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Current Status and Threats to the North Atlantic Shortfin Mako Shark (*Isurus oxyrinchus*) Population 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

The Shortfin Mako Shark (*Isurus oxyrinchus*) is widely distributed pan-globally in temperate waters of the Atlantic, Pacific and Indian oceans. Although there is a small degree of mixing between areas, genetic studies indicate Shortfin Mako in the North Atlantic to be a discrete population. Both conventional and satellite tagging studies show Shortfin Mako to be highly migratory and widely distributed in the North Atlantic. Individuals tagged in Canadian waters travel long distances outside Canada's Exclusive Economic Zone and there is no evidence of year-round residency in Canadian waters.

Shortfin Mako Shark exhibit life history characteristics typical of Elasmobranchs. Age at maturity is high, particularly for females, fecundity is low at 4 to 17 pups per litter and estimates of gestation period are around 20 months. Based on estimates of natural mortality, generation time is estimated to be 26 to 30 years. The low productivity resulting from these characteristics makes this species vulnerable to over-exploitation.

There are no fishery independent indices of abundance for Shortfin Mako sharks in Canadian waters. A standardized catch rate index based on at-sea observer data shows a modest decline in recent years, but has high variability and may represent local changes in distribution rather than population abundance. A number of catch rate series reported for fleets outside Canadian waters show no trend or modest increases in recent years.

Most Shortfin Mako landings in Canadian waters are bycatches reported by Maritimes Region fishing vessels, primarily by the pelagic longline fleet. Landings data underestimate actual catches for this species, as about 30% of the total catch is discarded at sea. Of the sharks discarded, many will die but a proportion will survive. Here at-sea observer data have been extrapolated to calculate estimates of both discards and post release mortality by fleet. Combined with reported landings, this provides an estimate of total fishing related mortality. However, even when adjusted for these factors, the Shortfin Mako catch in Canadian waters is less that 2% of the total reported for the North Atlantic.

Situation actuelle de la population de requin-taupe bleu (*Isurus oxyrinchus*) de l'Atlantique Nord dans les eaux canadiennes de l'Atlantique et menaces pesant sur celle-ci

RÉSUMÉ

Le requin-taupe bleu (*Isurus oxyrinchus*) est largement répandu à l'échelle mondiale dans les eaux tempérées des océans Atlantique, Pacifique et Indien. Bien qu'il y ait un faible degré de mélange entre les zones, les études génétiques démontrent qu'il existe une population discrète de requins-taupes bleus dans l'Atlantique Nord. Les études de marquage traditionnel et par satellite indiquent que les requins-taupes bleus sont hautement migrateurs et répartis sur une grande échelle dans l'Atlantique Nord. Les individus marqués dans les eaux canadiennes se déplacent sur de longues distances en dehors de la zone économique exclusive du Canada, et il n'y a aucune preuve de résidence sur toute l'année dans les eaux canadiennes.

Le requin-taupe bleu présente des caractéristiques du cycle vital typiques des élasmobranches. L'âge à la maturité est avancé, plus particulièrement pour les femelles, le taux de fécondité est faible, c'est-à-dire de 4 à 17 petits par portée, et la période de gestation est estimée à environ 20 mois. Selon les estimations de la mortalité naturelle, la durée de génération est estimée entre 26 et 30 ans. La faible productivité découlant de ces caractéristiques rend cette espèce vulnérable à la surexploitation.

Il n'existe pas d'indice d'abondance indépendant de la pêche pour les requins-taupes bleus dans les eaux canadiennes. Un indice normalisé du taux de prise fondé sur les données recueillies par les observateurs en mer révèle une légère baisse au cours des dernières années, mais il est caractérisé par une grande variabilité, ce qui pourrait représenter des changements dans la répartition à l'échelle locale plutôt que l'abondance des populations. Un certain nombre de séries de taux de prises déclarées pour les flottilles à l'extérieur des eaux canadiennes ne montrent aucune tendance ni faible augmentation au cours des dernières années.

La plupart des débarquements de requins-taupes bleus dans les eaux canadiennes sont des prises accessoires déclarées par les navires de pêche de la région des Maritimes, principalement près de la flottille de pêche pélagique à la palangre. Les données sur les débarquements sous-estiment les prises réelles pour cette espèce, car environ 30 % des prises totales sont rejetées en mer. Parmi les requins rejetés, bon nombre d'entre eux meurent, mais certains survivent. Ici, les données recueillies par les observateurs en mer ont été extrapolées pour estimer les rejets et les mortalités après la remise à l'eau par flottille. Combiné aux débarquements déclarés, cela donne une estimation de la mortalité totale par pêche totale. Cependant, même après l'ajustement selon ces facteurs, le taux de prise des requins-taupes bleus dans les eaux canadiennes est inférieur à 2 % du total déclaré pour l'Atlantique Nord.

INTRODUCTION

The Shortfin Mako Shark (*Isurus oxyrinchus*) is a large pelagic shark of the family Lamnidae. This species has a pan-global distribution in temperate waters of the Atlantic, Pacific, and Indian oceans.

Bigelow and Schroeder (1948) reported that the northernmost limit for Shortfin Mako Shark was Cape Cod, Massachusetts, although the possibility of more northern offshore encounters was not excluded, noting its presence of the Gulf Stream.

While unsubstantiated captures of 'mako sharks' had been reported frequently north of Cape Cod, Massachusetts, the possibility existed that these were cases of misidentification of other shark species (such as Porbeagle). The first published, authenticated report on the Mako Shark was by Scattergood (1962). This report described and positively identified a specimen, based on teeth that had been captured in a commercial fishing operation off the coast of Maine in 1957. At that time, Scattergood (1962) commented that "there are no Canadian Atlantic records of the mako".

The first occurrence of Shortfin Mako Shark in Canadian waters was reported by Tibbo et al. (1963). Two specimens of Mako were captured by a Canadian longline research vessel in the summer of 1962, near Browns Bank on the Scotian Shelf. Both capture locations were considerably shoreward of the Gulf Stream in relatively cool water temperatures - at or below the temperature where Bigelow and Schroeder (1948) thought this species "rarely if ever occurs". These two specimens represented extensions of the known range of Mako Shark in the northwest Atlantic, both eastward and northward.

Clearly Shortfin Mako Shark was present in Canadian waters, and was likely a bycatch in the Canadian longline swordfish fishery (which had expanded greatly since 1950 (Anon, 2014)) and the Japanese longline fishery within Canadian waters. Prior to 1994, the Department of Fisheries and Oceans (DFO) did not have an active research program for Shortfin Mako Shark in Atlantic Canadian waters; although a tagging program was conducted in 1961-1985 (Burnett et al. 1987). O'Boyle et al. (1996) provided a summary of Shortfin Mako Shark in Canadian waters, and evaluated consequences of a 250 t catch level that had been set in 1995 as part of a Canadian Shark Management Plan (full details of this plan presented in Campana et al. 2002a). O'Boyle et al. (1996) concluded that a directed fishery for this species in Canadian waters would not be sustainable, and would likely result in significant bycatch of other pelagic species such as Swordfish and tuna.

Campana et al. (2004, 2005) provided an analytical evaluation of the Shortfin Mako Shark, assessing its status in Atlantic Canadian waters for the first time. A standardized catch rate series was produced from Japanese (in Canada's Exclusive Economic Zone (EEZ)) and Canadian commercial fisheries data. This index suggested stable abundance since 1988; although there were high confidence limits (CL) around annual estimates, which implied that only a large change could be detected. Based on the magnitude of Mako Shark catches in Canadian waters, Campana et al. (2004, 2005) suggested it was unlikely that current exploitation rates were having an appreciable impact on the North Atlantic population.

In 2006, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated Mako Shark as 'Threatened' and recommended that it be listed on Schedule 1 of Canada's *Species at Risk Act* (SARA). This classification was based on life-history characteristics that make this species vulnerable to increased mortality and a long-term decline in abundance indicators. Following the COSEWIC listing decision, a Recovery Potential Assessment (RPA) for Shortfin Mako was conducted by DFO (DFO 2006; Campana et al.

2006), in which catches outside Canada's EEZ were identified as the primary source of mortality. Live release and a maximum annual catch limit (100 t) were also recommended as measures to mitigate mortality of Shortfin Mako, in addition to fishery-independent surveys of this species to obtain more accurate population estimates for Canadian waters.

Shortfin Mako is scheduled for re-assessment by COSEWIC in 2016 (i.e., a ten-year cycle). This Research Document updates information on the status of and threats to this species in support of this COSEWIC evaluation.

OVERVIEW OF THE SPECIES

First described by Rafinesque (1810) from the Mediterranean Sea, *Isurus oxyrinchus* was one of a number of quite similar nominal shark species described around the world from 1810 to 1957 (Garrick 1967). These included at least 10 species, spread across 6 genera:

- Isurus spallanzaini (Mediterranean)
- Squalus cepedii (tropical Atlantic)
- Oxyrhina glauca (Japan)
- Isuropsis dekayi (New York)
- Caracharias tigris (Massachusetts)
- Lamna guentheri (India)
- Lamna huidobrii (Chile)
- Isurus mako (New Zealand)
- Isurus bideni (South Africa)
- Isurus africanis (South Africa)

Garrick (1967) undertook a review of the Genus *Isurus*, examining published original descriptions and available preserved type material for these species. Garrick's conclusion was that, with one exception, all these species were in fact *Isurus oxyrinchus*, described by Rafinesque. The one exception identified by Garrick (1967) was a new species of *Isurus* - the Longfin Mako Shark (*Isurus paucus*), which had previously been described as *Lamna punctada*.

Given this reclassification and recognizing the global distribution of *Isurus oxyrinchus* attention turned to the degree to which these various populations might be isolated.

LIFE-HISTORY CHARACTERISTICS

Maturity

Age at 50% maturity was estimated by Natanson et al. (2006) to be 8 years for males (185 cm fork length (FL)) and 18 years for females (275 cm FL). Similar values were reported by Bishop et al. (2006), with 50% maturity at 7-9 and 19-21 years for males and females, respectively.

Fecundity

Fecundity appears to quite variable. Mollett et al. (2000) reported litter sizes of 4-25 from a wide variety of areas (23 measured and pregnant females). Joung and Hsu (2005) reported 4-15 pups per litter for 24 measured and pregnant females from the northwestern Pacific, while Semba et al. (2011) found a range of 8-17 pups per litter for 9 measured and pregnant females in the western and central North Pacific. There was disagreement on the relationship between litter size and maternal size, with Mollett et al. (2000) and Semba et al. (2011) reporting a positive correlation, while Joung and Hsu (2005) did not find a significant relationship. Some of the differences in estimates might be due to the size ranges of the pregnant females in the studies, with both the Mollet et al. (2000) and Semba et al. (2011) studies including larger animals than Joung and Hsu (2005). The difference in size ranges is especially pronounced for Semba et al. (2011), who discuss the differences between these studies, suggesting the contrast in results between their study and that of Joung and Hsu (2005) might be attributable to the fact that most of the pregnant females in the Semba et al. (2011) were larger than those in the Joung and Hsu (2005) study. However all these studies are also characterized by small sample sizes. As well, the pregnant females derive from a wide range of years and locations, both within and between studies, which might add environmental components as influences on litter sizes. Semba et al. (2011) also expressed this concern with respect to their own study, suggesting differences in temperature might play a role.

Gestation

Gestational periods reported for Shortfin Mako vary greatly. Mollet et al. (2000), while examining growth rates of young-of-the-year fish, estimated a gestation time of 19-20 months for a 3-year reproductive cycle for Shortfin Mako in the North Atlantic. For the central North Pacific, Semba et al. (2011) suggested a shorter period, at 9–13 months. Duffy and Francis (2001) suggest a longer period (21 months), while Joung and Hsu (2005) reported a preliminary reproductive cycle of 21+ months for Shortfin Mako in the northwestern Pacific.

Ageing

Ageing of Shortfin Mako has changed over time. Pratt and Casey (1983) were the first to develop an age model, employing tagging data, length frequency analysis, and counts of growth rings on vertebral centra. Their interpretation of the ring structure assumed two rings formed on the centrum each year. Based on this technique, males and females showed similar growth rates, and the largest fish in their sample (n=32) was a 328 cm female estimated to be 11.5 years of age.

Campana et al. (2002b) and Natanson et al. (2006) reported a very different growth pattern than Pratt and Casey (1983), based on bomb radiocarbon validation and a single tetracycline tagged recapture. Results of this study indicated that Shortfin Mako Shark in the North Atlantic Ocean had been under aged by approximately 50%. Using the new methodology, Shortfin Mako growth was half, and maturity and longevity double what had been previously reported. These findings were supported by Bishop et al. (2006) who found a similar growth pattern for Shortfin Mako around New Zealand using the same technique.

More recently, Wells et al. (2013) examined growth in juvenile Shortfin Mako tagged and injected with oxy-tetracycline. Results of their study provided a new interpretation of more rapid growth during the juvenile phase, and suggested age estimates using the Natanson (2006) method would be overestimated by as much as 5 years.

Natural Mortality

Natural mortality (M) for Shortfin Mako has been reported in the range of 0.10 to 0.15 by Bishop et al. (2006), and later (Bishop, unpublished manuscript) as 0.14 to 0.15. Smith et al. (1998) calculated M to be 0.16. Au et al. (2015) assumed a natural mortality of 0.15 for this species. Tsai et al. (2014) calculated M by sex, arriving at 0.12 to 0.14 and 0.09 to 0.12 for males and females respectively.

Generation Time

Several methods for calculating generation time are described by the International Union for Conservation of Nature (IUCN (2012)). For Shortfin Mako Shark, the most appropriate method is “1/adult mortality + age of first reproduction”. Since most of the reproductive potential for this species is related to females, it is suggested the estimated age of 50% reproduction for females (20 years) be used in the calculation, with 0.15 as the natural mortality rate. Generation time, therefore, would be (1/.15)+20) which equals approximately 27 years. As reported above, estimates of M ranged from 0.10 to 0.16, giving a range of possible generation times between 26 and 30 years.

POPULATION STRUCTURE

Heist et al. (1996) studied the population structure of Shortfin Mako by analysing mitochondrial DNA samples collected at five locations: North (2 sites) and South (1 site) Atlantic; North (1 site) and South (1 site) Pacific. Results indicated that there was considerable partitioning of haplotypes between the North Atlantic and the other three regions, as well as similar (but weaker) differences between the Indo-Pacific and South Atlantic areas. Heist et al. (1996) highlighted implications of these differences between the North and South Atlantic populations on their management, stating “If the Shortfin Mako is overfished in the North Atlantic, replenishment will have to rely on intrinsic rather than migrational growth.”

Using similar techniques, Taguchi et al. (2011) confirmed the genetic separation of North Atlantic and Pacific populations, but did not provide a comparison of North and South Atlantic Shortfin Mako.

Schrey and Heist (2003) analyzed microsatellite DNA collected from five areas: North and South Atlantic, North and South Pacific, and both the Atlantic and Indian Ocean coasts of South Africa. Based on the four microsatellite loci screened, multi-locus measures of population subdivision were lower than expected, indicating mixing between various populations: an apparent inconsistency with mitochondrial DNA results. An explanation was proposed to resolve this by using gender-based dispersal of individuals: males travelled further and more frequently; while females remained close to oceanic pupping grounds.

TAGGING

Shark tagging programs have been conducted since the 1960s.

Kohler et al. (1998) reported on a United States (US) National Marine Fisheries Service (NMFS) tagging study from the early 1960s to 1993, with 3,457 Shortfin Mako sharks tagged along the eastern seaboard of the US (Figure 1; 320 fish recaptured). From the 1960s to 1986, Burnett et al. (1987) conducted tagging on research vessels from the Scotian Shelf into US waters; although only five Shortfin Mako tags were recovered (Figure 2). The Canadian Shark Research Laboratory (DFO-Maritimes Region) has conducted both conventional (2006-2015, Figure 2) and satellite tagging programs (2011-2013, Figure 3). In 2012, the International Commission for the Conservation of Atlantic Tunas (ICCAT) Secretariat presented a summary of conventional tagging information in the ICCAT database (including US tagging under the NMFS Apex Predators Program tagging project): 9,200 tagged Shortfin Mako with 1,200 recaptures (Figure 4).

While Shortfin Mako were seen to travel extensively in all studies, most movements of this species occurred along easterly or westerly directions in the North Atlantic, with relatively few recaptures below 20°N and none south of 5°N (Figure 4). These tagging data also indicate that Shortfin Makos spend considerable time outside Canada’s EEZ, and that movement of this species is restricted to the North Atlantic Ocean. Combined with mitochondrial DNA data, tagging results support a proposal that the North Atlantic population comprises a separate stock that inhabits one North Atlantic Designated Unit.

Area of occupancy within Canada's EEZ was defined as the sum of the Canadian portion of North Atlantic Fisheries Organization (NAFO) areas 3KL+3NOP+4R+4VWX+5Y+5Ze: 1.06 million sq. km. Based on an estimate of 42.5 million sq. km occupied by the North Atlantic Shortfin Mako population, the Canadian portion thus comprises approximately 2.5% (Figure 5).

HABITAT

Shortfin Mako Shark habitat is associated with deep continental shelf and offshore waters. Atlantic Canadian waters are at the northern edge of this species' range, as they are most commonly found in warm waters of the Gulf Stream.

A lack of data has prevented any identification of habitats necessary for critical life functions (e.g., mating, pupping) of this species in Canadian waters. While a high proportion of this species in Atlantic Canada consists of juveniles, mating and pupping are thought to occur south of Canada's EEZ in warm Gulf Stream waters (O'Boyle et al. 1996).

COMMERCIAL FISHERIES REMOVALS

LANDINGS

Shortfin Mako Shark landings from Canadian vessels landing sharks in the Maritimes Region are entered in the DFO-Maritimes Region (MAR) Fisheries Information System (MARFIS): representing fishers' logbook entries (1979-2002), and dockside monitoring data since 2003. Newfoundland and Labrador (NL) fishers only record "shark" in their fishing logbooks when landing any shark species in the NL Region: unspeciated shark data that, along with dockside monitors' reports, are subsequently entered in the DFO-NL Zonal Interchange File Format (ZIFF) database. Catches by foreign fishing vessels operating within Canada's EEZ were monitored by Canadian at-sea fisheries observers (ASOs) in 1977-1993, after which foreign fleets were prohibited to fish in Canadian waters with 100% coverage since 1987. Landings data for vessels fishing outside the Canadian EEZ are available from other fisheries organizations, such as ICCAT and the Food and Agricultural Organization of the United Nations (FAO). As with these and NAFO-reported data, MARFIS and ZIFF landings do not include discards at-sea, nor represent the extent of Shortfin Mako bycatch; thus, mortalities will continue to be higher than what available statistics indicate. This ongoing impediment to assessing the impacts of teleost-directed fisheries on this species in Canadian waters is also reflected on a global scale, where some regions experience bycatch mortalities of Shortfin Mako and other large pelagic sharks that are at least twice as high as reported landings indicate (Campana et al. 2006, Benjamins et al. 2010, Cosandey-Godin and Worm 2010, ICES 2013, Worm et al. 2013).

With respect to foreign countries, the Faroe Islands and Japan caught significant amounts of Shortfin Mako in Canadian waters before prohibition by Canada in 1994. Landings reported for international waters of the Northwest Atlantic Ocean are higher, including Japan from FAO statistics, and US from ICCAT records (Table 1). Records from the US include recreational catches, which can be substantial. Japan records from FAO must be viewed with caution, as they represent an aggregate of shark and skate/ray species. ICCAT-reported landings for statistical areas AT-NW and AT-NE are much higher: almost an order of magnitude larger than the previously mentioned sources combined (Table 1).

With the prohibition of foreign-registered vessels from fishing stocks inside Canada's EEZ as of 1994, Canadian fishers became the main source of reported Shortfin Mako landings. In Atlantic Canada, this species is caught only as bycatch in fisheries targeting other species. The Atlantic Canadian pelagic longline fishery (i.e., Swordfish, tunas) has one of the highest shark bycatch of any Canadian fishery, in which sharks comprise on average 40% of the total catch by weight (Cosandey-Godin and Worm 2010). This fishery annually receives ≤5% ASO coverage since 2004, while the majority of Canadian groundfish fisheries had 0-5% ASO coverage over the past decade. It must be noted that Canadian ASOs constitute the sole source of data on total catch and at-sea discards by species.

Overall, Canadian-reported landings (all Regions combined) of Shortfin Mako Shark in Atlantic Canada were highest in the mid-1990s, but have generally declined to the present (Table 1; details by Region and gear type in Table 2). Reported landings in Maritime waters have averaged 60 tons since 1993, with a general decline afterwards (Figure 6). Landings by pelagic longline in DFO-Maritimes Region were highest in 1994, but have declined to their lowest level in 2012. Figure 7 shows the distribution of Shortfin Mako pelagic longline catches relative to total catches (all species) for this fishery. Reported landings from the gillnet fishery were highest in 1994-2009, but have been negligible in recent years (Figure 6, distribution in Figure 8). Shortfin Mako landings from groundfish otter trawls (OTB) were also reported early in this time series; albeit only in very small quantities (Figure 6, distribution in Figure 9).

As most Shortfin Mako sharks are not landed by Canada, ASO data represents a more reliable source of information in that discards are observed and recorded. However, observer coverage in most fisheries is generally low (< 5%) and variable (Table 3).

The distribution of catches based DFO-Maritime ASOs is similar to that derived from MARFIS landings data, with coverage levels of to 13% from 2006-2014 (Figure 10). Given that only 25 sets were observed by ASOs in the Maritimes groundfish gillnet and longline fisheries over 1998-2014, there were insufficient data for comparison with MARFIS gillnet landings (Figure 11). Furthermore, the low amount (≤5%) of annual observer coverage of OTB fisheries was concentrated on Georges Bank; resulting in catch locations that differed from those in MARFIS (Figure 12).

Given that DFO-NL does not conduct a dedicated shark survey, data analyzed for this Research Document were NAFO-reported landings, Canadian commercial landings (ZIFF; preliminary for 2014), and Canadian at-sea fisheries observers' catches (incomplete for 2013-2014). It must be noted that Canadian ASO data were only from observed fishing sets, not scaled up to entire fisheries, and limited by the annual observer coverage level for each fishery. Based on NAFO-reported data (which do not include discards at-sea), landings of Shortfin Mako, particularly in Div. 3MN, apparently increased in recent years relative to reported landings in 1998-2004 (Figure 13). DFO-NL ZIFF landings (i.e., no discards) of Shortfin Mako in NL waters were mainly from Div. 3P, and have been declining in recent years (Figure 14, top left panel). Previously, larger landings occured in Div. 3MNO (2000-2001), as well as smaller amounts in Div. 3KL. Canadian landings were due primarily to directed Swordfish and tuna longline fisheries and, to a lesser extent, Atlantic Cod gillnet fisheries (Figure 14, top right and bottom panels). ZIFF-reported landings of this species (2000-2014) occured mainly from sets in warmer and deeper waters off of the Grand Banks, and occasionally from the Bank edge, from shallower waters of the southwest Grand Banks, and from deeper waters of the Laurentian Channel (Figure 15). However, the lack of data on shark discarding in both NAFO and ZIFF statistics prevents definitive conclusions. Canadian ASO data (including discards) from the NL Region in 1988-2014 showed a similar distribution of Shortfin Mako catches in Newfoundland waters (Figure 16).

In addition, NL ASO data in 1988-2012 indicated that Shortfin Mako was predominantly caught by gillnets in the Subdiv. 3Ps Cod fishery, the Div. 3OPs Monkfish/White Hake/skate mixed fishery, and the Div. 3L Greenland Halibut (Turbot) fishery (Figure 17, top left panel). Several Canadian ASOs and a number of NL groundfish fishers have also reported that bycatch mortality of the four most frequently seen large shark species in Newfoundland waters (i.e., Porbeagle, Blue Shark, Basking Shark, Shortfin Mako) is 100% with gillnets, due to the shark drowning after entanglement in this gear. Regarding longlines, Shortfin Mako bycatch was observed historically in the Div. 3MNO Swordfish/tuna and Div. 3LNO Porbeagle fisheries conducted by other countries (Figure 17, top right panel). More recently, bycatch of this species was observed in the Subdiv. 3Ps Cod longline fishery, although ASO coverage of this fishery has been almost non-existent. With bottom (otter) trawls, Shortfin Mako bycatch was observed mainly in the Div. 3NO Yellowtail Flounder fishery as of 2001, and in the Subdiv. 3Ps Cod fishery since 1999 (Figure 17, bottom panel).

With respect to gillnet fisheries, Shortfin Mako bycatch was observed predominantly in the Monkfish/White Hake/skate mixed fishery and Cod fishery prosecuted during June-August since 2000, with some recent occurrences as late as December (Figure 18, top left panel). Historically, bycatch of this species occurred in large pelagic longline fisheries conducted by other countries in September-February (Figure 18, top right panel). Recently, Atlantic Halibut and Cod longline fisheries were observed to catch Shortfin Mako in March-July. This species was also recently observed in bottom (otter) trawls fishing for Yellowtail Flounder, Cod, and redfish mainy during October and December (Figure 18, bottom panel).

Regarding average depth fished, Shortfin Mako bycatch was observed in recent years predominantly from gillnets soaking in 31-386 m waters (Figure 19, top left panel). Large pelagic longline fisheries were historically conducted by other countries in 19-170 m depths, with a few Shortfin Mako also observed caught in 1,097-3,500 m (Figure 19, top right panel). Bycatch of this species was recently observed on Cod longlines fishing in 20-170 m waters. Bottom (otter) trawls were also observed to catch Shortfin Mako while targeting Cod in 46-240 m depths, Yellowtail Flounder in 44-70 m, and redfish in 241-420 m (Figure 19, bottom panel).

Concerning discarding of Shortfin Mako at sea, Figure 20 (top panel) suggests that the Cod gillnet fishery in Subdiv. 3Ps discarded the observed majority of this species since 2000, while very few were observed landed in this fishery (and recorded in DFO ZIFF; Figure 20, bottom panel). However, it must be noted that Canadian ASO coverage of this fishery was 0-1%, while NL Swordfish/tuna fisheries received 2.6% observer coverage on average, implying that the vast majority of Shortfin Mako discards in NL waters were neither observed by ASOs nor reported by NL fishers.

Combining reported catch locations from the ZIFF/MARFIS data sources for all area and gear types provides an overview of relative catch density and distribution by Canadian fishers. Records from DF-NL (1995-2014), DFO-Maritimes (1988-2014), and DFO Gulf (1997-2013) Regions were combined. ArcGIS (10.2.2 / 2014) was used to calculate the magnitude per unit area from the point features via the “Kernel Density” function (available via the Spatial Analyst Extension). This function fits a smoothly tapered surface to each equally weighted point

Based on this analysis, while Candian catches were widely distributed from the Bay of Fundy to the Flemish Cap, highest densities were to the west, on Georges Bank (Div. 5Ze), the edge of the Scotian Shelf in Div. 4X, and in Emerald Basin (Figure 21).

ESTIMATION OF UNOBSERVED SHORTFIN MAKO BYCATCH

Given that MARFIS and ZIFF contain only reported landings data, bycatches of Blue (Campana et al. 2015a) and Porbeagle sharks (Campana 2015b) were recently estimated by multiplying

ASO-recorded shark catches by the ratio of observed directed species kept to fisher-reported landings of the directed species (see Campana et al. 2011 for detailed methodology). For Maritimes Region, Shortfin Mako discards were estimated for five fisheries (Swordfish and tuna longline, Porbeagle longline, groundfish longline, groundfish gillnet, groundfish otter trawl) by quarter, and summed for each year (Table 4). Based on the landings data above, Swordfish and tuna longline fisheries accounted for most of the estimated shark discards in Maritimes Region.

For various Newfoundland and Labrador fisheries, a similar method was used with the NL-ASO database for 1998-2010. Reported landings of the target species by fishery (summed by year) in ZIFF-NL was divided by the observed kept weight of this target species by year (e.g., Atlantic Cod; Swordfish). This factor was then multiplied by the observed catch weight (=kept+discards) of Shortfin Mako in each fishery by year in order to scale up Shortfin Mako bycatch estimates to the entire fishery. However, a lack of comparable data between ZIFF-NL and NL-ASO for each fishery in some years restricted the application of this method. Although the NL-ASO database contained adequate records of Shortfin Mako kept and discard weights for several fisheries in particular years (e.g., a Porbeagle-directed fishery conducted in NL waters by the Faroe Islands in 1987-93), the ZIFF-NL database either had no reported landings of the target species in those fisheries, or contained landings of said target species in years other than those covered by NL-ASOs.

Scaled up Shortfin Mako bycatch estimates suggested that a 67 t average was caught annually in the NL Atlantic Cod gillnet fishery from 1998 to 2010 (with peaks of 166 t in 2003 and 174 t in 2009; Figure 22). Estimates indicate that the Atlantic Cod longline fishery averaged 7 t of Mako annually over 2005-2010, while an annual average of 3-4 t was suggested for the White Hake/Monkfish mixed fishery and the Greenland Halibut gillnet fishery in 2003-2011. In that same period, a 1-2 t annual average of Mako bycatch was estimated for the Div. 3NO Yellowtail Flounder otter trawl fishery. Shortfin Mako Sharks were also captured in Div. 3LNO Swordfish and tuna-directed longline fisheries, in which a few ASOs and DFO-NL Fisheries Officers noted that Shortfin Mako bycatch was usually dead when discarded at sea, and never reported in fisheries statistics other than those of Canadian at-sea fisheries observers and DFO Fisheries Officers.

POST-RELEASE MORTALITY

Campana et al. (2015c) evaluated capture and post-release mortality for Blue, Porbeagle, and Shortfin Mako sharks in Canadian large pelagic longline fisheries. Capture mortality was estimated from at-sea observers' records of the physical condition (i.e., healthy, injured, dead, unknown) of each shark when hauled aboard the fishing vessel. Shark sampling by observers was made a higher ASO priority as of 2010: almost 500 fishing sets were sampled for shark condition in 2010-14. In total, 528 Shortfin Mako Sharks were evaluated for condition: on average, 51% were healthy; 22% injured; 26% dead; and very few unknown (Table 5).

To estimate post-release survival of discarded Shortfin Mako, a random sample of 33 sharks was tagged with pop-up satellite tags (PSAT), which recorded data on the condition of each shark after release (Table 6). Based on these data, a 30% mortality rate was estimated for "healthy" sharks, 33% for "injured" sharks, and a 31% overall post-release mortality rate for live Shortfin Makos. Using a 26% hooking mortality while assuming that live sharks were not kept, the overall fishing-related mortality rate for this species was estimated as 49% (Figure 23). This proportion was applied to live and dead discards in Table 4, in order to estimate total mortality (i.e., sum of landings plus discard mortalities; Table 7).

STATUS

Calculations of Shortfin Mako standardized Catch Per Unit Effort (CPUE; kgs per hook) used Atlantic Canadian large pelagic longline fishery data, which accounted for the majority of shark bycatch in Canada's EEZ. Pelagic longline fishers' logbook data were cross-matched to reported landings; for 1996-2014, these data were assumed to be relatively accurate. Previous examinations of shark catch rates (Campana et al. 2004, 2006; Fowler and Campana 2009) indicated that major data sources should be categorized by vessel identity (CFV), area fished (i.e., eastern Scotian Shelf in Div. 4VW; the southern region in Div. 4X5Z), season (quarter), and species sought (Bigeye Tuna, Swordfish, Bluefin Tuna, Yellowfin Tuna, Porbeagle Shark). Data were analyzed at the trip level; all fishing trips that reported at least one Shortfin Mako were assumed to have been accurately reported, and thus all sets of that trip (including zero sets) were used in the analysis. Trips with none of this species reported were excluded.

A number of generalized linear models (GLMs) were reviewed in the previous analyses of Shortfin Mako catch rates. Data were first analyzed at the set-by-set level with a GLM using a negative binomial error distribution and year, region, season, species sought, and vessel (CFV) as factors (Campana et al. 2004). However, the frequency of zero sets and missing cells for combinations of factor levels confounded these analyses. Therefore, data were aggregated to the trip level, and then restricted to factor levels with the most data: Scotian Shelf Swordfish-directed trips in July-September. Only vessels which fished more than one year were included in this model. The same data selection criteria were used in the model presented here, which included more recent years.

The final (and accepted) catch rate model was a trip-level GLM with a gamma error distribution using year and CFV as factors (Campana et al. 2006). Model results indicated that both year and CFV were significant factors. Since not all vessels fished in all years, an interaction term could not be tested. This model was also used in subsequent updates of Shortfin Mako catch rates (Fowler and Campana 2009; the current analysis). Fowler and Campana (2009) indicated that there was no evidence of a trend in the standardized catch rate over 1996-2007. The current assessment suggests a generally decreasing trend in catch rates since 2008 (Figure 24).

Based on data from outside Canada's EEZ, several other shark catch rate series have been derived. Hoey et al. (2002) used a GLM approach to combine US and Canadian observer data with US shark survey data, and found a generally increasing trend in 1985-2000 (Figure 25). Baum et al. (2003), examining commercial fishers' log records, reported an approximately 40% decline over 1986-2000 (Figure 26). ICCAT (2005) also reported long-term declines in indices, based on Japanese commercial longline data (Figure 27). Baum and Blanchard (2010) indicated a slight decline in 1992-2005 that was marginally significant (Figure 28). An ICCAT (2012) assessment of Shortfin Mako reported on six indices with data to 2010. With the exception of the US recreational shark fishing index, results suggested a modestly increasing trend since the mid1990s (Figure 29).

Size distribution of Shortfin Mako Sharks by sex and proportion mature from Maritimes ASO data is shown in Figure 30, for three periods (1986-1995, 1996-2005, and 2006-2015). A declining trend in size was seen for both sexes over the three periods. Fifty percent maturity was assumed to be 185 cm for males and 275 cm for females (Natansen et al. 2006). The proportion of mature males declined from 44% in 1986-1995 to 16% in 1996-2005, then declined further to 7% in 2006-2015. The proportion of mature females was much lower than males, but declined similarly from 1.6% in 1986-1995 to 0.5% in 1996-2005 then declined again to 0.4% in 2006-2015

Using Maritimes ASO data, Campana (2006) reported an increasing trend in the average total length of Shortfin Mako caught in the Japanese commercial fishery from 1986 to 1996 (Figure 31 top). The average length of Shortfin Mako caught by the Canadian large pelagic fleet from 1999 to 2014 was variable without a trend (Figure 31 bottom.).

ICCAT ASSESSMENT

The most recent assessment of the North Atlantic Shortfin Mako population was conducted by ICCAT (2012), incorporating data to 2010.

Official landings were not considered reliable due to inconsistent reporting, so a new landings series was derived, where landings that were reported were prorated to fill gaps in the time series (Table 8). As a result, the time series used for modelling purposes was substantially higher landings than that presented in Table 1 of this document.

A Bayesian Surplus Production Model (BSP) was used to estimate stock status, incorporating catch estimates as well as four of the indices mentioned above: the US longline logbook series; Japanese longline; Portuguese longline; and Spanish longline. Sixteen model formulations were run, using various combinations of indices and weighting options. Maximum Sustainable Yield (MSY) from the various runs ranged from 5,300 t to 24,000 t, with an average of about 19,000 t. A phase plot of the biomass and fishing mortality derived from the various combinations is presented in Figure 32. In all cases, estimates of biomass exceeded B_{MSY}, with most around 1.75 B_{MSY}. Fishing mortality estimates showed a similar pattern – most estimates were near 25% of F_{MSY}, with only a single model run exceeding F_{MSY}. However, as a result of small sample size and high variance (i.e., wide confidence intervals), the ICCAT (2012) analysis would have been unable to detect anything other than a severe change in biomass, so results should be interpreted with caution.

A second model incorporating only CPUE data was also explored. Ten formulations were run in this case, and produced similar results to that of the BSP model; although this model could not estimate yields and confidence intervals were not provided (Figure 33).

THREATS TO ABUNDANCE

All known anthropogenic threats to the Shortfin Mako shark population are due to commercial fishing, both in Canadian waters and throughout the Northwest Atlantic Ocean. Most catches occur in large pelagic longline fisheries; although ICCAT statistics indicate rod and reel catches in the US recreational fishery are significant. Most large pelagic longline fleets fishing in international waters are not monitored, and significant bycatches of Shortfin Mako remain unreported. Mortality of discarded sharks, through both hooking and post-release, is substantial.

No data currently exist regarding impacts of other anthropogenic activities (e.g., seismic surveys, oil and gas drilling, marine pollution) on Shortfin Mako or its habitat. In addition, environmental effects due to climate change (e.g., warming water temperatures, increasing ocean acidification) on the life stages (e.g., pups, breeding adults), prey abundance, and habitat (e.g., pupping grounds/nursery areas) of this species remain unknown.

Canadian catches (accounting for discard mortality) comprise about 1% estimated catches for the North Atlantic.

SOURCES OF UNCERTAINTY

- Canadian at-sea fisheries observers constitute the primary source of total catch data by species, and the only source of information on discards at sea. However, there is very low to non-existent at-sea observer coverage in many Atlantic Canadian fisheries.
- Discarding at-sea of shark bycatch remains unreported in Canadian and other fisheries; resulting in substantially higher removals from the Shortfin Mako population than what fisheries statistics indicate.
- A recent ageing study suggests that currently-accepted ageing methods are an overestimate by 5 years.
- Gestation period is uncertain; estimates range from 9 months to 2 years.
- While reports of fecundity are relatively consistent, some disagreement exists regarding the relationship between maternal shark size and litter size.

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TABLES

Table 1. Reported Shortfin Mako Shark landings (mt) by country.

	Canadian Atlantic (NAFO Areas 3-5)					Northwest Atlantic			North Atlantic
Year	Canada[1]	Faroes Is.[2]	Japan[2]	Other[2]	Total	Japan[4]	USA[3]	Other[3]	
1979	0	0	1	0	1	102	0	0	102
1980	0	2	0	0	2	228	0	0	228
1981	0	0	4	0	4	609	0	0	609
1982	0	0	0	0	0	226	0	0	226
1983	0	0	13	0	13	85	0	0	85
1984	0	0	4	0	4	213	0	0	213
1985	0	0	0	0	0	214	0	0	214
1986	0	0	5	0	5	231	0	0	231
1987	0	0	10	0	10	232	0	0	232
1988	0	0	17	0	17	168	0	0	168
1989	0	1	13	0	14	176	0	0	176
1990	0	5	8	0	13	140	268	0	736
1991	0	2	14	0	16	198	210	0	755
1992	0	2	29	0	31	345	250	0	889
1993	4	0	16	0	20	553	824	0	2072
1994	142	0	21	0	163	450	508	0	1406
1995	111	0	4	0	115	397	1574	0	2957
1996	67	0	5	0	72	238	342	1	1893
1997	110	0	2	0	112	99	332	1	2705
1998	71	0	1	0	72	107	145	2	2762
1999	70	0	2	0	72	98	69	3	1722
2000	79	0	0	0	79	74	290	0	1731
2001	70	0	0	0	70	93	360	0	1962
2002	79	0	0	1	80	104	388	0	2301
2003	74	0	0	0	74	23	114	10	2316
2004	81	0	0	0	81	90	469	186	3432
2005	96	0	0	0	96	129	407	20	1349
2006	69	0	0	0	69	142	352	25	1740
2007	71	0	0	0	71	179	317	43	2252
2008	46	0	0	0	46	526	320	38	2029
2009	52	0	0	0	52	233	344	118	2069
2010	45	0	0	0	45	217	379	84	2347
2011	40	0	0	0	40	303	366	79	3559
2012	29	0	0	0	29	268	395	114	4363
2013	35	0	0	0	35	204	367	127	2584
2014	55	0	0	0	55	n/a	n/a	n/a	n/a

Notes:
[1]Canada is from DFO Zonal Statistics File (1979-2001); 2003-2014 is MARFIS plus other Regional landings.
[2]Japan, Faroes and other countries in Canadian Atlantic are from Maritimes and Newfoundland observer data.
[3]NW Atlantic landings from countries other than Japan are from ICCAT statistics for area 92.
[4]Japan in NW Atlantic represents nominal catch of unspecified sharks and rays from FAO statistics.
[5]North Atlantic landings from ICCAT statistics for Atlantic Shark stock (1990-2013) including sport rod and reel.

Table 2. Canadian reported landings (mt) of Shortfin Mako Shark by year, fishing gear, and Region. Data are from DFO ZIFF and MARFIS, and do not include discards.

Year	Region	Longline	Handline	Gillnet	Otter Trawl	Other	Derby	Regional Total	Annual Total
1993	Maritimes	0.0	0.0	0.3	0.0	0.0	0.0	0.3	3.71
	NF	1.1	0.0	2.3	0.0	0.0	0.0	3.41	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.0	0.0	0.0	0.0	0.0	0.0	0	
1994	Maritimes	117.6	2.3	9.5	1.7	0.1	0.0	131.2	142.4
	NF	6.5	0.0	4.5	0.0	0.0	0.0	11	
	Quebec	0.0	0.2	.0	0.0	0.0	.0	0.2	
	Gulf	0.0	0.0	0.0	0.0	0.0	0.0	0	
1995	Maritimes	88.0	0.2	13.4	0.7	0.5	0.0	102.8	111.2
	NF	5.9	0.0	2.4	0.0	0.0	0.0	8.3	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.1	0.0	0.0	0.0	0.0	0.0	0.1	
1996	Maritimes	50.5	0.3	7.8	1.0	0.0	0.1	59.6	67.51
	NF	5.6	0.0	2.3	0.0	0.0	0.0	7.91	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.0	.0	0.0	0.0	0.0	0.0	0	
1997	Maritimes	90.2	0.2	9.3	1.5	0.0	0.0	101.2	109.5
	NF	4.0	0.0	4.0	0.1	0.0	0.0	8.1	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.2	0.0	0.0	0.0	0.0	0.0	0.2	
1998	Maritimes	46.2	0.2	8.0	2.2	0.6	0.0	57.2	70.9
	NF	9.5	0.0	4.0	0.0	0.0	0.0	13.5	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.2	0.0	0.0	0.0	0.0	0.0	0.2	
1999	Maritimes	45.8	0.0	4.8	1.8	0.7	0.0	53.1	70.4
	NF	7.8	0.1	9.2	0.1	0.0	0.0	17.2	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.1	0.0	0.0	0.0	0.0	0.0	0.1	
2000	Maritimes	48.2	0.1	5.3	0.4	0.8	0.49	54.8	79.5
	NF	10.7	0.0	12.9	0.1	0.5	0.0	24.2	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.3	0.3	
	Gulf	0.0	0.0	0.0	0.0	0.0	0.2	0.2	
2001	Maritimes	51.2	0.2	5.2	0.2	0.4	0.0	57.2	69.7
	NF	8.6	0.0	3.6	0.1	0.0	0.0	12.3	
	Quebec	0.0	0.1	0.0	0.0	0.0	0.0	0.1	
	Gulf	0.0	0.0	0.0	0.0	0.1	0.0	0.1	
2002	Maritimes	54.3	0.3	9.8	0.8	1.3	0.67	66.5	79.3
	NF	6.4	0.1	4.5	0.0	0.0	0.0	11	
	Quebec	0.0	0.0	0.1	0.0	0.0	0.0	0.1	
	Gulf	0.8	0.0	0.2	0.0	0.0	0.7	1.7	
2003	Maritimes	57.6	0.2	6.8	0.5	1.4	0.40	66.5	74
	NF	6.0	0.0	1.4	0.0	0.1	0.0	7.5	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.0	0.0	0.0	0.0	0.0	0.0	0	
2004	Maritimes	62.1	0.2	6.8	0.1	1.0	1.00	70.2	81.4
	NF	8.0	0.0	3.0	0.0	0.0	0.0	11	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.2	0.0	0.0	0.0	0.0	0.0	0.2	
2005	Maritimes	71.3	0.5	11.9	0.9	0.9	0.39	85.5	95.7
	NF	5.3	0.0	4.4	0.1	0.0	0.0	9.8	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	

Year	Region	Longline	Handline	Gillnet	Otter Trawl	Other	Derby	Regional Total	Annual Total
	Gulf	0.4	0.0	0.0	0.0	0.0	0.0	0.4	
2006	Maritimes	61.5	0.0	4.9	0.3	0.0	0.39	66.7	70.4
	NF	2.4	0.0	1.2	0.0	0.0	0.0	3.6	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.0	0.0	0.0	0.0	0.1	0.0	0.1	
2007	Maritimes	61.3	0.0	6.0	0.8	0.0	0.20	68.1	71.3
	NF	1.9	0.0	1.0	0.0	0.0	0.0	2.9	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.2	0.0	0.0	0.0	0.1	0.0	0.3	
2008	Maritimes	39.3	0.0	2.3	0.7	1.3	0.0	43.6	45.8
	NF	2.0	0.0	0.1	0.0	0.0	0.0	2.1	
	Quebec	0.1	0.0	0.0	0.0	0.0	0.0	0.1	
	Gulf	0.0	0.0	0.0	0.0	0.0	0.0	0	
2009	Maritimes	46.6	0.0	1.7	0.2	0.0	0.49	48.5	53.0
	NF	3.5	0.0	0.9	0.0	0.0	0.0	4.4	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.1	0.0	0.0	0.0	0.0	0.0	0.1	
2010	Maritimes	37.0	0.0	0.5	0.1	0.3	0.25	37.9	41.3
	NF	1.5	0.0	1.5	0.0	0.0	0.0	3	
	Quebec	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Gulf	0.2	0.0	0.2	0.0	0.0	0.0	0.4	
2011	Maritimes	35.6	0.0	0.1	0.0	0.1	0.15	35.8	37.6
	NF	1.3	0.0	0.0	0.0	0.0	0.0	1.3	
	Quebec	0.2	0.0	0.0	0.0	0.0	0.0	0.2	
	Gulf	0.2	0.0	0.0	0.0	0.1	0.0	0.3	
2012	Maritimes	28.4	0.0	0.2	0.5	0.0	0.42	29.1	29.7
	NF	0.0	0.0	0.4	0.0	0.0	0.0	0.4	
	Quebec	0.0	0.0	0.0	0.0	0.1	0.0	0.1	
	Gulf	0.1	0.0	0.0	0.0	0.0	0.0	0.1	
2013	Maritimes	34.4	0.0	0.4	0.0	0.0	0.32	35.1	35.3
*	NF	0.0	0.0	0.0	0.0	0.0	0.0	0	
	Quebec	0.1	0.0	0.0	0.0	0.0	0.0	0.1	
	Gulf	0.1	0.0	0.0	0.0	0.0	0.0	0.1	
2014	Maritimes	53.2	0.0	1.5	0.0	0.0	0.32	55.0	55.0
*	NF	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
	Quebec	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
	Gulf	n/a	n/a	n/a	n/a	n/a	n/a	n/a	

*NL, Quebec, and Gulf data incomplete.

Table 3. Estimates of ASO coverage levels (%), based on proportion of directed species observed to MARFIS directed species landings, by year, for DFO-Maritimes Region fisheries. Fishing gear: LL=longline; OTB=otter trawl-bottom.

Year	Pelagic LL	Directed Porbeagle LL	Groundfish LL	Ground OTB
1996	5	22	5	12
1997	9	6	4	8
1998	10	0	4	6
1999	12	0	4	9
2000	7	0	9	9
2001	16	0	5	9
2002	35	62	4	9
2003	13	0	5	9
2004	5	3	7	6
2005	5	2	4	8
2006	10	0	4	13
2007	7	0	7	29
2008	7	0	11	16
2009	11	0	11	9
2010	13	3	8	12
2011	11	0	11	14
2012	12	0	12	11
2013	4	0	11	16
2014	7	0	7	29
2015	1	0	4	16

Table 4. Summary of estimated live and dead Shortfin Mako Shark discards in DFO-Maritimes Region. Fishing gear: LL=longline; OTB=otter trawl-bottom.

	Shortfin Mako Discards (mt)*																			
Fishery	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Swordfish and Tuna LL	5	7	6	7	9	10	12	12	15	27	25	23	21	18	21	21	24	20	23	0
Porbeagle LL	0	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundfish LL	0	4	4	3	0	1	0	0	0	2	3	3	3	2	1	1	1	1	1	0
Groundfish Gillnet	0	4	4	2	0	0	0	0	0	0	1	1	1	1	4	0	0	0	0	0
Groundfish OTB	2	2	3	2	3	3	3	3	3	12	9	10	10	11	8	7	6	5	6	0
Total Discards	7	20	19	17	13	15	16	14	17	39	35	34	32	30	31	27	30	24	29	0

	Shortfin Mako Discards (mt)*																			
Source	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Reported Landings of Shortfin Mako Shark	60	101	57	53	55	57	67	66	70	86	67	69	44	49	38	37	29	35	55	9
Estimated Shortfin Mako Shark Discards (live and dead)	7	20	19	17	13	15	16	14	17	39	35	34	32	30	31	27	30	24	29	0

*discard ratios calculated by 5-year blocks.

Table 5. Shortfin Mako shark condition when unhooked aboard fishing vessels, as recorded by DFO-Maritimes Region at-sea fisheries observers. (from Campana et al. 2015c).

Shortfin Mako	**Status**				
Year	**Unknown**	**Healthy**	**Injured**	**Dead**	**Total**
2010	5	63	13	18	99
2011	1	51	7	17	76
2012	2	102	86	90	280
2013	0	28	8	5	41
2014	0	23	3	6	32
Total	8	267	117	136	528

Table 6. Breakdown of post-release survival and condition of Shortfin Mako sharks at the time of satellite tagging (from Campana et al. 2015c).

		Survival		**Total**
Species	**Condition at Tagging**	**Lived**	**Died**	
Shortfin Mako	Healthy	16	7	23
	Injured	2	1	3

Table 7. Total mortalities (landings + discard mortalities) for Shortfin Mako Shark, DFO-Maritimes Region, 1996-2015 (2015 incomplete).

Source	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Reported Landings	60	101	57	53	55	57	67	66	70	86	67	69	44	49	38	37	29	35	55	9
Hooking/Capture Mortality*	1	11	10	8	3	4	4	4	5	10	10	10	9	8	11	7	7	6	7	0
Estimated Mako Discards (live and dead)	7	20	19	17	13	15	15	14	17	39	35	34	32	30	31	27	30	24	29	0
Estimated Mortality (hooking+post-release) of Discards	3	13	13	11	6	7	7	7	8	17	16	16	15	14	16	12	13	11	13	0
Sum of Landings + all discard mortalities	**62**	**115**	**70**	**64**	**61**	**64**	**74**	**73**	**78**	**103**	**84**	**84**	**58**	**62**	**54**	**49**	**42**	**46**	**68**	**9**

*hooking and post-release mortality for pelagic LL and OTB gear as reported in text; assumed 100% mortality for groundfish LL and GN (fixed gillnets).

Table 8. ICCAT (2012) - assumed Shortfin Mako Shark North Atlantic landings for population modelling.

Year	Catch (mt)	Year	Catch (mt)
1971	3717	1991	4114
1972	3014	1992	3871
1973	3322	1993	5364
1974	3345	1994	4448
1975	4280	1995	5840
1976	3038	1996	4030
1977	3642	1997	3532
1978	3241	1998	3238
1979	2402	1999	2838
1980	3253	2000	2666
1981	3079	2001	2812
1982	3614	2002	3250
1983	4209	2003	3738
1984	4480	2004	4648
1985	6900	2005	3345
1986	6589	2006	3266
1987	6336	2007	3960
1988	5985	2008	3507
1989	4098	2009	4013
1990	3852	2010	4066

FIGURES

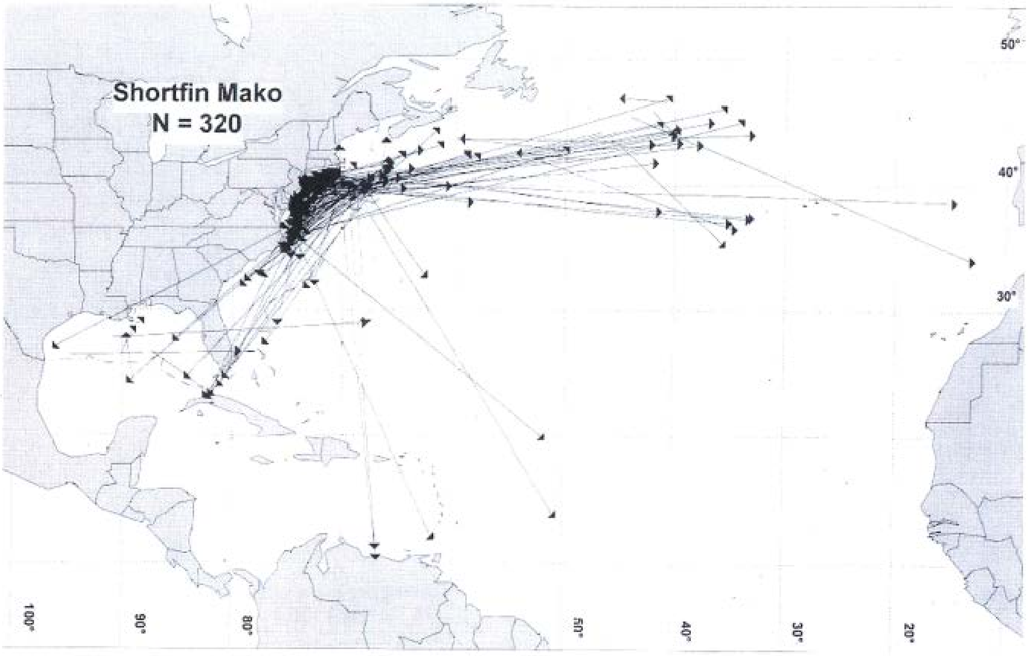


Figure 1. Recaptures of Shortfin Mako Shark tagged by the NMFS Shark Tagging Program, 1962-1993 (from Kohler et al. 1998). A total of 3457 fish were tagged and released.

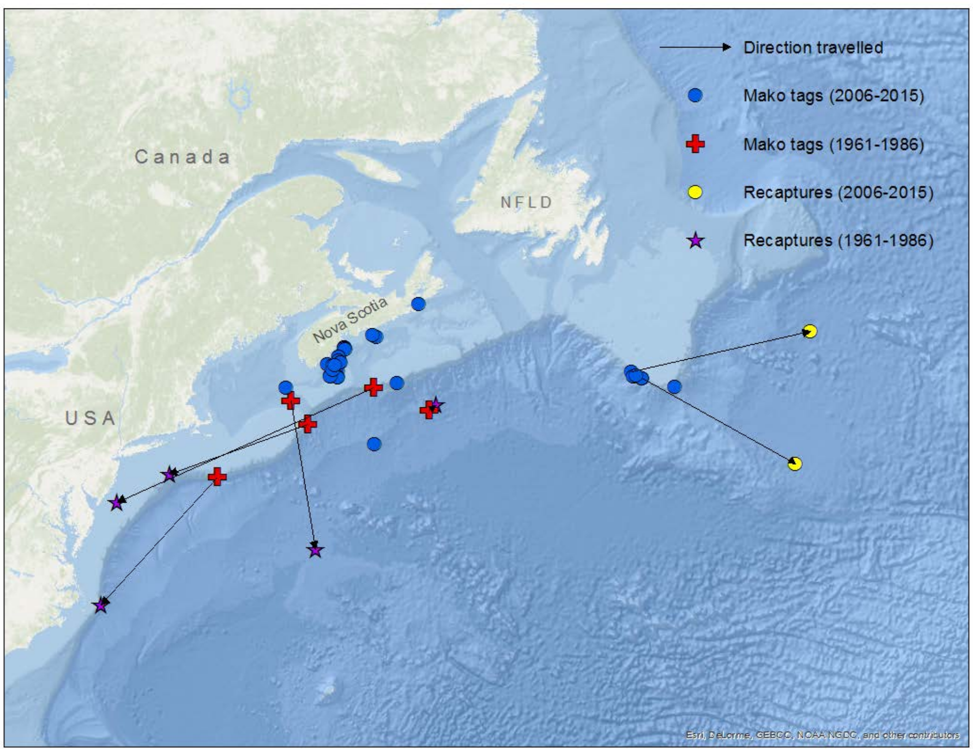


Figure 2. Canadian Shortfin Mako 'traditional' tag releases and recoveries (W. Joyce, pers. comm.; 32 fish tagged with 6 recaptures).

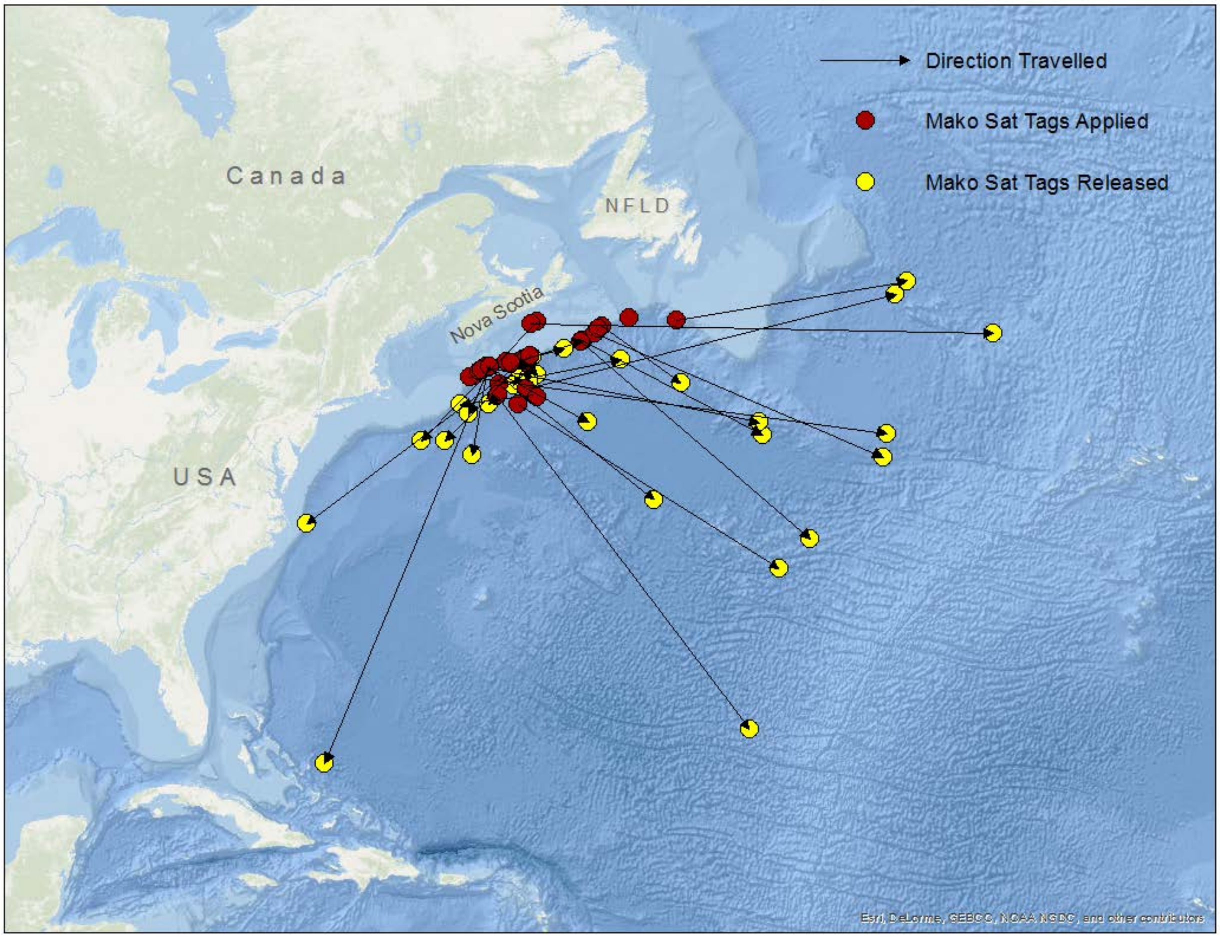


Figure 3. Canadian Shortfin Mako PSAT pop-up satellite tag application sites and data release positions (W. Joyce, pers. comm.; 43 fish tagged with 34 transmitted or recovered).

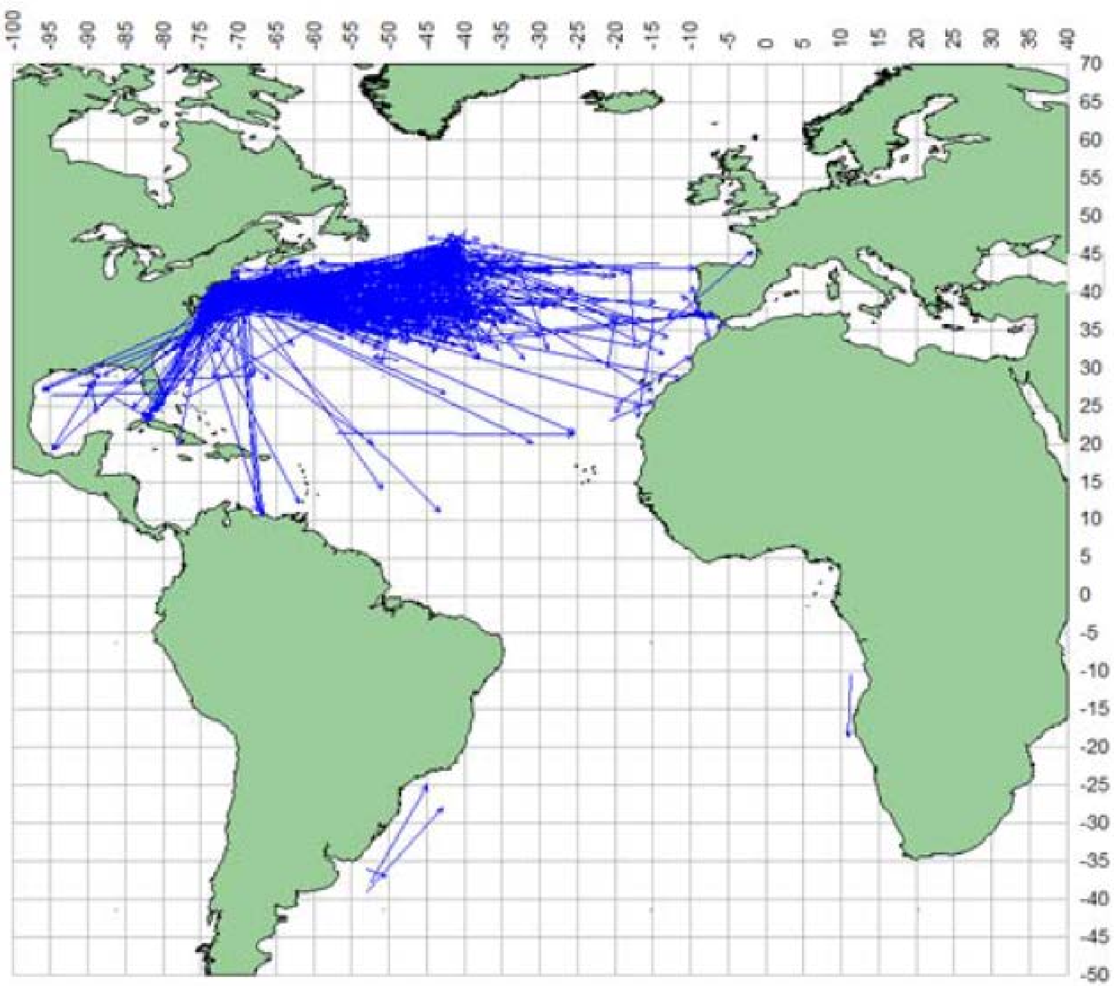


Figure 4. Current conventional tagging information from ICCAT (2012) – including additional data from US APEX tagging program. There are now more than 9200 releases and 1200 recaptures for Shortfin Mako, 1962-2012.

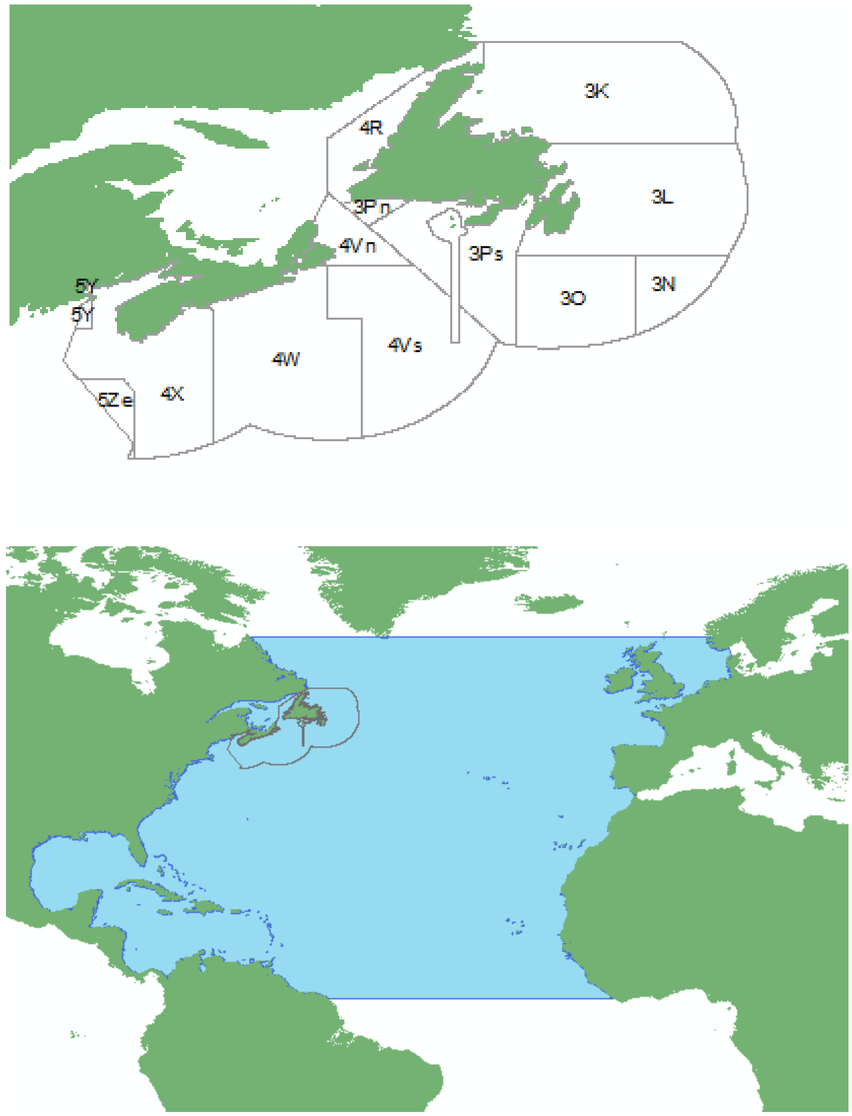


Figure 5. Area of occupancy for Shortfin Mako Shark based on NAFO areas within Canada's EEZ (top panel), and for the North Atlantic Ocean (bottom panel).

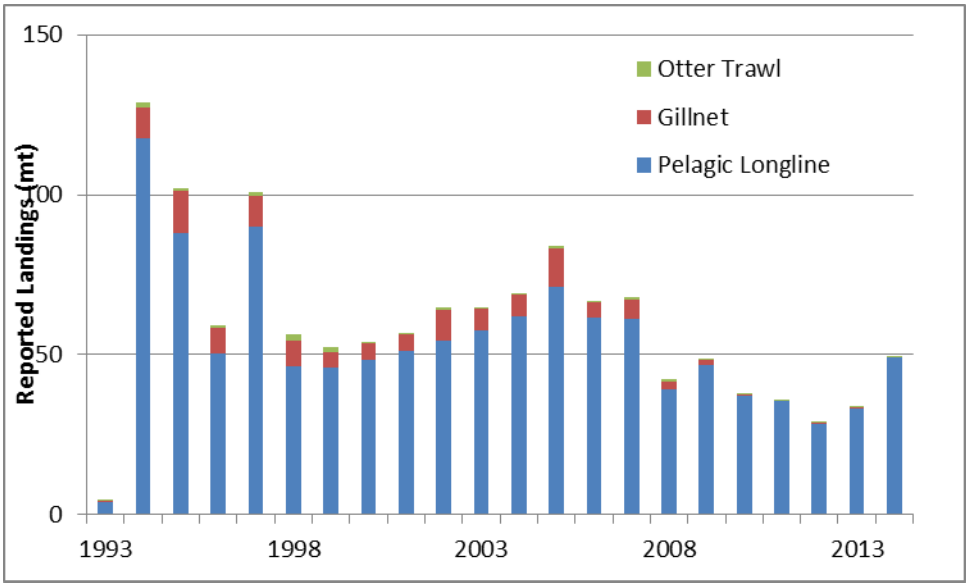


Figure 6. Reported Shortfin Mako Shark landings (mt; from DFO-Maritimes Region ZIFF and MARFIS), 1993-2014.

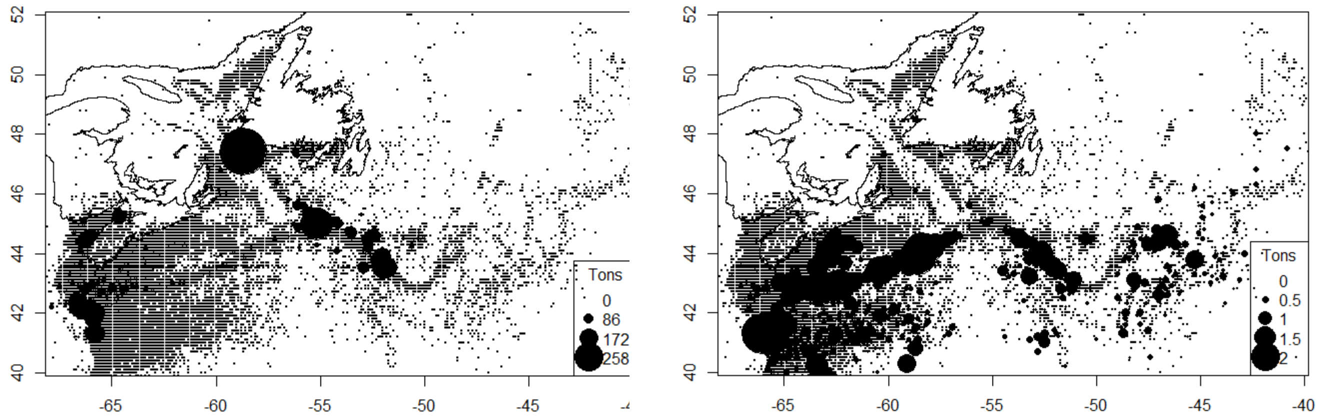


Figure 7. Distribution of reported gillnet total landings (mt; left panel) and Shortfin Mako catch (mt; right panel; from DFO-Maritimes Region ZIFF and MARFIS), 1998-2014.

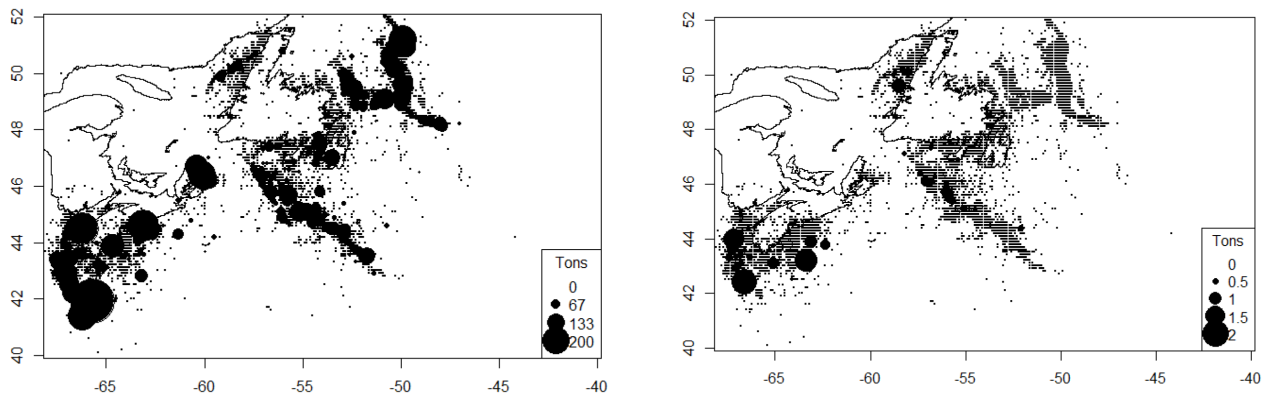


Figure 8. Distribution of reported gillnet total landings (mt; left panel) and Shortfin Mako catch (mt; right panel; from DFO-Maritimes Region ZIFF and MARFIS), 1998-2014.

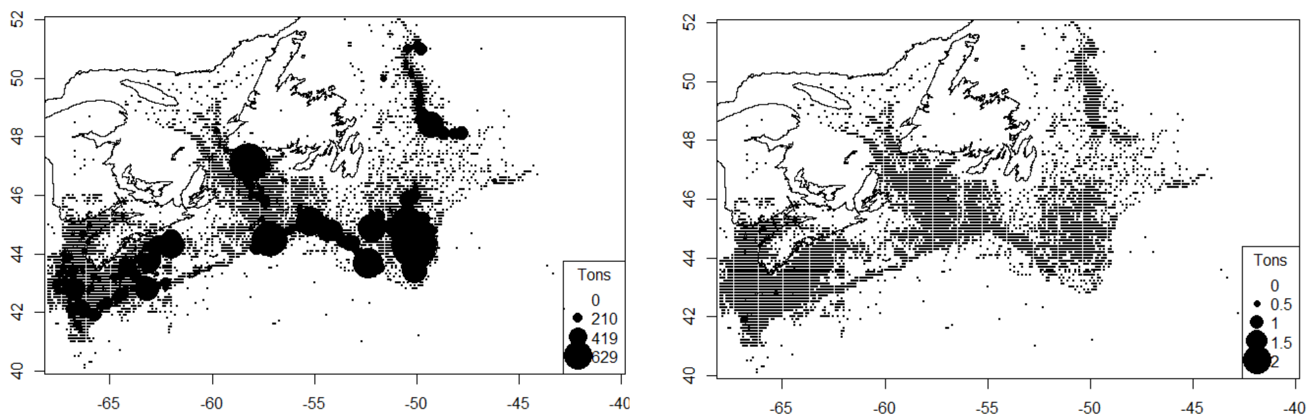


Figure 9. Distribution of reported groundfish otter trawl total landings (mt; left panel) and Shortfin Mako catch (mt; right panel; from DFO-Maritimes Region ZIFF and MARFIS), 1998-2014.

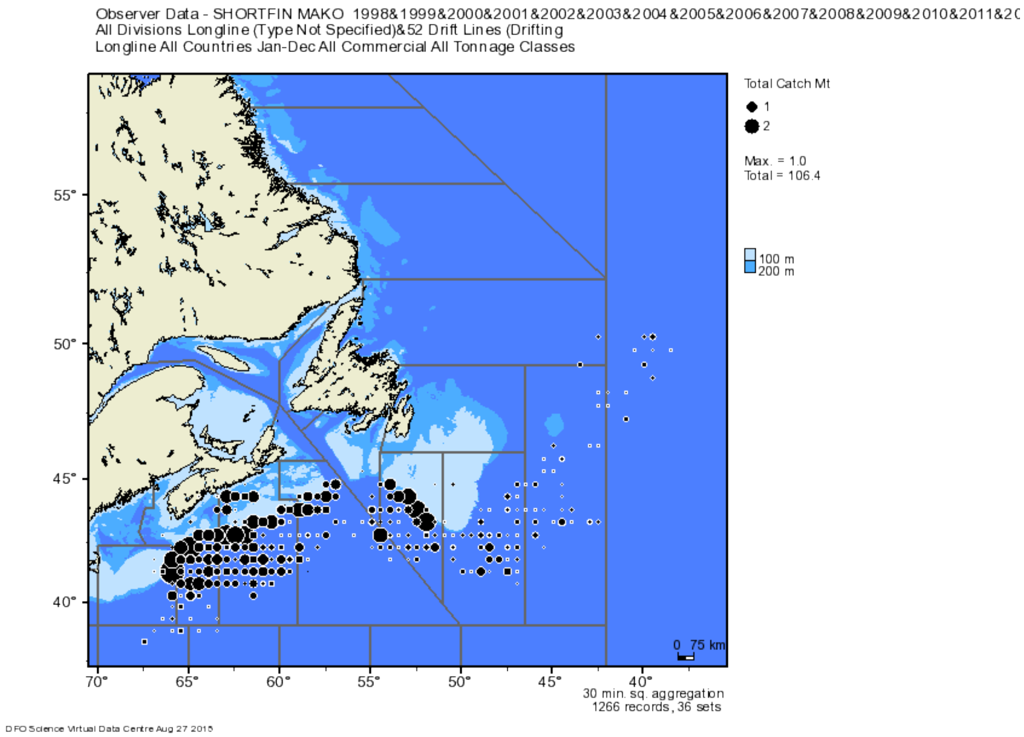


Figure 10. Shortfin Mako Shark pelagic longline catch locations (from Maritimes Region at-sea Observers), 1998-2014.

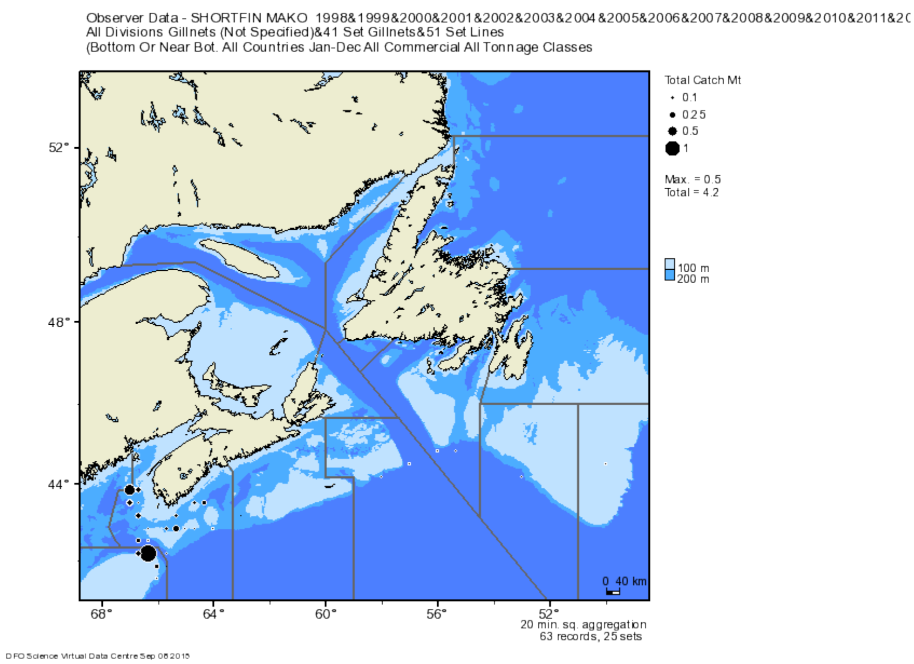


Figure 11. Shortfin Mako Shark groundfish gillnet and longline catch locations (from Maritimes Region at-sea Observers), 1998-2014.

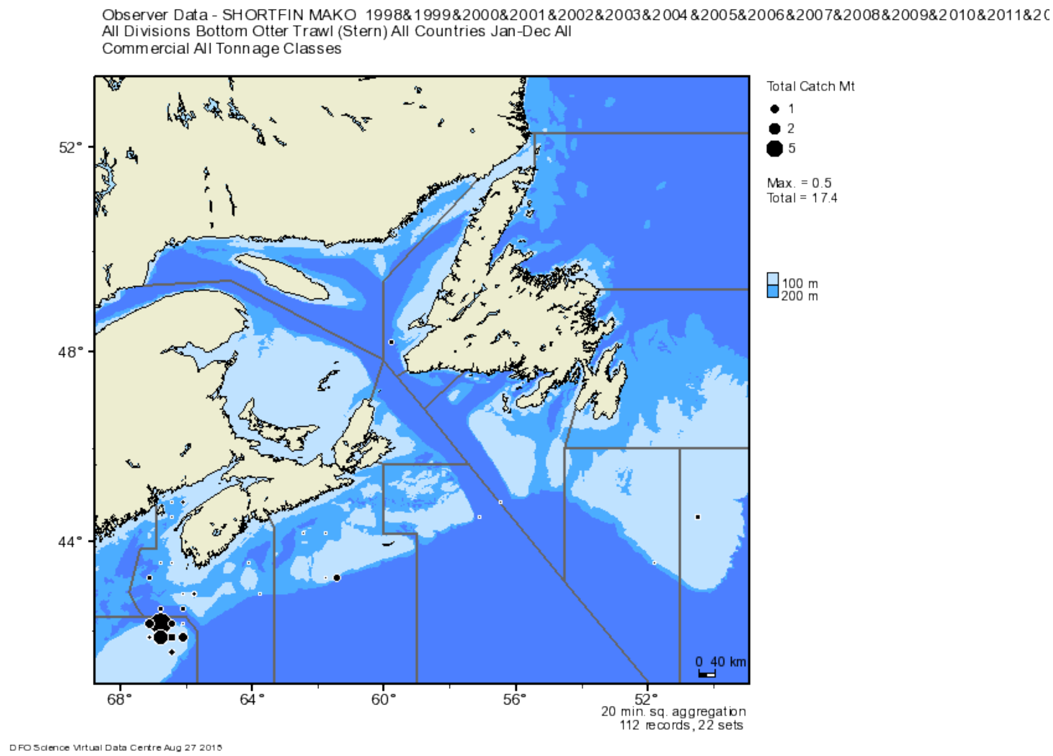


Figure 12. Shortfin Mako Shark otter trawl catch locations (from Maritimes Region at-sea Observers), 1998-2014.

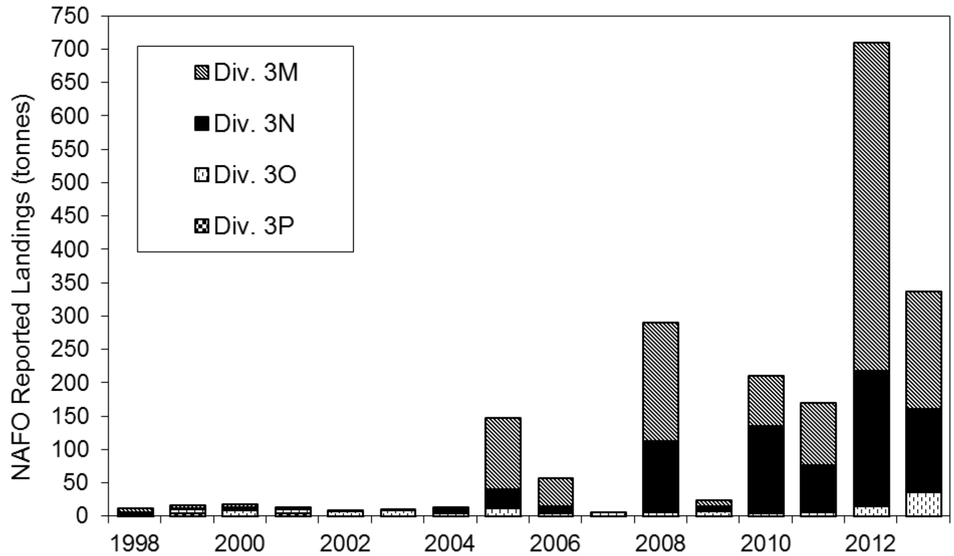


Figure 13. NAFO-reported landings (tonnes) of Shortfin Mako in Div. 3MNOP, 1998-2013.

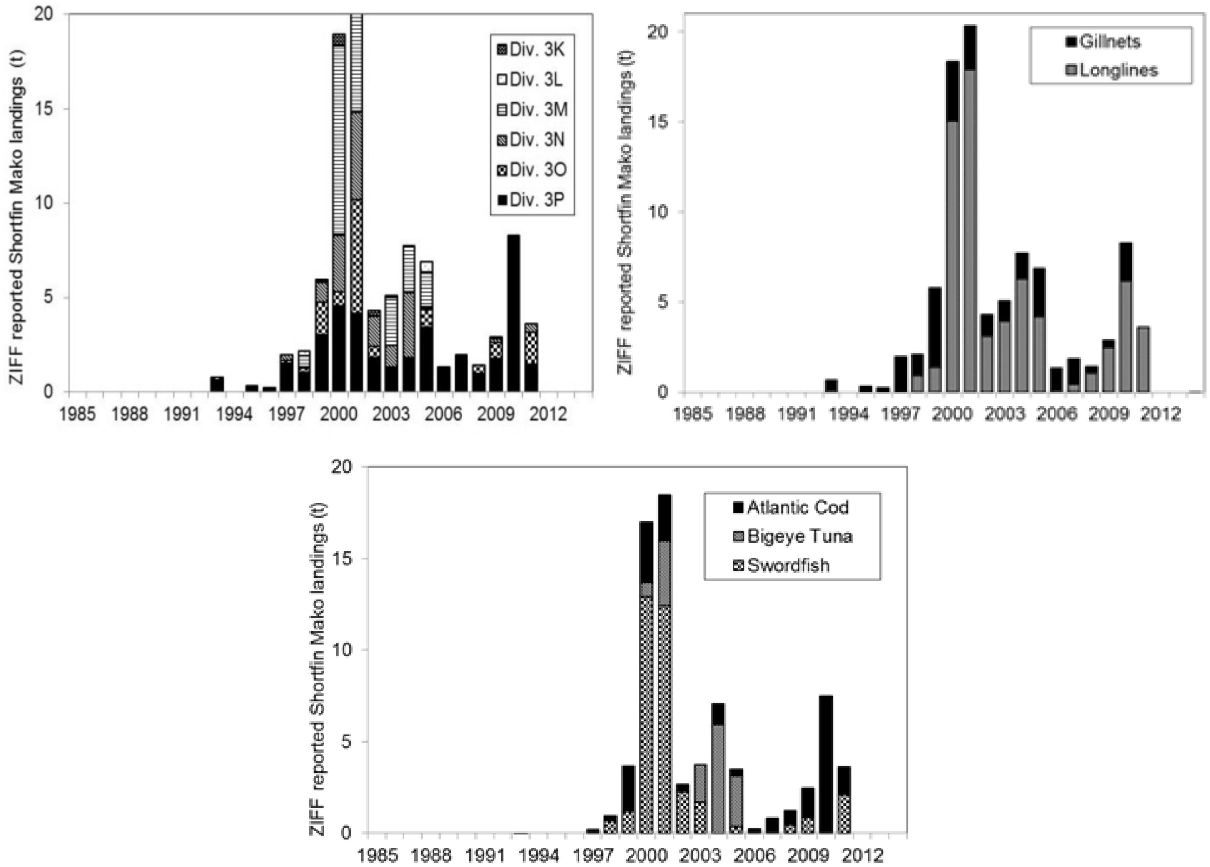


Figure 14. DFO-NL ZIFF-reported landings (t) of Shortfin Mako in Div. 3KLMNOP by Division (top left panel), gear type (top right panel), and directed species (bottom panel), 1985-2014.

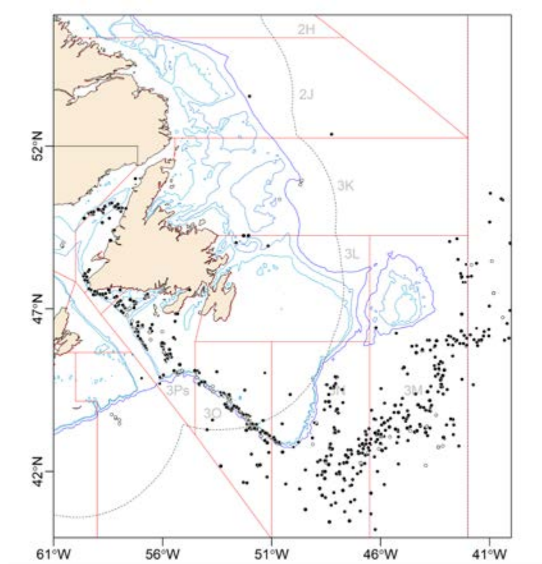


Figure 15. DFO-NL ZIFF-reported Shortfin Mako capture locations in Div. 2J3KLMNOP, 1985-2014.

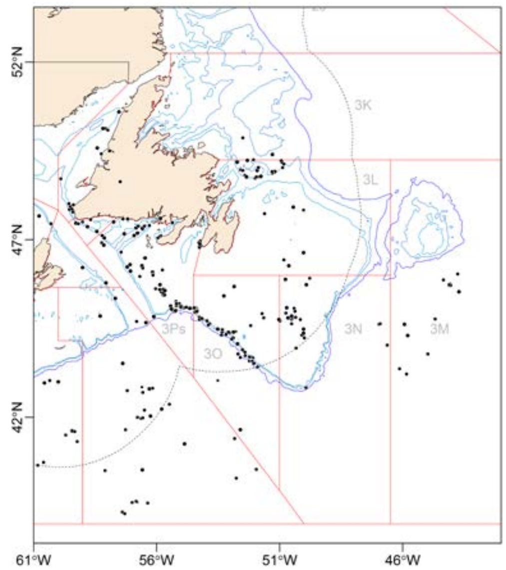


Figure 16. NL Region at-sea Observer-reported Shortfin Mako capture locations in Div. 3KLMNOP4R, 1988-2014.

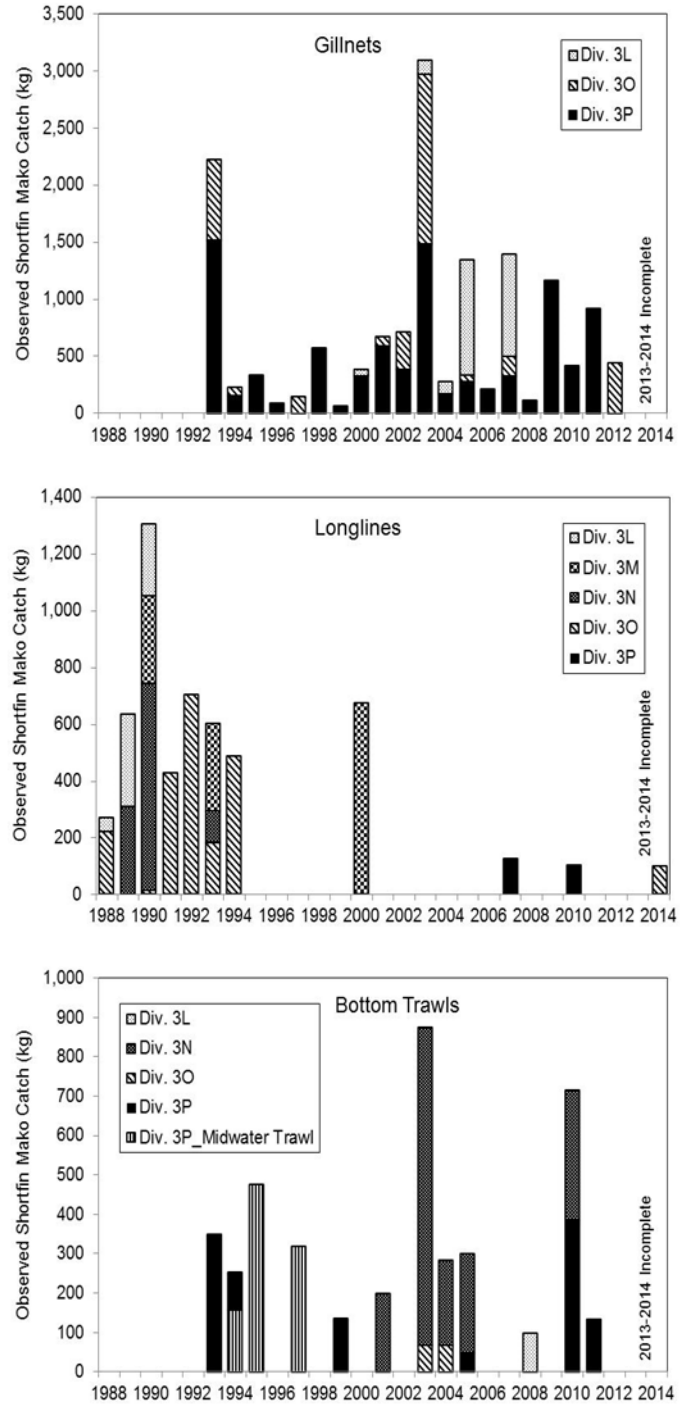


Figure 17. NL Region at-sea Observer-reported catches (kg) of Shortfin Mako in Div. 3KLMNOP by Division and gear (top panel: gillnets; middle panel: longlines; bottom panel: otter bottom trawls), 1988-2014.

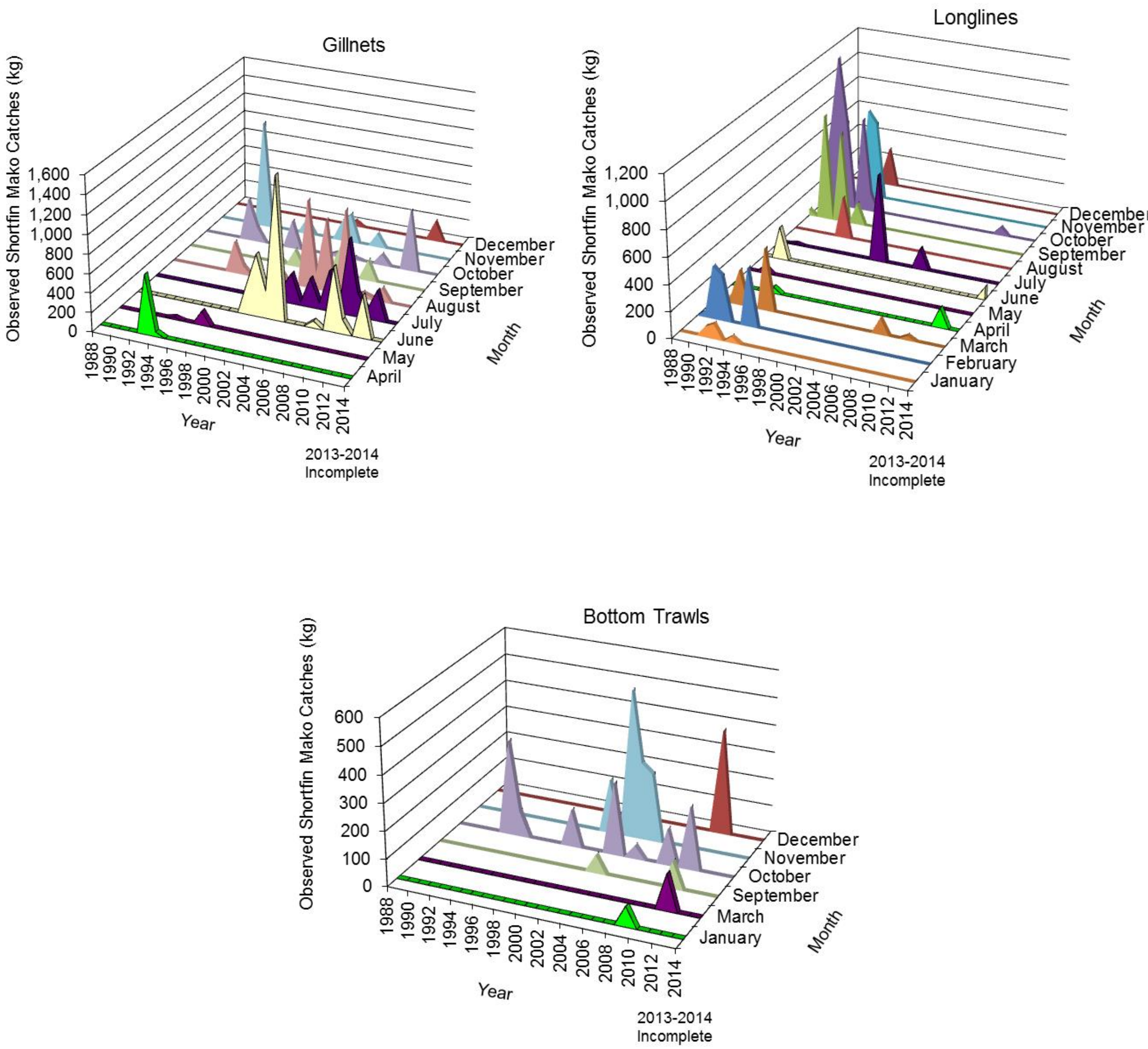


Figure 18. NL Region at-sea Observer-reported catches (kg) of Shortfin Mako in Div. 3KLMNOP by month and gear (top left panel: gillnets; top right panel: longlines; bottom panel: otter bottom trawls), 1988-2014.

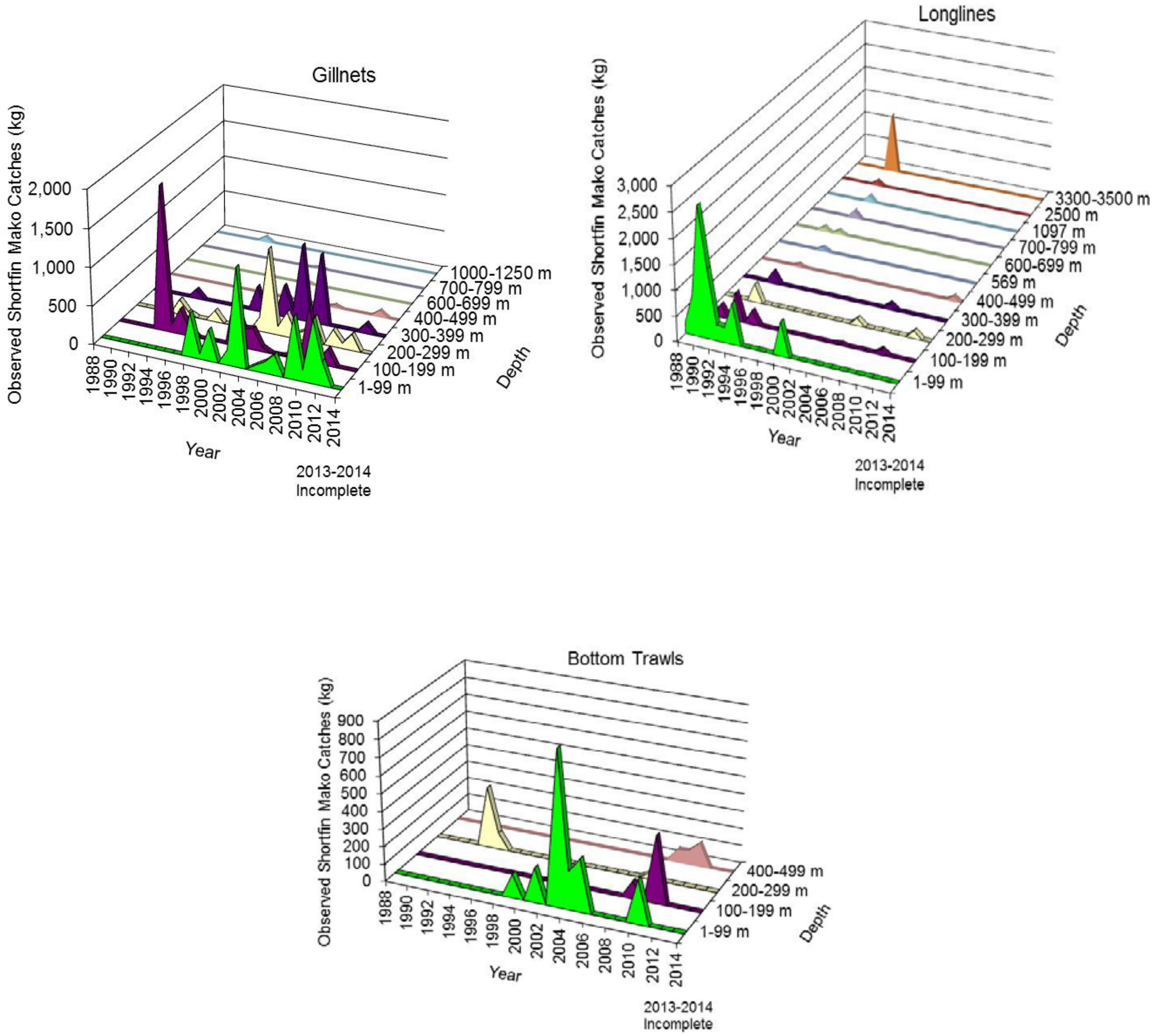


Figure 19. NL Region at-sea Observer-reported catches (kg) of Shortfin Mako in Div. 3KLMNOP by average depth fished and gear (top left panel: gillnets; top right panel: longlines; bottom panel: otter bottom trawls), 1988-2014.

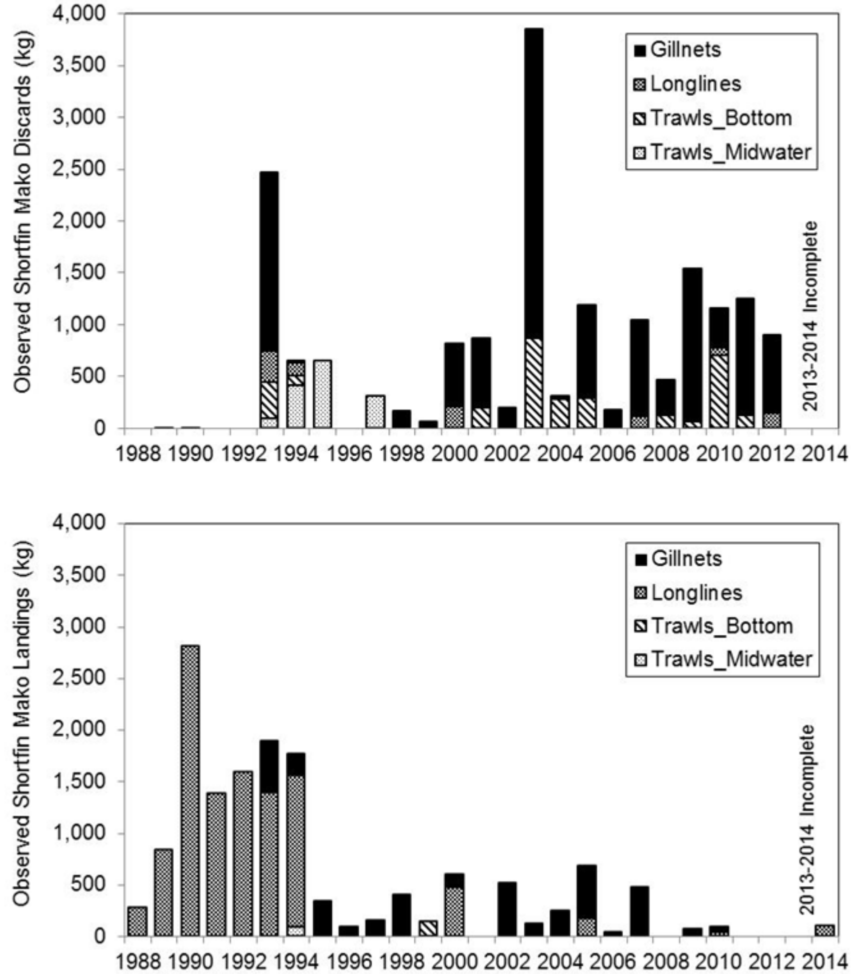


Figure 20. NL Region at-sea Observer-reported discards (kg; top panel) and landings (bottom panel) of Shortfin Mako in Div. 3KLMNOP by gear. Note that data are not scaled up to entire fisheries, and were limited by the annual extent of Observer coverage for each fishery.

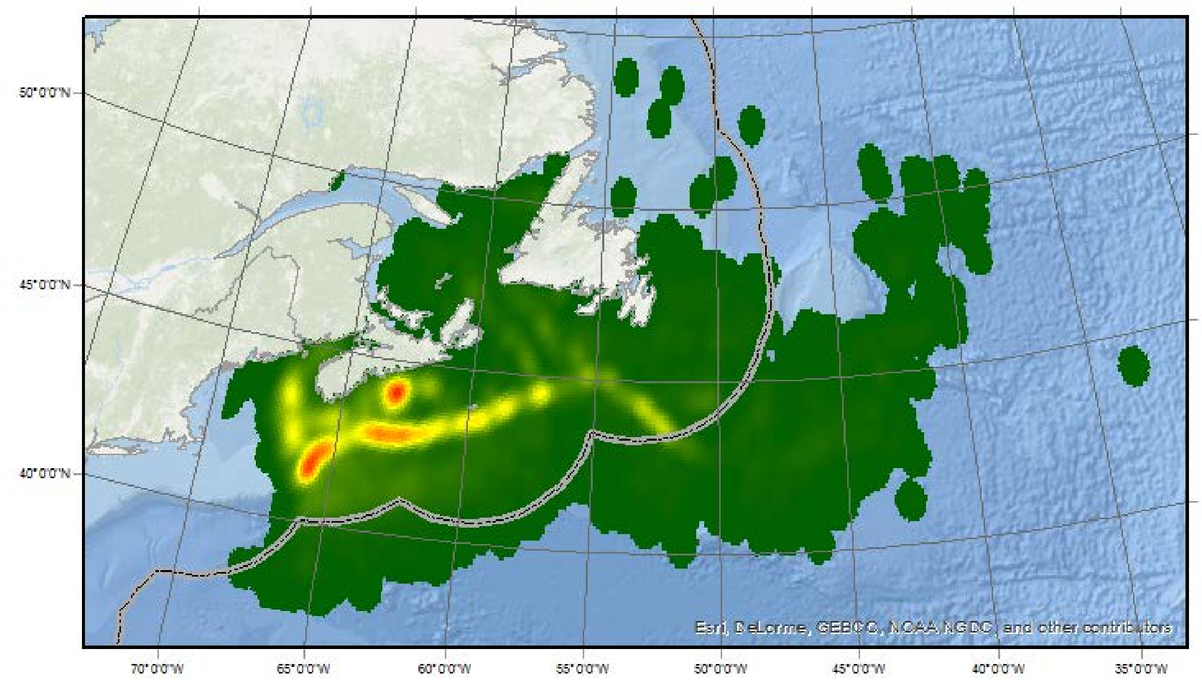


Figure 21. Aggregated reported catch locations from the ZIFF/MARFIS data sources for all area and gear types by Canadian fishers (DF-NL (1995-2014). DFO-Maritimes (1988-2014), and DFO Gulf (1997-2013). Relative density is indicated by colour, with green representing low, yellow medium and red high density.

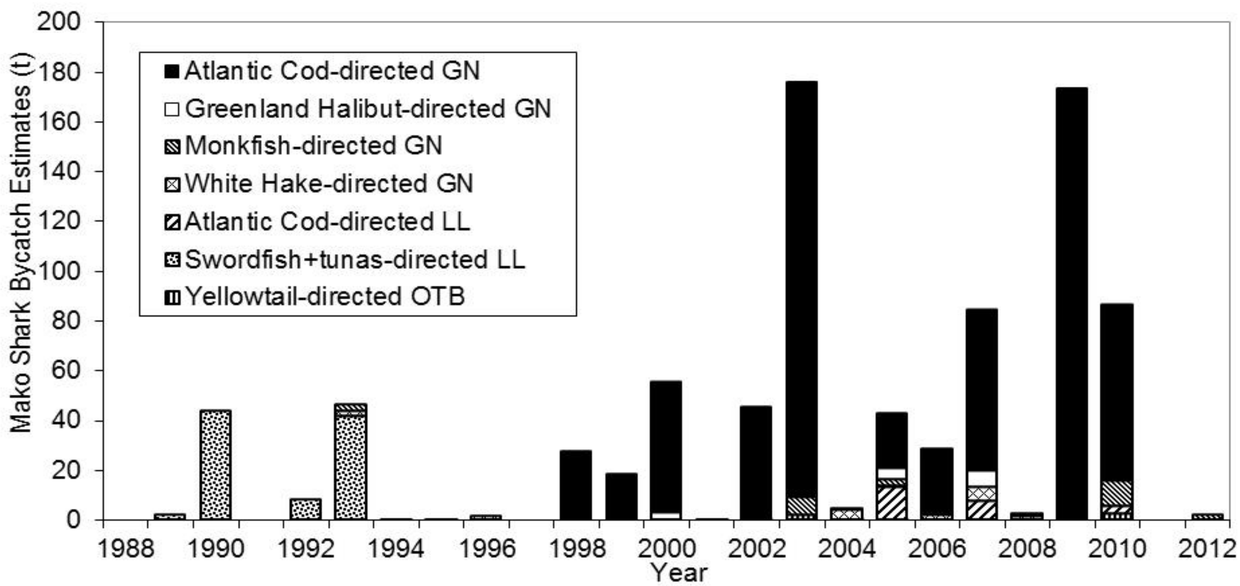


Figure 22. Estimated annual total bycatch (tons) of Shortfin Mako Shark by directed species and gear (GN=gillnet; LL=longline; OTB=otter trawl-bottom) in Canada's EEZ of Div. 3LNOP, 1998-2010. Data are from NL Region at-sea Observers and DFO-NL ZIFF in comparable years. Note that these unweighted estimates are scaled up to the entire fishery, and contingent on whether Canadian landings were reported in ZIFF, and the annual degree of NL-ASO coverage of each fishery.

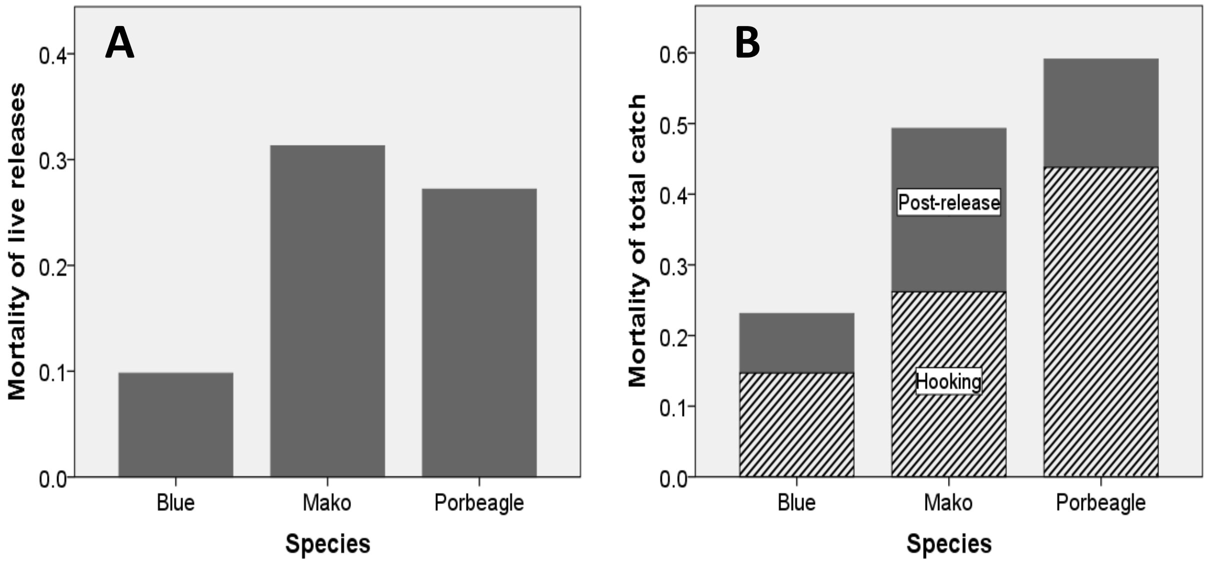
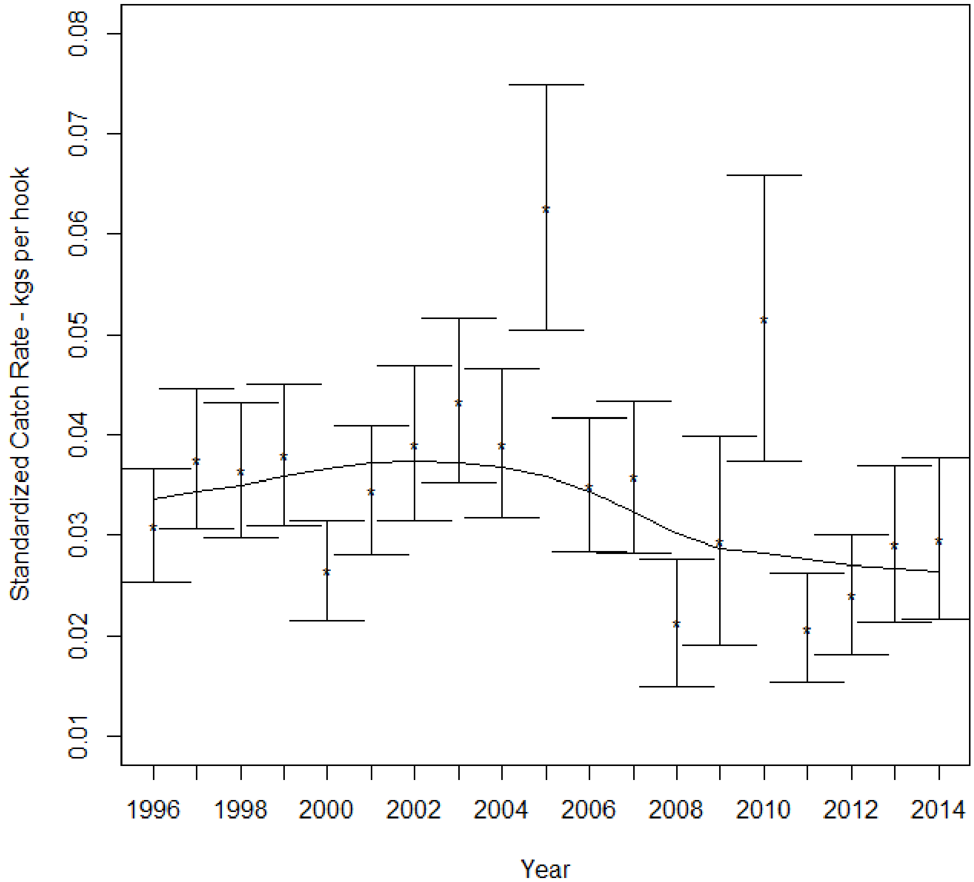


Figure 23. Summary of live release mortality (A) and total discard mortality (B) for Blue Shark, Shortfin Mako Shark, and Porbeagle Shark (from Campana et al. 2015c).



YEAR	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
N	95	89	91	84	70	68	59	86	67	66	65	38	15	11	22	27	44	28	29

Figure 24. Standardized Shortfin Mako Shark catch rates (kgs/hook; from Canadian Swordfish longline fishery), 1996-2014. Error bars represent a 95% confidence interval. Data are from Maritimes Region at-sea Observers.

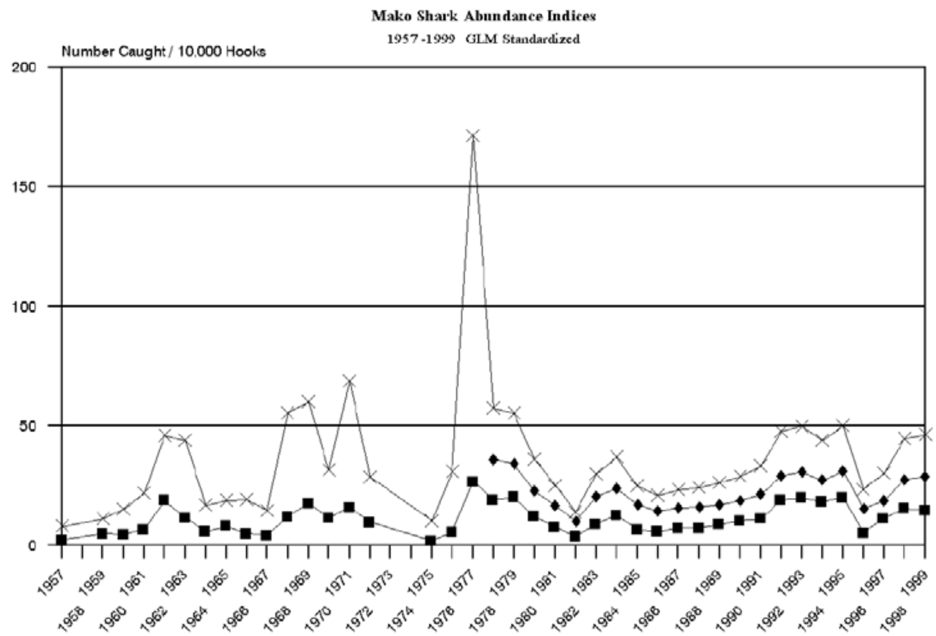


Figure 25. GLM standardized catch rates for Shortfin Mako Shark (from Hoey et al. 2002). Model 1 (squares) is a simple model run (year, source or target, area, month, bottom depth). Model 2 (Xs) represents results of a more complex model with categorical variables for set time, rig depth, percentage of lightsticks, and gear or hook depth added. Model 3 (diamonds) is Model 2 with 1978-1999 data only.

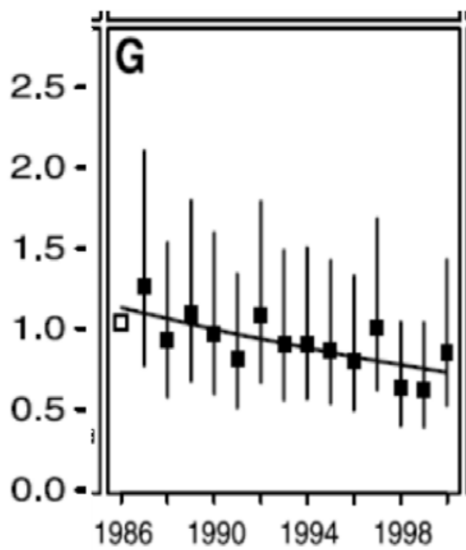


Figure 26. Normalized (relative) catch rates for Shortfin Mako Shark in the Northwest Atlantic Ocean, 1986-2000 (from Baum et al. 2003). Error bars represent 95% confidence interval.

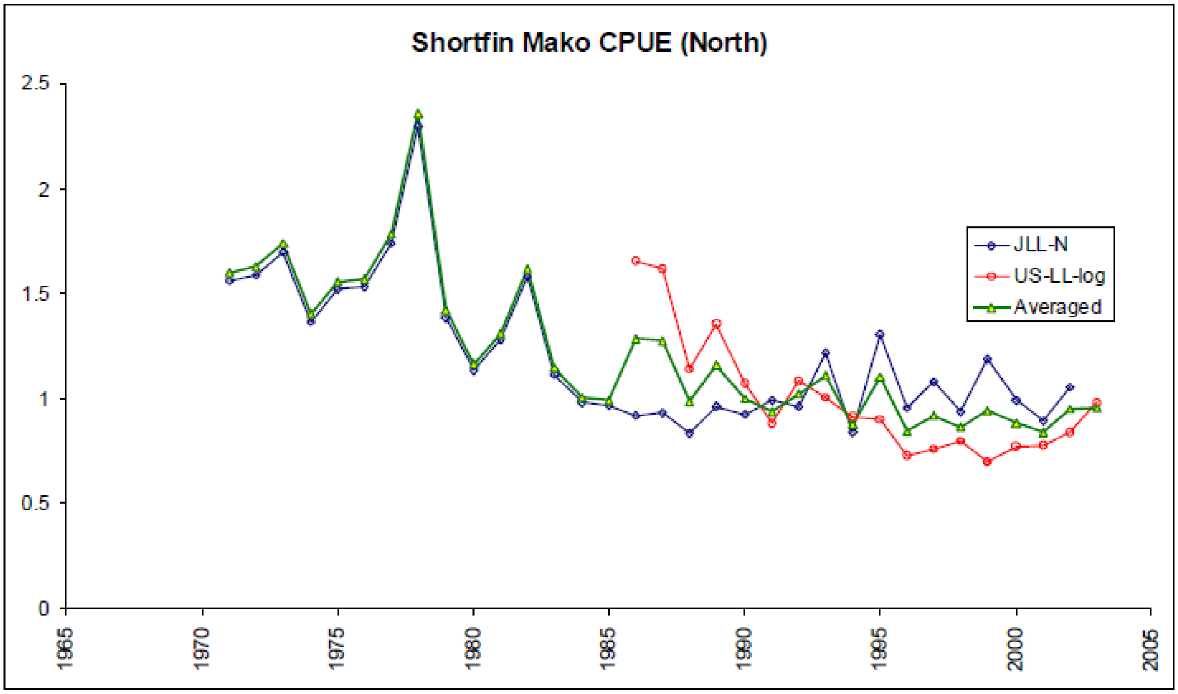


Figure 27. Japanese commercial longline (JLL-N) Shortfin Mako catch rates (standardized number/hook; from ICCAT 2005).

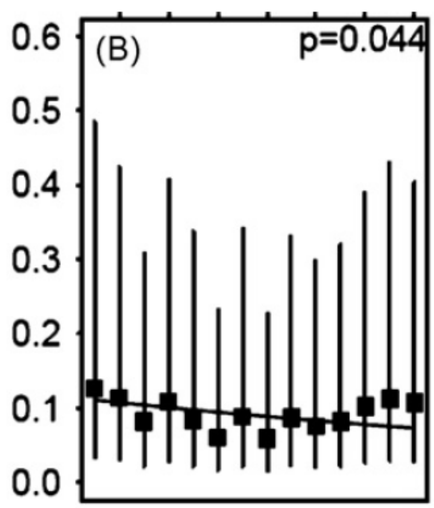


Figure 28. Change in relative abundance (standardized catch rates(#)/1000 hooks) for Shortfin Mako Shark, 1992-2005 (from Baum and Blanchard 2010). Error bars represent 95% confidence interval.

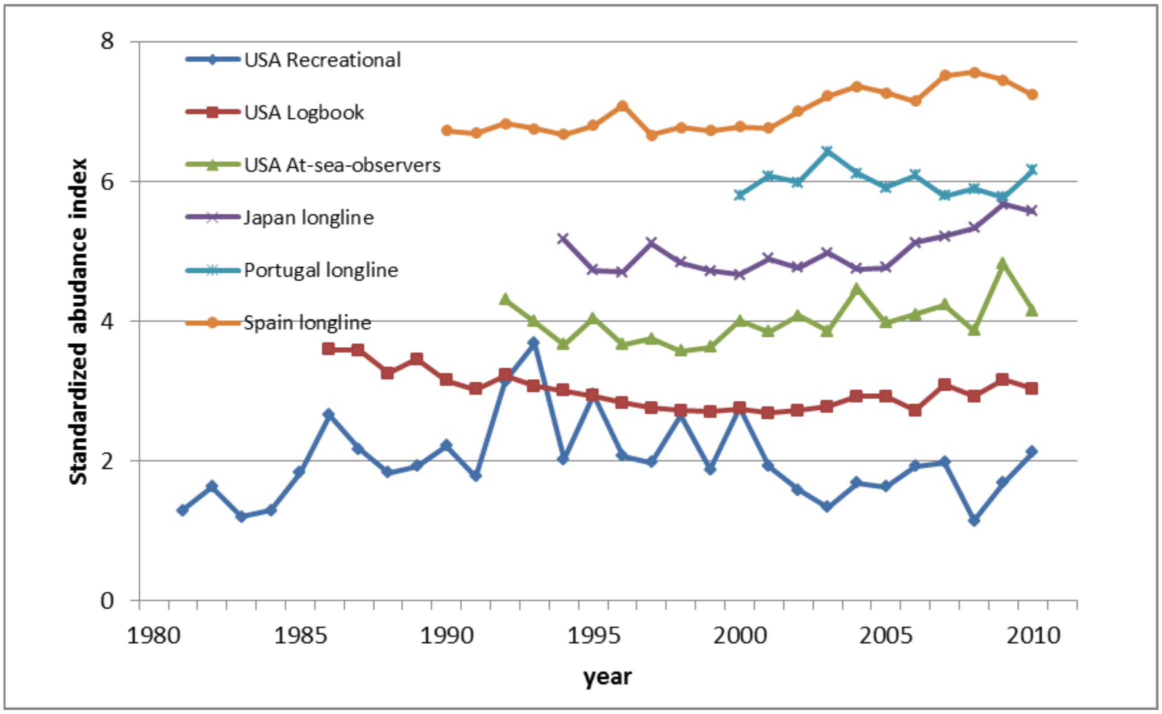
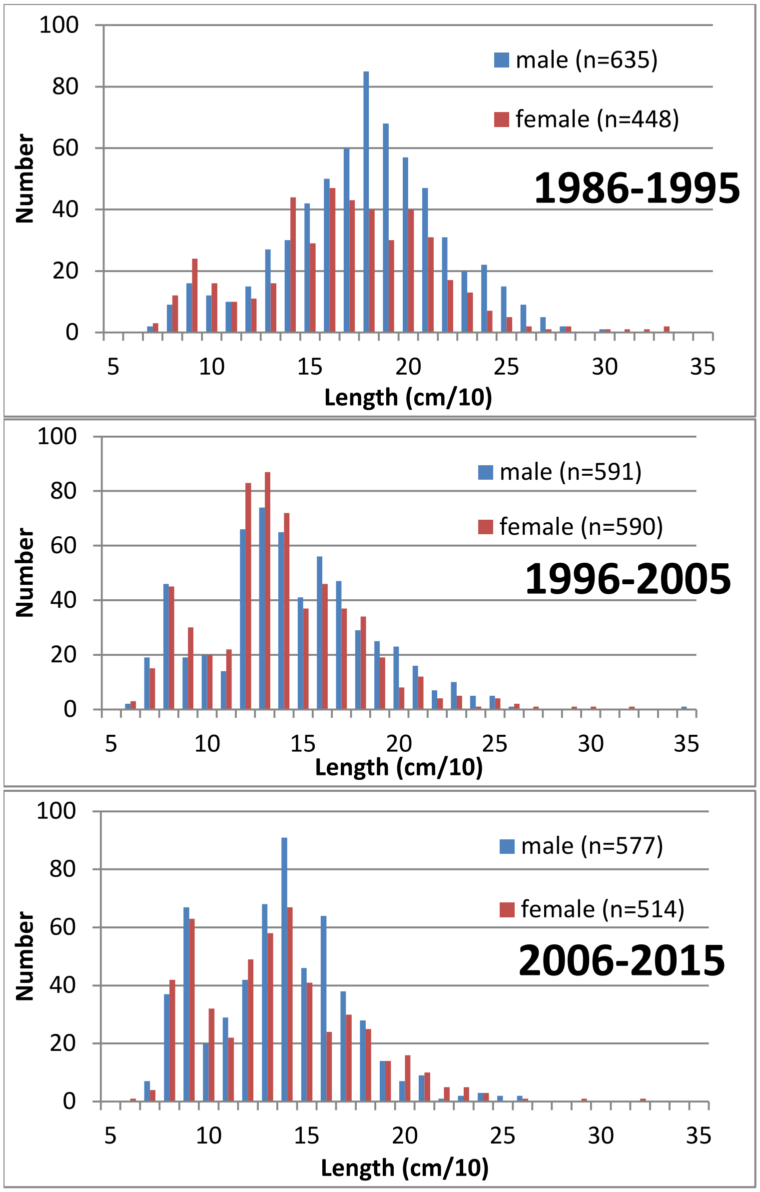


Figure 29. Shortfin Mako Shark catch rate indices, 1981-2010 (data from ICCAT 2012).



Proportion Mature	Male 185 cm+	Female 275 cm+
1986-1995	44%	1.6%
1996-2005	16%	0.5%
2006-2015	7%	0.4%

Figure 30. Shortfin Mako size (TL) distribution by sex from Maritimes at-sea Observers, 1986-2015 (3 panels). Table represents the proportion mature by sex for each time period.

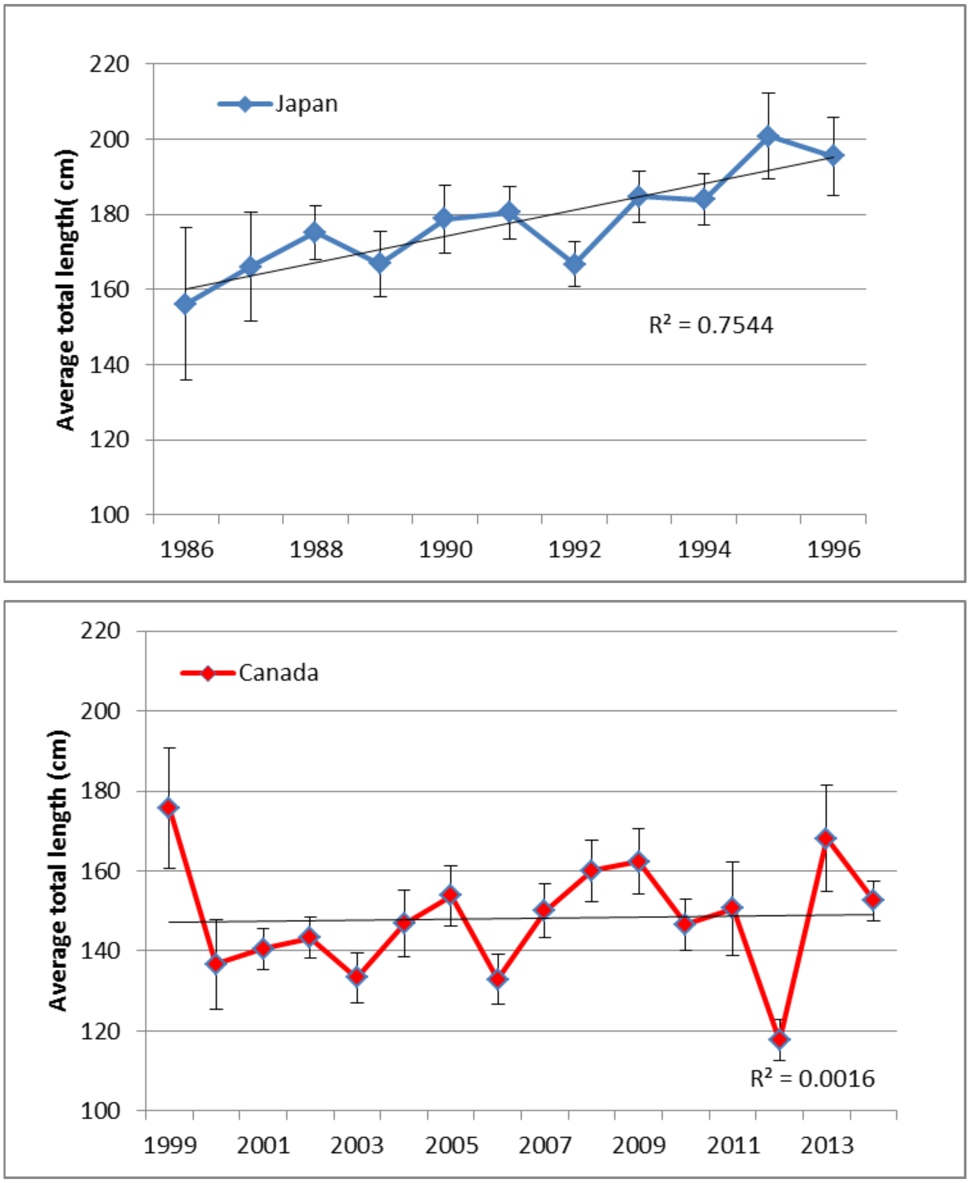


Figure 31. Average total length (±2 SE) of Shortfin Mako from Maritimes at-sea Observers, for Japan (top panel; 1986-1996) and Canada (bottom panel; 1999-2014).

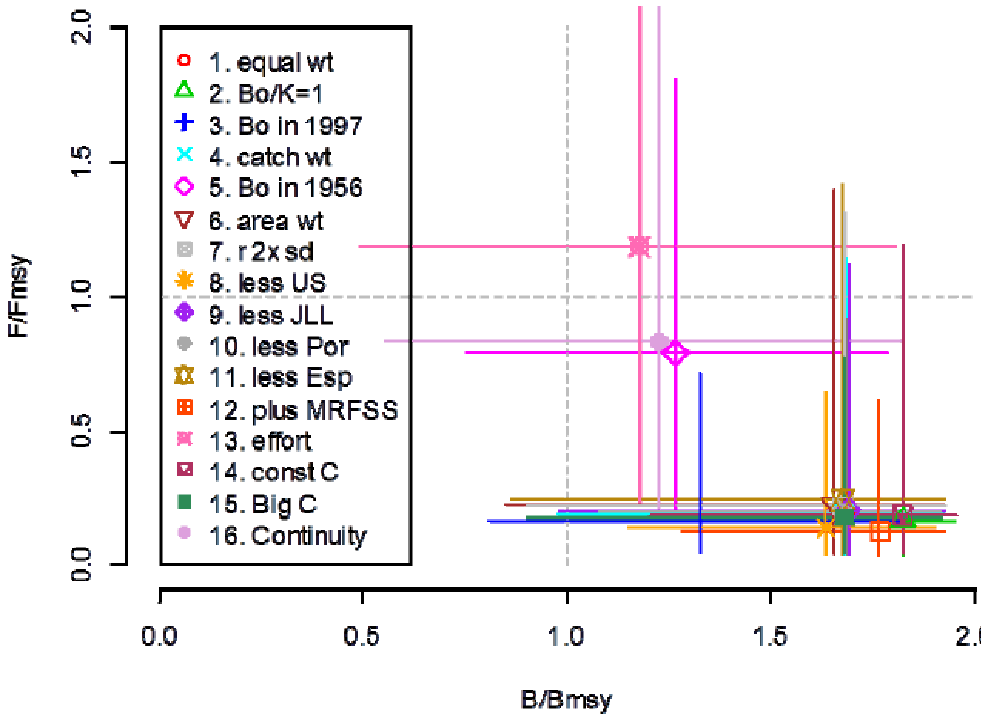


Figure 32. Phase plot of Bayesian surplus production model runs (from ICCAT 2012). Median biomass is relative to B_{MSY}; fishing mortality rate relative to F_{MSY}; confidence intervals are 80%.

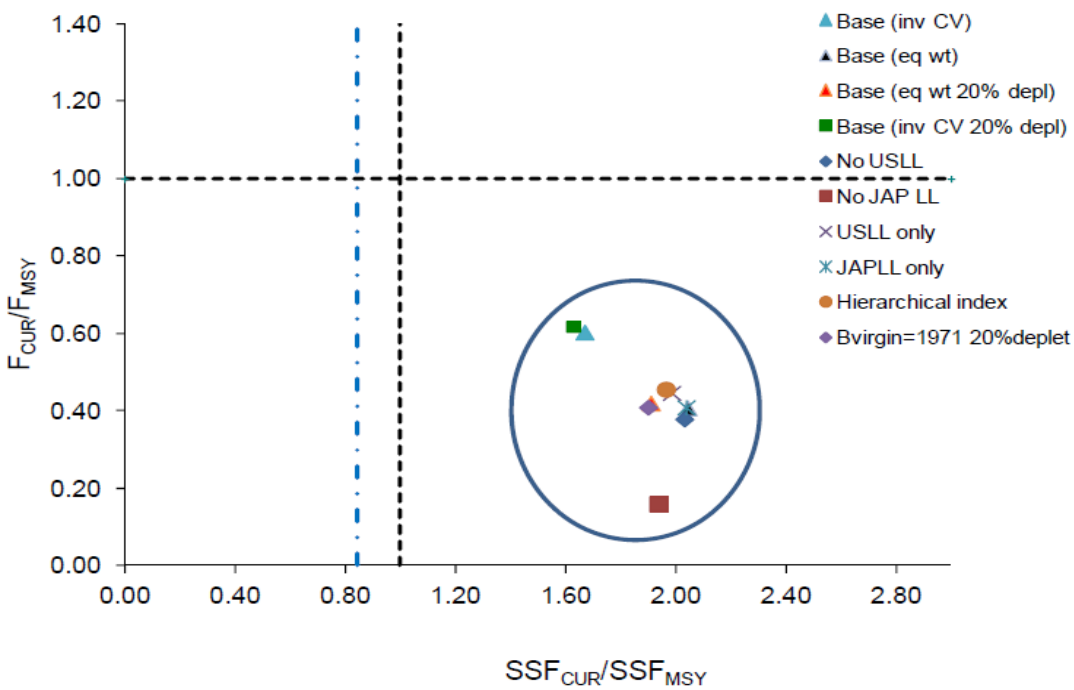


Figure 33. Phase plot of 'catch free' (CPUE only) production model runs (from ICCAT 2012). Median biomass is relative to B_{MSY}; fishing mortality rate relative to F_{MSY}.