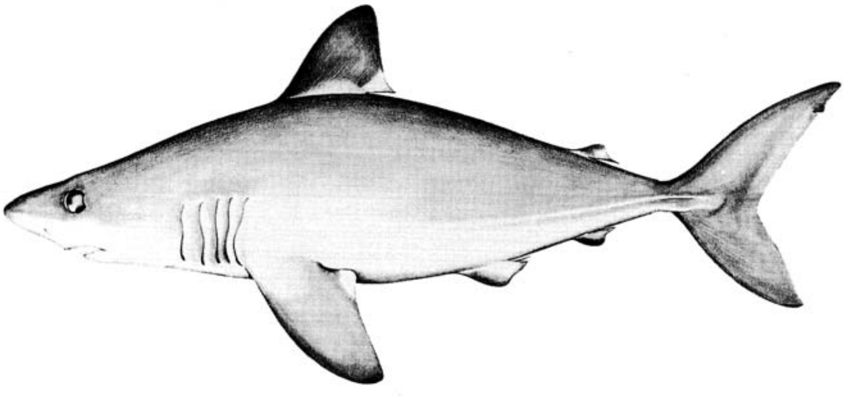
COSEWIC
Assessment and Status Report

on the

Porbeagle Shark
Lamna nasus

in Canada



ENDANGERED
2004

COSEWIC
COMMITTEE ON THE STATUS OF
ENDANGERED WILDLIFE
IN CANADA

COSEPAC
COMITÉ SUR LA SITUATION
DES ESPÈCES EN PÉRIL
AU CANADA

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

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Porbeagle shark — line drawing by M.H. Wagner (from Kato et al. 1967, Fig. 29). Reprinted with permission from the United States Fish and Wildlife Service.

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COSEWIC
Assessment Summary

Assessment Summary – May 2004

Common name
Porbeagle shark

Scientific name
Lamna nasus

Status
Endangered

Reason for designation
This wide-ranging oceanic shark is the only representative of its genus in the North Atlantic. The abundance has declined greatly since Canada entered the fishery in the 1990s after an earlier collapse and partial recovery. Fishery quotas have been greatly reduced, and the fishery has been closed in some areas where mature sharks occur. The landings now are comprised mostly of juveniles. Its life history characteristics, including late maturity and low fecundity, render this species particularly vulnerable to overexploitation.

Occurrence
Atlantic Ocean

Status history
Designated Endangered in May 2004. Assessment based on a new status report.

COSEWIC
Executive Summary

Porbeagle Shark
Lamna nasus

Species information

The porbeagle (*Lamna nasus*) is a large cold-temperate coastal and oceanic shark in the Family Lamnidae. Porbeagle reach a maximum size around 300 cm (Compagno 2001). Porbeagle have heavy spindle-shaped bodies with greatest depth at the dorsal fin (Figure 1; Scott and Scott 1988), and are dark bluish gray dorsally and white ventrally (Branstetter 2002).

Distribution

The porbeagle shark is distributed across the North Atlantic and in a circumglobal band in the southern Atlantic, southern Indian, southern Pacific and Antarctic Oceans (Figure 2; Compagno 2001). In the Northwest Atlantic, porbeagle are found in Greenland, Canada, United States, and Bermuda (Compagno 2001). Within Canada porbeagle are found contiguously from northern Newfoundland into the Gulf of St. Lawrence and around Newfoundland to the Scotian Shelf and Bay of Fundy (Figure 3; Scott and Scott 1988). The extent of occurrence of the porbeagle shark in Canada is a total area of 1,210,000 km^2. The area of occupancy, estimated from recent catch locations, is 830,000 k m^2. The range is not known to have changed since exploitation began in 1961 (Campana et al. 2003).

Habitat

The porbeagle is a pelagic, epipelagic, or littoral shark that is usually more common on continental shelves, but is also found far from land in ocean basins and occasionally close inshore (Scott and Scott 1988; Compagno 2001). Most porbeagle in Canadian waters occur between 5-10ºC with little variation throughout the year, suggesting that they adjust their location to occupy this preferred temperature range (Campana et al. 2001).

As with many sharks, porbeagle exhibit size- and sex-segregation (Compagno 2001). Immature porbeagle appear to primarily reside on the Scotian Shelf (Joyce 1997), whereas mature porbeagle undergo annual migrations. Fishery data indicate that males migrate along the Scotian Shelf towards the Newfoundland mating grounds in spring, followed by females (Campana et al. 2001). Mating in the Northwest Atlantic is thought to occur on the Grand Banks, off southern Newfoundland, and at the entrance to the Gulf of St. Lawrence (Campana et al. 2003). Gravid females are present from late September through December on the Scotian shelf and Grand Banks region, but are seldom seen from January through June. Indeed little is known of the porbeagle wintering grounds, but catches in the south in spring suggest a return migration southward in the winter.

Biology

The porbeagle has late sexual maturity and bears few young after a lengthy gestation period. These traits differ markedly from those of bony fishes and render this species particularly vulnerable to overexploitation.

Porbeagle are ovoviviparous and oophagous. Mating in the Northwest Atlantic occurs from late September through November, and parturition occurs eight to nine months later (Jensen et al. 2002). Females give birth to an average of four young, and the reproductive cycle is thought to be one year (Jensen et al. 2002). Age at maturity is eight years in males and thirteen years in females (Natanson et al. 2002). Generation time, the mean age of female parents, is estimated at 18 years. Porbeagle longevity is estimated to be between 25 and 46 years (Campana et al. 1999; Natanson et al. 2002).

Porbeagle have low natural mortality. Instantaneous natural mortality is estimated to be 0.10 for immature porbeagle, 0.15 for mature males, and 0.20 for mature females (Campana et al. 2001). A consequence of low fecundity and high juvenile survival is that recruitment variability (population abundance) is much more stable than that of bony fishes. The primary source of mortality for the Northwest Atlantic population of porbeagle sharks is fishing. Estimates suggest that recent fishing mortality rates have been substantially higher than the intrinsic rate of increase, r, which is estimated at ~0.05 (Campana et al. 2003).

The porbeagle is among the most cold tolerant pelagic shark species, preferring water colder than 18ºC (Compagno 2001). Like other members of the Family Lamnidae, porbeagle have countercurrent heat exchangers in their circulatory system, enabling them to maintain body temperatures 7-10ºC higher than the ambient water temperature (Carey and Teal 1969).

Tagging data provides strong evidence that there are distinct porbeagle populations in the Northeast and Northwest Atlantic (DFO 1999; Kohler et al. 2002), and that within the Northwest Atlantic there is a single population that undertakes extensive annual migrations between southern Newfoundland and the Gulf of St. Lawrence to at least Massachusetts (Figure 4; DFO 1999; Campana et al. 1999). The Northwest Atlantic porbeagle population straddles the Canadian and American 200 mi Exclusive Economic Zones, but most of the area of occupancy is within Canadian waters.

Evidence from tagging studies suggests that the Northwest Atlantic porbeagle population could not be enhanced by porbeagle from other areas.

The porbeagle is primarily an opportunistic piscivore that feeds on a wide variety of pelagic, epipelagic, and benthic species (Joyce et al. 2002). Joyce et al. (2002) found twenty-one species from twenty different families in the porbeagle diet, of which teleosts and then cephalopods were most important (Table 1). There are ontogenetic and seasonal shifts in the porbeagle diet (Joyce et al. 2002).

Population sizes and trends

There is strong quantitative evidence that the porbeagle population has declined precipitously since the 1960s. The best available estimates of porbeagle population size and trends are derived from a forward-projecting age- and sex-structured population dynamics model (presented in Campana et al. 2001 and Harley 2002), which indicates that the 2001 biomass of the porbeagle population was only 11% of the virgin level in 1961 (Figure 6). The current number of female spawners is estimated at 6,075, 10% of the virgin abundance. The model estimates that biomass declined sharply after the fishery began in 1961, recovered slightly by the 1980s, and then declined to an overall low in 2001 (Figure 6). Four additional model runs testing a range of assumptions about natural mortality and selectivity of the fishery produced similar results (Table 3).

Standardized catch per unit effort estimates for 1989 to 2000 also suggest that there has been a considerable decline in porbeagle abundance (Figure 7). The standardized catch rate of mature porbeagles increased between 1989 and 1992, as the new Canadian fishery developed, but declined sharply thereafter to only 10% of its 1992 value by 2000 (Campana et al. 2001). The catch rate of immature porbeagle declined to about 30% of its 1991 value (Campana et al. 2001).

Another indication of overexploitation is the decline in the median fork length of porbeagle on the Newfoundland–Gulf of St. Lawrence mating grounds in early fall, from more than 200 cm in 1961 to 140 cm in 2000 (Figure 8; Campana et al. 2001). Catches there in the 1990s were characterized by median lengths well below the size at maturity, indicating the low proportion of mature porbeagles. Indeed, the most abundant age-classes there declined from porbeagle between 10-15 years prior to 1991, to porbeagle less than age-3 between 1998 and 2000 (Campana et al. 2002a).

Limiting factors and threats

Overexploitation is the primary factor responsible for the decline of Northwest Atlantic porbeagle. The population is threatened by its limited compensatory ability to recover from overexploitation - a limitation that is exacerbated by continued (albeit reduced) exploitation. In the Northwest Atlantic, commercial porbeagle fisheries began in 1961 and collapsed the population within six years. Population recovery was limited: porbeagle increased only to 30% of their original abundance over the next two decades.

Exploitation increased again in the 1990s, and catches several times higher than F_{MSY} resulted in a precipitous decline to a record low population level.

It is uncertain if management measures to reduce exploitation are sufficient to allow for recovery of the porbeagle population. The quota for 2002-2007 of 200-250t represents a substantial reduction from catches in the mid-1990s, but even this amount now corresponds to a high exploitation rate because of the low population abundance. It is highly uncertain whether this quota reduction will be sufficient to halt the porbeagle decline, and if so, to what extent the population will recover, given that there is uncertainty in estimating F_{MSY} and the quota, that the number of mature animals remaining in the population is low, that at its current low abundance the population may experience depensation (Allee effects), and that reduction in fishing pressure is not always sufficient for population recovery (Hutchings 2001).

Special significance of the species

Porbeagle is the only representative of its genus in the North Atlantic. It is a highly marketable shark species (Rose 1998), and currently supports the only directed commercial shark fishery in Atlantic Canada (Hurley 1998). Porbeagle meat is one of the most highly valued shark meats (Rose 1998). In Canada, most porbeagle meat is exported to Europe (particularly Italy), but there is also a small market for fresh meat in the United States (DFO 2001; S. Campana, pers. comm.).

Existing protection or other status designations

In Canada, porbeagle shark management falls under the Department of Fisheries and Oceans. The initial Fisheries Management Plans for pelagic sharks in Atlantic Canada (1994 and 1995) prohibited shark finning, specified that licenses for the porbeagle fishery would be exploratory, limited the number of licenses, restricted gears and fishing areas, and established seasons and specific scientific requirements (O’Boyle et al. 1998). The objective of the comprehensive plan released in 1997 was to maintain a biologically sustainable resource that would support a self-reliant fishery (DFO 1997). Conservation was not to be compromised and a precautionary approach was to guide decision making (DFO 1997). DFO’s collaborative porbeagle research program initiated in 1998 with the support of the Canadian shark fishing industry (DFO 1999) led to two analytical porbeagle assessments (Campana et al. 1999; 2001).

Management based on these reduced the porbeagle fishery quota from 1000t to 850t for 2000-2001, and to 250t for 2002-2007. The DFO will assess porbeagle again in 2006.

The porbeagle shark is listed on the IUCN Red List as Lower risk/near threatened, and although global populations are not proven to have been depleted to a level qualifying for Vulnerable status, IUCN (2002) recognizes that North Atlantic populations have been seriously overexploited. There are no management measures in place pertaining to porbeagle for fisheries in international waters.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species and include the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal organizations (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biosystematic Partnership, chaired by the Canadian Museum of Nature), three nonjurisdictional members and the co-chairs of the species specialist and the Aboriginal Traditional Knowledge subcommittees. The committee meets to consider status reports on candidate species.

DEFINITIONS
(after May 2004)

Species	Any indigenous species, subspecies, variety, or geographically or genetically distinct population of wild fauna and flora.
Extinct (X)	A species that no longer exists.
Extirpated (XT)	A species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A species facing imminent extirpation or extinction.
Threatened (T)	A species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A species that has been evaluated and found to be not at risk.
Data Deficient (DD)***	A species for which there is insufficient scientific information to support status designation.

* Formerly described as “Vulnerable” from 1990 to 1999, or “Rare” prior to 1990.

** Formerly described as “Not In Any Category”, or “No Designation Required.”

*** Formerly described as “Indeterminate” from 1994 to 1999 or “ISIBD” (insufficient scientific information on which to base a designation) prior to 1994.

Environment Canada
Canadian Wildlife Service

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Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

COSEWIC Status Report

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Porbeagle Shark
Lamna nasus

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2004

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SPECIES INFORMATION

Name and classification

Class: Elasmobranchii
Order: Lamniformes
Family: Lamnidae
Latin name: *Lamna nasus* Bonnaterre 1758
Common names: English - Porbeagle shark
French - Maraîche

Description

The porbeagle is a large cold-temperate coastal and oceanic shark, described as being very active and strong-swimming (Compagno 2001). Porbeagle reach a maximum total length around 300 cm, possibly to 370 cm (Compagno 2001). According to Natanson et al. (2002), the largest reliably measured male and female porbeagles in the Northwest Atlantic are 262 and 317 cm FL respectively. In the largest tagging program in the Northwest Atlantic, the U.S. National Marine Fisheries Service Cooperative Shark Tagging Program (CSTP), males had a mean size of 116 cm FL (max. 275 cm FL) and females had a mean size of 108 cm FL (max. 244 cm FL) (Kohler et al. 2002). Branstetter (2002) states that individuals longer than 200 cm TL are uncommon, and most in the Gulf of Maine are 120-180 cm TL and less than 90 kg. Morphometric and length-weight equations for porbeagle in the Northwest Atlantic from Campana et al. (1999) are:

$$W(\text{kg})=0.5 \times 10^{-4} \times FL(\text{ cm})^{2.713} \quad (n=286)$$

$$\text{where } FL=0.99 + 0.885 \times TL(\text{cm}) \; (n=361)$$

Porbeagle have heavy spindle-shaped bodies with greatest depth at the dorsal fin (Figure 1; Scott and Scott 1988). The head is stout and snout pointed, with a preorbital length 5.9-9.0% of total length (Scott and Scott 1988; Compagno 2001). The mouth is moderate to large, with moderately large blade-like teeth that are similar in the upper and lower jaws and have a large central cusp and two lateral cusps, the latter often not evident on specimens less than 1.2 m long (Tibbo et al. 1963 in Scott and Scott 1988; Compagno 2001). The eyes are large and the space from the eye to first gill slit is 1.7 to 2.5 times the preorbital length (Compagno 2001). The gill slits are long, and the large pectoral fins, which are half as wide as long, originate behind the fifth gill slit (Scott and Scott 1988; Branstetter 2002). The first dorsal fin is large, triangular, and about as high as long; it originates slightly rearward of the pectoral fin. The second dorsal and anal fins are very small and originate directly over one another; the pelvic fins are a little larger (Branstetter 2002). The caudal peduncle is slender with a distinct lateral keel and a small secondary keel on the base of the caudal fin on either side, below and behind this primary keel (Scott and Scott 1988; Branstetter 2002). There are conspicuous precaudal pits present dorsally and ventrally. The caudal fin is crescentic, stout; the lower lobe is two-thirds to three-quarters as long as the upper lobe (Branstetter 2002).

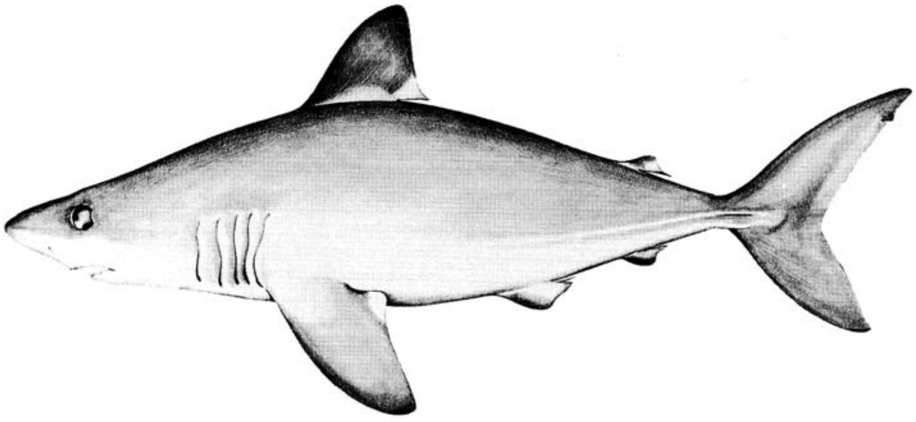


Figure 1. Line drawing of porbeagle shark (*Lamna nasus*) from Chile, male, 81 cm TL. Drawn by M.H. Wagner (from Kato et al. 1967; Fig. 29). Reprinted with permission from the United States Fish and Wildlife Service.

The total vertebrae 150-162; precaudal vertebrae 84-91 (Springer and Garrick 1964 in Branstetter 2002).

Porbeagle are dark bluish gray to bluish black above with a white tip on the lower trailing edge of the first dorsal fin, and changing abruptly on the sides to white ventral surfaces (Scott and Scott 1988; Compagno 2001; Branstetter 2002). The lower surfaces of the pectoral fins are dusky to black toward the apex and mottled toward their bases, with the anterior and posterior edges narrowly rimmed with black (Branstetter 2002).

The only sharks in Canada that might be confused with porbeagle are the white shark (*Carcharodon carcharias*) or shortfin mako (*Isurus oxyrinchus*). Porbeagle are distinguished from the former by their spikelike smooth-edged teeth and by the position of their second dorsal fin directly over the anal fin. They are distinguished from the latter by the presence of tooth cusplets and secondary caudal fin keels (Branstetter 2002).

DISTRIBUTION

Global range

Porbeagle are distributed across the North Atlantic and in a circumglobal band in the southern Atlantic, southern Indian, southern Pacific and Antarctic Ocean (Figure 2; Compagno 2001). In the North Atlantic, the porbeagle shark has a much narrower latitudinal range in the Northwest Atlantic than in the Northeast Atlantic (Bigelow and

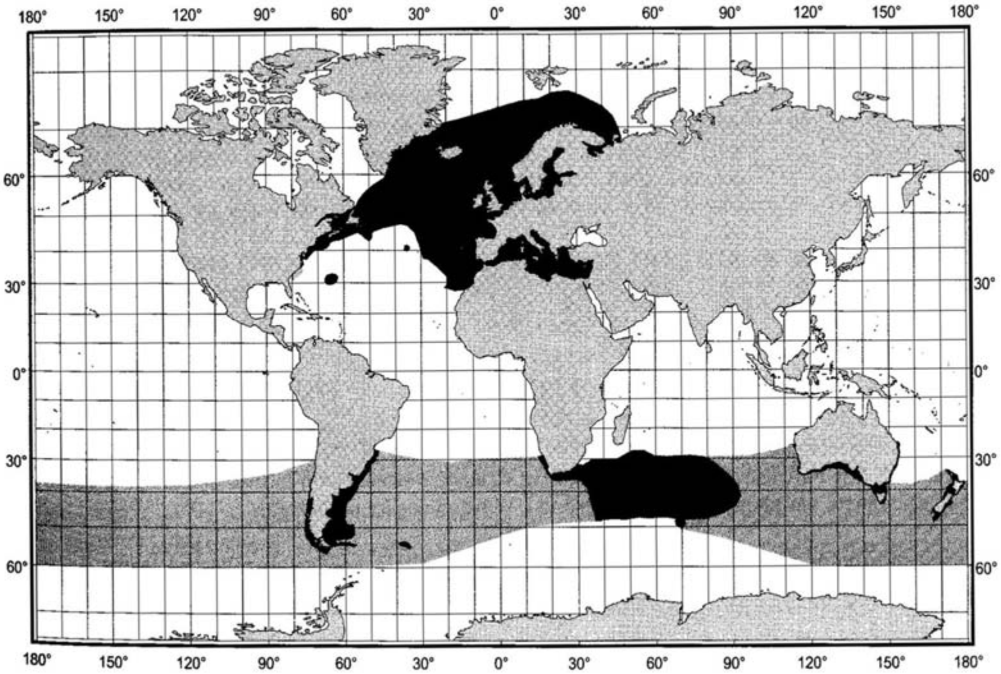
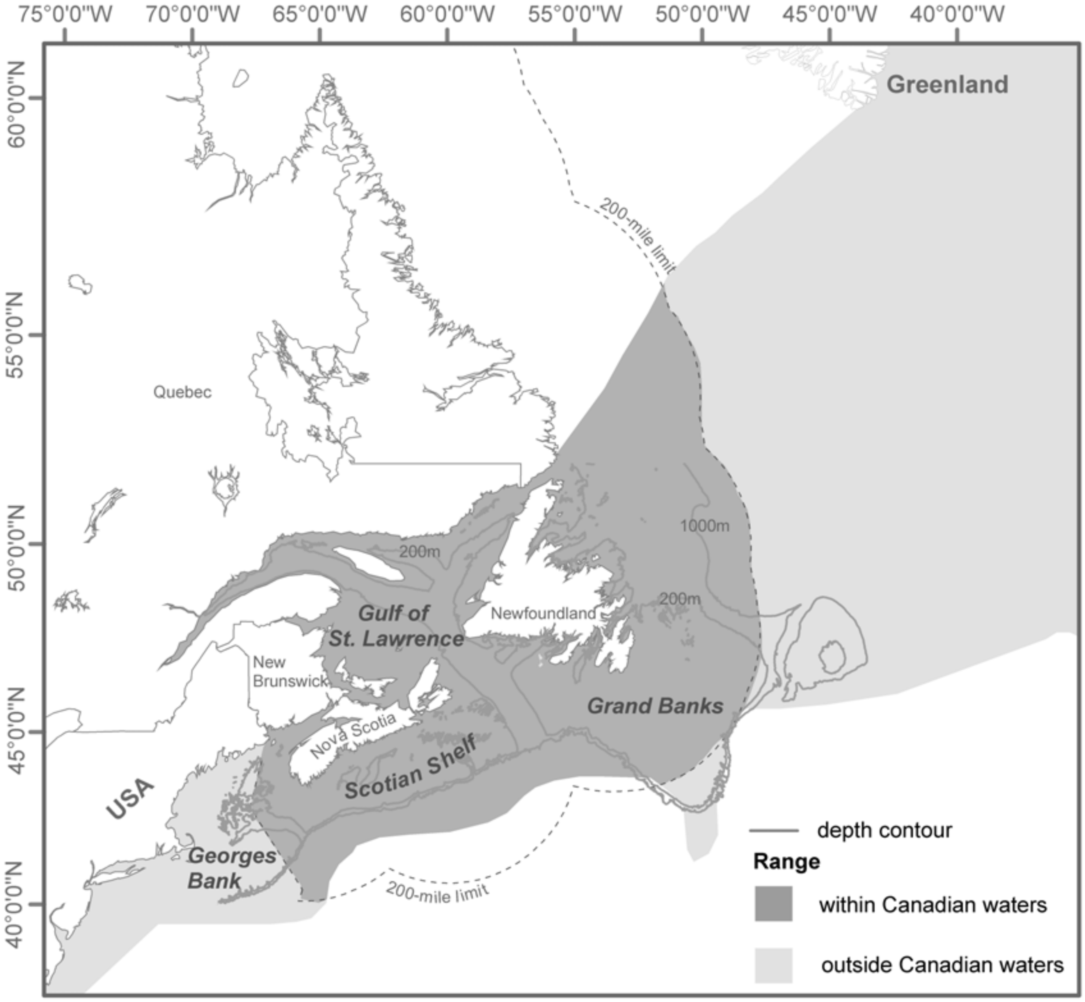


Figure 2. Global range of porbeagle shark (*Lamna nasus*) showing known distribution from reliable records (black) and suspected or uncertain distribution (shaded). Reprinted from Compagno 2001 with permission from the United Nations Food and Agriculture Organization (FAO).

Schroeder 1948). In the Northwest Atlantic the porbeagle is found in Greenland; Canada; the United States, including Maine, Massachusetts, Rhode Island, rarely New York, New Jersey and possibly South Carolina; and Bermuda (Scott and Scott 1988; Compagno 2001). In the Northeast Atlantic, the porbeagle is found from Iceland through the Norwegian Sea to the Barents Sea around Scandinavia to Russia, along the European coast including the British Isles, in the Baltic Sea, North Sea, English Channel, Straits of Gibraltar, offshore of Madeira and the Azores, and in the entire Mediterranean Sea, south to Morocco (Scott and Scott 1988; Compagno 2001). In the Southern hemisphere, the porbeagle occurs around South America from southern Brazil south along the Argentinean coast around Cape Horn and north along the coast of southern Chile; possibly in the Gulf of Guinea; in the south-central Indian Ocean from South Africa (eastern Cape and possibly KwaZulu-Natal), east to Prince Edward and Crozet Islands, between Kerguelen and St. Paul Islands and along the southern coast of Australia, including southern Western Australia, South Australia, Victoria, Tasmania, New South Wales and southern Queensland, New Zealand including Stewart Island, and in subantarctic waters off the coasts of South Georgia, Marion, Prince and Kerguelen Islands (Scott and Scott 1988; Compagno 2001). On a global scale, there is no information in the literature to indicate that the historical distribution of the porbeagle shark differs from that of its present distribution.

Canadian range

In Canada porbeagle are found contiguously from northern Newfoundland into the Gulf of St. Lawrence and around Newfoundland to the Scotian Shelf and Bay of Fundy (Figure 3; Scott and Scott 1988). The Northwest Atlantic population is described as being most abundant off the eastern coast of Canada between the Gulf of Maine and Newfoundland (Templeman 1963). Porbeagle abundance in Canadian waters is strongly affected by season migrations (see Movements/dispersal).



Map data sources: ESRI Limited, National Atlas of Canada, Compagno 2001, Campana et al 2001, O'Boyle et al 1998.

Figure 3. Range of the porbeagle shark, *Lamna nasus*, population in the Northwest Atlantic, within Canada (dark gray) and outside of Canada (light gray), showing 200 m and 1000 m contour lines and 200 mile Exclusive Economic Zone boundaries.

The extent of occurrence of the porbeagle shark in Canada, as shown in Figure 3, is a total area of 1,210,000 km^2. The area of occupancy, calculated based on catch locations in the 1990s (from O'Boyle et al. 1998, Campana et al. 2001), is 830,000 km^2. The distribution of this species within Canadian waters is not known to have changed since the fishery began in 1961 (Campana et al. 2003), however, it should be noted that because fisheries concentrate in areas of high fish density, changes at the edge of the range (i.e. range contractions) could go unnoticed.

HABITAT

Habitat requirements

The porbeagle is a pelagic, epipelagic, or littoral shark that is usually more common on continental shelves, but is also found far from land in ocean basins and occasionally close inshore (Scott and Scott 1988; Compagno 2001). It ranges in depth from the surface and inshore waters less than 1 m deep to at least 700 m (Compagno 2001). This species has been caught at the mouth of a brackish estuary in Argentina (Lucifora and Menni 1997), but does not enter freshwater (Compagno 2001). Nor is it known to occur in equatorial seas (Compagno 2001).

Porbeagle prefer water colder than 18ºC and have a lower temperature limit of 1ºC (Compagno 2001; Branstetter 2002). In Canadian waters, porbeagle appear to occupy well defined temperatures throughout the year (Campana et al. 2001). An analysis of more than 400 temperature profiles at mid-gear depth from the Canadian commercial fishery found that over half of the porbeagle were caught between temperatures of 5 and 10ºC and the mean temperature of 7.4ºC varied little among seasons, suggesting that porbeagle move to occupy their preferred temperature range (Campana et al. 2001). Porbeagle are caught in waters with a wider depth range in spring than in fall: spring catches occurred in waters of 200-2,800 m depth, while those in the fall occurred in waters less than 450 m deep, with most in waters less than 150 m deep (Campana et al. 2001). During most of the spring, porbeagle were caught most frequently in waters immediately adjacent to the frontal edge separating cool shelf waters from warmer offshore waters (Campana et al. 2001). Porbeagle were not associated with fronts in the fall (Campana et al. 2001).

Adult porbeagle range over a wider area than do juvenile porbeagle. Immature porbeagle, characterized by more limited migratory movements, appear to primarily reside on the Scotian Shelf (Joyce 1997; Campana et al. 2001). Analysis of catch data from the Canadian fishery suggests a seasonal migration of the larger sharks (>180 cm FL), particularly males, along the Scotian Shelf towards the Newfoundland mating grounds in spring (Campana et al. 2001; Campana et al. 2003). Migration of females to the mating grounds lags behind the males.

Mating in the Northwest Atlantic is thought to occur on the Grand Banks, off southern Newfoundland, and at the entrance to the Gulf of St. Lawrence (Campana et al.

2003). Gravid females have been observed between Georges Bank and the Grand Banks (Jensen et al. 2002). Between late September and December, most gravid females are caught on the Scotian Shelf and Grand Banks region (Jensen et al. 2002). Mature gravid or nongravid female porbeagle are seldom seen from January through June in the Canadian fishery (Jensen et al. 2002), but there is little fishery effort in the winter. Little is known about their overwintering grounds (see Movements/dispersal) or about the pupping grounds of porbeagle.

Protection/ownership

An area of 2364 km^2 in the Gully, a deep canyon ecosystem situated at the edge of the Scotian Shelf near Sable Island, is expected to be officially designated a marine reserve under the Oceans Act in 2004 (Canada Gazette 2003; M. King, WWF Canada, pers. comm.). The marine reserve will comprise three management zones; pelagic longlining will be prohibited only in Zone 1, the core area. Because the marine reserve in total will cover a very small proportion (<1%) of the Northwest Atlantic porbeagle's population, it is expected to have little effect on the porbeagle population.

BIOLOGY

General

In general, the life history traits of sharks differ markedly from those of bony (teleost) fishes, and are characteristic of species with low intrinsic rates of increase. Sharks tend to be large, slow growing, and have late maturity. They have long gestation periods and produce low numbers of offspring. These traits render sharks vulnerable to overexploitation. Relative to other shark species, the porbeagle has low productivity and is particularly susceptible to overexploitation (Castro et al. 1999; Cortes 2000a; 2002a).

Reproduction

In the Northwest Atlantic, the occurrence of early-stage gravid females, the ripe condition of males, and the presence of recent mating scars on most mature females from late September through November indicates that mating occurs during this period (Aasen 1963; Pratt 1993; Jensen et al. 2002). Moreover, by December all observed females were gravid (Jensen et al. 2002). Little is known about the breeding requirements or behaviour of porbeagle sharks. Mating in the Northwest Atlantic porbeagle population probably occurs on the Grand Banks, off southern Newfoundland, and at the entrance to the Gulf of St. Lawrence because large females collected in these areas in the fall were pregnant (Campana et al. 2001). Gravid females were caught primarily in this area, but also on the Scotian shelf, between late September and December (Jensen et al. 2002). Templeman (1963) reported three gravid females on the southwest Grand Banks between January and February in the 1950s, and a few late-stage gravid females have been observed on the Scotian Shelf and in the Gulf of

Maine in February and April (Jensen et al. 2002). In general, however, the overwintering location of gravid females is largely unknown (Campana et al. 2001; Jensen et al. 2002), since there is little fishing effort in the winter.

Porbeagle are ovoviviparous; embryos develop within the uterus without forming a placental connection with the mother. The embryos are nourished by oophagy, whereby after absorbing the yolk of their own egg, embryos consume the numerous unfertilized eggs produced by the mother (Shann 1911, 1923 in Francis and Stevens 2000; Jensen et al. 2002). The embryos develop grossly distended abdomens as they store large quantities of yolk material (Francis and Stevens 2000). Small porbeagle embryos possess fang-like functional teeth to tear open egg capsules and release the contained ova; the fangs are shed at 34 to 38 cm FL (Francis and Stevens 2000). Unlike some shark species, however, there is no evidence that adelphophagy (competitive embryonic cannibalism) occurs in porbeagles (Jensen et al. 2002). Embryonic growth for porbeagle in the Northwest Atlantic is estimated at about 8 cm per month (Jensen et al. 2002).

Parturition in the Northwest Atlantic occurs between early April and early June, indicating a gestation period of eight to nine months (Jensen et al. 2002). Females give birth to an average of four young (Jensen et al. 2002). Litter size in Jensen et al.'s (2002) study ranged from three to six young; other studies have reported litter sizes between one and five young (Shann 1911, 1923; Gauld 1989; Francis and Stevens 2000; Compagno 2001). No parental care is provided after birth. Few neonates have been observed during the parturition period; however, the smallest free-swimming porbeagles in the National Marine Fisheries Service historical tagging database range in size from 55 to 79 cm FL (mean 71 cm FL) from April to June (Jensen et al. 2002), suggesting a birth size similar to 67 cm FL predicted by Aasen (1961 in Natanson et al. 2002; 1963) and to 58-67 cm FL estimated for porbeagle in the Southwest Pacific (Francis and Steven 2000). Juvenile porbeagle have high rates of natural survival to maturity (see Survival).

Porbeagle have relatively rapid growth during their first year, followed by slow growth and late maturation. In the Northwest Atlantic, analysis of modal length-frequency progressions indicates that age-0 porbeagle recruited to the fishery in July at a mean length of 85 cm FL and grew to a mean length of 98 cm FL by December (Natanson et al. 2002). Age-1 individuals had an annual growth of 25 cm/year, reaching a mean of 123 cm FL by the next December (Natanson et al. 2002). A recent study estimated growth parameters for porbeagle from vertebral annuli on 578 vertebrae, and validated the annuli up to an age of 11 years using vertebrae from recaptured oxytetracycline-injected and known-age sharks (Natanson et al. 2001). Sharks older than age 11 were assumed to have been aged correctly because of similar interpretation of the bands (Natanson et al. 2002). Males and females grew at similar rates until approximately 170 cm FL, the size of male sexual maturity (Jensen et al. 2002), after which the relative growth of males declined (Natanson et al. 2002). The growth rate of the females declined in a similar manner at the onset of maturity (approximately 218 cm FL; Jensen et al. 2002; Natanson et al. 2002). As a result of this change in growth rate females reach a larger maximum size than males; however, the overall growth rate for both sexes is not substantially different (Natanson et al. 2002). Jensen et al.'s (2002) study of 393 male and 382 female porbeagles in the Northwest Atlantic found that males mature between 162 and 185 cm FL with 50% mature at 174 cm FL, while females mature between 210 and 230 cm FL, with 50% mature at 218 cm FL (Jensen et al. 2002). These sizes correspond to ages at sexual maturity of eight years in males and thirteen years in females (Natanson et al. 2002).

The longevity of porbeagle is uncertain. Ageing elasmobranchs is difficult, and estimates therefore vary among methods. The maximum ages based on vertebral band pair counts were 25 and 24 years for males and females respectively, but this likely underestimates longevity because of the long-term fishing pressure on this population (Natanson et al. 2002). Bomb radiocarbon, which is based on date-specific incorporation of radiocarbon into vertebral growth bands, has been used to confirm the validity of porbeagle vertebral growth band counts as accurate annual age indicators to an age of 26 years (Campana et al. 2002b). Two longevity calculations, based on the assumption of a constant instantaneous mortality rate of M=0.10 in an unfished population, suggest a maximum of age of 45 or 46 years (Campana et al. 1999; Natanson et al. 2002). If natural mortality were not constant, but instead increased in sexually mature or senescent fish (Roff 1992), the estimate of longevity would be lower. If female natural mortality rate were M=0.20 after the age of sexual maturity, estimated longevity would be 29 years (Campana et al. 1999).

The reproductive cycle for porbeagle is thought to be one year (Jensen et al. 2002). Although many shark species have an extended latency period after birth, this does not appear to be the case for porbeagle, since virtually all sexually mature females observed in the fall are pregnant (Campana et al. 2003). It is possible that a nongravid mature portion of the female population resides elsewhere, but there is no evidence of this to date (Jensen et al. 2002).

Generation time, the average age of parents in the current cohort, reflects the turnover rate of breeding individuals in the population. For porbeagle, females mature at a later age than males (thirteen vs. eight years; Jensen et al. 2002), and generation time is calculated as the mean age of female parents. Generation time is estimated as the age at which 50% of females are mature + 1/M, where M is the instantaneous rate of natural mortality. For porbeagle shark, with 50% of females mature at age 13 (Jensen et al. 2002), and the natural mortality for mature females estimated at 0.20 (Campana et al. 2001), generation time is 13 + 1/0.20 = 18 years. Note that, as is usual for marine fishes, there is some uncertainty around the natural mortality estimate. If the natural mortality for mature female porbeagle sharks is lower, M=0.15 or 0.10, generation time would be longer, 20 or 23 years respectively.

Survival

As expected from life history theory for a species with low productivity (Roff 1992), porbeagle have low natural mortality. Instantaneous natural mortality (M) for porbeagle has been estimated from catch curves of the lightly-fished virgin population of 1961 as 0.1 for maturing males on the Scotian Shelf, 0.15 for mature males on the Newfoundland mating grounds, and 0.20 for mature females on the mating grounds (Campana et al. 2001). Natural mortality could not be estimated for immature females in 1961, but is assumed not to differ from males (Campana et al. 2001). In the most recent porbeagle assessment, natural mortality for pups (age-0 porbeagle) was estimated as M=0.2 (Campana et al. 2001). A consequence of low fecundity and high juvenile survival is that recruitment variability (population abundance) will be much more stable than that of bony fishes. However, porbeagle also have low ability to compensate from exploitation pressure. Life history table analysis indicates that the maximum rate of increase, r, is about 0.05 (Campana et al. 2003).

The primary source of mortality for the Northwest Atlantic population of porbeagle sharks is fishing. Indeed, apart from humans, porbeagle predators are unknown (Compagno 2001). Estimates suggest that in the late-1990s instantaneous fishing mortality rates (detailed in Limiting Factors and Threats) were between 0.11 and 0.26, substantially higher than the intrinsic rate of increase. A decline in the most abundant age class of porbeagles on the mating grounds to well below the age of maturity (Campana et al. 2002a) suggests that recruitment into the adult population has not been sufficient to balance the fishing mortality rate in recent years.

Physiology

Porbeagle are among the most cold tolerant pelagic shark species, preferring water colder than 18ºC (Compagno 2001). Like other members of the Family Lamnidae, porbeagle have a system of countercurrent heat exchangers in their circulatory system which enable them to conserve metabolic heat and maintain body temperatures 7-10ºC higher than the ambient water temperature (Carey and Teal 1969; Carey et al. 1971), thereby operating more efficiently in cool water (Scott and Scott 1988). Elevated muscle temperature supplies porbeagle with the power needed for high-speed swimming.

Movements/dispersal

Tagging data from the North Atlantic provide strong evidence that there are distinct porbeagle populations in the Northeast and Northwest Atlantic. Canada, Norway, and the United States have each conducted tagging studies of porbeagle in the Northwest Atlantic. In the 1960s, 542 porbeagle were tagged and 53 recaptured as part of a Norwegian study of the virgin population (Aasen 1963; Natanson et al. 2002). A Canadian study between 1994 and 1996 tagged 256 porbeagle and recaptured 25. Between 1962 and 2000, 1228 porbeagles were tagged in the Northwest Atlantic and 65 in the Northeast Atlantic as part of the U.S. National Marine Fisheries Service Cooperative Shark Tagging Program (CSTP) (Kohler et al. 2002). Distances traveled by the 143 porbeagle recovered from the U.S. study ranged from 4-1,005nm, with a mean distance of 234nm (Kohler et al. 2002). Over 90% of the tagged porbeagles traveled less than 500nm from the original tagging location (Kohler et al. 2002). No porbeagle were recaptured on the opposite side of the Atlantic in these three tagging studies, indicating that there is no mixing between the Northwest and Northeast Atlantic (DFO 1999; Kohler et al. 2002). Similarly, tagging studies of porbeagle conducted in the Northeast Atlantic did not have any recaptures reported from the Northwest Atlantic, and concluded that the porbeagle in these two areas are separate populations (Stevens 1990; Kohler et al. 2002).

In the Northwest Atlantic, tagging and catch data indicate that there is a single porbeagle population that undertakes extensive annual migrations between southern Newfoundland and the Gulf of St. Lawrence to at least Massachusetts (DFO 1999; Campana et al. 1999). Campana et al. (2003) noted that the monthly shifts in the location of the Canadian porbeagle fishery indicate migrations up and down the east coast of Canada that are reproducible from year to year (Figure 4). Between January and February, porbeagles are caught in the Gulf of Maine, Georges Bank and southern Scotian shelf (Campana et al. 1999). An analysis of fisheries observer data indicates that they are present on the edge of the Scotian Shelf and offshore basins in the early spring (Joyce 1999). They move northeast through spring, and are found off the southern coast of Newfoundland and in the Gulf of St. Lawrence in the summer and fall (Campana et al. 1999). Gravid females are present from late September through December on the Scotian Shelf and Grand Banks area (Jensen et al. 2002). Mature gravid or nongravid female porbeagle are seldom seen from January through June in the Canadian fishery (Jensen et al. 2002), but there is little fishery effort in the winter. Catches in the late fall suggest a return movement to the southwest (Campana et al. 1999), but in general the overwintering grounds of porbeagle are not well known. Porbeagle are thought to move into deeper water in late fall, and indeed they have been caught off the continental shelf, and in deep water basins such as Emerald Basin and the Gulf of Maine in winter (O'Boyle et al. 1996). Tagging data support these seasonal movements, in that tags applied in the first half of the year were usually recaptured in more easterly and northerly locations, while the reverse was seen for tags applied in the second half of the year (Campana et al. 1999).

The seasonal migrations made by porbeagle appear to be related to temperature and to spawning grounds. Most porbeagle in Canadian waters occur between 5-10ºC with little variation throughout the year, suggesting that porbeagle adjust their location to occupy this preferred range (Campana et al. 2001). It is after parturition, in May and June, that mature porbeagle begin to migrate northward to the Gulf of St. Lawrence and Grand Banks of Newfoundland, where they remain until mating in the fall (Joyce 1999).

The Northwest Atlantic porbeagle population straddles the Canadian and American 200 mi Exclusive Economic Zones, although most of the area of occupancy is within Canadian waters. Evidence from tagging studies suggests that the Northwest Atlantic porbeagle population could not be enhanced by porbeagle from other areas.

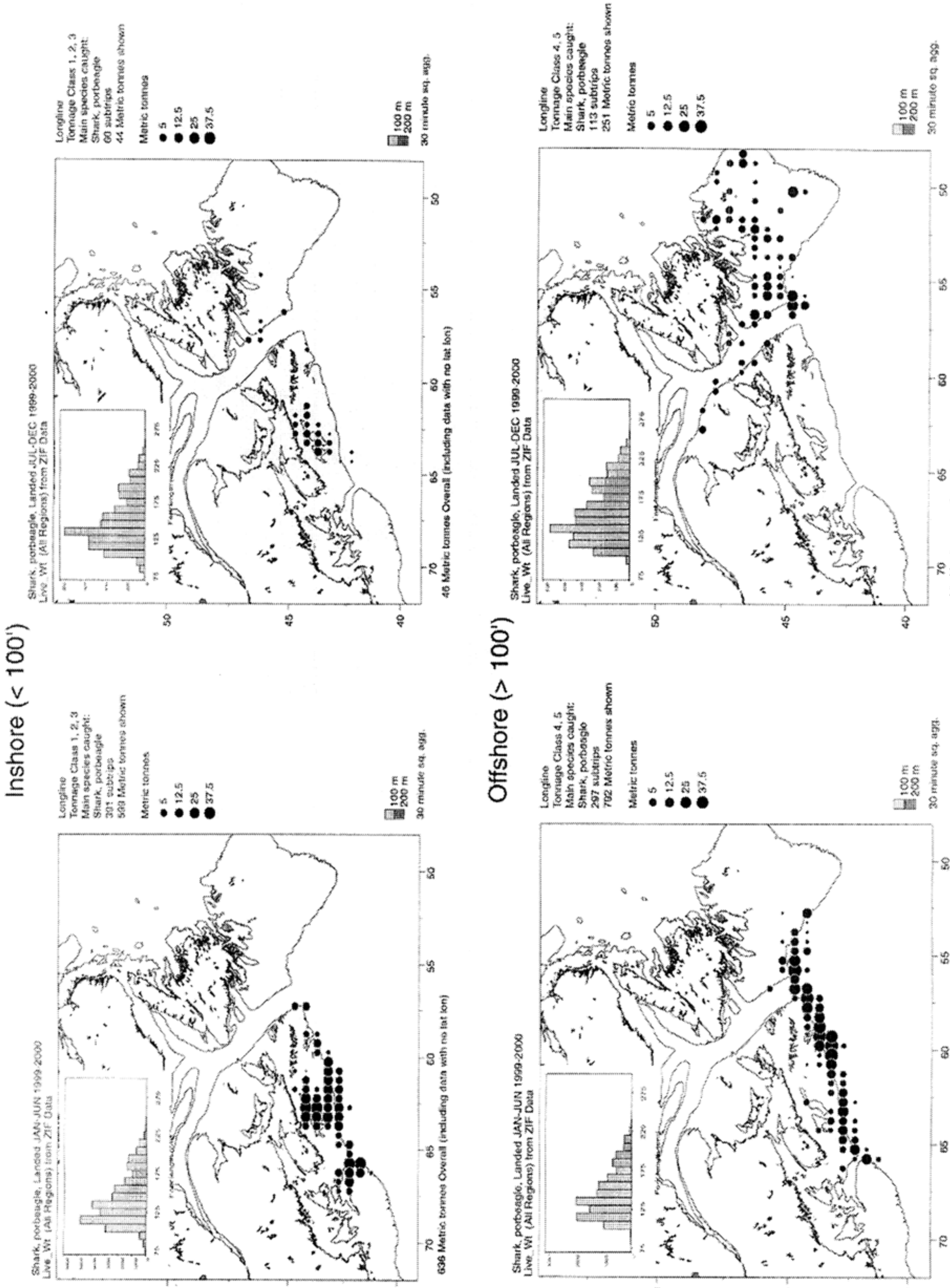


Figure 4. Catch location for inshore and offshore vessels between January and June and between July and December of 1999 and 2000, showing seasonal changes in porbeagle distribution. Also shown are the associated porbeagle length-frequency histograms. Reprinted with permission from Campana et al. 2001.

Nutrition and interspecific interactions

The porbeagle is primarily an opportunistic piscivore that feeds on a wide variety of pelagic, epipelagic and benthic species (Joyce et al. 2002). Compagno (2001) describes the porbeagle as a proverbially voracious feeder. Examination of a few individuals from the Bay of Fundy and Gulf of Maine in the 1940s found herring, gaspereau, mackerel, redfish, and squid in the stomachs (Scattergood 1949 cited in Scott and Scott 1988). A recent study of six porbeagle in the Northwest Atlantic found that over 99% of the stomach contents (by volume) were squid, primarily *Illex illecebrosus* (Bowman et al. 2000 cited in Branstetter 2002). The most comprehensive diet study examined stomachs of 1,022 porbeagle, ranging in size from 85 to 264 cm, that were caught in the Canadian porbeagle shark fishery and on a scientific cruise in the Northwest Atlantic between February 1999 and January 2001 (Joyce et al. 2002). Overall, Joyce et al. (2002) found that teleosts occurred in the majority of stomachs and constituted 91% of the diet by weight, while cephalopods were the second most important food group, occurring in 12% of stomachs. The study identified twenty-one species from twenty different families in the porbeagle diet (Table 1). Of the identified teleost fish, lancetfish, unknown flounders, lumpfish, and Atlantic cod occurred most frequently and contributed most by weight (Joyce et al. 2002). Compared to other Lamnidae sharks, porbeagle feed more on cephalopods, less on other elasmobranches, and there was no evidence that porbeagle feed on marine mammals (Joyce et al. 2002). Based on a summary of four diet studies on porbeagle comprising 115 stomachs, Cortes (1999) estimated a trophic level of 4.2 for porbeagle.

The porbeagle diet does not differ significantly between the sexes, but does vary between juvenile (<150 cm), subadult (150-200 cm), and adult (>200 cm) porbeagles, and also among seasons (Joyce et al. 2002). Porbeagle appear to become more piscivorous with increased size, with larger porbeagle capable of capturing large teleosts and even small elasmobranchs (Joyce et al. 2002). Adult porbeagle contained more groundfish and fewer cephalopods and pelagic fish than juveniles and subadults. Indeed, adult porbeagle seem to favour groundfish based on the percent contribution to stomach weight content. The porbeagle diet shifts with seasonal movements from deep to shallow water. In the spring when most of the population is located on the Scotian Shelf, the diet of juvenile and subadult porbeagle is dominated by pelagic fish and cephalopods, and the adult diet is dominated by groundfish, pelagic fish and cephalopods. In the fall, the percent weight of pelagic fish was noticeably reduced and groundfish increased in the diet of each size class (Joyce et al. 2002). This increase is attributed to the migration into the shallow waters of the Grand Banks and the Gulf of St. Lawrence where the available prey spectrum includes more benthic fish species (Joyce et al. 2002).

Behaviour/adaptability

The behaviour and sociobiology of porbeagle shark are poorly known (Compagno 2001). Its size, high swimming speed, and offshore distribution in deep water, has made the porbeagle shark a difficult species to study (Jensen et al. 2002), and most data available have a fisheries context. Porbeagle are known to undertake both sex-and size-segregation in the Northwest (see Movements/dispersal) and Northeast Atlantic (Compagno 2001). It is a generalist in its diet (Jensen et al. 2001). Porbeagle are found singly and in schools and feeding aggregations; may come inshore and to the surface in summer, but will winter offshore and beneath the surface (Compagno 2001).

Table 1. Prey species observed in porbeagle shark stomachs from the Northwest Atlantic, grouped by major prey categories (N: number of organisms; %Wt: percentage weight; F_o frequency of occurrence). Adapted from Joyce et al. 2002; common names follow Collette and Klein- MacPhee 2002.

Prey category		N	%Wt	F_o
Crustaceans				
Chionecetes opilio	Snow crab	3	0.12	0.20
Cephalopods				
Illex illecebrosus	Boreal squid	186	5.41	11.84
Unidentified invertebrates		45	0.20	0.29
Elasmobranchs				
Squalus acanthias	Spiny dogfish	14	3.61	0.59
Pelagic teleosts		196	26.18	13.41
Alepisaurus ferox	Longnose lancetfish	97	16.47	8.02
Clupea harengus	Atlantic herring	42	6.20	3.42
Scomberesox saurus	North Atlantic saury	3	0.40	0.20
Scomber scombrus	Atlantic mackerel	54	3.11	2.45
Groundfish		466	42.56	11.45
Ammodytes dubius	Offshore sandlance	267	1.29	3.33
Anarhichas lupus	Atlantic wolfish	3	3.27	0.29
Hemitripterus americanus	Sea raven	1	0.89	0.10
Myoxocephalus scorpius	Shorthead sculpin	4	0.09	0.10
Cyclopterus lumpus	Lumpfish	51	11.76	3.13
Gadus morhua	Atlantic cod	15	8.07	1.17
Melanogrammus aeglefinus	Haddock	8	1.94	0.68
Merluccius albidus	Offshore hake	4	0.85	0.29
Merluccius bilinearis	Silver hake	16	0.93	0.20
Unknown flounders		88	12.43	2.64
Sebastes fasciatus	Acadian redfish	9	1.05	0.59
Other teleosts		19	0.99	1.17
Anguilla rostrata	American eel	3	0.77	0.29
Arotopteus pharaoh		1	0.12	0.10
Unknown dragon fish		1	0.08	0.10
Unknown myctophid		1		0.10
Nemichthys scolopaceus	Slender snipe eel	1		0.10
Petromyzon marinus	Sea lamprey	12	0.02	0.49
Unidentified teleosts		526	21.01	19.18
Totals		3817	100	48.63

POPULATION SIZES AND TRENDS

Population structure

All evidence indicates that the porbeagle shark constitutes a single population in the Northwest Atlantic (see Movements/dispersal). Catch data indicate that the porbeagle sex ratio varies temporally and spatially (O'Boyle et al. 1998), but according to tagging data the overall sex ratio of the Northwest Atlantic population of porbeagle is 1:1 (Kohler et al. 2002). The population undertakes extensive annual migrations between the Gulf of Maine and Georges Bank to Newfoundland and the Gulf of St. Lawrence. Although not restricted to Canadian waters, the majority of this population's range is within Canadian waters.

Population assessment

Population abundance estimates and trends

All evidence clearly indicates that the Northwest Atlantic porbeagle population has declined precipitously since commercial fisheries for it began in 1961. Biomass estimates are derived from an age- and sex-structured population dynamics model, and from Peterson calculations of tag recaptures. The trend in abundance over time is also derived from the age- and sex-structured model, while a model of standardized catch per unit effort (CPUE) provides an index of abundance over time. Results from each of these methods, as well as the methods' assumptions and sources of uncertainty are presented here.

Population size and trends for the Northwest Atlantic porbeagle population are estimated from a forward-projecting age- and sex-structured population dynamics model (presented in Campana et al. 2001 and Harley 2002). The model structure was based on the generalized age-structured model Coleraine (Hilborn et al. 2000) and the mechanism for fitting to the catch-at-length data was that used in MULTIFAN (Fournier et al. 1990). In this type of model the population is projected forward from an equilibrium starting point by adding recruitment and removing catches. The model assumed that the porbeagle population was at an unfished equilibrium at the beginning of 1961 (when commercial fisheries for porbeagle began), and separated the Canadian fishery into two components, the Scotian Shelf (Shelf) and the Grand Banks-Gulf of St. Lawrence (NFGulf), because these areas represent different spatial and temporal strata between which the size composition of the catch differs (Harley 2002). The model was based on data of total catches by area for the years 1961 to 2000, CPUE indices for immature and mature fish, and samples of the length frequency composition of the landings by sex and area, and included information on maturity ogives, mortality rates, sex-specific growth parameters (based on the vonBertalanffy growth model in Natanson et al. 2002), and the length-weight relationship. The selectivity-at-age of the fishery on porbeagle was assumed known in some model runs, and estimated in others (Campana et al. 2001). The model estimated recruitment, catchability, and selectivity parameters, by using nonlinear estimation techniques to minimize the difference (negative log likelihood) between observed and predicted catch composition (by year, fishery, sex) and CPUE indices (by fishery, immature/ mature).

Table 2. Reported porbeagle landings (mt) in the North Atlantic, separated by country in the Northwest Atlantic. From Campana et al. 2001; Canadian Shark Research Laboratory 2003.

Year	Canada	Faroe Islands	France	Iceland	Japan	Norway	Spain	USSR	USA	Total	Northeast Atlantic
1961	0	100				1824				1924	1600
1962	0	800				2216				3016	500
1963	0	800				5763				6563	300
1964	0	1214		7		8060				9281	400
1965	28	1078				4045				5151	500
1966	0	741				1373				2114	500
1967	0	589			36					625	600
1968	0	662			137	269				1068	1000
1969	0	865			208					1073	1000
1970	0	205			674					879	4300
1971	0	231			221					452	4400
1972	0	260				87				347	3500
1973	0	269								269	400
1974	0									0	343
1975	0	80								80	577
1976	0	307								307	497
1977	0	295								295	374
1978	1	121								122	3120
1979	2	299								301	1295
1980	1	425								426	1172
1981	0	344			3					347	1031
1982	1	259			1					261	341
1983	9	256			0					265	886
1984	20	126			1	17				164	556
1985	26	210			0					236	440
1986	24	270			5			1		300	425
1987	59	381			16			0	12	468	404
1988	83	373			9			3	32	500	523
1989	73	477			9			3	4	566	444
1990	78	550			8			9	19	664	684
1991	329	1189			20			12	17	1567	450
1992	814	1149			7			8	13	1991	643
1993	920	465			6			2	39	1432	840
1994	1573				2				3	1578	1023
1995	1348		7		4				5	1364	730
1996	1043		40		9				8	1100	411
1997	1317		13		2				2	1334	539
1998	1054		20		0				12	1086	465
1999	955				6					961	
2000	899				0					899	
2001	498										
2002	224										

Although there are uncertainties associated with the age- and sex-structured population dynamics model, these statistical catch-at-age models are considered to be an extremely powerful fisheries assessment method (Hilborn and Walters 1992). This flexible method is advantageous because it can include many different data types, linking them through a dynamic model, and allowing examination of inconsistencies among data types (Jennings et al. 2001, Harley 2002). A known general limitation of forward-projection models is the requirement to specify a spawner-recruitment relationship. For porbeagle, however, low recruitment variability (a consequence of low fecundity and high juvenile survival) meant that a spawner-recruitment relationship, and reasonable bounds for the parameters, could be derived from biological data (Harley 2002). The main uncertainty in the model is one common to most assessments, namely that natural mortality and fishery selectivity were confounded (Harley 2002). Of the five different model runs presented by Campana et al. (2001; Table 3), the base model and run 5 best address this uncertainty by testing the range of possibilities, either that mortality increases at the age of maturity while selectivity remains high (base model with fixed selectivity; Figure 5) or that mortality remains constant and selectivity declines in mature porbeagle (run 5).

Table 3. Estimates of number of female spawners, total biomass, current exploitation rates and maximum sustainable yield (MSY) from the age- and sex-structured population model for Northwest Atlantic porbeagle, fit to catch-at-length and CPUE data by season and area. Adapted from Campana et al. 2001; 2003.

Run	**Number of female spawners**					**Total biomass (t)**				
	1961	1991	2001	1991/ 1961	2001/ 1961	1961	1991	2001	1991/ 1961	2001/ 1961
Base	63,694	16,618	6,075	0.26	0.10	38,967	13,260	4,409	0.34	0.11
Run2	64,710	18,835	7,500	0.28	0.12	39,589	14,357	4,991	0.36	0.13
Run3	69,186	15,048	2,612	0.22	0.04	42,327	12,461	1,572	0.29	0.04
Run4	69,664	15,273	2,934	0.22	0.04	42,619	12,908	1,928	0.30	0.05
Run5	100,979	29,606	13,847	0.29	0.14	44,317	16,500	7,695	0.37	0.17

Base case: increased M in first year and at age of maturity; fixed selectivity; combined growth curve for males and females
Run 2: As above, but with no recruitment deviates
Run 3: Estimating selectivity and recruitment deviates
Run 4: Estimating selectivity without recruitment deviates
Run 5: Estimating selectivity and recruitment deviates; M does not increase at maturity

(cont'd)

Run	**Exploitation rates**								
	Age 2	Age 5	Age 8	-Ln likelihood	F_{MSY}	MSY(t)	B_{MSY}	B_{MSY}/B_0	B_{2001}/B_{MSY}
Base	0.16	0.25	0.26	-543	0.046	1069	24,402	0.63	0.18
Run2	0.14	0.22	0.23	-405	0.046	1086	24,791	0.63	0.20
Run3	0.41	0.64	0.80	-1005	0.047	1138	26,362	0.62	0.06
Run4	0.35	0.52	0.65	-992	0.047	1143	26,519	0.62	0.07
Run5	0.14	0.21	0.26	-918	0.063	1079	21,275	0.48	0.36

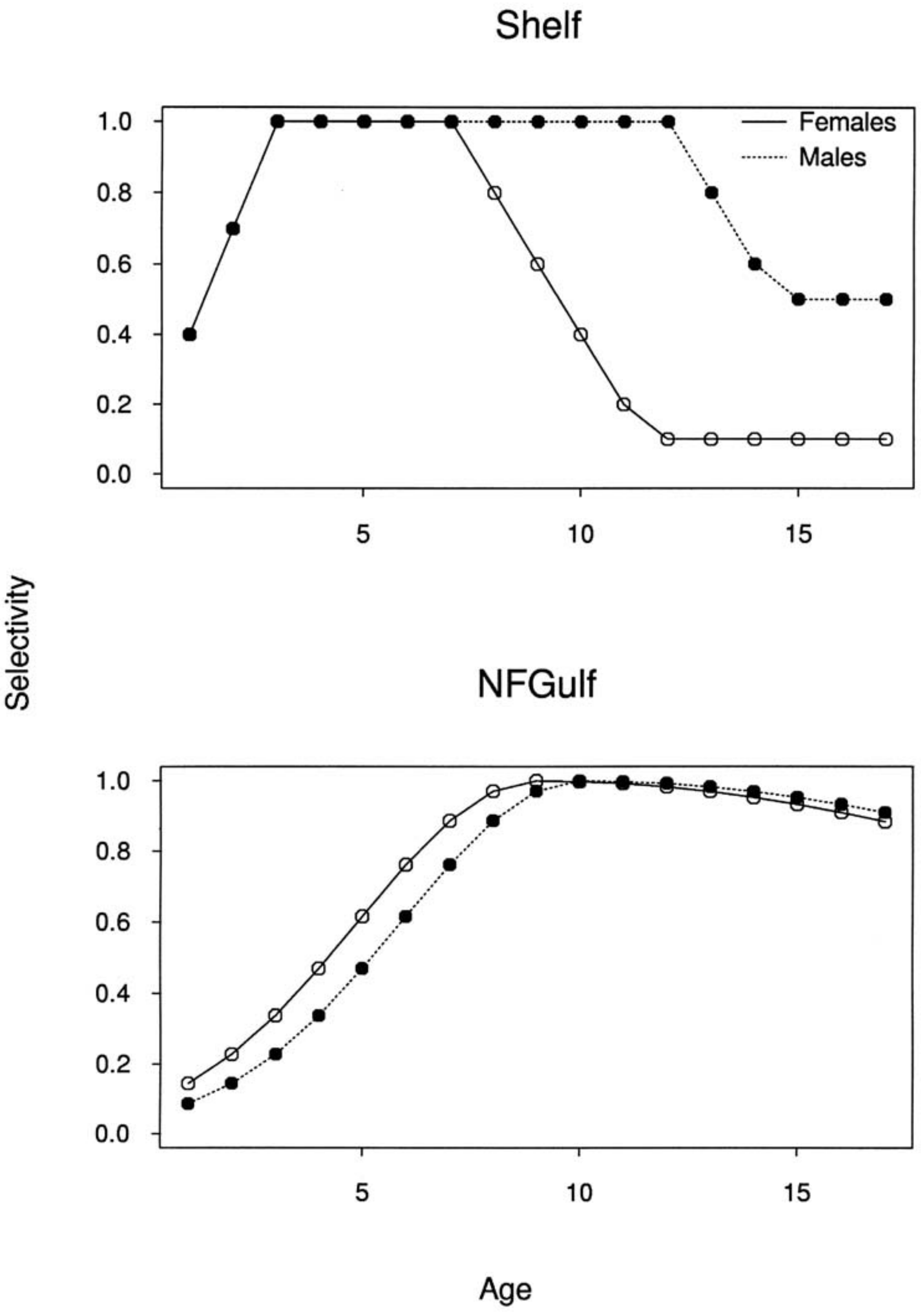


Figure 5. Age- and sex-specific selectivity curves fixed in the base case model. Reprinted with permission from Campana et al. 2001.

According to the base model, biomass of the porbeagle population in 2001 was estimated at 4,409 tons, a decline of 89% from the virgin biomass (Table 3). The model estimates that biomass declined sharply after the fishery began in 1961, recovered slightly by the 1980s, and then declined to an overall low in 2001 (Figure 6). The current number of female spawners is estimated at 6,075, 10% of the virgin abundance (Table 3). Results from model run 5, indicate a similar biomass trajectory, with a slightly higher estimate of current biomass (17% of virgin biomass), and number of female spawners (14% of virgin abundance) (Table 3). The other model runs estimated similar or greater declines. The robustness of these results across five model runs testing a range of assumptions is strong quantitative evidence of the precipitous decline in the Northwest Atlantic porbeagle population.

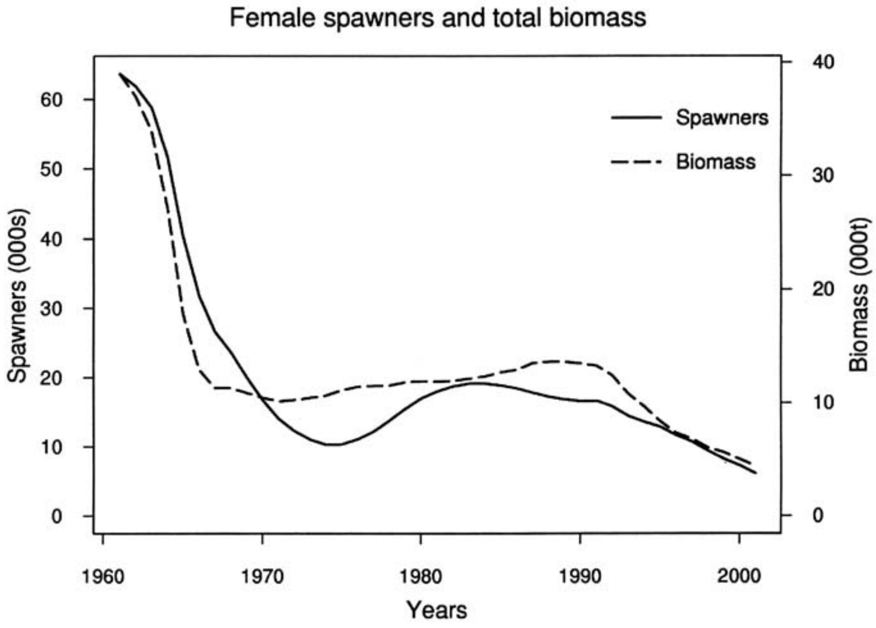


Figure 6. Trends in total biomass and female spawner abundance from the base case age- and sex-structured population dynamics model. Reprinted with permission from Campana et al. 2001.

Abundance estimates from tag recaptures suggest a population decline between 80-85% from the virgin population tagged by the Norwegians (Campana et al. 2003), slightly less than that estimated by the age- and sex-structured base model. The abundance of the porbeagle population in the 1960s and in the mid-1990s was estimated through Peterson calculations of recaptures (as detailed in Ricker 1975) from the Canadian and U.S. tagging studies (Campana et al. 2003). Rates of tag loss, tag-induced mortality, and tag recovery reporting, must be included in the calculation, however, because published estimates for these factors were not available for sharks tagged with steel dart tags, Campana et al. (2002) used approximate values based on teleosts. Campana et al. (2002) reported that the probability of nonreporting was very low through the 1990s given the few vessels in the fishery and the high level of motivation to tag and recapture. It should be noted that biomass estimates from this method were substantially higher for both time periods than those estimated from the catch-at-age model. Indeed, using the tagging data to compare abundance between the two time periods is tenuous given that in the 1960s many large sharks were tagged, whereas in the 1990s, mainly age-0 and age-1 porbeagle were tagged (Campana et al. 2001, 2003). Moreover, Hilborn and Walters (1992) caution that there is usually serious bias in population estimation from tagging studies, and do not recommend them as a way of estimating abundance for most fish populations.

Standardized catch per unit effort estimates for 1989 to 2000 also suggest that there has been a considerable decline in porbeagle abundance (Figure 7). Campana et al. (2001, 2002) standardized catch per unit effort (Ln-catch/hook) separately for mature (>200 cm FL) and immature porbeagle, after converting catch rate in weight to numbers and pooling numbers for mature and immature porbeagle respectively. The analysis was based on data from the directed Canadian porbeagle fishery, which accounts for almost all known porbeagle catches during this time period. Catch rates were standardized according to the general linear model approach of Gavaris (1980), with subarea (southern Scotian Shelf, eastern Scotian shelf, and Newfoundland-Gulf), month, fishing vessel, and year as factors. All factors were significant in predicting the catch rate of mature porbeagles (Campana et al. 2001). Interaction terms were evaluated but not included in the final model because they did not affect the overall trend in catch per unit effort (Campana et al. 2002a). The standardized catch rate of mature porbeagles increased significantly between 1989 and 1992, as the new Canadian fishery developed, but declined sharply thereafter as effort increased and abundance declined (Figure 7; Campana et al. 2001). The estimated CPUE of mature porbeagle for 2000 is 10% of the 1992 value (Campana et al. 2001). The standardized catch rate model for immature porbeagles also showed a significant decline since the early 1990s, and the estimate for 2000 is approximately 30% of the 1991 value (Figure 7; Campana et al. 2001). The catch per unit effort for immature porbeagle has been fairly stable but low since 1996. Overall, the catch per unit effort for porbeagle has declined substantially in the past decade

Trends in population length and age composition

In addition to the declines in abundance, there has also been a long-term decline in the length composition of porbeagle catch on the Newfoundland–Gulf of St. Lawrence mating grounds in early fall (Figure 8; Campana et al. 2001). The median fork length of these porbeagle declined by 30%, from more than 200 cm in 1961 to 140 cm in 2000. Catches in the 1990s were characterized by median lengths well below the size at maturity, indicating the low proportion of mature porbeagles. Indeed, prior to 1991, the most abundant age-classes off southern Newfoundland in the fall were porbeagles

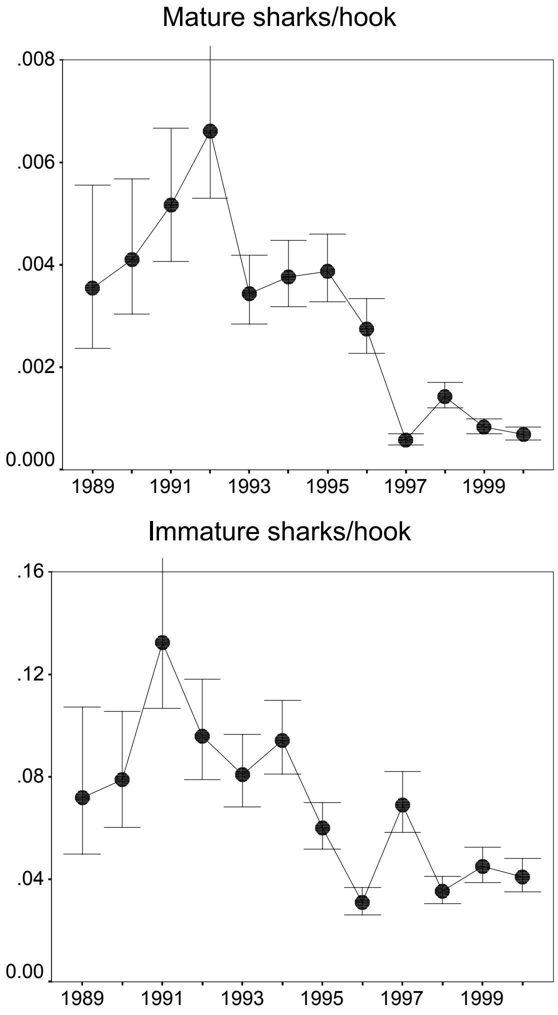


Figure 7. Standardized catch per unit effort (number/hook) of sexually mature (>200 cm FL) and immature porbeagle shark. Reprinted with permission from Campana et al. 2001.

between 10-15 years, consistent with the use of this area as a mating ground (Campana et al. 2002a). In contrast, between 1998 and 2000, porbeagles less than age-3 were the most abundant age classes in this area (Campana et al. 2002a). Although there were no consistent trends in length composition for porbeagle on the Scotian Shelf, this area is dominated by s maller, primarily immature porbeagle (Campana et al. 2002a). Overall, the age of full recruitment to the fishery has declined in recent years to only two to three years (Campana et al. 2002a), a decade before the age at maturity for females.

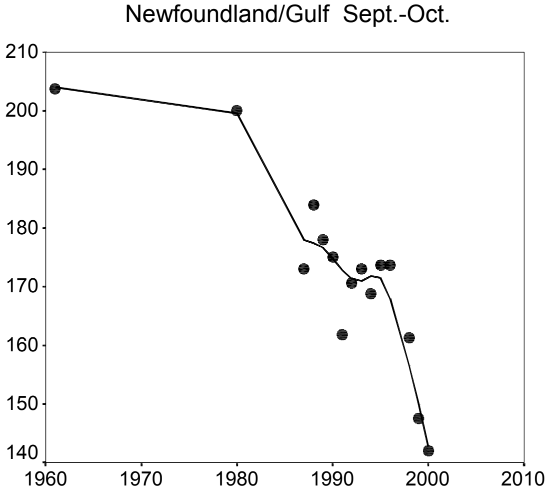


Figure 8. Trend in the median fork length of porbeagle caught by the offshore fleet on the Newfoundland-Gulf mating grounds. Reprinted with permission from Campana et al. 2001.

LIMITING FACTORS AND THREATS

Life history and vulnerability to overexploitation

Sharks have low productivity and consequently little resilience to fishing pressure relative to bony fishes. Indeed, shark fisheries have been characterized by increasing catches followed by rapid stock decline, and collapses (Ripley 1946; Olsen 1959; Parker and Stott 1965; Holder 1970), with decades to recovery, if at all (Anderson 1990; Hoff and Musick 1990). The pattern of collapsed shark fisheries led Holden (1973, 1974) and Walker (1998) to question if sharks can be exploited sustainably. Walker (1998) concluded that shark stocks can be harvested sustainably and, if carefully managed, can provide very stable fisheries. However, increased exploitation of sharks and demand for shark products globally in the past two decades is negatively impacting many shark species (Stevens et al. 2000; Baum et al. 2003).

The life history traits of the porbeagle shark typify those of a species with very low productivity. The porbeagle ranks lowest on the American Fisheries Society's categories of productivity (Table 4), which were proposed to be used as part of a system of extinction risk criteria for marine fishes (Musick 1999).

The porbeagle's life history traits render this species highly vulnerable to overexploitation and limit its capacity for recovery. For example, because population abundance and recruitment are strongly coupled in the porbeagle shark, recruitment overfishing, a reduction in spawning stock biomass to the point where recruitment is impaired, could occur rapidly (and appears to have occurred) in this species. Moreover, for sharks with very low productivity, like the porbeagle shark, Punt (2000) warned that the bio mass and fisheries mortality rate at which recruitment failure occurs may be quite close to the rates where population depensation and ultimate extirpation occur. Density-dependent compensation, which is expected in fish populations that are at low levels through increased fecundity or juvenile survival, will be very limited in porbeagle shark because of its low productivity. Hence, recovery from overexploitation would be expected, and appears to, take decades. The history of porbeagle fisheries reflects this species vulnerability to overexploitation: intensive fisheries have depleted porbeagle stocks in a few years wherever they have existed (Castro et al. 1999).

Table 4. Life history parameters of porbeagle shark relative to the American Fisheries Society values for productivity index parameters suggested as guidelines for species with very low productivity.

	Parameter				
Productivity	r (yr-1)	Von Bertalanfy k	Fecundity (yr-1)	Age at maturity	Maximum age
Very low productivity	<0.05	<0.05	<10	>10 yr	>30 yr
Porbeagle shark	0.05	Female 0.061 Male 0.08	4	Female: 13 yr Male: 8 yr	29-46 yr

Exploitation in the Northwest Atlantic (1961-2002)

Overexploitation of the porbeagle population in the Northwest Atlantic is frequently cited as an example of the vulnerability of sharks to overfishing. Porbeagle in the Northwest Atlantic were first commercially exploited in 1961 when Norwegian vessels, having overfished the species in the Northeast Atlantic (Rae 1962 in Castro et al. 1999), began exploratory fishing on the virgin population off Newfoundland and New England (Castro et al. 1999; DFO 1999). Vessels from the Faeroe Islands joined in during the next few years. Reported porbeagle landings in the Northwest Atlantic rose from 1,924t in 1961 to 9,281 in 1964, but by 1967 the Norwegian fleet had almost disappeared, and by 1970 catches had fallen to less than 1000t as a result of a collapse of the fishery and the fleet shifted to other species and areas (Figure 9; Castro et al. 1999; DFO 1999).

In the two decades following the collapse, the porbeagle population increased only to about 30% of its 1961 abundance (Figure 6). Porbeagle catches remained at low levels during this time period (<500t/annum) (DFO 1999), limited only by the low population abundance, since the fishery was unrestricted. The population's recovery was limited, but is in fact what is expected for a species with an estimated maximum rate of increase of 0.05. There is no information on size and age at maturity of porbeagle in the 1960s, thus it is not possible to discern if intense fishing pressure in that decade resulted in genetic change to these life history traits. A decrease in size and age at maturity could have also limited the porbeagle population's recovery.

When a resurgence of fishing effort directed at the porbeagle shark began in 1990 the population was still at low levels (Figure 6). By 1992 reported landings had risen to almost 2,000mt as a result of increased effort by Faroese vessels and the entry of

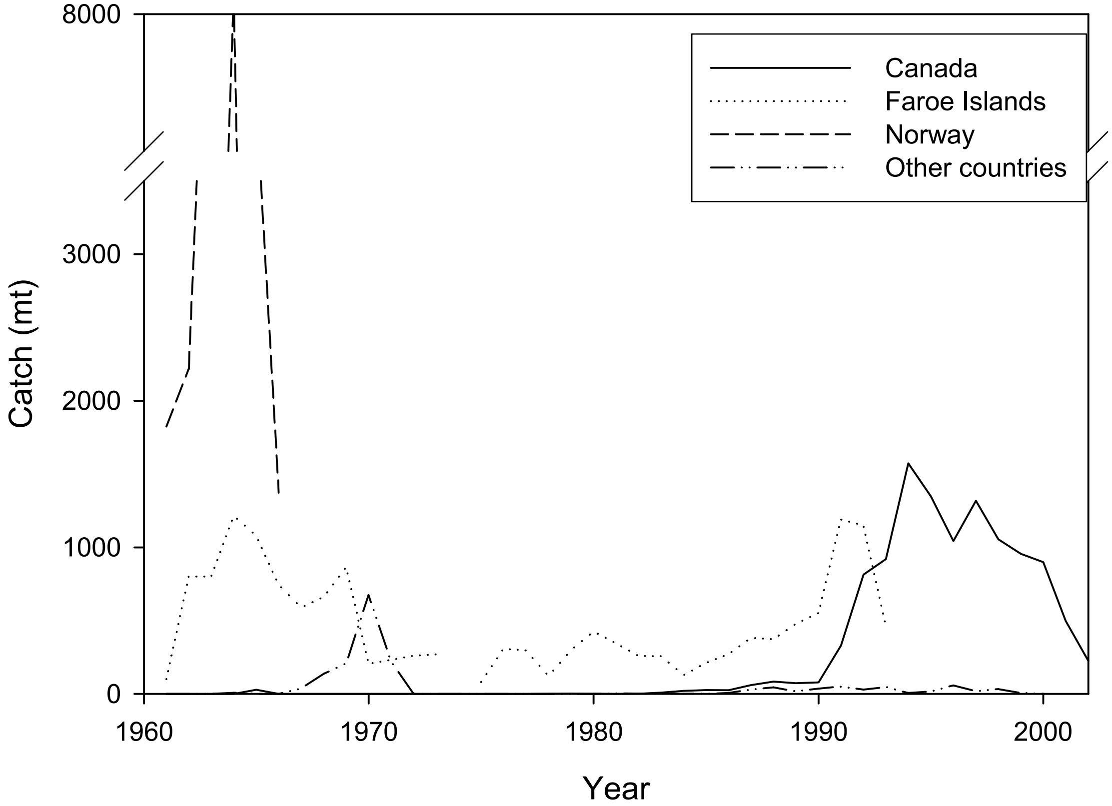


Figure 9. Reported landings of porbeagle in the Northwest Atlantic by country.

Canadian vessels into the fishery (Joyce 1999). Fishing by Faroese vessels within the Canadian 200 mile Exclusive Economic Zone was eliminated in 1994, and the Faroese ceased to fish porbeagle in the Northwest Atlantic altogether. In 1994, the Canadian fleet consisted of three offshore pelagic longline vessels and several inshore vessels (DFO 1999). Since then, almost all porbeagle catches have been taken by the Canadian fleet, and landings have declined from a peak of 1,615t in 1994 to 224t in 2002.

Currently in the Northwest Atlantic, porbeagle shark are primarily caught in the directed Canadian commercial fishery with pelagic longlines. Porbeagles are usually caught at a depth of 50 to 150 m using squid as bait (Canadian Shark Research Laboratory 2003). Until recently, the Canadian fishery focused its effort on largely immature porbeagles on the Scotian Shelf in spring and on large, primarily mature porbeagle off Newfoundland and in the Gulf of St. Lawrence in the fall (Campana et al. 2002a). The fishery was composed of inshore and offshore fleets that differ in the location and timing of their fishing (DFO 1999). Both fleets fished the Scotian Shelf in the spring, with the offshore fleet concentrating on the Shelf edge and the inshore fishery extending well onto the Shelf (DFO 1999; Campana et al. 2002a). In the fall, the minimal effort by the inshore fleet was on the Scotian Shelf, while most of the catch was made by the offshore fleet fishing in the Gulf of St. Lawrence, off southern Newfoundland and on the Grand Banks (DFO 1999; Campana et al. 2002a). There is almost no recreational fishery (DFO 1999). Since 2002, the fall fishery has been closed on the Newfoundland grounds (NAFO Divisions 4Vn and 3LNOP) (DFO 2002).

Although porbeagle catches from other sources are limited, because the porbeagle population is at such low abundance, these catches potentially account for a significant amount of fishing mortality, and should not be discounted. Within Canadian waters, porbeagle bycatch in the Canadian swordfish longline fishery, Japanese tuna longline fishery, and in various inshore fisheries averaged 31 mt per annum between 1994 and 2000 (DFO 1999; Table 5). In the U.S., porbeagle are caught in a small directed fishery off the coast of New England, and incidentally in the commercial tuna and swordfish pelagic longline fisheries, where it is considered a secondary target species (Table 5; NMFS 2001). The porbeagle quota for 2003 in the U.S. is 92mt, considerably more than has been landed in recent years (NMFS 2002). Catches by foreign vessels fishing outside of Canadian waters are unknown, but are believed to be small (DFO 1999). Incidental catches in international waters, however, are poorly monitored. Although the Japanese pelagic longline observer program in the Atlantic recorded catches of six porbeagle on 55 sets in an area northeast of the Canadian range (Matsushita and Matsunaga 2002), total porbeagle catches cannot be estimated without knowing the total fishing effort.

Table 5. Porbeagle shark landings (mt) by fishery in Canadian waters, Canadian porbeagle total allowable catch quota (TAC), porbeagle shark landings (mt) in U.S. and international waters.

Year	Canadian waters						TAC	U.S. waters	International waters
	Directed longline	Swordfish bycatch	Tuna bycatch	Other bycatch	Reported as other sharks	Total			
1991	329	0	0	0	185	514	-	?	?
1992	805	0	0	9	171	985	-	?	?
1993	912	0	0	8	178	1098	-	?	?
1994	1551	9	2	18	263	1844	-	?	?
1995	1313	21	0	15	151	1500	(1500)	?	?
1996	1024	6	1	24	87	1142	(1500)	?	?
1997	1295	6	0	40	(129)	1341	1000	2	?
1998	1020	8	0	28	(108)	1056	1000	9	?
1999	930	2	1	23	(80)	956	1000	2	?
2000	888	2	1	8	(75)	899	850	2	?
2001	?	?	?	?	?	498	850	<1	?
2002	?	?	?	?	?	224	250	?	?

Source: Campana et al. 2001; Canadian Shark Research Laboratory 2003; Cortes 2002b; NMFS 2003.
Notes: Pelagic sharks reported as other sharks until 1996 are thought to be porbeagle sharks, and therefore were included in the calculation of total porbeagle landings in Canadian waters. Quotas in 1995 and 1996 were non-restrictive.

Exploitation rates of porbeagle shark in the 1990s in the Canadian fishery were estimated from three different methods (the age- and sex-structured model, Paloheimo Zs, and tag-recaptures) as being several times above F_{MSY} (estimated from the age- and sex-structured model as F=0.046; Figure 10). The age- and sex-structured population dynamics model estimated that exploitation rates in 2000 on age-2 porbeagle were between F=0.14-0.16, between 0.21-0.25 for age-5 porbeagle, and 0.26 for age-8 porbeagle (base model; model 5; Table 3). Estimates from other model runs were either similar or higher (Table 3). Paloheimo Zs, which estimate the total instantaneous mortality rate based on the reduction in catch at age of a cohort between adjacent years (Ricker 1975), suggest a fishing mortality between 1998 and 2000 of 0.22 for immature porbeagles on the Scotian Shelf, and 0.18 for porbeagle age 9-12/13 in the Newfoundland-Gulf of St. Lawrence fishery (when no uncertainty in the estimates or in natural mortality is incorporated) (Campana et al. 2001). Peterson calculations on tag-recapture data from Canadian and U.S. studies, adjusted for age-specific selectivity, estimated fishing mortality between 1994-2000 between 5 and 20%, with mean of ~11% (Campana et al. 2001, 2002). Estimates from the latter method may be less reliable given the low number of tag recaptures and the assumption that tag mortality, tag loss and tag reporting rate are known. Despite uncertainty in the precise F in each estimate and among the estimates, however, it is clear that the fishing mortality on porbeagle throughout the 1990s was well above F_{MSY}.

As expected, this recent fishing mortality caused a precipitous decline in the Northwest Atlantic porbeagle population, reducing it to a record low abundance (Figure 6). When the porbeagle fishery increased in the 1990s, the Department of Fisheries and Oceans aimed to act in a precautionary manner and set low quotas, but the biological data needed to conduct quantitative stock assessments was initially lacking (see Existing Protection). Thus, quotas in the 1990s could not be based upon stock abundance estimates, but instead were based on historic catch levels (O'Boyle et al. 1998). As new data became available, it became evident that fishing mortality was too high, and in each successive shark management plan the porbeagle quota had to be reduced (Table 5). Not only were the quotas too high throughout the 1990s, but landings exceeded the quota in 1997, 1998, and 2000. Current exploitation levels and management measures are discussed below in Outlook and Canadian Management respectively.

Other factors

While the primary reason for the decline in Northwest Atlantic porbeagle is almost certainly overexploitation, other potential contributing factors should be considered. For example, declines in groundfish, which comprised over 40% of the porbeagle diet in the 1990s (Table 2), may have exacerbated porbeagle declines in this period. It is unlikely, however, that food availability is a significant limiting factor for porbeagle given their highly varied diet and considering that the population was recovering until catches increased in the 1990s. There is no evidence that other factors (e.g. climate change) have contributed to porbeagle declines.

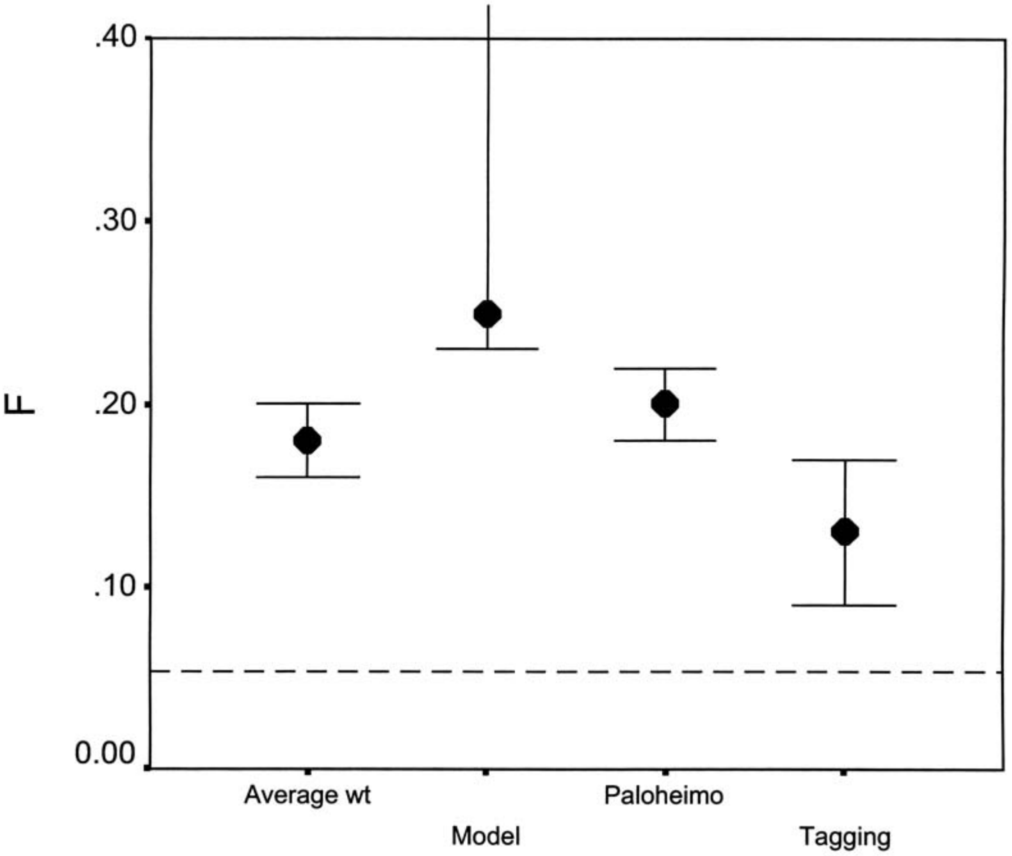


Figure 10. Estimates of recent instantaneous fishing mortality (F) from the age- and sex-structured population dynamics model, from Paloheimo Zs, and from Peterson calculations of tagging data, including the approximate range of uncertainty. All estimates of *F* are above F_{MSY} (dashed line). Reprinted with permission from Campana et al. 2001.

Outlook

Based on the 2001 porbeagle stock assessment (Campana et al. 2001), a management plan was implemented for 2002-2007 in which the quota was reduced to 250t per annum (200t for the directed fishery, with combined directed catch and bycatch not to exceed 250t; DFO 2002). Although higher catches (~350t per annum) allowed for some population recovery in the 1970s and 1980s, the current quota actually corresponds to a higher fishing mortality, *F*, than in the 1970s and 1980s because population abundance was substantially higher at that time than at present. Indeed, when population abundance is as low as the current porbeagle population, even small absolute catches can correspond to high exploitation rates. An additional concern is the very low number of mature porbeagle in the population.

The current porbeagle quota of 200-250t is thought to correspond to approximately FMSY (Campana 2003). FMSY was estimated from a life table analysis as 0.04 under the assumption of logistic growth. Using the average of the fishing mortality estimates for the 1990s from the three methods described above, F=0.20, and the average catches during this time period of 1000t per annum, the current quota was calculated to correspond to FMSY as: F=0.20/5=0.04 thus 1000t/5=200t. There are several sources of uncertainty in estimating FMSY and the quota that limit the precision of these estimates. Uncertainty in parameters used in the life table analysis, especially natural mortality, could significantly affect the results (Cortes 2002a), and should be considered (e.g. through a sensitivity analysis). The implications of uncertainty in the fishing mortality also should be considered. Differences in the fishing mortality estimates instead were averaged, although Quinn and Deriso (1999) advise against taking intermediate values given uncertainty among different datasets or methods. If the fishing mortality is in fact higher than 0.20, as the estimate from the age- and sex-structured population model suggests, the current quota would be overestimated. In the quota calculation the population is assumed to be at equilibrium over the time periods considered when in fact the population was declining (Figure 6). Consequently (all other things being equal), a quota that equated to 4% of the population in the mid-1990s (= 200t) would be greater in actual amount than a quota of 4% on the current smaller population. For example, if the current biomass is 4409t (Table 3), then the quota for F= 0.04 would be about 175t. In addition, the life table analysis used a combined selectivity pattern (for the two areas NFGulf and Scotian Shelf), but the fishery is now open only on the Scotian Shelf. Finally, a life table analysis is a deterministic assessment method that does not take into account demographic or environmental stochasticity, which can have a significant impact on the persistence of populations at low abundance (Lande 1993).

There are several reasons why harvesting at a fishing mortality of F_{MSY}, which should generally lead to a population moving toward its most productive level B_{MSY} (Quinn and Deriso 1999), is too high for porbeagle. First, relatively few fish populations have sufficiently accurate estimates of MSY and F_{MSY} for these values to be used for management (Quinn and Deriso 1999). The aforementioned uncertainties in the porbeagle F_{MSY} estimation and current quota calculation indicate that this is the case. Second, Quinn and Deriso (1999) suggest that for populations below some threshold (often recommended as 20%, i.e. higher than the current porbeagle population estimate) fishing mortality should be reduced or curtailed. Third, at its current low abundance, the porbeagle population may experience depensation (Allee effects). Punt (2000) demonstrated that in shark populations where depensation is occurring the F_{crash}, the fishing mortality at which the population is rendered extinct, moves closer to F_{MSY}.

Porbeagle management measures based on the 2001 stock assessment (e.g. reduced quota, DFO 2002) have not been in effect long enough to determine if they will have a demonstrably positive effect on the population. Statements in the most recent Department of Fisheries and Oceans' porbeagle report that the greatly reduced catch quota will allow the porbeagle population to recover (Campana et al. 2003) are thus premature, and tenuous given the above-described uncertainties. Similarly, DFO's comment that the porbeagle's decline has ceased and is reversible is also premature (Campana et al. 2003). In fact, the biomass trajectory from the age- and sex-structured model shows no indication that the decline in porbeagle abundance has ceased (Figure 6). At this point, it is also uncertain if the declines are reversible. Recent research has clearly demonstrated that reductions in fishing mortality, while necessary, are not always sufficient for population recovery (Hutchings 2001).

SPECIAL SIGNIFICANCE OF THE SPECIES

Porbeagle is the only representative of the genus *Lamna* in the entire North Atlantic Ocean. The species is highly marketable (Rose 1998), and currently supports the only directed commercial shark fishery in Atlantic Canada (Hurley 1998). In the early nineteenth century porbeagle was in great demand for its liver oil which was used for tanning purposes (Bigelow and Schroeder 1948). Currently, porbeagle meat can be sold fresh and dried-salted for food, the fins for shark-fin soup, the liver for oil, and the carcass for fish meal for fertilizer (Scott and Scott 1988; Compagno 2001). Porbeagle meat is one of the most highly valued shark meats, and is widely sold by dealers of sashimi-grade tuna and swordfish, with the quality of the meat compared to swordfish (Rose 1998). In Canada, most porbeagle meat is exported to Europe (particularly Italy), but there is also a small market for fresh meat in the United States (DFO 2001; S. Campana, pers. comm.). In the U.S. market, porbeagle meat is sold in specialty restaurants as shark, mackerel shark, or mako (Scott and Scott 1988).

Compagno (2001) noted that in the past porbeagle sharks were considered a nuisance to commercial fishermen because they wrecked light gear set for bony fishes (such as cod nets) and bit fish off hooks, but that this is likely no longer the case given the greatly depleted porbeagle stocks.

EXISTING PROTECTION OR OTHER STATUS

Canadian management

In Canada, porbeagle shark management developed in the 1990s in response to the new Canadian fishery for this species. Porbeagle management falls under the Department of Fisheries and Oceans. Efforts to develop a fisheries management plan for any pelagic shark species in Atlantic Canada first required amendments to the Fisheries Act because these species were not covered by fisheries regulations (O'Boyle et al. 1998). The amendments came into force in 1994 (O'Boyle et al. 1998). The porbeagle shark is now protected federally under the *Oceans Act* and the *Fisheries Act* (R.S. 1985, c. F-14) under the Atlantic Fishery Regulations (Department of Justice 2002).

The 1994 and 1995 Fisheries Management Plans for pelagic sharks in Atlantic Canada established several management measures for porbeagle shark. The 1994 management plan prohibited shark finning, the removal of the dorsal fin and at-sea disposal of the shark carcass (O'Boyle et al. 1998). The DFO also began its analysis of porbeagle catches in 1994, and produced the first stock status report on porbeagle that year (Canadian Shark Research Laboratory 2003). Since 1995, shark management plans have, among other management measures, limited the number of licenses, restricted gears and fishing areas, and established seasons and specific scientific requirements (O'Boyle et al. 1998; Campana et al. 1999). The 1995 management plan specified that licenses would be exploratory (1 year duration) (O'Boyle et al. 1998). Fisheries management plans for pelagic sharks in Atlantic Canada established non-restrictive catch guidelines of 1500t for porbeagle prior to 1997 (O'Boyle et al. 1998). A preliminary stock assessment based on commercial catch rates was presented in 1996 (Canada Shark Research Lab 2003). The catch guidelines approximated the reported landings of these species in Atlantic Canada in 1992, but could not be based upon estimates of stock abundance at that time (Campana et al. 1999).

The Canadian Atlantic Pelagic Shark Management Plan released in 1997 was a more comprehensive plan set to govern the exploitation of all large pelagic shark species (including porbeagle) from 1997 to 1999 (DFO 1997). The objective of the management plan was to maintain a biologically sustainable resource that would support a self-reliant fishery (DFO 1997). According to the plan, conservation was not to be compromised and a precautionary approach was to guide decision making (DFO 1997). All licenses issued under the plan were to be considered exploratory while scientific information was collected and the sustainability of the resources evaluated. The total allowable catch (TAC) quota was set at 1000t per annum for 1997-1999 based largely on historic catches and the observation that recent catch rates had declined (O'Boyle 1998). The scientific information available at the time was too limited to determine if the TAC was sustainable (Campana et al. 2001). Landings from 1998 onwards have been restricted by quota control (O'Boyle et al. 1998).

Based on the first analytical porbeagle stock assessment (Campana et al. 1999), the Atlantic Pelagic Shark Management Plan of 2000-2001 reduced the porbeagle fishery quota to 850t, and restricted the fleet's quota for the fall fishery on the porbeagle mating grounds off southern Newfoundland to 100t (DFO 2000). At the time, it was not known if the reduced quota would be sustainable over the long term, and additional porbeagle research in support of an improved stock assessment was carried out (Campana et al. 2001).

The 2002-2007 shark management plan (DF0 2002) is based on the 2001 porbeagle stock assessment (Campana et al. 2001), which again incorporated new scientific information, and was the first assessment to include a population dynamics model for porbeagle. Based on the assessment, the TAC was reduced to 250t and fishing access to the mating grounds south of Newfoundland was eliminated (Campana et al. 2002a); the Scotian Shelf remained open. Of the TAC, 200t is allocated to the directed fishery, and the remaining 50t to bycatch (DFO 2002). DFO will assess porbeagle again in 2006.

Research

Porbeagle assessments, and subsequent management, have benefited greatly from the biological information obtained through a collaborative research program on porbeagle shark. In 1998, a concentrated research effort began at DFO (at the Bedford Institute of Oceanography) with the financial and in-kind support of the Canadian shark fishing industry to obtain detailed life history and population dynamics data on porbeagle (DFO 1999). Data collection included detailed onboard measurements and tissue collection by scientific staff, and since 1998 measurements of at least 75% of all porbeagles landed have been made by members of the fishing industry (DFO 1999; Campana pers. comm.). In addition, collaboration with scientists at the Apex Predator Program of the U.S. National Marine Fisheries Service provided access to expertise and unpublished data (DFO 2000). This research program has resulted in several publications (Campana et al. 2002a,b; Jensen et al. 2002; Joyce et al. 2002; Natanson et al. 2002), and two porbeagle stock assessments (Campana et al. 1999; 2001). Further research, with the ongoing support of the Canadian fishing industry participants, is planned (DFO 2000).

U.S. Management

In the United States, the porbeagle shark is protected under the Magnuson-Stevens Act and managed by the National Marine Fisheries Service (Branstetter 1999). Current commercial regulations for porbeagle sharks include limited access permitting and reporting requirements, annual quotas, trip limits for incidental permits, a ban on finning, and fishing only by authorized gears (N MFS 2001). The first U.S. Fishery Management Plan for sharks (1993) concluded that pelagic sharks, as a group, were fully fished; however, to date, a formal stock assessment of this group has not been conducted to establish their status and to measure the efficacy of current regulations (NMFS 2003). Since 1999, porbeagle and other sharks have been managed under the Fishery Management Plan for Atlantic Tunas, Swordfish, and Sharks. This management plan has the objective of managing the fisheries for continuing optimum yield to provide the greatest overall benefit in terms of food production, while preserving traditional fisheries and protecting marine ecosystems (Cortes 2000b).

International Management & Status

There are no management measures in place pertaining to porbeagle for fisheries in international waters, and although efforts to collect data on shark catches in international waters have been initiated, there remains a paucity of data with which to conduct assessments. The International Plan of Action (IPOA) for the Conservation and Management of sharks set forth by the United Nations Food and Agriculture Organization (FAO) is a voluntary protocol designed to ensure the conservation and management of sharks and their long-term sustainable use (FAO 1998). In cooperation with the IPOA several regional fishing bodies in the North Atlantic, including the International Council for the Exploration of the Sea (ICES), the International Commission for the Conservation of Atlantic Tunas (ICCAT), and the Northwest Atlantic

Fisheries Organization (NAFO), have initiated efforts encouraging member countries to collect information about sharks, including porbeagle (FAO 1999). The Northwest Atlantic porbeagle population primarily falls within NAFO subareas 3-6. NAFO requires its members to provide reports on progress on developing their National Plan of Action for sharks and to report catch of shark species, but has not done any assessment of shark resources. The existing arrangement between ICCAT and ICES is that pelagic sharks (like porbeagle) that are bycatches in tuna fisheries should be assessed by ICCAT, because ICCAT should have better catch and discards data on these species (Clarke, pers. comm.). A porbeagle assessment within ICES is possible, but there are no specific plans to conduct one at this time (Clarke, pers. comm). An ICCAT workshop was held in 2001 to review the available data on porbeagle, blue, and shortfin mako sharks in the Atlantic, with the aim of planning assessments for these three species. However, while assessments are planned for the latter two species, ICCAT is currently not planning to conduct a porbeagle assessment in the near future (Restrepo, pers. comm.), likely because the Canadian assessment is considered to be sufficient.

The porbeagle shark is listed on the IUCN Red List as Lower risk/near threatened, meaning that it is close to qualifying for Vulnerable (IUCN 2002). The IUCN assessment stated that although global populations are not proven to have been depleted to a level where they qualify for a Vulnerable status, North Atlantic populations have been seriously overexploited in longline fisheries (IUCN 2002). In an assessment of the status of shark species, Castro et al. (1999) ranked porbeagle as a Category 4 on their scale out of 5, that is a species that shows substantial historical declines in catches, and stated that intensive fisheries have depleted the stocks of porbeagles in a few years wherever they have existed, demonstrating that this species cannot withstand heavy fishing pressure. In his new volume on sharks of the world, Compagno (2001) stated that the conservation status of the porbeagle is of major concern because of the drastic decline in catches from targeted fisheries in the North Atlantic, and because of continuing exposure of the species to finning in high-seas longline fisheries.

SUMMARY OF STATUS REPORT

The Northwest Atlantic population of porbeagle shark has been significantly affected by fishing pressure. Abundance of the population is at a record low, estimated at about 4,400t which corresponds to 11% of the virgin biomass in 1961 when commercial exploitation began. The current number of female spawners is estimated at 6,075, 10% of the virgin abundance. The decline is estimated for a forty year period (1961-2001), less than the estimate of three generations of fifty-four years. Also of concern is the 30% decline in the median length of porbeagle in the Newfoundland-Gulf of St. Lawrence area (the mating grounds). Catches there in the 1990s were characterized by median lengths well below the size at maturity, indicating the low proportion of mature porbeagles. Overall, the age of full recruitment to the fishery has declined in recent years to only two to three years (Campana et al. 2002a), a decade before the age at maturity for females.

The porbeagle population is threatened by its limited capacity for recovery and by exploitation. The life history characteristics of the porbeagle shark, late maturity and low fecundity, render this species highly vulnerable to overexploitation, as is evidenced by the history of its fisheries. Fishing pressure collapsed the population within six years in the 1960s, and after decades of low catches and modest recovery, when fishing increased in the 1990s the population collapsed again, to an overall low. Given the low productivity of this species, it would take at a minimum several decades to recover from its current low abundance level. It is uncertain, however, if the current quota, which is estimated to be at approximately F_{MSY} and is directed primarily on immature porbeagle, is sufficiently low enough to allow for recovery. At present, there is no evidence to indicate that the decline in porbeagle abundance has ceased.

TECHNICAL SUMMARY

Lamna nasus **Bonnaterre 1758**

Porbeagle shark Maraîche

Range of Occurrence in Canada: continental shelves and offshore from Newfoundland to the Bay of Fundy, including the Gulf of St Lawrence.

Extent and Area Information	
Extent of occurrence (EO)(km²)	1,210,000 km²
- *Specify trend in EO*	Unknown but thought to be stable
- *Are there extreme fluctuations in EO?*	
Area of occupancy (AO) (km²) [estimated from recent catch locations and mapping software]	830,000 km²
- *Specify trend in AO*	Unknown but thought to be stable
- *Are there extreme fluctuations in AO?*	No
- *Number of known or inferred current locations*	One contiguous
- *Specify trend in #*	Stable
- *Are there fluctuations in number of locations?*	No
- *Specify trend in area, extent or quality of habitat*	Stable
Population Information	
- *Generation time*	18 years
- *Number of mature individuals*	Estimated number of females in 2001: 6075 (range 2612-13847); with sex ratio 1:1, total adult estimate is 12150 (range 5224- 27694)
- *Total population trend:*	Declining
- *% decline since beginning of commercial exploitation in 1961 (~2.2 generations).*	90% (86-96%)
- *Are there fluctuations in number of mature individuals?*	No
- *Is the total population severely fragmented?*	No
- *Specify trend in number of populations*	Stable
- *Are there fluctuations in number of populations?*	No
- List populations with number of mature individuals in each: One population in the Northwest Atlantic, majority of individuals within Canadian territory	
Threats (actual or imminent threats to populations or habitats)	
Overexploitation, primarily from directed pelagic longline fishery in Canada but also from directed catches in the US and incidental catches in Canadian, US and international (primarily Japan) pelagic longline fleets targeting swordfish and tunas.	

Rescue Effect (immigration from an outside source)	
• *Status of outside population(s)?* **USA: not assessed but same population as in Canada**	
• *Is immigration known or possible?*	NW Atlantic population undertakes annual migrations outside Canadian waters. Tagging studies provide strong evidence that NW and NE Atlantic populations do not mix.
• *Immigrants adapted to survive in Canada?*	Yes
• *Sufficient habitat for immigrants in Canada?*	Yes
• *Rescue from outside populations likely?*	No
Quantitative Analysis	**Not done**
Other Status **IUCN: Lower risk/near threatened**	

Status and Reasons for Designation

Status: Endangered	**Alpha-nu meric code:** A2bd

Reasons for Designation:
This wide-ranging oceanic shark is the only representative of its genus in the North Atlantic. The abundance has declined greatly since Canada entered the fishery in the 1990s after an earlier collapse and partial recovery. Fishery quotas have been greatly reduced, and the fishery has been closed in some areas where mature sharks occur. The landings now are comprised mostly of juveniles. Its life history characteristics, including late maturity and low fecundity, render this species particularly vulnerable to overexploitation.

Applicability of Criteria

Criterion A (Declining Total Population): meets criterion for Endangered 2bd with an 89% decline over about 2.2 generations.

Criterion B (Small Distribution, and Decline or Fluctuation): does not apply because extent of occurrence is >20,000 km^2, occurs at >10 locations and extreme fluctuations are unknown.

Criterion C (Small Total Population Size and Decline): meets criterion for Threatened C1 because number of mature individuals is possibly <10,000 and there is a clear decline.

Criterion D (Very Small Population or Restricted Distribution): does not apply because number of mature individuals is >1000 and area of occupancy is > 20 km^2

Criterion E (Quantitative Analysis): not done

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LITERATURE CITED

Aasen, O. 1963. Length and growth of the porbeagle (*Lamna nasus*, Bonnaterre) in the North West Atlantic. Fisk. Skrift. Ser. Havund. 13(6):20-37.

Anderson, E.D. 1990. Estimates of large shark catches in the Western Atlantic and Gulf of Mexico, 1960-1997, In *Elasmobranchs as living resources: Advances in the biology, ecology, systematics, and the status of the fisheries.* Eds, Pratt, H.L., S.H. Gruber and T. Taniuchi. National Marine Fisheries Service, Silver Spring, MD (USA), pp. 443-454.

Baum, J.K., R.A. Myers, D.G. Kehler, B. Worm, S.J. Harley, and P.A. Doherty. 2003. Collapse and conservation of shark populations in the Northwest Atlantic. Science. 17 January 2003, 299:389-392.

Bigelow, H.B., and W.C. Schroeder. 1948. Fishes of the Western North Atlantic: Sharks. Sears Foundation for Marine Research Memoir No. 1:112-123.

Branstetter, S. 1999. The management of the United States Atlantic shark fisheries, In *Case studies of the management of elasmobranch fisheries*, Vol. 378 (Ed, Shotton, R.) FAO Fisheries Technical Paper, Rome, pp. 109-145.

Branstetter, S. 2002. Mackerel sharks, Family Lamnidae. In: Bigelow and Schroeder's Fishes of the Gulf of Maine. 3rd edition. Collette, B.B., and G. Klein-MacPhee editors. Washington: Smithsonian Institution Press p. 30-32.

Campana S, L. Marks, W. Joyce, P. Hurley, M. Showell, and D. Kulka. 1999. An analytical assessment of the porbeagle shark (*Lamna nasus*) population in the northwest Atlantic. Canadian Science Advisory Secretariat Research Document 99/158, Fisheries and Oceans Canada.

Campana, S., L. Marks, W. Joyce, and S. Harley. 2001. Analytical assessment of the porbeagle shark (*Lamna nasus*) population in the Northwest Atlantic, with estimates of long-term sustainable yield. Canadian Science Advisory Secretariat Research Document 2001/067, Fisheries and Oceans Canada.

Campana S.E., W. Joyce, L. Marks, L.J. Natanson, N.E. Kohler, C.F. Jensen, J.J. Mello, H.L. Pratt Jr, and S. Myklevoll. 2002a. Population dynamics of the porbeagle shark in the Northwest Atlantic. North American Journal of Fisheries Management 22:106-121.

Campana S.E., L.J. Natanson, and S. Myklevoll. 2002b Bomb dating and age determination of large pelagic sharks. Canadian Journal of Fisheries and Aquatic Sciences 59:450-455.

Campana, S.E., W. Joyce and L. Marks. 2003. Status of the porbeagle shark (*Lamna nasus*) in the Northwest Atlantic in the Context of Species at Risk. Canadian Science Advisory Secretariat Research Document 2003/007, Fisheries and Oceans Canada.

Canadian Gazette. 2003. Gully Marine Protected Area Regulations. http://canadagazette.gc.ca/partI/2003/20031206/html/regle1-e.html. Updated 5 December 2003.

Canadian Shark Research Laboratory 2003. http://www.mar.dfo-mpo.gc.ca/science/shark/english/index.htm. Updated 16 May 2003.

Carey, F.G. and J.M. Teal. 1969. Mako and porbeagle: warm-bodied sharks. Comparative Biochemical Physiology 28:199-204.

Carey, F.G., J.M. Teal, J.W. Kanwisher, K.D. Lawson, and J.S. Beckett. 1971. Warm bodied fish. Amer. Zool. 11:137-145.

Castro J.I., C.M. Woodley, and R.L. Brudek. 1999. A preliminary evaluation of the status of shark species. Rome: FAO Fisheries Technical Paper 380. 1-72 p.

Collette, B.B. and G. Klein-MacPhee, eds. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine, 3rd edition. Washington: Smithsonian Institution Press, 784 p.

Compagno L.J.V. 2001. Sharks of the world: an annotated and illustrated catalogue of shark species known to date. Volume 2 Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). Rome: Food and Agriculture Organization of the United Nations. 248 p.

Cortes, E. 1999. Standardized diet compositions and trophic levels of sharks. ICES Journal of Marine Science 56:707-717.

Cortes E. 2000a. Potential rates of increase and rates of increase per generation for three species of pelagic shark from the Atlantic Ocean. ICCAT Collective Volume of Scientific Papers SCRS/99/45 1822-1829.

Cortes, E. 2000b. 2000 Shark evaluation annual report. Technical report. NOAA Fisheries Southeast Fisheries Science Center.

Cortes, E. 2002a. Incorporating uncertainty into demographic modeling: application to shark populations and their conservation Conservation Biology 16:1048-1062.

Cortes, E. 2002b. Catches and catch rates of pelagic sharks from the northwestern Atlantic, Gulf of Mexico, and Caribbean. ICCAT Collective Volume of Scientific Papers SCRS/2001/060 54(4):1164-1181.

Department of Justice. 2002. Oceans Act. http://laws.justice.gc.ca/en/O-2.4/87463.html http://laws.justice.gc.ca/en/F-14/index.html. Updated to August 31, 2002.

DFO, 1997. Canadian Atlantic Pelagic Shark Management Plan 1997-1999, 42 p.

DFO, 1999. Porbeagle shark in NAFO subareas 3-6. DFO Science Stock Status Report B3-09 (1999).

DFO, 2000. Canadian Atlantic pelagic shark integrated fishery management plan 2000-2001, Fisheries and Oceans Canada, pp. 62.

DFO, 2002. Canadian Atlantic pelagic shark integrated fishery management plan 2002-2007, Fisheries and Oceans Canada, pp. 47.

FAO 1998. International plan of action for the conservation and management of sharks. Technical Report Document CSS/98/3, Food and Agriculture Organization, Rome.

Fournier, D.A., J.R. Sibert, J. Majkowski, and J. Hampton. 1990. MULTIFAN a likelihood-based method for estimating growth parameters and age composition from multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnus maccoyii*). Canadian Journal of Fisheries and Aquatic Science, 47:201-307.

Francis M.P., and J.D. Stevens. 2000. Reproduction, embryonic development, and growth of the porbeagle shark, *Lamna nasus*, in the Southwest Pacific Ocean. Fishery Bulletin 98(1):41-63.

Gauld, J.A. 1989. Records of porbeagles landed in Scotland, with observations on the biology, distribution and exploitation of the species. DAFS Scottish Fisheries Research Report 4; pp. 1-15.

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. Canadian Journal of Fisheries and Aquatic Sciences 37:2272-2275.

Harley, S.J. 2002. Statistical catch-at-length model for porbeagle shark (*Lamna nasus*) in the Northwest Atlantic. ICCAT Collective Volume of Scientific Papers SCRS/2001/073 1314-1332.

Hilborn, R., and C.J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics & uncertainty. Kluwer Academic Publishers, Boston, 570 pp.

Hilborn, R., M. Maunder, A. Parma, B. Ernst, J. Payne, and P. Starr. 2000. Coleraine: a generalized age structured stock assessment model. Downloaded from: www.fish.washington.edu/Publications/pdfs/0116.pdf

Hoff, T.B. and J.A. Musick. 1990. Western North Atlantic shark-fishery management problems and informational requirements. In *Elasmobranchs as living resources: Advances in the biology, ecology, systematics, and the status of the fisheries.* Eds, Pratt, H.L., S.H. Gruber and T. Taniuchi. National Marine Fisheries Service, Silver Spring, MD (USA), pp. 455-472.

Holden, M.J. 1970. The rational exploitation of the Scottish-Norwegian stocks of spurdogs, *Squalus acanthias*. Fishery Inves. Lond Ser. 2 25:8.

Holden, M.J. 1973 Are long-term sustainable fisheries for elasmobranchs possible? *Rapports et Procès-Verbaux des Réunions Conseil International Pour l'Exploration de la Mer,* 164:360-367.

Hurley P. 1998. A review of the fishery for pelagic sharks in Atlantic Canada. Fisheries Research Amsterdam 39:107-113.

Hutchings, J.A. 2001. Influence of population decline, fishing, and spawner variability on the recovery of marine fishes. Journal of Fish Biology (2001) 59 Supplement A 306-322.

IUCN 2002. 2002 IUCN Red List of Threatened Species. Downloaded on 15 April 2003.

Jennings, S., M. Kaiser, and J.D. Reynolds. 2001. Marine Fisheries Ecology, Blackwell Science, Oxford, 417 pp.

Jensen, C., L. Natanson, H.L. Pratt Jr, N.E. Kohler, and S.E. Campana. 2002. The reproductive biology of the porbeagle shark (*Lamna nasus*) in the western North Atlantic Ocean. Fishery Bulletin 100(4):727-738.

Joyce, W.N. 1997. Migration and population structure of the porbeagle shark, *Lamna nasus,* in the Northwest Atlantic. B.Sc. Honours thesis Dalhousie University, Halifax, Canada, 54 p.

Joyce, W.N. 1999. Management of shark fisheries in Atlantic Canada. In: *Case studies of the management of elasmobranch fisheries*, Vol. 378 (Ed, Shotton, R.) FAO Fisheries Technical Paper, Rome, pp. 74-108.

Joyce, W.N., S.E. Campana, L.J. Natanson, N.E. Kohler, H.L. Pratt J, and C.F. Jensen. 2002. Analysis of stomach contents of the porbeagle shark (*Lamna nasus* Bonnaterre) in the northwest Atlantic. ICES Journal of Marine Science 59(6):1263-1269.

Kohler, N.E., P.A. Turner, J.J. Hoey, L.J. Natanson, and R. Briggs. 2002. Tag and recapture data for three pelagic shark species, blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), and porbeagle (*Lamna nasus*) in the North Atlantic Ocean, ICCAT Collective Volume of Scientific Papers SCRS/2001/064 1231-1260.

Lande, R. 1993 Risks of population extinction from demographic and environmental stochasticity and random catastrophes. Am. Nat. 142: 911-927.

Lucifora, L., and R. Menni. 1998. First records of a porbeagle shark, *Lamna nasus,* in brackish waters of Mar Chiquita Lagoon, Argentina. Cybium, 22:87-88.

Matsushita Y., and H. Matsunaga. 2001. Species composition and CPUE of pelagic sharks observed by Japanese observers for tuna longline fisheries in the Atlantic Ocean, ICCAT Collective Volume of Scientific Papers SCRS/2001/085 1371-1380.

Musick, J.A. 1999. Criteria to define extinction risk in marine fishes. Fisheries, 24:6-14.

Natanson L.J., J.J. Mello, and S.E.Campana. 2002. Validated age and growth of the porbeagle shark, *Lamna nasus*, in the western North Atlantic Ocean. Fishery Bulletin 100:266-278.

NMFS 2001. United States National Plan of Action for the conservation and management of sharks. Technical report, Department of Commerce, NOAA, NMFS. http://www.nmfs.noaa.gov/sfa/Final%20NPOA.February.2001.htm

NMFS 2002. Atlantic Highly Migratory Species, Commercial Shark Management Measures, Federal register v. 67, no. 249, Friday Dec 27, 2002.

NMFS 2003. 2003 Stock assessment and fishery evaluation for Atlantic highly migratory species. Technical report, National Oceanic and Atmorspheric Association, NMFS, Silver Springs, MD. January 2003.

O'Boyle, R., M. Fowler, P. Hurley, M. Showell, and W. Stobo. 1996. Observations on porbeagle shark (*Lamna nasus*) in the North Atlantic. DFO Atl. Fish. Res. Doc. 96/24.

O'Boyle, R.N., G.M. Fowler, P.C.F. Hurley, W. Joyce, and M.A. Showell. 1998. Update on the status of NAFO SA 3-6 porbeagle shark (*Lamna nasus*). Canadian Stock Assessment Secretariat Research Document 98/41, Fisheries and Oceans Canada.

Olsen, A.M. 1959. The status of the school shark fishery in south-eastern Australia waters. Australian Journal of Marine and Freshwater Research 10:150-176.

Parker, H.W. and F.C. Stott. 1965. Age size and vertebral calcificiation in the basking shark, *Cetorhinus maximus* (Gunnerus). Zool. Meded. Leiden 40:305-319.

Pratt, H.L. Jr. 1993. The storage of spermatozoa in the oviducal glands of western North Atlantic sharks. Environmental Biology of Fishes. 38:139-149.

Punt, A.E. 2000. Extinction of marine renewable resources: a demographic analysis. Population Ecology, 42:19-27.

Quinn II, T.J., R.B. Deriso. 1999. *Quantitative Fish Dynamics,* Oxford University Press, New York, 542 pp.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Canada 191:382 pp.

Ripley, W.E. 1946. The soupfin shark and the fishery. California Fish and Game, Fisheries Bulletin 64:7-37.

Roff, D.A. 1992. The evolution of life histories theory and analysis. New York: Chapman and Hall. 535 p.

Rose, D. 1998. Shark fisheries and trade in the Americas, Volume I: North America. Technical report. TRAFFIC North America.

Scott, W.B., and M.G. Scott. 1988. Atlantic Fishes of Canada. University of Toronto Press. Canadian Bulletin of Fisheries and Aquatic Science, p. 20-22.

Shann, E.W. 1911. A description of the advanced embryonic stage of *Lamna cornubica.* Ann. Rep. Fish. Board Scotland 28(3):73-79.

Shann, E.W. 1923. The embryonic development of the porbeagle shark, *Lamana cornubica.* Proc. Zool. Soc. Lond. 11:161-171.

Stevens, J.D. 1990. Further results from a tagging study of pelagic sharks in the north-east Atlantic. Journal of the Marine Biology Association of the U.K. 70:707-720.

Stevens, J.D., R. Bonfil, N.K. Dulvy, and T.I. Walker. 2000. The effects of fishing on sharks, rays and chimeras (chondrichthyans), and the implications for marine ecosystems. ICES Journal of Marine Science 57:476-494.

Templeman, W. 1963. Distribution of sharks in the Canadian Atlantic (with special reference to Newfoundland waters). Fisheries Research Canada Bulletin 140.

Walker, T.I. 1998. Can shark resources be harvested sustainably: a question revisited with a review of shark fisheries. Marine and Freshwater Research. 49:553-572.

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