females have been caught on the continental shelf or slope or in the Gulf Stream areas. It is believed that mating can occur throughout the year, and once impregnated, females move far offshore and stay there through parturition. In late summer, most of the blue sharks along the eastern North American coast begin moving south and offshore, but the migration routes are not clearly defined (Casey, 1985). Part of the population appears to move off the continental shelf areas to the margin of the Gulf Stream (Casey, 1982), while others may move as far south as the Caribbean Sea. In the eastern Atlantic, blue sharks also show northward movement in the spring and southward movement in the fall (Casey, 1985); again these movements are related to size and sex.

The concept of a single transatlantic stock is based on a relatively small number of recoveries (figure 2) made in the eastern Atlantic from western Atlantic releases (21 of the 885 recoveries, or 2.4%), and made in the western Atlantic from eastern Atlantic releases (7 of 94 recoveries, or 7.4%). Further support for the single stock concept is taken from the limited information on very young and juvenile blue sharks. They are relatively rare in the Western North Atlantic compared to the Eastern North Atlantic. It has been inferred from these observations that the Eastern North Atlantic is the prime production grounds, and nursery area for young blue sharks (Casey, 1985). But in the Western North Atlantic, female blue sharks move beyond the Gulf Stream to pup, thus few of these young would be available to fisheries, either sport or commercial.

The Fishery

Blue sharks have been taken as bycatch in a number of fisheries in the past, but were usually discarded. Interest in developing markets for blue sharks has increased in the last few years and reported Canadian landings have fluctuated from a low of 8t in 1990 to a high of 133t in 1994, and were 123t in 1995 (table 2). Only in 1992, 1994 and 1995 have the majority of blue shark landings reportedly been directed for as a non-bycatch fishery.

Significant bycatches of blue sharks occur in most pelagic longline fisheries in the North Atlantic. Anecdotal information suggests that the bycatch of blue sharks by swordfish longliners often exceeds the catch of swordfish itself. The predominant fisheries known to be taking blue sharks as bycatch comprise the Canadian swordfish, porbeagle and tuna fisheries, the Faroese porbeagle fishery (up to and including 1993, when it terminated), and the Japanese tuna fishery.

Blue shark bycatches are often discarded and are for the most part not reported. In many cases, they represent an undocumented source of mortality as a result of finning - removal and retention of the fins but discarding of the carcass, then not reporting the fins as landings. A ban on this practice in Canadian waters was formulated in 1994 but was not implemented during 1995, and we have no control over finning outside the Canadian zone. Mortality levels due to finning are probably very high.

- **It is recommended that every effort be made to determine historical levels of finning through the Fisheries Observer Program.**

Some insight into the possible differences between reported landings and actual catches for blue sharks is provided by a comparison of North Atlantic Fisheries Organization (NAFO) landings data to Fisheries Observer Program (FOP) catch data for foreign catches of blue sharks in the Canadian zone. Total landings of blue sharks for the foreign components of these bycatch fisheries, as tabulated by NAFO, rarely approach catch totals derived from FOP. In the most extreme case, the difference was 62t landed versus 328t caught in 1994. For stock assessment purposes we would rarely know discard rates for all major fishery components, relying on landings data alone to determine fishing mortality. In this case we would underestimate fishing mortality by a factor of over five times. Most years within 1989-95 would give underestimates in the 2-3 times range.

Comparing total 1995 Canadian blue shark landings to catches of blue sharks by only that portion of Canadian vessels monitored by FOP shows a similar disparity. Reported landings of 123t of blue shark across all Canadian fishery components contrasts with observed catches of 182t by only the few Canadian longliners monitored by FOP. If we consider these vessels representative of at least the longliners, it can be inferred that their is substantial underreporting of blue sharks caught in the Canadian zone.

- **It is recommended that bycatch of blue sharks in Canadian longline fisheries be recorded and keypunched.**

The blue shark is regarded as an important sportfish in recreational fisheries in many parts of the species range. Interest in angling for sharks, especially blues, has increased in Atlantic Canada over the last few years. Removals by this developing fishery have not been recorded.

- **It is recommended that the historical records by each fishing derby be obtained to develop a time series of catches for these events.**

Management History

Efforts to develop a Fisheries Management Plan for pelagic sharks in Atlantic Canada began in 1992; however pelagic sharks were not covered by Fisheries Regulations and amendments were required to the Fisheries Act. These amendments did not occur 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 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 that the rationale and restrictiveness of the Plan should be strengthened 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 will be exploratory, 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 established scientific data collection.

The precautionary catch levels roughly approximate 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 last 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 they are issued with no obligation that they must be issued in the future. Fins may only be sold in proportion to a maximum of five percent of dressed carcass weight aboard a vessel and fins may not remain aboard the vessel after the associated carcasses are 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 are 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.

The Resource

Blue shark catches are under-reported, and the portion of the catch that does get reported is rarely associated with effort data (number of hooks fished per set for a longliner). An attempt to estimate stock abundance will require at least 3-5 years of valid catch/effort information.

- **It is recommended that measures of effort (hooks per set) associated with commercial landings of blue sharks be obtained.**

Analyses of catch rates in Canadian fisheries were hindered by problems in the data. However, very preliminary analyses of blue shark bycatches from the Faroese porbeagle and Japanese tuna fisheries was possible, and will be briefly summarized here.

Blue Shark Bycatch in the Faroese Porbeagle Fishery

Blue shark bycatch rates follow the monthly rise and fall seen in the porbeagle catch rates, showing a minor spring and major fall peak in bycatch rates. Blue shark bycatch rates decrease as the location of fishing activity progresses from south to north. There is a large increase in blue shark bycatch rates during 1991-93 relative to previous years, which does not appear to be due to a population trend but rather corresponds with the initiation of the Canadian fishery. This sudden increase in blue shark bycatch rates may also be associated with changes in the economic value of blue sharks, either through growth of a commercial market for blue shark or a decline in catches from otherwise more lucrative fisheries. We cannot resolve geographic or seasonal shifts in effort at this time without considering the Newfoundland component of the FOP.

- **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.**

Blue Shark Bycatch in the Japanese Tuna Fishery

Significant interactions between month and area were observed in the data. Examination of the monthly patterns by areas suggested that there was a gradual shift in the high bycatch rates, from 4X in November through to 4V in January. Vessel tonnage class confounded attempts to resolve blue shark bycatch trends due to the significant role of 'unknown' tonnage classes in any of the models attempted. There were also concerns that the recent rise in bycatch rates may reflect improving market conditions for blue shark, and not be related to population growth, as mentioned above. Given these problems, calculation of a standardized catch series from these data was not considered appropriate.

Outlook

There is very limited information for blue sharks 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 litter size, which is divided by two to provide the estimate for females

t_m is the average age of first maturity of a female

Thus, if we know the annual gross fecundity, E, and the 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 5 shows the relationship between Zi and Zm, using E of 13 and tm of 6. Here, Nakano's (1994) estimate of litter size is used due to the large sample size. All combinations of Zi and Zm to the right of the curve are unsustainable. Let us assume that Hoenig's (1983) estimate of natural mortality, 0.21, for females is correct. If the mortality of the immature individuals is about this level, then the mortality on the adults could go as high as 1.74. This seems unrealistic and could indicate that Zi is actually higher than 0.21. An increase into the range of 0.3 - 0.4 would reduce the maximum total mortality to 0.6 - 1.0, which is still enough to sustain a fishery. These calculations are very sensitive to the estimates of E and tm. If the reproductive cycle is annual, and not biannual, as assumed above, then E would be 26 and not 13. The 'allowable' Zm values roughly double. As well, increasing tm by one year to 7 decreases the replacement Zm to 2.79. The following table summarizes the replacement Zm values for a range of E and tm, under the assumption that Zi equals the natural mortality, 0.21.

Age of First Maturity	**Gross Annual Fecundity, E**	
tm	**13 (two year cycle)**	**26 (one year cycle)**
5	2.16	4.33
6	1.74	3.47
7	1.39	2.79

Let us now assume that natural mortality on the females is closer to Skomal's (1990) derived estimate of 0.34. Again assuming that the Zi is close to this level, the maximum Zm values are

Age of First Maturity	Gross Annual Fecundity, E	
tm	13 (two year cycle)	26 (one year cycle)
5	1.13	2.26
6	0.80	1.59
7	0.56	1.12

which are still sizable and would allow a fishery.

Based on these observations, blue shark may be more resilient to exploitation than other, less productive, shark species. A key assumption is that the natural mortality on the age one individuals is relatively low. The team was concerned with this and noted the need for further study of this assumption.

- **It is recommended that the impact of juvenile natural mortality assumption be investigated using demographic, and other like models.**

Sharks in general are slow growing, long-lived, and have delayed sexual maturity. They bear live young and produce low numbers of offspring. This combination of life history characteristics makes sharks highly susceptible to over-exploitation. Some shark fisheries have collapsed after a relatively brief period of exploitation. Relative to other species of sharks, the blue shark is faster growing with higher fecundity, offering some potential as a sustainable fishery if properly managed. However, substantial by-catches of blue sharks occur in tuna and swordfish longline fisheries. By-catch and incidental mortality rates in these fisheries need to be determined. Similarly the mortality associated with a hook and release recreational fishery should be determined.

It is not possible to make recommendations concerning harvest levels for this resource with the information available. The precautionary catch level of 250t in the 1995 Shark Management Plan was not based on an estimate of abundance and exploitation rates may already be high due to the by-catch in other pelagic, longline fisheries. Therefore, caution needs to be exercised in the development of a directed fishery for blue sharks. Any directed fishery should be characterized as exploratory until such time as the status of the resource can be determined. The fishery must have a comprehensive scientific component to collect the information necessary to fill the identified knowledge gaps. Specific provisions are required for the collection of catch and effort data, including the species, size and sex composition of all shark catches, on a set by set basis. Research into the basic biology and stock structure of this species is also required.

This species is part of a large pelagic species complex that includes other large sharks, tunas, swordfish, and billfishes. A directed fishery for blue sharks will likely require spatial and temporal limitations and careful monitoring to minimize by-catches of other species in the complex. In addition, international cooperation will be necessary to assess and manage a fishery for this species.

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 six 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 blue shark's life cycle.

2. It is recommended that measures of effort (hooks per set) associated with commercial landings of blue sharks be obtained.

3. It is recommended that the historical records by each fishing derby be obtained to develop a time series of catches for these events, and that future derbies use the log outlined in Appendix A to record shark catches.

4. It is recommended that bycatch of blue sharks in Canadian longline fisheries be recorded and keypunched.

5. It is recommended that every effort be made to determine historical levels of finning through the Fisheries Observer Program.

6. 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 recommendation relates to analyses of existing data to elucidate the trends in abundance:

7. It is recommended that monthly distribution maps of blue shark bycatch be produced that also show the full geographic range of the porbeagle and tuna fisheries.

The next six recommendations relate to studies on the blue shark's life history:

8. It is recommended that the impact of the juvenile natural mortality assumption be investigated using demographic, and other like models.

9. It is recommended that observations be made on the Canadian East Coast fisheries to clarify the life cycle of the blue shark in the Northwest Atlantic.

10. It is recommended that the current Canadian tagging effort be continued and collaboration with other existing programs be investigated.

11. It is recommended that historical and current Canadian shark tagging data sets be combined into a common database.

12. It is recommended that bycatches of blue shark in other North Atlantic fisheries should be examined to assist in the determination of blue shark distribution and movements.

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

References

Aasen, 0., 1966. Blahaien, *Prionace glauca* (Linnaeus), 1758. Fisken og Havet, 1: 1-15.

Anon. 1995. Scotia-Fundy Spring 1995 Stock Status Report for Pelagics, Invertebrates and Marine Mammals. DFO Atl. Fish. Scotia-Fundy Reg. SSR 95/1.

Bertalanffy, L. von, 1938. A quantitative theory of organic growth (inquiries on growth laws II). Hum. Biol., 10(2): 181-213.

Bigelow, H.B. and Schroeder, W.C. 1948. Fishes of the Western North Atlantic (cyclostomes and sharks). Memoir Sears Foundation for Marine Research. 1 (1): 576pp.

Bonfil, R. 1994. Overview of world elasmobranch fisheries. FAO Fisheries Technical Paper 341: 119p.

Brander, K. 1981. Disappearance of Common Skate Raja batis from Iris Sea. Nature. 290: 48 - 49.

Burnett, C.D., J.S. Beckett, C.A. Dickson, P.F.C. Hurley and T.D. Iles. 1987. A summary of releases and recaptures in the Canadian large pelagic fish tagging program 1961-86. Can. Rep. Fish. Aquat. Sci. 673: iii + 99p.

Carey, F.G., and J.V. Scharold. 1990. Movements of blue sharks (Prionace glauca) in depth and course. Mar. Biol. 106: 329-342.

Casey, J.G., 1982. Blue shark, *Prionace glauca*. synopsis, p. 45-48. In: M.D. Grosslein and T. Azarovitz (eds.), Ecology of the Middle Atlantic Bight fish and shellfish - Monograph 15, Fish Distribution, MESA New York Bight Atlas, New York Sea Grant Inst., Albany, N.Y.

Casey, J.G. 1985. Transatlantic migrations of the blue shark; a case history of cooperative shark tagging. pp. 253-268. *In* R.H. Stroud (ed.). World Angling Resources and Challenges: Proceedings of the first world angling conference, Cap d'Agde, France, September 12 to 18, 1985. International Game Fish Association, Fort Lauderdale, Fl.

Casey, J.G., L.J. Natanson, H.W. Pratt, Jr., R. Briggs, P.A. Turner and N.E. Kohler. MS 1995. The shark tagger 1994 summary: Newsletter of the cooperative shark tagging program. US Dept. Commerce. NMFS. Northeast Fisheries Science Center, Narraganset, R.I.

Casey, J.G., and N.E. Kohler. 1991. Long distance movements of Atlantic sharks from the NMFS cooperative shark tagging program. pp. 87-91. *In* S.H. Gruber (ed.). Discovering Sharks. American Littoral Society. N.J.

Castro, J.I. 1983. The Sharks of North American Waters. 180p. Texas A&M University Press.
Nakano, H. 1994. Age, reproduction and migration of blue shark in the north Pacific Ocean. (Japanese text; english summary and figures). Bull. Nat. Res. Inst. Far Seas Fish., no. 31.

Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the World. An Annotated and Illustrated Catalogue of Shark Species known to date. Part 1. Hexanchiformes to Lamniformes. FAO Fisheries Synopsis. (125) 4: Pt 1: 249 pp.

Connett, S., 1987. Blue sharks studied in the eastern Atlantic, p. 8-10. In: J. Casey, H.L. Pratt, Jr., N. Kohler, and C.E. Stillwell (eds.), The shark tagger: 1987 summary. U.S. Dept. Comm., NOAA/NMFS/NEFC, Newsl. Coop. Shark Tag. Prog., Narragansett, RI, 12 p.

Hoenig, J.M. 1983. Empirical Use of Longevity Data to Estimate Mortality Rates. Fish. Bull (US). 81: 898 - 902.

Hoenig, J. M.and S.H. Gruber. 1990. Life-History Patterns in the Elasmobranchs: Implications for Fsiheries Management. *In* H.L. Pratt, S.H. Gruber and T. Tanaka [ed.] Elasmobranchs as Living Resources: Advances in the Biology, Ecology, Systematics, and the Status of the Fisheries. NOAA Tech. Rep. NMFS 90.

Holden, M.J. 1974. Problems in the Rational Exploitation of Elasmobranch Populations and Some Suggested Solutions. In F.R. Harden Jone's [ed] Sea Fisheries Research. Elek Science. London.

Kohler, N.E. 1987. Aspects of the Feeding Ecology of the Blue Shark in the Western North Atlantic. PhD. Dissertation. University of Rhode Island. Kingston.

Nakano, H. 1994. Age, Reporduction and Migration of Blue Shark in the North Pacific Ocean. Bull. Nat. Res. Inst. Far Seas Fish. 31: 141-257.

Pratt, H.L. Jr. 1979. Reproduction in the blue shark, *Prionace glauca*. Fish. Bull. 77: 445-470.
Scott, W.B., and M.G. Scott. 1988. Atlantic Fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219: 731p.

Skomal, G. B. 1990 Master of Science Thesis. University of Rhode Island. 103pp.

Stevens, J.D., 1975. Vertebral rings as a means of age determination in the blue shark (*Prionace glauca* L.).J. Mar. Biol. Assoc. UK, 55(3): 657-665.

Stevens, J.D., 1976. First results of shark tagging in the Northeast Atlantic, 1972-1975. J. Mar. Biol. Assoc UK, 56(41): 929-937.

Tanaka, S., G.M. Cailliet and K.G. Yudin. 1990. Differences in Growth of the Blue Shark, Prionace glauca: Technique or Population? *In* H.L. Pratt, S.H. Gruber and T. Tanaka [ed.] Elasmobranchs as Living Resources: Advances in the Biology, Ecology, Systematics, and the Status of the Fisheries. NOAA Tech. Rep. NMFS 90.

Taylor, C.C. 1958. Cod Growth and Temperature. J. Cons. Inter. Explor. Mer. 23: 366 - 370.

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) of Blue Shark in the Canadian Zone

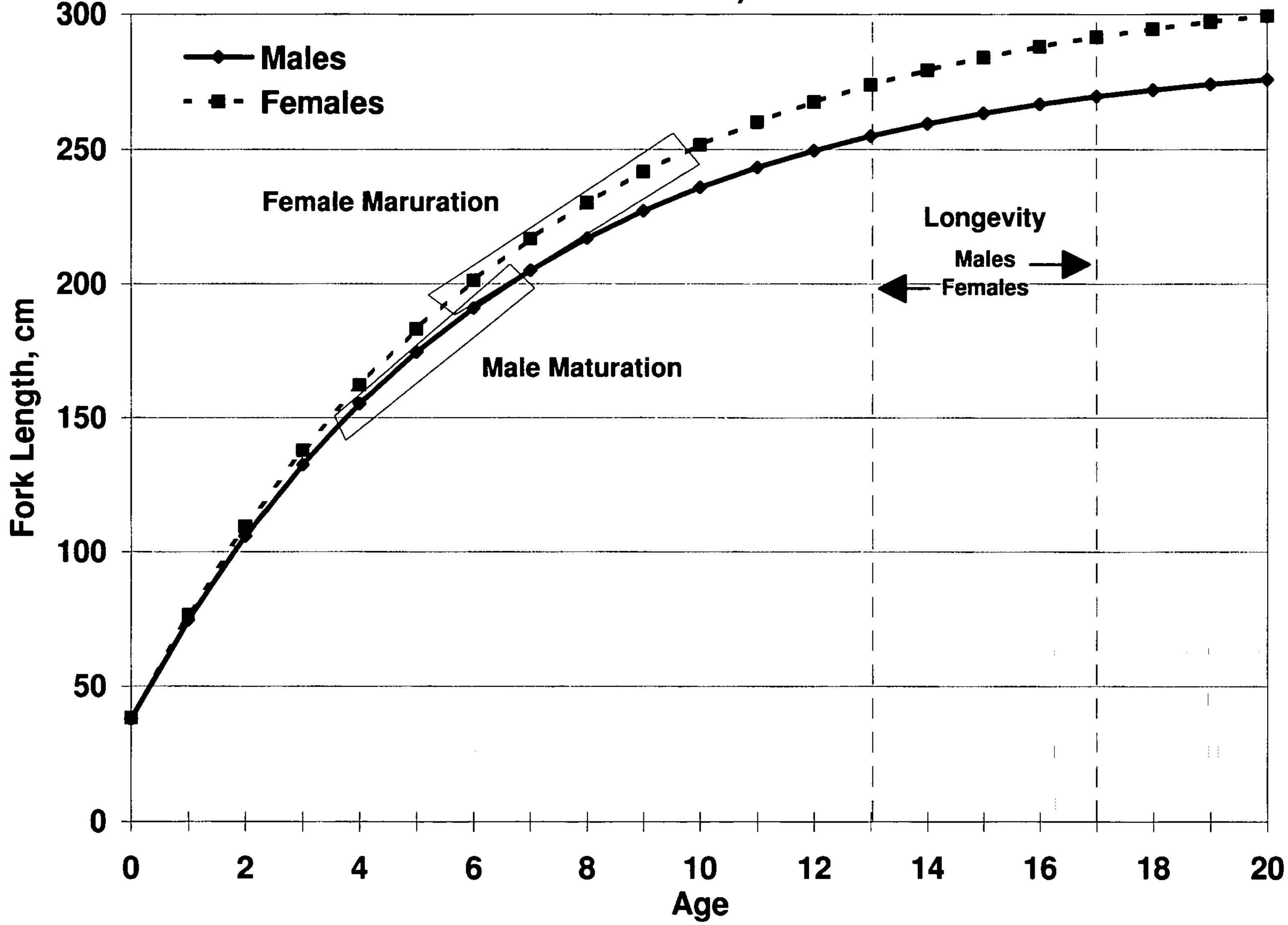
Canada

Year	Directed Longline	Bycatch Swordfish	Bycatch Groundfish	Bycatch Other	Total
1987					
1988					
1989					42
1990	1		7		8
1991	7	2	23		32
1992	72	1	27	1	101
1993	9		7	5	21
1994	99	1	4	29	133
1995	90	1	3	29	123

Foreign

Bycatch Faeroe Is.	Bycatch Japan	Bycatch Other	Total
1	159	0	160
2	134	1	137
2	174	1	177
2	115	1	118
46	134	18	198
112	232	1	345
36	233	0	269
	325	3	328
	110	0	110

Figure 1. Von Bertalanffy Growth Curve for Blue Sharks (from Skomal, 1990)



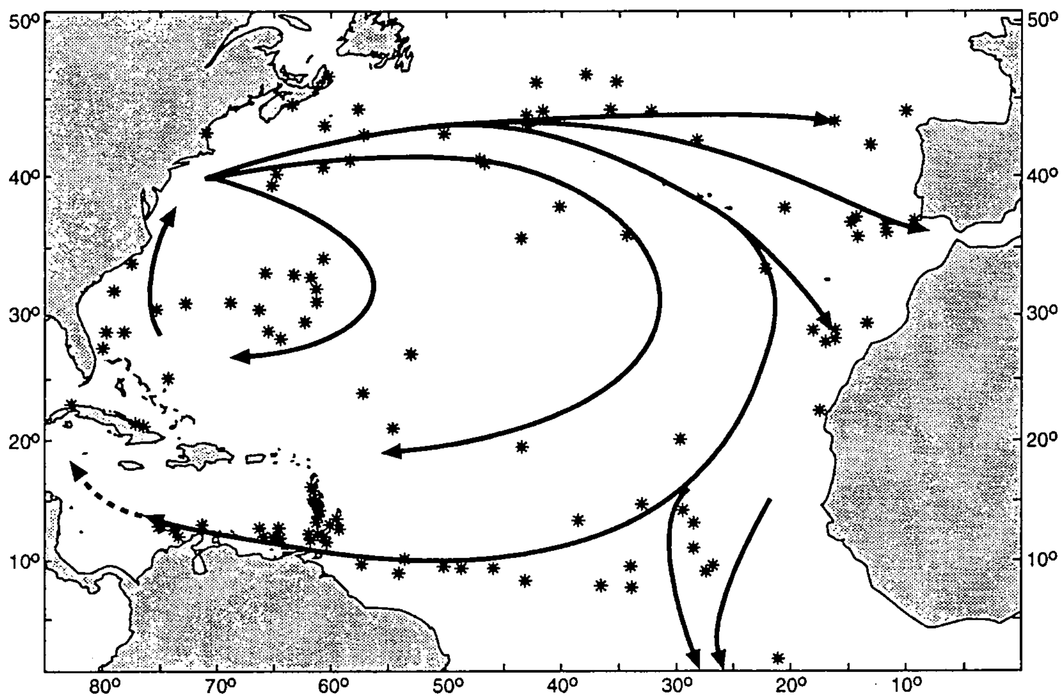


Figure. 2 Movements of blue shark based on recoveries from tagging releases by the NMFS Cooperative Tagging Project (after Casey and Kohler, 1991).

Blue Shark - Catch (Kg.): 1978 - 1994 Jan - Dec. - Faroes - Unsp Longline

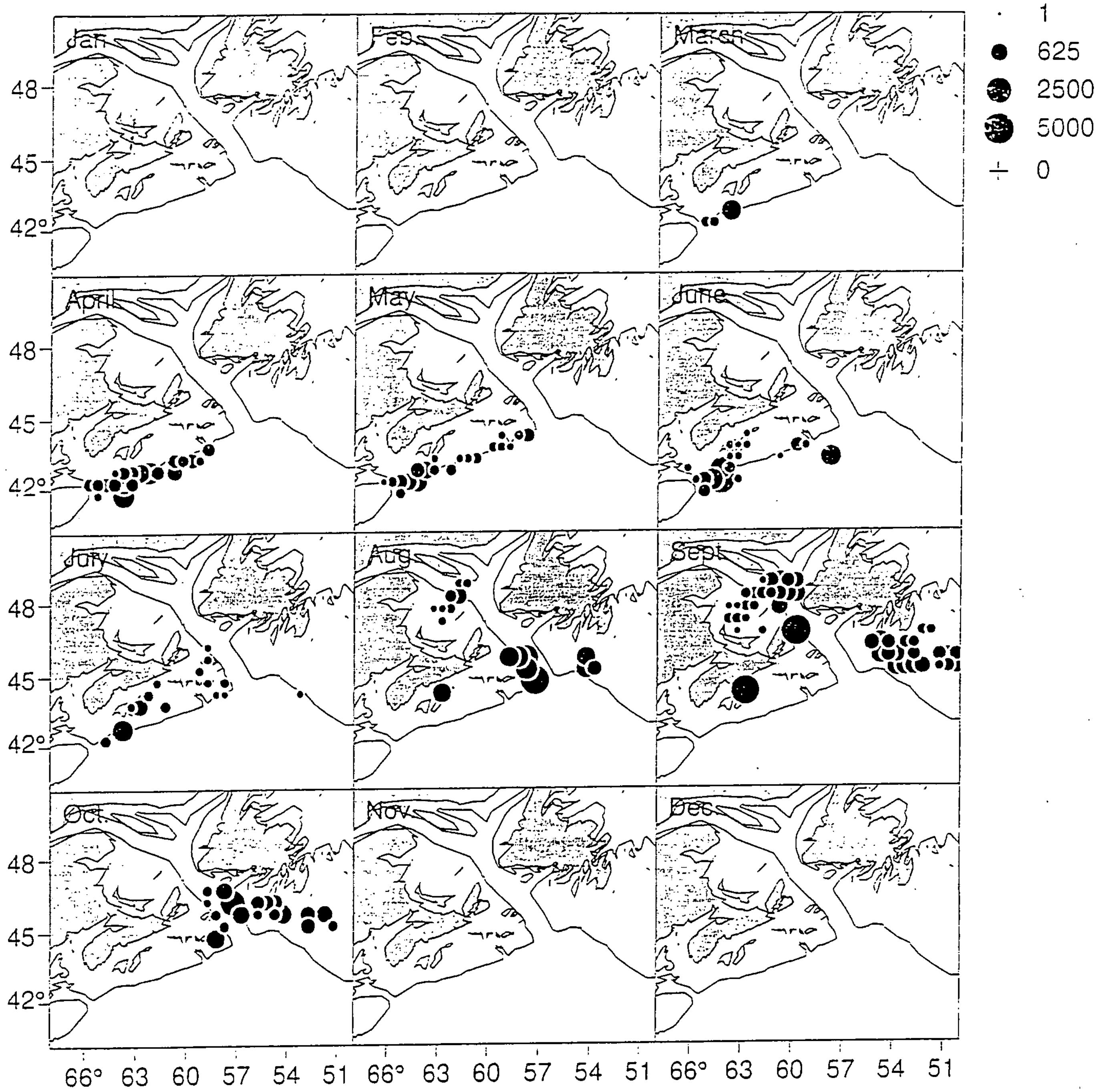


Figure 3. Monthly distribution of blue shark by-catch (kg) in the Faeroe Is. longline fishery for porbeagle shark.

Blue Shark - Catch (Kg.): 1978 - 1994 Jan - Dec. - Japan - Unsp Longline

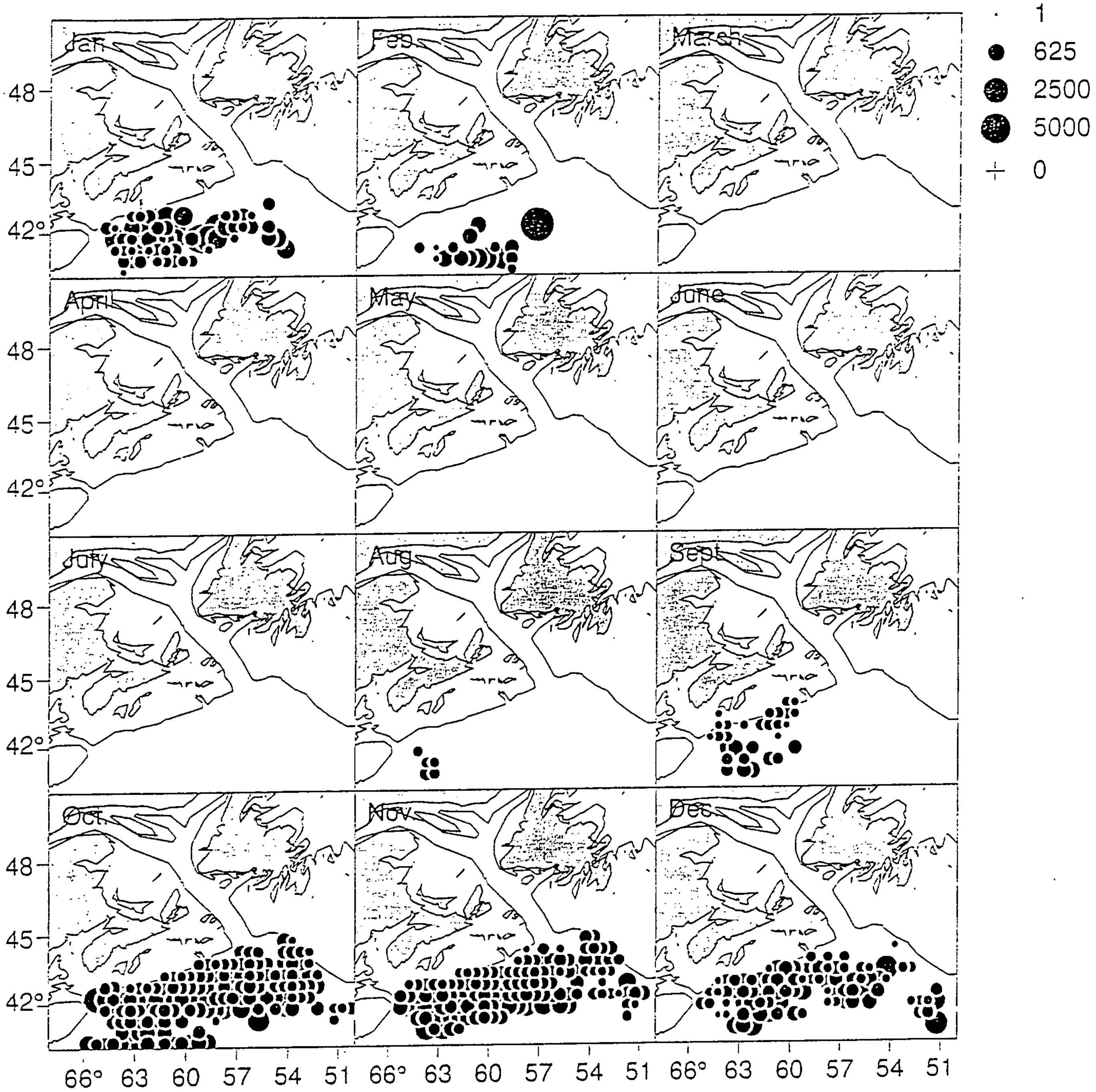


Figure 4. Monthly distribution of blue shark by-catch (kg) in the Japanese longline fishery for tuna.

Figure 5. Z_i and Z_m for Equilibrium in a Blue Shark Population