Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S
Canadian Science Advisory Secretariat

S C C S
Secrétariat canadien de consultation scientifique

Research Document 2008/004

Document de recherche 2008/004

Not to be cited without
permission of the authors *

Ne pas citer sans
autorisation des auteurs *

Status of Basking Sharks in Atlantic Canada

État du requin-pèlerin de l'Atlantique canadien

Steven E. Campana, Jamie Gibson, John Brazner, Linda Marks and Warren Joyce
Population Ecology Division, Bedford Institute of Oceanography, Dartmouth, NS B2Y 4A2

Jean-François Gosselin
Pêches et Océans Canada, Institut Maurice-Lamontagne, 850 Route de la Mer, C.P. 1000, Mont-Joli, Québec, G5H 3Z4

Robert D. Kenney
University of Rhode Island, Graduate School of Oceanography, Narragansett Bay Campus Box 41, Narragansett, RI 02882-1197, U.S.A.

Peter Shelton, Mark Simpson and Jack Lawson
Fisheries and Oceans Canada, NAFC, P.O. Box 5667, 80 East White Hills Road, St. John's, NL A1C 5X1

* This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

This document is available on the Internet at:

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1499-3848 (Printed / Imprimé)

Canada

Abstract

The life history characteristics of basking sharks are inadequately known, and key parameters such as growth rate, natural mortality and fecundity are assumed rather than measured. However, there is little doubt that the species is relatively unproductive and incapable of sustaining even modest mortality rates. Basking shark distribution appears to be restricted to temperatures between 6 and 16 °C, which implies that observations of basking sharks north of Newfoundland and in cold waters elsewhere are likely to be misidentifications of Greenland sharks.

There is no directed fishery for basking sharks in Canadian waters. Observed bycatch in foreign fisheries peaked in the 1980s and early 1990s at about 150 mt per year, but has averaged only a few mt annually (i.e., a few individual fish) since 2000. Basking sharks are caught incidentally in domestic fisheries, with most observed bycatches having occurred in groundfish and redfish trawl fisheries. When scaled to total landings, total estimated bycatch has averaged 164 mt annually (corresponding to 164 basking sharks) since 1986. It is possible that bycatch is somewhat larger than estimated, since there has been little in the way of observer coverage of inshore fishing gear such as gill nets and cod traps.

None of the existing fish surveys provide an abundance index for basking sharks. An annual index derived from surveys for right whales in the Bay of Fundy indicated a sharp increase in abundance in the 1990s, followed by an equally abrupt decline to 2000. The apparent change in abundance was likely due to changes in distribution due to oceanographic factors, rather than mortality. Estimates of absolute basking shark abundance from aerial surveys of whales in the Bay of Fundy, the Scotian Shelf, Gulf of St. Lawrence and Newfoundland waters suggest numbers of 4,200, 5367 and 558 respectively, for a total of 10,125 in the summer of 2007. These estimates are uncertain due to the number of assumptions that were invoked, but particularly that associated with the proportion of time at the surface.

A life table analysis indicated that the intrinsic rate of basking shark population growth (*r*) in an unfished population is 0.040, which is near the maximum sustainable bycatch mortality. With F_{crit}= 0.043, and the annual mean number of discards being 164, and assuming 100% mortality of discards, this would suggest that the average population size which could support the estimated number of discards N_{crit} would be about 4,800. The best available estimate of population size for 2007 is above N_{crit}. The Monte Carlo simulation model results indicate a median value of *r* of 0.032, of F_{crit} of 0.035 and of N_{crit} of about 5900 sharks, the latter value still being less than the 2007 population size estimate. The results of this population model, which are consistent with the results of the life table analysis, suggest a 23% probability (about a 1-in-5 chance) that the population is decreasing, although the uncertainty associated with the model inputs is large. This result is more or less consistent with SPUE indices in U.S. waters that show no evidence of a decline since 1979.

Given the life history characteristics of the basking shark, high discard mortality associated with bycatch could lead to population collapse. Therefore it is important that basking shark bycatch continue to be monitored and kept to a minimum. Measures to improve species identification accuracy in the observer program, record the numbers of individuals and sex in the bycatch, and to reduce discard mortality would be useful.

Résumé

Les caractéristiques biologiques du requin-pèlerin sont mal connues et les principaux paramètres, tels que le taux de croissance, de mortalité naturelle et de fécondité, sont hypothétiques plutôt que véritablement mesurés. Toutefois, il ne fait aucun doute que l'espèce est relativement peu productive et incapable de soutenir un taux de mortalité, même modeste. Sa répartition semble limitée aux eaux dont les températures oscillent entre 6 et 16 °C, ce qui porte à croire que les observations de requins-pèlerins au nord de Terre-Neuve et dans d'autres eaux froides seraient rassemblement des erreurs d'identification de requins du Groenland.

Il n'existe pas de pêche dirigée du requin-pèlerin dans les eaux canadiennes. Les prises accessoires observées dans le cadre des activités de pêche de pays étrangers ont atteint un sommet au cours des années 1980 et au début de la décennie de 1990, à environ 150 tm par année, mais leur moyenne n'est que de quelques tonnes métriques par année (c.-à-d. quelques individus) depuis 2000. Le requin-pèlerin est capturé accessoirement au cours de certaines pêches canadiennes, la plupart des prises ayant lieu au cours de pêches du poisson de fond et du sébaste au chalut. Par rapport au total des débarquements, les prises accessoires estimatives totalisent en moyenne 164 tm par année (ce qui correspond à 164 requin-pèlerins) depuis 1986. Il est possible que les captures réelles soient légèrement plus importantes que l'estimation, car peu d'observateurs sont affectés aux pêches aux engins côtiers comme les filets maillants et les trappes à morue.

Aucun des relevés de poissons existants ne donne d'indice d'abondance du requin-pèlerin. Un indice annuel, tiré des relevés de baleines noires de la baie de Fundy, révèle une hausse sensible de l'abondance au cours des années 1990, suivie d'une diminution tout aussi radicale jusqu'en 2000. Cette apparente variation de l'abondance est probablement due à des changements de la répartition, elle-même attribuable à des facteurs océanographiques, plutôt qu'à des mortalités. Une estimation de l'abondance absolue du requin-pèlerin réalisée au moyen de relevés aériens des baleines de la baie de Fundy, du plateau Néo-Écossais, golfe du Saint-Laurent, et des eaux de Terre-Neuve aurait permis de l'établir à 4 200, 5 367 et 558, respectivement, pour un total de 10 125 à l'été 2007. Cette estimation est toutefois incertaine en raison du nombre de suppositions invoquées, mais particulièrement celles qui sont associées à la proportion de temps passé à la surface.

Une analyse de la table de survie a montré que le taux intrinsèque de croissance (r) de la population de requin-pèlerin au sein d'une population non exploitée est de 0,040, ce qui est près du taux de mortalité accessoire assurant un rendement maximum constant. Si F_{crit} = 0,043 et que le nombre moyen de rejets à la mer annuels est de 164, et si l'on suppose un taux de mortalité des rejets de 100 %, on pourrait en conclure que la taille moyenne de la population pouvant soutenir le nombre approximatif de rejet N_{crit} serait d'environ 4 800. La meilleure estimation disponible de l'effectif pour 2007 est supérieure à N_{crit}. Les résultats d'une analyse à l'aide du modèle de simulation Monte Carlo donnent une valeur médiane de r de 0,032, de F_{crit} de 0,035 et de N_{crit} d'environ 5 900 requins, cette dernière valeur étant toujours inférieure à l'estimation de l'effectif de 2007. Les résultats du modèle, qui sont conformes à ceux de l'analyse de la table de vie, semblent indiquer une probabilité de 23 % (environ une chance sur cinq) que la population diminue, bien que l'incertitude associée aux intrants du modèle soit importante. Ces résultats

coïncident plus ou moins avec les indices des observations par unité d’effort dans les eaux américaines qui ne montrent aucun signe de diminution depuis 1979.

Compte tenu des caractéristiques biologiques du requin-pèlerin, le haut taux de mortalité des captures accessoires rejetées à la mer pourrait entraîner un effondrement de la population. Il est donc important de continuer à surveiller et à limiter au minimum les prises accessoires de requin-pèlerin. Il serait également utile de prendre des mesures en vue d’améliorer l’exactitude de l’identification de l’espèce dans le cadre du programme d’observateurs, de consigner le nombre de captures accessoires et leur sexe et de réduire la mortalité des individus rejetés à la mer.

Background

The basking shark (*Cetorhinus maximus* Gunnerus, 1765) is the sole member of the family Cetorhinidae belonging to the order Lamniformes. Basking sharks are named after their conspicuous behaviour of 'basking' (more accurately feeding) at the surface. Other common names include the sun shark, bone shark, and elephant shark. The term ground shark is often used in Atlantic Canada, but this term is equally applied to both the basking shark and the Greenland shark (*Somniosus groenlandicus*). In French this species is known as Pélerin.

The basking shark is the second largest fish in the world, second in size only to another filter feeder, the whale shark. It has a conical snout and the gill slits extend almost completely around the top and bottom of its head. The gill rakers are dark in colour and bristlelike and are used to catch zooplankton as water filters through the mouth and over the gills. The basking shark is usually grayish-brown to black in colour and often seems to have a mottled appearance. The caudal fin has a strong lateral keel and a crescent shape. The teeth in the basking shark are very small and numerous and often number one hundred per row. The teeth themselves have a single conical cusp, are curved backwards and are the same on both the upper and lower jaws.

Basking sharks are found circumglobally in temperate coastal shelf waters but are patchy in distribution (Compagno 2001). The basking shark is found throughout the north and south Atlantic Ocean, the Mediterranean Sea, north and south Pacific Ocean, the Sea of Japan, off southern Australia and around New Zealand. Canadian records from both Atlantic and Pacific waters indicate they utilize virtually all coastal temperate waters where temperatures exceed 6 or 7 °C.

The population structure of basking sharks is currently being studied using genetic techniques, but nothing has been published to date. Although basking sharks from the northeast and northwest Atlantic are assumed to be distinct, a satellite-tagged basking shark recently migrated from off Ireland to off Newfoundland (Gore et al. 2008). COSEWIC has designated the Atlantic and Pacific populations of basking sharks as separate Designatable Units (DUs) (Wallace et al. 2005).

Basking sharks have been listed under Appendix 2 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). IUCN has listed the species as vulnerable globally, and endangered in the northeast Atlantic and in the north Pacific. COSEWIC has listed the Pacific population of basking sharks as Endangered. The status of the Atlantic population is expected to be assessed in the near future.

Life History

The life cycle and reproduction of basking sharks are poorly understood, but assumed to be similar to other lamnoid sharks. They are believed to be ovoviviparous, giving birth to live pups during the summer after a gestation period of 2.5-3.5 years (Parker and Stott 1965; Pauly 2002). Length at birth has been measured in only six embryos from a single litter, where the young were 1.5 to 2 meters in length (Compagno 2001; Martin and Harvey-Clark 2004). It is believed that males mature at a length of 4.6 to 6.1 m. Females presumably reach sexual maturity at a slightly larger size. Pregnant females are very seldom encountered (one report in 1776) suggesting that they may separate themselves from other individuals observed in the field. Breeding has not been observed but putative mating aggregations have been observed in June off the coast of Nova Scotia (Harvey-Clark et al. 1999), off the northeastern coast of the U.S. in spring and summer and off the southeastern coast of the U.S in winter (unpublished North Atlantic Right Whale Consortium data), and in early summer off Europe (Matthews 1950; Sims et al. 2000). Only one juvenile basking shark has ever been seen (off the British Isles). There is speculation that basking shark populations may segregate spatially and seasonally by sex or maturity, but supporting data are sparse.

Longevity is presumed to be approximately 50 years, but the basis for age estimation in this species is weak. Parker and Stott (1965) reported a longevity of 8 yr based on vertebral ring counts, but assumed that rings formed twice per year. This assumption is unlikely to be correct. Pauly (2002) re-analyzed Parker and Stott's (1965) data in conjunction with other shark data, concluding that a longevity of 50 yr was likely. In a recent paper, Natanson et al. (2008) counted up to 33 growth bands in vertebral sections, but concluded that the vertebrae were unlikely to provide accurate age estimates. Unpublished research in our laboratory indicates that basking sharks over 8 m in length possess up to 44 growth bands in vertebral sections (Campana et al., unpublished). However, bomb radiocarbon dating suggests that these ages are suspect. It is possible that vertebral sections overestimate age in these fish by 7-8 yr. Such an interpretation would provide reasonable consistency between Pauly's von Bertalanffy growth curve and the vertebral age estimates of Natanson et al. (2008) and Campana et al. (unpublished) (Fig. 1). This presumed growth curve has the following form:

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

where L_∞ = 10 m, K = 0.062, and t_0 = -2.62.

Basking shark age at maturity has been tentatively estimated at 12 to 16 years for males and 16 to 20 years for females, but the problems with age estimation noted above mean that these estimates must be taken with a grain of salt (UK CITES proposal 2002). Male length at maturity is more accurately estimated at 4.6 to 6.1 m based on clasper development, with females presumed to mature at a larger size (Bigelow and Schroeder 1953).

The term r_{msy} is a measure of annual productivity, since it is the rate at which a population will initially grow when suddenly released from a fishing mortality equal to the value that achieves maximum sustainable yield. Estimates of 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 (UK CITES proposal 2002). 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 Smith et al. (1998). Pauly (2002) calculated the natural mortality (M) to be 0.068. 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 (Wallace et al. 2005). In contrast, the UK CITES proposal (2002) reports the generation time as 22 years.

Distribution and Habitat

Basking sharks are generally associated with coastal temperate waters globally. Off Atlantic Canada, interpretation of their range has been confused by occasional misidentifications with another large, oddly-shaped shark, the Greenland shark (*Somniosus groenlandicus*). Since Greenland sharks are benthic sharks, very large sharks seen near the surface can usually be safely assumed to be basking sharks. For this reason, surface observations of basking sharks are probably the most reliable indicator of basking shark distribution in Atlantic Canada.

Aerial surveys and ship surface observations of whales and other marine mammals routinely record the presence of basking sharks when observed. Most of the aerial surveys have been for right whales in the Bay of Fundy and Gulf of Maine since 1977 during the summer (SEAMAP, Maritimes Region Cetacean Database, North Atlantic Right Whale Consortium), where numerous basking sharks have also been observed (Fig. 2a-c). Fig. 2c also includes documented observations by our staff or other reliable sources reporting to our lab in recent years. Fig. 2d shows the distribution of basking sharks on the Scotian Shelf, in the Gulf of St. Lawrence, and off Newfoundland and Labrador in July-Aug 2007 as recorded in DFO's TNASS aerial surveys for marine mammals. Together, these aerial and ship-based surface observations indicate that basking sharks are widely distributed in the Gulf of St Lawrence, off southern Newfoundland, on the Scotian Shelf and in the Gulf of Maine, at least during the summer months. Although the Newfoundland RV groundfish survey has captured only three basking sharks since 1971, one of those was caught in NAFO 2J at a latitude of 55.3°N, indicating that the distribution of basking sharks can occasionally extend north of Newfoundland.

Based on pop-up archival tags attached to basking sharks in both the northeast and northwest Atlantic, basking sharks are routinely associated with water temperatures of 8-16 °C, and have seldom (if ever) been seen at temperatures less than 6 °C (Compagno 2001; Sims et al. 2003, 2005; Skomal et al. 2004). Of 3,473 basking shark records with associated sea-surface temperatures (SST) in the NARWC database, only 17 (0.05%) were recorded at SST<6 °C, and 69 (2.0%) at SST<7 °C. Based on 78 basking sharks entangled in fishing gear off Newfoundland in 1982-1983, Barrington (2000) documented that virtually all of the sharks 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. Therefore, it seems that water temperature may set a limit for the distributional range of the basking shark, with 6-7 °C being the lower limit for habitat. If this is the case, maps of sea surface temperature (SST) could provide useful proxies for basking shark distributional range. Using 2007 as an example, but noting that temperature varies from year to year, SST in June would limit the northward extension of basking shark range to the Scotian Shelf, the southern Gulf of St Lawrence and the southern coast of Newfoundland (Fig. 3). By August (the warmest month), SST would allow the movement of basking sharks as far north as the northern tip of Newfoundland, but no further (Fig. 3).

In principle, observations by fisheries observers should provide a reliable source of information concerning basking shark occurrence in fisheries catches in Atlantic Canada. In practice, it appears that basking shark identifications are sometimes confused with those of Greenland sharks. Observer records from the Newfoundland and Maritimes Observer Programs suggest that basking sharks are often caught not only in the Gulf of St Lawrence, off the coast of Newfoundland and on the Scotian Shelf, but along the edge of the continental shelf and well up into Labrador (Fig. 4). The distribution of some of these catches reflects those of Greenland sharks recorded by observers, which tend to occur in deep, cold waters along the shelf edge and into the Arctic (Fig. 5). As a result, it appears likely that at least some of the observer records of basking sharks are actually Greenland sharks, especially those north of Newfoundland and those collected at the shelf edge and in water temperatures < 6°C.

While cold waters probably limit the northward extension of basking sharks into Canadian waters, there is no corresponding limit for the southward extent of their range in Canada. Indeed, the largest concentrations of basking sharks in Canada have been observed in the Bay of Fundy, near the Canada-U.S. border.

Basking sharks are known to occur, sometimes at high densities, in U.S. waters (Kenney et al. 1985; Skomal et al. 2004). Conventional tagging studies have provided no information on movement patterns or stock structure in the northwest Atlantic, presumably because most tag returns come from rod & reel and longline fisheries that seldom catch basking sharks (Kohler et al. 1998). However, recent studies in the northwest Atlantic using archival satellite popup (PAT) tags have provided some information (Skomal et al. 2004; Skomal 2005). Of three individuals that were tagged off Massachusetts, one migrated 800 km south to North Carolina (Skomal et al. 2004) and two migrated more than 1600 km to waters off of Florida and Jamaica, all over a period of less than five months (Skomal 2005). When these long migration paths are combined with the observed distribution of basking sharks in Atlantic Canada, it appears likely that Canadian basking sharks are part of the same population as basking sharks in the U.S.

The water depths occupied by basking sharks are relevant to the use of aerial surveys for estimating abundance. Only one study of basking shark depth habitat has been conducted in the northwest Atlantic (Skomal et al. 2004). In that study, an archival tag recorded that less than 10% of the time was spent in the upper 10 m of water. However, the study was conducted in the fall, a time of year when basking sharks are suspected to be spending more time at depth. In addition, the recording period was considerably later than the June-August period characteristic of Canadian aerial surveys. In the northeast Atlantic, 4 basking sharks spent an average of 36% of their time in surface waters between June-August (Sims et al. 2003). However, a subsequent analysis indicated that the proportion of the time spent at the surface was related to the characteristics of the water column and zooplankton prey, whereby basking sharks near frontal zones spent 60% of their time near the surface during the day, and <1% of their time near the surface when in well-stratified waters (Sims et al. 2005). It is unclear if these results can be generalized to other regions and systems.

The Emerald Basin on the Scotian Shelf is suspected to be a mating area for the population, but the pupping area remains unknown.

Trends and Current Status

The only assessment of abundance in U.S. waters estimated basking shark numbers at 6,700-14,300 off the New England coast and in the Gulf of Maine in 1979-1981 (Owen 1984).

An attempt was made to develop a time series of relative abundance for basking sharks in the Maritimes using CPUE in those fleets most likely to catch basking sharks – groundfish and redfish bottom trawls in the Scotia-Fundy observer database (Fig. 6). However, the data were too sparse and too variable to provide a useful index.

Aerial and Shipboard Surveys of Abundance

Trends in the relative abundance of basking sharks in the Bay of Fundy were assessed by using the number of observations of basking sharks seen during aerial surveys and shipboard surveys looking for right whales as collated by the North Atlantic Right Whale Consortium (NARWC) (Fig. 7). Relative abundance was quantified in terms of sightings per unit effort (SPUE), where SPUE=sharks per 1,000 km of qualifying effort on a 5-minute lat/long grid, by year (n = 2570).

The basking shark SPUE index varies considerably but suggests a relatively clear peak in abundance in 1998 followed by a rapid decline to near-zero levels in recent years (Fig. 8). These changes were too abrupt to be explicable by changes in overall population abundance, and were more likely attributable to changes in distribution due to oceanographic factors.

Basking shark SPUE indices for 7 sub-regions along the eastern seaboard were also calculated (Table 1a). Each panel in the table summarizes the data by year and season for one region; the regional definitions are given in the table headers. Effort in the table is in terms of kilometers.

SPUE indices were calculated as follows. All available survey data for all years from the NARWC dataset were extracted. Valid aerial and shipboard survey effort was defined as any track segment completed in at least 2 nautical miles visibility, with sea state of Beaufort 3 or lower, with altitude below 1200 feet (aerial only), and with at least one observer on watch. All valid effort tracks and basking shark sightings were partitioned into a 10-minute X 10-minute latitude-longitude grid, by year, season, and survey type (aerial or shipboard) and summed. Seasons were defined as Winter=Jan–Mar, Spring=Apr–Jun, Summer=Jul-Sep, and Fall=Oct–Dec. Only sightings made during valid survey effort and classified as “definite” or “probable” species IDs were included. Univariate statistical analysis was carried out on the aerial and shipboard effort distributions to define the quartile values of the respective data distributions. A subset of the data was then created, using only the cells with both aerial and shipboard effort greater than the first quartile (25th percentile) of their respective distributions. With that subset, a least-squares linear regression of shipboard SPUE versus aerial SPUE was run, with the regression forced through a zero intercept. The results of the regression analysis confirmed that shipboard surveys detect fewer basking sharks than aerial.

Shipboard SPUE = 0.293 (Aerial SPUE); SE = 0.022, $P < 0.0001$

Using only aerial survey data would have eliminated much of the available information for the Bay of Fundy, where shipboard effort predominates, therefore the regression results were used to scale the number of sharks sighted from shipboard surveys upwards by the inverse of the slope factor from the regression (3.42). The effort and numbers of sharks per cell were summed, and used to compute a new combined SPUE index as:

$$\frac{1000\ (\text{Aerial sharks} + 3.42\ (\text{Shipboard sharks}))}{\text{Total aerial and shipboard effort}}$$

The combined data were then partitioned into seven regions, the effort was summed by year and season and used to compute a mean SPUE by year and season, weighted by effort per cell.

Least-squares linear regressions of mean SPUE data versus year (Table 1a) were run for all 28 combinations of region and season (Table 1b). In no case did the results suggest a significant decline in relative abundance. Four of the indices—those for the Nova Scotian shelf in summer, southern Gulf of Maine in summer and the southeastern U.S. in winter and fall—showed statistically significant increasing trends ($P < 0.026$, allowing for multiple comparisons) (Table 1b, Fig. 9). There was no obvious inverse relationship between the SPUE indices in the Gulf of Maine and those in the Bay of Fundy. There was no way to distinguish between repeat sightings in these data, an issue which would affect shipboard surveys (which often involves numerous vessels) much more than aerial surveys (which are often limited to very few per year). Since the proportion of data originating from aerial surveys was low in the Bay of Fundy, the accuracy of the Bay of Fundy estimates may be lower than that of the other regions. However, this should not affect the temporal trend in observations within any given area.

As an alternate measure of relative abundance, we analyzed the number of basking shark observations in the NARWC database relative to the number of right whales observed. Since the observations of the two species were made as part of the same surveys, and involved (on average) the same observers, and given that the population size of right whales is known to be about 300-400 (of which an annual average of 123 unique whales has been observed in the Bay of Fundy since 1989), the ratio of observation numbers should provide an index of relative abundance of basking sharks. The relative index can be converted to an absolute index if the factors affecting the relative visibility of basking sharks compared to right whales can be quantified. Those factors would include the proportion of time spent at or near the surface, any recording bias towards right whales by individual observers, and the relative visibility of the two species once at the surface.

The number of basking sharks observed in Canadian waters during the right whale surveys peaked in the mid-1990s (Fig. 10). The Bay of Fundy accounted for the vast majority of the observations. The pattern for right whale observations was very similar (Fig. 11). As a result, there was no strong time trend in the ratio of basking shark: right whale observations (Fig. 12). The mean ratio across the years 1990-2005 was 0.17. Taken at face value, without accounting for the factors affecting the relative visibility of basking sharks compared to right whales, this would suggest that the number of basking sharks in the Bay of Fundy was 0.17 of 123, or about 21.

There is no doubt that the relative visibility of right whales is high compared to basking sharks, which would artifactually deflate the numbers of basking sharks. There are no published values relating right whale visibility to basking shark visibility, so the effects of somewhat arbitrary values were explored. With respect to proportion of time at the surface, the values are highly dependent on which values from Sims et al. (2003, 2005) are adopted. However, if the overall average of 36% from Sims et al. (2003) is used, this is probably roughly equivalent to the proportion of time spent at the surface by right whales in mid-summer. With respect to recording bias, anecdotal comments from whale observers indicate that most basking sharks are recorded when whales are absent, but that all attention is focused on whales when they are encountered, especially if they are in a group. Therefore, we have arbitrarily assumed that the bias was a factor of two. Finally, with respect to relative visibility while at the surface, we were guided by the fact that right whales can be observed at great distance when they breach, or when they spout. In contrast, basking sharks generally swim below the surface, and their dorsal fins stick out of the water only when the water is very calm. We assumed that a basking shark could only be observed from a ship within about 50 m, whereas the spout from a right whale could be observed more than 5 km away. The bias would be less from a plane, but the vast majority of observations from the Bay of Fundy in the NARWC database are ship-based. Arbitrarily then, we have assumed a surface visibility factor of 5000 m:50 m = 100. When combined with the recording bias factor of two, the relative visibility of right whales compared to basking sharks would be a factor of 2 x 1 x 100 = 200. This would suggest an average of 21 x 200 = 4200 basking sharks in the Bay of Fundy. An additional factor that we were unable to quantify is that right whales are strongly aggregated within a relatively small area of the Grand Manan Basin, while basking sharks are distributed more broadly beyond the area of the ship-based right whale surveys.

The absolute abundance of basking sharks on the south, east and north coast of Newfoundland and Labrador out to the edge of the continental shelf was estimated from data collected during DFO's Trans North Atlantic Sightings Surveys (TNASS) aerial survey of marine megafauna in 2007 (Fig. 13a). The Newfoundland and Labrador portion of the TNASS survey was conducted in an equal-angle, zigzag pattern, with no spatial overlap with the TNASS survey components of the Gulf of St. Lawrence and Scotian Shelf discussed below. A DeHavilland DH-6 Twin Otter aircraft with large bubble windows was used to complete a survey of 48,269 km of on-effort trackline. Three trained observers, one on each forward side of the aircraft and a third in the right rear noted weather conditions (sea state, glare from the sun, cloud cover) and sightings of marine megafauna. These sightings were recorded using a specialized software programme (VOR) operated by a fourth observer acting as data recorder and navigator. Observers rotated positions at the ends of transect lines The Twin Otter flew at an altitude of 183 m (600 ft), as determined with a radar altimeter, and groundspeed of 204 km/h (110 kt). Aircraft position and altitude from a GPS receiver was recorded automatically by the survey programme every 2 sec. An electronic temperature probe mounted in the belly of the aircraft recorded sea surface temperature data into the survey programme every two seconds (with data averaged from samples taken at 300 ms intervals by the probe). Sea surface temperature readings ranged between 4° and 14°C, and were validated against POES satellite data. The temperature probe system was calibrated before and after the survey using a known heat source in the laboratory and found to be within specifications for the device. The sea surface temperature values where the sharks were seen were 10 (northeast coast), 13, 13, 13, and 12 degrees C. Distance of sightings from the trackline were measured using an inclinometer (Suunto) as groups were passing abeam. Line transect density and abundance analyses were completed using Distance 5.0 (Thomas et al. 2006). Abundance and density were estimated without considering covariates and effective strip half-width was selected between half normal and hazard rate models using AIC. During this portion of the Canadian TNASS survey five lone basking sharks were sighted, with none in Labrador. Based on this limited sample size, effective strip half-width was estimated at 442 m with a CV of 93%. The overall estimate of basking sharks in the survey area was 201, with a 95% confidence interval of 42-970 animals. Assuming a 36% time at surface, the total basking shark number in the Newfoundland area was 558.

The absolute abundance of basking sharks on the Scotian Shelf and in the Gulf of St. Lawrence was estimated from DFO's TNASS aerial survey of marine megafauna in 2007, carried out in tandem with the Newfoundland and Labrador component of this aerial survey (Fig. 13b).

Stratification was based on the areas where concentrations of marine mammals have been detected in previous surveys, to be covered in the shortest time period, and to allow lines to be arranged perpendicularly to the isobaths. Lines in the St. Lawrence estuary from Rimouski to Île-aux-Coudres were 4 nm apart and perpendicular to the main axis of the estuary, similar to previous visual surveys for belugas in the area. All remaining lines were 10 nm apart and arranged to be perpendicular to the isobaths. Two Cessna 337 aircraft with bubble windows were used to complete the survey with each plane flying every second line of the systematic design. Two recorders, one in the rear left seat and one in the copilot seat, recorded conditions (sea state, glare from the sun, cloud overcast, and water colour) and sightings on audio tape recorders. Planes flew at a target altitude of 198 m (650 feet) and airspeed of 185 km/h (100 kt). Plane position and altitude from the GPS was recorded every 10 seconds with electronic map software (Fugawi). The GPS altitude output was used in the estimation of the perpendicular distance (note: average difference between GPS altitude reading and actual airport elevation was 1.7 m (n = 637, SD = 7.4 m, max = 36.7 m). Distance of sightings from the trackline were measured using an inclinometer (Suunto) as groups were passing abeam. Line transect density and abundance analyses were completed using Distance 5.0 (Thomas et al. 2006). Abundance and density were estimated without considering covariates and effective strip half-width was selected between half normal and hazard rate models using AIC.

A total of 23,458 km of lines was flown, including 9,111 km over the Scotian Shelf. There were 51 groups detected overall, including 33 groups on the Scotian Shelf. Although sightings were reported as groups, all basking sharks were detected as single individuals, except for one pair swimming within a few body lengths from each other on the Scotian Shelf. The effective strip half-width of 250 m (CV=0.10, 95% CI: 202-308) was estimated from the overall sighting distribution using the half normal model. The overall abundance estimate for the Gulf and Scotian Shelf was 1932 (CV=0.20, 95% CI: 1309-2852). For the Scotian Shelf, the estimate was 1254 (CV=0.24, 95%CI: 781-2012). Assuming that basking sharks spend an average of 36% of their time at the surface (Sims et al. 2003), the total number of basking sharks present on the Scotian Shelf and in the Gulf of St. Lawrence during the summer of 2007 was 5,367.

A visual estimate of basking shark numbers in the Bay of Fundy during the summer of 2007 is not currently available, although the U.S. National Marine Fisheries Service conducted surveys as part of the TNASS project that extended into the lower Bay of Fundy. Assuming that Bay of Fundy and Scotian Shelf numbers are independent (which they are probably not), the total number in Atlantic Canadian waters in 2007 was 4,200 + 558 + 5,367 = 10,125. This estimate is subject to a number of assumptions, particularly that associated with the proportion of time at the surface, and thus is highly uncertain.

Bycatch

There is no directed fishery for basking sharks in Canadian waters. However, there are observer records of basking sharks caught in commercial fisheries. The observer program has maintained 100% coverage of foreign vessels in Canadian waters since 1987, allowing a straight forward determination of foreign basking shark discards. However, observer coverage is typically less than 5% of the domestic fishery, thus requiring that the observer data be scaled to reported landings. Therefore, the observer coverage was stratified by fishery, region, season and year to estimate the total discards of basking shark, similar to the method that was used to estimate the bycatch of blue sharks in the pelagic longline fishery (Campana et al., 2002, 2005).

Data on basking shark catches were obtained from a combination of the Scotia-Fundy and Newfoundland observer program databases, which span the period 1978-2007. These data include observations from the Scotia-Fundy area, the Gulf of St. Lawrence and Newfoundland. Based on observed catches, data were stratified into relatively homogeneous fishery components: 1) silver hake fishery; 2) groundfish trawl fishery; 3) groundfish longline fishery; 4) redfish fishery; 5) shrimp fishery; 6) turbot fishery; 7) squid fishery; 8) tuna and shark longline fishery. Data were further stratified by fishing nation (Canada or foreign), area (NAFO 4VWX5Z, 3Pn4RST, and 2J3KLNOPs), quarter of each calendar year, and year of observed catch. The observer programs have maintained almost complete coverage of foreign vessels in Canadian waters since 1987, allowing a straight forward determination of foreign basking shark discards. Observer coverage on domestic vessels has typically been less than 5%. For the domestic fisheries, the ratio between observed basking shark discards and observed target species catch was first calculated for each fishery and strata from the IOP data. Total reported landings of the target species were then calculated for each fishery and strata from ZIF and MARFIS data sources. The ratios of observed basking shark discards to observed target species kept were multiplied by reported landings for the same fishery and strata to estimate total basking shark discards. An example of the discard calculation is shown in Table 2.

Most of the observed foreign catch of basking sharks came from vessels fishing for silver hake, and to a lesser extent, redfish (Tables 3a-c, 5). Basking shark catch peaked in the 1980s and early 1990s at about 150 mt per year, but has averaged only a few mt annually since 2000 as a result of the near-exclusion of foreign vessels fishing in the Canadian EEZ. The average since 1986 has been 35 mt (Table 5).

Observed domestic catches of basking sharks in Scotia-Fundy also peaked in the 1980s and 1990s, averaging about 10 mt per year across all fleets (Tables 4a-e). Most of this observed catch was in the redfish and groundfish trawl fisheries on the Scotian Shelf (Fig. 14). When scaled to total landings, estimated basking shark discards averaged 122 mt annually in the Scotian Shelf groundfish trawl fishery between 1986-1996, and considerably less in the other fisheries (Tables 4a-e; Fig. 14). Estimated discards in Newfoundland waters were largest in the most northerly areas (NAFO 2GHJ3K), which may suggest misidentification of Greenland sharks. Therefore, the original paper records of each of the 430 captures were examined to determine if they were likely to have been basking or Greenland sharks. Catches in cold waters (eg- Nov to Mar) or catch weights of less than 150 kg were assumed to have been Greenland sharks. This left only 35 records of basking sharks, which averaged 4 mt annually if two anomalously-high values are excluded (Table 5). Considering all regions and fisheries, estimated basking shark discards peaked at 741 mt in 1990 and have averaged 164 mt annually since 1986 (Table 5; Fig. 15). In general, most of the basking sharks have been caught in Scotia-Fundy domestic fisheries (Fig. 15).

International observers recorded the estimated weight of basking sharks caught in each set, but not the numbers. In order to convert weights to numbers, the average weight of the individual sharks must be known. The distribution of set weights in both the Scotia-Fundy and Newfoundland data sets was highly skewed, with similar means of about 1725 kg (Fig. 16). Mean set weights remained relatively constant through time, with the exception of an increase in the early 1990s (Fig. 16c). Due to the skewness in the weight data, median weight values should be more appropriate for use in calculating discard numbers than mean values. Median discard weights were 1000 kg in the Scotia-Fundy observer data, but only 500 kg in the Newfoundland data. To explore the possibility that the Newfoundland weight data might include measurements of (smaller) Greenland sharks, the analysis was repeated using only observations south of the northern tip of Newfoundland (latitude 51 °N). The calculated Newfoundland median weight increased to 1000 kg, identical to that of Scotia-Fundy. Accordingly, a median weight of 1000 kg was used to calculate discard numbers from discard weights. The resulting discard numbers are shown in Table 5, and have averaged 164 basking sharks annually since 1986.

It is possible that bycatch is somewhat larger than estimated, since there has been little in the way of observer coverage of inshore fishing gear such as gill nets and cod traps. Estimates from fishers participating in a voluntary reporting network indicate that a total of about 370 basking sharks was captured by inshore fishing gear in coastal waters of Newfoundland from 1980 to 1983 (Lien and Fawcett 1986). Inshore fishing effort in coastal Newfoundland has declined substantially since the 1990s. However, inshore fisheries remain important throughout eastern Canada and few of these fisheries have observer coverage.

Sustainable Mortality Rate

Life table analysis uses age-structured estimates of survival rate, sexual maturation and fecundity to project population growth under various scenarios. It is well suited for use in sharks given their well-defined reproductive cycle and high rates of survival (Cortés 1998). In this case, we used life table analysis to estimate both the intrinsic rate of population growth (*r*) and the critical or human-induced mortality (F_{crit}) at which population growth is zero. The following life history parameters were assumed for a deterministic base run:

> M = 0.068 as per Pauly (2002)
> $M_{age\ 0}$ = 0.136 (= 2*M) (assumption)
> Age at maturity = 18 yr as per UK CITES proposal (2002)
> Longevity = 50 yr as per Pauly (2002)
> Fecundity = 6 pups over a 3-yr gestation period, with 50% female as per Compagno (2001)
> Lag between parturition and becoming pregnant = 0 (assumption)
> Selectivity (assumed knife edge) = 2

Three methods of estimating the intrinsic rate of population growth from life table data are: the generation time method, the Leslie matix projection method and the Euler-Lotka method (McAllister et al. 2001). The generation time method is known to be inaccurate for some life histories (McAllister et al. 2001). A requirement of the Leslie matrix method is that the population converges to a stable age structure when projected into the future, a requirement that was not met with this set life history parameters, as well as for some sets of parameters used in the population simulations of extinction risk (see below). Rather than converging to a single estimate of *r*, a repeating series of numbers was at times obtained. Comparison of the estimates of *r* obtained from Euler-Lotka method with those obtained from the Leslie matrix projection method indicated that the estimates from the Euler-Lokta method were the same as the average values of the repeating series of numbers from the Leslie matrix projection method. The Euler-Lotka method was adopted for these reasons. Using the Euler-Lotka method, r is approximated using the following 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 cannot be solved analytically, so a computer search algorithm implemented in S-Plus was used. The S-Plus code is provided in Appendix 1.

Given the above life history parameters, the life table analysis indicated that the intrinsic rate of population growth (r) in an unfished population is 0.040, that a newly born female basking shark is expected to produce 3.17 female offspring throughout its life, and that its annual reproductive rate (the number of spawners produced by each spawner per year, after a lag of a years, where a is the age at maturity - Myers et al. 1999) is 0.208. This latter value is very low compared to most fishes (Myers et al. 1999), and indicates that the basking shark population is intrinsically unproductive and slow to recover from stock depletion. The estimate of r of 0.040 is higher than the value of 0.02 reported in the UK CITES proposal (2002). The reason for this difference appears to lie in the assumption of M=0.091 used in the CITES calculation (the source of this value of M is not described, nor is its basis clear), and the non-standard use of r_{msy} in the CITES calculation (r = 2*r_{msy} for standard logistic growth).

Also based on a life table analysis, we estimated the value of a limit reference point, F_{crit}, defined as the fishing mortality rate above which the population would be driven to extinction. This value was estimated by finding the value of the instantaneous fishing mortality rate, F, such that the net reproductive rate equals one:

$$\sum_{x=0}^{A} m_x l_x = 1 .$$

In this equation, survivorship is given by:

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

The solution to this algorithm is also found using a computer search algorithm implemented in S-Plus (Appendix 1).

Based on our life history parameters and assuming that fishing selectivity is knife-edged at age-2, F_{crit} is estimated to be 0.043.

Finally, we estimated N_{crit}, defined as the size of the population that would be required such that, given the average number of removals from the population, F would equal F_{crit}. This value given by:

$$N_{crit} = \frac{removals}{1-\exp(-F_{crit})} \frac{\sum_{x=0}^{A} l_x}{\sum_{x=sel}^{A} l_x} .$$

The second half of the equation corrects for the proportion of the population that is subject to fishing mortality, and is appropriate when selectivity is knife-edged. The annual mean number of discards is 164 sharks (Table 5). Again, assuming that fishing selectivity is knife-edged at age-2 and assuming 100% mortality of discards, this would suggest that the size of the population which could support the estimated number of discards would be 4,798 sharks. If discard mortality was less than 100%, N_{crit} would be smaller. If there were sources of mortality, such as inshore fishery sectors or boat strikes, not captured in the discard analysis, the required population size would have to be larger.

Recent population trends and extinction risks

Using an approach similar to Caswell *et al*. (1998) for western north Atlantic harbor porpoise, and Dans *et al.* (2003) for dolphins off Patagonia, Argentina, a demographic analysis of basking shark in the western north Atlantic was carried out to determine the risk of decline and extinction under incidental fishing-induced mortality. This approach uses Monte Carlo methods to calculate uncertainty in the potential population growth rate and in recent abundance trends. The Caswell *et al.* (1998) study used a model life table approach in which life tables for various species, adapted in ways that would plausibly make them fit the harbor porpoise life history, were used to obtain a distribution of survivorship curves $l(x)$ which were then randomly re-sampled. Given the unusual life-history of basking shark and hence the paucity of data for similar species, we took a simpler approach in which we assumed minimum and maximum values for each life history parameter, sampled from uniform distributions defined by these limits, estimated *r* for each combination of parameter values, and used the resulting distribution of estimates of *r* in the following analysis.

Given that the western north Atlantic population of basking shark is considered to be at low population size and potentially a species at risk, we ignored density dependence and apply an exponential population growth model,

$$\frac{dN}{dt} = rN ,$$

where *N* is population size and *r* is the intrinsic rate of natural increase (population growth rate for a stable age composition at low population size where density dependent compensation is negligible). In our simulation model, *r* is determined by the life expectancy (maximum age in the population), age at first reproduction, sex ratio, litter size, gestation period, lag between parturition and next pregnancy, and the annual natural mortality rate. Assuming exponential growth, the population size in one year (N_y) equals the population size in the previous year multiplied by *r*, minus the number of human-induced mortalities in the previous year (D_{y-1}):

$$N_y = e^r N_{y-1} - D_{y-1} .$$

This equation can be rearranged as:

$$N_{y-1} = \frac{(N_y + D_{y-1})}{e^r}.$$

Thus, if a time series of the number of human-induced mortalities is available, and *r* and the abundance in a single year are known, an abundance time series can be calculated using this equation. This assumes that birth and natural death processes occur first and that incidental deaths occur subsequently. This could slightly exaggerate the effect of incidental deaths relative to modeling these as a continuous process throughout the year. This is not considered an issue given the low demographic rates and the low numbers of incidental deaths.

Estimates of *r* (0.040), abundance in 2007 from aerial surveys (10,100 individuals), and annual mortalities from fishing were provided earlier in this document, but all of these values are quite uncertain. The aforementioned Monte Carlo method of sampling from assumed distributions for the input parameters was used to address this uncertainty. Uniform distributions (integer values only for population size, age-at-maturity and litter size, lag and maximum age) were assumed for each life history parameter and for population size in 2007 using the following bounds:

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)	0.058	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.

We then randomly drew values from the distributions for each of the life history parameters and calculated *r* using the Euler –Lotka method. Some of the resulting estimates of *r* were less than 0, and some appeared unrealistically high. We reviewed estimates of *r* for 39 species of sharks obtained by Cortés (2002). In his analysis, larger sharks tended to have lower values of *r* than smaller sharks. The median value of *r* for the 21 species with a maximum length greater than 2 m was 0.057. Given the large size, and late age-at-maturity of basking shark, we believed that it was unlikely that basking shark would have a reproductive rate greater than half the shark species in this size category. We therefore choose 0.057 as the upper threshold value of *r* in the simulations based on this reasoning. Simulations that produced values of r that were above this threshold or less than zero were discarded.

A set of 1,000 values of *r* were generated using this method. For each value of *r*, we then drew a random value for N_{2007}, and back-calculated an abundance time series using the estimates of fishing-induced mortalities. We then fit an exponential decay model,

$$\ln(N_y) = \alpha + \beta y ,$$

to the abundance time series to determine whether it was increasing or decreasing (β is the instantaneous rate of change in population size, positive values indicate an increasing population). The S-Plus code for this analysis is provided in Appendix 1.

The results of this analysis for the base model run are shown in Figure 17. The histograms for the population size in 1986, the population size in 2007, *r* and the instantaneous rate of change in the population size show the uncertainty in both past and present population sizes as well as the uncertainty in *r*. This uncertainty carries over into the analysis of trends, with 23% of the simulated populations showing declines over the period 1986-2007. The median estimate of *r* from the Monte Carlo analysis is 0.032, which is lower than the deterministic estimate based on fixed inputs. The median value of the estimate of N_{crit} (Table 6) is slightly higher than the value obtained from the deterministic calculation; similarly the median value for F_{crit} is lower. These results are sensitive to input values. For example, the possibility exists that the number of human induced mortalities was underestimated. We evaluated the impact of this possibility by repeating the analysis with the annual number of discards doubled. In this case, the percentage of simulated populations showing a decreasing trend increased to 64% (Table 6). Note that in these simulations, most of the decline is earlier in the time series followed by only slight increases, decreases or near-stability in recent years (Figure 18). Additionally, the model output is sensitive to the range of values assumed for the population size in 2007; when lower values were used, a larger proportion of simulated populations showed a decline (Table 6). As expected, changing life history parameters in a way that increases *r* has the effect of decreasing the proportion of populations showing a decline, whereas changing inputs such that *r* is decreased or removals are increased has the effect of increasing the proportion of populations showing a decline. Interestingly, the results are also somewhat sensitive to the pattern of the removals. If the average number of removals is removed each year, the percentage of populations showing a decline decreases to 19% (Table 6). If the age of selectivity to the fishery is increased, the resulting estimates of N_{crit} are also increased. Additionally, we investigated the effect of truncating the distribution of r at 0.057 by repeating the base model run without this truncation, although the truncation at $r = 0$ was maintained. The median value of r obtained in this scenario was 0.036, and 20.5% of the simulated populations showed a declining trend.

Conclusions

The life history characteristics of basking sharks are inadequately known, and key parameters such as growth rate, natural mortality and fecundity are assumed rather than measured. However, there is little doubt that the species is relatively unproductive and incapable of sustaining even modest mortality rates.

Basking shark distribution appears to be restricted to temperatures between 6-16 °C, which implies that observations of basking sharks north of Newfoundland and in cold waters elsewhere are likely to be misidentifications of Greenland sharks.

There is no directed fishery for basking sharks in Canadian waters. Observed bycatch in foreign fisheries peaked in the 1980s and early 1990s at about 150 mt per year, but has averaged only a few mt annually since 2000. Basking sharks are caught incidentally in domestic fisheries, with most observed bycatches having occurred in groundfish and redfish trawl fisheries. When scaled to total landings, total estimated bycatch has averaged 164 mt annually (corresponding to 164 basking sharks) since 1986.

It is possible that bycatch is somewhat larger than estimated, since there has been little in the way of observer coverage of inshore fishing gear such as gill nets and cod traps.

None of the existing fish surveys provide an abundance index for basking sharks. An annual index derived from surveys for right whales in the Bay of Fundy indicated a sharp increase in abundance in the 1990s, followed by an equally abrupt decline to 2000. The apparent change in abundance was likely due to changes in distribution due to oceanographic factors, rather than mortality.

Estimates of absolute basking shark abundance from aerial surveys of whales in the Bay of Fundy, the Scotian Shelf/Gulf of St. Lawrence and Newfoundland waters suggest numbers of 4,200, 5340 and 560 respectively, for a total of 10,100 in the summer of 2007. These estimates are uncertain due to the number of assumptions that were invoked.

A deterministic life table analysis indicated that the intrinsic rate of basking shark population growth (*r*) in an unfished population is 0.040. With F_{crit}= 0.043, and the annual mean number of discards being 164, and assuming 100% mortality of discards, this would suggest that the average population size which could support the estimated number of discards N_{crit} would be about 4,800 sharks. The best available estimate of population size for 2007 is about 10,100, which has a high level of uncertainty, but is still above N_{crit}. The Monte Carlo simulation model results indicate a median value of *r* of 0.032, of F_{crit} of 0.035 and of N_{crit} of about 5900 sharks, the latter value still being less than the 2007 population size estimate. The results of this population model, which are consistent with the results of the life table analysis, suggest a 23% probability (about a 1-in-5 chance) that the population is decreasing, although the uncertainty associated with the model inputs is large. This result is more or less consistent with SPUE indices in U.S. waters that show no evidence of a decline since 1979.

Given the life history characteristics of the basking shark, high discard mortality associated with bycatch could lead to population collapse. Therefore it is important that basking shark bycatch continue to be monitored. Measures to improve species identification accuracy in the observer program, record the numbers of individuals and sex in the bycatch, and to reduce discard mortality would be useful.

Future Research

Aerial surveys of the Bay of Fundy and/or Scotian Shelf were conducted by NMFS on six occasions since 1995. Analysis of these data, along with any bycatch and abundance estimates, would improve the estimates of population size.

Biological sampling of fish taken as bycatch and associated research to better estimate the biological characteristics of basking sharks (ie- age at maturity, longevity, fecundity) would allow more realistic values to be used.

Acknowledgements

We thank Travis Shepherd and Dan Ricard for extracting and summarizing the commercial discards, and Kurtis Trzcinski for his detailed review of the population model. The data from U.S. waters were provided by the North Atlantic Right Whale Consortium. The aerial surveys in 2007 were funded by Canada's International Governance, Species at risk (SARCEP) and the Center of Expertise in Marine Mammalogy (CEMAM), and were part of an international survey effort of the north Atlantic (TNASS) coordinated by NAMMCO.

Literature Cited

Barrington, K.A. 2000. An ecological model for the basking shark, *Cetorhinus maximus* (Gunnerus), using water temperature, calanoid copepod characteristics and shark entrapments as indicators of basking shark movement in Newfoundland, Canada. BSc. Hon Thesis, Dept. of Biology, Memorial University, St. John’s, Newfoundland. 41p.

Bigelow, H. B. and Schroeder, W. C. 1953. Fishes of the Gulf of Maine. U.S. Fish Wildl. Serv. Fish. Bull. 74, Vol. 53: 577 p.

Campana, S., Gonzalez, P., Joyce, W., and Marks, L. 2002. Catch, bycatch and landings of blue shark (*Prionace glauca*) in the Canadian Atlantic. CSAS Res. Doc. 2002/101. 40 p.

Campana, S., Marks, L., Joyce, W., and Kohler, N. 2005. Catch, bycatch and indices of population status of blue shark (*Prionace glauca*) in the Canadian Atlantic. Col. Vol. Sci. Pap. ICCAT, 58: 891-934.

Caswell, H., Brault, S., Read, A.J., and Smith, T.D. 1998. Harbor porpoise and fisheries: uncertainty in analysis of incidental mortality. Ecol. Appl. 8:1226-1238.

CITES 2002. Consideration of proposals for amendment of Appendices I and II. Proposal: Inclusion of Basking Shark (Cetorhinus maximus) on Appendix II of CITES. Prop. 12.36.

Compagno, L. J. V. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Volume 2: Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). FAO Species Catalogue for Fisheries Purposes No. 1, Vol. 2: 269 p. Food and Agriculture Organization of the United Nations. Rome. 269 p.

Cortés, E. 1998. Demographic analysis as an aid in shark stock assessment and management. Fish. Res. 39:199-208.

Cortés, E. 2002. Incorporating uncertainty into demographic modeling: application to shark populations and their conservation. Conser. Biol. 16:1048-1062.

Dans, S.L., Koen Alonso, M., Pedraza, S.N., and Crespo, E.A. 2003. Incidental catch of dolphins in trawling fisheries off Patagonia, Argentina: can populations persist? Ecol. Appl. 13:754-762.

Gore, M. A., Rowat, D., Hall, J., Gell, F. R., and Ormond, R. F. 2008. Transatlantic migration and deep mid-ocean diving by basking shark. Biol. Lett. doi 10.1098/rsbl.2008.0147.

Harvey-Clark, C. J., Stobo, W. T., Helle, E., and Mattison, M. 1999. Putative mating behaviour in basking sharks off the Nova Scotia coast. Copeia 1999:780-782.

Kenney, R. D., Owen, R. E., and Winn, H. E. 1985. Shark distributions off the northeast United States from marine mammal surveys. Copeia 1985:220-223.

Kohler, N. E., Casey, J. G., and Turner, P. A. 1998. NMFS cooperative shark tagging program, 1962-93: an atlas of shark tag and recapture data. Mar. Fish. Rev. 60:1-87.

Lien, J. and Fawcett, L. 1986. Distribution of basking sharks, *Cetorhinus maximus*, incidentally caught in inshore fishing gear in Newfoundland. Can. Field-Nat. 100:246-252.

Martin, R. A. and Harvey-Clark, C. 2004. Threatened fishes of the world: *Cetorhinus maximus* (Gunnerus 1765) (Cetorhinidae). Env. Biol. Fish. 70:122.

Matthews, L.H. 1950. Reproduction in the basking shark (*Cetorhinus maximus*, Gunner). Proc. Zool. Soc. Lond. 120:535-587.

McAllister, M. K., E. K. Pikitch, and E. A. Babcock. 2001. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. Can. J. Fish. Aquat. Sci. 58: 1871-1890.

Mollet, H. (2001) Demographic analysis of the basking shark Cetorhinus maximus (Gunnerus, 1765). Website publication: http://homepage.mac.com/mollet/cm/demography.html

Myers, R. A., Bowen, K. G., and Barrowman, N. J. 1999. Maximum reproductive rate of fish at low population sizes. Can. J. Fish. Aquat. Sci. 56:2404-2419.

Natanson, L. J., Wintner, S. P., Johansson, F., Piercy, A., Campbell, P., de Maddalena, A., Gulak, S. J. B., Human, B., Fulgosi, F. C., Ebert, D. A., Hemida, F., Mollen, F. H., Vanni, S., Burgess, G. H., Compagno, L. J. V., and Wedderburn-Maxwell, A. 2008. Ontogenetic vertebral growth patterns in the basking shark *Cetorhinus maximus*. Mar. Ecol. Prog. Ser. 361267-278.

Owen, R.E. 1984. Distribution and ecology of the basking shark *Cetorhinus maximus* (Gunnerus 1765). M.S. Thesis. University of Rhode Island, Kingston, RI. 80 p.

Parker, H. W. and Stott, F. C. 1965. Age, size and vertebral calcification in the basking shark, *Cetorhinus maximus*. Zool. Mededelingen Rijk. Natuur. Hist. Leiden 40:306-319.

Pauly, D. 2002. Growth and mortality of basking shark *Cetorhinus maximus* and their implications for management of whale sharks *Rhincodon typus*. P. 199-208. In: Fowler, S. L., Reid, T., and Dipper, F. A. [eds] Elasmobranch biodiversity: conservation and management. Occ. Papers IUCN Survival Commission 25. Gland, Switzerland.

Sims, D. W., Southall, E. J., Quayle, V. A., and Fox, A. M. 2000. Annual social behaviour of basking sharks associated with coastal front areas. Proc. R. Soc. Lond. B 267:1897-1904.

Sims, D. W., Southall, E. J., Richardson, A. J., Reid, P. C., and Metcalfe, J. D. 2003. Seasonal movements and behaviour of basking sharks from archival tagging: no evidence of winter hibernation. Mar. Ecol. Prog. Ser. 248:187-196.

Sims, D. W., Southall, E. J., Tarling, G.A. and Metcalfe, J. D. 2005. Habitat-specific normal and reverse diel vertical migration in the plankton-feeding basking shark. J. Anim. Ecol. 74:755-761.

Skomal, G. B., Wood, G., and Caloyianis, N. 2004. Archival tagging of a basking shark, *Cetorhinus maximus*, in the western North Atlantic. J. Mar. Biol. Ass. U.K. 84:795-799.

Skomal, G. B. 2005. Basking shark tagging update. Mass. Div. Mar. Fish., DMF News. 25:6.

Smith, S. E., Au, D. W., and Show, C. 1998. Intrinsic rebound potentials of 26 species of Pacific sharks. Mar. Freshwater Res. 49:663-678.

Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H., Bishop, J.R.B. and Marques, T.A. 2006. Distance 5.0. Release “x”1. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

United Kingdom CITES Proposal. 2002. Inclusion of the basking shark (*Cetorhinus maximus*) on Appendix II of CITES. Conference to the Parties, Proposal 12.36.

Wallace, S., S. Campana, G.S. McFarlane, J. King. 2005. COSEWIC Status Report on Basking Shark (*Cetorhinus maximus*). Prepared for the Committee on the Status of Endangered Wildlife in Canada, May 2005.

Table 1a. Effort-corrected relative abundance of basking sharks based on aerial and ship-based surveys for right whales by region and season along the Atlantic coast of North America, Fall 1978 through 2006.

REGION = Bay of Fundy. East of the Hague Line (approximated), northwest of Nova Scotia, and north of 44°N.

	Winter		**Spring**		**Summer**		**Fall**	
Year	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**
1978	na	0	na	0	na	0	na	0
1979	0.0	32	0.0	135	3.6	277	0.0	116
1980	na	0	na	0	8.5	827	na	0
1981	0.0	70	0.0	75	na	0	na	0
1982	na	0	na	0	na	0	na	0
1983	na	0	na	0	na	0	na	0
1984	na	0	na	0	na	0	na	0
1985	na	0	na	0	na	0	na	0
1986	na	0	na	0	na	0	na	0
1987	na	0	na	0	1.2	2824	0.0	452
1988	na	0	na	0	4.5	1504	0.0	147
1989	na	0	na	0	9.8	1744	0.0	266
1990	na	0	na	0	231.8	2355	71.3	96
1991	na	0	na	0	70.9	3319	6.0	567
1992	na	0	na	0	63.4	2746	0.0	107
1993	na	0	na	0	121.8	980	na	0
1994	na	0	0.0	359	59.8	5654	na	0
1995	na	0	na	0	33.2	7199	36.7	465
1996	na	0	na	0	59.0	7654	38.0	179
1997	na	0	0.0	365	62.8	10740	7.3	3896
1998	na	0	0.0	452	257.3	7299	19.4	352
1999	na	0	2.5	1181	32.7	5908	0.0	176
2000	na	0	4.3	793	48.2	9980	62.6	436
2001	na	0	7.5	455	33.3	8736	0.0	708
2002	na	0	0.0	1066	20.3	13716	27.1	310
2003	na	0	0.0	346	32.5	6486	0.0	148
2004	na	0	0.0	325	51.2	2286	0.0	93
2005	0.0	195	0.0	142	13.4	2434	0.0	218
2006	0.0	125	0.0	10	33.1	2996	10.7	560

Table 1a – continued.

REGION = Nova Scotian Shelf. East of the Hague Line (approximated), southwest of Nova Scotia and south of 44°N or southeast of Nova Scotia (includes the Northeast Peak of Georges Bank).

	Winter		Spring		Summer		Fall	
Year	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**
1978	na	0	na	0	na	0	na	0
1979	0.0	672	4.6	2369	0.0	2627	0.0	1156
1980	0.0	1701	9.9	2222	5.0	5161	1.5	653
1981	0.0	1141	0.0	550	0.0	248	na	0
1982	na	0	na	0	na	0	na	0
1983	na	0	na	0	na	0	na	0
1984	na	0	na	0	na	0	na	0
1985	na	0	na	0	na	0	na	0
1986	0.0	15	0.0	211	na	0	na	0
1987	na	0	na	0	0.5	1934	0.0	117
1988	na	0	na	0	0.0	1341	na	0
1989	na	0	na	0	2.7	1275	na	0
1990	na	0	na	0	0.0	522	na	0
1991	na	0	na	0	0.0	2011	0.0	894
1992	na	0	5.8	1035	5.7	2940	na	0
1993	na	0	na	0	0.0	517	na	0
1994	na	0	na	0	0.7	1468	na	0
1995	na	0	na	0	0.0	5054	na	0
1996	na	0	na	0	0.0	474	na	0
1997	na	0	na	0	0.0	3702	0.0	617
1998	na	0	0.5	1911	1.8	8366	0.0	78
1999	na	0	17.3	1790	0.0	5991	na	0
2000	na	0	4.2	2613	5.3	2697	na	0
2001	na	0	0.7	1434	8.9	1976	0.0	707
2002	0.0	51	0.7	2557	5.7	3279	1.7	598
2003	na	0	6.6	2258	5.0	2397	2.6	769
2004	0.0	108	3.6	2535	1.9	1618	2.8	1088
2005	0.0	1154	0.0	847	3.5	3431	0.0	1332
2006	0.0	958	5.6	1259	12.6	1489	1.0	1000

Table 1a – continued.

REGION = Northern Gulf of Maine. West of the Hague Line (approximated) and north of 43°N.

	Winter		Spring		Summer		Fall	
Year	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**
1978	na	0	na	0	na	0	na	0
1979	0.0	750	21.8	1379	2.8	1795	0.0	1542
1980	0.0	992	31.3	957	5.5	2763	0.0	512
1981	0.0	312	0.0	774	na	0	na	0
1982	na	0	na	0	na	0	na	0
1983	na	0	na	0	na	0	na	0
1984	na	0	na	0	na	0	na	0
1985	na	0	na	0	na	0	na	0
1986	na	0	na	0	na	0	na	0
1987	na	0	na	0	0.0	40	na	0
1988	na	0	na	0	0.0	84	na	0
1989	na	0	na	0	0.0	48	na	0
1990	na	0	na	0	0.0	28	0.0	11
1991	na	0	na	0	4.8	706	0.0	548
1992	na	0	na	0	18.0	1322	na	0
1993	na	0	na	0	111.6	31	na	0
1994	na	0	na	0	0.0	22	na	0
1995	na	0	na	0	2.9	2387	na	0
1996	na	0	na	0	0.0	314	na	0
1997	na	0	na	0	22.8	817	0.0	131
1998	na	0	24.9	322	0.0	1235	0.0	1267
1999	0.0	327	5.9	3711	0.0	40	na	0
2000	0.0	88	20.3	1723	4.3	470	na	0
2001	0.0	227	1.6	1924	58.3	309	na	0
2002	na	0	0.0	2407	3.4	2636	1.0	967
2003	na	0	6.4	3904	4.2	710	1.6	1988
2004	0.0	133	6.1	3603	15.9	1412	0.5	2059
2005	0.0	1381	0.8	2485	11.9	2531	1.9	1598
2006	0.0	2305	5.4	1287	17.2	1904	6.7	1934

Table 1a – continued.

REGION = Southern Gulf of Maine. West of the Hague Line (approximated), south of 43°N, and east of 70°W from Cape Cod south.

	Winter		Spring		Summer		Fall	
Year	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**
1978	na	0	na	0	na	0	na	0
1979	0.0	3660	0.8	7431	0.9	5453	0.4	4815
1980	0.0	7155	3.6	17375	5.0	8940	0.0	6098
1981	0.0	3279	1.6	14019	0.7	5760	0.9	2325
1982	0.0	226	na	0	na	0	na	0
1983	na	0	na	0	na	0	na	0
1984	na	0	6.0	1334	na	0	na	0
1985	na	0	4.0	4009	na	0	na	0
1986	0.0	893	10.4	1922	na	0	na	0
1987	0.0	373	8.6	4752	17.6	1021	na	0
1988	0.0	1111	3.5	8255	na	0	na	0
1989	0.0	564	12.3	8666	na	0	na	0
1990	0.0	288	0.0	37	7.2	278	na	0
1991	0.0	110	23.4	3334	1.4	8393	8.4	2018
1992	0.0	421	9.1	3825	8.9	1120	na	0
1993	na	0	20.5	549	1.2	800	na	0
1994	na	0	na	0	na	0	na	0
1995	na	0	na	0	12.6	2980	na	0
1996	na	0	na	0	na	0	na	0
1997	0.0	1860	4.2	2411	10.3	998	na	0
1998	0.0	11589	6.7	11744	1.4	2517	2.5	3217
1999	0.0	10958	27.6	35051	0.0	540	0.0	258
2000	0.0	11597	15.4	26190	5.6	1325	0.0	817
2001	0.0	9325	36.3	38391	27.0	2634	0.0	559
2002	0.1	11769	10.4	21814	12.6	7913	0.0	4231
2003	0.0	7696	12.0	27944	36.0	4144	4.0	3994
2004	0.0	13613	8.2	20117	28.5	2087	0.5	8196
2005	0.1	18145	1.1	44675	40.4	10265	3.6	4686
2006	0.0	20223	4.2	19024	14.1	3618	2.3	3478

Table 1a – continued.

REGION = Mid-Atlantic Bight. North of 37°N and west of 70°W.

	Winter		Spring		Summer		Fall	
Year	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**
1978	na	0	na	0	na	0	0.0	1594
1979	0.0	5427	0.7	7170	1.0	8137	0.0	7506
1980	0.0	3885	18.8	9786	9.5	8538	0.0	3554
1981	0.0	2326	9.1	5140	0.2	4120	0.0	2857
1982	0.0	433	na	0	na	0	na	0
1983	na	0	na	0	na	0	na	0
1984	na	0	na	0	na	0	na	0
1985	na	0	na	0	na	0	na	0
1986	0.0	104	16.7	204	na	0	na	0
1987	na	0	na	0	na	0	na	0
1988	na	0	0.0	11	na	0	na	0
1989	na	0	0.0	486	na	0	na	0
1990	na	0	na	0	na	0	na	0
1991	na	0	na	0	0.0	7301	0.0	370
1992	na	0	0.0	108	0.0	120	na	0
1993	na	0	na	0	na	0	na	0
1994	na	0	na	0	na	0	na	0
1995	na	0	na	0	0.0	6032	na	0
1996	na	0	na	0	na	0	na	0
1997	na	0	na	0	0.0	19	na	0
1998	na	0	12.0	581	0.0	2327	0.0	3113
1999	0.0	2530	0.0	5852	0.0	559	na	0
2000	0.0	1485	0.6	1600	na	0	na	0
2001	0.0	82	0.3	3237	na	0	na	0
2002	0.0	846	2.0	3564	4.4	1574	0.0	1259
2003	na	0	6.0	3165	6.7	1631	54.1	796
2004	0.0	703	34.0	2529	0.0	109	0.0	1770
2005	0.0	8937	2.0	6573	2.2	1792	1.4	4230
2006	0.0	1323	2.9	1396	3.2	631	3.8	1325

Table 1a – continued.

REGION = North Carolina/Virginia. Between 33°N and 37°N.

	Winter		Spring		Summer		Fall	
Year	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**
1978	na	0	na	0	na	0	0.0	91
1979	0.0	1704	0.0	2286	0.0	2295	0.0	2674
1980	0.0	1202	0.0	2978	0.0	1722	0.5	1930
1981	na	0	na	0	na	0	na	0
1982	na	0	na	0	na	0	na	0
1983	na	0	na	0	na	0	na	0
1984	na	0	na	0	na	0	na	0
1985	na	0	na	0	na	0	na	0
1986	na	0	na	0	na	0	na	0
1987	na	0	na	0	na	0	na	0
1988	na	0	na	0	na	0	na	0
1989	na	0	na	0	na	0	0.0	269
1990	na	0	na	0	na	0	na	0
1991	0.0	1519	na	0	0.0	5249	0.0	2525
1992	2.8	6482	na	0	na	0	na	0
1993	na	0	na	0	na	0	na	0
1994	na	0	na	0	na	0	na	0
1995	na	0	na	0	0.0	270	na	0
1996	na	0	na	0	na	0	na	0
1997	na	0	na	0	na	0	na	0
1998	na	0	na	0	0.0	610	0.0	2909
1999	0.0	1257	0.0	1984	0.0	1354	na	0
2000	4.0	1497	na	0	na	0	na	0
2001	0.8	6196	na	0	na	0	na	0
2002	0.0	6845	na	0	na	0	na	0
2003	na	0	na	0	na	0	na	0
2004	na	0	na	0	na	0	na	0
2005	na	0	na	0	na	0	na	0
2006	na	0	na	0	na	0	na	0

Table 1a – continued.

REGION = Southeastern United States. South of 33°N.

	Winter		Spring		Summer		Fall	
Year	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**	**SPUE**	**Effort**
1978	na	0	na	0	na	0	na	0
1979	na	0	na	0	na	0	0.0	376
1980	0.0	29	na	0	0.0	641	na	0
1981	na	0	na	0	na	0	na	0
1982	na	0	na	0	na	0	na	0
1983	na	0	na	0	na	0	na	0
1984	na	0	na	0	na	0	na	0
1985	na	0	na	0	na	0	na	0
1986	na	0	na	0	na	0	na	0
1987	0.0	1988	na	0	na	0	na	0
1988	0.0	7762	na	0	na	0	na	0
1989	0.2	8312	na	0	na	0	0.1	15811
1990	0.0	3678	0.0	1957	na	0	0.0	14844
1991	0.0	20148	na	0	na	0	0.0	5952
1992	1.1	15788	0.7	1344	na	0	0.0	3356
1993	0.1	22959	0.0	1441	na	0	0.1	19508
1994	0.4	43235	0.0	526	na	0	0.1	12406
1995	1.0	49401	0.0	1181	na	0	0.1	9797
1996	0.7	58347	0.0	6919	na	0	0.8	33691
1997	6.6	100272	0.0	10744	na	0	0.3	12815
1998	1.1	80213	na	0	na	0	0.1	19210
1999	0.1	89811	na	0	na	0	0.0	22048
2000	1.3	101360	na	0	na	0	0.2	14571
2001	2.9	85836	na	0	na	0	0.2	17987
2002	2.0	76542	na	0	na	0	0.1	36566
2003	1.2	42987	na	0	na	0	0.6	6271
2004	1.7	16597	na	0	na	0	0.5	5608
2005	6.5	25023	na	0	na	0	1.9	3612
2006	2.9	20560	na	0	na	0	na	0

Table 1b. Results of 28 linear regressions of basking shark sightings-per-unit-effort (SPUE) versus year for each region and season shown in Table 1. 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 (slope different from zero) at $P < 0.0259$ (the critical value adjusted for conducting 28 separate hypothesis tests with $\alpha = 0.05$), which are also plotted in Fig. 9.

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
Nova Scotian Shelf	***Summer***	***0.224***	***0.204***	***0.083***	***0.023***	***23***
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
Southern Gulf of Maine	***Summer***	***0.347***	***0.860***	***0.286***	***0.008***	***19***
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
Southeastern U.S.	***Winter***	***0.330***	***0.162***	***0.053***	***0.007***	***21***
Southeastern U.S.	Spring	0.115	-0.040	0.049	0.456	7
Southeastern U.S.	Summer	na	na	na	na	1
Southeastern U.S.	***Fall***	***0.278***	***0.039***	***0.016***	***0.024***	***18***

Table 2. Example of basking shark discard calculation by year and quarter for the silver hake fishery in NAFO 4VWX5Z.
Similar calculations were carried out for other years, regions and fisheries.

QUARTILE 1		1999	2000	2001	2002	2003	2004	2005	2006
	silver hake kept catch (kg) from IOP	63699	447790	182554	529821	189915	77283	57439	302381
	basking shark (discarded) in IOP (kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	basking shark proportion in IOP	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
	silver hake catch (mt) from MARFIS	805	2829	4009	3296	2786	3837	3302	3725
	estimated basking shark discarded in fishery (mt)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	observed effort (subtrips)	339	657	455	1160	515	216	114	1167
	cpue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

QUARTILE 2		1999	2000	2001	2002	2003	2004	2005	2006
	silver hake kept catch (kg) from IOP	301902	98657	513917	235007	161790	217014	154435	94373
	basking shark (discarded) in IOP (kg)	0.00	0.00	0.00	0.00	0.00	1400.00	1500.00	0.00
	basking shark proportion in IOP	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.01*	*0.01*	*0.00*
	silver hake catch (mt) from MARFIS	3985	3517	6191	5987	3627	4124	3403	3277
	estimated basking shark discarded in fishery (mt)	0.00	0.00	0.00	0.00	0.00	26.60	33.05	0.00
	observed effort (subtrips)	971	336	1286	544	425	459	251	164
	cpue	0.00	0.00	0.00	0.00	0.00	3.05	5.98	0.00

QUARTILE 3		1999	2000	2001	2002	2003	2004	2005	2006
	silver hake kept catch (kg) from IOP	36300	69728	108385	126590	34320	58939	38110	8954
	basking shark (discarded) in IOP (kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	basking shark proportion in IOP	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
	silver hake catch (mt) from MARFIS	5721	1388	4674	2991	1088	2369	1542	2348
	estimated basking shark discarded in fishery (mt)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	observed effort (subtrips)	162	320	240	309	173	55	201	46
	cpue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

QUARTILE 4		1999	2000	2001	2002	2003	2004	2005	2006
	silver hake kept catch (kg) from IOP	33140	90715	93166	90479	47467	32714	42564	37318
	basking shark (discarded) in IOP (kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	basking shark proportion in IOP	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
	silver hake catch (mt) from MARFIS	2986	4338	3811	3904	3629	3030	3113	2977
	estimated basking shark discarded in fishery (mt)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	observed effort (subtrips)	68	342	184	133	113	34	73	84
	cpue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TOTALS		1999	2000	2001	2002	2003	2004	2005	2006
	Total target catch (mt)	435	707	898	982	433	386	293	443
	Total basking shark (discarded) in IOP (mt)	0.00	0.00	0.00	0.00	0.00	1.40	1.50	0.00
	Total effort (subtrips)	1540	1655	2165	2146	1226	764	639	1461
	CPUE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total estimated basking shark discarded (mt)	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*26.60*	*33.05*	*0.00*
	Total reported landings (mt)	16233	15213	18481	13819	11627	12639	11233	12407

Table 3a. Observed basking shark discards from foreign fleets fishing for silver hake and redfish.

	Foreign silver hake fishery		Foreign redfish fishery			
	Scotian shelf (NAFO 4VWX5Z)		NL (NAFO 2J3KLNOPs)		Scotian shelf (NAFO 4VWX5Z)	
Year	Observed target catch (mt)	Observed basking shark discards (mt)	Observed target catch (mt)	Observed basking shark discards (mt)	Observed target catch (mt)	Observed basking shark discards (mt)
1978	14,474.4	7.0	294.1	0.0	0.0	0.0
1979	24,206.6	2.5	0.0	0.0	0.0	0.0
1980	25,837.6	43.7	0.0	0.0	0.0	0.0
1981	21,789.4	40.2	0.0	0.0	0.0	0.0
1982	27,092.1	5.5	0.0	0.0	0.0	0.0
1983	14,429.6	31.3	0.0	0.0	0.0	0.0
1984	29,552.7	10.9	0.0	0.0	865.1	12.5
1985	32,162.4	16.9	187.9	0.0	781.4	3.9
1986	35,299.1	5.1	862.3	1.0	1,527.6	10.2
1987	57,976.4	23.2	638.1	0.0	1,193.0	2.9
1988	70,429.3	68.6	369.9	1.0	372.7	0.5
1989	85,614.2	58.1	0.0	0.0	121.5	0.0
1990	66,089.6	66.3	479.0	0.0	1,334.7	0.0
1991	67,642.9	140.9	0.0	0.0	1,018.5	0.0
1992	31,707.4	139.8	0.0	0.0	861.3	4.0
1993	29,095.2	77.4	0.0	0.0	0.0	0.0
1994	5,570.2	5.0	0.0	0.0	0.0	0.0
1995	16,820.4	19.2	0.0	0.0	0.0	0.0
1996	22,437.8	9.4	0.0	0.0	0.0	0.0
1997	11,705.7	3.0	0.0	0.0	0.0	0.0
1998	6,114.1	4.3	0.0	0.0	0.0	0.0
1999	3,933.1	4.0	0.0	0.0	0.0	0.0
2000	1,662.4	0.7	0.0	0.0	0.0	0.0
2001	2,048.3	3.0	0.0	0.0	0.0	0.0
2002	2,478.0	2.0	0.0	0.0	0.0	0.0
2003	133.9	3.5	0.0	0.0	0.0	0.0
2004	534.2	0.0	0.0	0.0	0.0	0.0
2005	0.0	0.0	0.0	0.0	0.0	0.0
2006	0.0	0.0	0.0	0.0	0.0	0.0
Totals		791.2		2.0		34.0

Table 3b. Observed basking shark discards from foreign fleets fishing for groundfish and squid.

	Foreign groundfish trawl fishery Gulf of St. Lawrence (NAFO 3Pn4RST)		Foreign squid fishery Scotian shelf (NAFO 4VWX5Z)	
Year	Observed target catch (mt)	Observed basking shark discards (mt)	Observed target catch (mt)	Observed basking shark discards (mt)
1978	0.0	0.0	21,761.8	2.5
1979	329.0	0.0	30,132.6	0.5
1980	1,903.0	0.0	17,502.4	1.0
1981	557.2	0.0	5,746.7	0.0
1982	4,128.0	0.0	32.4	0.0
1983	5,913.7	0.8	68.4	0.0
1984	8,440.8	0.0	0.0	0.0
1985	6,366.4	0.2	0.0	0.0
1986	8,323.3	0.0	0.0	0.0
1987	580.5	0.0	65.6	0.0
1988	0.0	0.0	0.0	0.0
1989	1,636.2	0.0	556.4	0.0
1990	0.4	0.0	2,863.2	5.9
1991	0.0	0.0	136.1	0.0
1992	647.9	0.0	0.0	0.0
1993	0.0	0.0	0.0	0.0
1994	0.0	0.0	3,818.6	0.0
1995	0.0	0.0	0.1	0.0
1996	0.0	0.0	0.0	0.0
1997	0.0	0.0	1,724.3	0.5
1998	0.0	0.0	467.3	0.0
1999	0.0	0.0	0.0	0.0
2000	0.0	0.0	0.0	0.0
2001	0.0	0.0	0.0	0.0
2002	0.0	0.0	0.0	0.0
2003	0.0	0.0	0.0	0.0
2004	0.0	0.0	0.0	0.0
2005	0.0	0.0	13.1	0.0
2006	18.6	0.0	0.0	0.0
Totals		1.0		10.4

Table 3c. Observed basking shark discards from foreign fleets fishing for tuna and shark.

	Foreign tuna/shark fishery			
	Scotian shelf (NAFO 4VWX5Z)		Newfoundland (NAFO 2J3KLNOPs)	
Year	Observed target catch (mt)	Observed basking shark discards (mt)	Observed target catch (mt)	Observed basking shark discards (mt)
1978	0.0	0.0	0.0	0.0
1979	0.0	0.0	0.0	0.0
1980	0.0	0.8	0.0	0.0
1981	27.6	0.0	0.0	0.0
1982	1.2	3.1	0.0	0.0
1983	0.0	1.1	0.0	0.0
1984	0.8	0.0	0.0	0.0
1985	0.0	0.0	0.0	0.0
1986	3.4	0.0	0.2	0.0
1987	247.7	2.0	0.3	0.0
1988	252.7	0.0	0.1	0.0
1989	314.4	6.6	0.3	0.0
1990	407.0	2.5	0.0	0.0
1991	580.3	3.0	93.4	0.0
1992	633.0	7.0	223.5	0.0
1993	376.3	0.0	27.5	0.0
1994	0.4	0.0	0.0	0.0
1995	3.2	0.0	0.0	0.0
1996	5.2	0.0	0.0	0.0
1997	2.1	0.0	0.0	0.0
1998	0.0	0.0	0.0	0.0
1999	0.0	0.0	0.0	0.5
2000	0.0	0.0	0.0	0.0
2001	0.0	0.0	0.0	0.0
2002	0.0	0.0	0.0	0.0
2003	0.0	0.0	0.0	0.0
2004	0.0	0.0	0.0	0.0
2005	0.0	0.0	0.0	0.0
2006	0.0	0.0	0.0	0.0
Totals		26.1		0.5

Table 4a. Observed and estimated basking shark discards in domestic fisheries for groundfish

	Groundfish trawl fishery							
	Scotian Shelf (NAFO 4VWX5Z)				Gulf of St. Lawrence (NAFO 3Pn4RST)			
Year	Observed basking shark discards (mt)	Observed target catch (mt)	Reported Landings (mt)	Estimated basking shark discards (mt)	Observed basking shark discards (mt)	Observed target catch (mt)	Reported Landings (mt)	Estimated basking shark discards (mt)
1978	0.0	1,403			0.0	0		
1979	0.0	3,019			0.5	1,105		
1980	0.0	6,314			0.0	530		
1981	11.7	13,441			0.0	4		
1982	0.5	10,410			0.0	132		
1983	1.0	6,489			0.0	112		
1984	4.9	8,196			2.0	590		
1985	0.0	11,667			0.0	150		
1986	1.5	8,285	105,651	18.5	1.0	133	60,789	36.3
1987	0.3	8,925	87,027	1.6	0.0	298	60,018	18.1
1988	2.0	10,421	91,542	22.1	0.0	323	51,156	22.8
1989	23.9	11,359	82,849	237.2	0.0	83	48,497	0.0
1990	59.9	17,347	79,230	606.0	0.0	294	26,845	0.0
1991	9.8	12,757	82,754	99.6	0.0	542	33,722	0.0
1992	2.0	8,323	73,920	11.6	0.0	724	31,092	0.0
1993	9.5	5,884	30,734	44.8	0.0	422	10,245	0.0
1994	13.9	3,209	17,368	134.4	0.0	0	108	0.0
1995	3.5	1,281	12,891	25.5	0.0	0	67	0.0
1996	16.3	2,277	16,089	146.6	0.0	0	200	0.0
1997	0.0	892	18,383	0.0	0.0	0	317	0.0
1998	3.5	1,557	20,497	28.1	0.0	0	429	0.0
1999	0.0	1,121	14,318	0.0	0.0	21	1,507	0.0
2000	4.8	1,288	12,861	45.9	0.0	15	1,219	0.0
2001	0.0	1,362	16,575	0.0	0.0	20	1,446	0.0
2002	0.0	852	49,695	0.0	0.0	39	733	0.0
2003	0.0	805	43,657	0.0	0.0	0	472	0.0
2004	0.0	1,845	43,822	0.0	0.0	0	548	0.0
2005	0.0	3,066	45,331	0.0	0.0	0	660	0.0
2006	0.4	4,426	38,966	3.5	0.0	28	38	0.0
Totals				1,425.2				77.2

Table 4b. Observed and estimated basking shark discards in domestic deepwater trawl fisheries.

	Deep water trawl			
	Scotian Shelf (NAFO 4VWX5Z)			
Year	Observed basking shark discards (mt)	Observed target catch (mt)	Reported Landings (mt)	Estimated basking shark discards (mt)
1986	0.0	0	0	0.0
1987	0.0	0	0	0.0
1988	0.0	0	0	0.0
1989	0.0	0	0	0.0
1990	0.0	0	0	0.0
1991	0.0	0	0	0.0
1992	0.0	0	0	0.0
1993	0.0	346	983	0.0
1994	0.2	93	443	0.9
1995	5.5	357	633	5.6
1996	0.0	47	204	0.0
1997	0.0	12	21	0.0
1998	0.0	0	0	0.0
1999	0.0	0	0	0.0
2000	0.0	0	1	0.0
2001	0.0	0	0	0.0
2002	0.0	0	0	0.0
2003	0.0	0	1	0.0
2004	0.0	0	0	0.0
2005	0.0	0	0	0.0
2006	0.0	0	0	0.0
Totals				6.5

Table 4c. Observed and estimated basking shark discards in domestic fisheries for redfish.

	Redfish fishery							
	Scotian Shelf (NAFO 4VWX5Z)				Gulf of St. Lawrence (NAFO 3Pn4RST)			
Year	Observed basking shark discards (mt)	Observed target catch (mt)	Reported Landings (mt)	Estimated basking shark discards (mt)	Observed basking shark discards (mt)	Observed target catch (mt)	Reported Landings (mt)	Estimated basking shark discards (mt)
1978	0.8	28			0.0	1		
1979	0.0	91			0.0	0		
1980	0.0	148			0.0	0		
1981	0.0	226			0.0	673		
1982	0.0	334			0.0	0		
1983	4.3	1,041			0.0	590		
1984	3.5	343			3.0	1,687		
1985	0.0	437			3.5	1,798		
1986	0.0	127	10,074	0.0	0.0	2,350	34,890	0.0
1987	0.0	1,722	18,887	0.0	0.0	1,772	36,277	0.0
1988	0.0	1,367	15,503	0.0	0.0	2,233	41,666	0.0
1989	3.2	1,825	15,679	16.9	0.0	1,504	48,334	0.0
1990	0.3	2,494	15,477	3.3	10.9	5,979	36,683	56.0
1991	6.8	4,883	23,671	42.6	0.0	4,176	60,254	0.0
1992	8.8	2,611	25,223	72.9	2.0	2,902	62,283	21.1
1993	2.0	5,103	22,435	5.4	0.2	9,646	52,696	0.9
1994	4.5	4,563	21,074	19.1	0.0	1,894	19,494	0.0
1995	7.0	2,733	12,579	7.7	0.0	0	1,532	7.6
1996	1.1	2,129	8,328	3.2	1.0	133	716	1.7
1997	3.3	2,313	9,963	8.6	0.0	23	473	9.4
1998	1.5	611	7,192	3.7	4.0	120	828	18.1
1999	1.1	1,168	8,014	23.0	17.6	375	1,763	73.2
2000	0.4	497	7,152	4.9	0.0	134	1,290	0.0
2001	0.0	1,138	8,822	0.0	7.0	136	1,214	48.9
2002	1.0	1,912	7,364	2.8	0.0	197	576	0.0
2003	0.0	404	5,642	0.0	0.0	0	451	0.0
2004	2.0	251	5,726	24.0	0.0	73	457	0.0
2005	0.0	272	5,148	0.0	0.0	18	304	0.0
2006	0.0	243	5,775	0.0	0.0	0	35	0.0
Totals				238.1				236.9

Table 4d. Observed and estimated basking shark discards in domestic fisheries for silver hake.

	Silver hake fishery			
	Scotian Shelf (NAFO 4VWX5Z)			
Year	Observed basking shark discards (mt)	Observed target catch (mt)	Reported Landings (mt)	Estimated basking shark discards (mt)
1978	0.0	0		
1979	0.0	0		
1980	0.0	50		
1981	0.0	0		
1982	0.0	0		
1983	0.0	0		
1984	0.0	0		
1985	0.0	0		
1986	0.0	0	0	0.0
1987	0.0	0	3	0.0
1988	0.0	30	0	0.0
1989	0.0	250	337	0.0
1990	0.0	0	4	0.0
1991	3.5	48	51,787	1,811.4
1992	0.0	1	24,868	0.0
1993	0.0	53	25,562	0.0
1994	0.0	49	6,938	0.0
1995	0.0	143	14,944	0.0
1996	0.0	837	23,645	0.0
1997	0.0	34	19,991	0.0
1998	0.0	129	17,111	0.0
1999	0.0	435	16,233	0.0
2000	0.0	707	15,213	0.0
2001	0.0	898	18,481	0.0
2002	0.0	982	13,819	0.0
2003	0.0	433	11,627	0.0
2004	1.4	386	12,639	26.6
2005	1.5	293	11,233	33.1
2006	0.0	443	12,407	0.0
Totals				59.7

replaced very high value in 1991 with 30 mt

Table 4e. Observed and estimated basking shark discards in domestic groundfish longline fisheri

	Groundfish longline fishery			
	Scotian Shelf (NAFO 4VWX5Z)			
Year	Observed basking shark discards (mt)	Observed target catch (mt)	Reported Landings (mt)	Estimated basking shark discards (mt)
1978	0.0	0		
1979	0.0	0		
1980	0.0	0		
1981	0.0	0		
1982	0.0	0		
1983	0.0	0		
1984	0.0	0		
1985	0.0	81		
1986	0.0	0	9,927	0.0
1987	0.0	0	9,637	0.0
1988	0.0	49	28,689	0.0
1989	0.0	17	27,181	0.0
1990	0.0	18	29,468	0.0
1991	0.0	132	30,804	0.0
1992	0.5	122	31,840	69.2
1993	0.0	128	13,995	0.0
1994	0.0	203	9,589	0.0
1995	1.0	156	5,427	29.2
1996	0.0	518	7,408	0.0
1997	0.0	416	7,889	0.0
1998	0.0	411	7,425	0.0
1999	0.0	422	6,481	0.0
2000	1.0	628	6,690	9.6
2001	0.0	358	6,822	0.0
2002	0.0	295	11,941	0.0
2003	1.0	441	9,994	476.6
2004	6.4	487	8,905	121.9
2005	0.0	372	9,166	0.0
2006	0.0	298	9,865	0.0
Totals				229.9

replaced very high value in 2003 with 30 mt

Table 5. Total estimated discard weights (mt) and numbers of basking sharks in Atlantic Canadian waters. Foreign values in Scotia-Fundy (SF) and Newfoundland (NL) were fully observed, not estimated.

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

*** removes two disproportionately influential data points (2002 3Ps monkfish fishery; 1995 3Ps redfish fishery in 1**

Table 6. Examples of some alternate simulation model runs used to evaluate the sensitivity of the model conclusions with respect assumptions and input values. Values for *r*, F_{crit} and N_{crit} are the medians, and the numbers in brackets are the 5th and 95th perc of the simulated values. F_{crit} and N_{crit} are calculated using the average number of removals. "p" is the percentage of the simulated populations that showed a decline.

Scenario	*r*	F_{crit}	N_{crit}	p
Base model	0.032 (0.009 – 0.053)	0.035 (0.010 – 0.057)	5850 (3723 – 20386)	23.2
Base model using average removals	0.032 (0.009 – 0.053)	0.035 (0.009 – 0.057)	5898 (3745 – 21009)	19.1
Base model with the number of removals doubled	0.032 (0.009 – 0.054)	0.035 (0.009 – 0.058)	11640 (7335 – 41681)	63.7
Base model with a one year lag between parturition and next pregnancy	0.031 (0.007 – 0.051)	0.033 (0.008 – 0.056)	6116 (3797 – 23445)	26
Base model with the population size halved (2500 to 10000)	0.032 (0.009 – 0.053)	0.035 (0.009 – 0.058)	5840 (3695 – 21129)	61.9
Base model with a mortality rate of 0.091 (0.081 to 0.101)	0.017 (0.001 – 0.040)	0.018 (0.001 – 0.046)	11440 (4740 – 142248)	55.3
Base model with age of selectivity increased to 8 yr	0.032 (0.008 – 0.054)	0.045 (0.012 – 0.078)	8155 (5366 – 27879)	23.5
Base model with a mortality rate range of 0.048 – 0.088	0.033 (0.007 – 0.054)	0.036 (0.007 – 0.058)	5673 (3651 – 26937)	25
Base model without the truncation at *r* = 0.057	0.036 (0.008 – 0.067)	0.039 (0.009 – 0.073)	5275 (3008 – 21741)	20.5

Fig. 1. Candidate growth curves for basking sharks in the northwest Atlantic. The fitted line is the von Bertalanffy growth curve (L_∞=10 m; K=0.062; t_0=-2.62) proposed by Pauly (2002) based on life history theory, the open symbols show data obtained by Natanson et al. (unpublished) based on vertebral sections, and the closed symbol represents a basking shark stranded in Nova Scotia and aged in our laboratory from a vertebral section. None of the age interpretations have been validated.

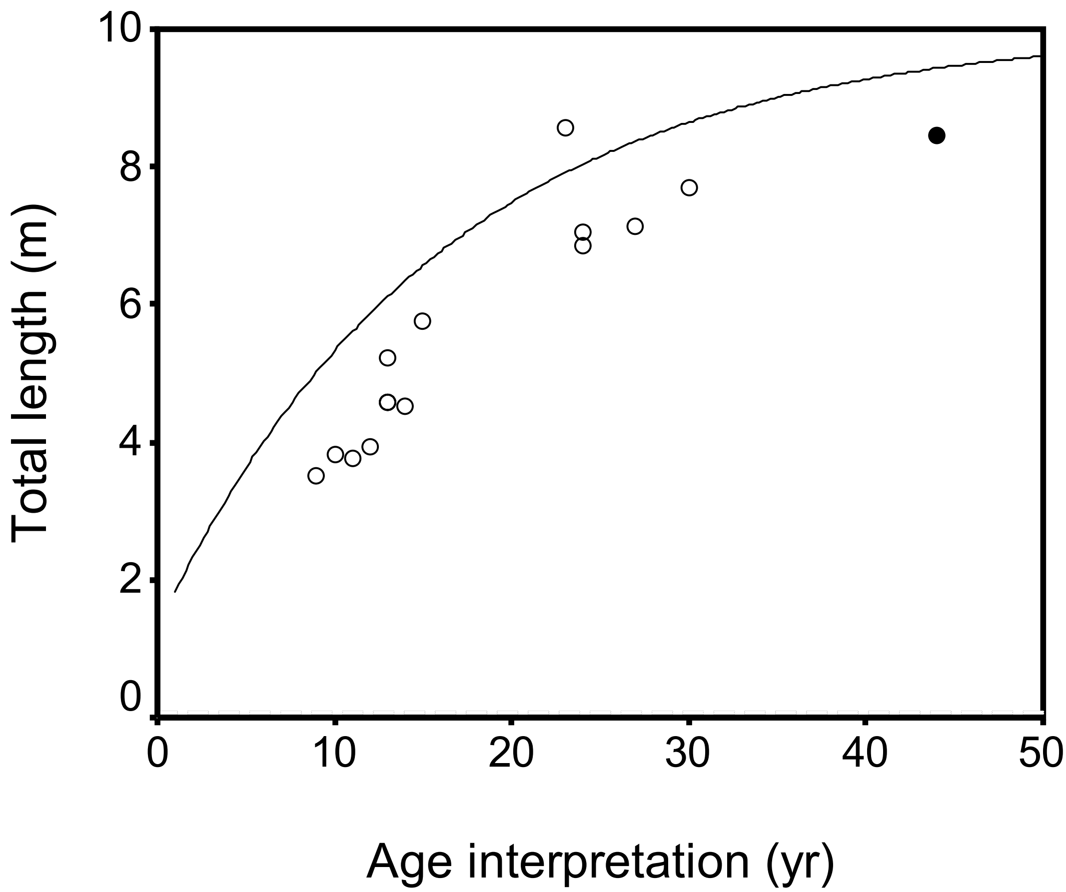


Fig. 2. Confirmed basking shark distribution as recorded in: A-C) aerial and shipboard surveys of right whales combined with reports phoned in to BIO between 1997 and 2006; D) aerial surveys of marine mammals on the Scotian Shelf and in the Gulf of St. Lawrence (red symbols) and in the waters off Newfoundland and Labrador (blue circles) in 2007.

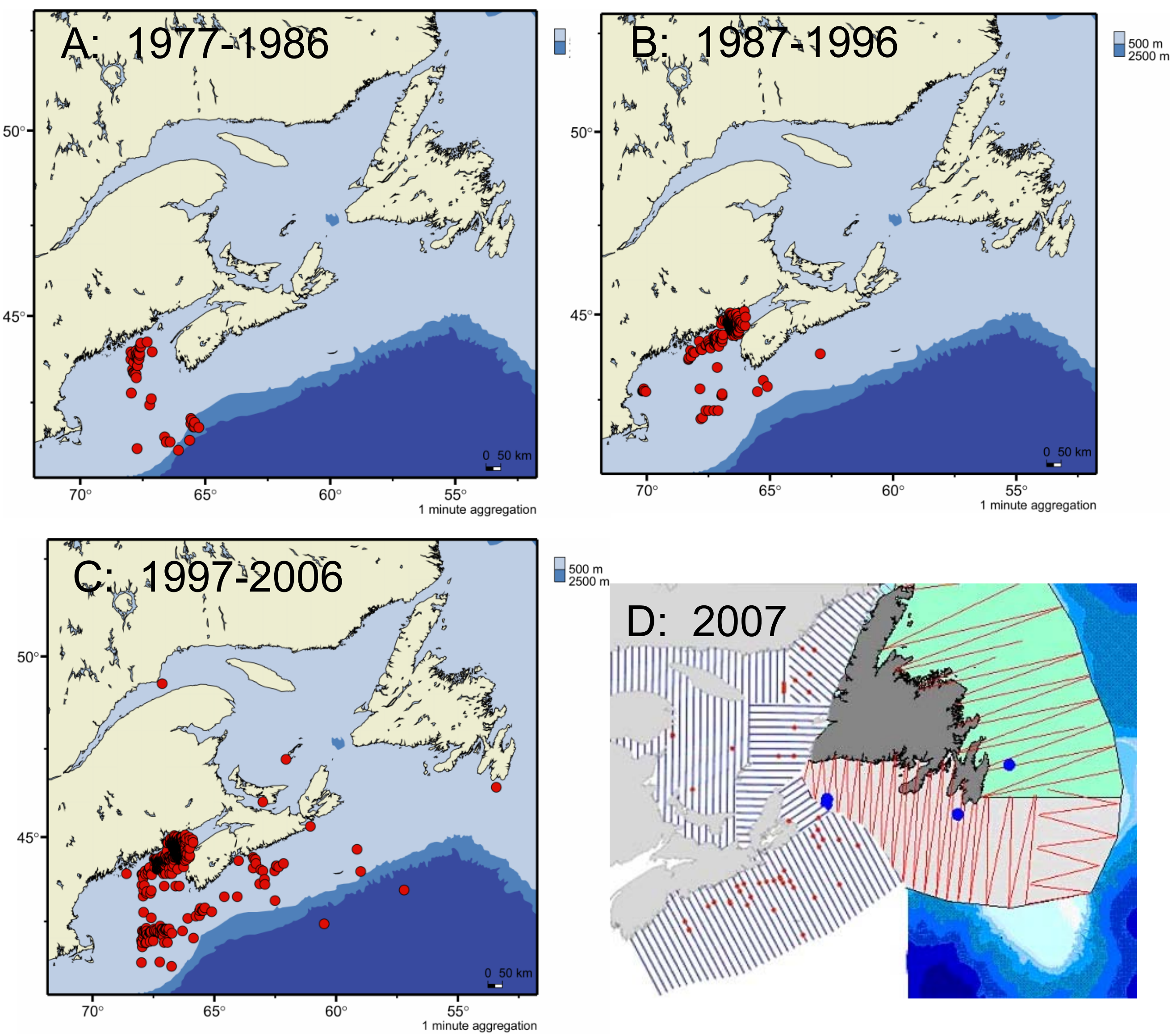


Fig. 3. Weekly mean sea surface temperatures in June (top) and August (bottom) of 2007. Basking sharks are seldom found in waters cooler than 6-7 deg C.

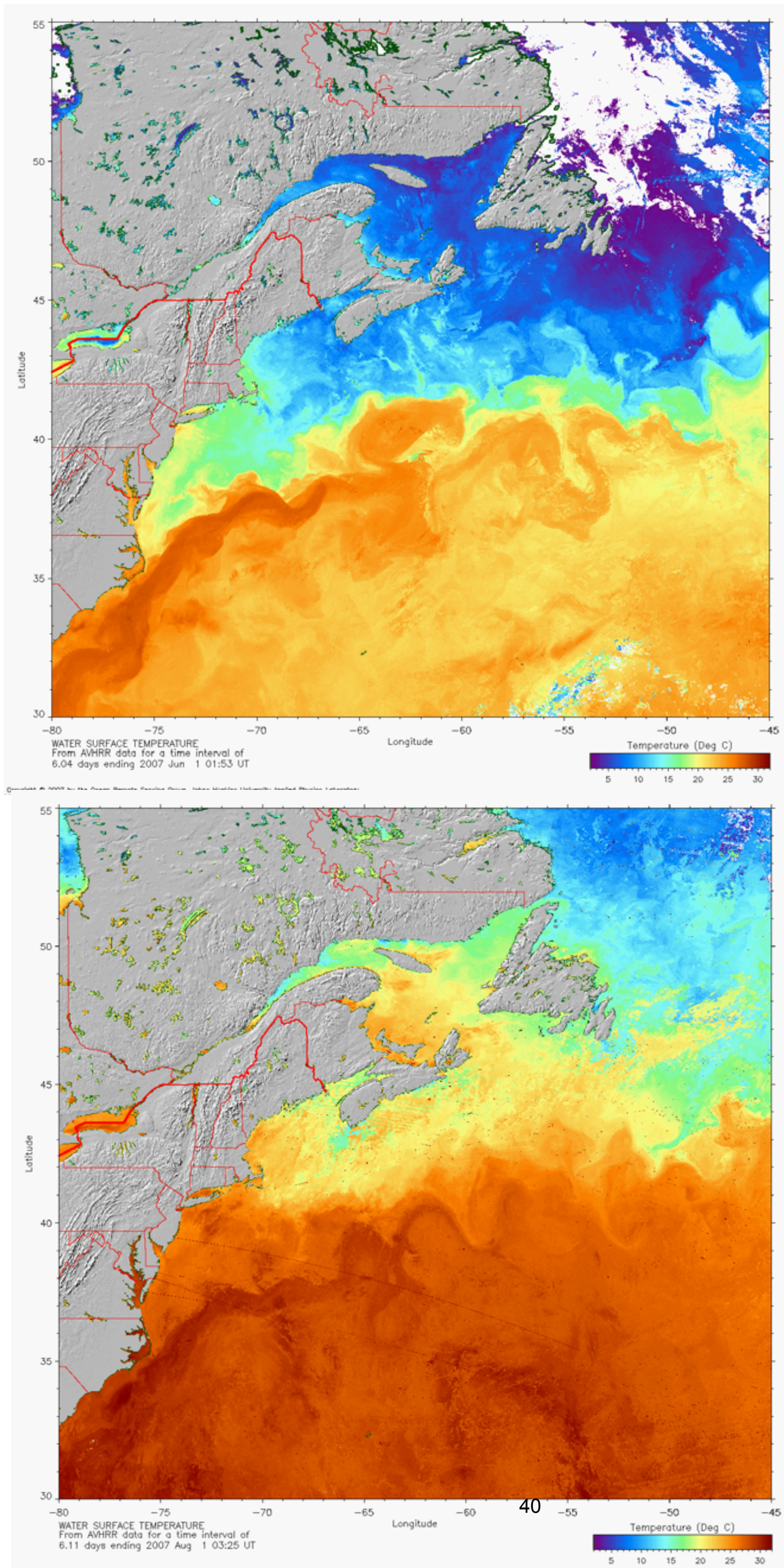


Fig. 4. Distribution of basking sharks between 1977-2007 as recorded in the Newfoundland and Maritimes Observer Programs. It appears that at least some of the recorded sharks were Greenland sharks, rather than basking sharks.

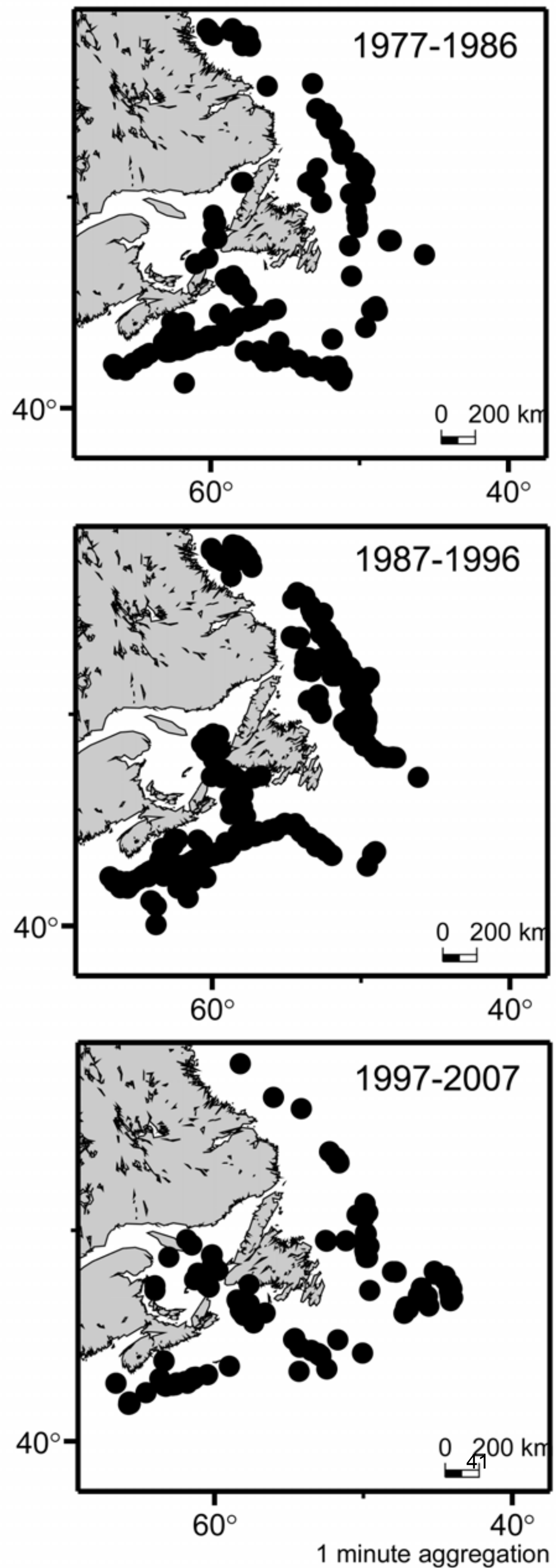


Fig. 5. Distribution of Greenland sharks between 1977-2001 as recorded in the Newfoundland and Maritimes Observer Programs.

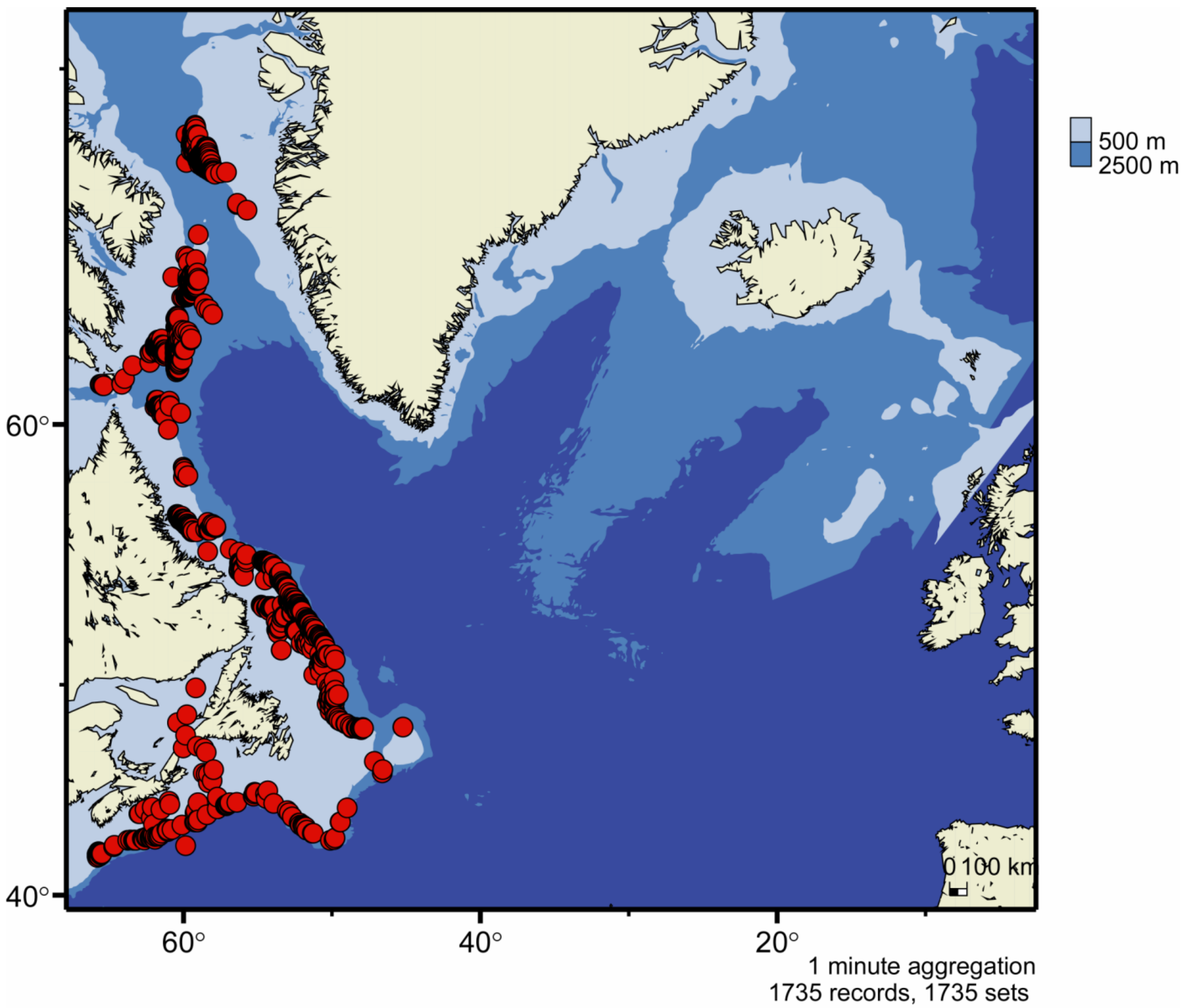


Fig. 6. Relative abundance of basking sharks as inferred from the catch per unit effort (CPUE) of groundfish and redfish trawls on the Scotian Shelf.

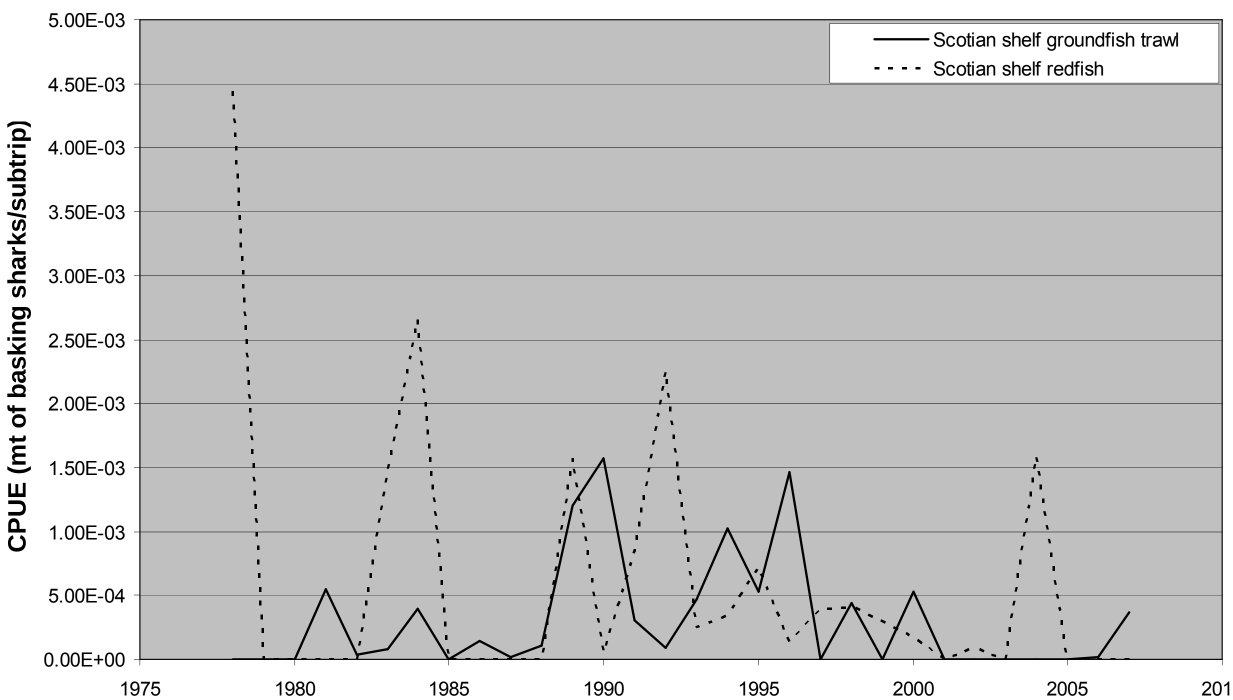


Fig. 7. Occurrence of basking sharks (numbers) sighted during systematic aerial and shipboard surveys for right whales conducted between 1979 and 2003. The size of the circles denotes the mean number of sightings at each location.

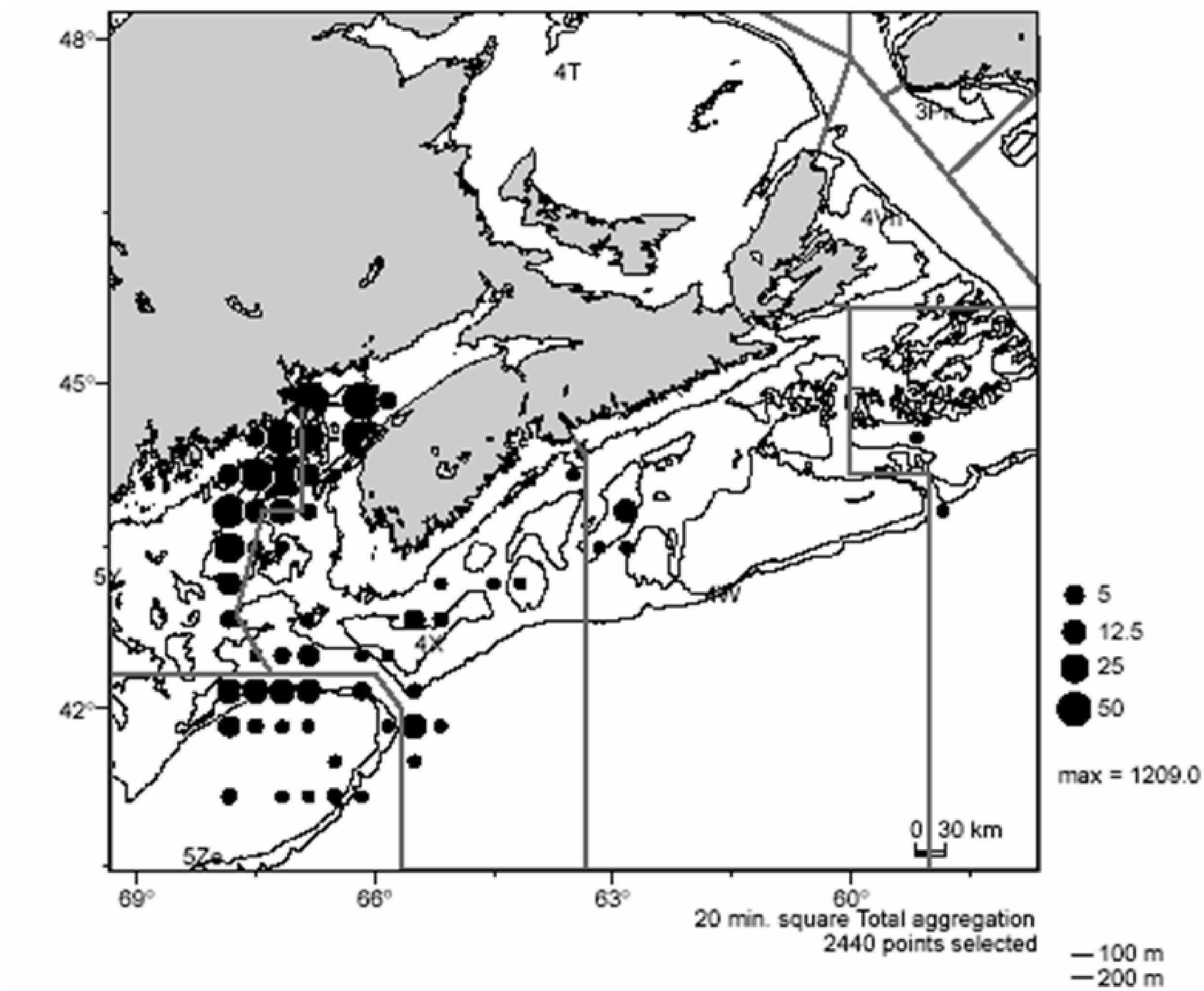


Fig. 8. Trend in relative abundance of basking sharks in the Bay of Fundy based on sightings per unit effort (SPUE) during surveys for right whales. Note: there are missing years on x axis. (A) Relative abundance based on a subset of strata common to all years and (B) relative abundance based on all 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.

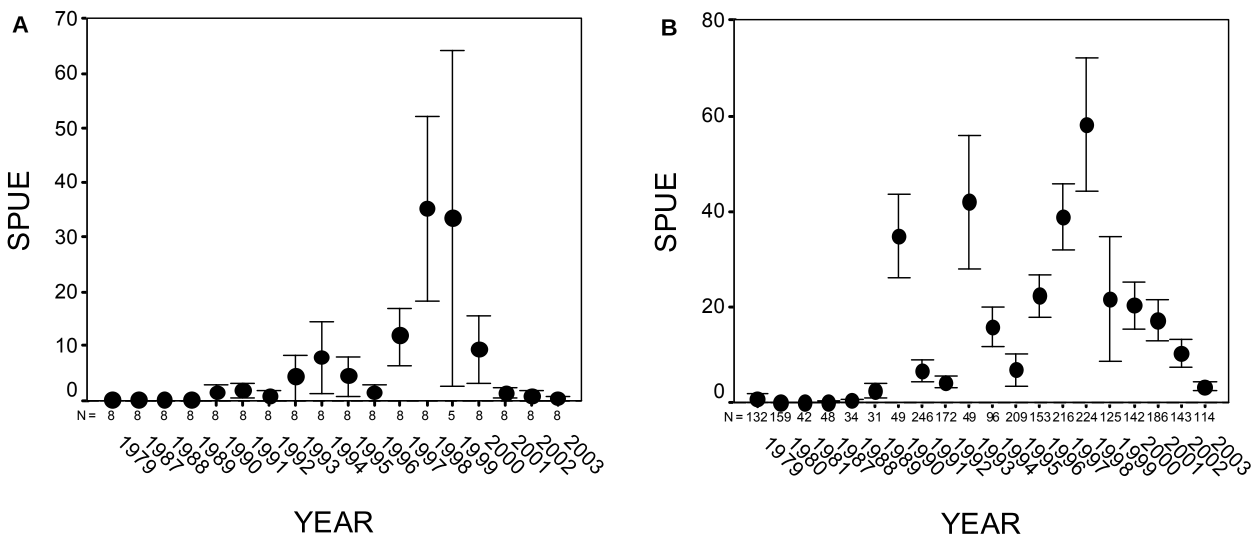


Fig. 9. Standardized sightings per unit effort (SPUE) of basking sharks in marine mammal surveys in the U.S. (A) Scotian Shelf in summer; (B) southern Gulf of Maine in summer; (C) southeastern U.S. in winter; (D) southeastern U.S. in fall.

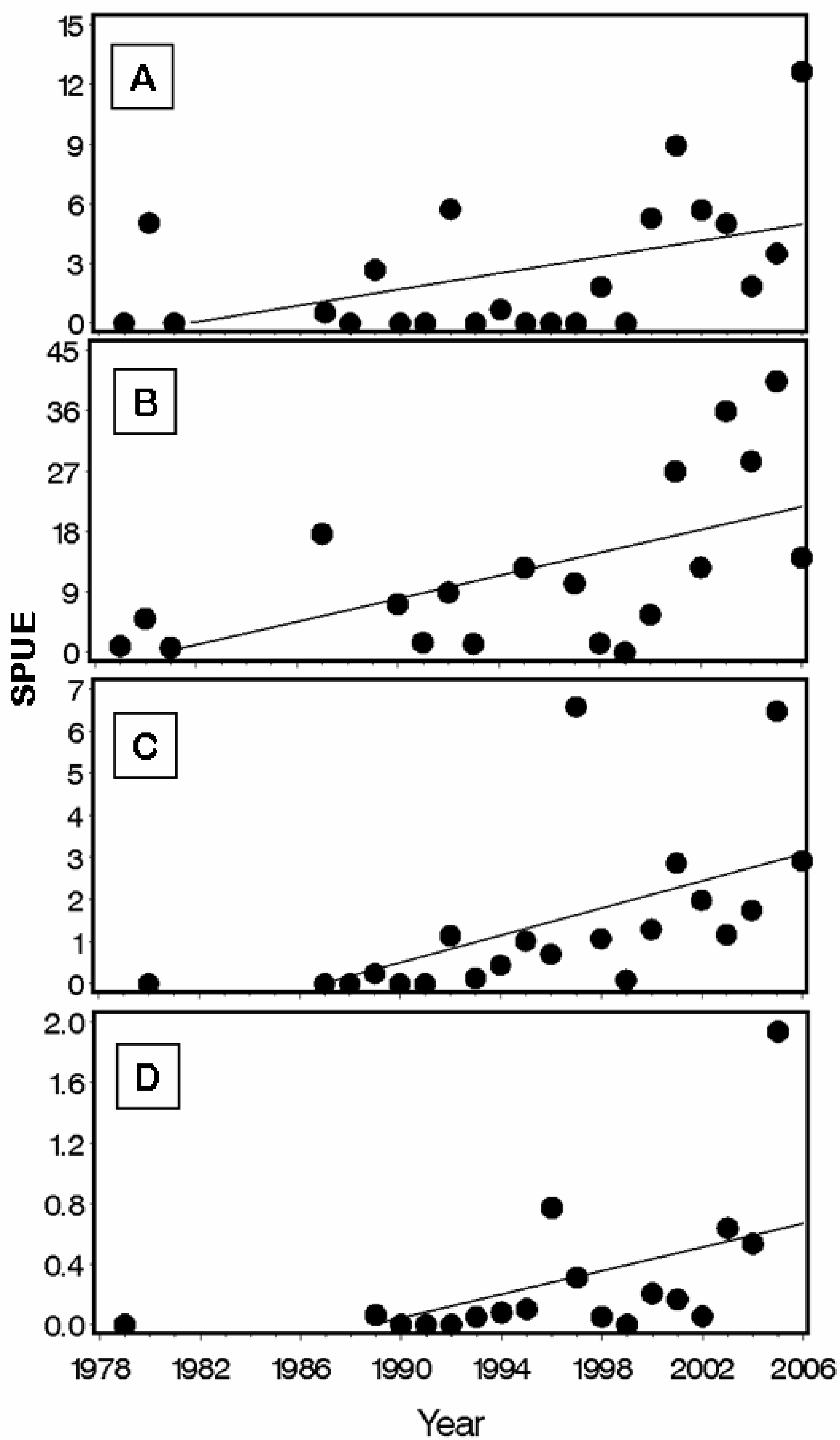


Fig. 10. Number of basking sharks observed each year in aerial and shipborne surveys for right whales in the Bay of Fundy, Gulf of Maine (South) and Scotian Shelf between 1975-2006.

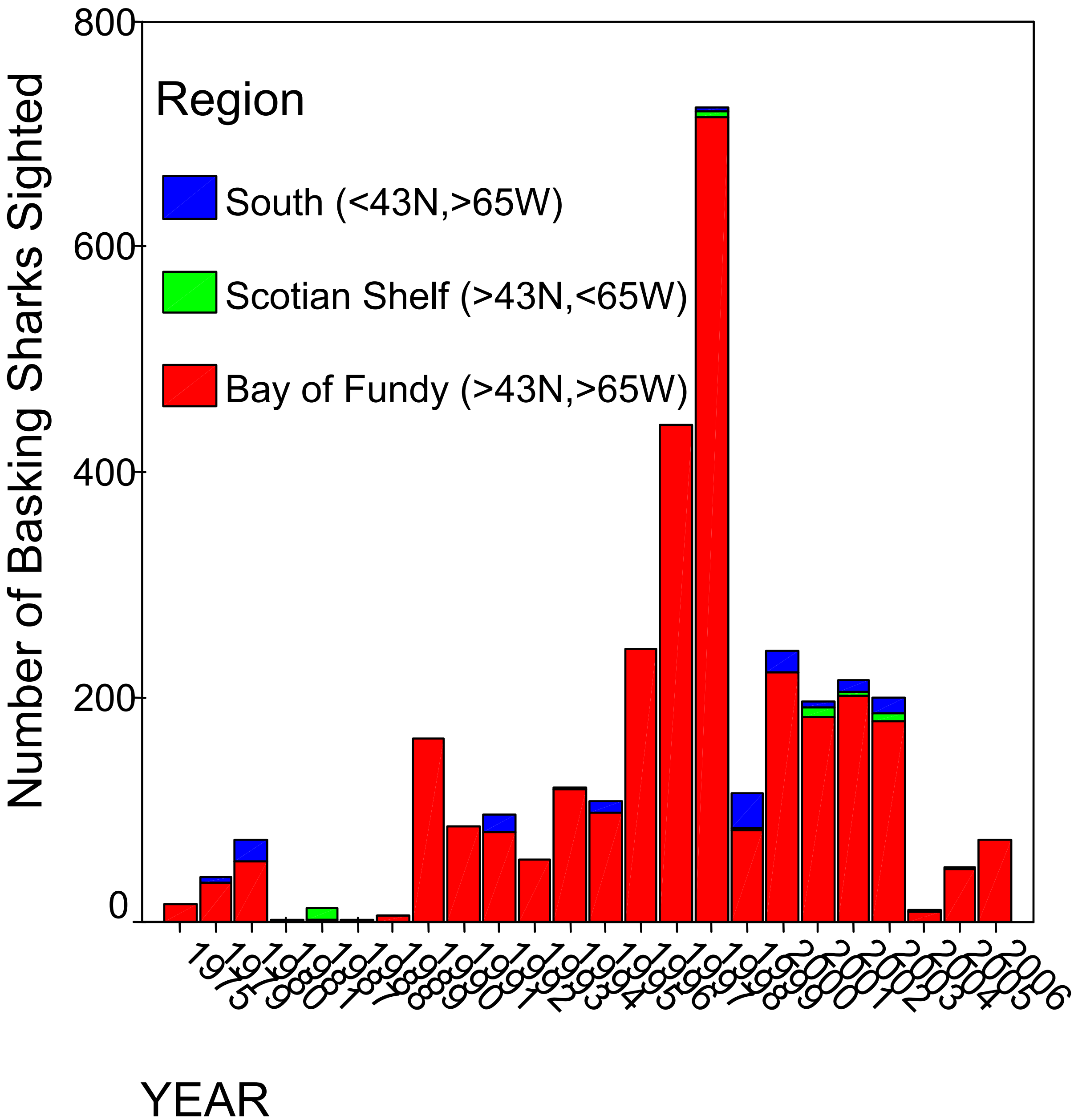


Fig. 11. Number of right whales observed each year in aerial and shipborne surveys for right whales in the Bay of Fundy, Gulf of Maine (South) and Scotian Shelf between 1975-2005.

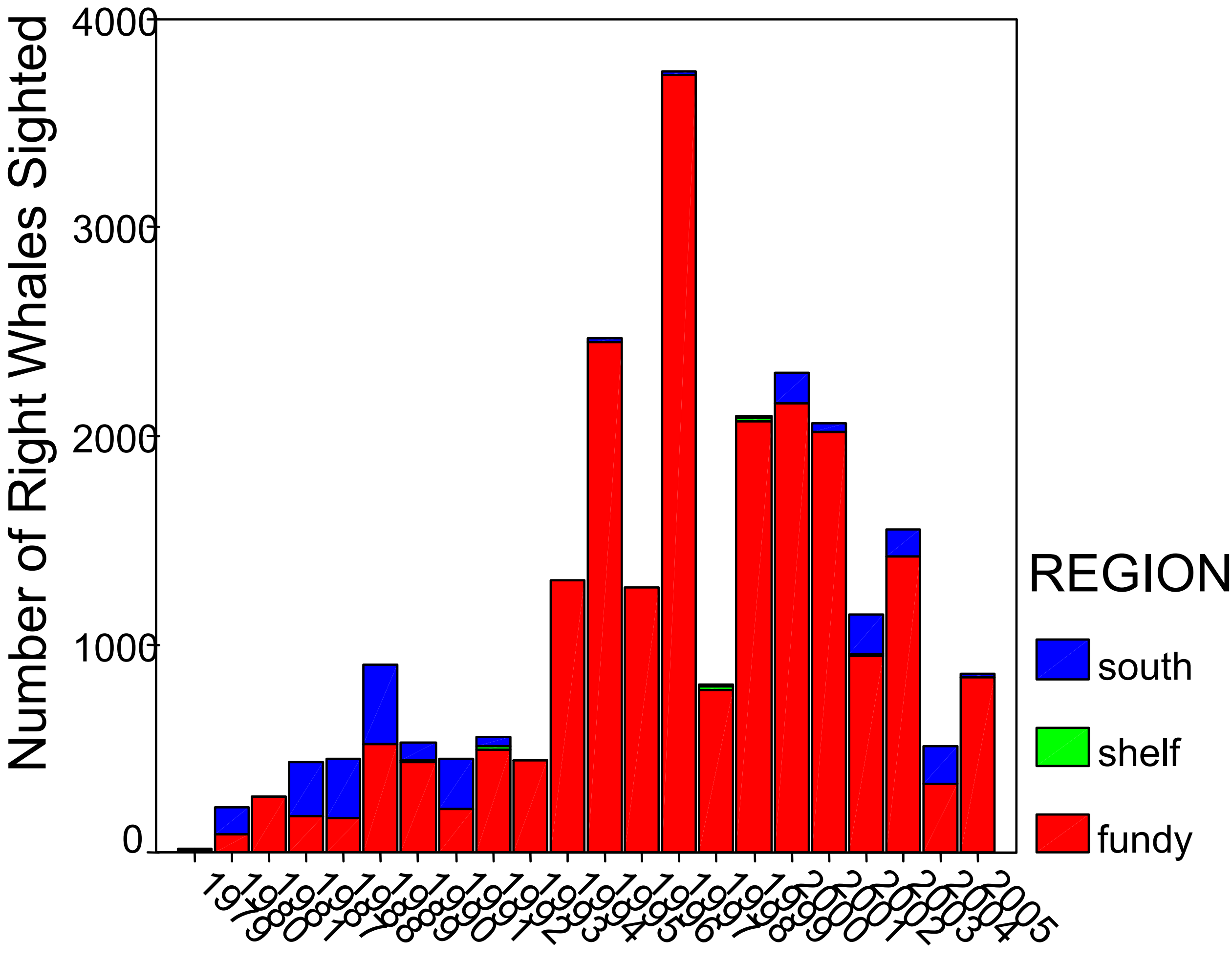


Fig. 12. Ratio of basking sharks to right whales observed in right whale aerial and ship-based surveys of the Bay of Fundy and approaches.

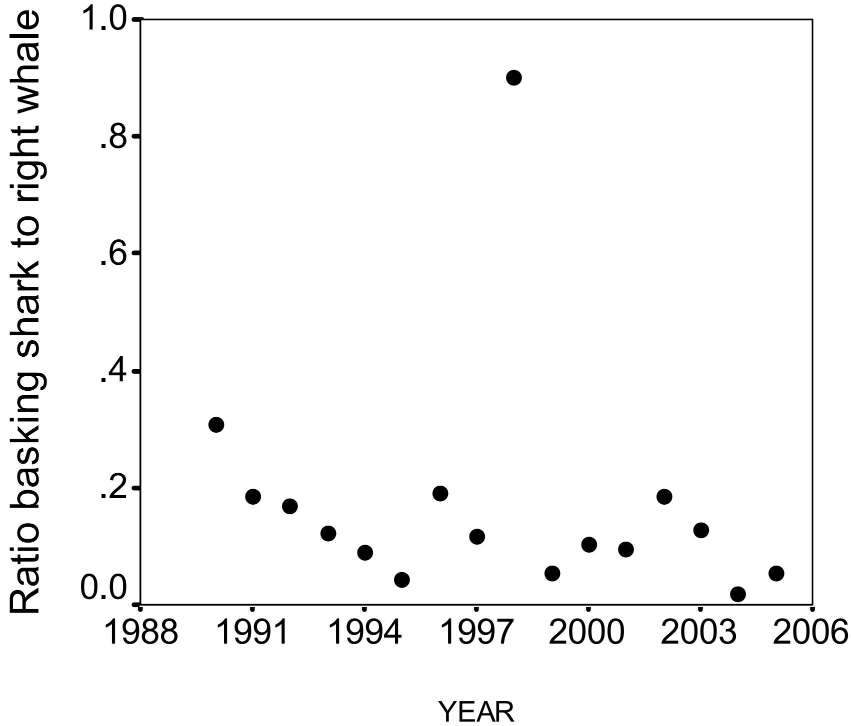


Fig. 13a. Sightings of basking sharks around Newfoundland and Labrador during DFO's 2007 TNASS aerial surveys for marine megafauna.

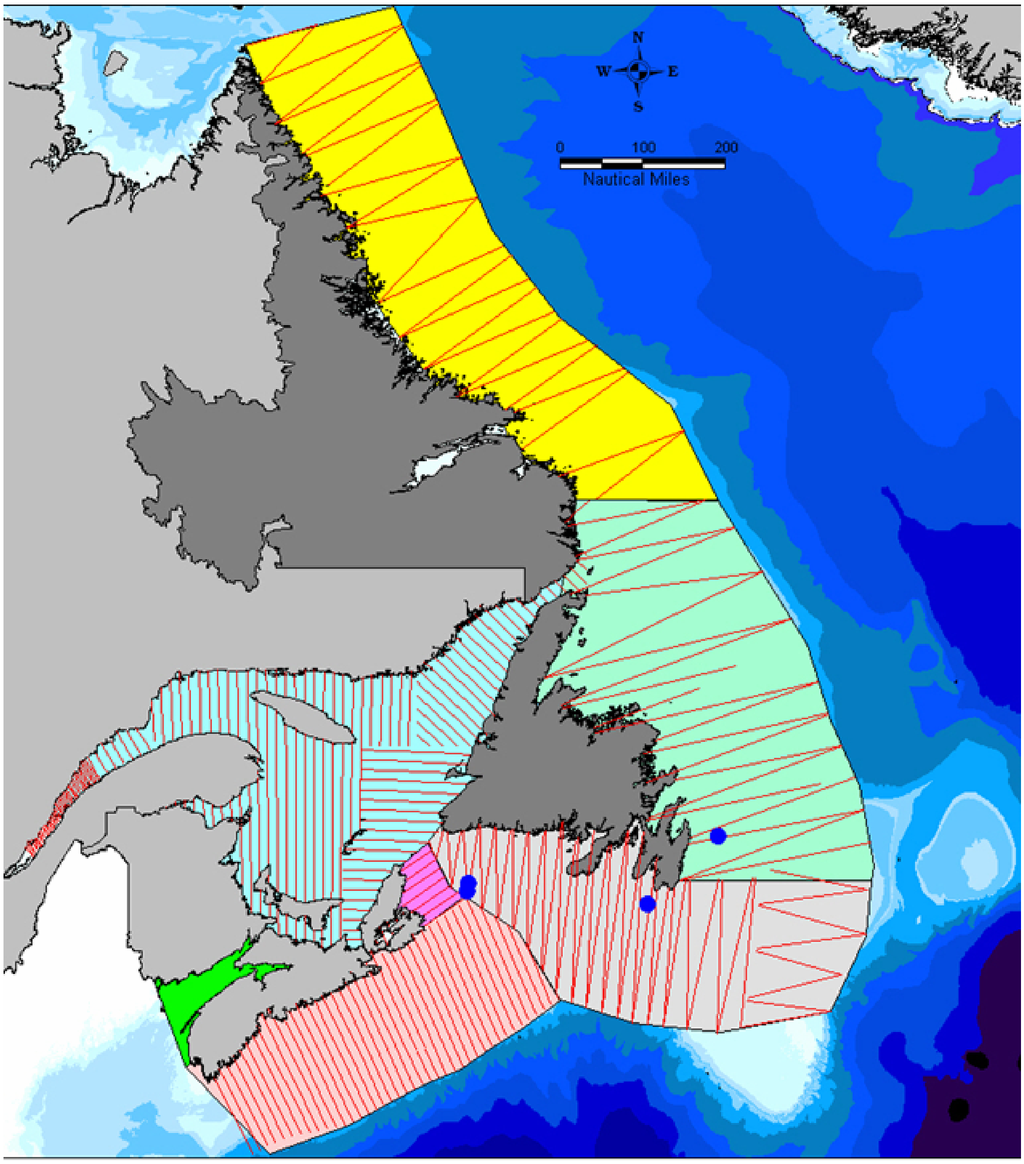


Fig. 13b. Sightings of basking sharks on the Scotian Shelf and in the Gulf of St. Lawrence during DFO's 2007 TNASS aerial surveys for marine megafauna.

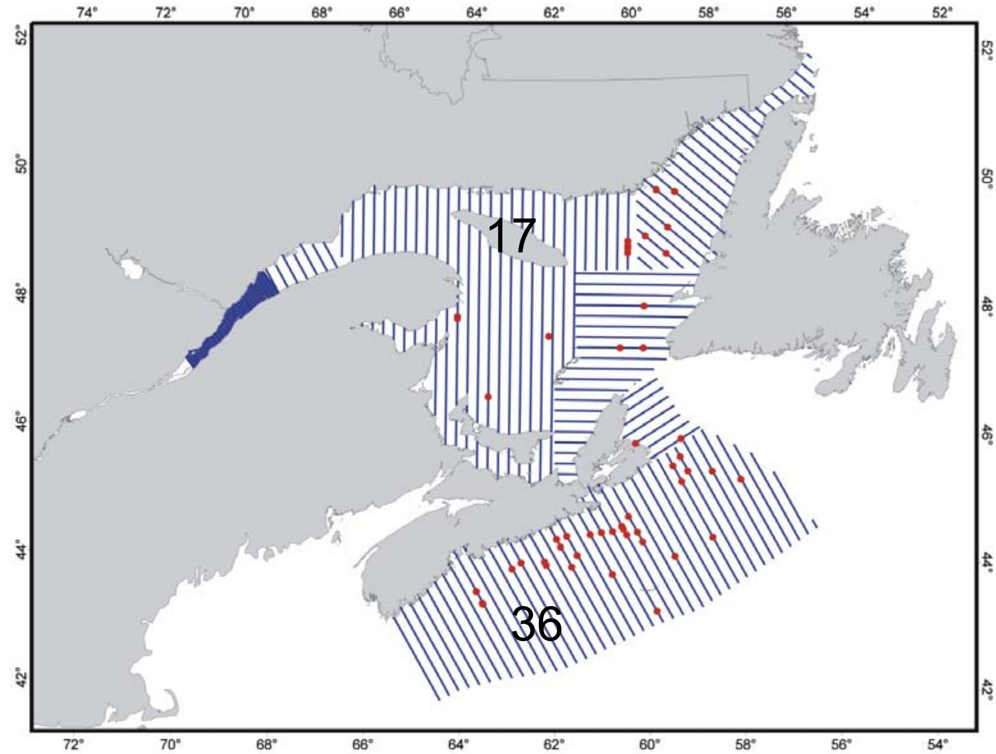


Fig. 14. Estimated basking shark discards from Scotia-Fundy domestic fisheries.

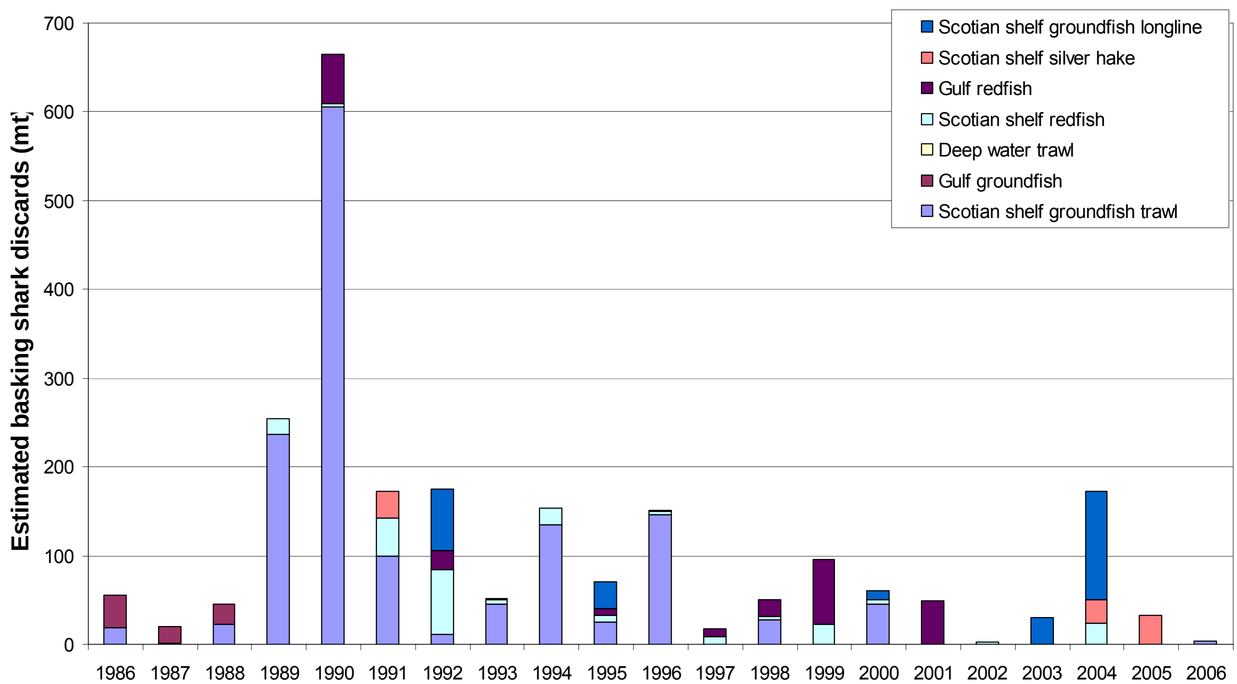


Fig. 15. Estimated (domestic) and known (foreign-reported by Scotia-Fundy) basking shark discards from domestic and foreign fisheries from all regions.

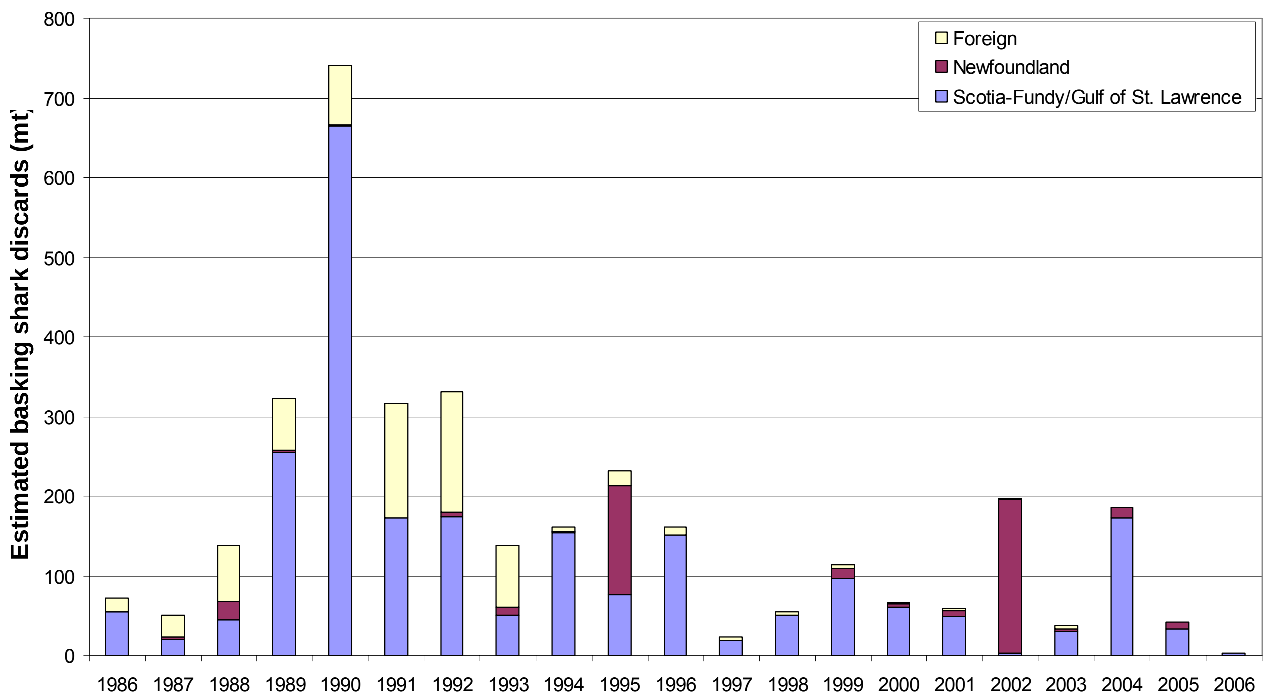


Fig. 16. Distribution of basking shark catch weights by set as recorded in the (A) Scotia-Fundy and (B) Newfoundland observer programs. Although the data are aggregated by set, almost all observations are based on a single basking shark. There was a suggestion of a trend in basking shark weight through time in the Scotia-Fundy data (C).

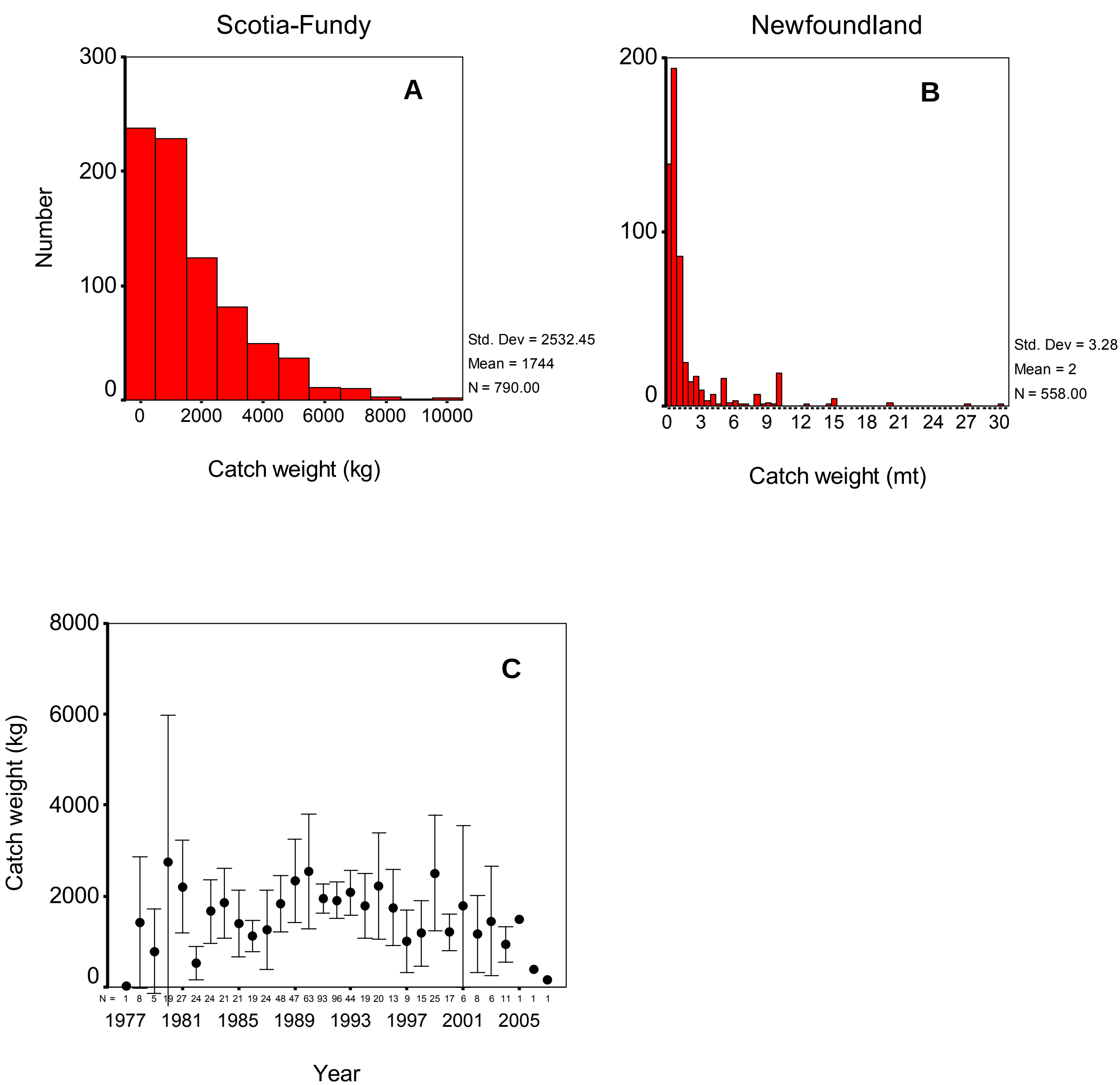


Figure 17. Simulation results from the base model in which *r* is constrained to be >0 and <0.057. The top panel shows 10 simulated population trajectories and the bottom panel shows the histograms, based on 1000 population simulations, of the population size in 2007, the population size in 1986, *r* and rate of change in population size (positive values indicate an increasing population).

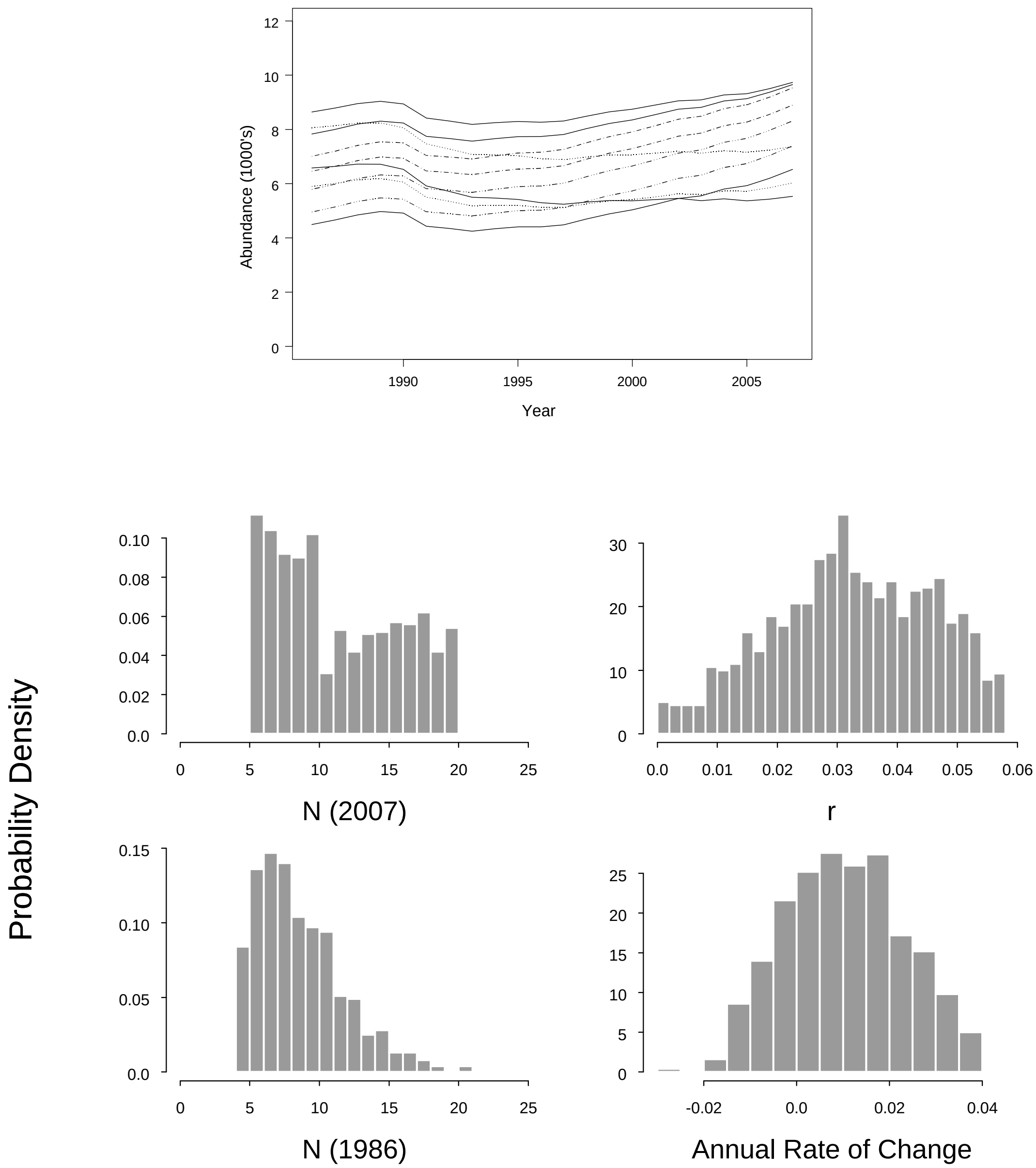
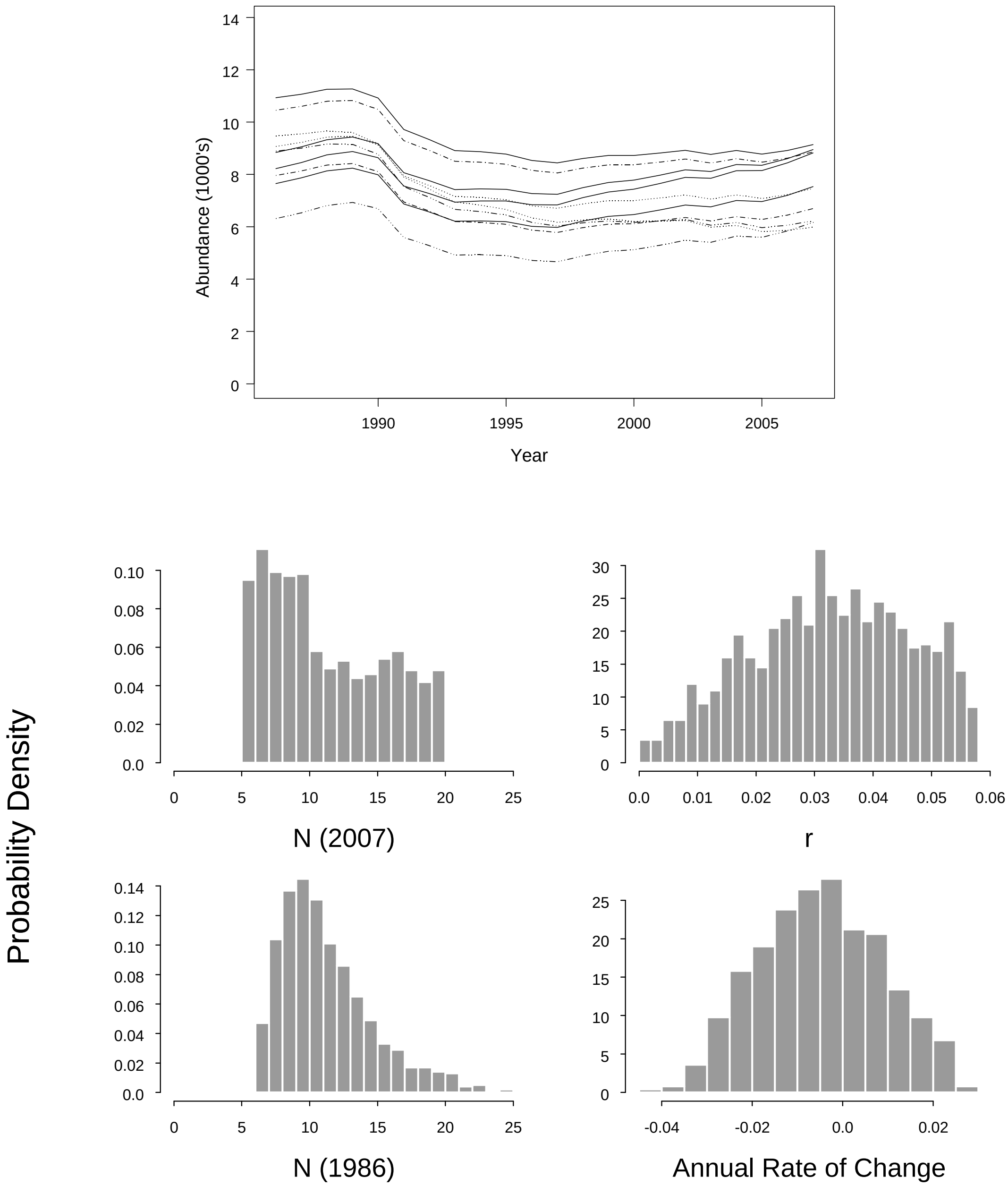


Figure 18. Simulation results from the model with the number of removals doubled. The top panel shows 10 simulated population trajectories, while the bottom panel shows the histograms of the population size in 2007, the population size in 1986, r and the rate of change in population size (positive values indicate an increasing population).



Appendix 1. S-Plus code used to estimate *r*, F_{crit}, N_{crit} and for the population simulations.

```
#ajf gibson Apr. 26/08

lotka.r<-function(age.mat,litter,gestation,nat.mort,juv.mult,max.age,lag)
            {
                  #age.mat<-18
                  #litter<-3
                  #gestation<-3
                  #nat.mort<-0.068
                  #juv.mult<-2
                #max.age<-50  #first.age=0 in this model
                #lag<-1 #time between giving birth and becoming pregnant

                gest.lag<-gestation+lag

                  #temp<-c(0,c(rep(0,age.mat),rep(c(rep(0,gestation-
1),litter),100))) #old doesn't work
                  temp<-c(0,c(rep(0,age.mat+gestation-
1),litter,rep(c(rep(0,gest.lag-1),litter),100)))
                mx<-temp[1:(max.age+1)]

                  r.M<-c(nat.mort*juv.mult,rep(nat.mort,max.age-1))

                  si<-exp(-r.M)
                  x<-0:(max.age)
                  lx<-0
                  lx[1]<-1
                  for(i in 2:(length(si)+1))
                  {lx[i]<-lx[i-1]*si[i-1]}

                  lxmx<-lx*mx
                assign(".lxmx",lxmx,frame=1)     # Store in expression frame
                assign(".x",x,frame=1)
                minimise<-function(start.r)
                    {
                   rx<-exp(-start.r*.x)
                     lotka<-sum(.lxmx*rx)
                     sumsq <- sum((lotka-1)^2)
                     return(sumsq)
                  }
           junk<-nlminb(start = 0.03,obj = minimise, lower=-0.2,upper=0.2)
             return(junk)
            }


#####################################################################

basking.sim6<-function()
{

#ajf gibson Apr. 26/08
#assign output to "basking.sim.result" which is an object used by the
plotting function below

years<-1986:2007
n.years<-length(years)
```

```
n.sims<-1000
Pop<-matrix(rep(0,n.years*n.sims),n.sims,n.years)    #matrix(data=NA,
nrow=<<see below>>, ncol=<<see below>>,byrow=F, dimnames=NULL)
Pop.vec<-rep(0,n.years)
r.vec<-rep(0,n.sims)
F.crit.vec<-rep(0,n.sims)
N.crit.vec<-rep(0,n.sims)
B1.vec<-rep(0,n.sims)
removals<-
c(71,51,138,322,741,317,331,138,161,232,161,23,54,114,66,59,197,37,185,42,4,0
) #0 is a place holder, doesn't matter
#removals<-removals*2
mean.removals<-mean(removals[removals>0])  #last value doesn't count in
average
print(mean.removals)
sel<-2
r.cutoff<-0.057  # 0.057 median of 21 species of sharks
K<-20000   #upper limit on population size used (high level of d.d.)

#create vectors of random pars

      age.mat.vec<-sample(16:20,n.sims*2,replace=T) #18
      litter.vec<-sample(2:4,n.sims*2,replace=T)    #6 total switched to
females =3
      gestation.vec<-sample(2:4,n.sims*2,replace=T) #3
      nat.mort.vec<-runif(n.sims*2,0.058,0.078) #0.068
      #nat.mort.vec<-runif(n.sims*2,0.081,0.101) #0.091
      juv.mult.vec<-runif(n.sims*2,1.5,2.5) #2
      lag.vec<-sample(0:2,n.sims*2,replace=T) #1
      #lag.vec<-rep(0,n.sims*2)
      max.age.vec<-sample(40:60,n.sims*2,replace=T) #50
      N.end<-
c(sample(5000:10000,size=n.sims/2,replace=T),sample(10000:20000,size=n.sims/2
,replace=T))
      #N.end<-
c(sample(2500:5000,size=n.sims/2,replace=T),sample(5000:10000,size=n.sims/2,r
eplace=T))

   #logic here is approx. 10000 sharks. guess at range is 1/2 to double; done
this way so that half are above and half are below

 for(i in 1:(1*n.sims*2))   #2 is a patch to get n.sims values for r that are
<r.cutoff
     {
     junk<-
lotka.r(age.mat.vec[i],litter.vec[i],gestation.vec[i],nat.mort.vec[i],juv.mul
t.vec[i],max.age.vec[i],lag.vec[i])
     junk2<-
F.crit.calc(age.mat.vec[i],litter.vec[i],gestation.vec[i],nat.mort.vec[i],juv
.mult.vec[i],max.age.vec[i],lag.vec[i],sel,mean.removals)

     r.vec[i]<-junk$par
     F.crit.vec[i]<-junk2$f
     N.crit.vec[i]<-junk2$N.crit
     }
     temp.r.vec<-r.vec[r.vec>0 & r.vec<r.cutoff]
     temp.F.crit.vec<-F.crit.vec[r.vec>0 & r.vec<r.cutoff]
     temp.N.crit.vec<-N.crit.vec[r.vec>0 & r.vec<r.cutoff]
```

```
     r.vec<-temp.r.vec[1:n.sims]
     F.crit.vec<-temp.F.crit.vec[1:n.sims]
     N.crit.vec<-temp.N.crit.vec[1:n.sims]



############################################################

#then do population projections

    for(i in 1:n.sims)
      {
      Pop.vec[n.years]<-N.end[i]
         for(y in 1:(n.years-1))
           {
           Pop.vec[n.years-y]<-(Pop.vec[n.years-y+1]+removals[n.years-
y])/exp(r.vec[i])
          #Pop.vec[n.years-y]<-(Pop.vec[n.years-
y+1]+mean.removals)/exp(r.vec[i]) #average value
           }

      Pop[i,]<-Pop.vec
      B1.vec[i]<-lm(log(Pop.vec)~years)$coef[2]
      } #end simulation

     r.summary<-quantile(r.vec,c(0.05,0.5,0.95))
     F.crit.summary<-quantile(F.crit.vec,c(0.05,0.5,0.95))
     N.crit.summary<-quantile(N.crit.vec,c(0.05,0.5,0.95))
     proportion.declining<-length(B1.vec[B1.vec<0])/length(B1.vec)

return(mean.removals,Pop,r.vec,B1.vec,r.summary,F.crit.summary,N.crit.summary
,proportion.declining)

} #end function
###############################################################
###############################################################


plot.basking.sim<-function()
{
graphsheet(orientation="landscape")
pop<-basking.sim.result$Pop/1000

r<-basking.sim.result$r.vec
B1<-basking.sim.result$B1.vec
ann.change<-basking.sim.result$ann.change
par(mfrow=c(1,1),las=1,omi=c(1,1,0.5,0.25),mar=c(3,3,1,1))

years<-1986:2007
plot(years,pop[1,],type="l",ylim=c(0,max(pop[1:20,])),xlab=" ",ylab="
",lty=1)
lines(years,pop[2,],lty=3)
lines(years,pop[3,],lty=5)
lines(years,pop[4,],lty=7)
lines(years,pop[5,],lty=9)
lines(years,pop[6,],lty=1)
lines(years,pop[7,],lty=3)
```

```
lines(years,pop[8,],lty=5)
lines(years,pop[9,],lty=7)
lines(years,pop[10,],lty=9)

mtext("Year",1,outer=T,cex=1.2)
mtext("Abundance (1000's)",2,outer=T,cex=1.2)

par(mfcol=c(2,2),las=1,omi=c(1,1,0.5,0.25),mar=c(4,4,2,2))

hist(pop[,length(years)],nclass=20,probability=T,cex=0.7,xlab="
",plot=T,xlim=c(0,25))
mtext("N (2007)",1,outer=F,cex=1.2,line=3)

hist(pop[,1],nclass=20,probability=T,cex=0.7,xlab=" ",plot=T,xlim=c(0,25))
mtext("N (1986)",1,outer=F,cex=1.2,line=3)

hist(r,nclass=20,probability=T,cex=0.7,xlab=" ",plot=T)
mtext("Probability Density",2,outer=T,cex=1.4,line=4)
mtext("r",1,outer=F,cex=1.2,line=3)

hist(B1,nclass=20,probability=T,cex=0.7,xlab=" ",plot=T)
mtext("Probability Density",2,outer=T,cex=1.4,line=4)
mtext("Annual Rate of Change",1,outer=F,cex=1.2,line=3)
#mtext("Slope",1,outer=F,cex=1.2,line=3)

}

#####################################################################
F.crit.calc_function(age.mat,litter,gestation,nat.mort,juv.mult,max.age,lag,s
el,removals)
{
#this function finds the value of F such that the population growth rate = 1
#this is based on an SPR calculation
#the population growth rate =1 where SPR = 1/number of age-0 female offspring
#fishing selectivity is knife-edge at age=sel
#N.crit is the size the total population would have to be such that F would
be less than F.crit
#with removals only above the age of selectivity given recent average
removals (161.8)

 gest.lag<-gestation+lag
 temp<-c(0,c(rep(0,age.mat+gestation-1),litter,rep(c(rep(0,gest.lag-
1),litter),100)))
 mx<-temp[1:(max.age+1)]

 M<-c(nat.mort*juv.mult,rep(nat.mort,max.age-1))

 assign(".M",M,frame=1)     # Store in expression frame
 assign(".mx",mx,frame=1)
 assign(".sel",sel,frame=1)
 assign(".max.age",max.age,frame=1)
 assign(".litter",litter,frame=1)
 minimise<-function(f)
   {
   f.vec<-c(rep(0,.sel),rep(f,.max.age-.sel))
   si<-exp(-(.M+f.vec))
   lx<-0
```

```
   lx[1]<-1                     #lx is the proportion alive at the start of
each age class
   for(i in 2:(length(si)+1))
   {lx[i]<-lx[i-1]*si[i-1]}
   spr<-sum(lx*.mx)
  # sumsq <- (spr-(1/.litter))^2  #litter is the number of female age-0
offspring
   sumsq <- (spr-1)^2
   return(sumsq)
   }

  junk<-nlminb(start = 0.1,obj = minimise, lower=0.0001,upper=4)


  f<-junk$par
  f.vec<-c(rep(0,.sel),rep(f,.max.age-.sel))
  si.f<-exp(-(.M+f.vec))         #values or vectors labelled .f are at f.crit
  lx.f<-0
  lx.f[1]<-1
  for(i in 2:(length(si.f)+1))
  {lx.f[i]<-lx.f[i-1]*si.f[i-1]}
  spr.f<-sum(lx.f*.mx)

  si.f0<-exp(-(.M))       #values or vectors labelled .f0 are in the absence
of fishing
  lx.f0<-0
  lx.f0[1]<-1
  for(i in 2:(length(si.f0)+1))
  {lx.f0[i]<-lx.f0[i-1]*si.f0[i-1]}
  spr.f0<-sum(lx.f0*.mx)



#N.crit
#given f.crit and catch and C=N(1-exp(-F))
 N<-removals/(1-exp(-f)) # these are at or above the age of selectivity
#add in number below the age of selectivity, calculated using lx
 N.crit<-N*(sum(lx.f)/sum(lx.f[(sel+1):length(lx.f)]))


  return(mx,M,f.vec,si.f,lx.f,spr.f,f,si.f0,lx.f0,spr.f0,N,N.crit)
}
```