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Recovery Potential Assessment for Porbeagle (*Lamna nasus*) in Atlantic Canada

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems 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.

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ABSTRACT

Porbeagle (*Lamna nasus*) were designated as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2014, and are currently under consideration for addition to Schedule 1 of the *Species at Risk Act* (SARA). The Recovery Potential Assessment (RPA) presented here provides the necessary background information, population status and mitigation options in support of the listing decision. Porbeagle are long-lived, slow-growing sharks with a delayed age of sexual maturation and a low fecundity, rendering them susceptible to overexploitation. Since they are widespread in Atlantic Canadian waters, habitat is not limiting to their recovery. Population size in 2009 was about 25% of its size in 1961, while female spawner abundance was about 14% of its 1961 level. Overfishing is the only known cause of their decline, and the only impediment to their recovery. Although a directed pelagic longline fishery contributed to their population decline, recent fishing mortality is largely due to capture and post-release mortality as bycatch in pelagic longlines and groundfish mobile gear. Mitigation options to reduce the threat due to fishing include a variety of options for reducing bycatch and post-release mortality. Recovery at 80% of female spawning stock numbers, or $SSN_{80\%}$, is expected to occur around 2042 under recent fishing mortality rates (approximately 2%).

Évaluation du potentiel de rétablissement de la maraîche (*Lamna nasus*) au Canada atlantique

RÉSUMÉ

La maraîche (*Lamna nasus*) a été désigné comme espèce en voie de disparition par le Comité sur la situation des espèces en péril au Canada (COSEPAC) en 2014, et est actuellement à l'étude en vue de son inclusion à l'annexe 1 de la *Loi sur les espèces en péril* (LEP). L'évaluation du potentiel de rétablissement (EPR) présenté ici fournit les renseignements de base nécessaires, l'état de la population et les options d'atténuation à l'appui de la décision d'inscription. La maraîche est un requin à grande longévité et à croissance lente présentant un âge tardif de maturité sexuelle et une faible fécondité, ce qui le rend vulnérable à la surexploitation. Étant donné que l'espèce est répandue dans les eaux du Canada atlantique, l'habitat ne constitue pas un obstacle à son rétablissement. La taille de la population en 2009 représentait environ 25 % de celle en 1961, tandis que l'abondance des femelles reproductrices représentait environ 14 % du niveau de 1961. La surpêche est la seule cause connue de son déclin, et le seul obstacle à son rétablissement. Même si une pêche dirigée à la palangre des poissons pélagiques a contribué au déclin de la population, la récente mortalité par pêche est due en grande partie aux captures et à la mortalité après la remise à l'eau des prises accessoires dans les palangres pour la pêche pélagique et les engins mobiles de pêche du poisson de fond. Les options d'atténuation pour atténuer la menace attribuable à la pêche comprennent plusieurs solutions visant à réduire les prises accessoires et la mortalité après remise à l'eau. Le rétablissement à 80 % de l'effectif du stock de femelles reproductrices, ou $ESR_{80\%}$, devrait se produire aux alentours de 2042, en dessous des récents indices de mortalité par pêche (environ 2 %).

INTRODUCTION

The Porbeagle (*Lamna nasus*) is a large cold-temperate pelagic shark species of the family Lamnidae that occurs in the North Atlantic, South Atlantic and South Pacific oceans. The species range in the Northwest Atlantic Ocean extends from Newfoundland to the Sargasso Sea, but most of the population resides within Canadian waters. Porbeagle is one of only two large shark species for which a directed commercial fishery has ever existed in Canadian waters.

In May 2004, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Porbeagle as an Endangered species, and recommended that it be listed under Schedule 1 of Canada's *Species at Risk Act* (SARA) (COSEWIC 2004). After extensive consultations both within and outside of government, the decision was taken not to list the species under SARA. The basis for the decision was that the Porbeagle population was lower than desirable, but was projected to be increasing, and that the total allowable catch (TAC) across all fisheries had already been set at levels which would allow the population to recover. Implicit in this decision was the recognition that if population recovery could not be demonstrated, the desirability of its directed fishery would be re-evaluated.

A pre-COSEWIC review of Porbeagle was conducted by Fisheries and Oceans Canada (DFO) in September 2012 (Campana et al. 2013; Simpson and Miri, 2013). In May 2014, Porbeagle was re-assessed as Endangered by COSEWIC. The rationale provided for this designation was:

"The abundance of this shark declined greatly in the 1960s after fisheries began targeting this species. A partial recovery during the 1980s was followed by another collapse in the 1990s. Numbers have remained low but stable in the last decade, since catch has decreased. Directed fisheries have been suspended since 2013, though there is still bycatch of unknown magnitude in Canadian waters and unrecorded mortality in international waters. This species' life history characteristics, including late maturity and low fecundity, render it particularly vulnerable to overexploitation."

Porbeagle are currently under consideration for addition to Schedule 1 of SARA. DFO's Recovery Potential Assessment (RPA) informs the listing decision, socio-economic analyses, and consultations with the public. Should this species be added to Schedule 1 of SARA, the advice from this RPA will also inform the recovery strategy and action plan developed for the species, and support decisions regarding the issuance of allowable harm permits or harvest agreements.

BIOLOGY, ABUNDANCE AND DISTRIBUTION

Element 1: Summarize the biology of Porbeagle.

Element 2: Evaluate the recent species trajectory for abundance, distribution and number of populations.

Element 3: Estimate the current or recent life-history parameters for Porbeagle.

STOCK STRUCTURE

There are two populations of Porbeagle in the North Atlantic: one in the northwest (NW) Atlantic and one in the northeast (NE) Atlantic, with no appreciable mixing between the two (Campana et al. 1999; Campana et al. 2001). Monthly shifts in the location of the NW Atlantic Porbeagle-directed fishery suggest that these sharks carry out extensive annual migrations up and down the east coast of Canada, with no indication of population substructure within the NW Atlantic. Porbeagle first appear in the Gulf of Maine, Georges Bank, and southern Scotian Shelf in

January-February, move northeast along the Scotian Shelf through the spring, and then appear off of the south coast of Newfoundland and in the Gulf of St. Lawrence in the summer and fall. Catches in the late fall suggest a return movement to the southwest. This pattern recurs annually. Figure 1 shows a map of geographic locations and fishing banks.

The results of tagging studies carried out by Norway, Canada and the U.S. document extensive annual migrations within the NW Atlantic. A total of 197 recaptures were reported in Campana et al. (1999). A further 12 recaptures have since been reported; all recaptures have been mapped in Figure 2. Movements between the Grand Banks, Scotian Shelf and Gulf of Maine were common. None of the tagged Porbeagle were recaptured on the east side of the Atlantic, and none of the Porbeagle tagged in the eastern Atlantic were recaptured off the North American coast (Stevens 1990).

Recent research using Pop-up Satellite Archival Tags (PSAT) demonstrated that most Porbeagle remained within the Canadian and American Exclusive Economic Zone (EEZ), although there was significant movement by some individuals into the high seas (Figure 3). All mature females whose tags popped off in the spring were found in the Sargasso Sea between Cuba and Bermuda, indicating that the Sargasso Sea is a major pupping ground for the NW Atlantic population (Campana et al. 2010a).

DISTRIBUTION

Porbeagle are widely distributed in coastal and offshore waters in Atlantic Canada, although most of the landed catch has been caught on the shelf edge and in the deep basins of the Scotian Shelf, especially since the time of a significant reduction in TAC in 2006 (Figure 4). All life history stages have roughly similar distributions (Campana et al. 2013).

Based on At-Sea Fishery Observer (ASO) data from the DFO Newfoundland and Labrador Region, the majority of commercial Porbeagle catches in Newfoundland waters occurred on the Grand Banks in Northwest Atlantic Fisheries Organization (NAFO) Division 3LNO (Figure 5). It must be noted that Observer coverage of some Newfoundland fisheries is less than one percent or non-existent in some cases (e.g., inshore small boat fisheries). Porbeagle also occur north of the Grand Banks in NAFO Division 2J3K, which is probably their northern limit in Canadian waters. Landings recorded in the DFO Newfoundland and Labrador Region Zonal Interchange File Format (ZIFF) database provided distributional results similar to those of ASO data: a majority of Newfoundland-based landings were from the Grand Banks in Div. 3LNO (Figure 6).

Porbeagle are known to be present in the southern and eastern Gulf of St. Lawrence, based both on commercial catches (often misidentified as Shorfin Mako) and the shark survey, but observer data are absent.

There is a paucity of information on commercial Porbeagle catches outside of Canada's EEZ. Mapping of American observed catches and tag releases in 2000-2007 indicated that Porbeagle are found in substantial numbers outside of Canadian waters, particularly off of the northeastern U.S. coast and shelf edge east of the Grand Banks (Campana et al. 2013). Young-of-the-year (YOY) Porbeagle were especially prevalent off of the eastern edge of the Grand Banks, along the shelf edge in Canadian and northeastern U.S. waters, and inshore in the latter area. Juveniles were similarly distributed, but with lesser numbers off of the Grand Banks, while adult Porbeagle were seldom caught.

Catch quantities and locations of Porbeagle by the international fleet on the high seas are poorly documented, but some Porbeagle have been caught south of Iceland.

BIOLOGY AND LIFE HISTORY PARAMETERS

Age, Growth, Longevity and Natural Mortality

The life span of Porbeagle is estimated to be between 25 and 46 years, and generation time is about 18 years (Campana et al. 2002; Natanson et al. 2002). In both sexes, growth rate appears to decrease slightly at the onset of sexual maturity. Since females mature at an older age than do males, females grow to a larger size. Figure 7 presents the von Bertalanffy growth parameters by sex, as well as that of the combined sexes. Predicted lengths and weights at each age are also shown, although observed sizes at age 0 and 1 were used to minimize distortions due to seasonality and partial recruitment of the young fish to the fishery.

It is possible that the ages of very old Porbeagle (greater than 25 years) are underestimated by vertebral band counts, as has been observed in the slow-growing New Zealand population (Francis et al. 2007). If true, the growth rate of old Porbeagle is somewhat slower than that suggested by the von Bertalanffy growth parameters. The fact that the L_{∞} growth parameter (asymptotic length) of the females is considerably larger than the largest Porbeagle normally observed suggests that growth overestimation of the oldest fish (and only the oldest fish) is a possibility. For this reason, the combined growth curve has been used in most analyses.

Porbeagle are thought to have a low natural mortality. Instantaneous natural mortality is estimated to be 0.10 for immature Porbeagle, 0.15 for mature males, and 0.20 for mature females (Campana et al. 2008). Although these estimates are conditional on the gear selectivity assumed in their calculation, they are presently the best available for this population.

Reproduction

Porbeagle have low fecundity and a late age of sexual maturation. Jensen et al. (2002) reported that males mature between 160 and 190 cm in Fork Length (FL) (median length at which 50% of Porbeagle are mature (L_{50}) equals approximately 174 cm; median age at which 50% of Porbeagle are mature (A_{50}) equals approximately Age 8), while females mature between 205 and 230 cm FL (L_{50} approximately 217 cm; A_{50} approximately Age 13). Porbeagle are ovoviparous and oophagous, with an average litter size of 3.9 pups in the NW Atlantic.

Research indicates that mating occurs in at least two locations. The first mating ground to be identified was on the Grand Banks, off southern Newfoundland and at the entrance to the Gulf of St. Lawrence. Most large females collected in these areas in the late summer or early fall were pregnant, suggesting that mating took place during the summer (Jensen et al. 2002). A second mating ground on Georges Bank was suggested in June 2007, based on similar aggregations of mature females which did not appear to be feeding and high catch rates. Mature males were absent at the time, suggesting that mating had not yet begun. Allowing for the delay between mating and the production of visible embryos, a summer mating period on Georges Bank and off Newfoundland is probably very similar. Birth apparently occurs in late winter or spring in the Sargasso Sea after an 8-9 month gestation period (Aasen 1963; Francis and Stevens 2000; Jensen et al. 2002; Campana et al. 2010a). There is no evidence of an extended latency period after birth, since virtually all sexually mature females are pregnant in the fall. Therefore, the reproductive cycle is 1 year.

Feeding and Diet

The Porbeagle is primarily an opportunistic piscivore with a diet characterized by a wide range of species (Joyce et al. 2002). Teleosts occurred in the majority of stomachs and constituted 91% of the diet by weight. Cephalopods occurred in 12% of sharks and were the second most important food category consumed. Diet composition changed seasonally following a migration from deep to shallow water. The relative contribution of groundfish increased with shark size,

while the contribution of cephalopods decreased. Other elasmobranchs were occasionally eaten by large Porbeagle, but marine mammals and birds were never found in the stomachs (Joyce et al. 2002).

ABUNDANCE

The abundance of Porbeagle in the NW Atlantic population was estimated with a forward-projecting age- and sex-structured population dynamics model (Campana et al. 2010b). Within this model, the population was projected forward from an equilibrium starting abundance and age distribution by adding recruitment and removing catches. A key assumption in the model is that the Porbeagle population was at an unfished equilibrium at the beginning of 1961, when the directed commercial fisheries for Porbeagle began. Model parameter estimates were obtained by fitting the model to catch, Catch Per Unit Effort (CPUE), length frequency, and tagging datasets using maximum likelihood. Four model variants were produced, differing only in their assumptions of population productivity.

Estimates of the population size in 2009 ranged from 196,911 to 206,956 sharks (Table 1). The estimated number of mature females ranged from 11,339 to 14,207 (Table 1), or about 6% of the population. The models indicated that the 2009 population was about 22% to 27% its size in 1961 (Table 1), and that female spawner abundance was about 16% of its 1961 level. The models also indicated that the reduced quotas since 2002 have more or less halted the decline in population size. Table 2 presents the time series of population size and female spawner abundance.

Trends in abundance were roughly similar between the models (Figure 8). Estimates of the number of spawners in 1961 were highest from Model 2. All models suggested an increase in spawner abundance in the late 1970s and early 1980s, although the increase was small. The estimated total number of Porbeagle also increased only slightly during the 1980's (Figure 8). Although abundance has been relatively stable since 2002, there has been a very slight increase in abundance of both spawners and recruits since 2006.

The total biomass was estimated at around 10,000 metric tonnes (mt) in 2009 (Table 1). Such a biomass would place the 2009 value at between 20-24% of its value in 1961, and 4-22% higher than it was in the year 2001. Estimates of the vulnerable biomass in 2009 differed depending on the assumed selectivity as well as among models. Assuming the Shelf-Edge selectivity, the models place the vulnerable biomass in 2009 (mid-year) for the entire population at about 4,700-5,100 mt.

All of the analyses indicated that the abundance of Porbeagle in the NW Atlantic declined during the late 1960s, increased slightly during the late 1970s and early 1980s, and decreased again during the late 1990s (Figure 8). The decline in total and spawner abundance appears to have halted sometime after the quota reductions in 2002, and may have entered the initial stages of recovery. Population size is expected to increase now that exploitation rates have been lowered, but that recovery times will be slow.

PORBEAGLE SHARK SURVEY

Canada's first fishery-independent survey of Porbeagle abundance was carried out by Atlantic Canadian fishermen working in conjunction with DFO scientists in June 2007. The objective of the survey was to provide a baseline for monitoring the population health and abundance of Porbeagle found off of Atlantic Canada. The second survey was carried out in June 2009, using identical methods. Any subsequent surveys would be carried out using the same design and stations; thus, allowing for a direct comparison with the 2007 and 2009 survey results.

The 2007 and 2009 shark surveys covered 50 fixed stations in Atlantic Canada stretching from the Canada-U.S. border up to northern Newfoundland, an area of more than 200,000 km² (Figure 9). Station spacing was not constant throughout the survey area, and tended to be denser on the Scotian Shelf. Pelagic longline gear fit with #8 or #9 J-hooks and baited with squid was fished from the surface to the bottom and back, at repeating intervals. A total of 600 hooks were fished each set, with a total soak time of about 6 hours. Scientific staff were present on the survey boats throughout the survey.

Porbeagle (n=865 in 2007; n=488 in 2009) were caught throughout the survey area, but were most common around the deep basins and on the edge of the continental shelf (Figure 9). Temperature frequency histograms indicated that catch rates were highest in water temperatures of 6°C (at the depth of the fishing gear) and at depths of 100 m; catch rates were very low in waters colder than 2°C and warmer than 10°C. Mature female Porbeagle were only caught on the shelf edge. Mean Porbeagle FL was 159 cm and 48 kg in weight. However, FL ranged between 83 cm and 245 cm.

Comparison of the survey abundance index with previous commercial catch rates was difficult, since June was not a popular fishing month historically, especially by small vessels. However, it appears that survey catch rates were roughly comparable with those from 2000-2006, as predicted by the population model; catch rates were higher in some areas such as near the shelf edge, and lower in other areas such as the Grand Banks.

No appreciable change in Porbeagle abundance would be expected between 2007 and 2009, given the low commercial catches during that period and the low intrinsic population productivity. Indeed, the population abundance model estimates almost identical population abundance in the two survey years. A simple comparison of survey catch rates is not appropriate, since inter-station spacing varied with the region, and was markedly greater on the Grand Banks. In addition, the proportion of the survey stations which were too cold (less than 2°C), and thus unsuitable habitat for Porbeagle, differed between the survey years. The real value of the shark survey will become apparent when comparing the 2007 and 2009 survey results (which are calibrated against the most recent year of the population model abundance estimate) with those from future survey years, by which time more change in population abundance might be expected.

HABITAT AND RESIDENCE REQUIREMENTS

Element 4: *Describe the habitat properties that Porbeagle needs for successful completion of all life-history stages. Describe the function(s), feature(s), and attribute(s) of the habitat, and quantify how the biological function(s) that specific habitat feature(s) provides varies with the state or amount of habitat, including carrying capacity limits, if any.*

Porbeagle are pelagic sharks, and thus have no affinity for the ocean bottom. They are widely distributed in inshore and offshore waters throughout Atlantic Canada (Figure 4), and their distribution appears limited only by salinity and temperature. Salinity is limiting only in that Porbeagle require saltwater, although they appear tolerant to temporary exposure to estuarine waters. Water depth is not limiting since satellite tags have recorded them anywhere between the surface and a depth of 1360 m (Campana et al. 2010a).

Porbeagle appear to occupy relatively cool water temperatures throughout the year (Campana and Joyce 2004). Based on temperature at the depth of the gear, Porbeagle were caught at a mean temperature of 7.4°C, with 50% being caught between 5-10°C. Temperature at depth was a significant predictor of catch rate; however, sea surface temperature was a poor predictor of catch rate. There was no significant seasonal pattern in temperature, suggesting that the

Porbeagle adjusted their location to occupy the preferred temperature range. Results from PSAT tags indicate that Porbeagle can reside in slightly warmer temperatures than those suggested by fishery captures: measurements from 34 Porbeagle provided a mean occupied temperature of 11°C, with 50% of their time being spent between 8 and 13°C and a complete range of 0-25°C. For much of the spring commercial fishery, Porbeagle were caught most frequently in waters immediately adjacent to the frontal edge separating cool Shelf waters from warmer offshore waters (Figure 10). Porbeagle were not associated with fronts in the fall fishery, although the temperature occupied was similar to that observed in the spring (5-10°C).

Porbeagle caught in the June shark survey were caught most frequently in water temperatures (at the depth of the hook) of 2-11°C (Figure 11).

There are only two life history stages of the Porbeagle which appear to be concentrated in specific areas: the pupping stage and the mating stage. Based on satellite tags, all pupping appears to take place in the spring in and around the Sargasso Sea (in international waters) at depths of around 500 m (Figure 3; Campana et al. 2010a). Based on captures of non-feeding mature or newly-pregnant females, mating appears to take place in the summer in two locations: on or around Georges Bank, and off southern Newfoundland and in the approaches to the Gulf of St. Lawrence (Figure 12).

Element 5: *Provide information on the spatial extent of the areas in Porbeagle's distribution that are likely to have these habitat properties.*

Porbeagle first appear in the Gulf of Maine, Georges Bank, and southern Scotian Shelf in January-February, move northeast along the Scotian Shelf through the spring, and then appear off of the south coast of Newfoundland and in the Gulf of St. Lawrence in the summer and fall. No specific habitat characteristics of the mating grounds have been identified. Since the Sargasso Sea pupping grounds are well outside of Canadian waters, their habitat characteristics have not been considered here.

Element 6: *Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.*

No spatial configuration constraints of the mating grounds have been identified.

Element 7: *Evaluate to what extent the concept of residence applies to the species, and if so, describe the species' residence.*

As a pelagic shark species, the concept of residence does not apply to Porbeagle.

THREATS AND LIMITING FACTORS TO SURVIVAL AND RECOVERY

Element 8: *Assess and prioritize the threats to the survival and recovery of the Porbeagle.*

Fishing is the only known source of human-induced mortality on Porbeagle in Atlantic Canada.

Overfishing (both directed and as bycatch) was identified as the most pressing threat to Porbeagle in the 2014 COSEWIC status report, although it was acknowledged that most of the population decline occurred due to overfishing in the 1960s (COSEWIC 2014). With the closure of the Porbeagle directed fishery in 2013, the only remaining sources of fishing mortality in Canadian waters are from bycatch. Porbeagle bycatch on the high seas (outside of Canada's EEZ) are unknown and unregulated, but were estimated to be about 20 mt annually between 2003 and 2007 (ICCAT 2010).

LANDINGS

Landings rose from about 1,900 mt in 1961 to over 9,000 mt in 1964 and then fell to less than 1,000 mt in 1970 as a result of collapse of the fishery (Table 3; Figure 13). Reported landings

remained less than 500 mt until 1989, and then increased to a high of about 2000 mt in 1992. Landings since 1998 have been restricted by quota, and have been less than the 185 mt quota since 2007. The directed fishery was closed in 2013, but landings have been less than 100 mt since 2009.

Most of the recent landings have been bycatch from the groundfish fixed gear and pelagic longline fisheries (Table 4). Reported landings of Porbeagle in fisheries outside the DFO Maritimes Region are much lower and have been under 1 mt since 2006 (Table 5). There is a very small recreational fishery for Porbeagle.

Fisheries data available in the DFO Newfoundland and Labrador Region include the NAFO STATLANT-21A database, which contains commercial landings from NAFO Subareas 0, 1, 2, and 3, as reported by member countries from 1961 to 2013. In addition, commercial bycatch, discards, and length frequency data from 1979 to 2012 were obtained from the DFO Newfoundland and Labrador Region ASO database, which contains set-by-set information collected at sea in a standardized format by trained Canadian ASOs. A third source of fisheries data was the DFO Newfoundland and Labrador Region ZIFF database, which was created in 1985 to compile commercial landings reported by Canadian fishers (as recorded in their logbooks and on fish plants' purchase slips). Given that discards (even of target species) are not reported to NAFO or to the DFO Newfoundland and Labrador Region Statistics Branch (for ZIFF), the only reliable source of data on total catches and discarding at sea comes from Canadian ASOs.

Porbeagle landings in Newfoundland waters peaked in the mid-1990s, and have remained relatively low in recent years (Figure 14). Over the past decade, there were occasional large landings reported in NAFO Division 3M, which is outside the Canadian EEZ. The majority of landings reported in the ZIFF database were from NAFO Division 3L, but landings have been minimal in the past decade (Figure 14). With the exception of a few metric tonnes reported from groundfish gillnets, all of the NAFO Division 3LNO landings in the 1990s were from Porbeagle-directed pelagic longline fisheries.

ESTIMATION OF DISCARDS

The DFO Maritimes Region, formerly Scotia-Fundy, Observer Program (SFOP) has maintained 100% coverage of foreign fisheries in the Canadian zone since 1987, thus allowing accurate determinations of foreign shark catch and bycatch. Since 1999, however, essentially all pelagic shark catch and bycatch has been by Canadian vessels, for which observer coverage has been substantially less (approximately 5% for the large pelagic fishery, and considerably less for groundfish fisheries). The magnitude of the Porbeagle bycatch in each of the Atlantic Canadian fisheries was estimated by fishery, quarter and year from SFOP observations made between 1996-2014, with bycatch defined as the weight of the discarded Porbeagle relative to the summed large pelagic kept catch (tuna, Swordfish and Porbeagle). The summed large pelagic catch accounted for virtually all of the catch, and its use in the estimation avoided problems associated with the species sought being unknown. Total landed pelagic catch for each cell was determined from DFO Newfoundland and Labrador Region ZIFF or DFO Maritimes Region Maritime Fishery Information System (MARFIS) catch statistics databases. Full details on the estimation protocol are presented in Campana et al. (2011).

Observer records were available for most fisheries, but were absent or sporadic when overall catches were low and for some of the groundfish fisheries. Based on the proportion of the reported fishery catch which was observed between 2010 and 2014, the observed catch accounted for 9% of the total Swordfish/tuna pelagic longline catch, 3% of the NAFO Division 4X groundfish longline fishery (18% on Georges Bank), 1% of the groundfish gillnet fishery (16% on Georges Bank), and 9% of the groundfish otter trawl fishery (33% on Georges Bank).

These percentages do not include reported catches for cells for which there were no observer entries, which means that the actual observer coverage percentages could be lower than shown.

HOOKING AND POST-RELEASE MORTALITY

Prior to 1994, most non-landed shark bycatch was killed by the removal of the fins and returning the carcass to the water (finning). After finning was banned in 1994, all Porbeagle caught with pelagic longlines (LL) in Canadian waters were either kept/landed or discarded/released after capture. Many of these sharks are alive at the time of retrieval to the boat, and continue to remain alive after release. However, a significant percentage of sharks die while on the hook (hooking or capture mortality), and a significant percentage of the live releases subsequently die due to stress or injury (post-release mortality). Hooking mortality can be measured by onboard observers, and has been assessed particularly carefully since 2010. However, post-release mortality requires monitoring through use of PSAT tags (Campana et al. 2009).

More than 900 Porbeagle have been observed on large pelagic fishing vessels between 2010 and 2014 (Table 6). Of those where condition could be assessed at release, and assuming that moribund and shark-bit sharks were dead, the annual percentage of dead Porbeagle ranged between 23-67% with an overall mean of 44%. This value is considerably higher than the 15% value observed for Blue Shark caught on pelagic longlines over the same period (Campana et al. 2015). However, there was significant variation in mortality within the pelagic longline category when disaggregated by species sought: hooking mortality was 65% when Bluefin Tuna was the species sought, whereas it was 30% when the target species was Swordfish. The hooking mortality rate of 20% for other tuna species was based on few observations. Injury rates of 13-18% did not differ significantly with the target species.

A total of 235 Porbeagle caught with otter trawlers (OTB) have been recorded by observers (Table 6). Of those where condition could be assessed at release, a mean of 7% were dead after capture, while 24% were reported as injured.

Post-release mortality rates of Porbeagle have never previously been reported. Preliminary analysis of 53 PSAT-tagged Porbeagle tagged between 2005-2013 provided 40 records where the PSAT transmitted successfully. All 40 of these sharks were tagged on board the fishing vessel, either by scientists, observers or the fishermen themselves. Fork lengths ranged between 101 and 249 cm, and included both sexes. Healthy Porbeagle tagged in short duration (1-2 hour) sets as part of a non-commercial research longline charter showed no post-release mortality, but given the short duration of the sets, are not representative of commercial fishing (Table 7). All four sharks caught and tagged on commercial otter trawlers fishing Georges Bank survived post-release. Of the 31 Porbeagle caught on pelagic longline, 21% of the healthy sharks died post-release, while both of the two injured sharks died.

Table 6 shows that a mean annual percentage of 15% of the Porbeagle were reported by observers as being injured at the time of release from pelagic longlines. Healthy sharks accounted for 41%. Applying the 21% PSAT-based mortality rate to the 41% healthy rate, and the 100% PSAT-based mortality rate to the 15% injury rates, implies that the overall post-release mortality rate of live Porbeagle is 42% for pelagic longlines. When combined with a 44% hooking mortality, and assuming that no Porbeagle were retained, and given that only 56% of the Porbeagle are still alive after capture and before release, the overall non-landed fishing mortality of Porbeagle in the pelagic longline fishery is estimated at 68%.

Although the post-release mortality of healthy sharks caught on otter trawlers was found to be zero, injured sharks were not satellite tagged, and thus assumed to be 50%. Post-release mortality of all sharks caught in groundfish longlines and gillnets was assumed to be 100%.

These estimates must be considered preliminary until a more thorough analysis is completed. The fact that the Porbeagle were brought on board for tagging could conceivably influence their post-release mortality rate. However, the 100% survival rate of both OTB-caught and short duration LL-caught Porbeagle suggests that any boarding effect was small.

DISCARD QUANTITIES

Estimates of shark discards by fisheries operating in the DFO Maritimes Region indicate that about 165 mt of Porbeagle have been discarded annually by all fisheries combined since 2010 (Table 8). The pelagic longline fishery for Swordfish/tuna and the otter trawl groundfish fishery accounted for most of the Porbeagle discards in recent years. Pelagic longline discards of approximately 60 mt per year were greatest in and around Emerald and La Have basins in August through October (Figure 15a). Pelagic longline mortalities due to hooking and discarding have exceeded landings each year since 2011.

The groundfish OTB fishery has discarded an average of about 96 mt of Porbeagle annually since 2010, with almost all of that being observed on and around Georges Bank in June and July (Figure 15b). Of the 14 Porbeagle that were measured by observers, 6 of them were females that were greater than 200 cm in length, making them sexually mature. The status of the mature sharks (dead versus alive) at the time of release is unknown. There is no other documented location in the NW Atlantic where such a high proportion of mature females have been observed in the catch of any fishery.

For both the pelagic longline and the OTB fisheries, the estimated total discards and discard mortalities can be refined for future assessments. For example, almost all of the Porbeagle caught by OTB were caught during haddock fishing on Georges Bank. As such, observer discard ratios should probably be based on Georges Bank Haddock alone, rather than OTB catches of all groundfish in NAFO Divisions 4X and 5Y, which would almost certainly result in lower total discard quantities. Similarly, pelagic longline discards could be disaggregated into those targeting Swordfish and other tunas, for which hooking mortalities are lower, and those targeting Bluefin Tuna, where hooking mortalities are higher. Given the higher observer coverage on Bluefin Tuna longline vessels, it is possible that the resulting sum of discard mortalities for pelagic longlines would be lower than has been calculated here.

In contrast to the pelagic longline and OTB fisheries, Porbeagle bycatch in the groundfish longline and gillnet fisheries have been relatively small (less than 10 mt each) and dispersed across the Scotian Shelf (Figure 15c). Anecdotal evidence suggests that actual Porbeagle bycatch in these fisheries is much larger, and has been underestimated because of very low observer coverage.

Porbeagle bycatch mortality from all sources (capture + post-release + landing) has averaged 110 mt annually since 2010.

ASO-observed catches (including discards) in Newfoundland waters occurred mainly in the Porbeagle-directed fishery, which is no longer prosecuted (Figure 16). Other fisheries that catch Porbeagle include Swordfish-directed longline fisheries and gillnet fisheries directing for White Hake, Atlantic Cod, Monkfish, and Greenland Halibut. Porbeagle are also caught in Yellowtail Flounder-directed otter trawls.

Porbeagle discards by the international high seas fleets are unknown, unregulated and seldom recorded.

Element 9: *Identify the activities most likely to threaten (i.e., damage or destroy) the habitat properties identified in elements 4-5 and provide information on the extent and consequences of these activities.*

Given the widespread distribution of Porbeagle sharks in Atlantic Canada, it is unlikely that any anthropogenic event could significantly alter the habitat of the entire population, at least in the short term. However, there are two possibilities that could conceivably affect the habitat of regions of high Porbeagle population density (Scotian Shelf) or the mating grounds off of southern Newfoundland and the approaches to the Gulf of St. Lawrence: offshore petroleum seismic surveys and large scale offshore petroleum spills (see: DFO 2011).

Sharks have acute hearing at low frequencies, which they use to locate prey. There has been no research on the effects of seismic sound on sharks to date, but seismic surveys could potentially exhibit behavioural impacts on large pelagic sharks; for example, a seismic survey in a shark mating area during mating season may lead to a cessation of mating behaviours or cause adult sharks to temporarily or permanently move away from the preferred site before copulating. This remains an unknown threat, but numerous seismic surveys on the Scotian Shelf and on Porbeagle mating grounds off of southern Newfoundland in recent years are of concern (Figure 17).

A second potential impact is that of catastrophic failure of oil and gas operations on or around the Porbeagle mating or feeding grounds. Oil and gas production operations around Newfoundland, Sable Island and southwest Scotian Shelf and Slope are particularly noted here, as well as the drilling being discussed for the Gulf of St. Lawrence.

The construction of undersea pipelines or electrical cables could conceivably disrupt mating activities off of southern Newfoundland as well.

Element 10: *Assess any natural factors that will limit the survival and recovery of the Porbeagle.*

The maximum intrinsic rate of increase (r_{\max}) for NW Atlantic Porbeagle is low relative to estimates for many other sharks, and much lower than most teleosts: on the order of 0.05 (Campana et al 2013). This low intrinsic productivity is due to a delayed age at maturation and low fecundity, and cannot be altered by mitigation measures. As such, the recovery of Porbeagle will necessarily take considerable time, even in the complete absence of fishing and other threats.

To this point, there has been no evidence of Allee effects or changes in body condition (indicative of reduced prey consumption), although there has been little monitoring of fecundity or condition in recent years.

Element 11: *Discuss the potential ecological impacts of the threats identified in element 8 to the target species and other co-occurring species. List the possible benefits and disadvantages to the target species and other co-occurring species that may occur if the threats are abated. Identify existing monitoring efforts for the target species and other co-occurring species associated with each of the threats, and identify any knowledge gaps.*

Given the cessation of the directed fishery for Porbeagle, the ecological impacts of the remaining fishing threats are largely associated with bycatch of other species, particularly those in the pelagic longline and groundfish fisheries. The impact in the pelagic longline fishery would be that of reduced abundance of target species such as Swordfish and tunas, as well as major bycatch species such as Blue Shark. Reduced fishing pressure would presumably result in greater abundance of Swordfish, tunas and Blue Shark as well as Porbeagle. The above would also apply to Newfoundland groundfish-directed gillnet fisheries (e.g., Atlantic Cod), in which significant and unreported Porbeagle bycatch is a primary source of mortality of this species in Newfoundland waters. Impacts on prey species are difficult to predict for all regions.

There are no existing monitoring programs for Porbeagle abundance or population status. The population model used to assess population status to date requires directed CPUE and length frequency data as input, and thus provides no useful information in the absence of a directed fishery. CPUE based on landings would provide too little data to be useful. It is likely that Porbeagle bycatch CPUE in the pelagic longline fishery could be used to provide an index of abundance, but the current ASO coverage (on the order of 5%) is too low to provide a useful index. Substantially higher observer coverage of the pelagic longline fleet, especially around Emerald Basin and near the edge of the Scotian Shelf, is the most feasible source of a Porbeagle abundance index for that area.

There have been two fishery-independent Porbeagle surveys conducted in the past. These surveys were conducted near the end of the population model time series, and thus could be scaled to the terminal population estimates from the model. With this scaling in place, any additional periodic surveys (e.g., at 5-year intervals) would be a useful way to monitor Porbeagle population recovery status.

RECOVERY TARGETS

Element 12: *Propose candidate abundance and distribution target(s) for recovery.*

There is no accepted recovery or fishing reference points for Porbeagle. As a species managed by ICCAT, Maximum Sustainable Yield (MSY) is usually used as a fishing target reference point. An Upper Stock Reference Point of 80% of female spawning stock numbers ($SSN_{80\%}$) at MSY ($SSN_{80\%} = 27,658$ under Model 3; range of 24,000-32,000 across all models) is therefore proposed as the population recovery target. The time frame for recovery would be the same as that used by COSEWIC to assess decline: three generations (or approximately 54 years).

With respect to distribution targets for recovery, there is no evidence for a reduction in the area occupied by Porbeagle. A reasonable recovery target would be to maintain current distribution.

Element 13: *Project expected population trajectories over a scientifically reasonable time frame (minimum of 10 years), and trajectories over time to the potential recovery target(s), given current Porbeagle population dynamics parameters.*

In the last complete Porbeagle stock assessment (Campana et al. 2010b), population viability analysis (PVA) was used to evaluate recovery potential, recovery trajectories and recovery times. At the time, recovery targets had not yet been established for Porbeagle, so it was assessed how differing levels of incidental harm (mortality associated with bycatch in fisheries not targeting Porbeagle) affected the recovery timelines relative to two commonly used fishery reference points $SSN_{20\%}$ and SSN_{MSY} . These are not recovery targets, but are reference points against which population growth can be evaluated. The recovery target proposed here (i.e., $SSN_{80\%}$) was not considered at the time, and therefore has not been shown on Figure 18.

Estimates of reproductive rate (as characterized via the spawner-recruit model), maturity schedules and mortality rates were available for Porbeagle, but estimates of the variances or the temporal autocorrelation were not; these two factors can effect recovery times and population viability. Therefore, the analysis projected the population forward deterministically (no variability added) from the estimated 2009 population size and age-structure using the estimated life history parameters and an assumed bycatch rate. The analysis used the selectivity parameters from the Shelf-Edge fishery for these simulations. Simulations were carried out for 17 levels of bycatch mortality (defined as the proportion of the vulnerable biomass taken as bycatch) ranging from 0.0 to 0.1. Population projections were 100 years in length.

All four modeled scenarios indicated that the NW Atlantic Porbeagle population could recover if levels of human induced mortality were to be kept low (Figure 18). Estimated recovery times to

SSN_{msy} (shown) and $SSN_{80\%}$ (not shown) varied depending on the assumed productivity and harvest rate. Based on lower productivity Models 2 and 3, in the absence of human-induced mortality, recovery to $SSN_{80\%}$ was expected to occur between 2030 and 2045, whereas higher productivity Models 1 and 4 predicted recovery as early as 2022. An incidental harm rate of 4% of the vulnerable biomass was expected to delay recovery to $SSN_{80\%}$ to somewhere between 2030 (Model 1, best case scenario) and the 22nd century (Model 2, worst case scenario).

Model 3 was considered to be the most realistic productivity model. Under this scenario, recovery to $SSN_{80\%}$ in the absence of fishing would occur around 2033, while recovery under recent fishing mortality rates (approximately 2%) would occur around 2042. For purposes of the modeling analysis, Porbeagle fishing mortality outside of Canada's EEZ is assumed to remain low and constant.

Element 14: *Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present and when the species reaches the potential recovery target(s) identified in element 12.*

There is no indication that the availability of habitat would limit the recovery of Porbeagle at any stage.

Element 15: *Assess the probability that the potential recovery target(s) can be achieved under current rates of population dynamics parameters, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters.*

Monte Carlo simulations were used to introduce variability around the life history parameters used in the PVA (Gibson and Campana 2005). At the time, neither the proposed recovery target ($SSN_{80\%}$) nor the recent exploitation rate (approximately 2%) was considered. Nevertheless, all of the simulations made at the harvest rate of 2% recovered to SSN_{MSY} (Figure 19).

SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

Element 16: *Develop an inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat (as identified in elements 8 and 10).*

Canada has measures in place to ensure that it does not overharvest this stock within the Canadian EEZ, including a science based TAC. Management objectives include minimization of retained bycatch, mitigation of total mortality from discards and improved stock assessment accuracy.

Specific management measures protecting Porbeagle include restricting shark landings (e.g., in groundfish fisheries), mandatory release of live sharks in trawl fisheries (e.g., mobile groundfish) and the voluntary release of any incidental catches of live sharks in other fisheries (e.g., Swordfish or tuna longline). The use of non-metallic leaders, circle hooks and cutting the gangion without bringing the shark on board the vessel are used to reduce Porbeagle post-release mortality in the large pelagic longline fishery. However, it must be noted that restricting "landings" of shark bycatch does not reduce gear entanglements of Porbeagle in groundfish-directed gillnets, which result in 100% shark mortality in Newfoundland waters.

While spawning abundance and biomass are expected to increase under existing biomass estimates, if a reduction in harvest was determined to be required with current fishing practices and harvest levels, the main threat to Porbeagle is due to mortality caused by bycatch. Feasible mitigation measures to minimize the threat posed include:

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- Elimination of landings of Porbeagle through:
 - No authorization for a bycatch harvest of Porbeagle in any commercial or derby fishery.
 - Although this option is easily introduced, with the current low levels of landed Porbeagle (less than 40 mt since 2011), the reduction would have limited impact on the recovery of the stock. This is true, particularly in the groundfish longline and gillnet fisheries, where much of the released bycatch may already be dead.
 - Reduction in the amount of Porbeagle bycatch through:
 - Promote fishing practices that avoid bycatch species
 - Use of alternate gear – Use of harpoon and trolling gears reduce the bycatch of shark. However, expanding this to other fisheries without major changes could eliminate some fisheries such as those where quota allocations are provided based on gear type (e.g., groundfish longline) or fisheries not currently allowed the use of other gear.
 - Time and Area Closures – While it was still active, directed shark fishing in NAFO Divisions 4Vn3LNOP was closed from September to December to protect one of the Porbeagle mating grounds. Additional limitations to fisheries with a Porbeagle bycatch in sensitive life history areas (e.g., southern Newfoundland mating ground in summer/fall, Georges Bank mating ground in June-July, Emerald Basin in fall) could significantly reduce recovery times. The extent of the closure would need to be determined since closing large areas (e.g., Emerald Basin in fall; all of Georges Bank in the summer) could significantly impact some fisheries such as that for Swordfish and groundfish.
 - Increase the post release survival of Porbeagle:
 - Development of a release protocol – Currently shark may be brought on board before release or have the gangion cut leaving varying lengths of monofilament attached to the hook. The development and implementation of a 'Best Practices for Shark Handling' and the use of a line cutter as close to the hook as possible could increase survivability of released Porbeagle. This could decrease post release mortality, but the overall level of impact would be low.
 - Ensure that impacts on sharks of commercial fishing in Canadian waters can be effectively measured through improved knowledge of the populations and enhanced monitoring of discarded shark bycatch:
 - Estimate post-release mortality.
 - Post release mortality studies on Porbeagle caught by the Swordfish and tuna longline fleet were initiated in 2013 using PSAT tags. Similar studies for groundfish fisheries in all regions would improve species-specific estimates of post-release mortality in fisheries with a high degree of shark bycatch.
 - Improve knowledge on discards
 - Increase observer coverage to ensure statistically robust estimation of bycatch levels. In general, higher observer coverage leads to more reliable estimates of discards.
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- Explore the use of comprehensive video monitoring of catch and bycatch as an alternative to higher observer coverage in all fisheries that have a high bycatch of Porbeagle.

Element 17: *Develop an inventory of activities that could increase the productivity or survivorship parameters (as identified in elements 3 and 15).*

- The mitigation measures outlined above to limit impacts on the stock would be consistent with a goal of increasing survivorship in domestic waters.
- Porbeagle productivity in Canadian waters is related to the mating areas on the Grand Banks, the entrance to the Gulf of St. Lawrence and Georges Bank, and to the areas with high densities of juveniles such as Emerald Basin.
 - Restrict fishing activity in these areas by fisheries with high levels of Porbeagle bycatch.

Element 18: *If current habitat supply may be insufficient to achieve recovery targets (see element 14), provide advice on the feasibility of restoring the habitat to higher values. Advice must be provided in the context of all available options for achieving abundance and distribution targets.*

The 2007 and 2009 shark surveys demonstrated that although the distribution of the directed Canadian Porbeagle fishery contracted since the 1990s the overall population distribution of Porbeagle had not contracted, and that areas of high Porbeagle density were not restricted to the areas being fished. Although bycatch would be expected throughout the population range, it does not appear that the current habitat supply is limiting recovery.

Element 19: *Estimate the reduction in mortality rate expected by each of the mitigation measures or alternatives in element 16 and the increase in productivity or survivorship associated with each measure in element 17.*

Element 20: *Project expected population trajectory (and uncertainties) over a scientifically reasonable time frame and to the time of reaching recovery targets, given mortality rates and productivities associated with the specific measures identified for exploration in element 19. Include those that provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.*

Given the fact that the population model is now five years out of date, and that the selectivity of the various mitigation scenarios was so different, it was not possible to project population trajectories under the various scenarios. For example, the impact of reducing the bycatch of the mature Porbeagle caught by mobile gear on Georges Bank is very different than that of reducing the same weight of bycatch by pelagic longlines.

As a very coarse guideline, each reduction in bycatch mortality of 50 mt would correspond to about a 1% reduction in harvest rate and a decline in fishing mortality (F) of 0.01.

Element 21: *Recommend parameter values for population productivity and starting mortality rates and, where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts in support of the listing process.*

Estimates of F_{MSY} from the four models ranged from 0.036 to 0.075 (0.051 for preferred Model 3). Estimates of SSN_{MSY} decreased with estimated or assumed productivity (α) from 40,089 females for an α of 2.0 to 27,945 females for an α of 3.6 (α from Model 3 was 2.5).

ALLOWABLE HARM ASSESSMENT

Element 22: *Evaluate maximum human-induced mortality and habitat destruction that the species can sustain without jeopardizing its survival or recovery.*

The equilibrium fishing mortality rate at which the population goes extinct, F_{col} , is determined by the slope of the SR relationship at the origin α , and is the value of F where $1/SPR_F = \alpha$.

Estimates of F_{col} from the four models ranged from 0.075 to 0.160, and equalled 0.108 for the preferred model (Model 3).

Estimates of vulnerable biomass in 2009 (using Shelf-Edge selectivity) varied from 4700-5100 mt (Campana et al. 2010b). The TAC of 185 mt corresponds to slightly less than a 4% harvest rate, and would allow population recovery. The current 2% total mortality rate (which is approximately half of MSY) would be about 100 mt and would allow population recovery under all scenarios.

SOURCES OF UNCERTAINTY

- There are no current monitoring programs for Porbeagle abundance or population status. The population model used to assess population status to date requires directed CPUE and length frequency data as input, and thus provides no useful information in the absence of a directed fishery. While anecdotal comments have been made about increases in Porbeagle abundance, there is no current monitoring program to corroborate this.
- The observer-based reporting level of Porbeagle condition has declined in recent years, which affects the precision of the post-release mortality estimates.
- Observer coverage is very low or non-existent in some fisheries, which leads to higher uncertainty in the catch rates, discards, and status of Porbeagle, especially when scaling limited information up to entire fisheries. There continues to be unreported bycatch in many fisheries, both in Canadian and international waters.
- The post-release mortality of injured Porbeagle is uncertain because of the small sample size. Further investigation is needed to reduce the uncertainty in these estimates. Furthermore, post-release mortality was only studied in the pelagic longline and otter trawl fisheries. The post-release mortality of Porbeagle in all other fisheries is unknown.
- The impact of anthropogenic activities in the marine environment (e.g. offshore petroleum seismic, marine development projects, etc.) on Porbeagle is unknown but could be significant.

RESEARCH RECOMMENDATIONS

- Update trends and status of Porbeagle:
 - There are no existing monitoring programs for Porbeagle abundance or population status. The population model used to assess population status to date requires directed CPUE and length frequency data as input, and thus provides no useful information in the absence of a directed fishery. CPUE based on landings would provide too little data to be useful. It is likely that Porbeagle bycatch CPUE in the pelagic longline fishery could be used to provide an index of abundance, but the current ASO coverage (on the order of 5%) is too low to provide a useful index. Substantially higher observer coverage of the pelagic longline fleet, especially around Emerald Basin and near the edge of the Scotian Shelf, is the most feasible source of a Porbeagle abundance index for that area.

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- There have been two fishery-independent Porbeagle surveys conducted in the past. These surveys were conducted near the end of the population model time series, and thus could be scaled to the terminal population estimates from the model. With this scaling in place, any additional periodic surveys (e.g., at 5-year intervals) would be a useful way to monitor Porbeagle population recovery status.
 - Increase observer coverage in fleets with high sources of uncertainty to improve the accuracy of the total bycatch and discard amounts.
 - Investigate capture mortality for all gear types that have not been investigated yet and incorporate into population models.
 - Study site fidelity of mature female Porbeagle in Canadian waters to determine if those mating off of Georges Bank use the same pupping ground as those mating off of southern Newfoundland.

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TABLES

Table 1. Estimates of population size and total biomass in metric tonnes (mt) obtained from four models fit to the Porbeagle data. SSN = spawning stock number; N = population abundance; and σ = population productivity.

Assumptions	Parameter	Model 1	Model 2	Model 3	Model 4
		σ estimated	$\sigma = 2.0$	$\sigma = 2.5$	$\sigma = 3.2$
1961	SSN	71,858	86,447	79,722	73,838
	N	760,620	915,048	843,866	781,582
	Biomass	41,744	50,219	46,312	42,894
1971	SSN	17,439	33,087	25,947	19,868
	N	291,174	422,212	362,599	310,002
	Biomass	11,958	19,541	16,048	13,013
1981	SSN	20,842	35,013	28,561	22,759
	N	284,362	383,292	339,358	299,446
	Biomass	14,292	20,404	17,672	15,220
1991	SSN	20,935	30,661	26,385	22,516
	N	347,711	397,555	374,428	354,463
	Biomass	16,587	20,335	18,636	17,131
2001	SSN	10,999	17,031	14,377	12,062
	N	190,024	206,680	198,163	192,162
	Biomass	8,082	9,664	8,908	8,299
2009	SSN	11,339	14,207	12,886	11,809
	N	206,956	196,911	198,970	204,482
	Biomass	9,890	10,078	9,903	9,891
2009/1961	SSN	0.158	0.164	0.162	0.160
	N	0.272	0.215	0.236	0.262
	Biomass	0.237	0.201	0.214	0.231
2009/2001	SSN	1.031	0.834	0.896	0.979
	N	1.089	0.953	1.004	1.064
	Biomass	1.223	1.043	1.112	1.192

Table 2. Estimates of population abundance (N) and female spawning stock number (SSN) by year obtained from four models fit to the Porbeagle data.

Year	Model 1		Model 2		Model 3		Model 4	
	SSN	N	SSN	N	SSN	N	SSN	N
1961	71858	760620	86447	915048	79722	843866	73838	781582
1962	70398	724557	85227	877843	78424	807113	72452	745310
1963	67657	671014	82898	822375	75959	752425	69838	691436
1964	61379	553681	77528	700937	70286	632648	63834	573387
1965	51009	387974	68555	530187	60827	463948	53855	406769
1966	41668	307139	60241	448183	52131	382609	44764	325811
1967	34701	290759	53526	431292	45305	366282	37855	309646
1968	29639	306840	48034	444711	39942	381091	32692	325615
1969	24867	304562	42560	440548	34697	378099	27753	323422
1970	20788	297350	37519	431220	29988	370059	23454	316271
1971	17439	291174	33087	422212	25947	362599	19868	310002
1972	14790	291883	29405	419030	22653	361326	17001	310380
1973	12712	290825	26455	413907	20037	358161	14739	308926
1974	11235	287867	24404	406990	18206	353145	13134	305554
1975	10530	287925	23567	403304	17419	351252	12384	305197
1976	10728	284482	24077	396814	17817	346285	12626	301428
1977	11842	277123	25773	387016	19315	337778	13852	293816
1978	13729	272977	28231	380654	21603	332604	15871	289422
1979	16112	276039	30934	381371	24246	334521	18352	292174
1980	18450	279657	33263	382093	26643	336605	20734	295337
1981	20482	284362	35013	383292	28561	339358	22759	299446
1982	22153	293079	36203	388045	29988	345811	24382	307469
1983	23350	304893	36801	395483	30861	355097	25503	318515
1984	23954	317026	36769	402859	31113	364468	26018	329817
1985	24089	330796	36266	411592	30890	375311	26058	342717
1986	23751	341865	35342	417397	30223	383327	25629	352886
1987	23113	350038	34191	420200	29298	388392	24911	360152
1988	22309	353019	32959	417839	28258	388295	24039	362240
1989	21605	353904	31899	413519	27361	386192	23278	362260
1990	21102	352393	31097	407003	26697	381821	22727	359925
1991	20935	347711	30661	397555	26385	374428	22516	354463
1992	20342	326215	29848	371532	25680	350363	21902	332225
1993	19223	298943	28536	340072	24466	320729	20778	304286
1994	18404	282670	27471	320080	23515	302385	19938	287468
1995	17648	261331	26416	295351	22593	279165	19147	265652
1996	16487	247655	24914	278409	21241	263675	17944	251537
1997	15511	237495	23526	265231	20030	251846	16907	241000
1998	14305	221276	21867	246095	18564	233998	15630	224410
1999	13120	210158	20188	232187	17095	221324	14363	212955
2000	12136	199455	18686	218800	15812	209116	13289	201926
2001	10999	190024	17031	206680	14377	198163	12062	192162
2002	10239	187734	15764	201796	13325	194408	11210	189559
2003	9735	190978	14782	202369	12545	196128	10618	192466
2004	9477	194669	14085	203234	12033	198173	10277	195754
2005	9422	195477	13630	200981	11746	197152	10144	196060
2006	9590	196501	13431	198668	11701	196143	10241	196484
2007	9973	198019	13475	196514	11887	195390	10559	197295
2008	10560	202488	13739	196923	12287	197320	11086	200944
2009	11339	206956	14207	196911	12886	198970	11809	204482

Table 3. Reported landings in metric tonnes (mt) by country for NAFO areas 2 to 6. Canadian landings have been converted to live equivalent weight, which differs in some cases from the live weight recorded in the statistics. Dash (-) indicates no value.

Year	Canada	Faroe Islands	France	Iceland	Japan	Norway	Spain	USSR	USA	Total
1961	0	100	-	-	-	1824	-	-	-	1924
1962	0	800	-	-	-	2216	-	-	-	3016
1963	0	800	-	-	-	5763	-	-	-	6563
1964	0	1214	-	7	-	8060	-	-	-	9281
1965	28	1078	-	-	-	4045	-	-	-	5151
1966	0	741	-	-	-	1373	-	-	-	2114
1967	0	589	-	-	36	-	-	-	-	625
1968	0	662	-	-	137	269	-	-	-	1068
1969	0	865	-	-	208	-	-	-	-	1073
1970	0	205	-	-	674	-	-	-	-	879
1971	0	231	-	-	221	-	-	-	-	452
1972	0	260	-	-	-	87	-	-	-	347
1973	0	269	-	-	-	-	-	-	-	269
1974	0	-	-	-	-	-	-	-	-	0
1975	0	80	-	-	-	-	-	-	-	80
1976	0	307	-	-	-	-	-	-	-	307
1977	0	295	-	-	-	-	-	-	-	295
1978	1	121	-	-	-	-	-	-	-	122
1979	2	299	-	-	-	-	-	-	-	301
1980	1	425	-	-	-	-	-	-	-	426
1981	0	344	-	-	3	-	-	-	-	347
1982	1	259	-	-	1	-	-	-	-	261
1983	9	256	-	-	0	-	-	-	-	265
1984	20	126	-	-	1	17	-	-	-	164
1985	26	210	-	-	0	-	-	-	-	236
1986	24	270	-	-	5	-	-	1	-	300
1987	59	381	-	-	16	-	-	0	12	468
1988	83	373	-	-	9	-	-	3	32	500
1989	73	477	-	-	9	-	-	3	4	566
1990	78	550	-	-	8	-	-	9	19	664
1991	329	1189	-	-	20	-	-	12	17	1567
1992	814	1149	-	-	7	-	-	8	13	1991
1993	920	465	-	-	6	-	-	2	39	1432
1994	1573	-	-	-	2	-	-	-	3	1578
1995	1348	-	7	-	4	-	-	-	5	1364
1996	1043	-	40	-	9	-	-	-	8	1100
1997	1317	-	13	-	2	-	3	-	2	1337
1998	1054	-	20	-	0	-	9	-	12	1095
1999	955	-	-	-	6	-	3	-	3	967
2000	899	-	13	-	24	-	5	-	-	941
2001	499	-	2	-	25	-	3	-	-	528
2002	229	-	1	-	0	-	5	-	0	236
2003	139	-	2	-	0	-	2	-	0	143
2004	218	-	4	-	0	-	5	-	1	228
2005	203	-	-	-	-	-	7	-	0	210
2006	190	-	-	-	-	-	9	-	0	199
2007	93	-	-	-	-	-	6	-	-	99
2008	125	-	-	-	-	-	37	-	-	162
2009	63	-	-	-	-	-	-	-	-	63
2010	84	-	-	1	21*	-	-	-	3	88
2011	31	-	2	-	21*	-	-	-	11	44
2012	34	-	4	-	74*	-	-	-	4	42
2013	19	-	-	-	98*	-	-	-	31	50
2014	9	-	-	-	-	-	-	-	-	9

* Japanese landings from 2010-2014 reported from International Commission for the Conservation of Atlantic Tunas (ICCAT) area 94A, which may or may not represent the NW Atlantic population.

Northwest Atlantic data for 1950-1960 is from the Food and Agricultural Organization of the United Nations (FAO) (ICCAT Report of Shark Working Group, Miami, 26-28 February 1996), 1964-1986 from NAFO, 1987-2004 from DFO Maritimes Region and DFO Newfoundland and Labrador Region Industry Observer Programs (IOP) (includes landings and discards), and 2000-2008 from FAO Fishstat Plus v 2.32 Capture Production March 2008, NAFO Database 21B or ICCAT Task 1 Dataset 2009.

Canada data for 1961-1990 is from NAFO, 1991-2002 from DFO Zonal Statistics File, corrected to appropriate live equivalent weight, and 2003-2014 from DFO MARFIS database.

Faroe Island (Is) data for 1961-1963 is from FAO (ICCAT Report of Shark Working Group, Miami, 26-28 February 1996).

France data is from FAO Statistics (1998), 2000-2006 from FAO Fishstat Plus v 2.32.

Northwest Atlantic data for 2000-2006 (**Japan**) from NAFO Database 21B, catch for code 469, large sharks.

Norway data for 1961-1986 is from NAFO.

NAFO catch data for **Spain** for 2005 (231 mt) and 2006 (230 mt) were errors, and not reported here

Northwest Atlantic data for **USA** from 1961-1994 is from FAO (ICCAT Report of Shark Working Group, Miami, 26-28 February 1996).

Table 4. Porbeagle landed bycatch in kilograms (kg) in Canadian DFO Maritimes Region fisheries. Dash (-) indicates no value.

Year:	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total Allow able Catch (kg)	850000	850000	250000	250000	250000	250000	185000	185000	185000	185000	185000	185000	185000	185000	185000
FISHERY:															
Groundfish fixed gear 45-65	997	789	958	2400	2031	1196	509	851	848	1119	3957	1064	3443	934	866
Groundfish fixed gear <45	4743	6925	13141	13041	14344	15286	9870	18258	14409	20396	34628	15419	17368	8946	4475
Groundfish inshore	-	-	-		56	197	687	100	170	1106	-	-	-	-	-
Groundfish midshore	461	518	697	1384	101	166	-	780	448	-	-	-	-	-	-
Groundfish offshore	191	285	-	220	600	1131	594	323	288	229	422	675		54	-
Groundfish unspecified	456	1059	1184	1105	1010	2747	3908	1597	317	1628	701	-	1388	293	85
Total Groundfish	6848	9576	15980	18150	18141	20723	15568	21909	16481	24479	39706	17158	22199	10227	5426
Directed porbeagle	870741	476703	172001	86059	172520	161997	123913	49965	87637	28535	17415	4622	0	0	0
Sw ordfish	5482	9582	18939	29160	22155	11641	14157	9120	10533	6510	22967	6689	10396	1612	655
Tuna	1266	577	18435	5558	6156	8569	36221	12245	10137	921	680	1606	6023	1567	2075
Herring	-	256	-	-	23	-	-	-	-	-	-	-	-	-	-
Total (kg)	884337	496694	225355	138927	218995	202930	189859	93239	124788	61567	82892	30076	38618	13406	8156
Total from Bycatch (kg)	13596	19991	53354	52868	46475	40933	65946	43274	37151	31910	63353	25453	38618	13406	8156
Percent Total from Bycatch	2%	4%	24%	38%	21%	20%	35%	46%	30%	52%	76%	85%	100%	100%	100%

Table 5. Porbeagle catch in kilograms (kg) in Canadian fisheries outside of DFO Maritimes Region. Dash (-) indicates no value.

Fishery Region	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Newfoundland fixed gear	1071	142	27	105	-	-	-	-	-	-	-	-
Newfoundland mobile gear	-	-	-	-	-	-	-	-	-	-	-	-
Newfoundland (all gears)	-	-	-	-	-	16	796	515	49	0	255	0
Gulf (all gears)	2565	12968	52	691	55	0	0	0	0	12	84	68
Gulf (unspecified shark)	5090	3512	3347	-	-	182	-	-	-	268	0	0
Quebec	-	-	-	-	-	423	328	0	393	126	-	-

Table 6. Observed Porbeagle condition at the time of release/discard from the pelagic longline fishery (top – aggregated for all longline) and Otter trawl (bottom) from 2010-2014. Fishing practices for different target species will result in variable injury and mortality rates.

Condition at Release/Discard	2010	2011	2012	2013	2014	Total
Pelagic Longline:						
Unable to Determine	20	0	52	172	4	248
Alive - No Injury	143	129	11	0	1	284
Alive - Injured	42	38	19	0	1	100
Dead	55	193	36	0	4	288
Shark Bit - Not Intact	1	4	1	0	0	6
Moribund	0	5	0	0	0	5
Total	261	369	119	172	10	931
Otter Trawl (Mobile Gear):						
Unable to Determine	0	4	0	9	1	14
Alive - No Injury	16	11	18	74	33	152
Alive - Injured	1	0	0	35	17	53
Dead	1	0	1	2	7	11
Shark Bit - Not Intact	0	0	0	0	0	0
Moribund	0	0	1	0	4	5
Total	18	15	20	120	62	235

Table 7. Preliminary summary of post-release mortality of 40 Porbeagle tagged with Pop-up Satellite Archival Tags (PSAT) on board commercial fishing vessels. LL = Pelagic Longline and OT = Otter Trawl. Short Duration LL were sets in which the longline was soaked for only 2-3 hours, which greatly reduced hooking mortality and improved condition.

Condition	LL		Short Duration LL		OT	
	Healthy	Injured	Healthy	Injured	Healthy	Injured
Lived	23	0	5	0	4	0
Died	6	2	0	0	0	0

Table 8. Estimated discards (live and dead) of Porbeagle by DFO Maritimes Region (Scotia-Fundy) fisheries (upper section of the table). Estimated mortality (hooking + post-release) of discards (lower section of the table). All values in metric tonnes (mt).

Category	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Porbeagle Discards by Fishery (mt): ^a																			
Swordfish and Tuna LL ^d	9	13	10	11	20	20	31	34	38	41	40	35	31	27	52	60	61	62	61
Porbeagle LL	8	11	10	10	9	7	2	1	2	2	1	1	1	0	0	0	0	0	0
Groundfish LL	0	0	0	0	2	3	2	2	2	3	2	2	2	2	1	9	9	8	8
Groundfish Gillnet	2	5	4	3	5	4	4	5	4	1	1	1	1	1	11	6	5	4	5
Groundfish OTB	1	1	2	1	9	11	10	9	10	35	30	32	32	34	121	100	106	71	81
Total	21	30	25	26	53	45	56	53	56	83	75	70	67	64	194	176	181	146	155
Porbeagle Discards by Source (mt): ^a																			
Reported Landings	1014	1223	916	951	884	497	225	139	219	203	190	93	125	62	83	31	34	19	9
Estimated Total Porbeagle Catch ^c	1046	1260	949	984	946	554	294	220	302	334	314	207	232	157	281	219	232	180	181
Hooking/capture Mortality ^d	10	16	13	13	20	19	20	24	25	26	24	21	19	17	52	49	48	45	46
Estimated Porbeagle Discards (live + dead)	21	30	25	26	45	45	49	53	56	83	75	70	67	64	194	176	181	146	155
Estimated Discard Mortality (hooking + post-release)	15	21	18	18	28	28	30	34	36	41	38	34	31	28	82	77	77	69	72
Sum of Landings and All Discard Mortality	1029	1245	934	969	912	524	255	173	255	244	228	127	156	90	164	108	111	88	81

^a Discard ratios calculated by five-year blocks.

^b Hooking and post-release mortality calculated separately for each gear type, as indicated in text.

^c The sum of total discards + landings does not necessarily equal the estimated total catch, since landings were measured and discards were estimated.

^d Discards have been calculated for all pelagic longline bycatch and not separated between target species.

FIGURES

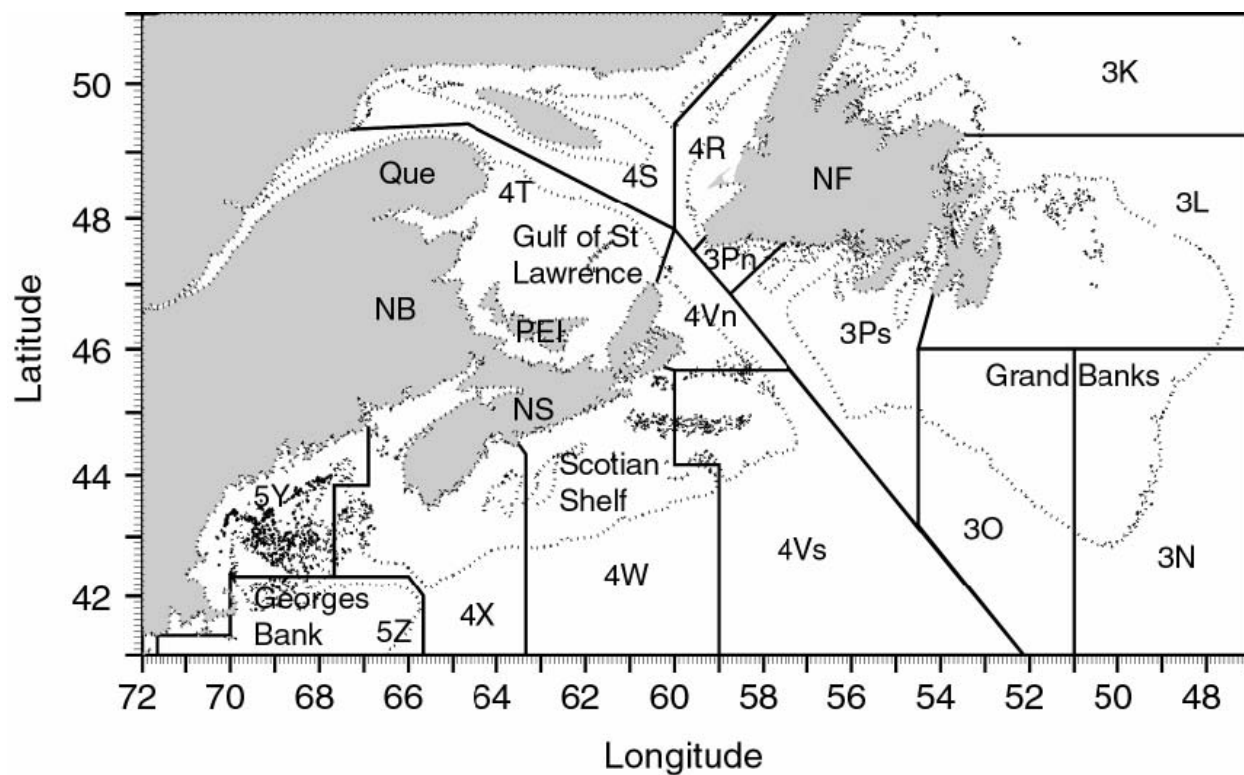


Figure 1. Map of eastern Canada showing NAFO Divisions and fishing banks.

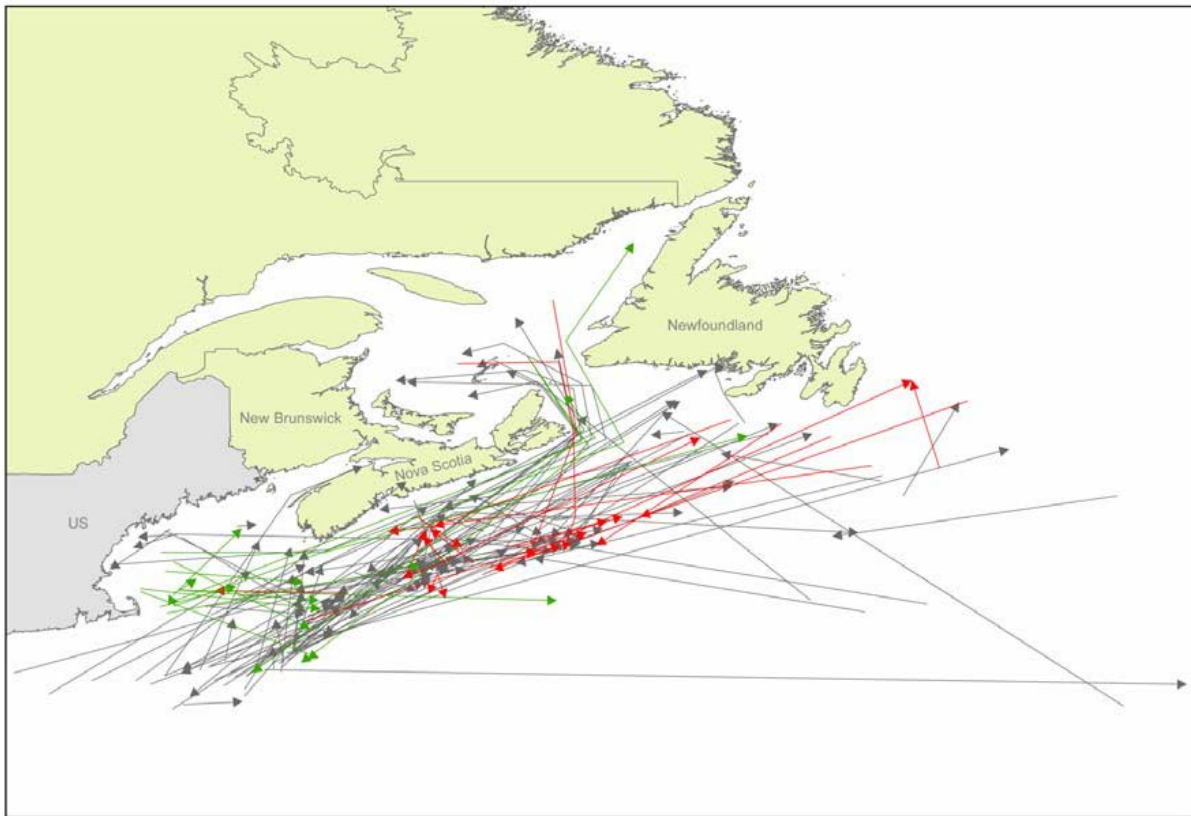


Figure 2. Summary of Porbeagle tag movements from tagging location (line origin) to recapture location (arrowhead) from 1961-2008. Norwegian tags are in green; U.S. tags are in grey; Canadian tags are in red.

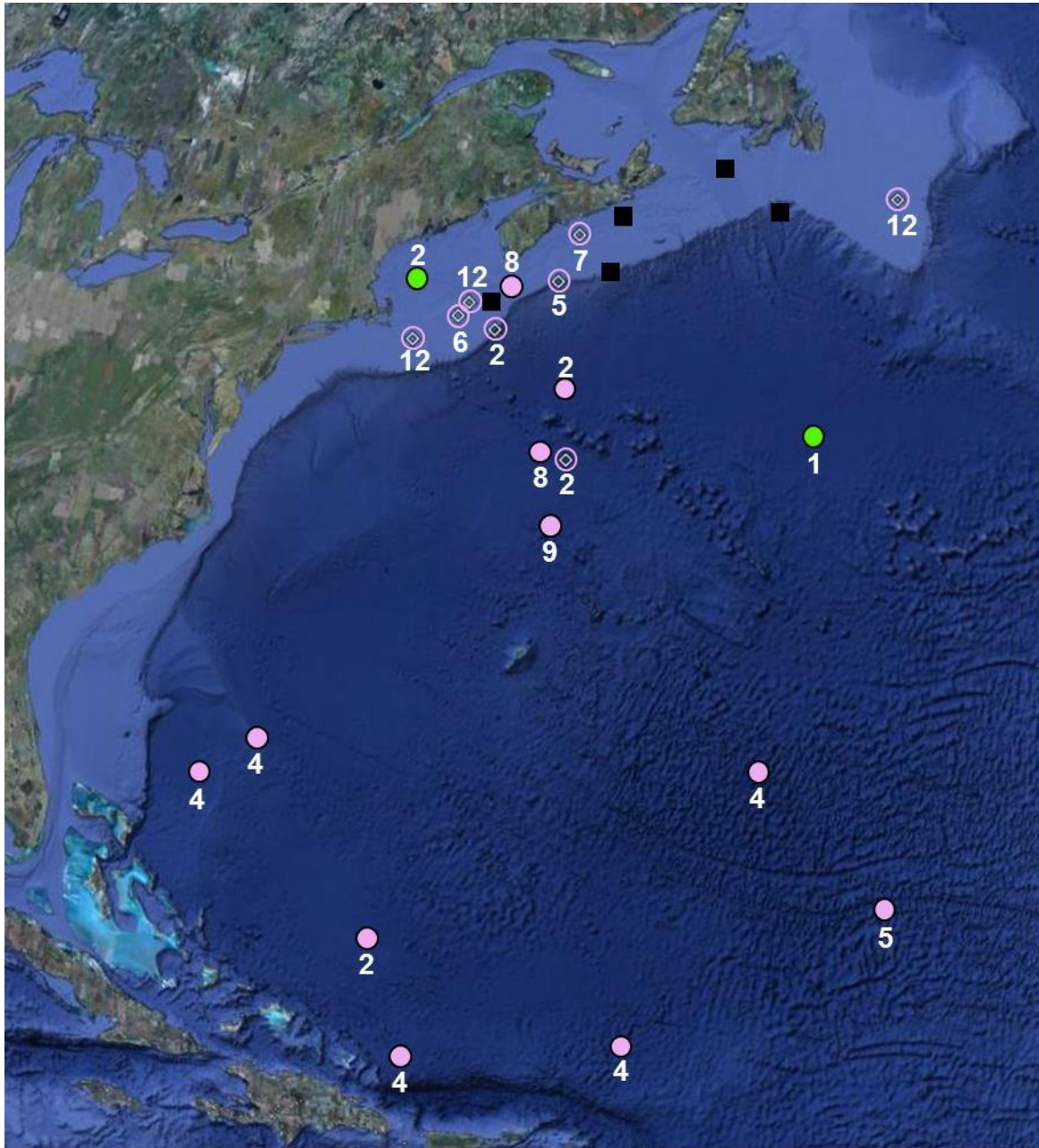
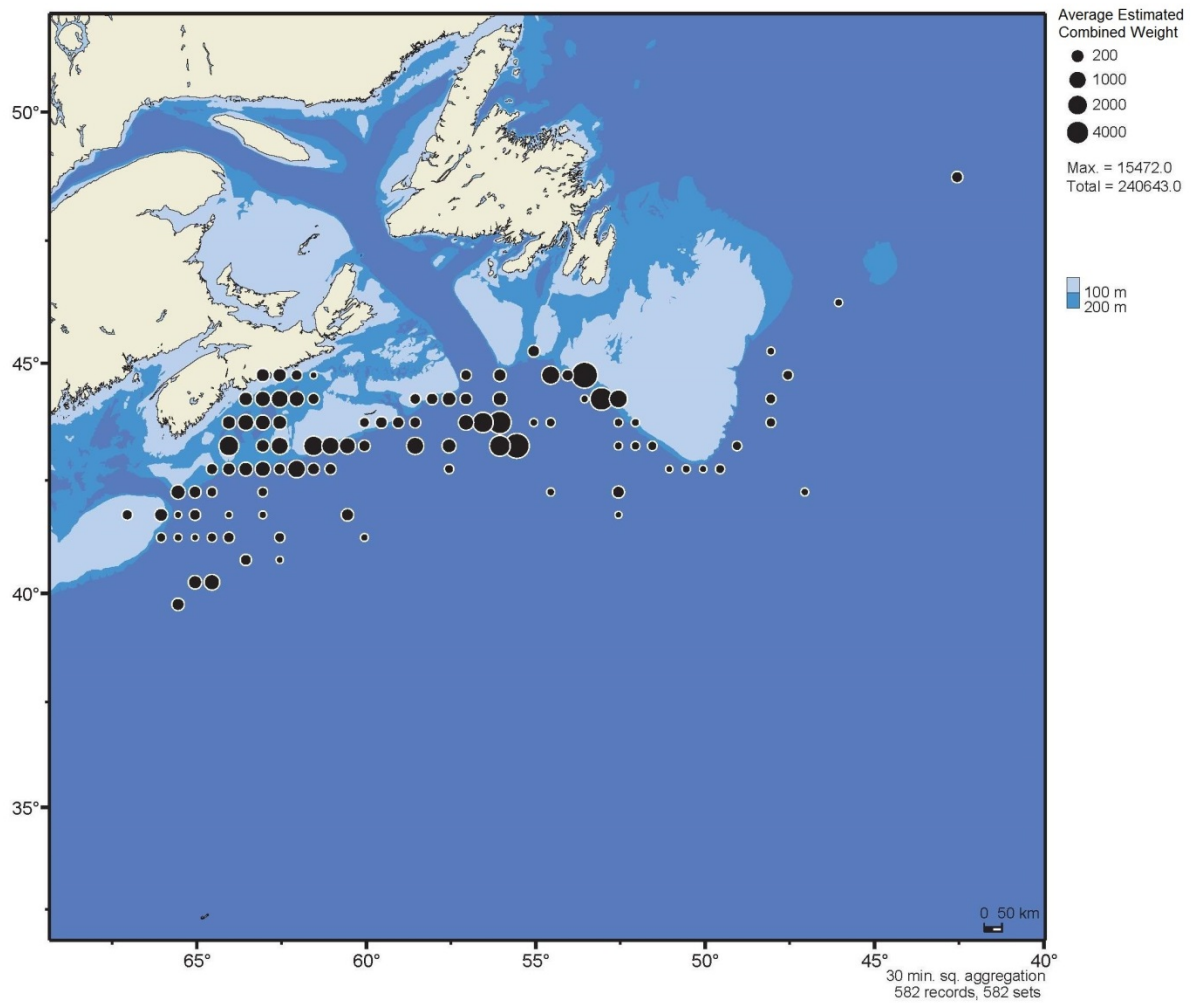


Figure 3. Map showing tagging (■) and pop-up locations for 21 Porbeagle tagged off the eastern coast of Canada. Male (●) and immature female (⊗) sharks remained north of latitude 37°N. All mature female sharks (●) migrated to the Sargasso Sea by April. Month of pop-up is indicated by the number.

Catch by species, pick year, country and trip type if desired. Makes use of SQLMAP options and allows for drilling down through the data. S Bond Oct 28, 2004



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Figure 4. Porbeagle catch location in all pelagic longline fisheries recorded by at-sea observers in the DFO Maritimes Region from 1998-2014.

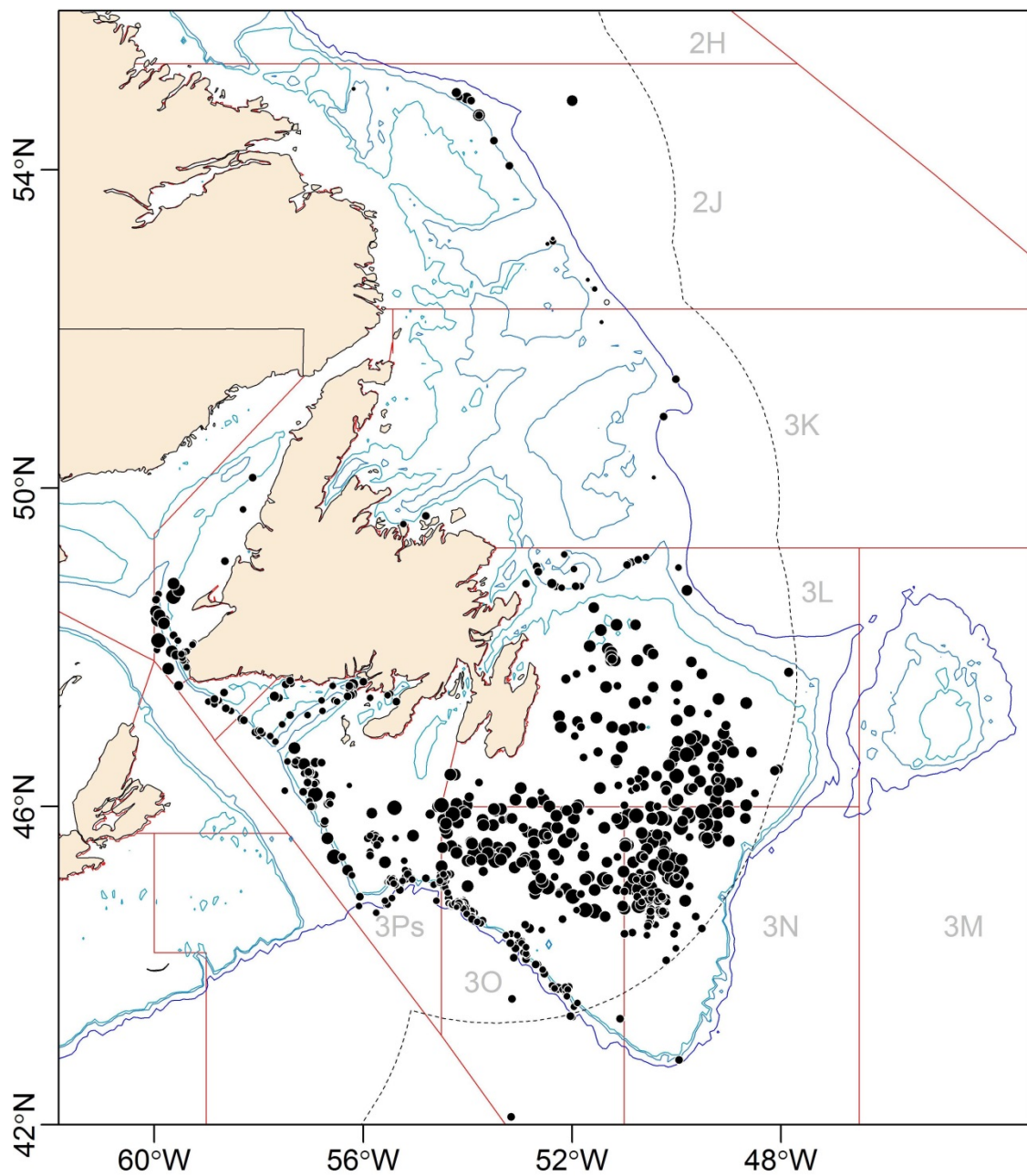


Figure 5. Porbeagle distribution recorded by at-sea observers operating in the DFO Newfoundland and Labrador Region from 1995-2013.

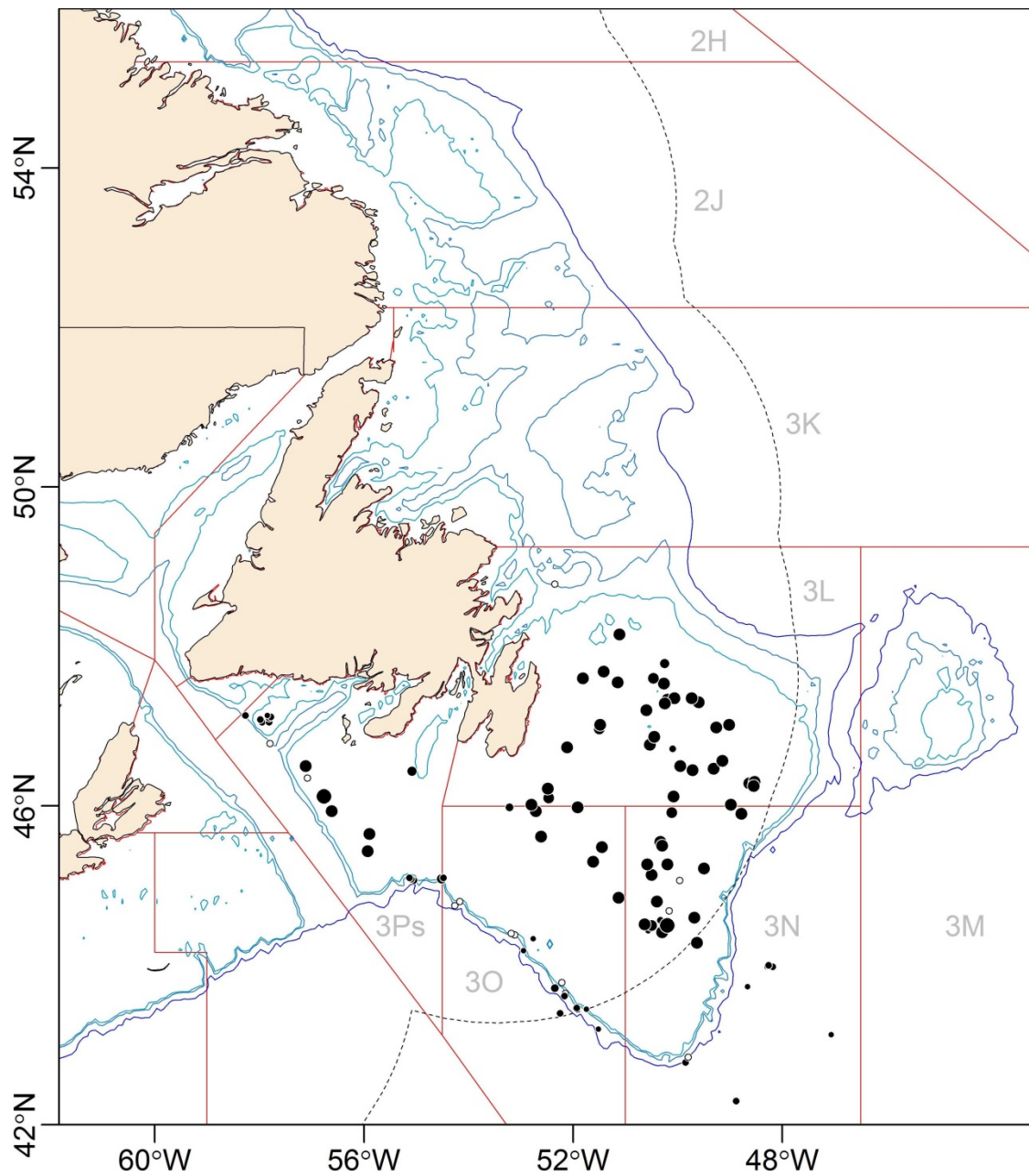
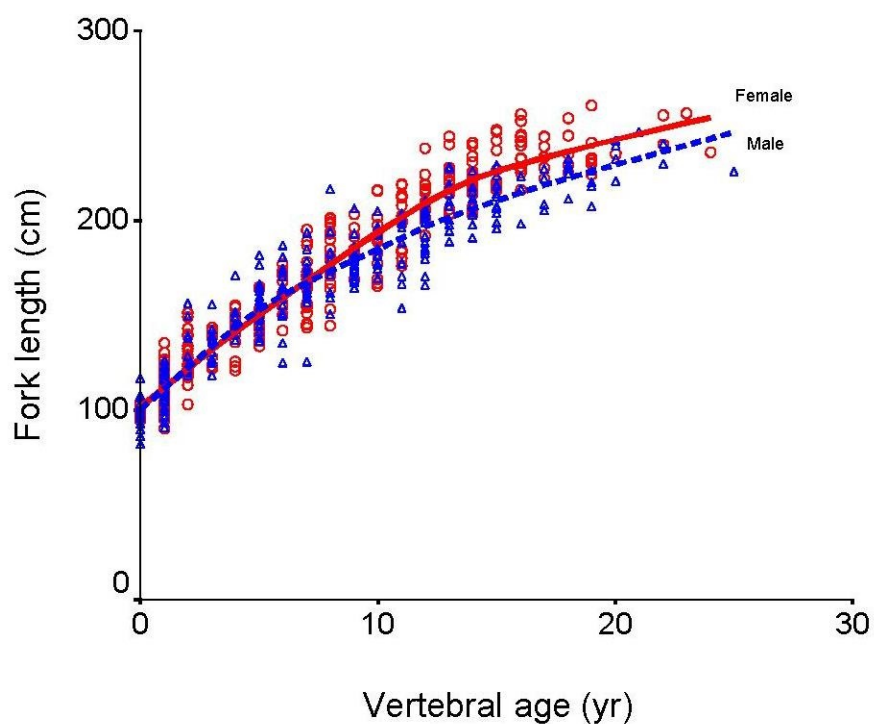


Figure 6. Porbeagle distribution in the offshore of Newfoundland based on DFO Newfoundland and Labrador Region Zonal Interchange File Format (ZIFF) landings data from 1995-2013.



Age	FL (cm)	Wt. At age (kg)
0	68	4.68
1	100	13.33
2	119	21.38
3	130	27.17
4	140	33.22
5	149	39.34
6	158	46.12
7	166	52.74
8	174	59.92
9	181	66.69
10	188	73.92
11	195	81.63
12	201	88.62
13	206	94.73
14	212	102.40
15	217	109.09
16	221	114.63
17	226	121.81
18	230	127.74
19	233	132.31
20	237	138.57

Von Bertalanffy growth model

$$L_t = L_{\infty}(1 - e^{-K(t-t_0)})$$

Sex	L_{∞}	K	t_0	N
Combined	289.4	0.066	-6.06	576
Male	257.7	0.080	-5.78	283
Female	309.8	0.061	-5.90	291

Figure 7. Growth curve for Porbeagle showing a reduction in growth rate for both sexes at the age of sexual maturity. Fitted lines are LOESS curves by sex. The age-length table is based on the von Bertalanffy growth model, substituting observed lengths for ages 0 and 1. Ages have been validated.

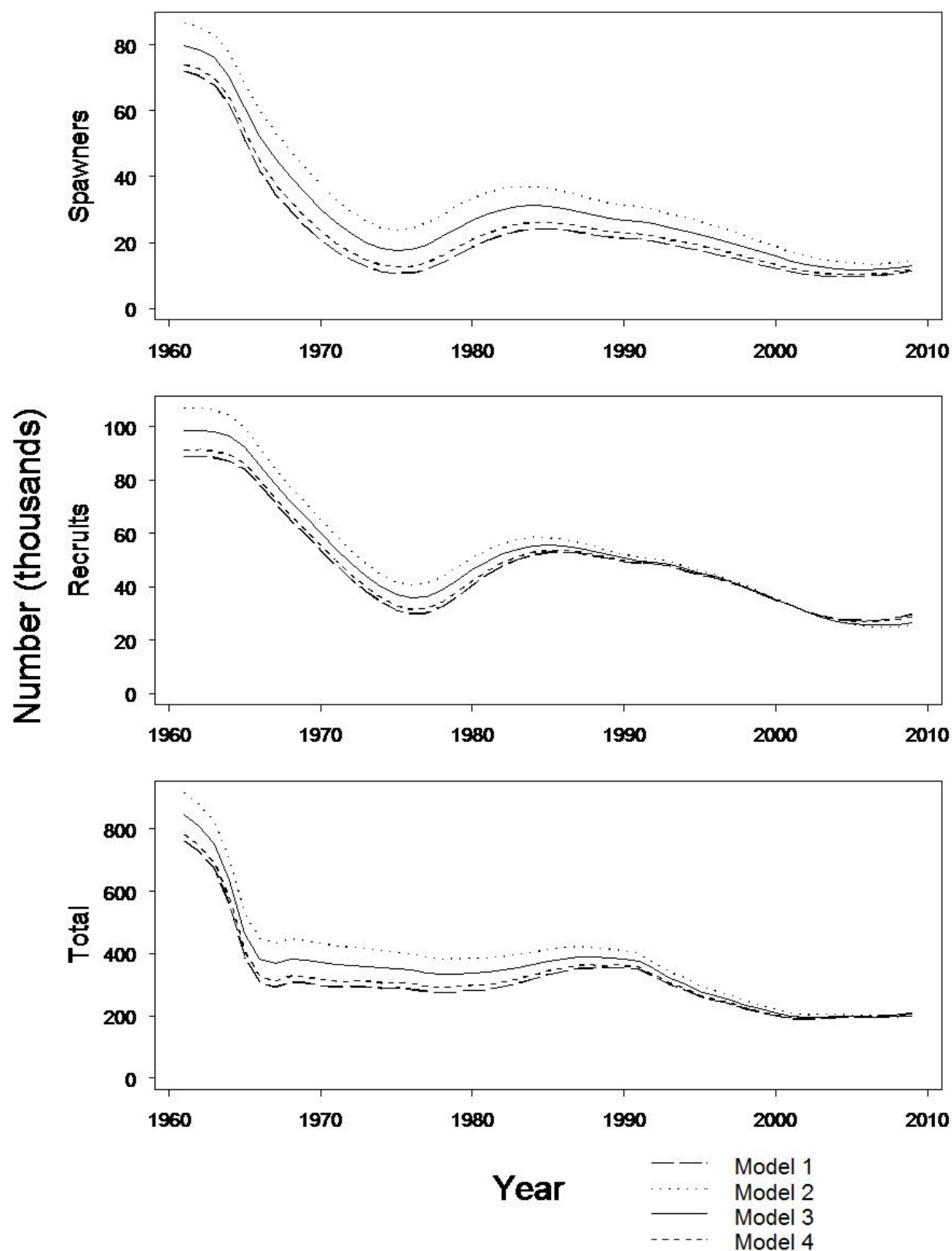


Figure 8. Comparison of the predicted time series for female spawner abundance (SSN), recruitment at age-1 and total number from each of the four population models.

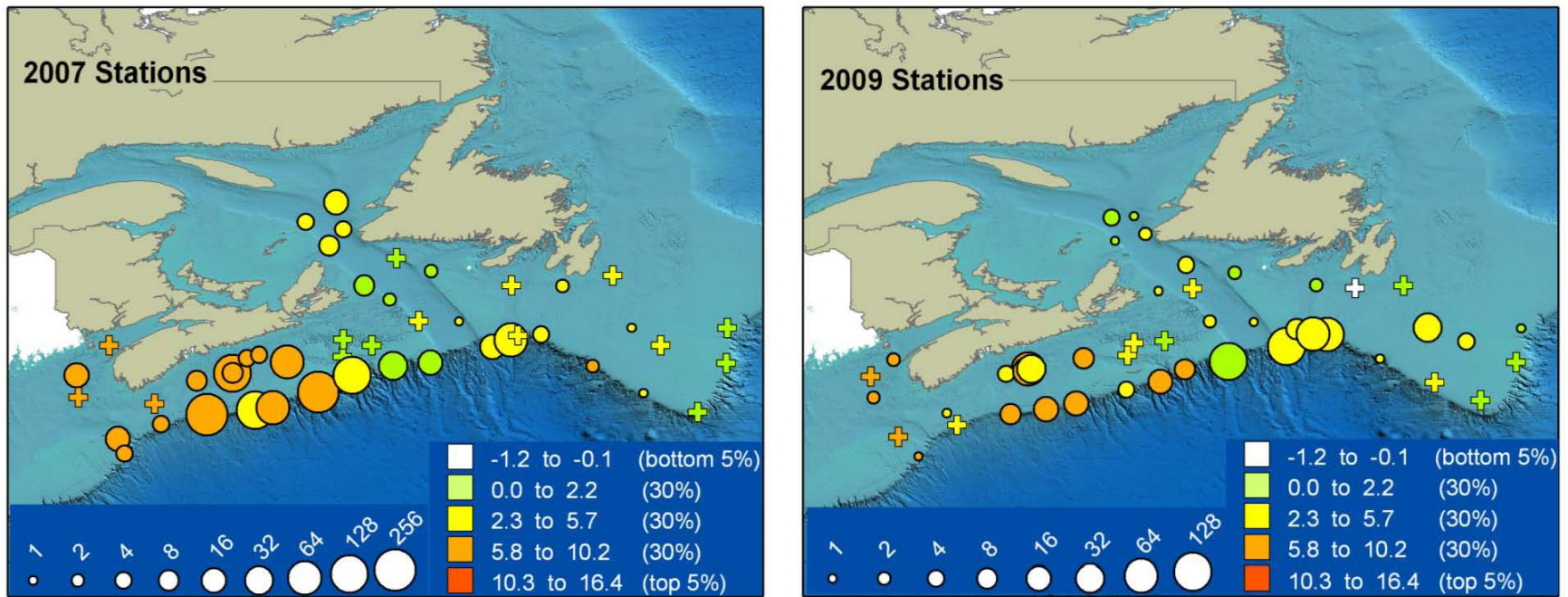


Figure 9. Comparison of Porbeagle survey abundance in 2007 (left panel) and 2009 (right panel). Circles indicate Porbeagle catch and crosses indicate nulls. Catch abundance per survey station is represented by a graduated symbology and average temperature at the depth of gear is represented by a colour ramp.

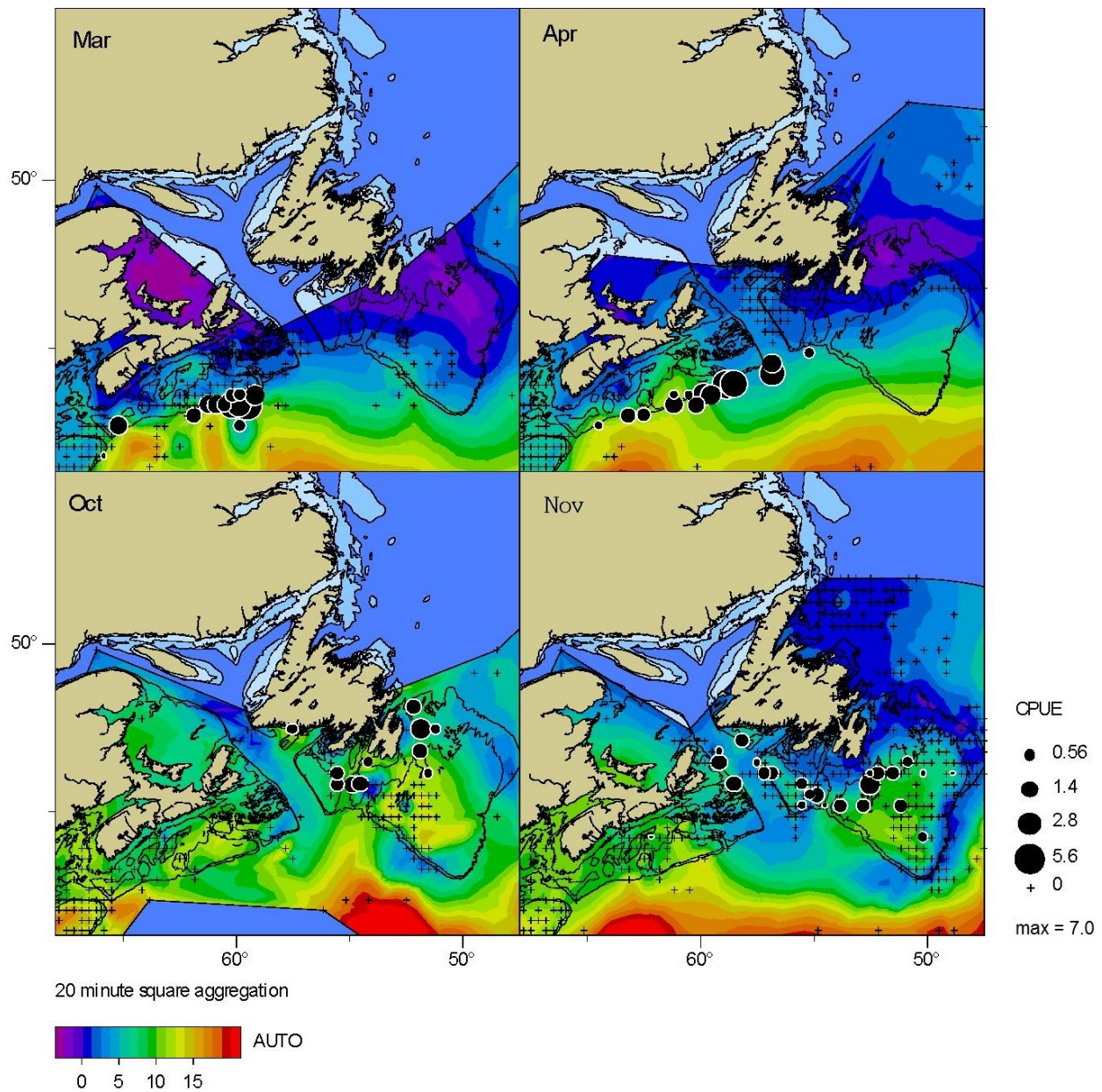


Figure 10. Porbeagle commercial catch per unit effort (CPUE) and water temperature at mid-gear depth for 1999 (from: Campana and Joyce 2004). Catch rate is represented by a graduated symbology and water temperature represented by a colour ramp.

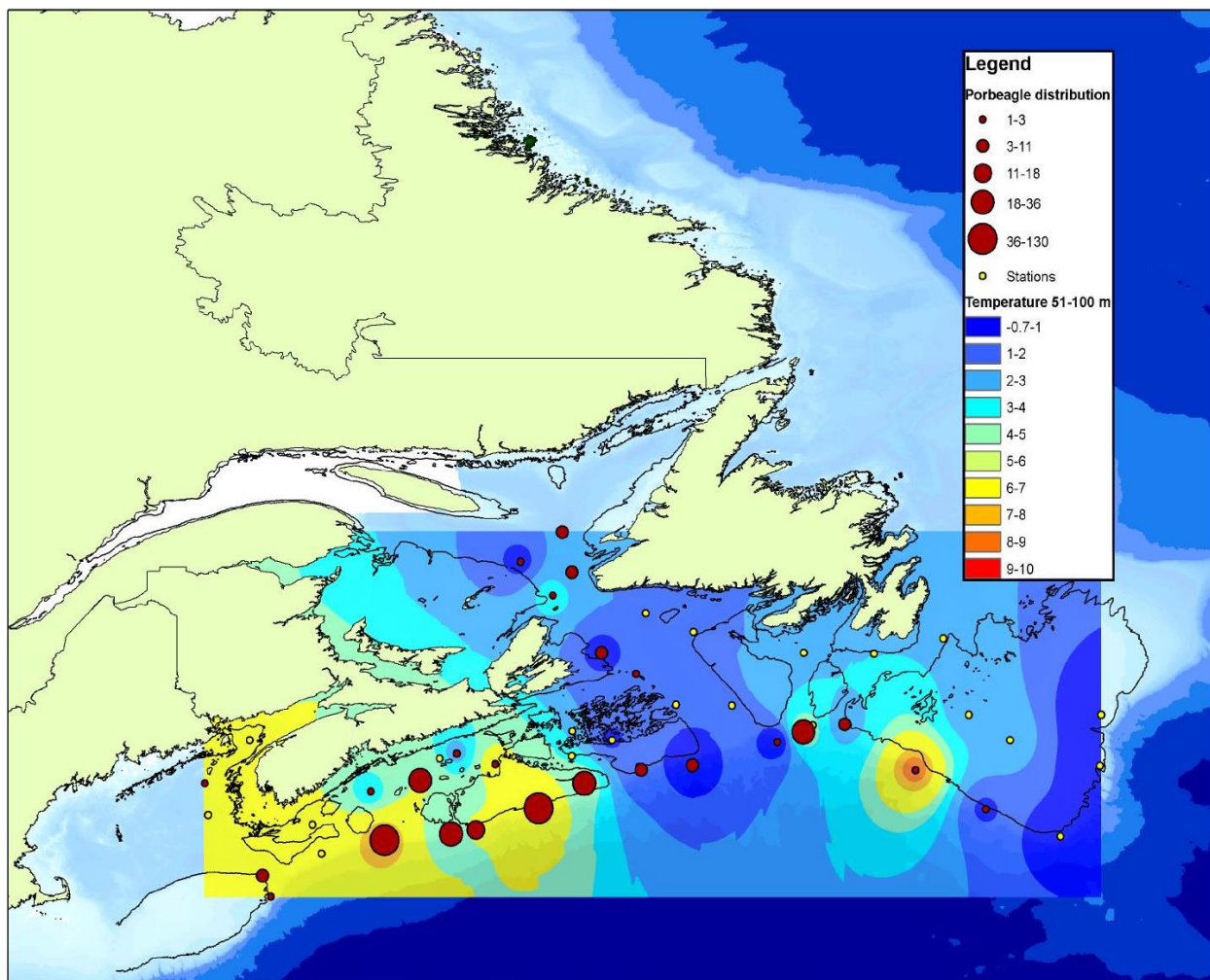


Figure 11. Porbeagle survey catch distribution in 2007 with water temperature at depth. Catch distribution is represented by a graduated symbology and water temperature represented by a colour ramp.

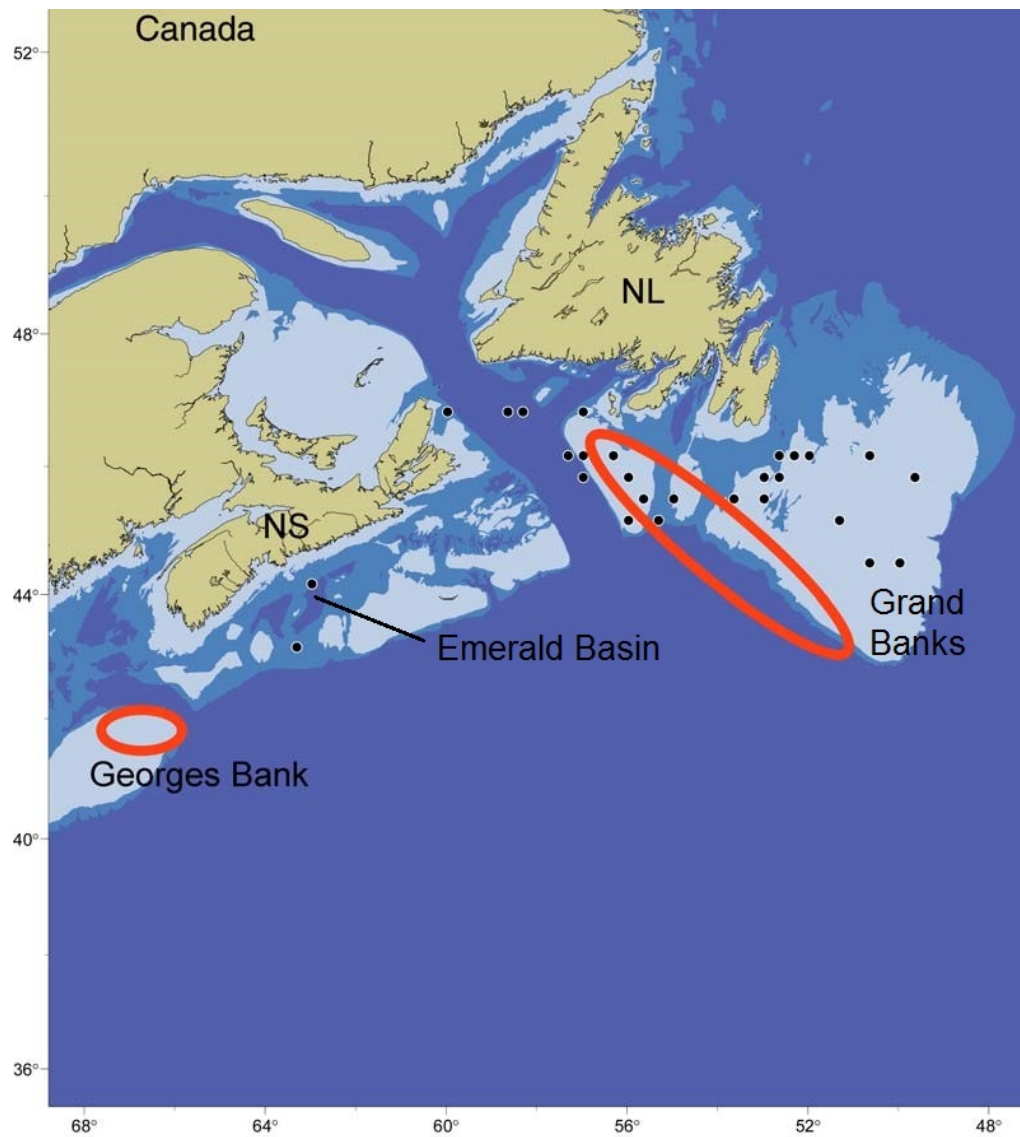


Figure 12. Known and suspected mating grounds for Porbeagle shark in the Northwest Atlantic represented by red ovals. Black symbols show capture locations for pregnant females. The Georges Bank site in summer is characterized by the highest known concentrations of mature female Porbeagle in the world; thus, is almost certainly a mating site.

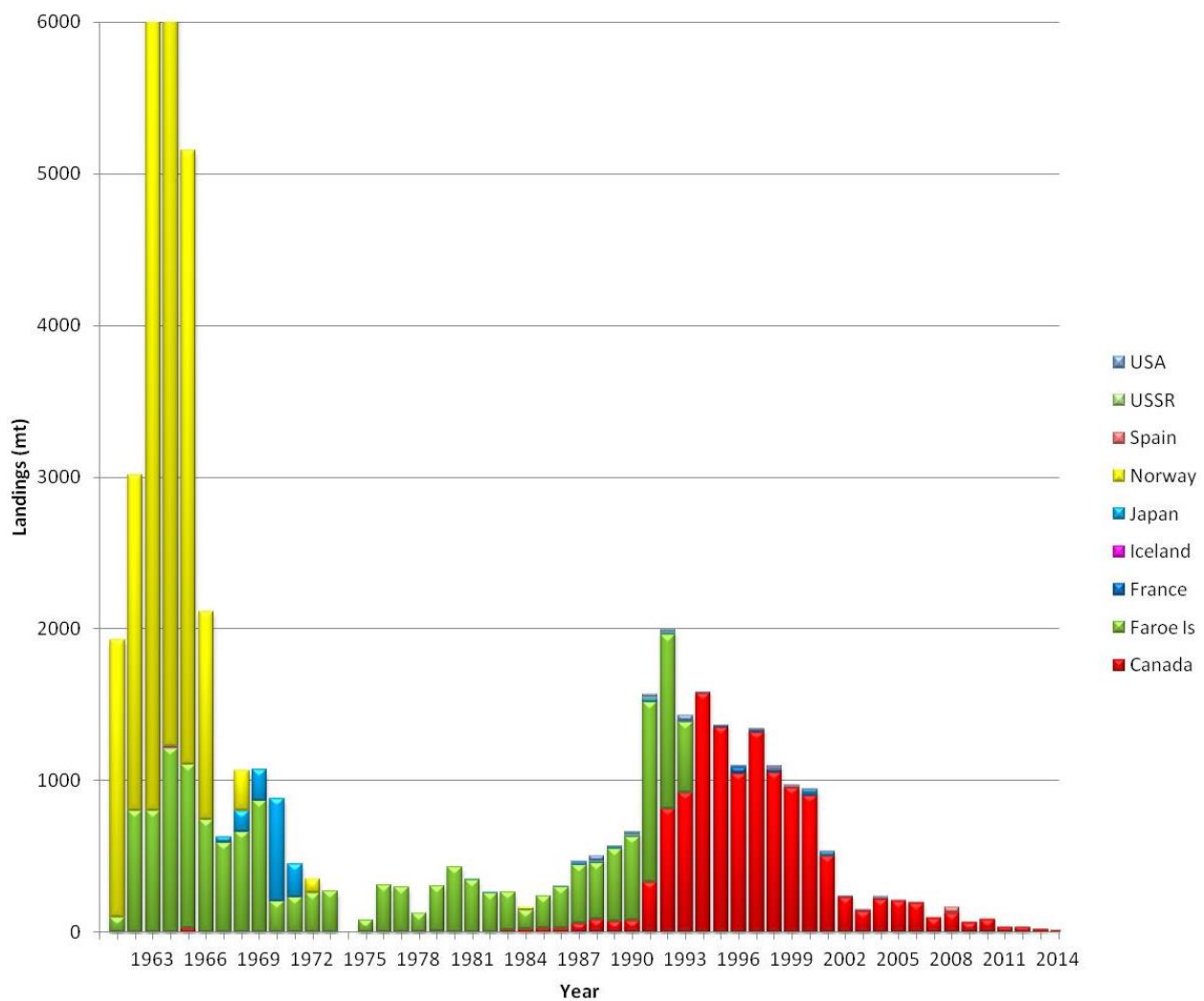


Figure 13. Porbeagle landings in metric tonnes (mt) in the northwest Atlantic (NAFO 2-6) from 1961-2014. The 1963 and 1964 landing values are higher than indicated on the figure (see: Table 3).

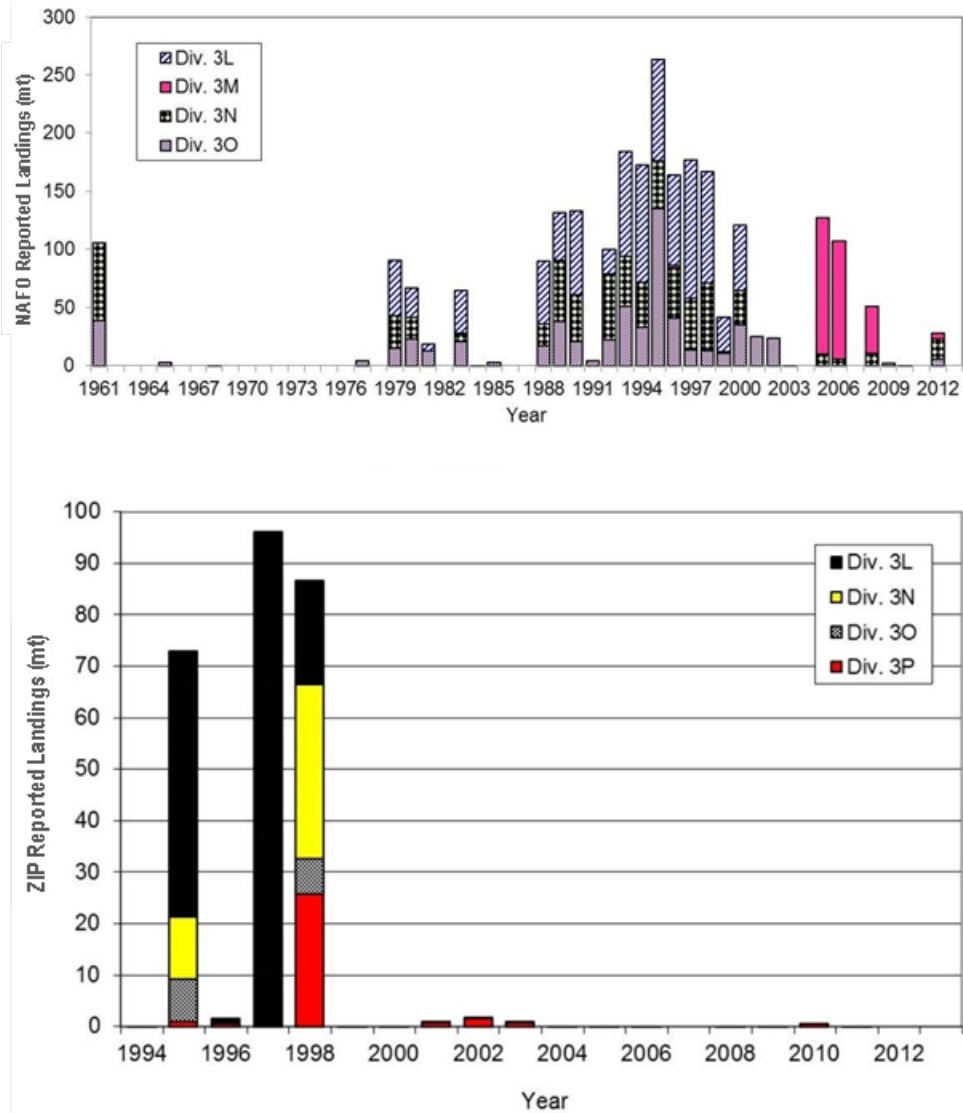
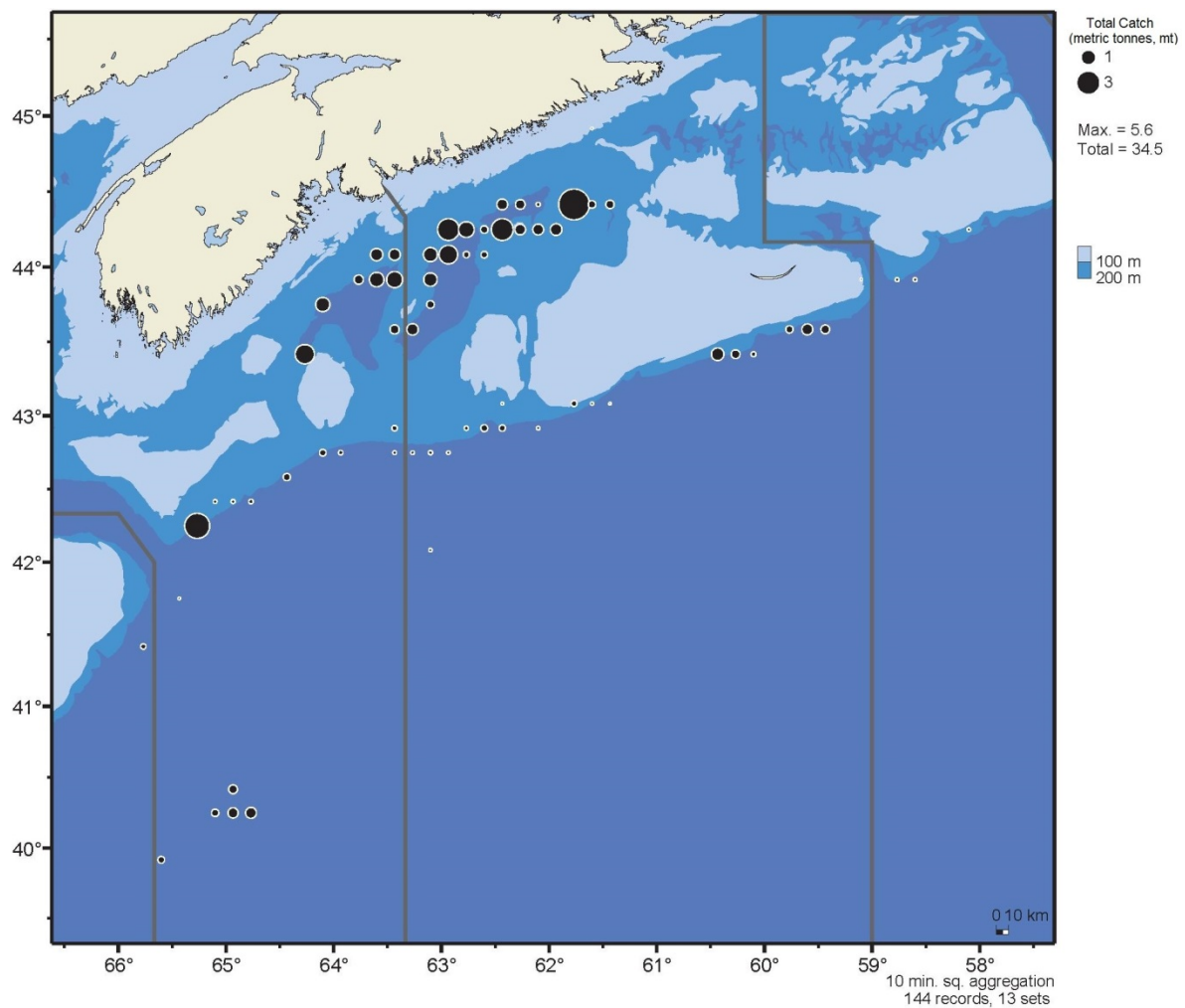
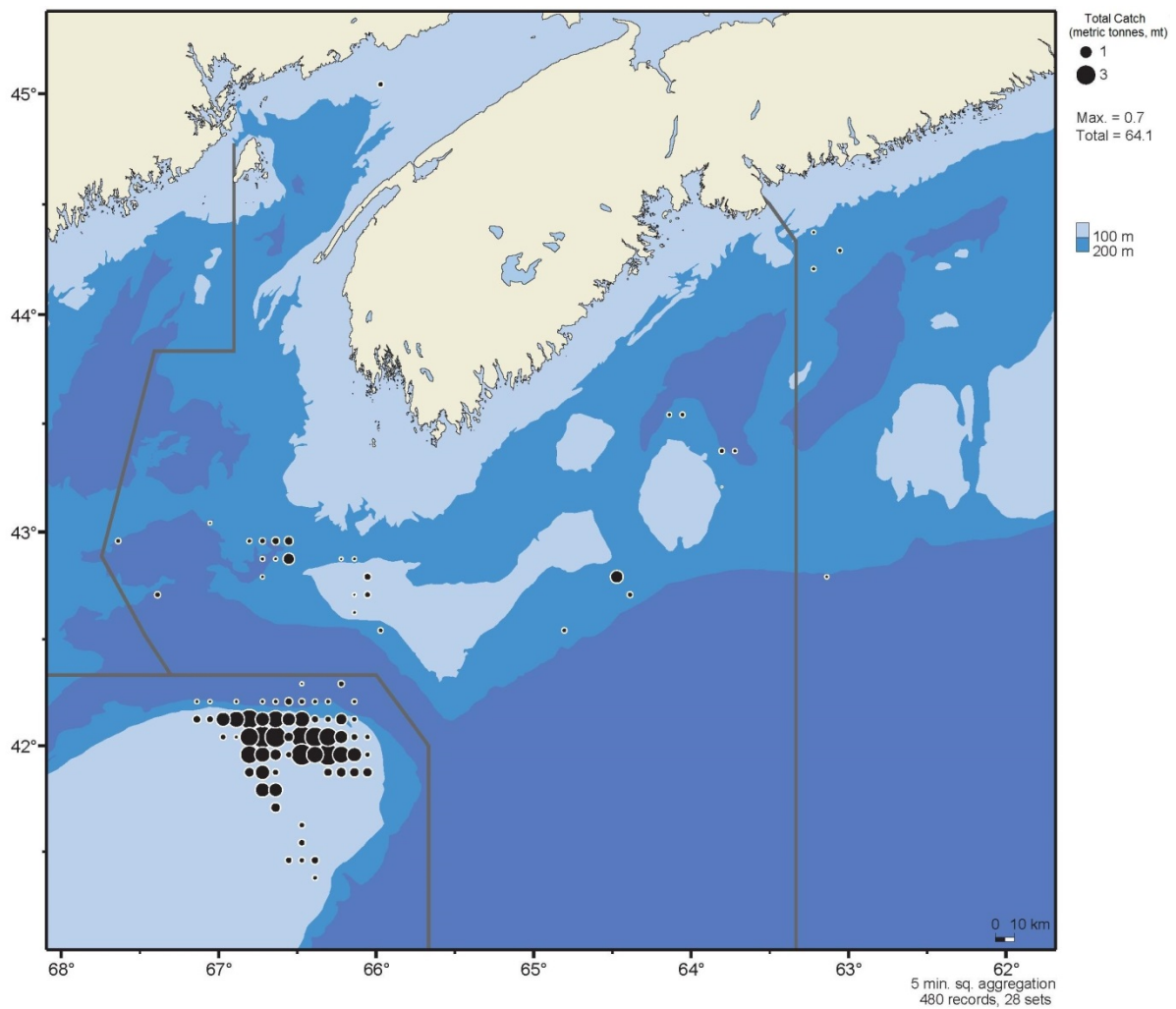


Figure 14. Landings in metric tonnes (mt) of Porbeagle around Newfoundland, as reported to NAFO (top panel) and ZIF (bottom panel). Data updated in September 2014.



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Figure 15a. Observed Porbeagle bycatch caught by pelagic longliners in the DFO Maritimes Region from 2010-2014.



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Figure 15b. Observed Porbeagle bycatch caught by mobile gear in the DFO Maritimes Region from 2010-2014.

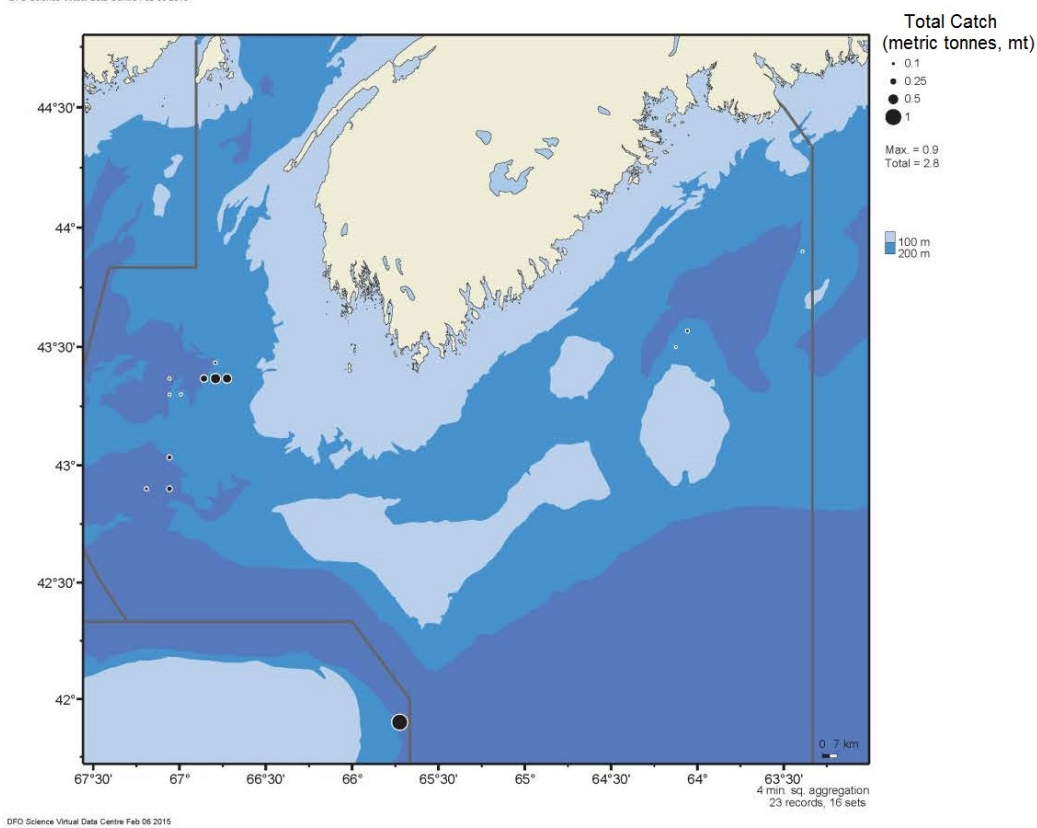
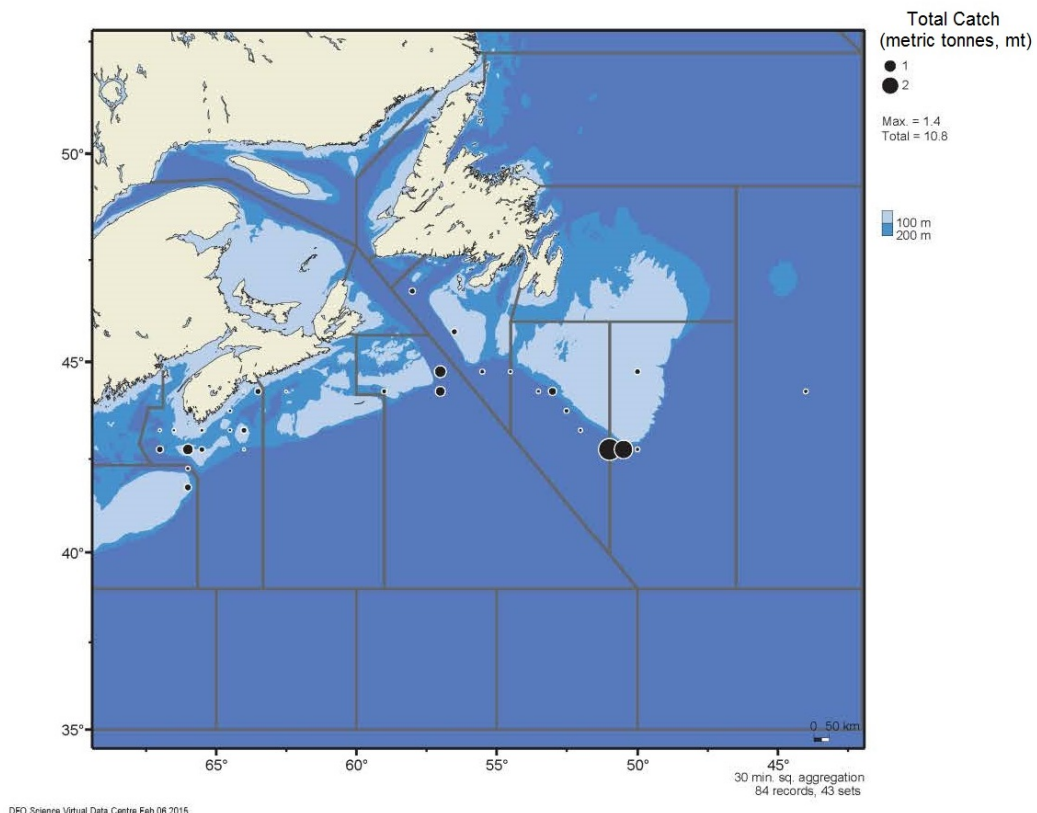


Figure 15c. Observed Porbeagle bycatch caught by bottom longlines (top panel) and gillnets (bottom panel) in the DFO Maritimes Region from 2010-2014.

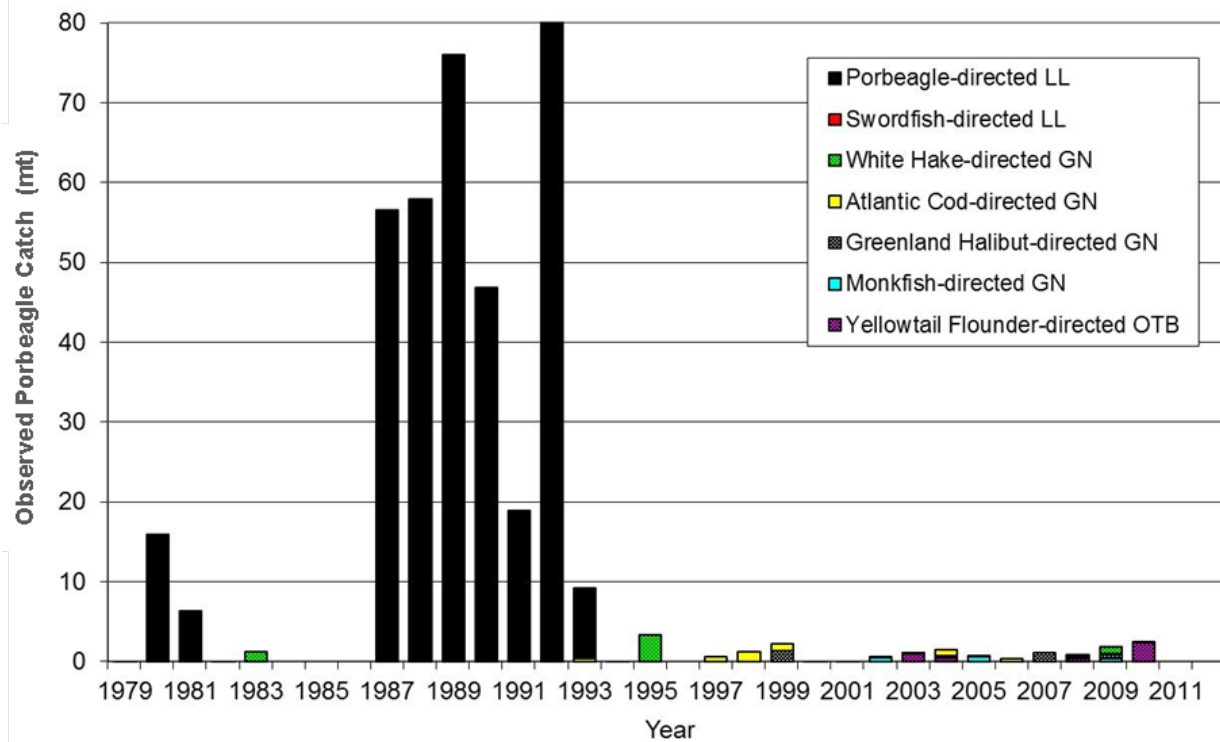


Figure 16. Observed catch of Porbeagle in metric tonnes (mt) by fishery in the DFO Newfoundland and Labrador Region, as Observed by at-sea observers (includes discards). LL = longline; GN = gillnet; and OTB = otter trawl.

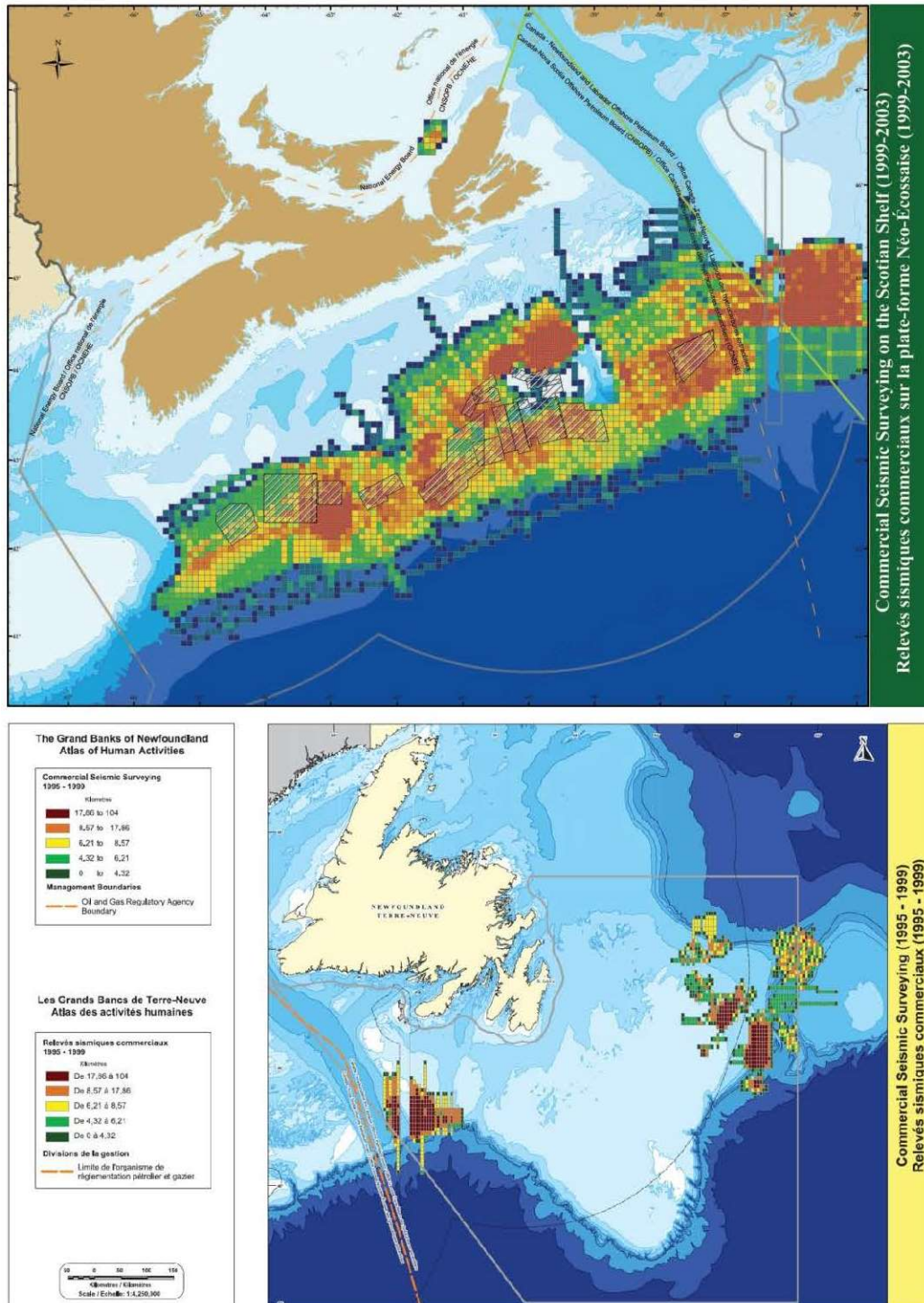


Figure 17. Location and intensity of offshore petroleum seismic surveys conducted in the DFO Maritime Region from 1999-2003 (top panel) and DFO Newfoundland Region from 1995-1999 (bottom panel). Sources: Breeze et al. (2002) and DFO (2007), respectively.

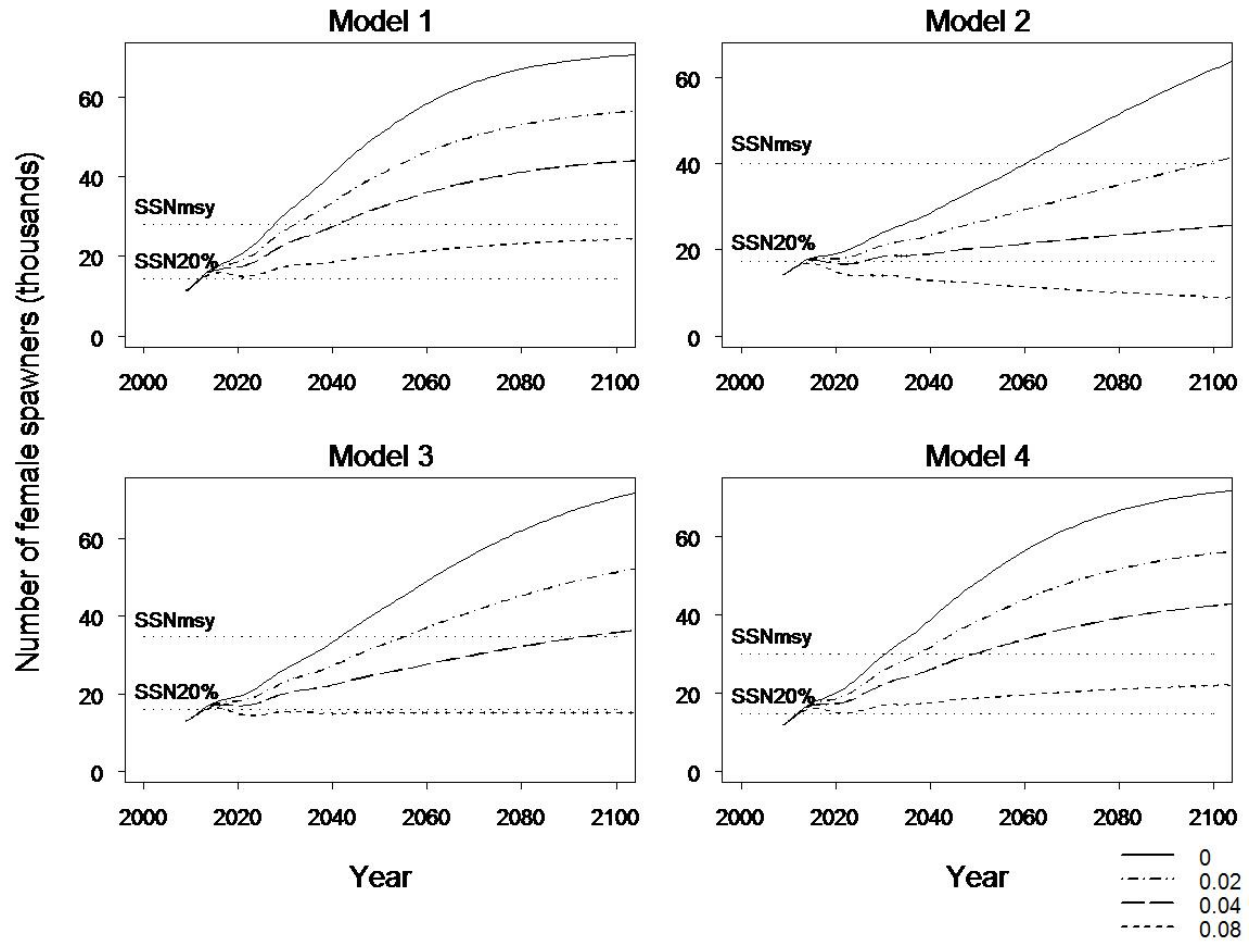


Figure 18. Comparison of recovery trajectories obtained from each of the four models (see: text for description) assuming four different exploitation rates and a Shelf-Edge selectivity. Population projections begin in 2009 from the abundance by age and sex, predicted by the model, and are projected deterministically using life history parameters obtained from the model and an assumed exploitation rate. The line styles indicate differing incidental harm rates.

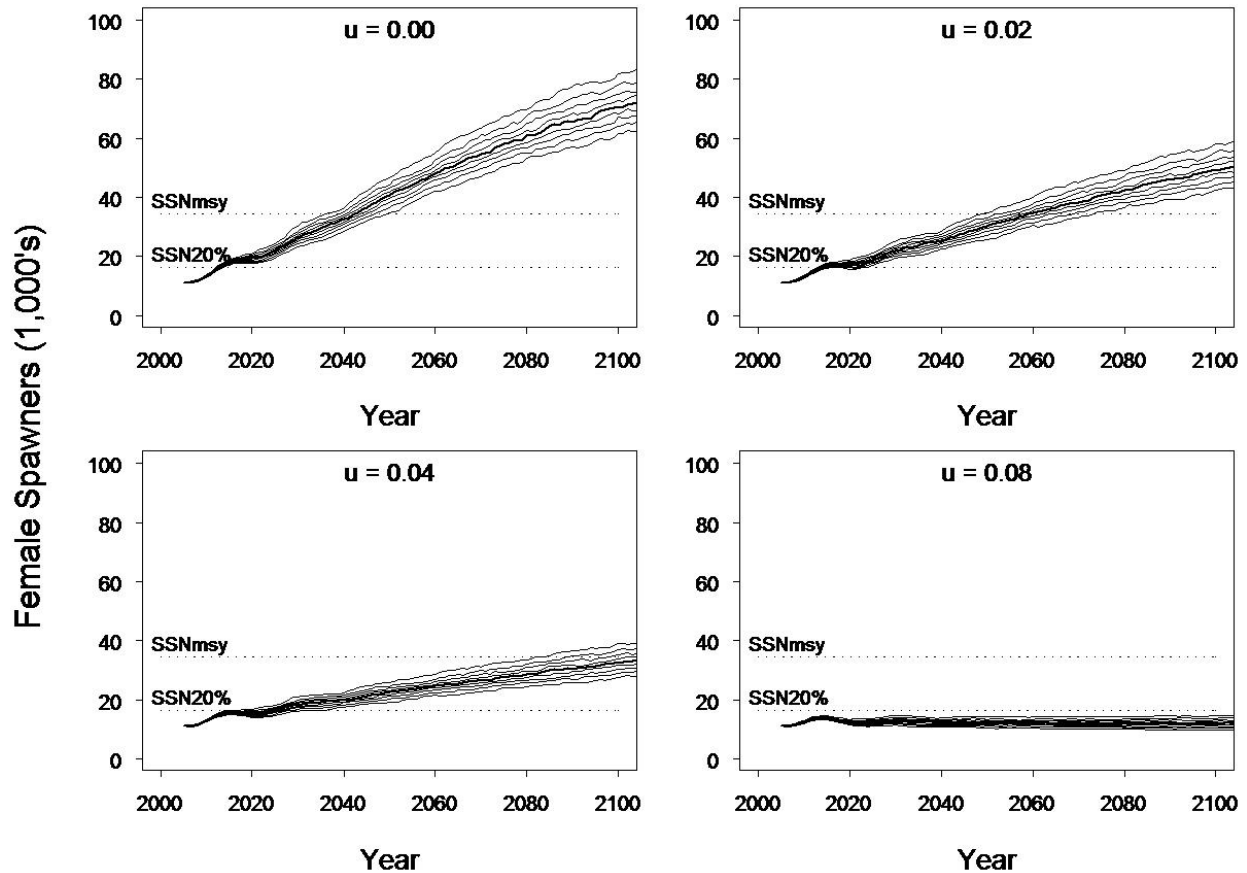


Figure 19. Recovery trajectories for Porbeagle obtained from population viability analysis under four exploitation scenarios (u). Each plot summarizes the results of 200 Monte Carlo population simulations with random variability added to reproduction and survival (see: Gibson and Campana 2005). The lines connect the quantiles of the population size in each year from low (bottom line = 0.1) to high (top line = 0.9). The line styles indicate differing incidental harm rates. A Shelf-Edge selectivity was used to model exploitation.