

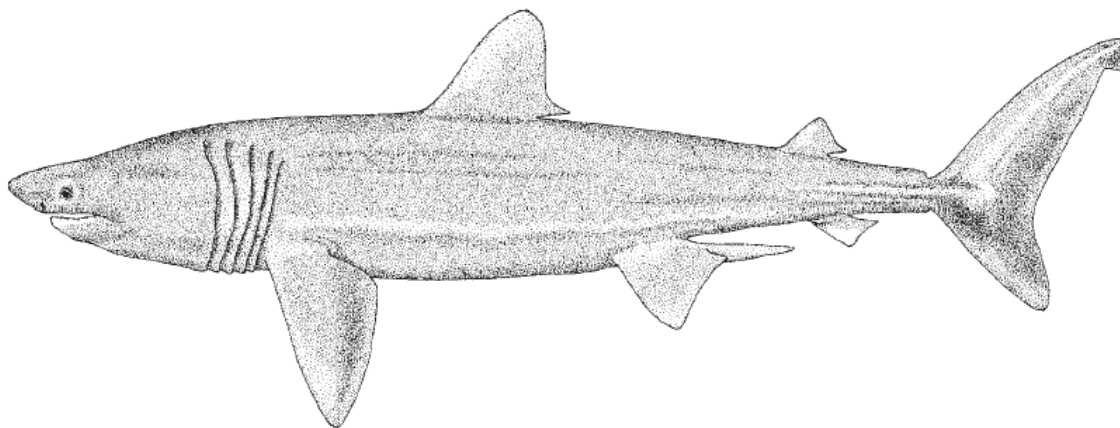
COSEWIC
Assessment and Status Report

on the

Basking Shark
Cetorhinus maximus

Atlantic population

in Canada



SPECIAL CONCERN
2009

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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COSEWIC Assessment Summary

Assessment Summary – November 2009

Common name

Basking Shark - Atlantic population

Scientific name

Cetorhinus maximus

Status

Special Concern

Reason for designation

This species, which attains a maximum length of over 15 m (the second largest living fish) is highly vulnerable to human-caused mortality because of its extremely low productivity. Females mature at 16 to 20 years old, gestate for 2.6 to 3.5 years (the longest known gestation period of any vertebrate), and produce litters of about 6 offspring. Based on recent tagging information, individuals in Canada are considered to be part of an Atlantic population shared with the USA, Europe, the Caribbean and northern South America. Population estimates in Canadian waters have large uncertainties and may number between 4918-10125 individuals. Population estimates outside Canadian waters are not available. Information from surveys along the Atlantic coast from Nova Scotia to Florida indicates no decline over the past two decades. However, available information suggests substantial population declines in the northeast Atlantic. The species is caught incidentally in trawl, longline, and gillnet fisheries in Atlantic Canada. Removals in fisheries with observer coverage have decreased since the 1980s consistent with a reduction in fishing effort, but information on bycatch from other fisheries is not available. There is no evidence of recovery following declines associated with fisheries in other parts of the range. Ship collisions are an additional threat.

Occurrence

Atlantic Ocean

Status history

Designated Special Concern in November 2009.



COSEWIC
Executive Summary

Basking Shark
Cetorhinus maximus

Atlantic population

Species information

The Basking Shark is named after its conspicuous behaviour of "basking" (more accurately feeding) at the surface. The Basking Shark is distinguished from other sharks by its large size (it is the second largest fish in the world), elongated gill slits, pointed snout, a large mouth with minute teeth, and a crescent shaped caudal fin. Colouration is typically blackish to grey-brown. Gill openings have prominent gill rakers.

Population structure and designatable units

Due to their biogeographic separation, the Atlantic and Pacific Canadian populations are treated as two COSEWIC designatable units (DUs); the Pacific population was assessed by COSEWIC as Endangered in 2007.

Although most available information suggested that individuals in the Canadian Atlantic are part of a northwest Atlantic population shared with the USA, recent tagging studies have shown transatlantic migration from Europe to Newfoundland and transequatorial migrations from the northeast USA as far as Brazil. Genetic diversity in this species is low worldwide, suggesting a historical population bottleneck. Some authors have suggested the existence of a single world population.

A single designatable unit in Canadian Atlantic waters is consistent with available information. Individuals in Canada are considered to be part of an Atlantic population shared with the USA, Europe, the Caribbean and northern South America.

Distribution

Basking Sharks are frequently seen in summer months but rarely in other seasons. They are found circumglobally in temperate coastal shelf waters, often in localized concentrations. Recent tagging studies have extended the distribution to tropical waters of the Sargasso and Caribbean seas and the northeast coast of South America. Canadian records from both Atlantic and Pacific waters indicate they utilize virtually all coastal temperate waters. Based on bycatch records from observer programs, visual surveys, and recent satellite tagging studies it appears that Basking Sharks in Atlantic Canada are most abundant south of the Newfoundland-Labrador shelf but may extend north to 51° latitude or beyond. Each year many individuals are observed in the mouth of the Bay of Fundy, consistent with the existence of localized concentrations in other areas where the species occurs.

Habitat

Areas where oceanographic events concentrate zooplankton appear to be the favoured summer habitat of Basking Sharks, typically including fronts where water masses meet, headlands, and around islands and bays with strong tidal flow. There is recent evidence that Basking Sharks also utilize deepwater habitats greater than 1000 m. The quality of foraging habitat changes over short spatial and temporal scales based on oceanographic conditions.

Biology

Information on the life history of this species is very limited. Maximum recorded length is 15.2 m. Animals less than 3 m in length are rarely encountered. Size at birth is probably 1.5 to 2 m. Litter size is known from only one animal with six young. Males are thought to reach maturity at between 12 and 16 years and females between 16 and 20 years. Pronounced sex segregation is evident based on data from surface catches. Gestation has been estimated at 2.6 to 3.5 years, the longest known for any animal, with time between litters estimated at 2 to 4 years. Longevity is likely about 50 years. The estimated annual productivity is the lowest of any shark known. Generation time is estimated between 22 and 33 years.

Adult Basking Sharks have no known predators but young individuals may be vulnerable to predation by other large shark species. Basking Sharks are primarily planktivores, seeking out areas of high zooplankton concentrations.

Population sizes and trends

Limited information on population sizes and trends is available. A total population estimate for Atlantic Canada of 10,125 individuals based on aerial and shipboard surveys is highly uncertain because of correction factors used; a more conservative estimate of 4,918 individuals also has high uncertainty but is based on minimum estimates for individual areas. Combined aerial and shipboard surveys (designed for Right Whales but also recording Basking Sharks) show high interannual variability and no overall trend from 1980 to 2003, both in the entrance to the Bay of Fundy and in areas off the US Atlantic coast where the same population is presumed to occur. A population model using information on recent population size, known removals in fishery bycatch over two decades, and life history parameters from literature suggests a relatively low likelihood of decline over the past 20 years, and low probability of decline to extinction levels in the next 100 years, but these results are susceptible to input conditions about which there is high uncertainty. In the northeast Atlantic, there are indications of substantial declines, but the indices are poorly quantified and some may reflect changes in oceanographic conditions as well as abundance changes.

Limiting factors and threats

The Basking Shark's life history make it vulnerable to human impacts. Characteristics making it vulnerable include late age of maturity, low fecundity, long gestation period (apparently the longest of any vertebrate), long periods between gestations, low productivity, sex-segregated populations, overlapping habitats with commercial fisheries, surface behaviour, and naturally small populations.

Bycatch in fisheries is the most important known threat in the northwest Atlantic. Observations and estimates of bycatch in foreign and domestic offshore fisheries in Atlantic Canada from 1986 to 2006 show an average over that period of 164 t/yr (or individuals/yr as median weight in catches is 1 t) and a total removal of 3444 t (individuals). Bycatch from these fisheries has been declining with declining fishing effort; the maximum recorded was 741 t in 1990 and average bycatch in the most recent decade for which figures are available (1997-2006) has been 78 t/yr. Basking Sharks are taken in inshore fisheries but little information on amounts is available; 370 individuals were entangled in Newfoundland coastal fisheries in 1980-83 but effort in these fisheries has declined substantially since then. Survival rate following capture is unknown.

Ship collisions may be another threat given the surface-living habits of this species.

Directed harvests occurred in European waters for some 200 years, and 100,000 individuals were removed in fisheries between 1946 and 1997. A directed fishery was undertaken by Faroese vessels in the southern Gulf of St. Lawrence in 1981-82 but no information on removals is available.

Special significance of the species

The Basking Shark is the only species in its family. The earliest fossil Basking Shark is 29 to 35 million years old. It qualifies for the category “charismatic megafauna” by virtue of its large size (second largest fish in the world) and conspicuous surface activity. On the Pacific coast Basking Sharks are the most plausible explanation for sea serpents, sea monsters, and the Cadborosaurus (“Caddy”). The high value of Basking Shark fins has promoted a lucrative trade to Asian countries. The recent inclusion of Basking Shark under Appendix II of CITES is intended to regulate this trade. The Basking Shark may be more vulnerable to human impacts than any other marine fish.

Existing protection

The Pacific population of Basking Shark was designated Endangered by COSEWIC in 2007 and is currently a candidate for listing on Schedule 1 of the *Species at Risk Act*; the Pacific population was the subject of an eradication program in the 1950s and 1960s. In Canada this species receives de facto protection by broad regulations that prohibit finning of any shark species. Given that there is no market for other parts of Basking Sharks in Canada, there is no directed exploitation. Directed kill of Basking Sharks is prohibited by European Community countries, the United States, and New Zealand. Internationally, the IUCN Red List assessment has categorized Basking Sharks as Vulnerable (A2d) globally and Endangered (A1d, 2d, D) in the northeast Atlantic and north Pacific and Critically Endangered (A1d, 2d, and possibly C1) in the case of “Barkley Sound”.



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. Species designated at meetings of the full committee are added to the list. 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 for 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 entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS (2009)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife 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 wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* 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. Definition of the (DD) category revised in 2006.



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

COSEWIC Status Report

on the

Basking Shark *Cetorhinus maximus*

Atlantic population

in Canada

2009

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SPECIES INFORMATION

Name and classification

The Basking Shark (*Cetorhinus maximus* Gunnerus, 1765) is the sole member of the family Cetorhinidae belonging to the order Lamniformes. Other common names include sun shark, bone shark, and elephant shark. In French this species is known as Pélerin. In Pacific Canada, the Basking Shark was also commonly but incorrectly referred to as mud shark in early historical accounts.

Morphological description

This animal is most readily distinguished in the field from other sharks by its large size (maximum reported 15.2 m), elongated gill slits which extend almost to the mid-dorsal of the head, pointed snout, a large subterminal mouth with minute hooked teeth, caudal peduncle with strong lateral keels, and crescent shaped caudal fin (Compagno 2001, Figure 1). Colour is typically blackish to grey-brown, grey or blue-grey above and below on body and fins, undersurface sometimes lighter, often with irregular white blotches on the underside of the head and abdomen (Compagno 2001). Internal gill openings have prominent gill rakers formed from modified dermal denticles.

Basking Shark is the second largest fish in the world, following the whale shark.

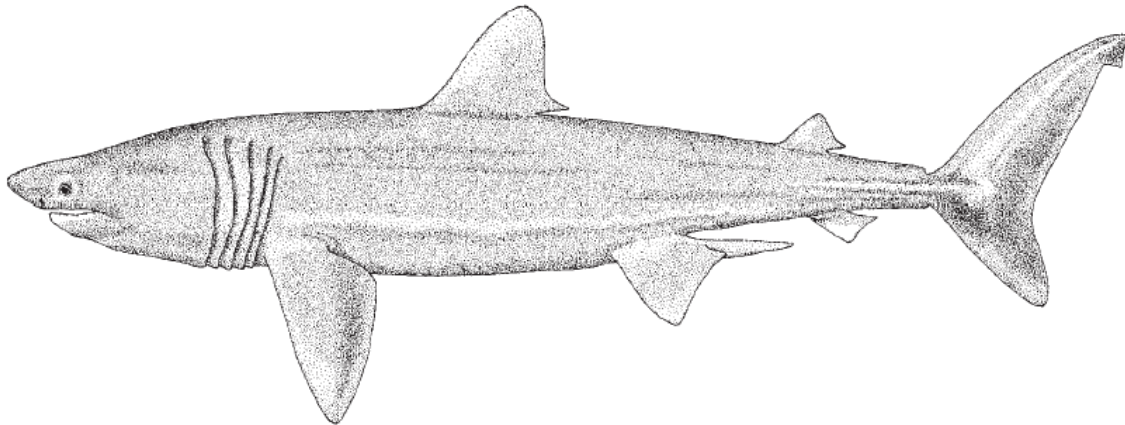


Figure 1. Basking Shark (*Cetorhinus maximus*). Source of figure: Compagno 2001.

Genetic description

The population structure of Basking Sharks is relatively poorly known, although recent studies have led to better understanding.

In Canada, Basking Shark populations in the North Atlantic and North Pacific are geographically disjunct and have been considered to be reproductively isolated from one another due to their apparent preference for temperate waters that would preclude migration through the Arctic Ocean. Canada's Pacific population of Basking Shark was the subject of an earlier Status Report (COSEWIC 2007), on the basis of which it was designated "endangered".

Tagging studies prior to 2006 provided little information on stock structure, and suggested separate populations in the northeast and northwest Atlantic. In the North Atlantic, there was one conventional tagging study where 156 Basking Sharks were tagged but none were recaptured (Kohler *et al.* 1998). Studies in the northwest Atlantic using pop-up archival transmitting tags provided evidence for a latitudinal migration between seasons, but no evidence for transoceanic migrations, therefore suggesting separate stock structure between eastern and western Atlantic populations (Skomal *et al.* 2004; Skomal 2005). Of three individuals released with pop-up archival transmitting tags, one tagged in September 2001 migrated 800 km from Massachusetts south to North Carolina over 71 days (Skomal *et al.* 2004). Two sharks tagged within 7.5 km of one another in September 2004 off Nantucket migrated southward approximately 1600 km and 2500 km to waters off Jacksonville, Florida and waters between Jamaica and Haiti respectively over four months (Skomal 2005). These data suggested the possibility of a single population along the eastern seaboard of North America.

More recent tagging work with pop-up tags suggests that migrations may be much broader than previously thought. Gore *et al.* (2008) described a transatlantic migration by a female tagged off the Isle of Man, for a total distance of 9600 km, to off eastern Newfoundland. Skomal *et al.* (2009) described the results from tagging 25 individuals off the eastern USA; ten individuals moved considerably beyond the range previously described into subtropical and tropical waters, including the Sargasso and Caribbean seas and the coasts of Guiana and Brazil. Both studies showed that Basking Sharks are capable of spending long periods at great depths, thus suggesting a much broader distribution than that based on prior observations. In light of the recent tagging results Skomal *et al.* (2009) have suggested that Basking Sharks may represent a single worldwide population.

Hoelzel *et al.* (2006) found remarkably low levels of genetic diversity among samples of Basking Shark from widely distributed sites throughout its global range, including the northeast and northwest Atlantic and north and south Pacific. No differences were found between individuals from Atlantic and Pacific basins. Genetic diversity was lower than that observed for other elasmobranch or teleost fishes with similar circumglobal distributions. The authors suggested that a population bottleneck within the Holocene may have been the cause of the low genetic diversity.

Throughout the global range, Basking Shark aggregations have been reported to occur repeatedly in discrete areas where they are typically found in large numbers and for only part of the year (Compagno 2001). Thus, philopatry and more complicated genetic population structure may exist.

Designatable units

There is no evidence for more than one designatable unit in Canada's Atlantic waters.

For the purposes of this report, individuals in Canada are considered part of an Atlantic population shared with Europe, the USA, the Caribbean and northern South America (based on recent indications of broad migratory capacity). Previously, evidence suggested that individuals in Canada were part of a northwest Atlantic population shared with the USA. Pending additional work on population structure, it appears appropriate to maintain separate Pacific and Atlantic DUs in Canada for this species.

DISTRIBUTION

Global range

Basking Sharks are found circumglobally in temperate coastal shelf waters but are frequently found in localized concentrations (Figure 2) occurring off the coast of fifty countries (Froese and Pauly 2005). In the North Atlantic, Basking Sharks have been observed in waters off countries as far south and east as Senegal, through to Europe (including the Mediterranean Sea), Norway, Sweden, Russia, westward to Iceland, Greenland (where it is rare), Canada (Newfoundland, Nova Scotia, New Brunswick), along the eastern seaboard of the United States and into the Gulf of Mexico. Although Basking Sharks had not previously been observed in tropical waters, recent pop-up tagging observations (Skomal *et al.* 2009) have extended the western Atlantic distribution into the Sargasso and Caribbean Seas and as far south as Guiana and Brazil. In the North Pacific, they are observed as far south and west as Japan, through to China, along the Aleutian Islands, Alaska, British Columbia, along the western seaboard of the United States and Mexico (Baja California and northern Gulf of California) (Compagno 2001).

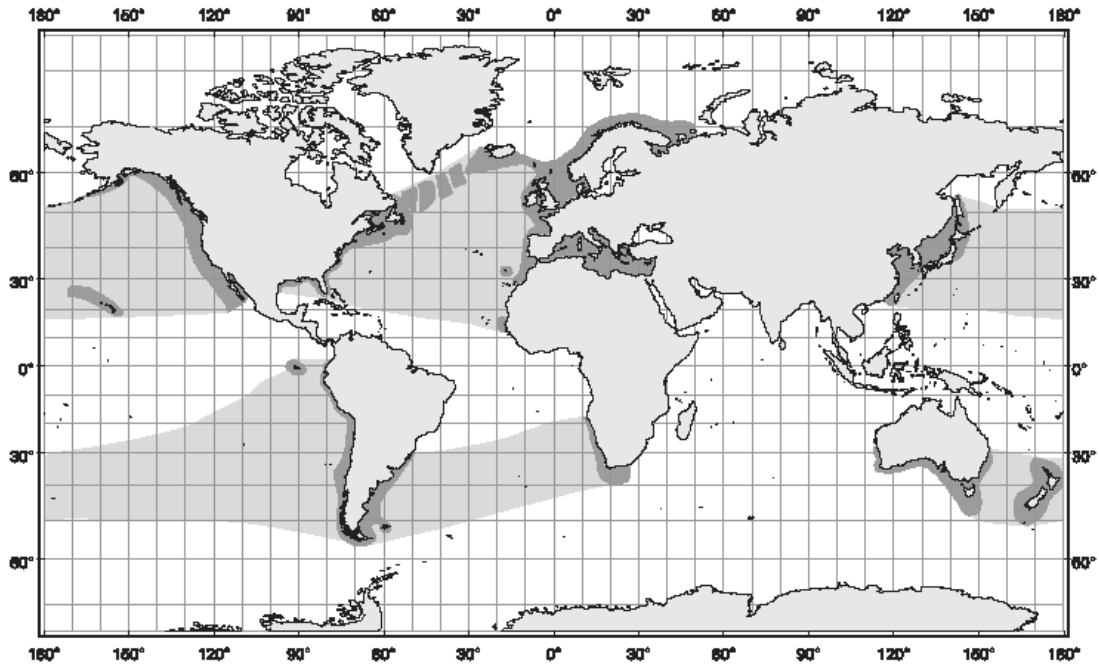


Figure 2. Global distribution of Basking Sharks. Dark grey areas represent known Basking Shark distribution and light grey areas represent possible distribution based on temperature preferences. Map source: Compagno 2001.

Range in Atlantic Canada

Basking Sharks have been observed throughout Atlantic waters including the Gulf of St. Lawrence, Bay of Fundy, Scotian Shelf and Grand Banks. Lien and Fawcett (1986) show locations where 371 Basking Sharks were caught incidentally in nearshore waters off Newfoundland. Catches were concentrated between Port aux Basques and Hermitage, with most captures occurring near headlands. Lien and Fawcett's study corroborates the spatial and temporal distribution reported by Templeman (1963) based on catch records from 1876 to 1962.

The distribution of Basking Sharks can be inferred from observed catches from the International Observer Program (IOP) from 1977 to 2004 (Figure 3) and from the Newfoundland Observer Program (NOP) from 1980 to 2004 (Figure 4). Records north of 51°N have been assumed (Campana *et al.* 2008) to be mostly misidentified Greenland sharks (another large shark taken as bycatch), since authenticated records of Basking Sharks are rare in this area and misidentification of these two species has been documented; however, recent satellite tagging results (Gore *et al.* 2008) confirm that Basking Sharks do occur north of 51°N. Further detail on distribution is available from aerial survey observations, confirmed observations communicated to DFO, and combined aerial/shipboard observations in the Bay of Fundy area (Figs. 5, 6). Based on observer data, it appears that Basking Sharks are distributed throughout the Atlantic continental shelf (extent of occurrence > 1.2 million km²).

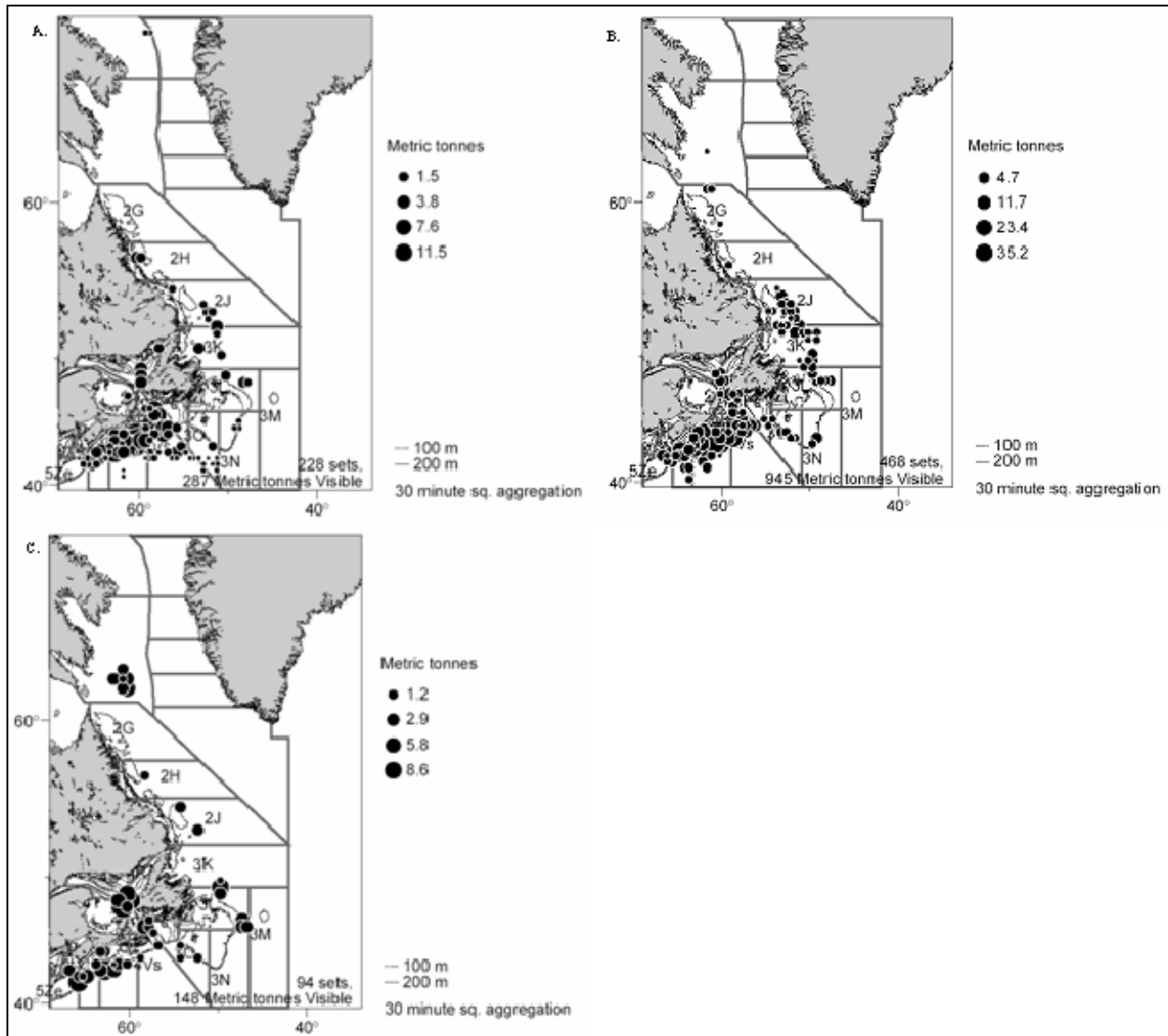


Figure 3. Occurrence of Basking Sharks in Atlantic Canada based on International Observer Program records between (A) 1977 and 1986, (B) 1987 and 1996, and (C) 1997 and 2004. Numbers refer to the cumulative catch (in metric tonnes) reported by observers during the specified period. Observers monitored a small proportion of all fishing effort so these numbers underestimate the total biomass of Basking Shark removed as bycatch by the fishery. Records north of 51°N may be misidentified Greenland sharks.

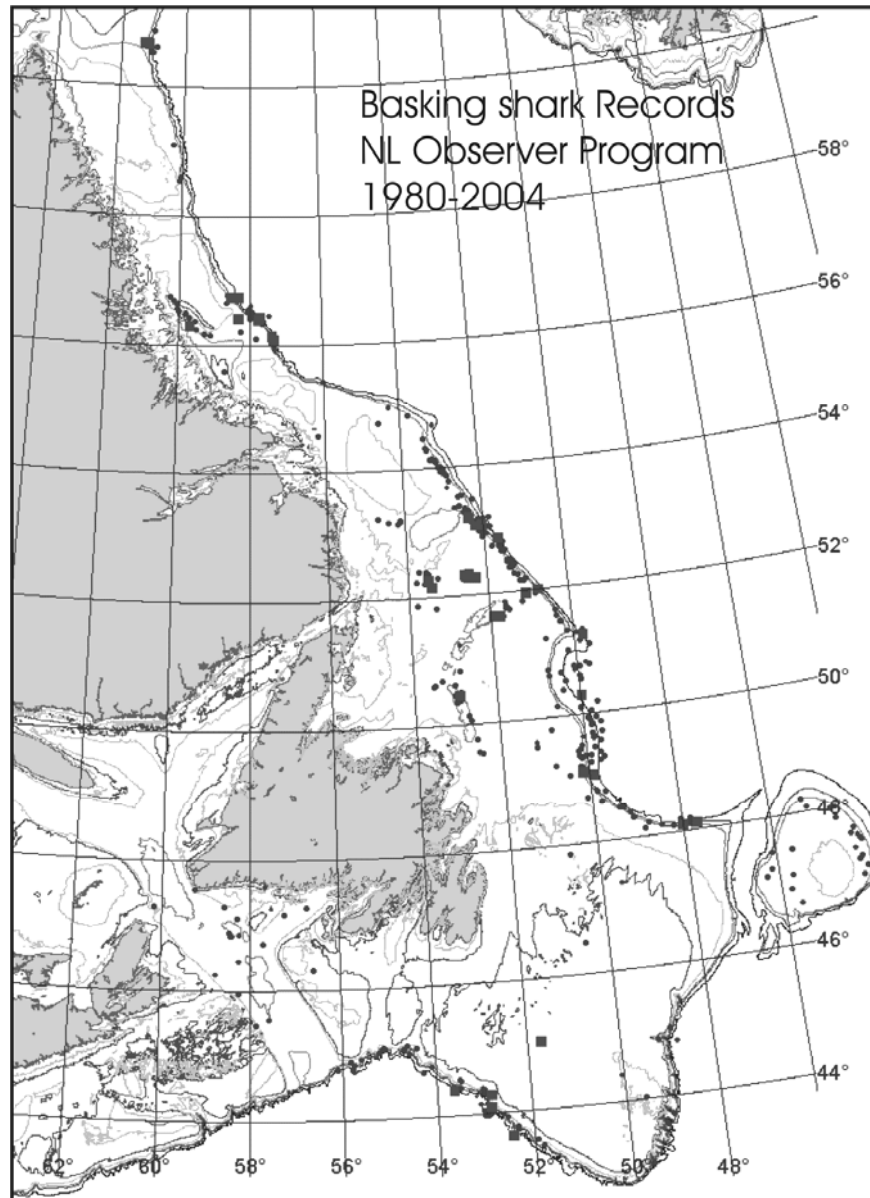


Figure 4. Occurrence of Basking Sharks in Atlantic Canada based on Newfoundland Observer Program records from 1980 to 2004. Small dots represents catches < 5 t, larger squares represent catches > 5 t. Source: Newfoundland Observer Program. Records north of 51°N may be misidentified Greenland sharks.

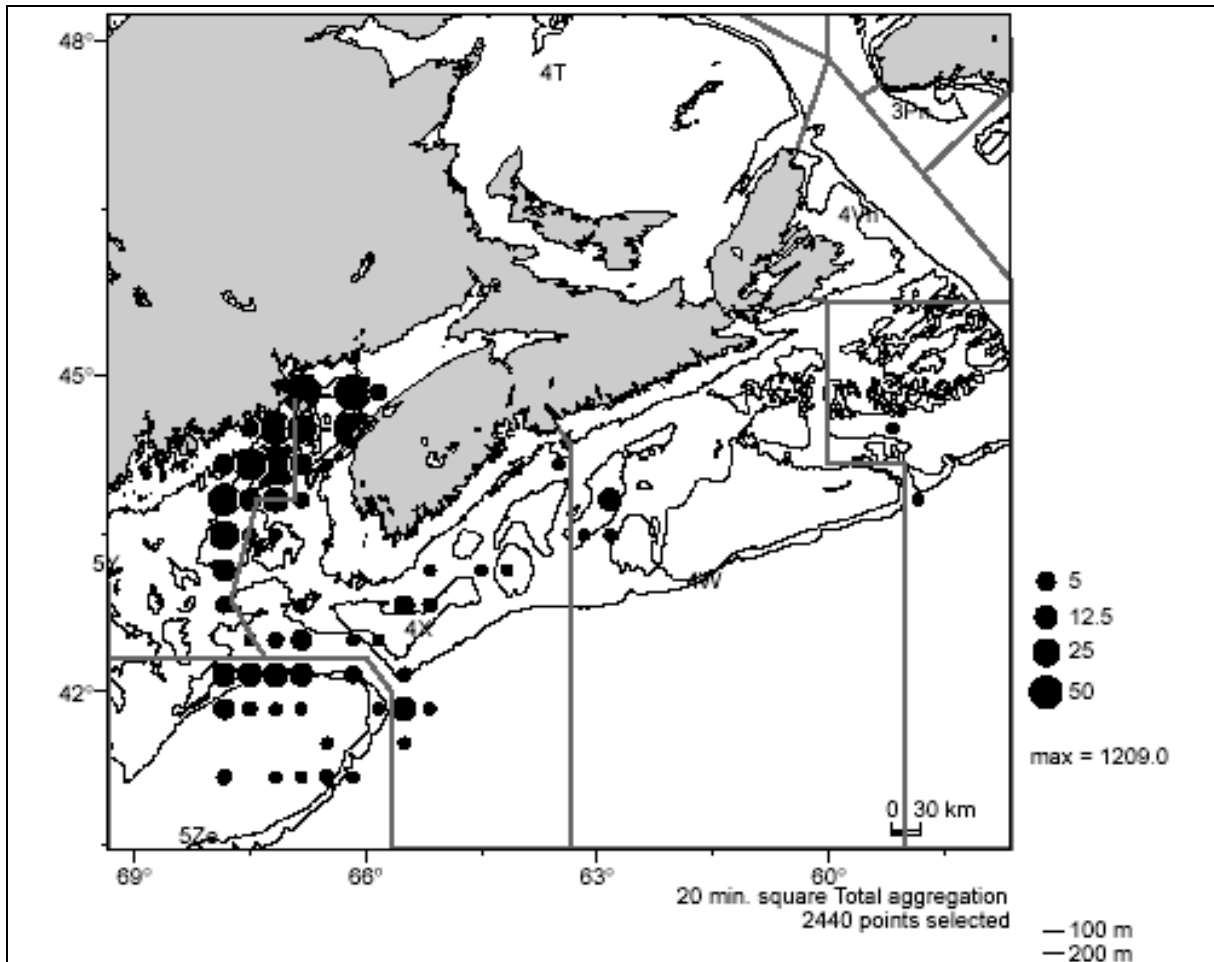


Figure 5. Occurrence of Basking Sharks (numbers) sighted during systematic aerial surveys for Right Whales conducted between 1979 and 2003 (Data from Robert Kenney, University of Rhode Island). The size of the circles denotes the number of sightings as shown in the legend.

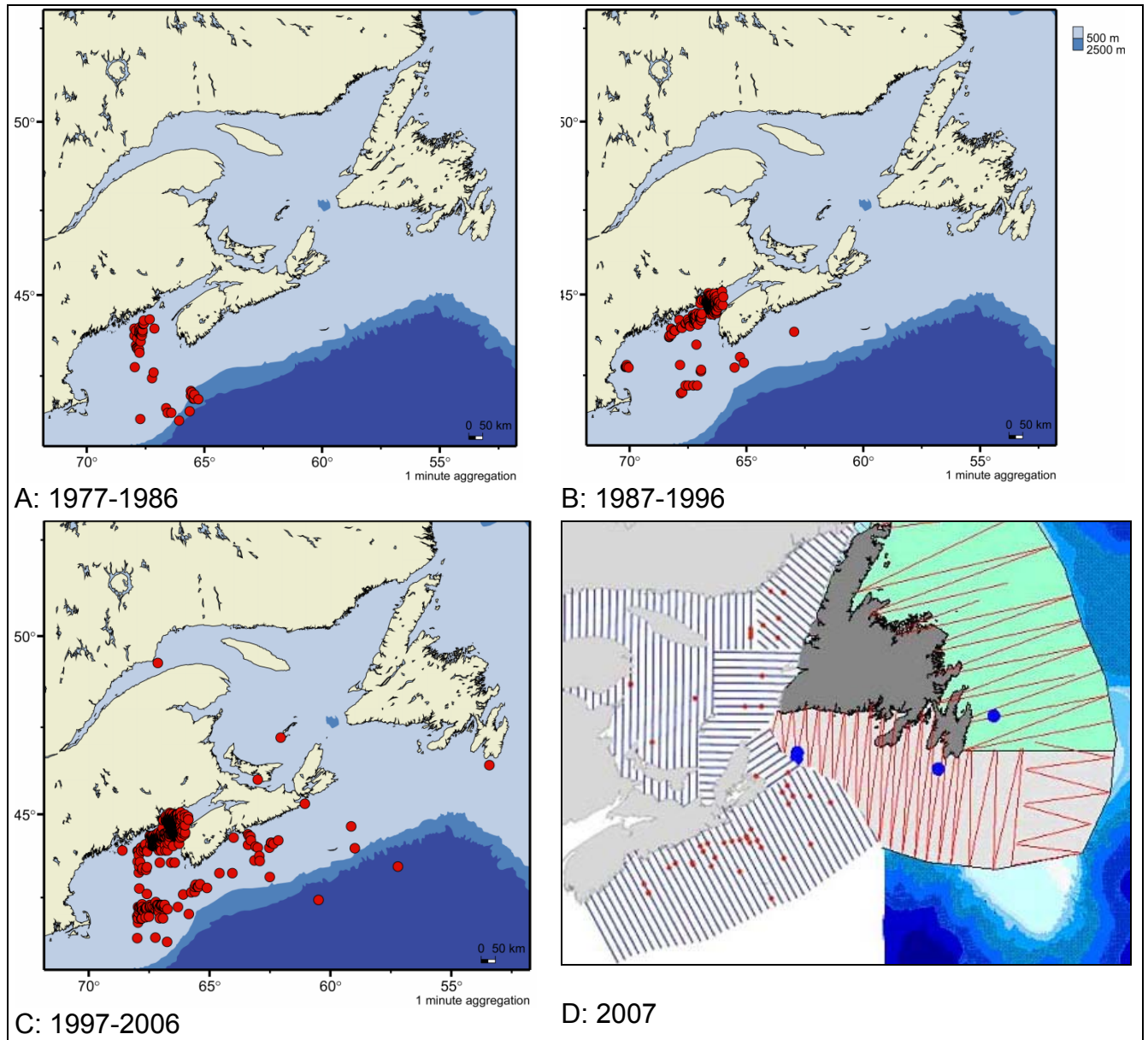


Figure 6. Confirmed Basking Shark distribution as recorded in: A-C) aerial and shipboard surveys of Right Whales combined with reports phoned in to DFO Shark Laboratory between 1997 and 2006; D) aerial surveys of marine mammals on the Scotian Shelf and in the Gulf of St. Lawrence (red symbols) and in the waters off Newfoundland and Labrador (blue circles) in 2007. Source: Campana *et al.* 2008.

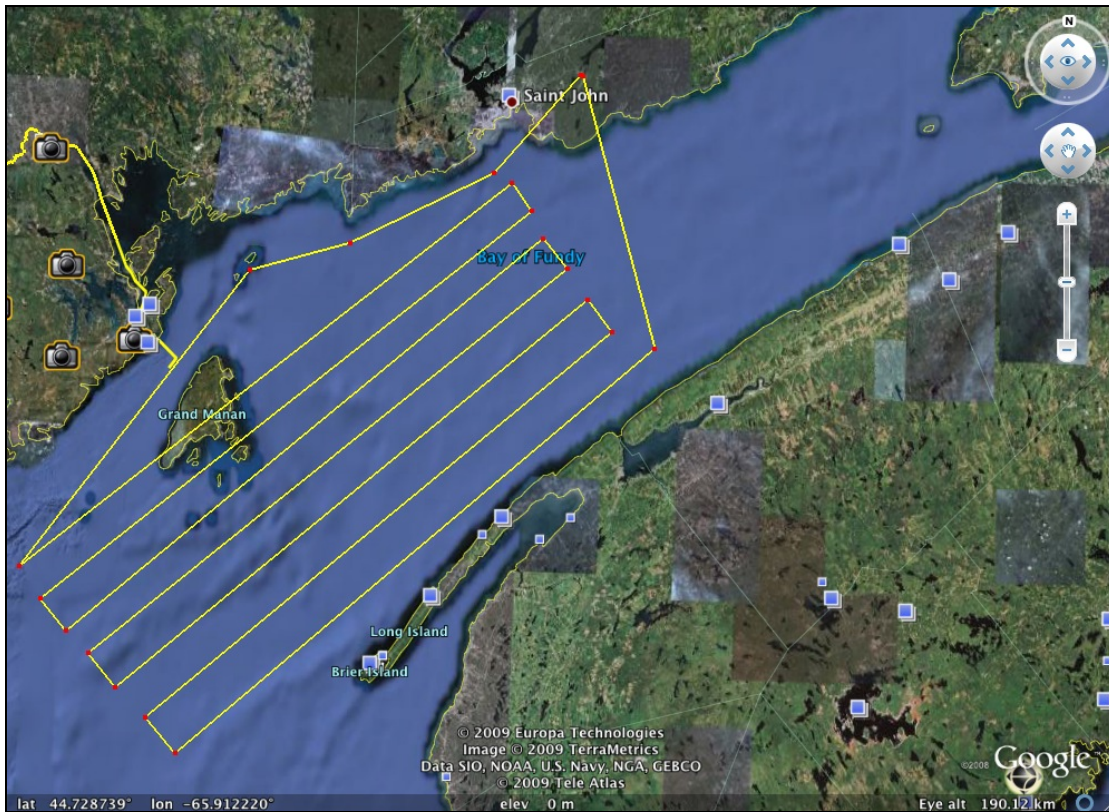


Figure 7. Track lines for aerial survey flown September 11, 2009, in the Bay of Fundy (Heather Koopman, pers. comm.).

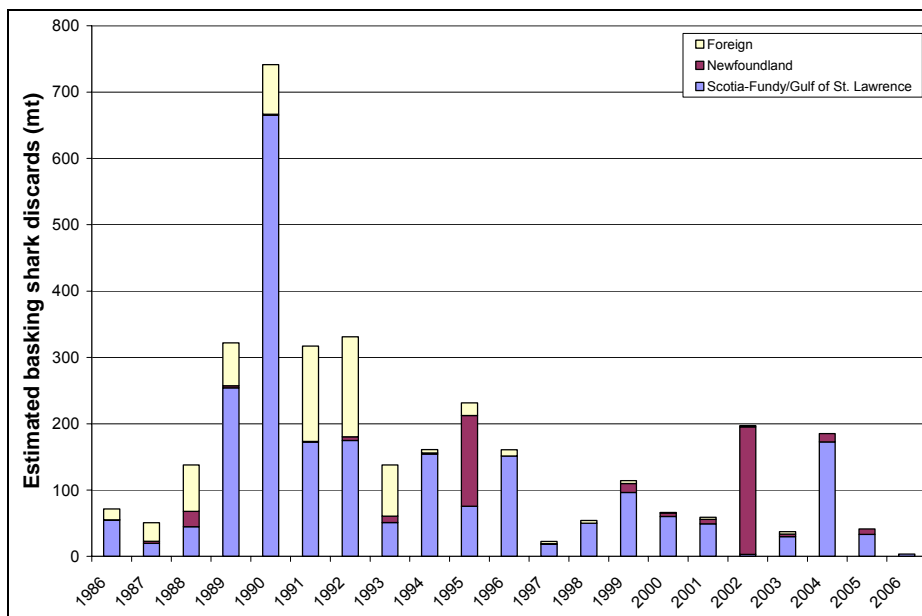


Figure 8. Estimated (domestic) and known (foreign) Basking Shark discards from domestic and foreign fisheries from all regions in Atlantic Canada. Source: Campana *et al.* 2008.

HABITAT

Habitat requirements

Basking Sharks are rarely encountered at the surface outside the summer months, and their distribution outside this period has been a matter of some speculation; it was hypothesized that individuals hibernated in deep shelf or slope waters during the winter when surface productivity was low (Sims 2008).

The habitat requirements for Basking Sharks in Canadian waters have not been investigated. In other jurisdictions Basking Sharks are often associated with oceanographic events that concentrate zooplankton, including fronts off headlands, around islands and in bays with strong fluctuation of water masses from tidal flow (Sims *et al.* 1997; Sims and Quayle 1998; Wilson 2004; Sims 2008). Although they appear to prefer shallow coastal waters, Basking Sharks have been recorded in the epipelagic zone by aerial surveys, pelagic driftnet fisheries, and have been caught in bottom trawls off the St. Lawrence River, Scotian Shelf and Scotland (Compagno 2001). Data from the Newfoundland Observer Program indicate that Basking Sharks have been taken in trawl nets fishing in depths up to 1370 m with 15% of the records (n=414) from waters deeper than 1000 m; however, individuals may not have been taken on the bottom but may have been taken on trawl retrieval.

Sub-surface diving behaviour was known from only seven animals which dived to depths well over 200 m and on one occasion to a depth of over 750 m (Sims *et al.* 2003; Skomal *et al.* 2004; Skomal 2005). Water column utilization varied considerably among individuals and is likely influenced by patterns of prey distribution varying by depth, location, and season. Skomal (2005) found that two Basking Sharks captured at the water surface, tagged and released in the same northwest Atlantic summer location (see Genetics section) moved to different wintering habitats. One individual wintered off Florida and spent most of its time at the surface whereas the other individual wintered off Jamaica and spent most of its time at depths below 480 m.

Recent tagging studies (Gore *et al.* 2008; Skomal *et al.* 2009) show that Basking Sharks can dive to great depths and can spend considerable time at these depths. The transatlantic migrant studied by Gore *et al.* (2008) dived to a maximum depth of 1260 m (well beyond previously recorded depths) and spent some 3 weeks at depths between 200 and 600 m in the mid-Atlantic. Some individuals observed by Skomal *et al.* (2009) also spent long periods at depths between 200 and 1000 m, with occasional excursions to the surface.

Habitat trends

Habitat availability for this species is not likely to have changed. Evidence from Basking Sharks studied off England suggest that the sharks target areas of high zooplankton concentrations associated with both large and small scale oceanographic conditions that change quickly (lasting hours to days) (Sims and Quayle 1998). Longer-

term trends in climate may influence prey availability but recent theoretical work suggests that Basking Sharks can achieve a net energy gain under moderate ($0.48-0.70 \text{ g/m}^{-3}$) concentrations of prey (Sims 1999). For the purposes of this report, fisheries interactions (i.e., entanglement) and vessel collisions are considered as direct threats (in a later section) rather than as degradation of aquatic habitat.

Habitat protection/ownership

All habitat of Basking Sharks in Canada falls under federal jurisdiction managed primarily by Fisheries and Oceans Canada (DFO). There is presently no intentional protection for Basking Shark habitat. In Pacific Canada, waters adjacent to Pacific Rim National Park (Broken Group and West Coast Trail components) are areas where Basking Sharks were sighted historically. Present restrictions in these waters would not afford much protection against perceived threats (i.e., vessel collisions, entanglement in fishing gear and salmon farming net pens).

BIOLOGY

Biological information for this section is primarily from Compagno (2001), from a United Kingdom proposal to list Basking Shark under Appendix II of CITES (United Kingdom 2002), and from Sims (2008).

Life cycle and reproduction

The life cycle and reproduction of Basking Sharks are poorly understood but likely similar to other lamnoid sharks. Pairing is thought to occur in early summer based on observed courtship behaviour (nose to tail circling) and scarring (Matthews 1950; Sims *et al.* 2000). Gestation period has been estimated at 3.5 years by Parker and Stott (1965) and, more recently, at 2.6 years by Pauly (2002) who assumed a length at birth of 1.5 m and a von Bertalanffy growth coefficient (K) of 0.062/yr. Information about pregnancy is based on a single Basking Shark with a litter of six young estimated to be between 1.5 and 2 m in length (Compagno 2001). Like other lamnoid sharks, the Basking Shark may exhibit embryonic ovophagy which supplies nutrients to the developing embryos (Compagno 2001). Time between successive litters may be two to three years (Compagno 2001). Only one juvenile Basking Shark has ever been observed, off the British Isles (Compagno 2001).

Longevity is presumed to be approximately 50 years and age at maturity is estimated at 12 to 16 years in males and 16 to 20 years in females (United Kingdom 2002). Length at maturity is estimated at 4.6 to 6.1 m for males based on clasper development (Bigelow and Schroeder 1948); females are presumed to mature at a larger size than males as in many other shark species. Pauly (2002) calculated the natural mortality (M) to be 0.068, while a slightly higher value of 0.102 was estimated by Mollet (2001). Based on an age of maturity of 18 years for females (midrange of 16-20 years), the generation time can be estimated as $18 + 1/0.068 = 33$ years. In contrast, the United Kingdom CITES proposal (2002) reports the generation time as 22 years. Estimates of annual productivity (r_{msy}) range from 0.013 to 0.023 based on the methodology of Smith *et al.* (1998) using age at maturity, maximum age and average fecundity (United Kingdom 2002). The median estimate of intrinsic rate of population increase (r_{max}) from a population model for the Atlantic Canada DU was 0.032, lower than the corresponding point estimate from life table analysis (Campana *et al.* 2008). This suggests that the potential for recovery (rebound rate) is lower for Basking Shark than for any of the 26 species of Pacific shark examined by the Smith *et al.* (1998).

Herbivory/predation

At birth, Basking Sharks are between 1.5-1.7 m in length, large enough to escape predation by most marine species. Large predators, such as the White Shark and Killer Whale might kill Basking Sharks but no such kills have ever been documented.

Basking Sharks feed on zooplankton, during the summer in concentrations associated with oceanographic fronts. Daily food consumption has been estimated to be 31 kg (Sims 2008).

Physiology

Basking Sharks have been recorded in surface waters ranging from 8 to 24°C, with most observations from 8 to 14°C (Compagno 2001). Four sharks tagged with temperature data loggers in the northeast Atlantic were typically found in waters between 9 and 16°C (Sims *et al.* 2003). Of 3,473 Basking Shark records with associated sea-surface temperatures (SST) in the NARWC (North Atlantic Right Whale Consortium) database, 17 (0.05%) occurred at SST < 6 °C, and 69 (2.0%) at SST < 7 °C (Campana *et al.* 2008). For 78 Basking Sharks entangled in fishing gear off Newfoundland in 1982-1983, Barrington (2000) noted that virtually all were caught at water temperatures of 7-15 °C, with a modal temperature of 12 °C. No sharks were caught at temperatures of less than 7 °C.

The number of individuals observed in a given month is highly correlated with sea surface temperature and with sea surface temperature the previous month off southwestern Britain (Sims 2008), indicating that local abundance is determined by environmental conditions as well as by population abundance.

Basking Sharks periodically shed their gill rakers and are presently thought to cease feeding while they regenerate new ones (4-5 months) (Compagno 2001). Their massive livers may act as a metabolic store that maintains energetic requirements while not feeding (Compagno 2001). Recent tagging has largely disproved the long-standing theory that Basking Sharks "hibernate" in deep water over the winter (Sims *et al.* 2003).

Dispersal/migration

Basking Sharks are observed in surface waters during the summer months, at which time they may form large concentrations. Tagging work since 2000 has shown that extensive movements occur in deep waters on continental shelves and in oceanic areas during winter months, which may explain the lack of observations of Basking Sharks at the surface during these months. Observations of long-distance movements through deep oceanic waters (Gore *et al.* 2008; Skomal *et al.* 2009) suggest that individuals may disperse over very wide areas and there may be a single worldwide population.

In the northeast Pacific, Basking Sharks were visibly most abundant in spring and summer off British Columbia and Washington, and off California in autumn and winter. It has been inferred from these observations that there is a single northeast Pacific population that migrates seasonally (Compagno 2001).

Similarly, off the U.S. Atlantic seaboard, seasonal appearances of Basking Sharks moving from south to north between spring and summer suggest an annual latitudinal migration. Recent tracking studies of three Basking Sharks in the northwest Atlantic provide evidence for strong latitudinal movements southward associated with a change in seasons from late summer to winter (Skomal *et al.* 2004; Skomal 2005). However, three satellite-tagged sharks in the northeast Atlantic (U.K.) tracked for 162, 197, and 198 days did not exhibit any strong latitudinal migration between seasons but rather horizontal movements associated with the continental shelf (Sims *et al.* 2003).

Although there is some evidence that Basking Shark populations may segregate spatially and seasonally by sex and/or maturity, overall the evidence does not support such differential distribution (Sims 2008). Watkins (1958) reported that most Basking Sharks caught in Scottish (95%) and Japanese (65-70%) surface fisheries were female. Compagno (2001) reported that in fisheries off the United Kingdom, Basking Sharks were frequently observed in summer, at which time most individuals observed were females (97.5%), but were uncommon in winter at which time most individuals observed were males. Lien and Fawcett (1986) reported that more males than females were caught incidentally in the inshore waters of Newfoundland.

Globally, there is an absence of pregnant specimens reported which might indicate a spatial or bathymetric segregation of breeding and non-breeding members of the population. Alternatively, the absence of records of pregnant females may simply reflect the low reproductive capacity of the species. A single pregnant female has been recorded in directed fisheries in Europe over the past 200 years (Sims 2008).

In Clayoquot Sound, Darling and Keogh (1994) identified two males by the presence of large white claspers hanging from the pelvic region. Basking Sharks are rarely encountered until they are 3 m in length. There is only one confirmed account of a juvenile Basking Shark (1.7 m) and it was observed off the British Isles (Compagno 2001).

Interspecific interactions

The presence of Basking Sharks on the ocean surface in areas of high zooplankton concentrations, combined with the anatomical adaptation of specialized gill rakers suggests that they are primarily planktivores. Stomach content analyses confirm that zooplankton is the preferred prey, but these analyses are based primarily on Basking Sharks that were active at the surface when they were captured in commercial fisheries. Deepwater pelagic shrimps have been found in the stomach of one Basking Shark from Japan suggesting that mesopelagic food sources may be important too. Compagno (2001) mentions an anecdotal report of Basking Sharks preying upon small schooling fishes such as herring. Similarly, a gillnet fisherman from British Columbia reported catching a 7.8 m Basking Shark which when hoisted by the tail with a crane, was found to be full of 20 cm herring (Gisborne pers. comm. 2004). Thus, a wider range of prey sources, aside from zooplankton, may be utilized.

Basking Sharks have been found to actively seek out areas of high zooplankton concentrations (Sims *et al.* 1997; Sims and Quayle 1998). Sims (1999) calculated that a minimum prey density of between 0.55 and 0.74 g·m⁻³ would be required for net energy gain and corroborated his estimate with field observations. This implies that Basking Sharks can survive and grow in conditions where prey concentrations are lower than previously thought necessary (Parker and Boeseman 1954).

Behaviour

Basking Sharks are known for their tendency to appear seasonally in large aggregations in particular localities where they are observed intermittently over several months before disappearing again (Darling and Keogh 1994; Compagno 2001). In British Columbia, anecdotal and newspaper accounts also indicate that several bays and small inlets were noteworthy for the regular occurrence of high densities of Basking Sharks. These aggregations may reflect some unknown breeding or foraging behaviour (Harvey-Clark *et al.* 1999; Sims *et al.* 2000)

An aggregation of Basking Sharks in Pachena Bay (west coast of Vancouver Island) was described firsthand by a journalist on board a fisheries patrol vessel as “*literally crawling with sharks. There were dorsal fins [Basking Shark] everywhere we looked*” (Vancouver Sun, May 16, 1956). Densities of Basking Sharks in the Alberni Canal (1921) (Barkley Sound, west coast of Vancouver Island) were described as being in the thousands by the owner of a whaling company (Port Alberni News, August 31, 1921). Similarly Gisborne (2004 pers. comm.) describes how “*one day, somewhere between 1960 and 1962, I was boating up Effingham Inlet (Barkley Sound, west coast of Vancouver Island) in my 16’ boat; when I got near the head of the inlet, all I could see were dorsal fins [Basking Shark].*” Anecdotal reports of aggregations in Clayoquot Sound are also reported in Darling and Keogh (1994).

There are no observations of specific areas of such dense aggregation in Atlantic Canadian waters, but the entrance to the Bay of Fundy is an area where Basking Sharks are consistently observed at relatively high concentrations. Although this may be because survey effort (NARWC Right Whale surveys) is typically higher in the Bay of Fundy than elsewhere, this does appear to be a consistent area of aggregation and concentrations here are higher than in other areas of eastern North America (Campana *et al.* 2008, Table 1a).

Table 1. Removals and population trends for Basking Shark in world populations for which information is available. Source: United Kingdom 2002. Note: information on “Canadian Pacific” has subsequently been improved by COSEWIC (2007) resulting in an “endangered” designation for the Canadian Pacific population of this species.

Trends in fisheries yields or sightings for the basking shark

Geographical area and description of records.	Time scale	Average catches or sightings per year	Overall (decline) or increase in catches	Average (decline) or increase per decade
Achill Island, Ireland. A targeted coastal basking shark fishery	1947-1975	360/year in 1947-1950, 1,475/year in 1951-1955, 489/year in 1956-1960, 107/year in 1961-1965, 64/year in 1966-1970, 50/year in 1971-1975. Rarely seen in 1990s	(>95% decline in 25 years)	1940s: increase as fishery develops (1950s: 65% decline) (1960s: 30% decline) (1970s: 20% decline and closure)
West coast of Scotland	1946-1953	121/year throughout fishery. 142/year in 1946-1949, 100/year in 1950-1953.	(~30% in 7 years, but trend unclear)	(~30%, but trend unclear)
Firth of Clyde, Scotland	1982-1994	58.6/yr in first 5 years, 4.8/yr in last 5 years.	(>90% in 12 years)	(~90%)
Norwegian catches	1946-1996	837/year in 1946-1950, 554/year in 1951-1955, 1,541/year in 1956-1960, 1,792/year in 1961-1965, 3,213/year in 1966-1970, 2,236/year in 1971-1975, 1,706/year in 1976-1980, 797/year in 1981-1985, 343/year in 1986-1990, 491/year in 1991-1995, 132/year in 1996 – 2000	(90% decline from peak landings in late 1960s to levels in the early 1990s)	~200% increase, 1950s ~100% increase, 1960s (1970s: 47% decrease) (1980s: 80% decrease) (1990s: 60% overall)
Northeast Atlantic (all catches combined)	1946-1996	1,254/year in 1946-1950, 2,094/year in 1951-1955, 2,030/year in 1956-1960, 1,899/year in 1961-1965, 3,277/year in 1966-1970, 2,385/year in 1971-1975, 1,706/year in 1976-1980, 848/year in 1981-1985, 355/year in 1986-1990, 494/year in 1991-1995, 132/year in 1996 – 2000	(>90% decline from the main period of peak landings in the late 1960s to landings in the 1990s). This followed 20 years of fluctuating but rising catches.	~40% increase, 1950s ~20% increase, 1960s (1970s: 40% decrease) (1980s: 65% decrease) (1990s: 80% overall)
Canadian Pacific	1956-1990s	50-60/year killed in 1950s <25/year sighted in 1990s	(50% decline)	Data unclear, but a few years of catches resulted in an approximately 50% decline in sightings over 40 years.
California	1946-1950s	300/yr in 1946, 200/yr in late 1940s. Fishery closed, early 1950s	(30% decline in first few years, then fishery closed)	Data unclear, but a few years of high catches was followed by closure of the fishery.

Japan	1967-1990s	127/yr average, 1967-1974 150 sharks in 1975 20 sharks in 1976 9 sharks in 1977 6 sharks in 1978 Fishery closed, early 1980s 0-2/year sighted in 1990s	(>95% decline in 10 years)	Data summarised for first 8 years of the fishery, so early trends unclear, but decline rapid in the 2nd half of the fishery and has persisted to present.
China	1960-1990	No quantitative data. Reported to be common in the 1960s, occasionally caught in the 1970s, and rare in 1980s and 1990s.	(No quantitative data, but decline to very low levels reported.)	(No quantitative data, but significant decline indicated in the 1960s and 1970s.)
Isle of Man sightings	1985-1998	Data available suggest a decrease in sightings/effort.	(Average sightings declined by ~90%)	(Average sightings declined by ~90%)

Adaptability

All known or inferred life history parameters imply that Basking Shark populations cannot recover quickly following a reduction in abundance. They may respond to changes in the environment by shifting their distribution to more favourable areas. Aquaculture or artificial captive breeding are not feasible options to promote recovery.

POPULATION SIZES AND TRENDS

Information available

Northwest Atlantic

Little published information is available on Basking Shark abundance or abundance trends for the northwest Atlantic. The most recent information, reviewed at a meeting organized by the Department of Fisheries and Oceans in January 2008, is summarized in a DFO Science Advisory Report (DFO 2008) and a Research Document providing detail on the analyses (Campana *et al.* 2008).

The following information sources are available to assess Basking Shark status in Atlantic Canada:

- Aerial surveys for marine mammals were conducted off Newfoundland and Labrador, in the Gulf of St. Lawrence, and on the Scotian Shelf in 2007 as part of the Trans North Atlantic Sightings Surveys (TNASS) program, in which Basking Shark sightings were recorded (Fig. 6)
- Combined aerial and shipboard surveys for Right Whales (with most effort on shipboard) have been conducted by the Right Whale Consortium in the entrance to the Bay of Fundy from 1979 to 2005, in which Basking Shark sightings are recorded
- Sightings survey information combining aerial and shipboard observations is available from the Right Whale Consortium for areas off the Atlantic coast of the USA, which can be used to track abundance trends in parts of the population outside Canadian waters
- Observers have recorded incidental catches of Basking Sharks on foreign and domestic trawl, longline and gillnet fisheries in Canadian waters; these observations, combined with fishery catch data, can be used to generate estimates of total Basking Shark bycatch in these fisheries (with due regard to potential for Greenland sharks being misidentified as Basking Sharks in some areas)
- A recent (September 2009) aerial survey estimate for the Bay of Fundy is available (Heather Koopman, pers. comm.)

DFO research vessel surveys were examined for Basking Shark catches; three individuals have been recorded in surveys off Newfoundland and Labrador in 1978 - 1981 (Campana *et al.* 2008), two were taken in recent surveys in the Scotia-Fundy region, one each in July 2003 and July 2005 (S. Campana pers. comm.), and two were taken in September surveys in the southern Gulf of St. Lawrence, one in the late 1990s and one in 2005 (Doug Swain/Tom Hurlbut, pers. comm.).

No published information is available on abundance, trends or bycatch from parts of the population elsewhere in the Northwest Atlantic, other than the information from sightings surveys along the US Atlantic coast and a single abundance estimate from the 1980s (see below).

Northeast Atlantic

Because individuals observed in Canadian waters are considered part of a north Atlantic population including individuals in European waters, information on abundance and trends from the northeast Atlantic are relevant to assessing status in Canada. Substantial declines in a number of indices such as fishery catch have been observed in many areas in the northeast Atlantic (Table 1); all indices available have shown decline. In many cases the indices are not well quantified in terms of population abundance, however. The time series of observations off Achill Island, Ireland, showing substantial decline (Table 1) may have been influenced by long-term changes in zooplankton abundance, not just by depletion of a local population (Sims 2008).

Population size estimates

Worldwide

Hoelzel *et al.* (2006) estimate effective population size to be 8,200 globally, based on genetic evidence. They noted that N_e in marine fishes is much lower than census population size, citing a meta-analysis suggesting that N_e may generally be 10% of census population, although there is substantial variability between species and studies.

Northwest Atlantic

Basking Shark abundance in U.S. waters off the New England Coast and in the Gulf of Maine was estimated 6,700-14,300 in the early 1980s (Owen 1984). It is not certain how this estimate relates to abundance of the Canadian population.

Abundance estimates for individuals in Canadian waters have been developed based on aerial surveys of Newfoundland-Labrador, Gulf of St. Lawrence and Scotian Shelf waters (DFO 2008, Campana *et al.* 2008). Counts of Basking Sharks from the surveys were converted into population estimates by correcting for effective strip width and for proportion of time spent at the surface (36% based on 4 observations off the UK by Sims *et al.* 2003).

Abundance estimates from 2007 aerial surveys			
Area	Sharks observed	Estimated population at surface and 95% confidence interval	Estimated population corrected for time at surface
Newfoundland-Labarador	5	201 (42-970)	558
Gulf of St. Lawrence	17	included below	included below
Scotian Shelf	36	1932 (1309-2852)	5367

A separate estimate of abundance for the Bay of Fundy area was developed from combined aerial and shipboard surveys directed at Right Whales (DFO 2008, Campana *et al.* 2008). A mean ratio of Basking Sharks to Right Whales was estimated over the 24 years of the survey (0.17), which applied to the known average number of unique Right Whales over this period (123) gives an estimate of 21 Basking Sharks seen per year on average. This estimate was corrected for relative visibility of Basking Sharks and Right Whales (factor of 100) and for the relative likelihood of an observer sighting Basking Sharks and Right Whales (factor of 2), providing an estimate of average abundance in Basking Sharks in this area of 4,200.

Total abundance was estimated for Canadian waters as $558+5367+4200 = 10,125$ individuals (DFO 2008, Campana *et al.* 2008). This estimate is subject to many uncertainties, particularly in the correction factors applied and since the surveys were not synoptic. In addition it is not certain to what the extent the Bay of Fundy and Scotian Shelf estimates are additive, since Basking Sharks move between these areas depending on oceanographic conditions.

A further source of uncertainty is the proportion of the population found in Canadian waters. Assuming that Canadian individuals are part of a population also inhabiting US waters to the south, the estimates here might underestimate the total northwest Atlantic population.

A minimum estimate of individuals in Canada based on the information above can be obtained by taking the lower 95% confidence limit as a minimum value: 42 for Newfoundland-Labrador, 1309 for Gulf of St. Lawrence-Scotian Shelf. For the Bay of Fundy, using a correction factor of 10 instead of 100 for relative visibility of Basking Sharks and Right Whales (this factor is highly influential in developing the estimate) would produce a minimum estimate of 420 (the only basis for use of 10 is to attempt to produce a minimum estimate). A minimum estimate would thus be $42+1309+420 = 1771$ individuals, uncorrected for time at the surface. Correcting this for time at surface would give an estimate of 4918 individuals. These estimates are subject to the same uncertainties and caveats as above.

The number of Basking Sharks in the Bay of Fundy area was estimated on an aerial survey flown on September 11, 2009 (Heather Koopman, pers. comm.). The survey covered 991 km of tracklines (Fig. 7) and used methods and correction factors similar to those on the aerial surveys described above. Based on sightings of 12 Basking Sharks, the abundance estimate was 732 individuals (CV 243-2208). Results of this survey have not yet been published or peer-reviewed but are part of the best available information on this species at this time. This estimate provides additional information on a key unknown with respect to Basking Shark abundance in Canada (abundance in the area of aggregation in the Bay of Fundy), since the estimate above (DFO 2008) is heavily influenced by the correction factor for relative visibility of Right Whales and Basking Sharks.

Northeast Atlantic

No population abundance estimates are available for the northeast Atlantic.

Bycatch mortality

Bycatch of Basking Sharks was estimated for three Atlantic fisheries: foreign fleets, Newfoundland/Labrador, and Scotian Shelf/Gulf of St. Lawrence (DFO 2008, Campana *et al.* 2008). Observer records of Basking Sharks in these fisheries were compiled and where observer coverage was not 100% (as in domestic fisheries), ratios of bycatch to total catch and records of total catches were used to estimate Basking Shark bycatch.

For Newfoundland/Labrador, several corrections were applied to observer records:

- All records north of 51° N were removed as these were considered more likely to be misidentified Greenland sharks
- Coding and data entry errors were corrected
- Where possible observers were interviewed in cases of doubtful records

Most bycatch was taken in trawl fisheries for Silver Hake and Redfish, with bycatch also observed in other groundfish trawl fisheries and to a lesser extent in longline and gillnet fisheries (Campana *et al.* 2008). Bycatch of Basking Shark in the observed fisheries, both foreign and domestic, peaked in the 1980s and declined into the early 2000s (Fig. 8), consistent with a reduction in foreign and Canadian trawl fisheries during this period. Maximum estimated bycatch was 741 t in 1990; average annual bycatch in 1986-2006 was 164 t and the total estimated bycatch during this period was 3444 t. Average annual bycatch in the last decade (1997-2006) has been 78 t/yr.

Median weight per individual in bycatch was estimated at 1 t (Campana *et al.* 2008) so estimated bycatch was 164 individuals per year and 3444 individuals over the period 1986-2006.

Several uncertainties affect estimates of bycatch and of the resulting mortality. Some Basking Sharks and Greenland Sharks may not have been identified accurately by observers. A correction was applied by excluding all records of Basking Sharks north of 51° latitude, which is probably generally accurate, but Basking Sharks are known to occur north of this latitude. Some Basking Shark records at the Scotian shelf edge were probably Greenland Sharks but no correction was made. Observer coverage is relatively low (5%) in most domestic fisheries so estimating bycatch from observations is subject to error.

There has been no routine recording of Basking Shark bycatch in inshore fisheries. About 370 Basking Sharks were captured by inshore fishing gear in coastal waters of Newfoundland from 1980 to 1983 (Lien and Fawcett 1986); inshore fishing effort in Newfoundland has declined substantially since then so current bycatch levels are probably lower. No information is available for other areas or periods, although there are occasional reports of bycatch; unobserved fisheries which could take Basking Shark are widely distributed in Atlantic Canada.

Proportion of incidentally caught Basking Sharks which survive encounters is unknown. Individuals are often left in the water and released rather than being brought on board, which would probably reduce mortality rate.

Bycatch mortality outside Canada is also unknown and could add to total bycatch mortality on the population.

Population trends

Catch per unit effort values have been calculated for bycatch in commercial fisheries but the input data are sparse and the resulting indices are highly variable, probably because of changes in Basking Shark distribution with changing oceanographic conditions (Campana 2008; DFO 2008).

Sightings survey information from the Right Whale consortium has been compiled to show trends in sightings from 1979 to 2003 in the Bay of Fundy entrance area (DFO 2008). Two analyses of standardized sightings per unit effort (SPUE) show low levels of SPUE in the 1980s, higher levels in the 1990s, and a decline into the 2000s (Figure 9). The changes are too rapid to realistically reflect population abundance of this species, and probably reflect changes in distribution with changing oceanographic conditions.

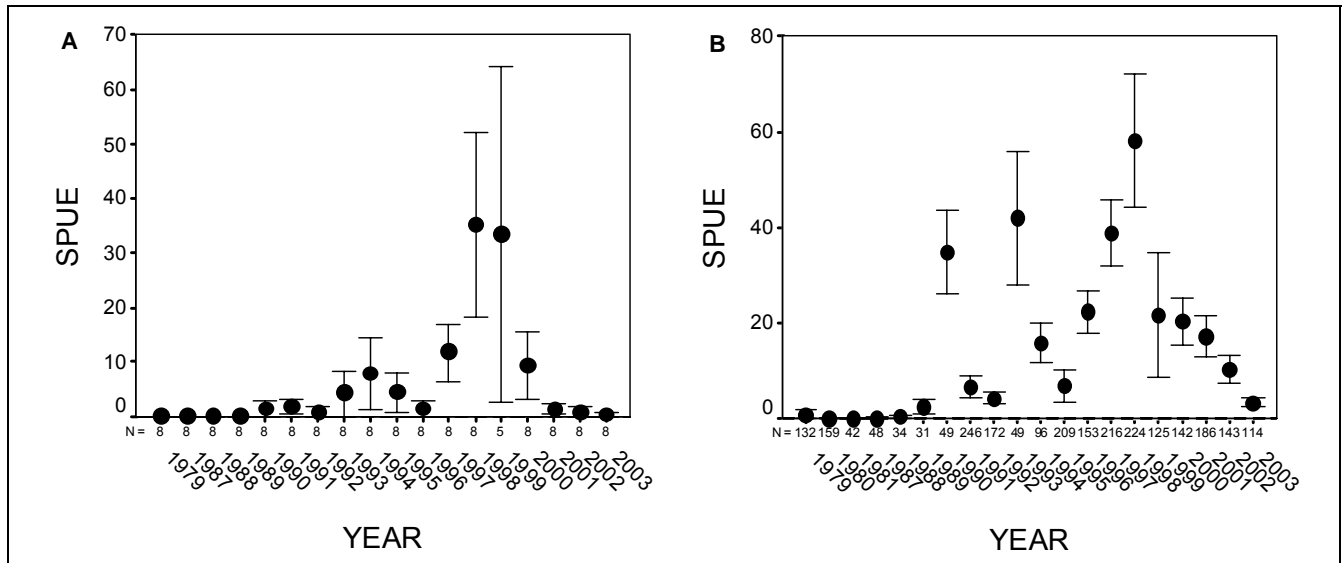


Figure 9. Trend in relative abundance of Basking Sharks in the Bay of Fundy based on sightings per unit effort (SPUE) during surveys for Right Whales. Note: there are missing years on x axis. (A) Relative abundance based on a subset of strata common to all years and (B) relative abundance based on all strata. SPUE=sharks per 1,000 km of qualifying effort on a 5-minute lat/long grid, by year (n = 2570). Sightings identified only as "possible" Basking Sharks were excluded. Both aerial and shipboard surveys were included in quantifying effort. Acceptable effort criteria were established as sea state of Beaufort 3 or lower, visibility at least 2 nautical miles, altitude below 1200 feet, and at least one observer on watch. Only shark sightings made during qualifying effort were included. Source: Campana *et al.* 2008.

Similar sightings data have been analyzed as SPUE for areas off the Atlantic coast of the USA, which are believed to be inhabited by the same population of Basking Sharks as that seen in Canada during the summer months (Campana *et al.* 2008). SPUE values were compiled by quarter and by region for 6 regions from the northern Gulf of Maine to the southeastern USA (Campana *et al.* 2008). Regressions on these time series show no trend in most areas, but for the northern Gulf of Maine and for the southeast USA regressions in some seasons have positive slope with r^2 values around 0.3 (Table 2). It seems doubtful that these indices indicate a real increase in abundance, but there is no indication of decline in the northwest Atlantic from the SPUE information. While trends in abundance over time may be influenced by oceanographic conditions as well as by abundance, examining trends over a wide area such as the entire Atlantic coast of North America may help to reduce the effect of local oceanographic conditions on the trends.

Table 2. Results of 28 linear regressions of Basking Shark sightings-per-unit-effort (SPUE) versus year for regions of the Atlantic coast of Canada and the USA. N – the number of years with surveys in that region/season. The four rows in bold italics are those where there was a statistically significant increasing trend. “SE” is standard error on the slope. “na” represents cells in which there were insufficient observations to estimate slope. Source: Campana *et al.* 2008, Table 1b. Observations on which these analyses are based are compiled in Campana *et al.* 2008, Table 1a.

REGION	SEASON	R ²	Slope	SE	P	N
Bay of Fundy	Winter	na	na	na	na	4
Bay of Fundy	Spring	0.027	0.045	0.082	0.592	13
Bay of Fundy	Summer	0.005	0.609	1.989	0.763	22
Bay of Fundy	Fall	0.001	0.107	0.748	0.888	19
Nova Scotian Shelf	Winter	na	na	na	na	8
Nova Scotian Shelf	Spring	0.001	-0.014	0.042	0.922	14
<i>Nova Scotian Shelf</i>	<i>Summer</i>	<i>0.224</i>	<i>0.204</i>	<i>0.083</i>	<i>0.023</i>	<i>23</i>
Nova Scotian Shelf	Fall	0.094	0.035	0.034	0.333	12
Northern Gulf of Maine	Winter	na	na	na	na	9
Northern Gulf of Maine	Spring	0.251	-0.540	0.295	0.097	12
Northern Gulf of Maine	Summer	0.016	0.432	0.757	0.575	22
Northern Gulf of Maine	Fall	0.265	0.107	0.056	0.087	12
Southern Gulf of Maine	Winter	0.130	0.001	0.001	0.109	21
Southern Gulf of Maine	Spring	0.106	0.354	0.224	0.129	23
<i>Southern Gulf of Maine</i>	<i>Summer</i>	<i>0.347</i>	<i>0.860</i>	<i>0.286</i>	<i>0.008</i>	<i>19</i>
Southern Gulf of Maine	Fall	0.030	0.039	0.065	0.556	14
Mid-Atlantic Bight	Winter	na	na	na	na	12
Mid-Atlantic Bight	Spring	0.002	-0.049	0.270	0.860	16
Mid-Atlantic Bight	Summer	0.004	-0.020	0.092	0.831	14
Mid-Atlantic Bight	Fall	0.095	0.425	0.437	0.357	11
North Carolina/Virginia	Winter	0.098	0.053	0.066	0.452	8
North Carolina/Virginia	Spring	na	na	na	na	3
North Carolina/Virginia	Summer	na	na	na	na	6
North Carolina/Virginia	Fall	0.125	-0.009	0.012	0.492	6
<i>Southeastern U.S.</i>	<i>Winter</i>	<i>0.330</i>	<i>0.162</i>	<i>0.053</i>	<i>0.007</i>	<i>21</i>
Southeastern U.S.	Spring	0.115	-0.040	0.049	0.456	7
Southeastern U.S.	Summer	na	na	na	na	1
<i>Southeastern U.S.</i>	<i>Fall</i>	<i>0.278</i>	<i>0.039</i>	<i>0.016</i>	<i>0.024</i>	<i>18</i>

Population modelling

Population simulations have been undertaken to explore plausible population trajectories under various combinations of life history parameters, removals and final population sizes (Campana *et al.* 2008). Given information on removals and a final population estimate in 2007, a Monte Carlo simulation approach based on a range of input parameters was used to estimate population trajectories and intrinsic rate of increase (r_{\max}). Life history parameter values based on “best” values from literature are summarized below (further detail on methods is available in Campana *et al.* 2008). Model runs which showed r_{\max} values greater than 0.057 were deleted from the final results as this appeared from literature review to be the maximum plausible value for Basking Shark.

Inputs for the simulation model		
Parameter	Minimum	Maximum
Estimated population size in 2007:	5,000	20,000
Estimated age at maturity (assumed knife edge):	16 yr	20 yr
Estimated female litter_size (thought to be 3):	2	4
Estimated gestation_period (thought to be 3 yr):	2 yr	4 yr
Lag between parturition and next pregnancy	0 yr	1 yr
Maximum age	40 yr	60 yr
Estimated natural mortality (thought to be 0.068)	0.058	0.078
Ratio of age-0 mortality to mortality of older fish	1.5	2.5

Results for each run show the likely distribution of population size in 2007 and 1986, of r and of the slope of the population trajectory (results from the most likely, “base” run, are shown in Figure 10).

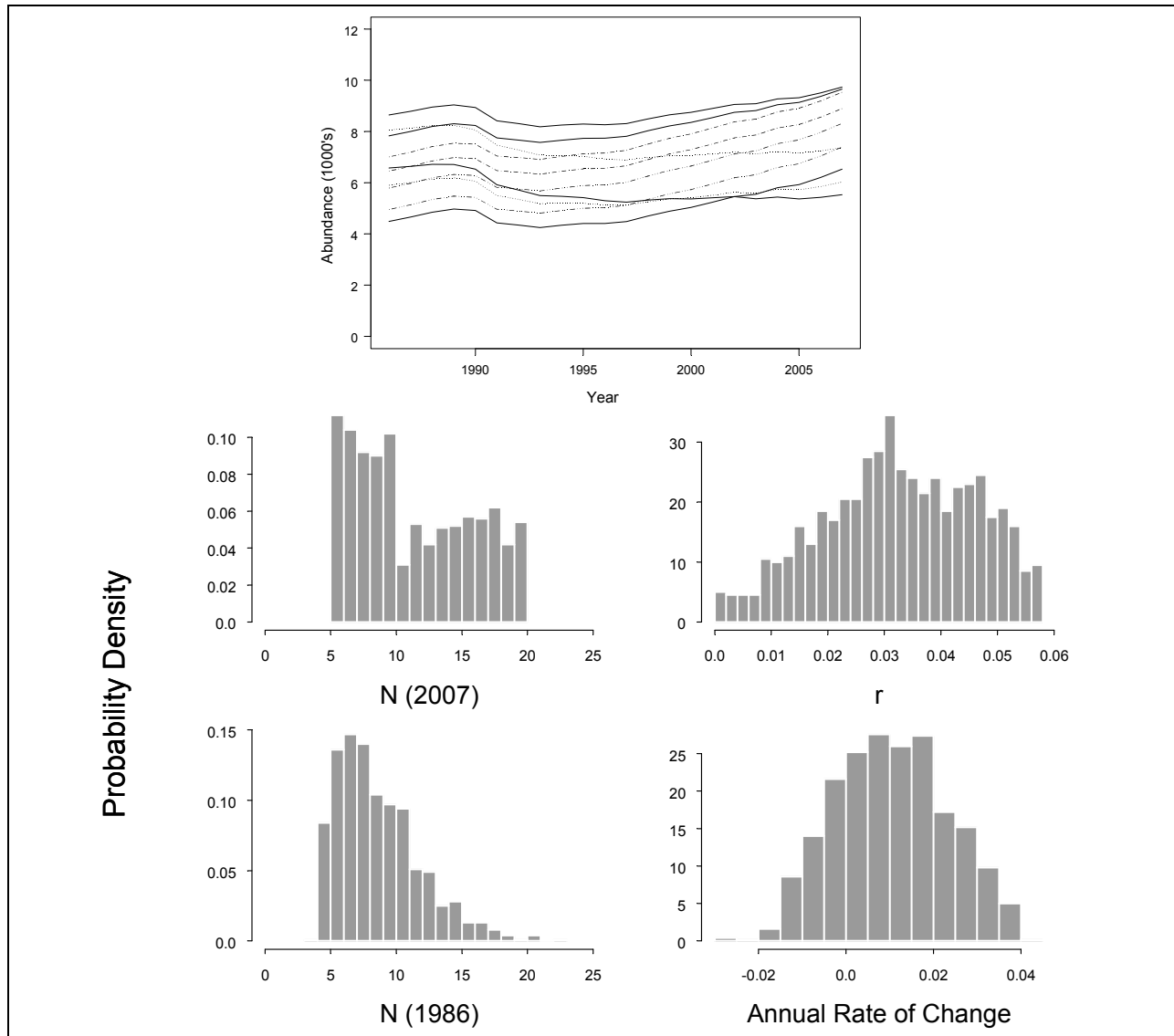


Figure 10. Basking Shark population simulation results from the base model. The top panel shows 10 simulated population trajectories, while the bottom panel shows the histograms of the population size in 2007, the population size in 1986, r and rate of change in population size (positive values indicate an increasing population). Source: DFO 2008.

Of all simulations done using these inputs, 23% showed a decline between 1986 and 2007. Several alternate population runs were carried out to examine the robustness of this conclusion to the model inputs. For example, if the number of discards were doubled, the proportion of populations that were decreasing increased to 64%. Additionally, the model output is sensitive to the range of values assumed for the population size in 2007; when lower values are used, a larger proportion of simulated populations show a decline.

The probability of decline can also be explored by calculating the population size needed to support the observed removals (N_{crit}), based on the fishing mortality which would eventually lead to population extinction (F_{crit}). The life table results indicated a best estimate of the intrinsic rate of population growth (r) in an unfished Basking Shark population to be 0.040. Based on this rate of population growth and assuming that fishing selectivity is knife-edged at Age 2, the fishing mortality rate which would drive the population to extinction (F_{crit}) is estimated to be 0.043. Given an annual mean number of discards of 164, and assuming 100% mortality of discards and no human-induced mortality on Ages 0-1, this would suggest that the average population size which could support the estimated number of discards (N_{crit}) would be about 4,800. Similarly, the median value of N_{crit} from stochastic simulation modeling was 5900. If discard mortality was less than 100%, N_{crit} could be smaller. If there were sources of mortality, such as inshore fishery sectors, not captured in the discard analysis, the required population size would have to be larger. Estimates of population size for 2007 in the range of 4,900 - 10,100 appear plausible (see earlier section), although these have a high level of uncertainty. These overlap the estimates of N_{crit} .

Modelling was undertaken by COSEWIC's Marine Fishes Species Subcommittee, using the same general approach, to explore the influence of unknown mortality due to ship strikes or bycatch in fisheries, and to forward project in a population viability analysis to assess the probability of extinction within 100 years¹. Using inputs in the table above, and additional mortality rates of 0.000, 0.005, 0.010, and 0.020, the simulations showed a 20% to 50% chance that the population is currently decreasing. Although a significant proportion of the simulated populations showed a decline, most of the decline rates were low enough that time to extinction was greater than 100 years. Using the average observed bycatch from the most recent decade (1995-2006) rather than for the full time series available (1986-2006) reduced the probability of extinction, since observed bycatch has declined since the mid-1990s. Using the bycatch observations from 1995-2006, additional mortality rates greater than 1% are needed to bring a majority of simulated populations to extinction within 100 years. All of these analyses are highly dependent on input parameters, and population scenarios where abundance is increasing, stable, decreasing or decreasing to extinction within 100 years are plausible based on available information; this lack of clarity in outputs clearly reflects the incomplete, uncertain and contradictory nature of the available information.

¹ Details of the modelling methods and results are available from the COSEWIC Secretariat.

Northeast Atlantic

Substantial declines in abundance have been observed or inferred from proxies such as catch or catch per year in areas of the northeast Atlantic (Table 1; Fig. 11). The information available on these indices, while compelling, is not well quantified and would not strongly support drawing conclusions based on COSEWIC's quantitative criteria. The index series from Achill Island, Ireland, which shows a particularly clear and drastic decline, may reflect long-term changes in zooplankton abundance as well as changes in population abundance (Sims 2008). Total catch information (Fig. 11), while showing a substantial decline, could be affected by long-term changes in fishing effort as well as by abundance.

Summary of population and trend information

Based on the information and analyses summarized above, there is a high degree of uncertainty in inferring population sizes and trends for Basking Sharks in the Canadian Atlantic. Population simulations show a generally low probability of decline to "at-risk" levels under inputs which appear plausible, but these are all subject to uncertainty, and scenarios of decline to extinction are also consistent with the available information, depending on inputs chosen. The minimum population size required to support recent removals, from population simulations, is near or below the current estimated population size (required population sizes of 4800 or 5900 vs current estimates of 4,900 - 10,100). The lack of decline in sightings surveys over a number of areas off eastern North America suggests that probability of decline in the northwest Atlantic is low. The decline in observed bycatch levels over the past two decades and the general decline in effort in fisheries in which bycatch occurs suggest that the level of threat to the species, at least in those fisheries, has declined.

Many concerns remain about status of this species. Life history is extremely conservative and the population could only support low levels of mortality from human activities. Bycatch of Basking Shark continues, some of it in inshore fisheries which are not monitored. Other potential sources of mortality also exist, such as ship collisions, which were explored in population modelling but which are essentially unquantified. Big declines in indices have been observed in other areas where Basking Shark have been targeted or taken as incidental catch (Table 1), including areas considered part of the larger population of which Canadian individuals are part; while these are poorly quantified and may be influenced by oceanographic trends, they are compelling evidence for large declines in these areas.

Rescue effect

Evidence suggests that Basking Sharks found off the east coast of the United States are likely part of the same population utilizing Canadian waters. Population status in American waters is unknown. The only published estimate is from Owen (1984) who estimated that the population off the New England Coast and Gulf of Maine may have numbered as many as 6,700-14,300. Migration to and from US waters could account for the 1998 peak and subsequent decline in sightings of Basking Shark documented in the Bay of Fundy abundance index. Data from the North Atlantic Right Whale Consortium sightings surveys from areas off the Atlantic coast of the United States suggest that abundance is not declining. Sightings per unit effort are generally much lower in areas off the USA than in the Bay of Fundy and there is high interannual variability.

Although rescue via exchange with the northeast Atlantic has been thought unlikely in the past, recent tagging information (Gore *et al.* 2008) suggests that this could occur. However, the population in the northeast Atlantic is considered endangered due to over-fishing (Fowler 2000; Figure 11). Severe declines in fisheries yields from the 1940s to the early 1980s are presumed to reflect abundance (United Kingdom 2002) and therefore even under the scenario of transoceanic movement there would be limited potential for a rescue effect.

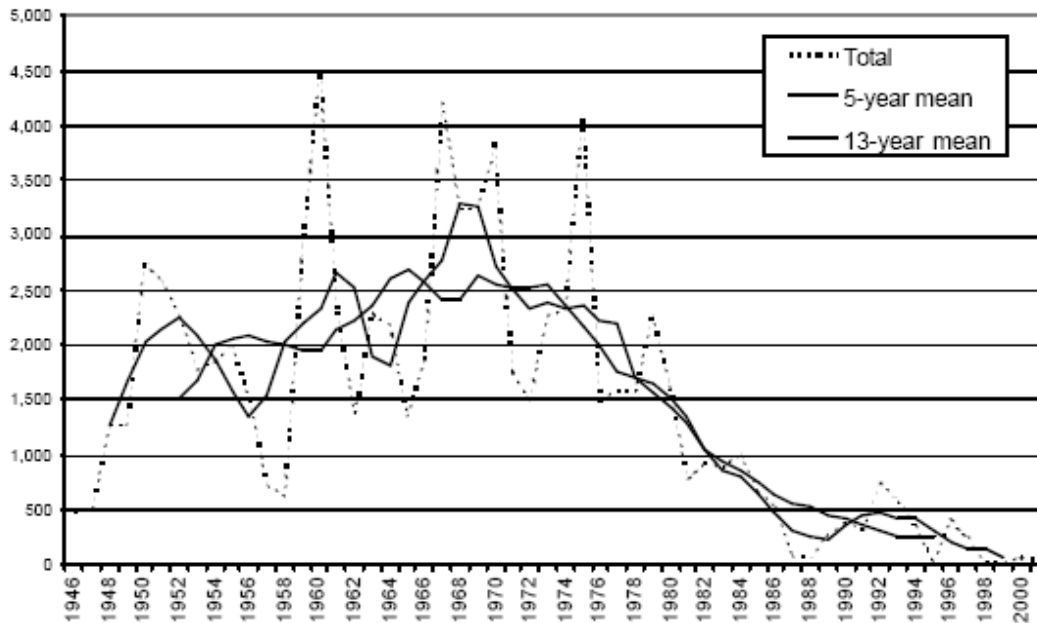


Figure 11. Combined landings data, with running means, of Basking Sharks captured in the northeast Atlantic by all nations from 1946 to 2001. Source: UK CITES proposal 2002.

Dispersal between Atlantic and Pacific appears possible (Sokal *et al.* 2009), although mixing rate may be low.

LIMITING FACTORS AND THREATS

Limiting factors

Basking Sharks are particularly vulnerable to any human-induced mortality because of their late age of maturity, low fecundity, long gestation period, long periods between gestations, low productivity, sex-segregated populations, and use of habitat that supports commercial fisheries.

Threats

Human-induced mortality in Canadian Atlantic waters is primarily from continued interactions with fishing gears. Records indicate that Basking Sharks are readily caught by trawl (bottom, midwater, and shrimp), and easily become entangled in longlines, gillnets, prawn traps, cod traps, and even herring seines. Although the information presented in this report represents the best available information on bycatch levels, it does not cover all fisheries in which bycatch might occur. The information available indicates that known bycatch has declined since the mid-1990s.

A directed fishery for Basking Sharks was conducted in the southern Gulf of St. Lawrence in 1981-1982 by vessels from the Faroe Islands (Doug Swain/Tom Hurlbut pers. comm.). No information is available on magnitude of catches in this fishery.

Collisions with ships are a potential source of mortality, given the habit of this species of slow movement at the surface, but only anecdotal information exists on the actual importance of this potential threat. Observations of a satellite-tagged individual in the Bay of Fundy in September 2009 indicated that this shark spent part of its time in shipping lanes in this area, confirming that ship strikes are a potential threat (Heather Koopman, pers. comm.).

The Basking Shark was the subject of directed fisheries in the northeast Atlantic over a 200-year period; 100,000 individuals were removed between 1946 and 1997 (Sims 2008). Landings peaked in the late 1960s and have since declined to near zero in the early 2000s (Fig. 11).

SPECIAL SIGNIFICANCE OF THE SPECIES

The Basking Shark is monotypic within the family Cetorhinidae and is one of only three genera of filter feeding sharks. The earliest fossil records for Basking Sharks are thought to have originated between 35 and 29 million years ago (Leriche 1905; Martin pers. comm. 2005). Other noteworthy life history characteristics include possibly the longest gestation of any vertebrate (estimated at 2.6 to 3.5 years), very late maturity, slow growth, probable low fecundity, all contributing to an extremely low intrinsic population growth rate. The Basking Shark is the world's second largest fish.

The trade of Basking Shark fins to Asian countries continues to be of international concern. The fins from Basking Sharks have fetched \$30,000 (US)/t in international trade (Fairfax 1998). In 2000, the fins from Basking Sharks caught in Norway were valued at \$2,000 (US) per shark. The recent inclusion of Basking Sharks under Appendix II of CITES is intended to regulate this trade. At present, there is a zero quota from European waters and the World Conservation Monitoring Centre has no recent records (Fowler pers. comm. 2004).

Basking Sharks are a plausible explanation for some reports of sea serpents, sea monsters, and the Cadborosaurus (Caddy). There have been 181 "Caddy" sightings in British Columbia since 1881 (Leblond and Bousfield 1995). Many of the stranded sea monsters between 1930-1960 were Basking Sharks; all known strandings of Basking Sharks (n=3) occurred in late fall, perhaps reflecting some unknown aspect of their life history.

Basking Sharks fit the description of large charismatic mega-fauna and as such have proven to provide socio-economic benefits in places where their populations are accessible to eco-tourists.

ABORIGINAL KNOWLEDGE

No Aboriginal traditional knowledge from Atlantic Canada was obtained.

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

There is no explicit protection of Basking Sharks in Canada. This species receives de facto protection by broad regulations that prohibit finning of any shark species. Given that there is no market for other parts of Basking Sharks in Canada, there is no directed exploitation. The Pacific population of Basking Shark was designated as "endangered" by COSEWIC in 2007 and is currently being considered for listing on Schedule 1 of Canada's *Species at Risk Act*. The Pacific population had been subjected to an eradication program in the 1950s and 1960s to protect salmon fishing nets and individuals are now rarely seen.

Elsewhere in their global range, they fall under a variety of protective measures or status designations. Internationally, the IUCN Red List assessment has categorized Basking Sharks as Vulnerable (A2d) globally and Endangered (A1d, 2d, D) in the northeast Atlantic and north Pacific and even Critically Endangered (A1d, 2d, and possibly C1) in the case of “Barkley Sound” (Canada) (Fowler 2000). In 2002, a CITES Appendix II proposal put forth by the government of the United Kingdom was accepted and came into effect at the end of February 2003; under this listing trade in Basking Shark products requires a permit from the exporting country, facilitating control and reporting of trade.

In US federal Atlantic waters Basking Sharks are protected by a National Marine Fisheries Service regulation for Atlantic shark fisheries which prohibits directed commercial fishing, landing and sale. The United Kingdom is the only country with strict protection for Basking Sharks, which in addition to any form of killing also has laws against disturbance and harassment. New Zealand’s *Fisheries Act* prohibits the targeting of Basking Sharks but allows the bycatch to be utilized. In the Mediterranean Sea Basking Sharks are listed on Annex II of the *Barcelona Convention for the Protection of the Mediterranean Sea Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean*. To date only Malta has legally protected Basking Sharks. The Mediterranean population is also listed on Appendix I of the *Bern Convention for the Conservation of European Wildlife and Habitats*.

Basking Sharks have not been assessed by the Atlantic Conservation Data Centre or the British Columbia Conservation Data Centre.

TECHNICAL SUMMARY

Cetorhinus maximus, Atlantic population

Basking Shark

Pèlerin

Range of Occurrence in Canada : Atlantic waters from Nova Scotia to Labrador

Demographic Information

Generation time • estimates between 22 and 33 years are available	33 years
Population trend and dynamics	
Observed percentage of reduction in total number of mature individuals over the last 10 years or three generations: no observed decline in sightings per unit effort off Atlantic coast of North America since 1980s • population simulations for northwest Atlantic indicate possible decline, depending on inputs • indications of substantial decline in northeast Atlantic but not well quantified	Unknown, no clear indication of decline in NW Atlantic
Projected percentage of reduction in total number of mature individuals over the next 10 years/3 generations.	N/A
Observed percentage reduction in total number of mature individuals over any 10 year/3 generation period, over a time period including both the past and the future.	N/A
Are the causes of the decline clearly reversible?	N/A
Are the causes of the decline clearly understood?	N/A
Are the causes of the decline clearly ceased?	N/A
Observed trend in number of populations	Not applicable (a single population)
Are there extreme fluctuations in number of mature individuals?	No
Are there extreme fluctuations in number of populations?	Not applicable

Number of mature individuals in each population

Population	N Mature Individuals
Total	4,900 – 10,100 total individuals; high uncertainty
cited estimates are of total individuals; mature individuals would be lower	
Grand Total	4,900 - 10,100; high uncertainty

Extent and Area Information

Estimated extent of occurrence (km ²)	1.2 million km ²
Observed trend in extent of occurrence	Probably stable
Are there extreme fluctuations in extent of occurrence?	No
Estimated area of occupancy (km ²)	1.2 million km ² ?
Observed trend in area of occupancy	Probably stable
Are there extreme fluctuations in area of occupancy?	No
Is the total population severely fragmented?	No
Number of current locations	Not applicable
Trend in number of locations	Not applicable
Are there extreme fluctuations in number of locations?	Not applicable
Observed trend in area of habitat	Probably stable

Quantitative Analysis

Exploratory population simulations under some sets of plausible inputs are not consistent with Threatened or Endangered status, but runs under other sets of plausible inputs are consistent with these	Information inadequate to support quantitative analyses of risk of extinction
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Threats (actual or imminent, to populations or habitats)

Incidental catch in fisheries is the principal known threat; known bycatch in Canada has declined but information is not available for some fisheries which could affect this species (Canadian coastal fisheries, US fisheries). Ship collisions are a potential threat.

Rescue Effect (immigration from an outside source)

Status of outside population(s)? Assuming individuals in Canada are part of an Atlantic population, immigration would come from other parts of the world ocean; northeast Pacific is depleted.	
Is immigration known or possible?	Possible (tagging results)
Would immigrants be adapted to survive in Canada?	Unknown but probably; species is circumglobal
Is there sufficient habitat for immigrants in Canada?	Yes
Is rescue from outside populations likely?	Unlikely

Current Status

COSEWIC: Special Concern (November 2009)
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Status and Reasons for Designation

Status: Special concern	Alpha-numeric code: Not applicable
<p>Reasons for Designation: This species, which attains a maximum length of over 15 m (the second largest living fish) is highly vulnerable to human-caused mortality because of its extremely low productivity. Females mature at 16 to 20 years old, gestate for 2.6 to 3.5 years (the longest known gestation period of any vertebrate), and produce litters of about 6 offspring. Based on recent tagging information, individuals in Canada are considered to be part of an Atlantic population shared with the USA, Europe, the Caribbean and northern South America. Population estimates in Canadian waters have large uncertainties and may number between 4918-10125 individuals. Population estimates outside Canadian waters are not available. Information from surveys along the Atlantic coast from Nova Scotia to Florida indicates no decline over the past two decades. However, available information suggests substantial population declines in the northeast Atlantic. The species is caught incidentally in trawl, longline, and gillnet fisheries in Atlantic Canada. Removals in fisheries with observer coverage have decreased since the 1980s consistent with a reduction in fishing effort, but information on bycatch from other fisheries is not available. There is no evidence of recovery following declines associated with fisheries in other parts of the range. Ship collisions are an additional threat.</p>	

Applicability of Criteria

Criterion A (Declining Total Population): Not met – no quantitative indications of decline in available abundance indices.
Criterion B (Small Distribution, and Decline or Fluctuation): Not met – extent of occurrence and index of area of occupancy larger than applicable thresholds.
Criterion C (Small Total Population Size and Decline): Not met – population size of mature individuals estimated to be below threshold values, but there is no indication of a decline in Canadian waters.
Criterion D (Very Small Population or Restricted Distribution): Not met.
Criterion E (Quantitative Analysis): Exploratory population simulations under some sets of plausible inputs are not consistent with Threatened or Endangered status, but runs under other sets of plausible inputs are consistent with these.

ACKNOWLEDGEMENTS

This report was handled for COSEWIC by Howard Powles (Co-chair Marine Fishes) and Chris Wood (SSC Member). Jamie Gibson of DFO's Maritimes Region, a member of COSEWIC's Marine Fishes Specialist Subcommittee, conducted the population viability analyses described in this report.

AUTHORITIES CONSULTED

Federal government (DFO) authorities on this species are co-authors of the Research Document summarizing available population abundance information (Campana *et al.* 2008). Neither the British Columbia Conservation Data Centre nor the Atlantic Canada Conservation Data Centre have assessed Basking Shark. Findings from international conservation organizations are included in the report (i.e., IUCN and CITES).

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BIOGRAPHICAL SUMMARY OF REPORT WRITER

Dr. Scott Wallace is an independent fisheries scientist (PhD UBC Fisheries Centre) and operates a consulting firm, Blue Planet Research and Education, on Vancouver Island, BC. His interests are best management practices and the sustainability of Pacific fisheries.

Appendix 1. Population Viability Analysis for Basking Shark

Summary

Campana *et al.* (2008) presented a model to estimate abundance from the 1986-2007 time period based on life history parameters, the estimates of the number of removals from the population based on fishery observer records, and an estimate of abundance in 2007. Uncertainty was evaluated using Monte Carlo methods.

Here, this model is modified to produce output that can be evaluated under COSEWIC's Criterion E. Modifications include:

- splitting the human induced mortality rates into two components: that which can be quantified from the fishery observer program and an unquantified component to cover ship collision mortality and mortality from bycatch in fisheries without observer programs. Assumed rates were used for this second component to evaluate the magnitude of mortality that would be necessary for the species to exceed the "Threatened" threshold under Criterion E.
- a forward projecting PVA (population viability analysis), including uncertainty in r (intrinsic rate of increase), uncertainty in the population size in 2007 and an assumed rate of random variability in r so that the probability of extinction within 100 years could be evaluated.

A Monte Carlo analysis based on the life history of Basking Sharks and bycatch data was used to evaluate recent trends in abundance using log-linear regression over the 1986-2007 time period. The results of this population model, which are consistent with the results of the life table analysis of Campana *et al.* (2008), suggest a 1-in-2 to 1-in-5 chance that the population is decreasing.

Although a significant portion of the simulated populations show a decline, most of the declines rates are low enough that (for those simulations showing a decline), the time to extinction is not likely less than 50 years and is more likely greater than 100 years. This result is conditional on the model inputs and assumptions.

The reduction in known bycatches for the 1995-2006 period relative to 1986-1994 reduces extinction risk in the simulations, relative to that which would be estimated when the average fishing mortality rate for the full time period (1986-2006) is used.

Again based on model inputs and assumptions, when the average fishing mortality rate based on known bycatches for the 1995-2006 is used, mortality from all other sources would need to be greater than about 1% annually, and the annual variability (standard deviation) in r greater than about 0.10, in order for the population to exceed the threshold for threatened under COSEWIC's Criterion E. It is plausible that these values are exceeded given what is known about ship strike rates for North Atlantic Right Whales and fisheries without observer coverage.

Background

Campana *et al.* (2008) presented a model to evaluate trends in abundance of Basking Shark using an estimate of abundance in 2007. A description of this model and a summary of the results are provided in DFO (2008).

From the perspective of evaluating extinction risk, there are two issues that are not fully addressed by the Campana *et al.* (2008) model. First, these analyses indicated that both the probability that the population is in decline as well as the rates of decline are sensitive to the magnitude of mortality from unquantified sources. Their analysis did not address the question of the level of mortality that would be required for the population to be considered at-risk. Second, some of the potential rates of decline estimated were quite low; potentially too low for the population to be considered at-risk under COSEWIC's Criterion E. Under this Criterion, a population is considered to be "endangered" if a quantitative analysis indicates the probability of extinction in the wild to be at least 20% in 20 years or 5 generations, whichever is longer (up to a maximum of 100 years), and is considered to be "threatened" if a quantitative analysis indicates the probability of extinction in the wild to be at least 10% in 100 years.

We therefore modified the model presented by Campana *et al.* (2008) so the output could be better evaluated under Criterion E. These modifications include a change in the way that human-induced mortality is included in the model and the addition of a forward projecting population model that is used to both show the probability of extinction and time to extinction based on model input values. The results are similar to those of Campana *et al.* (2008), with greater detail added.

The Model

We used the same approach as Campana *et al.* (2008) to develop an abundance time series from 1986 to 2007 and to evaluate uncertainty in this time series, described as:

In order to apply this model, estimates of r , estimates of the number of removals from the population annually, and an estimate of the population size in 2007 are needed. Campana *et al.* (2008) provided estimates of the number of Basking Sharks taken as bycatch for the 1986 to 2006 time period. Their table is reproduced here as Appendix Table 2. Campana *et al.* (2008) estimated that the abundance of Basking Shark in Canadian waters was roughly 10,000 individuals. As did Campana *et al.* (2008), we estimated r using the Euler-Lotka equation:

$$1 = \sum_{x=0}^A e^{(-rx)} m_x l_x,$$

where A is the maximum age, l_x is the survivorship to age x ($l_0=1$), and m_x is the expected reproductive output at age x (a function of the probability of being mature, the sex ratio and fecundity). This equation was solved using a numerical search algorithm.

The survivorship vector was calculated as:

$$l_x = \prod_{i=0}^{x-1} \exp(-(M_i + F_i)).$$

The instantaneous fishing mortality rate, F , in this equation was sub-divided into two components: a component for which mortality has been quantified from the fishery observer records (Table 2) and that which has not been quantified. This second component is intended to represent mortality potentially occurring in the fisheries without observer coverage as well as from other sources such as ship strikes. This approach differs from that of Campana *et al.* (2008). They examined the effects of the unquantified sources of mortality by doubling the number of known removals to see if population trends changed. Here, when calculating abundance backwards through time, we calculated l_x using only the assumed F for the unquantified component, whereas when projecting the population forward from 2007, we recalculated l_x using both components. As did Campana *et al.* (2008), we assumed fishing mortality to be knife-edged at age-2. Given the assumption that mortality is age-selective, calculating the exploitation rate for the human induced mortality that has been quantified requires an assumption about the age distribution of the population. Assuming the population is at an equilibrium age structure for a given fishing mortality rate, the exploitation rate, u , defined as the proportion of the population vulnerable to exploitation that is captured annually, in a given year t can be calculated as:

$$u_t = \frac{\text{removals}_t}{\frac{\sum_{x=sel}^A l_x | u_t}{\sum_{x=0}^A l_x | u_t}}.$$

Because u exists on both sides of this equation, a search algorithm was used to find the value of u that solves this equation. The average exploitation rate was then calculated and used in the forward population projections using:

$$N_t = \exp(r_u + \varepsilon_t) N_{t-1},$$

where r_u is the intrinsic rate of population growth at the average exploitation rate (from both quantified and unquantified sources) obtained for that model run, and ε_t is a normally distributed random variable: $\varepsilon_t \sim N(0, \sigma)$. Here, u includes the combined effects of the average exploitation rate for fisheries with observer coverage as well as assumed rates of mortality from unquantified sources.

Using the equations above, the population viability was assessed by repeating the following steps 500 times for each set of parameter values. The probability of extinction was evaluated as the proportion of a set of simulated population trajectories that went

extinct within a given time period (100 years as per the threshold for the “threatened” category under Criterion E).

1. Select values for σ , the mortality rate for the unquantified mortality component, and the extinction threshold (values used are described below).
2. Draw random values for the life history parameters from uniform distributions with the bounds provided in Table 1 (as per Campana *et al.* 2008).
3. Estimate r assuming no human induced mortality and check whether it is within bounds (as per Campana *et al.* 2008 – see quoted text above). If not, repeat step 2.
4. Recalculate r using the assumed mortality rate for unquantified mortality.
5. Draw a random value for the population size in 2007 (N_{2007}) from a uniform distribution with the bounds provided in Table 1 (as per Campana *et al.* 2008).
6. Project abundance backwards from 2007 to 1986 using the known removals and the sampled values of r and N_{2007} . (as per Campana *et al.* 2008).
7. Calculate the annual exploitation rate for the quantified mortality component and calculate its average.
8. Recalculate r including both the average quantified exploitation rate and the assumed mortality rate for the unquantified mortality component.
9. Draw a set of random values of r (one for each year in the forward projections) from a normal distribution with the mean calculated in step 8 and the standard deviation given by σ .
10. Project the population forward from 2007 using the random values for r (step 9) and the N_{2007} (step 5).
11. Evaluate whether or not abundance drops below the extinction threshold. Populations that drop below the threshold are considered extinct (they can't recover).

Model Parameter Assumptions

1. Population models based on exponential growth or decline never actually predict abundances less than zero; and an extinction threshold needs to be established below which the population is considered extinct. Here we set the extinction threshold at 500 animals, representing a decline to 5% of the abundance estimate of 10,000 by Campana *et al.* (2007). We evaluated sensitivity to this value by running a set of simulations with the threshold set at 250 animals.

2. We do not have information on the random annual variability in r for Basking Shark. We set $\sigma=0.10$ base model runs under the assumption that a low level of random variability would be expected. Robustness trials were also carried out assuming $\sigma = 0.00$ and $\sigma = 0.05$ to ensure that this selection was not determining the model results. Given a mean value of r of 0.32 (the median of the simulated values) the assumed values of σ of 0.10 and 0.05 place 90% of the values of r used in the forward projections in the range of -0.13 to 0.19 and -0.05 to 0.11 respectively. Autocorrelation (good years more likely to follow good years; bad years more likely after bad) in the random variability in r , which almost certainly exists and is known to increase extinction risk, was not included. Additionally, the value of σ , which combines the effects of both demographic and environmental stochasticity, is included as a constant. It would be expected to increase at low population size as the importance of demographic stochasticity increases, thereby increasing extinction risk and decreasing time to extinction. Lastly, σ would also include variability in the annual rate of human-induced mortality, which would also be expected to increase its magnitude.
3. As mentioned, human-induced mortality of Basking Shark can be subdivided into two components: the known bycatch mortality in fisheries with observer coverage, as summarized by Campana *et al.* (2008), and an unquantified component consisting of bycatch in fisheries without observer coverage, ship strike mortality, as well as any other causes. When estimating trends in abundance for Basking Shark, Campana *et al.* (2008) addressed the unquantified component by first running a base set of simulations using only the known removals from the population, and then ran a second set of simulations with an arbitrary doubling of the number of removals. Here, rather than changing the number of mortalities to assess the effect of unknown mortality, we ran scenarios in which a given proportion of the population (age 2+ to be consistent with the selectivity assumption) is assumed to be killed as a result of human activities other than the fisheries with observer coverage. Exploitation rates of 0.00, 0.005, .010 and 0.020 were used to evaluate the effects of low levels of mortality on population viability. Because there has been little in the way of observer coverage of inshore fishing gear such as gill nets and cod traps, there is no basis to choose an appropriate value for bycatch mortality in the fisheries without observer coverage, although it almost certainly exists. Similarly, little is known about mortality from ship collisions with Basking Sharks, although this rate has been estimated for another species. Vanderlaan *et al.* (2009) estimated that the number of North Atlantic Right Whale mortalities observed annually in the North Atlantic is 0.91, but that the actual number of Right Whale mortalities (adjusted for both detection rate and number of deaths from unknown causes) is 9.7. Assuming a population size of roughly 350 animals, the mortality rate from ship collisions for this species is in the range of 0.26% to 2.77%. If their analysis is repeated using only data for northern waters (north of the 40th parallel), the estimates of observed and actual number of mortalities are 1.0 and 4.22 per year, equating to mortality rates of roughly 0.28% to 1.21% annually. It is not known how applicable these rates are to Basking Shark.

4. Based on the analyses of Campana *et al.* (2008), removals by the observed fisheries were highest early in the time series when foreign fisheries were operating extensively in Canadian waters. We therefore ran the forward projecting model two ways: first using the average exploitation rate for the full time series (1986 to 2006), and second, using the average fishing mortality during second half of the series (1995 to 2006), a time period during which the landings by foreign fisheries (specifically Silver Hake) and domestic groundfish landings in 4VWX5Z were reduced.

Results

A total of 48 scenarios were modelled to encompass the values and assumptions presented above. For each scenario, the same set of random numbers was used so that the scenarios would be directly comparable. The results are split into two groups based on the time period used to calculate the exploitation rate for the quantified mortality component. A set of ten randomly selected population trajectories using the average exploitation rate for the 1986-2006 time period are shown in Figure 2, for each of 4 assumed rates of unquantified mortality and variability in r . These trajectories show the sensitivity of the population model to small changes in either the assumed exploitation rate or σ . For example, with $\sigma = 0.00$, a change in the assumed rate of mortality from 0.00 to 0.01, markedly slows the rate of growth of populations that are increasing (compare 1a and 1c). A summary of the simulated population sizes (Figure 3a or 3c) shows that when $\sigma = 0.00$ is assumed, populations either increase or decrease exponentially in size depending on the randomly drawn life history parameter and N_{2007} values. When random variation in r is included (e.g. Figures 3b and 3d), this overall pattern remains, although a greater portion of populations show decreasing or stable trajectories (compare Figures 3b and 3c). When simulated populations do go extinct, the time to extinction tends to be greater than 50 years (e.g. Figure 4b).

When the estimated mortality rate for the 1995-2006 time period is used, extinction risk is less than that predicted using the mortality rate for the 1986-2006 time period (compare Figs 3b and 5b). Additionally, population growth rates for increasing simulated populations are more rapid (compare Figures 2c and 4c). Of the 24 scenarios evaluated using the mortality rate for the 1986-2006 time period, eight scenarios exceeded the threshold for “threatened” (Appendix Table 3), whereas only one of the same 24 scenarios exceeded this threshold when the mortality rate of the 1995-2006 time period was used (Appendix Table 4).

A comparison of the proportion of simulated populations that showed a decline to the proportion that went extinct (right two columns of Appendix Table 3) shows that although the proportion of populations that are in decline is relatively large (when estimated by log-linear regression), the rates of decline are low enough that most populations do not drop below the extinction threshold within 100 years. Because the rates of decline are low, the proportion of populations that go extinct is sensitive to the assumed extinction threshold (compare the top and bottom halves of Appendix Table 3). Of the 12 scenarios evaluated using the mortality rate for the 1986-2006 time period

and an extinction threshold of 500 animals, 6 exceeded the threshold for “threatened”, where as only 2 of the same scenarios exceeded this threshold when the extinction threshold was set at 250 animals.

Conclusions

A Monte Carlo analysis based on the life history of Basking Sharks and bycatch data was used to evaluate recent trends in abundance. The results of this population model, which are consistent with the results of a life table analysis (Campana *et al.* 2008), suggest a 1-in-2 to 1-in-5 chance that the population is decreasing, although the uncertainty associated with the model inputs is large.

Although a portion of the simulated populations show a decline, most of the declines rates are low enough that for that portion showing a decline, the time to extinction is not likely less than 50 years and is more likely greater than 100 years. This result is conditional on the model inputs and assumptions.

Based on the change in the numbers of Basking Shark taken in fisheries with observer coverage, the reduction in catches shown for the 1995-2006 period reduces simulated extinction risk relative to that which would be estimated when the average fishing mortality rate for the full time period (1986-2006) is used.

Again based on model inputs and assumptions, when the average fishing mortality rate for 1995-2006 is used, mortality from all other sources would need to be greater than about 1% annually, and the annual variability (standard deviation) in r greater than about 0.10, in order for the population to exceed the threshold for threatened under COSEWIC’s Criterion E. It is plausible that these values are exceeded given what is known about ship strike rates for Right Whales and fisheries without observer coverage.

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Appendix Table 1. Life history parameter values used in estimating the intrinsic rate of population growth (r) for Basking Shark (from Campana *et al.* 2008).

Parameter	Minimum	Maximum
Estimated population size in 2007 ¹ :	5,000	20,000
Estimated age at maturity (assumed knife edge):	16 yr	20 yr
Estimated female litter size (thought to be 3):	2	4
Estimated gestation period (thought to be 3 yr):	2 yr	4yr
Lag between parturition and next pregnancy	0 yr	1 yr
Maximum age	40 yr	60 yr
Estimated natural mortality (thought to be 0.068)	0058	0.078
Ratio of age-0 mortality to mortality of older fish	1.5	2.5

¹ The logic behind the selection of these limits is that the population size could be half or double the estimate of 10,000 individuals. Sampling was done such that half the values were above 10,000 and half were below so that the median of the simulated values would not be inflated.

Appendix Table 2. Total estimated discard weights (mt) and numbers of Basking Sharks in Atlantic Canadian waters (Table 5 of Campana *et al.* 2008). Foreign values in Scotia-Fundy (SF) and Newfoundland (NL) were fully observed, not estimated.

Year	SF and Gulf	Foreign-SF	NL	NL*	Foreign-NL	Estimated Discard Numbers Total
1986	55	16	0	0	0	71
1987	20	28	0	0	3	51
1988	45	70	20	20	3	138
1989	254	65	0	0	3	322
1990	665	75	1	1	1	741
1991	172	144	0	0	1	317
1992	175	151	1	1	5	331
1993	51	77	3	3	6	138
1994	154	5	2	2	0	161
1995	76	19	137	23	0	232
1996	151	9	0	0	0	161
1997	18	3	0	0	1	23
1998	50	4	0	0	0	54
1999	96	5	14	14	0	114
2000	60	1	0	0	5	66
2001	49	3	0	0	7	59
2002	3	2	189	8	3	197
2003	30	4	0	0	3	37
2004	172	0	7	7	6	185
2005	33	0	8	8	0	42
2006	4	0				4

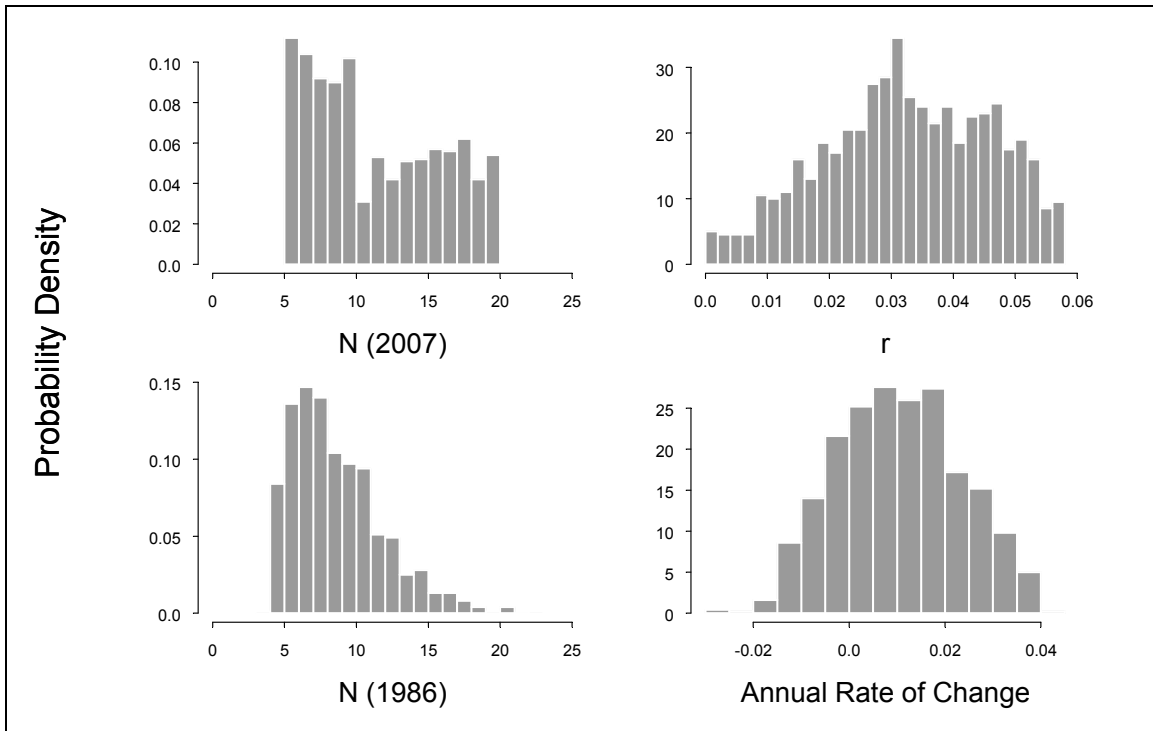
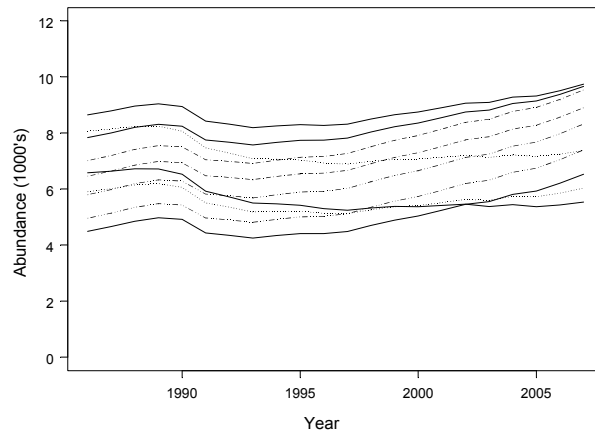
* removes two disproportionately influential data points (2002 3Ps monkfish fishery; 1995 3Ps redfish fishery)

Appendix Table 3. Summary of Basking Shark population viability analysis model runs using the average exploitation rate (known removals) for the 1986 to 2007 time period. Population projections were carried out under three assumed rates for the standard deviation (σ) of the intrinsic rate of population growth (r), four assumed rates for human induced mortality from unquantified sources (μ) and two extinction thresholds. Values for r and the population sizes are the medians and 10th and 90th percentiles (in brackets) of 500 population simulations. The proportion of populations showing a decline between 1986 and 2001, as well as the proportion of simulations that went extinct within 100 years are shown. Bolded scenarios meet the COSEWIC's Criterion "E" threshold for "Threatened".

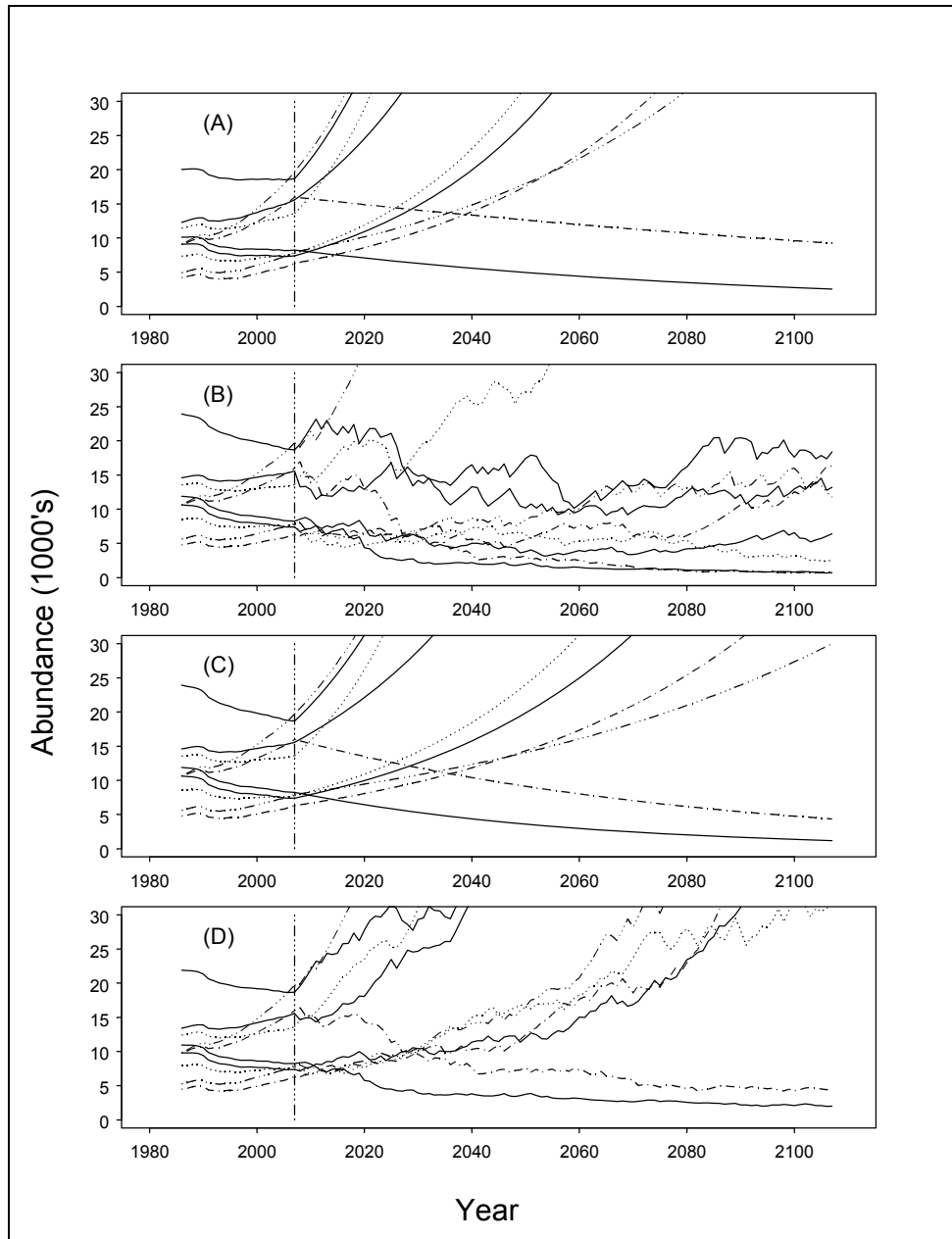
	σ	μ	Ext'n Thres.	r (no human induced mortality)	r_u (human induced mortality included)	Population Size 1986	Population Size 2008	Population Size 2108	Prop. Declining	Prop. Extinct
1	0.10	0.000	500	0.032 (0.012 - 0.051)	0.013 (-0.014 - 0.04)	7945 (5127 - 13135)	10252 (5970 - 18539)	4996 (0 - 39396)	0.24	0.13
2	0.10	0.005	500	0.032 (0.012 - 0.051)	0.009 (-0.017 - 0.036)	8606 (5488 - 14299)	10218 (5956 - 18469)	3935 (0 - 32523)	0.34	0.16
3	0.10	0.010	500	0.032 (0.012 - 0.051)	0.006 (-0.02 - 0.033)	9319 (5884 - 15586)	10183 (5941 - 18399)	3091 (0 - 25557)	0.42	0.19
4	0.10	0.020	500	0.032 (0.012 - 0.051)	-0.002 (-0.027 - 0.025)	10954 (6798 - 18576)	10111 (5909 - 18255)	1844 (0 - 15443)	0.62	0.26
5	0.05	0.000	500	0.032 (0.012 - 0.051)	0.013 (-0.014 - 0.04)	7945 (5127 - 13135)	10161 (5956 - 18135)	24157 (1554 - 223080)	0.24	0.03
6	0.05	0.005	500	0.032 (0.012 - 0.051)	0.009 (-0.017 - 0.036)	8606 (5488 - 14299)	10128 (5943 - 18063)	17987 (1136 - 180866)	0.34	0.04
7	0.05	0.010	500	0.032 (0.012 - 0.051)	0.006 (-0.02 - 0.033)	9319 (5884 - 15586)	10095 (5928 - 17990)	13186 (837 - 138964)	0.42	0.06
8	0.05	0.020	500	0.032 (0.012 - 0.051)	-0.002 (-0.027 - 0.025)	10954 (6798 - 18576)	10026 (5890 - 17842)	6851 (0 - 77311)	0.62	0.11
9	0.00	0.000	500	0.032 (0.012 - 0.051)	0.013 (-0.014 - 0.04)	7945 (5127 - 13135)	10231 (5972 - 18299)	37185 (2078 - 766234)	0.24	0.04
10	0.00	0.005	500	0.032 (0.012 - 0.051)	0.009 (-0.017 - 0.036)	8606 (5488 - 14299)	10196 (5954 - 18230)	25611 (1477 - 517461)	0.34	0.04
11	0.00	0.010	500	0.032 (0.012 - 0.051)	0.006 (-0.02 - 0.033)	9319 (5884 - 15586)	10161 (5936 - 18161)	17600 (1037 - 347996)	0.42	0.06
12	0.00	0.020	500	0.032 (0.012 - 0.051)	-0.002 (-0.027 - 0.025)	10954 (6798 - 18576)	10088 (5897 - 18019)	8488 (451 - 166418)	0.62	0.10
13	0.10	0.000	250	0.032 (0.012 - 0.051)	0.013 (-0.014 - 0.04)	7945 (5127 - 13135)	10252 (5970 - 18539)	4996 (410 - 39396)	0.24	0.07
14	0.10	0.005	250	0.032 (0.012 - 0.051)	0.009 (-0.017 - 0.036)	8606 (5488 - 14299)	10218 (5956 - 18469)	3935 (341 - 32523)	0.34	0.08
15	0.10	0.010	250	0.032 (0.012 - 0.051)	0.006 (-0.02 - 0.033)	9319 (5884 - 15586)	10183 (5941 - 18399)	3091 (236 - 25557)	0.42	0.10
16	0.10	0.020	250	0.032 (0.012 - 0.051)	-0.002 (-0.027 - 0.025)	10954 (6798 - 18576)	10111 (5909 - 18255)	1844 (0 - 15443)	0.62	0.17
17	0.05	0.000	250	0.032 (0.012 - 0.051)	0.013 (-0.014 - 0.04)	7945 (5127 - 13135)	10161 (5956 - 18135)	24157 (1554 - 223080)	0.24	0.02
18	0.05	0.005	250	0.032 (0.012 - 0.051)	0.009 (-0.017 - 0.036)	8606 (5488 - 14299)	10128 (5943 - 18063)	17987 (1136 - 180866)	0.34	0.02
19	0.05	0.010	250	0.032 (0.012 - 0.051)	0.006 (-0.02 - 0.033)	9319 (5884 - 15586)	10095 (5928 - 17990)	13186 (837 - 138964)	0.42	0.03
20	0.05	0.020	250	0.032 (0.012 - 0.051)	-0.002 (-0.027 - 0.025)	10954 (6798 - 18576)	10026 (5890 - 17842)	6851 (453 - 77311)	0.62	0.05
21	0.00	0.000	250	0.032 (0.012 - 0.051)	0.013 (-0.014 - 0.04)	7945 (5127 - 13135)	10231 (5972 - 18299)	37185 (2078 - 766234)	0.24	0.01
22	0.00	0.005	250	0.032 (0.012 - 0.051)	0.009 (-0.017 - 0.036)	8606 (5488 - 14299)	10196 (5954 - 18230)	25611 (1477 - 517461)	0.34	0.02
23	0.00	0.010	250	0.032 (0.012 - 0.051)	0.006 (-0.02 - 0.033)	9319 (5884 - 15586)	10161 (5936 - 18161)	17600 (1037 - 347996)	0.42	0.03
24	0.00	0.020	250	0.032 (0.012 - 0.051)	-0.002 (-0.027 - 0.025)	10954 (6798 - 18576)	10088 (5897 - 18019)	8488 (498 - 166418)	0.62	0.05

Appendix Table 4. Summary of a Basking Shark population viability analysis model runs using the average exploitation rate (known removals) for the 1995 to 2007 time period. Population projections were carried out under three assumed rates for the standard deviation (σ) of the intrinsic rate of population growth (r), four assumed rates for human induced mortality from unquantified sources (μ) and two extinction thresholds. Values for r and the population sizes are the medians and 10th and 90th percentiles (in brackets) of 500 population simulations. The proportion of populations showing a decline between 1986 and 2001, as well as the proportion of simulations that went extinct within 100 years are shown. Bolded scenarios meet the COSEWIC's Criterion "E" threshold for "Threatened".

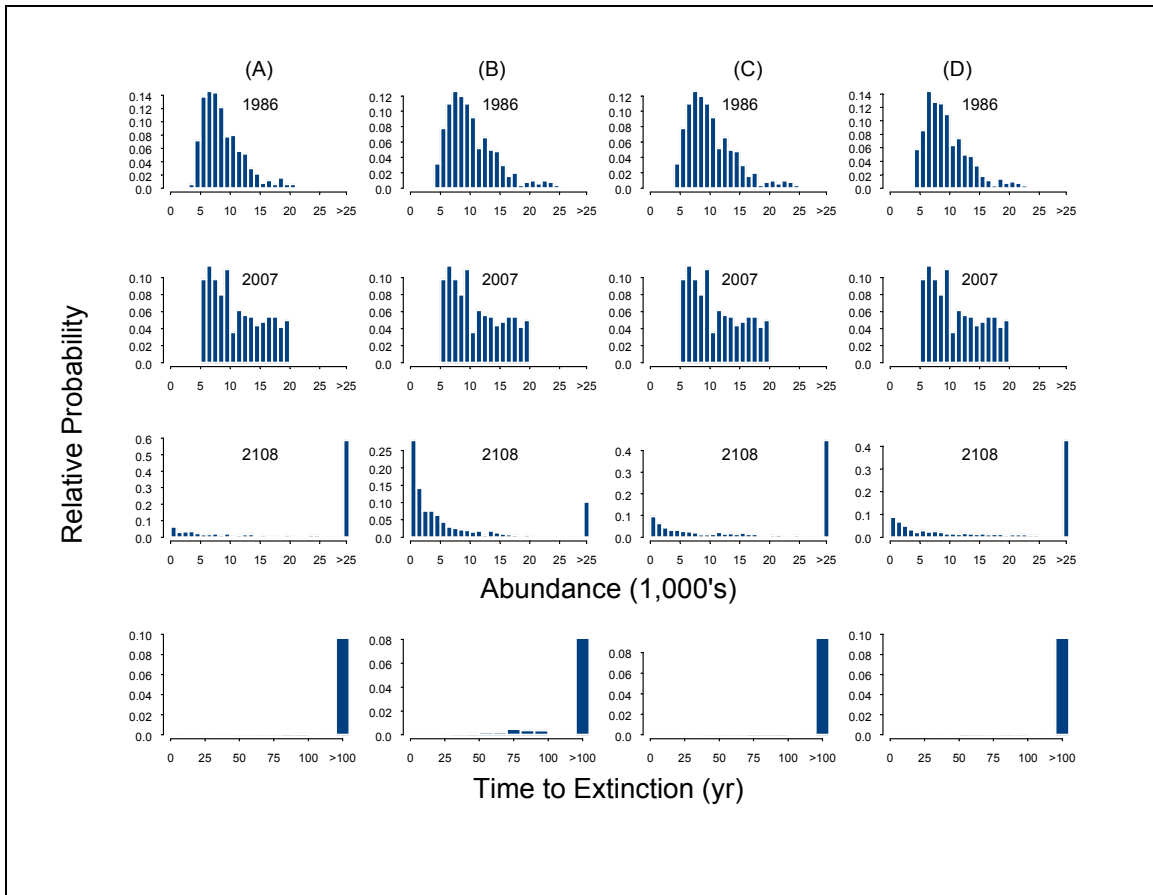
	σ	μ	Ext'n Thres.	r (no human induced mortality)	r_u (human induced mortality included)	Population Size 1986	Population Size 2008	Population Size 2108	Prop. Decline	Prop. Extinct
1	0.10	0.000	500	0.032 (0.012 - 0.051)	0.024 (0 - 0.048)	7945 (5127 - 13135)	10372 (6098 - 18708)	9650 (1132 - 63465)	0.24	0.04
2	0.10	0.005	500	0.032 (0.012 - 0.051)	0.02 (-0.004 - 0.044)	8606 (5488 - 14299)	10327 (6073 - 18625)	7351 (843 - 49040)	0.34	0.05
3	0.10	0.010	500	0.032 (0.012 - 0.051)	0.015 (-0.008 - 0.04)	9319 (5884 - 15586)	10282 (6047 - 18542)	5513 (621 - 38770)	0.42	0.08
4	0.10	0.020	500	0.032 (0.012 - 0.051)	0.007 (-0.017 - 0.031)	10954 (6798 - 18576)	10191 (5996 - 18375)	2947 (0 - 23229)	0.62	0.15
5	0.05	0.000	500	0.032 (0.012 - 0.051)	0.024 (0 - 0.048)	7945 (5127 - 13135)	10315 (6056 - 18252)	54238 (5590 - 373956)	0.24	0.00
6	0.05	0.005	500	0.032 (0.012 - 0.051)	0.02 (-0.004 - 0.044)	8606 (5488 - 14299)	10271 (6031 - 18171)	39308 (3822 - 293017)	0.34	0.01
7	0.05	0.010	500	0.032 (0.012 - 0.051)	0.015 (-0.008 - 0.04)	9319 (5884 - 15586)	10227 (6006 - 18090)	27956 (2593 - 219023)	0.42	0.01
8	0.05	0.020	500	0.032 (0.012 - 0.051)	0.007 (-0.017 - 0.031)	10954 (6798 - 18576)	10138 (5955 - 17928)	13613 (1145 - 121078)	0.62	0.03
9	0.00	0.000	500	0.032 (0.012 - 0.051)	0.024 (0 - 0.048)	7945 (5127 - 13135)	10377 (6064 - 18466)	110556 (7191 - 1703835)	0.24	0.00
10	0.00	0.005	500	0.032 (0.012 - 0.051)	0.02 (-0.004 - 0.044)	8606 (5488 - 14299)	10333 (6039 - 18384)	72097 (4729 - 1099983)	0.34	0.00
11	0.00	0.010	500	0.032 (0.012 - 0.051)	0.015 (-0.008 - 0.04)	9319 (5884 - 15586)	10289 (6014 - 18302)	47054 (3100 - 708510)	0.42	0.01
12	0.00	0.020	500	0.032 (0.012 - 0.051)	0.007 (-0.017 - 0.031)	10954 (6798 - 18576)	10200 (5963 - 18137)	19897 (1326 - 292511)	0.62	0.03
13	0.10	0.000	250	0.032 (0.012 - 0.051)	0.024 (0 - 0.048)	7945 (5127 - 13135)	10372 (6098 - 18708)	9650 (1132 - 63465)	0.24	0.01
14	0.10	0.005	250	0.032 (0.012 - 0.051)	0.02 (-0.004 - 0.044)	8606 (5488 - 14299)	10327 (6073 - 18625)	7351 (843 - 49040)	0.34	0.02
15	0.10	0.010	250	0.032 (0.012 - 0.051)	0.015 (-0.008 - 0.04)	9319 (5884 - 15586)	10282 (6047 - 18542)	5513 (621 - 38770)	0.42	0.03
16	0.10	0.020	250	0.032 (0.012 - 0.051)	0.007 (-0.017 - 0.031)	10954 (6798 - 18576)	10191 (5996 - 18375)	2947 (325 - 23229)	0.62	0.08
17	0.05	0.000	250	0.032 (0.012 - 0.051)	0.024 (0 - 0.048)	7945 (5127 - 13135)	10315 (6056 - 18252)	54238 (5590 - 373956)	0.24	0.00
18	0.05	0.005	250	0.032 (0.012 - 0.051)	0.02 (-0.004 - 0.044)	8606 (5488 - 14299)	10271 (6031 - 18171)	39308 (3822 - 293017)	0.34	0.00
19	0.05	0.010	250	0.032 (0.012 - 0.051)	0.015 (-0.008 - 0.04)	9319 (5884 - 15586)	10227 (6006 - 18090)	27956 (2593 - 219023)	0.42	0.00
20	0.05	0.020	250	0.032 (0.012 - 0.051)	0.007 (-0.017 - 0.031)	10954 (6798 - 18576)	10138 (5955 - 17928)	13613 (1145 - 121078)	0.62	0.01
21	0.00	0.000	250	0.032 (0.012 - 0.051)	0.024 (0 - 0.048)	7945 (5127 - 13135)	10377 (6064 - 18466)	110556 (7191 - 1703835)	0.24	0.00
22	0.00	0.005	250	0.032 (0.012 - 0.051)	0.02 (-0.004 - 0.044)	8606 (5488 - 14299)	10333 (6039 - 18384)	72097 (4729 - 1099983)	0.34	0.00
23	0.00	0.010	250	0.032 (0.012 - 0.051)	0.015 (-0.008 - 0.04)	9319 (5884 - 15586)	10289 (6014 - 18302)	47054 (3100 - 708510)	0.42	0.00
24	0.00	0.020	250	0.032 (0.012 - 0.051)	0.007 (-0.017 - 0.031)	10954 (6798 - 18576)	10200 (5963 - 18137)	19897 (1326 - 292511)	0.62	0.01



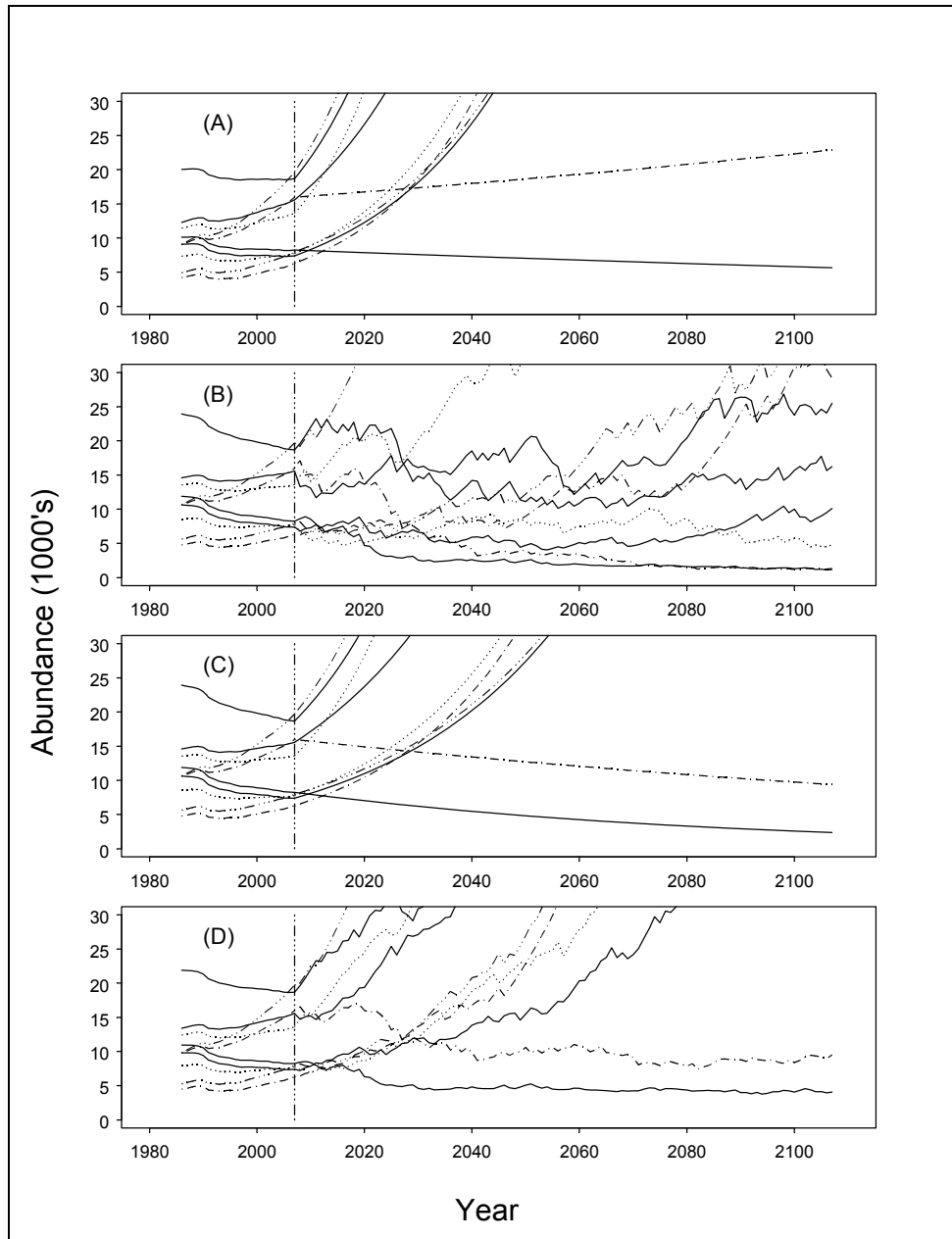
Appendix Figure 1. Simulation results from the base model in which r is constrained to be >0 and <0.057 . The top panel shows 10 simulated population trajectories and the bottom panel shows the histograms, based on 1000 population simulations, of the population size in 2007, the population size in 1986, r and rate of change in population size (positive values indicate an increasing population). – from Campana *et al.* (2008).



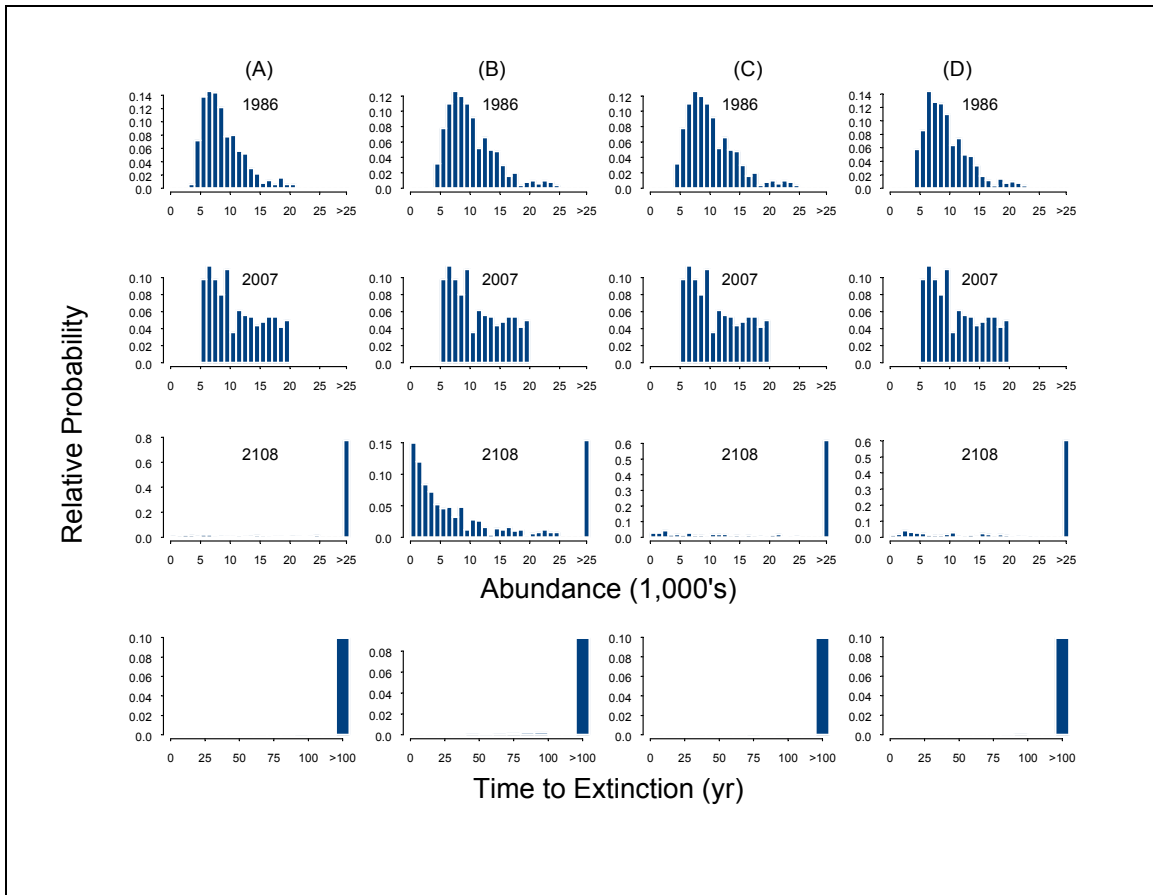
Appendix Figure 2. Ten examples of population trajectories using the average exploitation rate for the 1986 to 2007 time period for each of 4 assumed rates of unquantified mortality and variability in r . a) standard deviation of $r = 0.00$; assumed rate of mortality from unquantified sources = 0.000; b) standard deviation of $r = 0.10$, assumed rate of mortality from unquantified sources = 0.010; c) standard deviation of $r = 0.00$, assumed rate of mortality from unquantified sources = 0.010; and d) standard deviation of $r = 0.05$, assumed rate of mortality from unquantified sources = 0.005.



Appendix Figure 3. Box plots summarizing 500 simulated population trajectories using the average exploitation rate for the 1986 to 2007 time period for each of 4 assumed rates of unquantified mortality and variability in r . a) standard deviation of $r = 0.00$; assumed rate of mortality from unquantified sources = 0.000; b) standard deviation of $r = 0.10$, assumed rate of mortality from unquantified sources = 0.010; c) standard deviation of $r = 0.00$, assumed rate of mortality from unquantified sources = 0.010; and d) standard deviation of $r = 0.05$, assumed rate of mortality from unquantified sources = 0.005. The time to extinction is calculated using a quasi-extinction threshold of 500 individuals.



Appendix Figure 4. Ten examples of population trajectories using the average exploitation rate for the 1995 to 2007 time period for each of 4 assumed rates of unquantified mortality and variability in r . a) standard deviation of $r = 0.00$; assumed rate of mortality from unquantified sources = 0.000; b) standard deviation of $r = 0.10$, assumed rate of mortality from unquantified sources = 0.010; c) standard deviation of $r = 0.00$, assumed rate of mortality from unquantified sources = 0.010; and d) standard deviation of $r = 0.05$, assumed rate of mortality from unquantified sources = 0.005.



Appendix Figure 5. Box plots summarizing 500 simulated population trajectories using the average exploitation rate for the 1995 to 2007 time period for each of 4 assumed rates of unquantified mortality and variability in r . a) standard deviation of $r = 0.00$; assumed rate of mortality from unquantified sources = 0.000; b) standard deviation of $r = 0.10$, assumed rate of mortality from unquantified sources = 0.010; c) standard deviation of $r = 0.00$, assumed rate of mortality from unquantified sources = 0.010; and d) standard deviation of $r = 0.05$, assumed rate of mortality from unquantified sources = 0.005. The time to extinction is calculated using a quasi-extinction threshold of 500 individuals.