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Recovery Potential Assessment for the North Atlantic Designatable Unit Of Shortfin Mako Shark (*Isurus oxyrinchus*)

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Canada

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.

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ABSTRACT

The North Atlantic Designatable Unit (DU) of Shortfin Mako Shark was assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as Endangered in April 2019, and is currently under consideration for listing under Schedule 1 of the *Species at Risk Act* (SARA). The Recovery Potential Assessment (RPA) presented here provides information to support the listing recommendation and any recovery actions, should the species be listed.

Shortfin Mako occurs throughout the Northern Hemisphere of the Atlantic Ocean. The biological characteristics of Shortfin Mako (i.e., relatively long lifespan, late maturity, and low reproductive output) make the population very susceptible to fishing pressure, which is the main threat identified in the North Atlantic. Multiple international and Canadian fisheries intercept Shortfin Mako as bycatch, and the most recent assessment of the DU predicts that it is overfished relative to biomass at Maximum Sustainable Yield (MSY). Reducing total removals in the North Atlantic to 500 mt is projected to have a > 50% probability of population recovery by 2070. For comparison, international and Canadian removals in 2019 totalled 1,863 mt and 63 mt, respectively. Considering just Canadian fleets, interception probabilities are highest from pelagic longline, with an average of 48% of observed sets encountering Shortfin Mako, followed by bottom longline (0.4% of sets) and otter trawl (0.2% of sets).

The most effective Canadian mitigation measure for Shortfin Mako will be the new landings prohibition, implemented in 2020 for pelagic longline and scheduled for implementation in 2021 for fixed-gear groundfish fisheries. The effectiveness of other mitigation measures are relatively unclear and, in many cases, would require dedicated experimentation to test. The current requirement to use circle hooks may need to be revised due to new evidence that increased catchability outweighs any reduction in post-release mortality for Shortfin Mako, thus leading to greater total mortality as compared to using J-hooks. Given the current level of international fisheries removals and the extent of mitigation already in place in Canada, there is very little scope for mitigation actions by Canada to measurably affect recovery potential.

INTRODUCTION

The North Atlantic Designatable Unit (DU) of Shortfin Mako Shark occurs throughout the Northern Hemisphere of the Atlantic Ocean from 60° N to the equator (COSEWIC 2017). Uncertainty regarding the status of this DU (Anon 2013, Anon 2018) resulted in the population being downgraded from Threatened (COSEWIC 2006) to Special Concern in 2017 (COSEWIC 2017), and then re-assessed as Endangered in 2019 (COSEWIC 2019). After the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designates an aquatic species as Threatened, Endangered, or Extirpated, Fisheries and Oceans Canada (DFO) undertakes a number of actions required to support implementation of the *Species at Risk Act* (SARA). Many of these actions require scientific information on the current status of the wildlife species, threats to its survival and recovery, and the feasibility of recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA), which is conducted shortly after the COSEWIC assessment. This timing allows for consideration of peer-reviewed scientific analyses into SARA processes, including recovery planning.

In support of listing recommendations for Shortfin Mako Shark by the Minister, DFO Science has been asked to undertake an RPA, based on the national RPA Guidance (DFO 2014). The advice in this RPA may be used to inform both scientific and socio-economic aspects of the listing decision, development of a recovery strategy and action plan, and to support decision-making with regards to the issuance of permits or agreements, and the formulation of exemptions and related conditions, as per sections 73, 74, 75, 77, 78, and 83(4) of SARA. The advice in this RPA may also be used to prepare for the reporting requirements of SARA s.55. The advice generated via this process will update and/or consolidate any existing advice regarding Shortfin Mako Shark.

Previous to this RPA, DFO Science conducted an RPA for Shortfin Mako Shark in 2006 (Campana et al. 2006), and a pre-COSEWIC assessment in 2015 (Showell et al. 2017). The first international assessment of the North Atlantic population was conducted by the International Commission for the Conservation of Atlantic Tunas (ICCAT) in 2012 (Anon 2013). A more recent assessment occurred in 2017 (Anon 2018), with an update in 2019 (Anon 2020). The most recent ICCAT assessments have been used in this RPA to evaluate population status, propose recovery targets for abundance, and evaluate mitigation options in the North Atlantic.

An RPA summarizes the life history, population status, threats, mitigation options, and potential for allowable harm for a wildlife species. In total, there are 22 Elements that must be considered (DFO 2014). However, 6 of these were deemed not relevant to Shortfin Mako Shark (Elements 6, 7, 9, 14, 17, and 18) and, therefore, were not evaluated in detail.

SPECIES INFORMATION

Element 1: Summarize the biology of Shortfin Mako Shark.

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

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

BIOLOGY

The Shortfin Mako Shark (*Isurus oxyrinchus*) is a large pelagic shark of the family Lamnidae. More commonly called mackerel sharks, this family includes the Porbeagle Shark (*Lamna nasus*) and White Shark (*Carcharodon carcharias*). They have a large cylindrical body shape characterized by distinct countershading, with a colouration transitioning from deep-metallic blue-grey dorsally to white ventrally. Shortfin Mako have visibly protruding teeth from the lower jaw and large black eyes (Compagno 2001). Although morphologically similar, this species can be readily distinguished from the Porbeagle Shark by having a single caudal keel and lack of lateral cusps on the teeth (Castro 2011). It is considered to be the fastest shark in the ocean, able to reach swimming speeds of 18.8 m/s (68 km/h; Graham et al. 1990). Globally, populations of Shortfin Mako are decreasing and this species is considered Endangered by the International Union for Conservation of Nature (IUCN) (Rigby et al. 2019).

Shortfin Mako is a circumglobal species, inhabiting all tropical to temperate seas between 50°N (60°N in NE Atlantic) and 50°S (Compagno 2001), including the Atlantic, Pacific, and Indian oceans. Analyses of mitochondrial DNA markers suggest population separation between the North and South Atlantic (Heist et al. 1996), as well as between the North Atlantic and Pacific populations, with a lack of migration across the Indian Ocean (Taguchi et al. 2011). Trans-oceanic or trans-equatorial migration events are rare. However, dispersal may be gender-based, with males having low rates of migration across oceans and hemispheres and females remaining in their natal ocean basin (Corrigan et al. 2018).

This species has a wide thermal tolerance; preferred water temperatures range from 17–22 °C (Compagno 2001) but individuals have been tracked through water as cold as 4.6 °C (Abascal et al. 2011) and as warm as 31 °C (Nasby-Lucas et al. 2019). Young Mako remain close to continental shelf edges and slope habitats (Rodgers et al. 2015), and disperse into deeper oceanic waters as they age (Kai et al. 2015). Juvenile sharks may also switch between transient and resident behaviors, spending long periods of time (up to several months) in shallow continental shelf areas before undertaking long-distance oceanic trips (Byrne et al. 2019, Francis et al. 2019). Adults are highly mobile, with migrations of over 10,000 km documented by satellite tagging (Rodgers et al. 2015, Nasby-Lucas et al. 2019). Adult movement patterns have been linked to Sea Surface Temperature (SST) and primary productivity hotspots, presumably due to higher prey availability in these areas (Vaudo et al. 2016, 2017).

Shortfin Mako spend the majority of their time close to the sea surface (Holts and Bedford 1993, Sepulveda et al. 2004), but make numerous deep dives (periodically > 800 m) usually during the day (Abascal et al. 2011, Vaudo et al. 2016). Diel patterns of vertical movement include deeper average depths and larger depth ranges during the day (Loefer et al. 2005). This behaviour is temperature-dependent, with warm-water populations maintaining deeper average depths as compared to individuals sampled in cooler waters (Vaudo et al. 2016). It is generally accepted that diel diving behaviour is linked to feeding behaviour (Sepulveda et al. 2004). Depth of these feeding dives may be restricted by temperature (Vaudo et al. 2016, Abascal et al. 2011) or anoxic conditions (Vetter et al. 2008, Abascal et al. 2011).

As a generalist apex predator, Shortfin Mako consume a wide variety of prey species, including teleost fish, marine mammals, and cephalopods (Campana et al. 2005). Along United States (US) coastal regions during summer, the most important prey species is Bluefish (*Pomatomus saltatrix*), which comprises 77.5–86.9% of Shortfin Mako diet by volume (Stillwell and Kohler 1982, Wood and Wetherbee 2009) and 92.6% by weight (Wood and Wetherbee 2009). There is evidence for a seasonal shift in diet from cephalopods to Bluefish in spring (MacNeil et al. 2005). Diet shifts have also been recorded while individuals are farther out to sea (Stillwell and Kohler 1982, Wood and Wetherbee 2009, Logan et al. 2013). Teleost fishes were the predominant prey of Shortfin Mako sampled from Canadian commercial and recreational fisheries, yet larger species (juvenile seals, porpoises and Loggerhead Sea Turtle) were also found[1]. Sampling from the eastern North Atlantic confirmed that teleost fish form the majority of their diet (Maia et al. 2006, Harford 2013), although larger fishes or marine mammals are also

[1] Joyce, W. 2000. Stomach sampling and morphological data collection. [Unpublished Raw Data]. Fisheries and Oceans Canada, Dartmouth, NS. Manuscript submitted for publication.

consumed (Monteiro et al. 2006, Porsmoguer et al. 2015a). Off the California coast, Pacific Shortfin Mako have a much more diverse diet and eat more cephalopods, but also prey on mackerel species, dolphin species (Vetter et al. 2008, Preti et al. 2012) and sea lions (Lyons et al. 2015). Populations sampled in the Indian Ocean near South Africa most commonly eat teleost fish, other elasmobranchs, and cephalopods (Cliff et al. 1990, Groeneveld et al. 2014). Stable isotope analysis has demonstrated that the diet of Shortfin Mako will shift to include higher trophic levels as individuals grow (Malpica-Cruz et al. 2013).

LIFE HISTORY

Age and Growth

In the North Atlantic, Shortfin Mako pups measure approximately 70–80 cm Total Length (TL) or 60–70cm Fork Length (FL) at birth (Mollet et al. 2000, Joung and Hsu 2005, Natanson et al. 2006). Juvenile growth is relatively rapid, with individuals increasing 30–40 cm in length during their first year. In both sexes, the growth rate slows with the onset of maturity, which occurs at smaller sizes for males. Therefore, growth becomes sexually dimorphic after the first 7 years of life (Bishop et al. 2006, Semba et al. 2009, Doño et al. 2015). Based on asymptotic length (L_∞) estimates from growth models, Shortfin Mako reach maximum sizes of 366 cm FL for females and 253 cm FL for males in the western North Atlantic (Natanson et al. 2006; Table 1). The corresponding longevity estimates from vertebral aging are 38 years for females and 21 years for males (Natanson et al. 2006, Campana et al. 2002; Table 1). Similar age and growth parameters have recently been estimated for Shortfin Mako populations in the North Pacific (Semba et al. 2009) and eastern South Pacific oceans (Cerna and Licandeo 2009).

Age and growth parameters can vary depending on the assumed growth model, the criteria used for age determination and the quality of the underlying data (Pratt and Casey 1983, Ribot-Carballal et al. 2005, Kai et al. 2015, Barreto et al. 2016), making age determination in sharks relatively uncertain (Cailliet 2015). The use of vertebral band counts has historically been the most widely accepted mode for aging shark species; however, the number of bands deposited each year is disputed (Wells et al. 2013, Barreto et al. 2016). Early work assumed the deposition of two band pairs (Pratt and Casey 1983), where more recent research has argued that one pair is more likely (Campana et al. 2005, Natanson et al. 2006, Cerna and Licandeo 2009). However, recent research has also found that band pair deposition may be linked to somatic growth (increase in girth) and not necessarily to time or age (Natanson et al. 2018), suggesting that vertebral counts may underestimate longevity, particularly for older mature sharks.

Maturity and Reproduction

Shortfin Mako are sexually dimorphic, with females maturing at later ages and larger sizes than males (Bishop et al. 2006, Natanson et al. 2006). The most recent estimates of median length-at-maturity (L_{50}) and median weight-at-maturity (WT_{50}) are 280 cm FL and 275 kg for females, and 182 cm FL and 64 kg in males (Natanson et al. 2020; Table 1). These values for length-at-maturity are nearly identical to those of the Shortfin Mako population in the Southern Ocean, near New Zealand (Francis and Duffy 2005) and in the North Pacific (Semba et al. 2011). Based on the growth model in Natanson et al. (2006), median age-at-maturity (A_{50}) would be 18 years for females and 8 years for males (Table 1).

As with the majority of pelagic shark species, Shortfin Mako have high reproductive investment and produce relatively few, well developed young (Stevens et al. 2000). Eggs are fertilized and pups hatch internally (ovoviviparous reproduction) and feed on unfertilized eggs (oophagy) until birth (Gilmore 1993). Gestational periods and fecundity estimates for Shortfin Mako are uncertain, given the relative scarcity of sampling from mature and pregnant females in all reproductive stages (Maia et al. 2007, Semba et al. 2011).

A gestation period of 15–18 months and a reproductive cycle of 3 years was reported by Mollet et al. (2000), with parturition thought to occur during late spring (April–May) in the North Atlantic (Pratt and Casey 1983, Mollet et al. 2000). However, both shorter (9–13 months; Semba et al. 2011) and longer (21 months; Duffy and Francis 2001) gestation periods have been proposed. Reported litter sizes vary from 4–25 pups with an average of 10–16 in the North Atlantic (Mollet et al. 2000, Stevens 1983, Duffy and Francis 2001, Joung and Hsu 2005, Castro 2011) and there is some evidence that fecundity may be positively correlated with maternal size (Mollet et al. 2000, Semba et al. 2011).

Derived Parameters

Natural mortality (M), generation time (G), and population growth rates (*r*) are derived from the age, growth, and reproductive parameter estimates given above (e.g., Cortés 2016). Thus, as our understanding of life history changes (e.g., with a re-evaluation of age), it becomes necessary to re-derive parameter values, which may cause discrepancies with previous research.

To estimate M, we have used the mean regression equation for teleosts and marine mammals developed by Hoenig (1983), which is consistent with the majority of previous studies reporting M estimates for Shortfin Mako Shark (Smith et al. 1998, Bishop et al. 2006, Au et al. 2015). This estimation method is based on maximum age, and we applied it separately for males and females, given the degree of sexual dimorphism in the population. Assuming a maximum age of 38 years for females and 21 years for males, M would be 0.119 and 0.212, respectively. The latter value is greater than previously reported estimates for males and females combined (0.16, Smith et al. 1998; 0.15, Au et al. 2015) owing to differences in the assumed maximum age for the population.

We estimated *r* using the Euler-Lotka equation (McAllister et al. 2001), which approximates population growth from the life-history characteristics of females. It is a density-independent model, where the estimate of *r* represents the maximum rate that the population can increase from severely-depleted population size (Gedamke et al. 2007). Given the deterministic values for life-history characteristics in Table 1, we estimated *r* to be 0.036.

Calculation of G can be from the annual reproductive output of the population and the population growth rate (Smith et al. 1998, DFO 2017). This method of calculation means that G represents the average renewal time of the population. From the outputs of the Euler-Lotka equation above, G is estimated to be 25 years for Shortfin Mako in the North Atlantic. This is similar to the 24–25 year generation time listed in the global assessment of Shortfin Mako (Rigby et al. 2019).

ABUNDANCE

Recent Trajectory

We did not propose a method to calculate abundance or trends in abundance that is specific to Canadian waters, but use output from the most recent ICCAT assessment to represent abundance trends in the North Atlantic. A Catch-Per-Unit-Effort (CPUE) index from the Canadian pelagic longline fleet for Swordfish (*Xiphias gladius*) showed a non-significant decline from 1996–2014, based on a Gamma Generalized Linear Model (GLM) that incorporated the fixed effects of year and vessel (Showell et al. 2017). Even though bycatch of Shortfin Mako still occurs in this fishery, we did not update this analysis because Canadian waters are at the northern fringe of the range of Shortfin Mako and thus are more likely to index changes in distribution rather than changes in abundance (Maunder et al. 2006). We consider the abundance trends from the most recent ICCAT assessment (Anon 2020) to be more robust, because multiple indices of relative abundance are used as inputs to stock assessment through

ICCAT and represent CPUE occurring throughout a greater range in the North Atlantic for Shortfin Mako (since their assessment area combines the NW and NE Atlantic; Figure 1). As compared to exclusively Canadian data, the output from the ICCAT stock assessment model is more likely to index abundance rather than changes in distribution.

All stock assessment models used in the 2019 assessment of the North Atlantic Shortfin Mako population predicted substantial abundance declines from the 1950s until 2018 (Anon 2020). Assessment results were given as a relative-abundance index (rather than absolute estimates of biomass or numbers), representing a ratio of estimated biomass/biomass at MSY for each model to ensure comparability. The age-structured assessment models (Stock Synthesis) suggested that relative abundance declined by approximately 54% (values decreasing from approximately 2.4 in the 1950s to approximately 1.1 in 2018). The Bayesian Surplus Production models (BSP2JAGS) gave similar results, with predicted declines ranging from 53–65% over the same time period. Although the time series of data spanned 69 years (nearly 3 generations), the majority of the decline occurred from the 1980s onwards (approximately 39 years; less than 2 generations). Also, there is no indication that population decline has slowed or ceased.

Recent research did not find evidence of systematic variation in Shortfin Mako distribution over time in the North Atlantic, based on a compilation of US, Canadian, and Portuguese observer data (Natanson et al. 2020). There is only one population, so there has been no trend over time in the number of populations in the North Atlantic.

DISTRIBUTION AND HABITAT

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

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

HABITAT PROPERTIES

Environmental preferences for Shortfin Mako were determined from the depth and temperature profiles encountered by sharks tagged with Wildlife Computers miniPAT and PAT MK10 (Table 2), and Lotek PSATLife (Table 3) archival satellite tags. Consistent with previous research (Abascal et al. 2011, Vaudo et al. 2016), individuals exhibited cyclical daily diving behaviour throughout the top 600 m of the water column (Figure 2). Interestingly, two of the tagged animals undertook exceptionally deep dives (> 900m; Figure 3) in August and September, to depths beyond 888 m, the maximum currently reported for the species (Abascal et al. 2011, Vaudo et al. 2016).

Tagged sharks showed a clear preference for warmer water throughout June to December, spending the majority of their time in waters between 10–25 °C (Figures 2–4). This corresponds well with Shortfin Mako in the Central Pacific, which were found to spend 95% of their time in waters ranging from 9.4–25 °C (Musyl et al. 2011). As previously seen from tagged Porbeagle Shark (Campana et al. 2010), sharp increases in temperature were associated with movements into the Gulf Stream or lower latitudes (top panel, Figure 4). In general, sharks made brief forays into surficial or deep waters less than 10 °C, suggesting that the population will rarely use habitats dominated by the cold Labrador current and will remain in more southerly waters close to the Gulf Stream. However, the temperature data is consistent with the hypothesis that Shortfin Mako congregate in areas of warm and cold water mixing where productivity is high (Bigelow et al. 1999).

SPATIAL EXTENT

Atlantic Canadian waters represent the most northern extent of the range of Shortfin Mako Shark in the North Atlantic. In Canada, Shortfin Mako are most commonly found in warm waters along the continental shelf and in offshore waters near or within the Gulf Stream (Campana et al. 2005). Based on captures of pregnant females, mating and pupping were originally hypothesized to occur in the Gulf of Mexico (Gilmore 1993). However, a recent analysis of At-Sea Observer (ASO) data suggests a widespread distribution for neonates (captures of 63.2–68 cm FL cm animals representing size at birth) throughout the western North Atlantic (example for males: Figure 5; Natanson et al. 2020). Although habitats critical for mating and pupping were generally believed to take place outside of the Canadian Exclusive Economic Zone (EEZ; Campana et al. 2006, Showell et al. 2017), the distribution of neonates raises the possibility that pupping is not concentrated in southern areas and could be occurring in Atlantic Canadian waters. Note that information on distribution came entirely from fishery-dependent data and was therefore dependent on fishing effort (Natanson et al. 2020). However, distinct seasonal aggregations of neonates or Young-Of-the-Year (YOY) were not found, suggesting that pupping is widespread and may encompass the majority of continental shelf waters.

We have used two main data types to characterize the distribution of Shortfin Mako in Canadian waters: commercial captures recorded via fishery logbooks and fishery-independent satellite-tagging data. Although At-Sea Observer (ASO) data are also available, observer reports represent a subset of the commercial captures and have the potential to be biased by non–random deployment across the various fisheries. Logbook records primarily represent landed catches and exclude the majority of discards, yet we do not anticipate that the tendency to discard is dependent on geographical location (i.e., it is relatively unbiased). We combined all positional data from Maritimes (MAR) and Newfoundland and Labrador (NL) regions, and restricted the years to 2001 onwards to reduce the potential for species misidentification. Note that there are extremely few records of Shortfin Mako from NL Region in recent years, with ≤ 23 records each year since 2010 from commercial logbooks. For any maps in this document generated from geographical data, we have used the WGS84 projection for the latitude and longitude coordinates.

Based on commercial records, Shortfin Mako have a broad distribution along the Atlantic coast, encompassing areas from the Bay of Fundy, into the Gulf of St Lawrence, out to the Grand Banks towards the Flemish Cap, and off the eastern coast of Newfoundland (Figure 6). This overall pattern appears to be relatively consistent over time. The apparent shifts from 2001–2009 and 2010–2019 can be largely explained by changes in the distribution of fishing effort and the closure of the directed Porbeagle fishery in 2013 (Figure 7). Additionally, there do not appear to be marked shifts on a seasonal basis, as captures in Q1 to Q4 are broadly overlapping (Figure 8). However, distribution may not extend as far into northern waters (i.e., into NL Region) in the winter/spring (Q1 and Q4). There would be much less fishing effort during these times of year, but Shortfin Mako would also be expected to leave these areas as water temperatures become colder.

Our understanding of distribution does not markedly change when fishery-independent data are considered. A total of 29 miniPAT and PAT MK10 tags (Wildlife Computers) have been deployed on Shortfin Mako (Table 2). These archival tags record depth, temperature and light-level. We used a state-space model (GPE3 software) to generate probable movement tracks. Tracked individuals remained well offshore near the continental edge along the southern extent of Canada's EEZ, with many individuals swimming east to the south-eastern tip of the Grand Banks (Figure 9). Two individuals undertook long-distance southern migrations, one along the eastern seaboard of the US and the other well offshore into the North Atlantic. Tagged Shortfin Mako remained within the Canadian EEZ primarily from July to December. Only two individuals were tracked during January to June and both traveled south on long-distance migrations. This temporal distribution resembles the pattern from the commercial data where the majority of Shortfin Mako observations occurred in quarters 3 and 4 (Figure 8). However, the commercial data also contain a substantial number of observations in quarter 2, a discrepancy likely due to the small sample size of satellite-tagged individuals during this timeframe.

SPATIAL CONSTRAINTS: NOT RELEVANT

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

There are no spatial configuration constraints that affect the movement or habitat use of Shortfin Mako Shark in the North Atlantic Ocean. This species moves freely, inhabiting a wide vertical distribution in the water column as well as a broad spatial distribution (Loefer et al. 2005, Vaudo et al. 2016, Banez 2019, Byrne et al. 2019).

RESIDENCE REQUIREMENTS: NOT RELEVANT

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

The concept of a residence does not apply to Shortfin Mako, in that they do not show strong seasonal or ontological aggregation behaviour in the North Atlantic (Natanson et al. 2020).

THREATS AND LIMITING FACTORS

Element 8: Assess and prioritize the threats to the survival and recovery of the Shortfin Mako.

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

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.

IDENTIFIED THREATS

A threat is identified as:

> *Any human activity or process that has caused, is causing, or may cause harm, death, or behavioural changes to a wildlife species at risk, or the destruction, degradation, and/or impairment of its habitat, to the extent that population-level effects occur (DFO 2014).*

Mortality from various directed and bycatch fisheries was the only threat to the North Atlantic DU of Shortfin Mako identified by COSEWIC (2019). Outside of Canadian waters, international commercial longline fleets were considered to be the primary sources of mortality, with lesser mortalities associated with coastal or artisanal fisheries, including the US recreational fishery (Anon 2018, COSEWIC 2019). In Canadian waters, bycatch was considered most frequent in pelagic and benthic longline fisheries with fewer interactions in groundfish gillnet and trawl fisheries. The contribution of Canadian recreational fisheries to mortality was thought to be very low (COSEWIC 2019).

Other large-scale changes to marine ecosystems include underwater noise, marine pollution, ocean acidification and climate change. There is little quantitative information on whether such changes would be considered threats to Shortfin Mako. For example, high mercury concentrations have been found in juvenile Shortfin Mako in the North Atlantic, with evidence that mercury accumulation is proportionately faster as compared to Blue Shark for animals of similar size (Biton-Porsmoguer et al. 2018). However, these results are not interpreted as threatening Shortfin Mako survival but as threatening humans following consumption. Other changes to oceanic habitats (e.g., temperature, salinity, prey distributions) due to large-scale processes such as climate change would be expected to affect distribution patterns, yet it is difficult to predict whether they will also threaten Shortfin Mako survival. For example, forecasted changes in SST and chlorophyll a concentrations in the North Pacific suggest that Shortfin Mako will lose approximately 35% of habitat area by 2100, but with the strong caveat that the response of pelagic predators is extremely difficult to predict due to their migratory nature, time spent below the surface of the ocean, and adaptable physiology (Hazen et al. 2013). For the purposes of this RPA, we consider the primary threats to the population to be those posed by fisheries.

International

Catches of Shortfin Mako in the North Atlantic are reported annually to ICCAT and are published on the ICCAT website as Task I data. This time series represents the current state of knowledge of all fisheries removals in the North Atlantic. Although the data are intended to include landings plus dead discards, very few countries record the condition of discards or report discard values. Consequently, these catches are typically considered a minimum estimate of fisheries removals from the North Atlantic during stock assessment (Anon 2018).

Throughout the time series, catches of Shortfin Mako in the North Atlantic have been dominated by European (notably Portugal and Spain) and US fleets (Table 4). Catches from all countries combined peaked in 1995 and 1996, exceeding 5,000 mt in both of those years. Since 1994, annual catches of Shortfin Mako have averaged 3,685 mt in the North Atlantic, with an average of 67 mt coming from Canada (Table 4). Until 2017, there was no systematic trend over time with catches (landings + dead discards) in the preceding 5 years, remaining close to the long-term average. However, catches in 2018 and 2019 have declined, presumably due to Recommendation 17-08 from ICCAT which stipulates that all live animals must be released. Note that the zeros in the time series for Canada (1994) and Morocco (1994–2002) represent a lack of data, rather than true zeros.

Canadian commercial fisheries

There has never been a directed fishery for Shortfin Mako Shark in Atlantic Canada, all landings represented bycatch in other commercial fisheries. In 1995, a non-restrictive quota of 250 mt annually was implemented (Campana et al. 2004b), which was reduced to 100 mt following the original RPA for Shortfin Mako (Campana et al. 2006). Only Canadian, Japanese, and Faroese vessels are known to have caught significant quantities of Shortfin Mako Shark in Canadian waters, although the contribution of foreign vessels to catches has been negligible since 1999 (Campana et al. 2004b).

Landings

Landings of Shortfin Mako Shark were extracted from the Zonal Interchange File Format (ZIFF) database. This database mirrors the independent regional databases of commercial landings from Maritimes, Gulf, Quebec, and Newfound and Labrador regions. As an example, landings in Maritimes Region have been tracked via logbook entries (1979–2002) and then 100% dockside monitoring since 2003 (Showell et al. 2017) and data are currently housed in the Maritimes Region Fisheries Information System (MARFIS) database. To be consistent with previous evaluations of landings (e.g., Showell et al. 2017), we have not attempted to incorporate post-processing edits made to the data prior to annual submission to ICCAT. Thus, there are minor differences between the time series of data provided to ICCAT relative to Table 5. The Canadian contribution to Task I data (*International Fisheries* section above) should be used as the more complete record of total fisheries removals, while the data described in this section give the relative contribution by region.

Historically, many shark landings in both Maritimes and Newfoundland and Labrador regions were reported as unidentified sharks (any species) or mackerel shark (a combined category for Porbeagle and Shortfin Mako). Also, the morphological differences between Porbeagle and Shortfin Mako are relatively subtle and it is likely that some of the early landings records of Shortfin Mako were actually Porbeagle. Plotting the landings data for Maritimes Region prior to 2001 supports the idea that species identification was poor, given that it closely matches the known distribution for Porbeagle (Campana et al. 2015) rather than being concentrated along the warmer waters of the shelf edge. Therefore, we consider landings to be approximate prior to 2001, even though monitoring effort was relatively high.

The majority of landings of Shortfin Mako come from fisheries in Maritimes Region (Table 5). Quebec and Gulf regions contribute minimally to the total in any year. Landings from Newfoundland and Labrador were as high as 44% of those in Maritimes (in 2000), but were more often 10% or less, and were zero for 2018 and 2019 (Table 5). Overall, landings declined from around 70 mt in the early 2000s to the series minimum of approximately 30 mt in 2012. In more recent years, landings increased to a high of 96 mt (in 2017; 109 mt ICCAT submission) yet have dropped to approximately 54 mt for 2019 (Table 5). The decrease in 2018 and 2019 is partially related to a change in license conditions that stipulates the release of all live captures and only permits landings of animals that are dead at vessel (ICCAT Rec. 17-08). In the most recent 5 years, the vast majority of landings of Shortfin Mako (> 99%) come from benthic and pelagic longline (Table 5).

The only information on the length-frequency distribution of the landings comes from dockside monitoring of the pelagic longline fleet in Maritimes Region and is archived in the Tallies database. Data from 1999–2017 were extracted in advance of the 2017 ICCAT assessment for Shortfin Mako and provided as input to the assessment model (Anon 2018). In all years, the peak of the distribution occurs between 100–200 cm FL (Figure 10), with exceptionally few landings of animals > 250 cm FL. This indicates that the pelagic longline fishery almost exclusively catches juvenile animals.

Discards

The information on discards of Shortfin Mako Shark used in this document comes from ASO programs. Although mandatory reporting of bycatch via a new supplementary logbook was introduced for the pelagic longline fleet in 2018, this regulatory change does not apply to all fisheries that interact with Mako. For the ASO data, it is important to remember that the proportion of commercial fishing effort that is observed varies among fleets, years, and regions. As with the landings data, species identification by fisheries observers is expected to be more accurate from 2001 onwards. In Maritimes Region, data are housed in the Industries Surveys Database (ISDB). Data extractions from the ISDB were done in January 2020 and will not incorporate edits made after this date.

From Maritimes Region, the gear types associated with incidental catches of Shortfin Mako include pelagic or drift longline, bottom longline, and otter trawl; with minimal amounts in purse seine, fixed gillnet, handlines, and troll lines. Note that extremely few records from midwater trawl and side-stern otter trawl are combined in the general category for otter trawl. For the last three years, discards have only been observed from otter trawl and pelagic longline, and have remained below 5 mt since 2008 (Table 6). In 2019, observed discards were extremely low at < 1 mt.

In Maritimes Region over the last 20 years, the vast majority of Shortfin Mako discards have come from two fisheries: the otter-trawl fishery for Haddock and the pelagic longline Swordfish and Other Tunas fishery (Figure 11). Minimal discards of Shortfin Mako have been recorded by the fleets targeting other species.

ASOs in Maritimes Region record the length of individual fish from measurements of kept catches or from length estimates of discarded animals. We compared the length-frequency information from the ASO data to the Tallies data and found a very close match between the two for each year (Figure 10). This confirms that the pelagic longline fishery tends to capture juvenile animals and provides no evidence of 'high-grading' or preferentially discarding a specific size of Mako.

NL Region ASO data indicated that Shortfin Mako was predominantly caught by gillnets in the Subdivision 3Ps Cod fishery, the Divisions 3OPs Monkfish/White Hake/skate mixed fishery, and the Division 3L Greenland Halibut fishery (Figure 12). Note that only the NAFO Divisions (Figure 13) where Shortfin Mako observations occurred are listed, rather than all NAFO Divisions encompassed by the fisheries. Historically, Shortfin Mako bycatch was observed in the Division 3MNO longline Swordfish/tuna and Division 3LNO Porbeagle fisheries. More recently, bycatch of this species was observed in the Subdivision 3Ps Atlantic Halibut longline fishery. It must be noted that ASO coverage of fisheries in Subdivision 3Ps has been almost non-existent since 2012; hence the near-absence of recorded Shortfin Mako bycatch in an area where this (and other large shark) species continued to be incidentally caught by gillnets. In bottom- (otter-) trawl fisheries, Shortfin Mako bycatch was observed mainly in the Division 3NO Yellowtail Flounder fishery and in the Subdivision 3Ps Atlantic Cod fishery. Since 2016, recorded catches (kept catch + discards) in the ASO database were < 1.5 mt, but data collection was constrained by the very low to non-existent annual ASO coverage in the majority of fisheries in recent years.

Interception probability

To evaluate interception probability from various fisheries in Maritimes Region, we calculated the proportion of observed sets that captured Shortfin Mako. We first identified the commercial fleets that had any record of incidental catch (kept or discarded) on the basis of gear type and target species from ASO data. Then, we extracted all ASO records from commercial fleets using the same gear type and targeting the same species. Finally, we identified all of the sets which caught Shortfin Mako in a given year and calculated the proportion. If warranted, a similar analysis of interception probability from NL Region fleets could be done in the future.

Relative interception probabilities were high for the pelagic longline fleet, with an average of 48% of observed sets encountering Shortfin Mako. No other fishery had an annual interaction rate higher than 1% and most were consistently below 0.5%. For example, benthic longlines were rarely observed to catch Shortfin Mako in the Maritimes Region, with only 88 observations in over 31,000 sets (0.28%; Table 7). This is likely due to the limited amount of time that Shortfin Mako spend below the mixed layer, thus minimizing the encounter rate with benthic gear. Although discard amounts from otter-trawl fisheries appear the most substantial next to pelagic longline (Table 6), it is important to keep in mind that only 171 otter-trawl sets intercepted Shortfin Mako, out of 117,561 observed since 1994 (0.1%; Table 7).

Other gear types account for only sporadic, usually small, observed interactions with Shortfin Mako. Since 1994, there has been very little incidental catch of Shortfin Mako by these fisheries, where < 1% of sets by set gillnets, handlines, and troll lines and 1.1% of purse seine caught Mako. (Table 8). Within the last 10 years, only 13 Shortfin Mako interactions have been recorded across all fisheries using these gear types (Table 8).

Note that these interaction rates do not give information that can be used to approximate fleetwide discards (total discards from observed as well as unobserved trips). That would require an analysis of possible sources of bias in ASO coverage (i.e., deployment, temporal, or spatial effects), coupled with a method to scale up observed discards by fishery (e.g., Stock et al. 2019). Also, we have reported by gear type (e.g., otter trawl) rather than by a specific fleet (e.g., mobile gear < 45 ft). However, ASO coverage rates are high (up to 100%) in groundfish otter-trawl fisheries operating on Georges Bank and in the annual benthic longline survey for Atlantic Halibut. Coverage rates are much lower in other components of the benthic longline fishery and for the gear types associated with sporadic captures in Maritimes Region. Coverage targets are 10% for pelagic longline. ASO coverage for fisheries associated with sporadic interactions (e.g., set gillnet and purse seine) are extremely low relative to other groundfish fisheries or pelagic longline.

Seasonality

The ASO data in Maritimes Region was partitioned by fishing quarter for pelagic longline (Figure 14), benthic longline (Figure 15), and otter trawl (Figure 16) in order to evaluate seasonality. Incidental catches in all other fisheries were too small and/or sporadic to provide useful information on seasonality.

Shortfin Mako observations in ASO data show a clear pattern throughout the year. There are few observations in Quarter 1 (Jan–Mar), followed by the majority of catches in Quarter 2 (Apr–Jun) and 3 (Jul–Sep), and a decrease in Quarter 4 (Oct–Dec) (Table 9). This pattern corresponds to the likely timeframe where sea temperatures are higher and more habitable for Shortfin Mako (10–25 °C). Otter trawl seemed to interact with Shortfin Mako only in a small area off the southern tip of Nova Scotia (Figure 16) regardless of season, despite being fished across all areas where Shortfin Mako are caught on other gear types. This suggests that Mako may be present near the Hague Line (i.e., along the boundary between the US and Canadian EEZ) in all seasons. The pelagic longline fleet is most active in Q2, Q3, and Q4 and encountered Shortfin Mako in these quarters throughout the spatial extent of the fishery (Figure 14). Anecdotally, the fleet tends to move from more southern areas during Q2 towards the edge of the continental shelf (Browns, Sable Island, and Banquereau Banks), and within the Emerald Basin in Q3 and Q4. Interception probabilities from the pelagic longline fleet were higher in Q2 and Q3, and dropped substantially in Q4 (Table 9). Although there is proportionately less fishing effort in the winter months (Q1 and Q4), it is likely that Shortfin Mako are also encountered less frequently because of their thermal preferences.

At-vessel mortality

Fishing mortality can be separated into three components: landings, capture/at-vessel mortality, and post-release mortality of discards (Campana et al. 2016). Combined, these sources of mortality represent total removals. Shark condition is a known predictor of mortality (e.g., Ellis et al. 2017) so tracking shark condition gives information on the proportion of animals that come up dead at-vessel as well as the relative frequency of injury for live releases. In 2010, an expanded shark monitoring protocol was implemented by ASOs in Maritimes Region for the pelagic longline fishery in order to characterize the condition of shark captures. Kept catches (i.e., landings) are characterized as either alive or dead upon gear retrieval (Table 10), while discarded catches are categorized as dead, injured, healthy, sharkbit or unknown (Table 11). Taking into account the recorded condition of both landed and discarded catches, an average of 30.6% (max = 69%, min = 18%) of hooked Shortfin Mako are dead upon retrieval of the gear (Table 12).

Post-release mortality

Post-Release Mortality (PRM) for live discards has only been quantified for the pelagic longline fishery, taking into account the condition of the fish (i.e., healthy or injured). Details on the tag deployments can be found in Bowlby et al. (2019) for tagging that occurred between 2017–2019 and in Campana et al. (2016) for earlier deployments. Bowlby et al. (2019) fit survival mixture models to all data combined (early and recent deployments) and reported PRM estimates of 0.27 (CI = 0.15, 0.44) for healthy and 0.33 (CI = 0.08, 0.73) for injured Shortfin Mako. At that time, the probability of a live release being injured was 0.14 (CI = 0.08, 0.20), suggesting a weighted mean PRM rate of 0.28 (Bowlby et al. 2019). In other words, after taking into account the relative proportion of live releases that are injured, about 28% of live releases are expected to subsequently die. The fact that injured and healthy Shortfin Mako had very similar PRM rates is likely due to the relative difficulty in accurately assigning condition category (Campana et al. 2016), rather than suggesting that the extent of physical injury is not an important predictor of mortality (Ellis et al. 2017).

Canadian Recreational Fisheries

In the Maritimes Region, the annual recreational shark fishery is catch and release except for a limited number of shark tournaments (4–6 per year) that allow retention. In both of these components of the recreational fishery, the main species targeted is Blue Shark. A total of 52 Shortfin Mako were landed in the fishing tournaments since their inception in 1994, with a maximum of 6 animals retained in a single year (2004; Table 13). Taking into consideration the poor status of Shortfin Mako from the 2017 ICCAT assessment, management regulations for the shark tournaments were changed in 2018 to permit Blue Shark retention only. Currently, all recreational shark fisheries in Gulf, Quebec, Newfoundland and Labrador, and Maritimes regions are catch and release. Post-release survival from rod and reel capture has been estimated at 90% (French et al. 2015), so recreational shark fisheries in Canada are unlikely to have a significant effect on Shortfin Mako in the North Atlantic.

Other marine recreational fisheries (e.g., groundfish) do not have licence requirements and are largely unmonitored. Anecdotal information suggests that Blue Shark and Porbeagle Shark are occasionally captured, but there are no known reports of Shortfin Mako Shark. These recreational fisheries should be considered data deficient.

Threats summary

We have used guidance from DFO (2014) in categorizing threats to Shortfin Mako in the North Atlantic. Typically, there are two steps to this process:

Step 1 – Evaluate threats at the population level. This includes evaluating:

- Likelihood of Occurrence;
- Level of Impact;
- Causal Certainty;
- Population Threat Risk (product of Likelihood of Occurrence and Level of Impact);
- Population-Level Threat Occurrence;
- Population-Level Threat Frequency; and
- Population-Level Threat Extent.

Step 2 – Evaluate threats at the species level. This includes evaluating:

- Species Threat Risk (Roll-up of Population Threat Risk);
- Species-Level Threat Occurrence;
- Species-Level Threat Frequency; and
- Species-Level Threat Extent (Roll-up of Population-Level Threat Extent).

Here, we are only concerned with a single population of the species (North Atlantic DU) so we have not rolled up threats at the species level. However, we have applied the threat evaluation twice: first to do a comparison between Canadian and International fisheries (Table 14) and second to compare amongst individual Canadian fisheries (Table 15).

International fisheries are by far the greatest threat to the North Atlantic population of Shortfin Mako, both in terms of recorded landings as well as the potential for discards. The latest ICCAT assessment suggests that the population has declined by approximately 50% since the early

1980s, and that declines are expected to continue at least until 2035 (Anon 2020). If current fishing mortality rates continue, the population projections suggest a non-negligible probability of extirpation. In other words, it is possible that the population will decline to zero at current levels of fishing mortality. Therefore, we have scored the level of impact as ‘Extreme’ for international fisheries. Canadian fisheries removals are < 10% (and typically < 5%) of the total reported to ICCAT and given the results presented for Element 22 (Allowable Harm Assessment), are unlikely to jeopardize survival or recovery in isolation. Therefore, we scored the overall level of impact of Canadian fisheries as ‘Low’. In addition, the frequency of occurrence and extent of the threat is lower for Canadian fisheries because Shortfin Mako are primarily seasonal occupants of Canadian waters. However, it is important to note that Canadian fisheries do not occur in isolation; they are concurrent with international fisheries and any other threats. Although the individual threat posed from each is Low, they do contribute to cumulative fishing mortality and consequently to population decline for Shortfin Mako in the North Atlantic.

The threat assessment of Canadian fisheries has been broken out by gear type as in previous evaluations of landings and discards (Campana et al. 2006, Showell et al. 2017). For all categories, we consider there to be strong evidence that the threat is occurring (i.e., the gear type is in use in Canada) and that the magnitude of the impact to the population can be quantified in a relative sense. Therefore, we have ‘very high’ Causal Certainty that the threat is linked to the survival and recovery of the population and all fisheries are given a rank of 1 (Table 14). We have quantified the likelihood of occurrence from observed interactions within the previous 10 years, where fisheries with interactions every year are scored as ‘Known (100%)’ and those with lower percentages are considered less likely (e.g., bottom longline; Likely [80%]). Note that we have added ‘Very Low’ and ‘Negligible’ categories to the Level of Impact linked to a threat (Table 15), to avoid a situation where all threats were scored as ‘Low’. (Low is defined as: 1–10% change in population or threat is unlikely to jeopardize survival or recovery).

NATURAL FACTORS

Mako sharks are a robust and adaptable genus, having survived in the world’s oceans for close to 100 million years. As a generalist top predator, food availability and, therefore, competitive exclusion, is unlikely to be a limiting factor for Shortfin Mako. This species exhibits a tolerance for a wide range of oceanographic conditions including temperature (Compagno 2001, Abascal et al. 2011, Nasby-Lucas et al. 2019), and dissolved oxygen (Vetter et al. 2008, Abascal et al. 2011) and is able to migrate and survive within a host of habitat types (Compagno 2001). Mature Shortfin Mako have very few natural predators, with the exception of Orca (*Orcinus orca*) (Visser et al. 2000) and potentially larger sharks, so natural mortality is expected to be very low.

Despite the beneficial life history traits listed above, Shortfin Mako are vulnerable to fishing pressure given their late age at maturity and relatively slow reproductive rate. Female Shortfin Mako mature after approximately 18 years, have a relatively short lifespan (38 years), up to a 3-year reproductive cycle (Mollet et al. 2000), and small average litter sizes (approximately 7 pups). Demographic analyses of these life history traits suggest their population growth rates following exploitation are on the lower end of the spectrum of elasmobranch life histories (Au et al. 2015). Ecological risk assessment (Anon 2013) confirms that Shortfin Mako are more at risk from exploitation than other shark species.

Not only is the species thought to be highly susceptible to fisheries in the North Atlantic (McCully et al. 2013, Queiroz et al. 2016), a recent electronic tagging study suggested that fishing mortality rates of Shortfin Mako in the North Atlantic may be ten times higher than previously estimated. Globally, this prompted an increase in concern about status (Byrne et al. 2017, Anon 2018) and contributed to its listing as ‘endangered’ on the IUCN Red List (Rigby et al. 2019) and its listing on Appendix II of CITES in 2019.

ECOSYSTEM CONSIDERATIONS

The three main gear types that interact with Shortfin Mako (pelagic and benthic longline, and otter trawl) are non-selective in the sense that they do not exclude non-target organisms from the catch. Species with similar biology, habitat, and/or distribution have a high probability of being intercepted and retained by such fisheries in the North Atlantic (e.g., Queiroz et al. 2016). The most comprehensive assessment of bycatch from fisheries in Maritimes Region (2002–2006) demonstrated that the pelagic longline fleet was associated with catches of approximately 22 different species, including several sharks, birds, marine mammals, turtles, and other pelagic fishes (Gavaris et al. 2010). The groundfish otter-trawl fleet as well as the bottom-longline fishery for Atlantic Halibut were associated with catches of an even larger suite of species, including teleost fishes, various skates, invertebrates, and pelagic fishes (Gavaris et al. 2010). One important difference between bottom gears and pelagic ones is the potential to influence bottom structure and habitats, as shown by discards of seaweeds and corals from groundfish otter trawl. We consider this information to be indicative of the potential for interaction with various components of the ecosystem and is the most useful for comparison. Gavaris et al. 2020 pointed out that particular estimates of discard amounts should not be construed as definitive or accepted uncritically. Further work on bycatch is required to understand and quantify the ecosystem impacts of the fisheries that interact with Shortfin Mako.

THREATS TO HABITAT PROPERTIES: NOT RELEVANT

Element 9: Threats: 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.

Large-scale oceanographic changes that would affect marine habitats in Canada (e.g., acidification, climate change; Belkin 2009, Bates et al. 2012) are diffuse, systemic and result from essentially all activities that contribute to industrialization, both in Canada and internationally.

RECOVERY TARGETS AND POPULATION PROJECTIONS

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

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 Shortfin Mako population dynamics parameters.

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.

RECOVERY TARGETS

Distribution

There is no proposed target for the distribution of Shortfin Mako in Canadian waters. This species would be expected to seasonally use continental waters from Brown's Bank east to the Grand Banks, concentrating along the northern boundary of the Gulf Stream (Natanson et al. 2020).

Abundance

International assessments for Shortfin Mako assess status relative to Maximum Sustainable Yield (MSY) to determine if a population is overfished or if overfishing is occurring.

Mathematically, these terms correspond to a population biomass (B) represented as $B < B_{MSY}$ (i.e., overfished) and a fishing mortality (F) rate $F > F_{MSY}$ (i.e., overfishing; Anon 2018). Status relative to these two reference points is assessed through a Kobe matrix, which gives the combined probabilities from all assessment models that the population is in any one of the four matrix quadrants (e.g., Figure 17). The population would be considered to have a healthy biomass level and to be fished sustainably provided the majority of the probability mass from the assessments fell into lower-right-hand green quadrant ($B > B_{MSY}$ and $F < F_{MSY}$). Given that future status evaluation for the North Atlantic population will be done through ICCAT, having the majority of the probability mass in either of the right-hand quadrants of the Kobe plot (where $B > B_{MSY}$) would be a useful abundance target. In other words, B_{MSY} or any proxy for B_{MSY} used in the ICCAT assessments could be considered the abundance target.

Unlike the majority of forums that undertake stock assessment using a specific framework model which is then compared to other formulations in 'sensitivity' runs (e.g., TRAC), shark assessments at ICCAT may change approaches entirely or give equal weight to outputs from several different modeling approaches to derive advice. This means that there is no single value for B_{MSY} in any given assessment. Also, the age-structured assessment used in 2017 and 2019 outputs the biomass of Spawning Stock Females (SSF) rather than B and use SSF_{MSY} as the abundance reference point. However, the threshold of MSY is used in both cases (i.e., $B > B_{MSY}$ or $SSF > SSF_{MSY}$) to define relative abundance.

In summary, an abundance estimate or fisheries assessment specific to Canadian waters cannot be provided, and ICCAT assessments of Shortfin Mako in the North Atlantic are used in this RPA to define recovery targets and assess status. ICCAT assessments use a variety of modeling approaches, which means that there is no single value (in biomass or in numbers of individuals) that can be defined as the limit reference point. Overfished status is determined relative to B_{MSY} or a proxy for B_{MSY} (e.g., SSF_{MSY}), which is proposed as the abundance target for Shortfin Mako. There is no proposed distribution target, given that the population occurs throughout the North Atlantic.

POPULATION PROJECTIONS

Current population dynamics parameters

During the majority of fisheries assessments, population projections are carried out to assess the probability of stock rebuilding under various levels of fishing mortality. The most recent ICCAT assessment used an age-structured model (implemented in Stock Synthesis) in the projections, assuming Total Allowable Catch (TAC) increments of 100 mt, from 0 to 1100 mt, and the most up-to-date values for population-dynamics parameters (Anon 2020). The population was projected forward until 2070 (representing approximately 2 generations) and the results were summarized as the probability of achieving a specific level of population increase in 5-year time increments.

The projections suggest that total removals (landings + dead discards + post-release mortality of live releases) of 500 mt or less would only have a 52% probability of rebuilding the stock to SSF_{MSY} by 2070 (Table 16; Anon 2020). Even if total removals were zero, there was only an 81% probability that the population would reach the abundance target by 2070 (Anon 2020). The highest level of fishing mortality that was assessed was 1100 mt, which resulted in a 10% probability that the stock could rebuild to SSF_{MSY} by 2070. For comparison, total fisheries removals (landings plus dead discards) were 1863 mt in 2019. Reporting of discards and the condition of discards is known to be poor, so total fisheries removals in any year are known to be underestimated.

Another important characteristic of the projections are that they predict continued population decline to 2035 under any removal scenario. This can be seen through the consistently lower probabilities of achieving SSF_{MSY} until 2035 (Table 16). This occurs because the fishery catches juvenile animals, which creates a lag between reductions in fishing and increased reproductive output. In other words, if we stop fishing on 8–10 year-olds, it will still take 10 years for these females to mature and begin to contribute to reproductive output, thus enabling population increase.

Unlike other fishes that can have large variations in recruitment, elasmobranchs have relatively fixed reproductive output and capacity for population growth (Kindsvater et al. 2016). There has been no measurable change in key reproductive parameters, such as length- or weight-at-maturity, over the last 50 years (Natanson et al. 2020) and large variations in survival over ontogeny are not expected for a long-lived top predator. Taken together, these characteristics suggest that population dynamics parameters are relatively fixed. We consider it unlikely that higher productivity could be achieved through changes to life-history rates in isolation of changes to fishing mortality, so we did not develop projections assuming higher productivity.

Persistent Limitation

The Policy on Recovery and Survival (Government of Canada 2021) broadly defines recovery as returning a species to its natural condition in Canada prior to it being put at risk by human activities. Recovery is considered to be technically feasible if there are scientific and management options or technological measures that could realistically be applied in time to achieve recovery targets. Recovery is biologically feasible if the life history characteristics of the species can still allow it to achieve a recovered state.

A Persistent Limitation is defined as a constraint on the ability to return a species to its natural condition. It may represent irreversible biological or ecological conditions that cannot be reasonably mitigated or a technical limitation on our ability to reverse changes to the species, its habitat, or the broader ecosystem (e.g., climate change). Shortfin Mako inhabit the entire North Atlantic and are subject to numerous international fisheries over which Canada has no direct control. Fishing mortality is the only known threat to the population (COSEWIC 2019) and despite scientific advice to prohibit retention of the species (Anon 2020), restrictive management measures, such as a TAC, have not been implemented internationally.

Based on the population projections, the current level of fishing mortality in the North Atlantic will not allow recovery, even though recovery remains biologically feasible. Fishing mortality needs to decline to 500 mt or less to have a > 50% probability of achieving recovery within two generations. Over the last 20 years, Canadian catches in the North Atlantic have been a fraction of those from other nations, only exceeding 100 mt in three years: 1995, 1997, and 2017 (Table 4). Even if Canadian fisheries removals (landings + dead discards + post-release mortality of live releases) became zero, total international removals would remain well above 500 mt under current management. In isolation, there is no scope for Canada to affect recovery of the DU.

SUPPLY OF SUITABLE HABITAT: NOT RELEVANT

Element 14: Recovery Targets: 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.

The abundance of Shortfin Mako is not limited by the amount of habitat available even if the population were to increase substantially in size. Beyond being widely distributed, this species is a generalist predator (Preti et al. 2012) and can partially regulate its body temperature (Block and Carey 1985, Bernal et al. 2001), two characteristics that ensure Shortfin Mako can thrive in a wide variety of conditions.

SCENARIOS FOR MITIGATION

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).

BYCATCH MITIGATION

There are two general types of mitigation measures, those that prevent capture and those that minimize mortality after capture. Preventing the initial capture of Shortfin Mako is the best-case scenario in terms of: (1) reducing at-vessel and post-release mortality from fisheries and (2) reducing detrimental impacts to fishers (e.g., by increasing the number of available hooks for valuable target species, lowering depredation of catch, decreasing the time needed to retrieve and fix gear, and limiting crew exposure to possible injury from shark bites; Gilman et al. 2008). Once a Shortfin Mako does interact with fishing gear, mitigation measures can reduce at-vessel mortality, mortality during handling, and/or post-release mortality.

It can be challenging to determine strategies to mitigate the impacts of bycatch while maintaining sustainable and economical commercial harvest levels of target species (O'Keefe et al. 2014). In some situations, bycatch mitigation approaches have been successful for conservation and socio-economic goals (e.g., Hall & Mainprize 2005). However, various methods can also lead to unintended biological and socio-economic impacts, including displacement of fishing effort, changes in the length-frequency distribution of the catches of non-target species, reduced catch of target species, increased operational costs, and increased administrative responsibility (Finkelstein et al. 2008, O'Keefe et al. 2014). It is also important to recognize that specific mitigation measures will not be optimal for all species of bycatch (Gilman et al. 2016b, Gilman et al. 2019). Also, it can be unclear if benefits relative to one component of mortality (e.g., at-vessel mortality) are offset by increases in other components (e.g., PRM); for examples, see the *Effectiveness of Mitigation: Hook Characteristics* section below. Finally, obtaining adequate sample size across all potential covariates is extremely difficult when assessing which factors are primarily related to mortality in pelagic sharks. This makes it extremely difficult to validate specific mitigation measures (see *Bycatch Mitigation: Handling Practices* section below).

This review of bycatch mitigation focuses on pelagic longline, largely because this gear type has been studied the most extensively in relation to pelagic shark bycatch. We also briefly consider Bycatch Reduction Devices (BRDs) for demersal trawls. We did not consider options specific to recreational fisheries, such as minimum size restrictions, given that Canadian recreational fishing is exclusively catch and release.

Current Management

There are multiple measures currently in place to monitor, as well as mitigate, Shortfin Mako bycatch from Canadian fisheries. Note that this list does not consider the relative strengths or weaknesses of specific programs.

ASO coverage and dockside monitoring – Integrated Fisheries Management Plans (IFMPs) are used to identify goals and measures relating to conservation, management, and science for a particular species. Given that Shortfin Mako have always been identified as a bycatch rather than a target species, they fall under multiple IFMPs (e.g., IFMP Atlantic Bluefin Tuna, Canadian Atlantic Swordfish and Other Tunas IFMP). Targets for ASO coverage, as well as dockside monitoring requirements, are detailed in IFMPs. Dockside monitoring has the dual goal of verifying the accuracy of landing data for management of the fishery and allowing monitoring for compliance and enforcement. The ASO program provides independent data on fishing activities, including information on effort, catches, and discards at sea.

Mandatory bycatch reporting – As of 2018, mandatory reporting of bycatch through a Supplementary Logbook was instituted for the pelagic longline fleet. This was intended to allow fleetwide Shortfin Mako discards to be quantified and enable a better characterization of total fishing mortality.

Shark Finning Ban – The practice of removing and retaining the dorsal, pectoral, and lower caudal fins at sea and discarding the finless carcass (Gilman et al. 2008) has been banned in Canadian waters since 1994 (Campana et al. 2004b). The ban applies to Canadian waters as well as to Canadian licensed vessels fishing outside of the EEZ (DFO 2007).

Fins Attached Policy – Groundfish license-holders are required to land all pelagic sharks with fins attached. Historically, large pelagic license-holders were permitted to remove shark fins so long as the carcass was also landed and the fin to body ratio was within 5% (DFO 2007). As of 2018, license conditions were changed for pelagic fisheries to require all sharks to be landed with fins attached.

International Trade in Fins – In 2019, Canada banned the import and export of shark fins as part of the revisions to the *Fisheries Act* under Bill C-68.

Section 74 Permitting for SAR – White Shark (*Carcharodon carcharias*) are currently listed on Schedule 1 of the *Species at Risk Act*. In 2018 and 2019, license conditions were added for regional and national fisheries with the potential to interact with White Shark. Only the recreational shark tournaments in Maritimes Region had licence conditions added in 2017. Many of these (e.g., recreational shark fisheries in Maritimes, Gulf and Newfoundland and Labrador regions) would also be expected to interact with Shortfin Mako. Given that the license conditions are designed to minimize the potential for harm to White Shark, they would also be expected to minimize the potential for harm to other large sharks, including Shortfin Mako.

Landings restrictions – In 2018, Canada implemented mandatory release of all live captures of Shortfin Mako intercepted by Canadian pelagic fisheries following ICCAT Recommendation 17-08. In 2020, license conditions for the pelagic longline fleet were amended to prohibit retention (no live or dead Mako can be landed) and a similar condition will be implemented in 2021 for fixed-gear groundfish.

Recreational Shark Tournaments – As of 2018, Shortfin Mako can no longer be landed at shark tournaments (typically 4–6 annually at multiple locations in Nova Scotia) owing to concerns over status (Anon 2018).

CITES listing – As of 2019, Shortfin Mako were listed on Appendix II of the Convention on International Trade in Endangered Species (CITES). This listing requires that any Shortfin Mako landed from captures in international waters, as well as any imports or exports of Shortfin Mako or Mako products have an associated Non-Detriment Finding (NDF). The NDF certifies that the catches come from fisheries or other sources (e.g., scientific sampling) that will not jeopardize the survival of the species in the wild.

Shark Finning Ban

Although the practice of shark finning appears to be declining on a global scale, fins continue to be the most valuable part of many species (Jaiteh et al. 2017). Canada was one of the first countries to ban the practice of finning and anecdotal information suggests that it was not common in Atlantic Canada, particularly in recent years. Canada's finning ban coupled with the requirement to land the animal with the fins attached is expected to ensure that finning does not contribute to fishing mortality for Shortfin Mako in Canadian waters.

Hook Characteristics

The use of circle hooks over the standard J-hook in pelagic fisheries has been advanced as a means of reducing both the frequency of interactions and rates of at-vessel/post-release mortality for bycatch. Early experiments along the Grand Banks conducted in 2002–2003 by the

US National Marine Fisheries Service suggested that the use of circle hooks substantially reduced catch rates as well as the incidence of gut-hooking for Loggerhead Sea Turtles, while maintaining high catch rates of Swordfish (Epperly et al. 2012). As circle hooks predominantly set in the jaw of caught fish, the removal of the hook may be possible, thus reducing the amount of gear left in a released fish (Cooke and Suski 2004). Also, circle hooks are generally thought to reduce the incidence of gut or foul hooking, leading to lower post-release mortality (Carruthers et al. 2009, Afonso et al. 2011, Epperly et al. 2012, Godin et al. 2012, Gilman et al. 2016b). However, hook retention times may be longer, based on an experiment with captive Pelagic Stingray (*Pteroplatytrygon violacea*) that showed all J-hooks were expelled within 6 days as compared to a mean of 45 days for circle hooks (Poisson et al. 2019). Relative retention times for J-hooks and circle hooks have not been assessed for Shortfin Mako.

Corrodible hooks, as opposed to stainless steel, are widely used as a bycatch mitigation measure to limit the amount of time that retained gear will remain in a shark, and are thought to reduce post-release mortality from infection or cessation of feeding (Mucientes and Queiroz 2019). Although corrodible hooks are expected to be shed more quickly, there is very little research that supports this due to the need to observe individual animals in captivity or as they are hooked/lose hooks. A recent study on Tiger Sharks (*Galeocerdo cuvier*), observed via cage diving over an 8-year period, found that stainless steel and corrodible circle hooks had similar median retention times of less than 1 year, yet all corrodible hooks were lost within 2.5 years as compared to 7.6 years for stainless (Begue et al. 2020). The authors found that residual hooks and trailing line did not impact Tiger Shark growth, yet they note that only a single gut-hooked shark was observed so there is the potential that their survival is lower than for jaw-hooked sharks.

Although the idea is largely untested, “weak” hooks have also been proposed as a mitigation measure. The hooks would be designed to have a lower breaking point so that larger individuals could escape the gear (Poisson et al. 2016).

Leader Characteristics

Different materials can be used to attach hooks to the gangions, including nylon, monofilament, and steel leaders. For pelagic sharks, monofilament or nylon leaders are expected to reduce capture probability because sharks are better able to bite through the leader and free themselves after being hooked (Afonso et al. 2012, Ward et al. 2008). Bite-offs reduce the amount of time a shark is attached to the gear and eliminate any handling—two factors which are thought to significantly decrease mortality (Marshall et al. 2012).

It is extremely difficult to determine the fate of a shark once it has escaped capture (e.g., no potential for tagging to assess mortality), meaning the effect of bite-offs has not been quantified when comparing leader materials or hook types. Monofilament leaders increase the prevalence of bite-offs, which could lead to high post-release mortality due to the hook and portion of leader still being attached (Mucientes and Queiroz 2019). In fisheries using good handling practices and where live sharks must be released, wire leaders may lead to less post-release mortality due to the reduction of gear left in sharks (Gilman et al. 2016b). Alternately, if time on the line is the more significant predictor of mortality (Gallagher et al. 2014), monofilament leaders may be optimal. Comparing the probability of shark survival after escaping from monofilament leaders with an ingested hook and trailing line versus when captured on wire leaders has been flagged as a research priority for pelagic sharks (Gilman et al. 2016a).

Bait Type

Small pelagic fishes such as mackerel, as well as squid, are commonly used baits in longline fisheries (Coelho et al. 2012a). The majority of studies report increased catch rates of Shortfin Mako when mackerel-type baits are used instead of squid (Foster et al. 2012, Coelho et al. 2012a), with the possible exception of smaller sharks (Fernandez-Carvalho et al. 2015). Also, gut-hooking of Shortfin Mako may be more prevalent from mackerel baits (Epperly et al. 2012), which would suggest that using squid is optimal. However, using squid as bait also significantly increases both Blue Shark and sea turtle catch rates (Watson et al. 2005, Foster et al. 2012), suggesting there are other ecosystem considerations for this type of a mitigation measure. Alternatively, selective artificial baits are promising, but tested versions are currently expensive, reduce target species catch, and/or have unknown effects on shark catch rates (Kumar et al. 2016).

Handling Practices

Handling practices for large pelagic sharks have shifted to minimize interaction times through in-water release. High mortality is expected from things like gaffing sharks during boarding, cutting jaws to remove hooks, and/or lifting animals by their caudal peduncle out of the water (Gilman et al. 2008, reviewed in Clarke et al. 2014). Less physiological damage is expected from keeping the shark in the water and either removing embedded hooks using a de-hooking tool (Curran et al. 2014) or cutting the leader as close as possible to the hook.

When pelagic sharks are released in the water, trailing line is thought to be related to subsequent post-release mortality, where the probability of mortality is hypothesized to be a function of: (1) the amount of line ingested, (2) the length of line relative to the organism's size, or (3) the materials making up the trailing line (e.g., steel cable, weights, monofilament, etc.). Unfortunately, when the biological significance of trailing line has been evaluated for pelagic sharks, studies do not demonstrate a clear relationship with mortality (e.g., Gilman et al. 2016a), typically because it is difficult to control for all correlated variables (e.g., hook type, leader type, or hooking location). For example, Silky Sharks and Blue Sharks with small amounts of trailing line (up to 2 m) exhibited no significant differences in mortality from other shark captures (Musyl and Gilman 2018), based on captures using monofilament as opposed to steal leaders. Although no effect on growth or feeding behavior was found for Tiger Sharks with trailing line (Begue et al. 2020), nearly all individuals were mouth-hooked rather than gut-hooked. Higher mortality was found for Common Thresher Sharks (*Alopias vulpinus*) with trailing line, but these individuals were tail-hooked rather than mouth- or gut-hooked (Sepulveda et al. 2015). Obtaining adequate sample size across all potential covariates is extremely difficult when assessing which factors are primarily related to mortality in pelagic sharks, which makes it extremely difficult to validate specific mitigation measures.

Deterrents

Adding magnets, electropositive and rare-earth metals, or electrical deterrents to the hook or leader have been explored as mitigation measures. Permanent magnets have been found to deter individuals of some species under differing circumstances (Rigg et al. 2009, O'Connell et al. 2011a, 2011b, 2014a); however, the opposite behaviour was reported in Blue Sharks which were caught more frequently on longlines with magnets attached (Porsmoguer et al. 2015b). Large, fast, active shark species like Shortfin Mako may be less likely to be deterred by these devices as they are primarily visual predators (Compagno 2001). Electropositive and rare-earth metals have been shown to repel some shark species (Brill et al. 2009) but this effect can be short-lived and species-specific (Godin et al. 2013, O'Connell et al. 2014b). Electrical field deterrents seem promising but are also highly species- and contextually-specific (Huveneers et al. 2013). Additional research into these attachments is necessary before they can be considered for use on large-scale commercial operations, particularly considering the high costs associated with equipping and maintaining this gear, and the unknown effects on catch rates of target species (O'Connell et al. 2014b).

Acoustic and chemical repellents have been tested to varying degrees of effectiveness. The use of Orca calls and specific audio tones have recently been shown to deter reef and White Sharks from baited experimental areas (Chapuis et al. 2019). As an occasional prey species of Orca, Shortfin Mako may also be deterred by these calls, although this has yet to be tested. One issue, however, is that species of teleost fish are also deterred by Orca calls, potentially limiting catch of target species as well (Wilson and Dill 2002, Doksæter et al. 2009). Semiochemical repellents have focused on shark necronomes, which are chemicals given off when a shark dies. This may deter sharks based on the potential of a predator in the area (O'Connell et al. 2014b), but may be less effective for a species such as Shortfin Mako that would be expected to prey on other sharks. A drawback of chemical deterrents is the need for the scent to remain concentrated and close to deployed gear, which may be unlikely for the entire deployment duration of a longline due to gear drift or water movement.

Landing Prohibitions

Estimates of the percentage of animals that are dead after capture (at-vessel mortality) range from 33–56% for Shortfin Mako (Coelho et al. 2011, 2012b). This means that the majority of captures can be released alive, albeit with varying degrees of injury associated with capture. In situations where all captures tend to be landed, live release measures are very effective at reducing fishing mortality, particularly when subsequent handling practices are designed to minimize post-release mortality (Gilman et al. 2008, reviewed in Clarke et al. 2014). A complete prohibition of landings may further reduce mortality, given that there is no potential for shark condition to be erroneously assigned (i.e., where injured animals are considered dead).

Prohibiting landings immediately reduces fishing mortality on a population and may lead to changes in behaviour by the fleet (e.g., increased avoidance). This has been the only conservation measure implemented for pelagic shark species that are of interest to ICCAT, and was strongly recommended by the science working group at the most recent stock assessment for North Atlantic Shortfin Mako (Anon 2020).

Gear Placement

The timing and depth of gear deployments has been proposed as a possible measure to minimize Shortfin Mako interactions with longline gear. Shortfin Mako predominately live within the mixed layer except for regular deep dives, mostly during the day (Abascal et al. 2011, Vaudo et al. 2016). Setting longline gear deeper and during the night could be an option to reduce interaction rates (Carruthers et al. 2011). One study found that a reduction of shallow-set hooks, in response to Leatherback Sea Turtle bycatch near Hawaii, significantly reduced the catch of Blue and Shortfin Mako sharks as well (Walsh et al. 2009). However, the shallow-set fishery targeted Swordfish and the deep-set fishery targeted Bigeye Tuna (*Thunnus obesus*). Additionally, deep sets were associated with higher levels of Thresher Shark bycatch. This would suggest that moving to deep-set hooks would negatively affect target species catch and could have negative effects on other pelagic shark species.

Restricting Effort

Total fishing effort could be reduced by limiting the total time that gear may remain in the water (i.e., soak time) as well as the total number of hooks that can be fished. Reducing the amount of time a Shortfin Mako remains on a hook reduces at-vessel mortality (Carruthers et al. 2011, Massey et al. 2019) given that hooked sharks expel significant amounts of energy. Mako must keep swimming to respire and thus experience lower oxygen uptake while hooked (Bouyoucos et al. 2017). Increased time on the hook has been linked to significant increases in stress response metabolites, including heat shock protein and lactate, which are associated with increased post-release mortality in Shortfin Mako (Marshall et al. 2012). Reduced soak times may also be more efficient as the scent cloud of bait dissipates quickly, typically within 3–4 hours (Ward et al. 2004) and there would be less opportunity for depredation of catch (Mandelman et al. 2008). Restricting the number of hooks would spatially constrain effort (i.e., a smaller area would be fished) and would likely reduce species-specific interaction rates with the gear, provided the total number of sets that could be in the water at any one time was limited as well. Given that electronic monitoring beacons are deployed on longlines, the potential for monitoring would be relatively high. Possible effects on target-species catch rates as well as any logistical challenges (i.e., working hours of vessel crew) associated with effort restrictions have not been tested.

Time-area closures

Temporal and spatial management measures have been used as effective mitigation tools for bycatch, where fishing activity is restricted within a defined region and/or at a defined time of year. Such measures work well when particular species occupy defined habitat types over a year, at specific times over ontogeny, and/or when the protected area is large relative to the species' capacity for movement. However, marine predators like Mako are not strongly associated with static spatial features and are highly mobile, which severely limits the effectiveness of permanent spatial or temporal closures (Hazen et al. 2018). All ontogenetic stages of Shortfin Mako are broadly distributed along the continental shelf of North America, seemingly without defined pupping or nursery areas (Natanson et al. 2020) that would lend themselves to spatial closures. Dynamic Ocean Management is currently considered to be a more effective approach in such situations.

Dynamic ocean management accounts for species movement, is robust to climate variability, and matches the spatial and temporal scales of fishing activity by providing end-users with predictions of relative catch and bycatch probabilities over space in near real-time, which they use to select fishing locations. Relative to static closures, simulation testing suggests that dynamic closures can be substantially smaller while still providing equivalent protection to species of conservation concern (Hazen et al. 2018). Although this approach is quite promising, it relies on two key components that do not currently exist in Canada: (1) a robust Species Distribution Model (SDM) for Shortfin Mako that quantifies the probability of occurrence relative to biologically-meaningful environmental predictors, and (2) an automated tool to use real-time environmental conditions to predict Shortfin Mako distribution that would be accessible to fishery participants. Developing either of these components is a multi-year undertaking with no guarantee of success. For example, the predictive power of the SDM needs to be high, which means that Shortfin Mako abundance and distribution must be strongly related to accessible environmental variables such as SST. Previous research in Canada on Porbeagle suggests this may be unlikely, as catches in the commercial fishery were not strongly associated with SST (Campana and Joyce 2004a).

Bycatch Reduction Devices (BRD)

Trawl nets can be fitted with widely-spaced bars at the opening of the net, which may or may not be combined with a vertical escape hatch at the top of the trawl (Wakefield et al. 2017). The efficacy of such devices for excluding marine megafauna (including various sharks) has been tested in demersal fisheries for teleosts in Australia and they tend to both prevent capture and lead to low injury rates for benthopelagic species (e.g., Lamniformes).

INVENTORY OF ACTIVITIES TO INCREASE PRODUCTIVITY: NOT RELEVANT

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

For Shortfin Mako in the North Atlantic, there has been no indication of changes to key life history parameters (i.e., length or weight at maturity) since monitoring began in the 1980s (Natanson et al. 2020). Outside of fishing pressure, there are no known changes to the ecosystem that would markedly influence natural mortality rates over ontogeny (e.g., large increases to predator populations). Thus, we consider it highly unlikely that survivorship or productivity parameters could be influenced by mitigation.

INVENTORY OF ACTIVITIES TO INCREASE HABITAT SUPPLY: NOT RELEVANT

Element 18: Mitigation: 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.

Restoring oceanographic conditions to their previous state is not an outcome that could realistically be expected from comparatively small-scale remediation activities occurring in Canada. It is also possible that threats like ocean warming could increase Shortfin Mako habitat use in Canadian waters, although it is unknown whether any redistribution would also result in population increase for the North Atlantic DU.

EFFECTIVENESS OF MITIGATION

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.

There are three main factors to keep in mind when discussing the effectiveness of mitigation: (1) how the measure affects capture probability, (2) how the measure affects at-vessel and post-release mortality rates, and (3) how the measure may influence the catch of the target species or other components of the ecosystem (e.g., other pelagic species). It is important to note that none of the mitigation measures identified in this document are known to optimize all three simultaneously. It is also worth considering whether specific mitigation options can be effectively enforced, given that they are unlikely to achieve their desired outcome if not.

Dedicated experimentation would be required to test the effectiveness of BRDs, various deterrents, bait/leader types, or gear placement for mitigating Shortfin Mako bycatch in the North Atlantic. We note that an exceptionally high level of monitoring effort would be required in such experiments because (1) large sample sizes are required for sufficient statistical power, and (2) Mako captures in various fisheries are relatively rare. We consider the potential to reduce mortality from such modifications to be very low in comparison with landings restrictions, particularly over the short term. The effectiveness of various spatial or temporal management strategies would need to be tested following their development from future spatio-temporal analyses of fleetwide catches. Similarly, the efficacy of effort restrictions in achieving a specified level of bycatch reduction or post-release mortality rate would need to be tested following implementation, given that catch rates of Shortfin Mako are not expected to be a linear function of effort.

Hook Characteristics

The effectiveness of using circle hooks as a bycatch mitigation measure for Shortfin Mako is controversial. There are studies reporting reductions in mortality, no reduction in mortality, or an actual increase in mortality (reviewed in Reinhardt et al. 2017) when using circle hooks as compared to J-hooks. The most recent meta-analysis suggests that a slight decrease in post-release mortality for Shortfin Mako would be expected from using circle hooks (Reinhardt et al. 2017). However, this same meta-analysis reports a much more substantial increase in capture probability from circle hooks (> 2x), which would lead to a greater proportion of the population being affected by the fishery. The slight decline in post-release mortality does not compensate for the increase in capture probability (particularly if captured individuals are landed), leading to higher total fishing mortality from pelagic longline when using circle hooks (Gilman et al. 2016b, Reinhardt et al. 2017, Semba et al. 2018). Although circle hooks appear to benefit sea turtles, odontocetes, and seabirds (Gilman et al. 2016b), they are unlikely to be an effective mitigation measure for Shortfin Mako, unless the mortality rate of gut-hooked animals that bite off after capture by J-hooks is extremely high. In addition, it is important to note that there is the possibility that J-hooks are expelled much more quickly (Poisson et al. 2019), which would minimize the amount of time that trailing gear would remain with the shark.

To our knowledge, the characteristics of weak hooks (e.g., suggested size or weight) as well as their effectiveness (e.g., the proportion of individuals released) has yet to be defined or tested (Poisson et al. 2016). One consideration is that juvenile Mako and Swordfish can be of similar size, so a weak hook is likely to reduce catch rates of the target species as well.

Handling Practices

Several tagging programs for pelagic sharks, including Canada's, have shifted towards tagging in the water as opposed to bringing animals on board in an effort to minimize handling effects. This affords a unique opportunity to assess how handling influences recovery time from datasets where the method of capture remains consistent (Bowlby et al. 2019). Longer recovery times are associated with processes that cause greater physical and physiological trauma to released animals (Ellis et al. 2017). Stresses associated with handling would be low relative to those associated with the capture process itself and are unlikely to be a large component of PRM (Campana et al. 2016, Musyl and Gilman 2019). However, handling effects are rarely evaluated, yet have important implications for how the capture process affects shark bycatch.

Bowlby et al. (2019) found a marked difference in Shortfin Mako dive-track characteristics among satellite-tagged individuals, where some animals tended to remain at constant, relatively shallow depths immediately following tagging rather than demonstrating cyclical dive patterns. The recovery period following tagging was identified from an analysis of dive-track variance, which found the point at which initial diving behavior was the most different from subsequent behavior. Comparing recovery times for individuals tagged in the water versus onboard a vessel, median recovery times were 1 day longer for Shortfin Mako (80th percentiles = 0, 5.5 days) and 1.5 days longer for Porbeagle (80th percentiles = -1.5, 5 days) when tagged onboard a vessel. Although credible intervals for both species included zero, the majority of the probability mass was positive, consistent with the idea that bringing an animal out of the water results in greater physiological stress (Bowlby et al. 2019). This analysis suggests that in-water release is optimal from fisheries that interact with Shortfin Mako.

Landings Prohibitions

From 2010–2017, at-vessel mortality rates from pelagic longline were consistently between 20–30%. There was a marked increase in 2018 and 2019 to 52% and 69% respectively, which coincides precisely with years where mandatory live release was a condition of license. Given the associated shift in the characterization of discards (where zero were classified as injured in 2019; Table 11), we consider it likely that ASOs were categorizing injured Shortfin Mako as dead so they could be legally landed. Coupled with the observation that injury category was not a good predictor of the potential for PRM (see Threats section), mandatory live release was not as effective as intended since the majority of captures were still being landed. Therefore, the switch to a complete prohibition of landings is expected to further reduce fishing mortality, in that injured animals will now have the possibility of survival.

We were not able to quantify the effect of the landings prohibition for the pelagic longline fleet, given apparent changes in at-vessel mortality rates. Either mortality at vessel is extremely high and a landings prohibition will have very little effect on total fishing mortality, or current at-vessel mortality rates are overestimated and a prohibition will have a much greater effect on total fishing mortality. Landings from other gear types are extremely low, so the prohibition will have very little impact in other fisheries.

PROJECTIONS AND EXPLORATION OF ADDITIONAL SCENARIOS

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.

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.

At present, we have limited ability to quantitatively link the levels of individual threats in Canada to an expected level of population response for Shortfin Mako in the North Atlantic. Until total fisheries removals approach a level that may allow population increase, incremental changes to variables such as interception probabilities, mortality rates, or the amount of bycatch will not be measurable. Also, due to the difficulties with properly controlling for all associated variables, the population-level impact of each specific mitigation measure is uncertain. This affects our ability to answer questions such as: How much will the implementation of mitigation measure X (or the combination of X, Y, and Z) change the population trajectory?

With the new regulations to prohibit landings of Shortfin Mako, the major components of fishing mortality in the future will be at-vessel and post-release. We consider the most credible estimate of at-vessel mortality to be 23% (mean value from 2010–2017; Table 12) following capture on pelagic longline. Of the released animals, an additional 28% (95% CI = 14%, 39%) would be expected to die following release (Bowlby et al. 2019). This combines to an overall mortality rate of 45% (CI = 34%, 53%), if only variability in the PRM rate is accounted for. The majority of captures are expected to live following interaction with the Canadian pelagic longline fishery.

Recent landings and discarding values can be used to approximate the magnitude of total mortality expected under the new prohibition on landings. As a very rough example, the approximate scale of unobserved discarding from the pelagic longline fleet would be in the realm of 10s of metric tons, based on ASO discards of 1–3 mt (Table 6) and approximate 10% observer coverage giving approximately 10–30 mt fleetwide discards in recent years. Reported Canadian landings ranged from 29.7 to 96.5 mt in the last 10 years (Table 5), giving a range of approximately 40–130 mt for total catches, ignoring discarding from other fleets. Under the landings prohibition, approximately 45% would be expected to die, leading to a total mortality estimate of approximately 18–59 mt by Canadian fisheries, ignoring variability in the overall mortality rate. Factors that would affect the magnitude of these estimates include: (1) whether or not observer coverage is representative, (2) the level of at-vessel mortality from the different fisheries that interact with Shortfin Mako, (3) correct propagation of error when combining multiple individual rate estimates, (4) incorporating discarding from fleets other than pelagic longline, and (5) any changes in fishing practices by the fleet that affect encounter probabilities, at-vessel or post-release mortality rates. This is not meant to be a definitive analysis, but to give a realistic scale for total fishing mortality under a zero-landings scenario to inform further discussion.

If scenarios that incorporate socioeconomic considerations are required for Shortfin Mako, one option would be to use a risk-based framework, such as the Mitigation Hierarchy (MH) for sharks proposed by Booth et al. (2020). This framework combines Ecological Risk Assessment (e.g., Cortés et al. 2010) with socioeconomic and societal goals and/or constraints to explore the management measures that would be most effective to reach a defined goal for the population (see the example workflow in Table 17). Although conceptually appealing, the methodology is complex and would require implementation through an international assessment body such as ICCAT to successfully define and reach recovery goals.

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 population projections carried out in the most recent Shortfin Mako assessment (Anon 2020) give the threshold of 500 mt as the maximum level of human-induced mortality that the population can sustain without jeopardizing its recovery. At this level of total removals (landings plus dead discards), there is an approximately 50% probability that the population will rebuild to MSY by 2070 (2 generations). Over the short term, the population is predicted to continue to decline until 2035 even if total removals drop to zero in the North Atlantic (Anon 2020). Even without any contribution from Canadian fisheries, international removals are well over the 500 mt threshold and are expected to remain high because a TAC has not been implemented.

Given this Persistent Limitation that constrains Canada's ability to recover Shortfin Mako, the concept of Allowable Harm from Canadian fisheries is not overly meaningful. Canadian fisheries have minimal contribution to total fishing mortality in the North Atlantic, remaining approximately 100 mt or less in recent years. In isolation, this level of mortality should not prevent population recovery, which would be predicted to occur between 2045 and 2050 with a 50% probability (Anon 2020). Conversely, if fishing mortality from Canadian fleets dropped to zero, the North Atlantic population of Shortfin Mako would still be threatened from international fisheries and would continue to decline over the long-term. The largest removals scenario considered in the population projections was 1100 mt (having a 10% probability of rebuilding to MSY by 2070), yet fisheries removals in 2019 were more substantially higher than that value. Eliminating Canadian fishing mortality would not be nearly enough to reduce current removals to the Allowable Harm threshold.

Considering the rough extrapolation of total fishing mortality above (Projections and Exploration of Additional Scenarios section), total removals from Canadian fisheries are expected to remain well below the 500 mt threshold for Allowable Harm for the North Atlantic population. Large increases in the potential for bycatch would require dramatic increases in total fishing effort from one of the main fleets that interact with Shortfin Mako or similarly large changes to interception probabilities, at-vessel mortality rates and/or post-release mortality.

CONCLUSIONS

Shortfin Mako are widely distributed throughout the North Atlantic and seasonally enter Canadian waters. Their general life-history characteristics include a relatively long lifespan, late age at maturity, and low reproductive output, which result in a low intrinsic rate of population increase (r = 0.036) and relatively long generation time (approximately 25 years). Low productivity makes the population highly susceptible to fishing pressure, the main threat identified in the North Atlantic.

There is no directed fishing for Shortfin Mako in Canada, although they are caught as bycatch in several Canadian fisheries, predominantly in Maritimes Region. Interception probabilities are highest from pelagic longline with an average of 48% of observed sets encountering Shortfin Mako, followed by bottom longline (0.4% of sets) and otter trawl (0.2% of sets). Recreational shark fishing is exclusively catch and release. Compared to international fisheries, the level of threat posed by individual Canadian fisheries is low to negligible.

Reliable physical or biochemical means of reducing interaction rates between Shortfin Mako and fishing gear (e.g., deterrents) have yet to be developed. Other changes to the manner of gear deployment are likely to negatively affect catch rates of Swordfish (e.g., deep-set longlines), increase bycatch of other pelagic species (e.g., switching to squid bait), or require dedicated experimentation to test (e.g., effort restrictions).

For mortality resulting from capture by pelagic longline (the most studied example), it is difficult to determine whether time on the line, the amount of trailing gear, or hooking location is the most influential predictor of total mortality (the combination of at-vessel mortality and PRM). For example: minimizing time on the line would suggest that using monofilament leaders, switching back to J-hooks (to increase bite-offs), and releasing animals in the water would be optimal, while recognizing that post-release mortality of gut-hooked sharks would be higher. Conversely, reducing the incidence of gut-hooking to decrease PRM would argue for the continued use of circle hooks, recognizing that catchability of Shortfin Mako will be higher and trailing gear is likely to persist for longer on released animals. On the balance of available evidence, the current practices of using mono-filament leaders and releasing sharks in the water by cutting the line as close as possible to the hook should be maintained. Mandatory use of circle hooks is likely not optimal for Shortfin Mako and this requirement could be revisited. However, we recognize that this would have implications for other species at risk in Canada, notably sea turtles.

The new landings prohibition is expected to lead to the greatest reduction in total mortality resulting from Canadian fisheries. If recent ASO data are representative, future mortality resulting from discarding by Canadian fleets is expected to remain below 100 mt annually, given recent PRM estimates and the average at-vessel mortality rate from 2010–2017. At this level of mortality, projections suggest that the population could recover to biomass at MSY (the proposed Recovery Target) in approximately 30 years. However, international fisheries represent a Persistent Limitation in the ability of Canada to reach this Recovery Target, and combined catches (e.g., 2,388 mt in 2018) must be reduced to 500 mt (i.e., the threshold for Allowable Harm) or less before recovery would be possible.

REFERENCES CITED

Abascal F.J., Quintans M., Ramos-Cartelle A., and Mejuto J. 2011. Movements and environmental preferences of the shortfin mako, *Isurus oxyrinchus*, in the southeastern Pacific Ocean. Mar. Biol. 158:1175–1184.

Afonso, A.S., Hazin, F.H.V., Carvalho, F., Pacheco, J.C., Hazin, H., Kerstetter, D.W., Murie, D., and Burgess, G.H. 2011. Fishing gear modifications to reduce elasmobranch mortality in pelagic and bottom longline fisheries off Northeast Brazil. Fish. Bull. 108:336–343.

Afonso, A.S., Santiago, R., Hazin, H., and Hazin, F.H.V. 2012. Shark bycatch and mortality and hook bite-offs in pelagic longlines: Interactions between hook types and leader materials. Fish. Res. 9(14):131–133.

Anon. 2013. 2012 Shortfin Mako stock assessment and ecological risk assessment meeting (Olhão, Portugal - June 11 to 18, 2012). ICCAT Col. Vol. Sci. Papers. 69 (4):1427–1570.

Anon. 2018. Report of the 2017 ICCAT Shortfin Mako assessment meeting (Madrid, Spain 12–16 June 2017). ICCAT Col. Vol. Sci. Papers. 74(4):1465–1561.

Anon. 2020. Report of the 2019 Shortfin Mako shark stock assessment update meeting (Madrid, Spain 20–24 May 2019).

Au, D.W., Smith, S.E., and Show, C. 2015. New abbreviated calculation for measuring intrinsic rebound potential in exploited fish populations — example for sharks. Can. J. Fish. Aquat. Sci. 72:767–773.

Banez, T. 2019. Masters Thesis. University of California San Diego. Examining Shortfin Mako and Blue Shark Movements in Relation to the Southern California Bight Oxygen Minimum Zone.

Barreto, R. R., de Farias, W. K. T., Andrade, H., Santana, F.M., and Lessa, R. 2016. Age, Growth and Spatial Distribution of the Life Stages of the Shortfin Mako, *Isurus oxyrinchus* (Rafinesque, 1810) Caught in the Western and Central Atlantic. PLoS ONE 11(4):e0153062.

Bates, N.R., Best, M.P.H., Neely, K., Garley, R., Dickson, A.G., and Johnson, R.J. 2012. Detecting anthropogenic carbon dioxide uptake and ocean acidification in the North Atlantic Ocean. Biogeosciences, 9:2509–2522.

Begue, M., Clua, C., Siu, G. and Meyer, C. 2020. Prevalence, persistence and impacts of residual fishing hooks on tiger sharks. Fish. Res. 224:105462.

Belkin, I.M. 2009. Rapid warming of Large Marine Ecosystems. Prog. Oceanogr. 81:207–213.

Bernal, D., Sepulveda, C., and Graham, J.B. 2001. Water-tunnel studies of heat balance in swimming mako sharks. J. Exp. Biol. 204:4043–4054.

Bigelow, K.A., Boggs, C.H., and He, X. 1999. Environmental effects on swordfish and blue shark catch rates in the US North Pacific longline fishery. Fish. Oceanogr. 8:178–198.

Bishop, S.D.H., Francis, M.P., Duffy, C., and Montgomery, J.C. 2006. Age, growth, maturity, longevity and natural mortality of the shortfin mako shark (*Isurus oxyrinchus*) in New Zealand waters. Mar. Freshwater Res. 57:143–154.

Biton-Porsmoguer, S., Banaru, D., Boudouresque, C.F., Dekeyser, I., Bouchoucha, M., Marco-Miralles, F., Lebreton, B., Guillou, G. and Harmelin-Vivien, M. 2018. Mercury in blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) from north-eastern Atlantic: Implication for fishery management. Mar. Pollut. Bull. 127:131–138.

Block, B.A. and Carey, F.G. 1985. Warm brain and eye temperatures in sharks. J. Comp. Physiol. B. 156:229–236.

Booth, H., Squires, D., Milner-Gulland, E.J. 2020. The mitigation hierarchy for sharks: A risk-based framework for reconciling trade-offs between shark conservation and fisheries objectives. Fish. Fisheries. 21:269–289.

Bouyoucos, I.A., Suski, C.D., Mandelman, J.W., and Brooks, E.J. 2017. The energetic, physiological, and behavioral response of lemon sharks (*Negaprion brevirostris*) to simulated longline capture. Comp. Biochem. Phys. A. 207:65–72.

Bowlby, H.D., Joyce, W., Benoit, H., and Sulikowski, J. 2019. Evaluation of post-release mortality for porbeagle and Shortfin Mako sharks from the Canadian pelagic longline fishery. ICCAT SCRS/2019/188:365–373.

Brill, R., Bushnell, P., Smith, L., Speaks, C., and Sundaram, R. 2009. The Repulsive And Feeding-Deterrent Effects Of Electropositive Metals On Juvenile Sandbar Sharks (*Carcharhinus Plumbeus*). Fish. Bull. 107:298–307.

Byrne, M.E., Cortés, E., Vaudo, J.J., Harvey, G.C.McN., Sampson, M., Wetherbee, B.M., and Shivji, M. 2017. Satellite telemetry reveals higher fishing mortality rates than previously estimated, suggesting overfishing of an apex marine predator. Proc. R. Soc. B. 284:20170658.

Byrne, M.E., Vaudo, J.J., Harvey, G.C.McN., Johnston, M.W., Wetherbee, B.M and Shivji, M. 2019. Behavioral response of a mobile marine predator to environmental variables differs across ecoregions. Ecography. 42:1569–1578.

Cailliet, G.M. 2015. Perspectives on elasmobranch life-history studies: a focus on age validation and relevance to fishery management. J. Fish Biol. 87:1271–1292.

Campana, S.E., Natanson, L.J., and Myklevoll, S. 2002. Bomb dating and age determination of large pelagic sharks. Can. Fish. Aquat. Sci. 59:450–455.

Campana, S.E. and Joyce, W.N. 2004a. Temperature and depth associations of porbeagle shark (*Lamna nasus*) in the northwest Atlantic. Fish. Oceanogr. 13:52–64.

Campana, S.E., Marks, L., and Joyce, W. 2004b. Biology, Fishery and Stock Status of Shortfin Mako Sharks (*Isurus oxyrinchus*) in Atlantic Canadian Waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/094.

Campana, S.E., Marks, L., and Joyce, W. 2005. The biology and fishery of shortfin mako sharks (*Isurus oxyrinchus*) in Atlantic Canadian waters. Fish. Res. 73:341–352.

Campana, S.E., Brasner, J., and Marks, L. 2006. Assessment of the Recovery Potential of Shortfin Mako Sharks in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/091.

Campana, S.E., Joyce, W., and Fowler, M. 2010. Subtropical pupping ground for a cold-water shark. Can. J. Fish. Aquat. Sci. 67:769–773.

Campana, S.E., Fowler, M., Houlihan, D., Joyce, W., Showell, M., Simpson, M.R., Miri, C.M., and Eagles, M. 2015. Recovery Potential Assessment for Porbeagle (*Lamna nasus*) in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/041.

Campana, S.E., Joyce, W., Fowler, M., and Showell, M. 2016. Discards, hooking, and post-release mortality of porbeagle (*Lamna nasus*), shortfin mako (*Isurus oxyrinchus*), and blue shark (*Prionace glauca*) in the Canadian pelagic longline fishery. ICES. J. Mar. Sci. 73(2):520–528.

Carruthers, E.H., Schneider, D.C., and Neilson, J.D. 2009. Estimating the odds of survival and identifying mitigation opportunities for common bycatch in pelagic longline fisheries. Biol. Cons. 142:2620–2630.

Carruthers, E.H., Neilson, J.D., and Smith, S.C. 2011. Overlooked bycatch mitigation opportunities in pelagic longline fisheries: Soak time and temperature effects on swordfish (*Xiphias gladius*) and blue shark (*Prionace glauca*) catch. Fish. Res. 108:112–120.

Castro, J. I. 2011. The sharks of North America. Oxford University Press, New York, New York

Cerna, F., and Licandeo, R. 2009. Age and growth of the shortfin mako (*Isurus oxyrinchus*) in the south-eastern Pacific off Chile. Mar. Freshwater Res. 60:394–403.

Chapuis, L., Collin, S.P., Yopak, K.E., McCauley, R.D., Kempster, R.M., Ryan, L.A., Schmidt, C., Kerr, C.C., Gennari, E., Egeberg, C.A., and Hart, N.S. 2019. The effect of underwater sounds on shark behaviour. Sci. Rep. UK. 9:6924.

Clarke, S., Sato, M., Small, C., Sullivan, B., Inoue, Y., and Ochi, D. 2014. Under Review. Bycatch in Longline Fisheries for Tuna and Tuna-like Species: a Global Review of Status and Mitigation Measures. WCPFC-SC10-2014/ EB-IP-04.

Cliff, G., Dudley, S.F.J., and Davis, B. 1990. Sharks caught in the protective gill nets off Natal, South Africa. 3. The shortfin mako shark *Isurus oxyrinchus* (Rafinesque). S. Afr. J. Marine Sci. 9(1):115–126.

Coelho, R., Lino, P.G., and Santos, M.N. 2011. At-haulback mortality of elasmobranchs caught on the portuguese longline swordfish fishery in the Indian Ocean. IOTC–2011–WPEB07–31.

Coelho, R., Santos, M.N., and Amorim, S. 2012a. Effects of hook and bait on targeted and bycatch fishes in an equatorial Atlantic pelagic longline fishery. B. Mar. Sci. 88(3):449–467.

Coelho, R., Fernandez-Carvalho, J., Lino, P.G., and Santos, M.N. 2012b. An overview of the hooking mortality of elasmobranchs caught in a swordfish pelagic longline fishery in the Atlantic Ocean. Aquat. Living Resour. 25:311–319.

Compagno, L. J. V. 2001. Sharks of the World. An annotated and illustrated catalogue of Shark species known to date. Volume 2. Bullhead, mackerel and carpet sharks (Heterodontformes, Lamniformes and Orectolobiformes). FAO species catalogue for fishery purposes 1. FAO, Rome. 269 pp.

Cooke, S.J., and Suski, C.D. 2004. Are circle hooks an effective tool for conserving marine and freshwater recreational catch-and-release fisheries? Aquat. Conserv. 14:299–326.

Corrigan S, Lowther, A.D., Beheregaray, L.B., Bruce, B.D., Cliff, G., Duffy, C.A., Foulis, A., Francis, M.P., Goldsworthy, S.D., Hyde, J.R., Jabado, R.W., Kacev, D., Marshall, L., Mucientes, G.R., Naylor, G.J.P., Pepperell, J.G., Queiroz, N., White, W.T., Wintner, S.P. and Rogers, P.J. 2018. Population Connectivity of the Highly Migratory Shortfin Mako (*Isurus oxyrinchus* Rafinesque 1810) and Implications for Management in the Southern Hemisphere. Front. Ecol. Evol. 6:187.

Cortés, E. 2016. Perspectives on the intrinsic rate of population growth. Methods Ecol. Evol. 7:1136–1145.

Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heupel, M., Holtzhausen, H., Santos, M.N., Ribera, M., and Simpfendorfer, C. 2010. Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. Aquat. Living Resour. 23:25–34.

COSEWIC. 2006. COSEWIC assessment and status report on the shortfin mako *Isurus oxyrinchus* (Atlantic population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 24 pp.

COSEWIC. 2017. COSEWIC assessment and update status report on the shortfin mako *Isurus oxyrinchus* Atlantic population in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 34 pp.

COSEWIC. 2019. *COSEWIC Assessment and Status Report on the Shortfin Mako (Isurus oxyrinchus)* Atlantic Population in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 38 pp. (Species at Risk Public Registry).

Curran, D. 2014. Shark Catch in Pelagic Longline Fisheries: A Review of Mitigation Measures. WCPFC-SC10-2014/ EB-IP-11

DFO. 2007. National Plan of Action for the Conservation and Management of Sharks. Communications Branch. Fisheries and Oceans Canada. Ottawa, ON.

DFO. 2014. Guidance on assessing threats, ecological risk and ecological impacts for Species At Risk. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/013.

DFO. 2017. Evaluation of Scope for Harm for White Shark (*Carcharodon carcharias*) in Atlantic Canada. DFO Can. Sci. Advis. Sec. Sci. Resp. 2017/025.

Doksæter, L., Godø, O.R., Handegard, N.O., Kvadsheim, P.H., Lam, F-P.A., Donovan, C., and Miller, P.J.O. 2009. Behavioral responses of herring (*Clupea harengus*) to 1–2 and 6–7kHz sonar signals and killer whale feeding sounds. J. Acoust. Soc. Am. 125:554.

Doño, F., Montealegre-Quijano, S., Domingo, A., and Kinas, P.G. 2015. Bayesian age and growth analysis of the shortfin mako shark *Isurus oxyrinchus* in the Western South Atlantic Ocean using a flexible model. Environ. Biol. Fish. 98:517–533.

Duffy, C., and Francis, M.P. 2001. Evidence of summer parturition in shortfin mako (*Isurus oxyrinchus*) sharks from New Zealand waters. New Zealand J. Mar. Freshwater Res. 35(2): 319–324.

Ellis, J.R., McCully, S.R., and Poisson, F. 2017. A review of capture and post-release mortality of elasmobranchs. J. Fish Biol. 90:653–722.

Epperly, S.P., Watson, J.W., Foster, D.G., and Shah, A.K. 2012. Anatomical Hooking Location and Condition of Animals Captured with Pelagic Longlines: The Grand Banks Experiments 2002–2003. Bull. Mar. Sci. 88(3):513–527.

Fernandez-Carvalho, J., Coelho, R., Santos, M.N., and Amorim, S. 2015. Effects of hook and bait in a tropical northeast Atlantic pelagic longline fishery: Part II—Target, bycatch and discard fishes. Fish. Res. 164:312–321.

Finkelstein, M., Bakker, V., Doak, D.F., Sullivan, B., Lewison, R., Satterthwaite, W.H., McIntyre, P.B., Wolf, S., Priddel, D., Arnold, J.M., Henry, R.W., Sievert, P., and Croxall, J. 2008. Evaluating the Potential Effectiveness of Compensatory Mitigation Strategies for Marine Bycatch. PLoS ONE 3(6):e2480.

Foster, D.G., Epperly, S.P., Shah, A.K., and Watson, J.W. 2012. Evaluation of Hook and Bait Type on the Catch Rates in the Western North Atlantic Ocean Pelagic Longline Fishery. Bull. Marine. Sci. 88(3):529–545.

Francis, M.P., and C. Duffy. 2005. Length at maturity in three pelagic sharks (*Lamna nasus*, *Isurus oxyrinchus*, and *Prionace glauca*) from New Zealand. Fish. Bull. 103:489–500.

Francis, M.P., Shivji, M.S., Duffy, C.A.J., Rogers, P.J., Byrne, M.E., Wetherbee, B.M., Tindale, S.C., Lyon, W.S., and Meyers, M.M. 2019. Oceanic nomad or coastal resident? Behavioural switching in the shortfin mako shark (*Isurus oxyrinchus*). Mar. Biol. 166:5.

French, R.P., Lyle, J., Tracey, S., Currie, S., and Semmens, J.M. 2015. High survivorship after catch-and-release fishing suggests physiological resilience in the endothermic shortfin mako shark (*Isurus oxyrinchus*). Conserv Physiol 3(1).

Gallagher, A.J., Serafy, J.E., Cooke, S.J., and Hammerschlag, N. 2014. Physiological stress response, reflex impairment, and survival of five sympatric shark species following experimental capture and release. Mar. Ecol. Prog. Ser. 496:207–218.

Gavaris, S., Clark, K.J., Hanke, A.R., Purchase, C.F. and Gale, J. 2010. Overview of Discards from Canadian Commercial Fisheries in NAFO Divisions 4V, 4W, 4X, 5Y and 5Z for 2002–2006. Can. Tech. Rep. Fish. Aquat. Sci. 2873.

Gedamke, T., Hoenig, J.M., Musick, J.A., DuPaul, W.D., and Gruber, S.H. 2007. Using Demographic Models to Determine Intrinsic Rate of Increase and Sustainable Fishing for Elasmobranchs: Pitfalls, Advances, and Applications. N. Am. J. Fish Manage. 27(2):605–618.

Gilman, E., Clarke, S., Brothers, N., Alfaro-Shigueto, J., Mandelman, J., Mangel, J., Petersen, S., Piovano, S., Thomson, N., Dazell, P., Donoso, M., Goren, M., and Werner, T. 2008. Shark interactions in pelagic longline fisheries. Mar. Policy. 32:1–18.

Gilman, E., Chaloupka, M., Merrifield, M., Malsol, N.D. and Cook, C. 2016a. Standardized catch and survival rates, and effect of a ban on shark retention, Palau pelagic longline fishery. Aquat. Con. Mar. Freshw. Ecosys. 26:1031–1062.

Gilman, E., Chaloupka, M., Swimmer, Y., and Piovano, S. 2016b. A cross-taxa assessment of pelagic longline by-catch mitigation measures: conflicts and mutual benefits to elasmobranchs. Fish Fish. 17:748–784.

Gilman, E., Chaloupka, M., Dagorn, L., Hall, M., Hobday, A., Musyl, M., Pitcher, T., Poisson, F., Restrepo, V., and Suuronen, P. 2019. Robbing Peter to pay Paul: replacing unintended cross-taxa conflicts with intentional tradeoffs by moving from piecemeal to integrated fisheries bycatch management. Rev. Fish. Biol. Fisheries. 29:93–123.

Gilmore, R. G. 1993. Reproductive biology of lamnoid sharks. Environ. Biol. Fish. 38:95–114.

Godin, A.C., Carlson, J.K., and Burgener, V. 2012. The effect of circle hooks on shark catchability and at-vessel mortality rates in longlines fisheries. Bull. Mar. Sci. 88(3):469–483.

Godin, A.C., Wimmer, T., Wang, J.H., and Worm, B. 2013. No effect from rare-earth metal deterrent on shark bycatch in a commercial pelagic longline trial. Fish. Res. 143:131–135.

Government of Canada. 2021. Species at Risk policy on survival and recovery: final version 2021. Species at Risk Act: Policies and Guidelines Series. Government of Canada, Ottawa. 9 pp.

Graham, J.B., Dewar, H., Lai, N.C., Lowell, W.R., and Arce, S.M. 1990. Aspects of shark swimming performance determined using a large water tunnel. J. Exp. Biol. 151:175–192.

Groeneveld, J.C., Cliff, G., Dudley, S.F.J., Foulis, A.J., Santos, J., and Wintner, S.P. 2014. Population structure and biology of shortfin mako, *Isurus oxyrinchus*, in the south-west Indian Ocean. Freshwater Res. 65:1045–1058.

Hall, S.J., and Mainprize, B.M. 2005. Managing by-catch and discards: how much progress are we making and how can we do better? Fish Fish. 6(2):134–155.

Harford, W.J. 2013. Trophic modeling of shortfin mako (*Isurus oxyrinchus*) and bluefish (*Pomatomus saltatrix*) interactions in the western north atlantic ocean. Bull. Mar. Sci. 89(1):161–188.

Hazen, E.L., Jorgensen, S., Rykaczewski, R.R., Bograd, S.J., Foley, D.G., Jonsen, I.D., Shaffer, S.A., Dunne, J.P., Costa, D.P., Crowder, L.B., and Block, B.A. 2013. Predicted habitat shifts of Pacific top predators in a changing climate. Nature. 3:234-238.

Hazen, E.L., Scales, K.L., Maxwell, S.M., Briscoe, D.K., Welch, H., Bograd, S.J., Bailey, H., Benson, S.R., Eguchi, T., Dewar, H., Kohin, S., Costa, D.P., Crowder, L.B., and Lewison, R.L. 2018. A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. Science Advances. 4(5):eaar3001.

Heist, E.J., Musick, J.A., and Graves, J.E. 1996. Genetic population structure of the shortfinmako (*Isurus oxyrinchus*) inferred fromrestriction fragment length polymorphismanalysis of mitochondrial DNA. Can. J. Fish. Aquat. Sci. 53(3):583–588.

Hoenig, J.M. 1983. Empirical Use of Longevity Data to Estimate Mortality Rates. Fisheries Bulletin. 82:898–903.

Holts, D.B., and Bedford D.W. 1993. Horizontal and Vertical Movements of the Shortfin Mako Shark, *Isurus oxyrinchus*, in the Southern California Bight. Aust. J. Mar. Freshwat. Res. 44:901–909.

Huveneers, C., Rogers, P.J., Semmens, J.M., Beckmann, C., Kock, A.A., Page, B., and Goldsworthy, S.D. 2013. Effects of an Electric Field on White Sharks: In Situ Testing of an Electric Deterrent. PLoS ONE 8(5):e62730.

ICCAT. 2020. 2020 SCRS Advice to the Commission. English version. Madrid Spain.

Jaiteh, V.F., Loneragan, N.R., and Warren, C. 2017. The end of shark finning? Impacts of declining catches and fin demand on coastal community livelihoods. Mar. Policy 82:224–233.

Joung, S-J. and Hsu, H-H. 2005. Reproduction and Embryonic Development of the Shortfin Mako, *Isurus oxyrinchus* Rafinesque, 1810, in the Northwestern Pacific. Zool. Stud. 44(4):487–496.

Kai, M., Shiozaki, K., Ohshimo, S., and Yokawa, K. 2015. Growth and spatiotemporal distribution of juvenile shortfin mako, *Isurus oxyrinchus*, in the western and central North Pacific. Mar. Freshwater Res. 66:1176–1190.

Kindsvater, H. K., Mangel, M., Reynolds, J. D., and Dulvy, N. K. 2016. Ten principles from evolutionary ecology essential for effective marine conservation. Ecol. Evol. 6:2125–2138.

Kumar, K.V.A., Pravin, P., and Meenakumari, B. 2016. Bait, Bait Loss, and Depredation in Pelagic Longline Fisheries–A Review. Rev. Fish. Sci. Aquac. 24(4):295–304.

Loefer J.K., Sedberry G.R., and McGovern J.C. 2005. Vertical Movements of a Shortfin Mako in the Western North Atlantic as Determined by Pop-up Satellite Tagging. Southeast Nat. 4:237–246.

Logan, J.M., Toppin, R., Smith, S., Galuardi, B., Porter, J., and Lutcavage, M. 2013. Contribution of cephalopod prey to the diet of large pelagic fish predators in the central North Atlantic Ocean. Deep-Sea Res. II 95:74–82.

Lyons, K., Preti, A., Madigan, D.J., Wells, R.J.D., Blasius, M.E., Snodgrass, O.E., Kacev, D., Harris, J.D., Dewar, H., Kohin, S., MacKenzie, K., and Lowe, C.G. 2015. Insights into the life history and ecology of a large shortfin mako shark *Isurus oxyrinchus* captured in southern California. J. Fish Biol. 87:200–211.

MacNeil, M.A., Skomal, G.B., and Fisk, A.T. 2005. Stable isotopes from multiple tissues reveal diet switching in sharks. Mar. Ecol. Prog. Ser. Vol. 302:199–206.

Maia, A., Queiroz, N., Correia, J.P., and Cabral, H. 2006. Food habits of the Shortfin Mako, *Isurus oxyrinchus*, off the southwest coast of Portugal. Environ. Biol. Fish. 77:157–167.

Maia, A., Queiroz, N., Cabral, H.N., Santos, A.M., and Correia, J.P. 2007. Reproductive biology and population dynamics of the Shortfin Mako, *Isurus oxyrinchus* Rafinesque, 1810, off the southwest Portuguese coast, eastern North Atlantic. J. Appl. Ichthyol. 23:246–251.

Malpica-Cruz, L., Herzka, S.Z., Sosa-Nishizaki, O., and Escobedo-Olvera, M.A. 2013. Tissue-specific stable isotope ratios of Shortfin Mako (*Isurus oxyrinchus*) and white (*Carcharodon carcharias*) sharks as indicators of size-based differences in foraging habitat and trophic level. Fish. Oceanogr. 22(6):429–445.

Mandelman, J.W., Cooper, P.W., Werner, T.B., and Lagueux, K.M. 2008. Shark bycatch and depredation in the U.S. Atlantic pelagic longline fishery. Rev. Fish Biol. Fisheries. 18:427–442.

Marshall, H., Field, L., Afiadata, A., Sepulveda, C., Skomal, G., and Bernal, D. 2012. Hematological indicators of stress in longline-captured sharks. Comp. Biochem. Phys. A. 162:121–129.

Massey, Y., Sabarros, P.S., Rabearisoa, N., and Bach, P. 2019. Drivers of at-haulback mortality of sharks caught during pelagic longline fishing experiments. IOTC–2019–WPEB15–14_Rev1.

Maunder, M.N., Sibert, J.R., Fonteneau, A., Hampton, J., Kleiber, P., and Harley, S.J. 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES J Mar. Sci. 63:1373–1385.

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

McCully, S.R., Scott, F., Ellis, J.R., and Pilling, G.M. 2013. Productivity and susceptibility analysis: application and suitability for data poor assessment of elasmobranchs in northern european seas. Collect. Vol. Sci. Pap. ICCAT. 69(4):1679–1698.

Mollet, H.F., Cliff, G., Pratt Jr., H.L., and Stevens, J.D. 2000. Reproductive biology of the female Shortfin Mako, *Isurus oxyrinchus* Rafinesque, 1810, with comments on the embryonic development of lamnoids. Fish. Bull. 98:299–318.

Mollet HF, Testi AD, Compagno LJV, Francis MP. 2002. Re-identification of a lamnid shark embryo. Fisheries Bulletin. 100:865–875.

Monteiro, M.S., Júnior, T.V., Barbosa, T.M., and Alves, M.D.O. 2006. Predation by a Shortfin Mako shark, *Isurus oxyrinchus*, Rafinesque, 1810, on a pantropical spotted dolphin, *Stenella atenuatta*, calf in central Atlantic waters. Lat. Am. J. Aquat. Mam. 5(2):141–144.

Mucientes, G., and Queiroz, N. 2019. Presence of plastic debris and retained fishing hooks in oceanic sharks. Mar. Pollut. Bull. 143:6–11.

Musyl, M.K., Brill, R.W., Curran, D.S., Fragoso, N.M., McNaughton, L.M., Nielsen, A., Kikkawa, B.S., and Moyes, C.D. 2011. Postrelease survival, vertical and horizontal movements, and thermal habitats of five species of pelagic sharks in the central Pacific Ocean. Fish. Bull. 109(4):341–368.

Musyl, M.K., and Gilman, E.L. 2018. Post-release fishing mortality of blue (*Prionace glauca*) and silky shark (*Carcharhinus falciformes*) from a Palauan-based commercial longline fishery. Rev. Fish. Biol. Fisheries. 28:567–586.

Nasby-Lucas, N., Dewar, H., Sosa-Nishizaki, O., Wilson, C., Hyde, J., Vetter, R.D., Wraith, J., Block, B.A., Kinney, M.J., Sippel, T., Holts, D.B., and Kohin, S. 2019. Movements of electronically tagged Shortfin Mako sharks (*Isurus oxyrinchus*) in the eastern North Pacific Ocean. Anim. Biotelem. 7:12.

Natanson, L.J., Kohler, N.E., Ardizzone, D., Cailliet, G.M., Wintner, S.P., and Mollet, H.F. 2006. Validated age and growth estimates for the Shortfin Mako, *Isurus oxyrinchus*, in the North Atlantic Ocean. Environ. Biol. Fish. 77:367–383.

Natanson, L.J., Skomal, G.B., Hoffmann, S.L., Porter, M.E., Goldman, K.J., and Serra, D. 2018. Age and growth of sharks: do vertebral band pairs record age? Mar. Freshwater Res. 69:1440–1452.

Natanson, L.J., Winton, M., Bowlby, H., Joyce, W., Deacy, B., Coelho, R., and Rosa, D. 2020. Updated reproductive parameters for the Shortfin Mako (*Isurus oxyrinchus*) in the North Atlantic Ocean with inferences of distribution by sex and reproductive stage. Fish. Bull. 118(1):21–36.

O'Connell, C.P., Abel, D.C., Gruber, S.H., Stroud, E.M., and Rice, P.H. 2011a. Response of juvenile lemon sharks, *Negaprion brevirostris*, to a magnetic barrier simulating a beach net. Ocean Coast Manage. 54:225–230.

O'Connell, C.P., Abel, D.C., Stroud, E.M., and Rice, P.H. 2011b. Analysis of permanent magnets as elasmobranch bycatch reduction devices in hook-and-line and longline trials. Fish. Bull. 109:394–401.

O'Connell, C.P., Andreotti, S., Rutzen, M., Meÿer, M., and He, P. 2014a. The use of permanent magnets to reduce elasmobranch encounter with a simulated beach net. 2. The great white shark (*Carcharodon carcharias*). Ocean Coast Manage. 97:20–28.

O'Connell, C.P., Stroud, E.M., and He, P. 2014b. The emerging field of electrosensory and semiochemical shark repellents: Mechanisms of detection, overview of past studies, and future directions. Ocean Coast Manage. 97:2–11,

O'Keefe, C.E., Cadrin, S.X., and Stokesbury, K.D.E. 2014. Evaluating effectiveness of time/area closures, quotas/caps, and fleet communications to reduce fisheries bycatch. ICES. J. Mar. Sci. 71(5) :1286–1297.

Poisson, F., Crespo, F.A., Ellis, J.R., Chavance, P., Bach, P., Santos, M.N., Séret, B., Korta, M., Coelho, R., Ariz, J., and Murua, H. 2016. Technical mitigation measures for sharks and rays in fisheries for tuna and tuna-like species: turning possibility into reality. Aquat. Living Resour. 29: 402.

Poisson, F., Catteau, S., Chiera, C., and Groul, J.-M. 2019. The effect of hook type and trailing gear on hook shedding and fate of pelagic stingray (*Pteroplatytrygon violacea*): New insights to develop effective mitigation approaches. Marine Policy. 107:103594.

Porsmoguer, S.B., Bănaru, D., Boudouresque, C.F., Dekeyser, I., Viricel, A., and Merchán, M. 2015a. DNA evidence of the consumption of short-beaked common dolphin *Delphinus delphis* by the Shortfin Mako shark *Isurus oxyrinchus*. Mar. Ecol. Prog. Ser. Vol. 532:177–183.

Porsmoguer, S.B., Bănaru, D., Boudouresque, C.F., Dekeyser, I., and Almarcha, C. 2015b. Hooks equipped with magnets can increase catches of blue shark (*Prionace glauca*) by longline fishery. Fish. Res. 172:345–351.

Pratt, H.L., and Casey, J.G. 1983. Age and Growth of the Shortfin Mako, *Isurus oxyrinchus*, Using Four Methods. Can. J. Fish. Aquat. Sci. 40:1944–1957.

Preti, A., Soykan, C.U., Dewar, H., Wells, R.J.D., Spear, N., and Kohin, S. 2012. Comparative feeding ecology of Shortfin Mako, blue and thresher sharks in the California Current. Environ. Biol. Fish. (2012) 95:127–146.

Queiroz, N., Humphries, N.E., Mucientes, G., Hammerschlag, N., Lima, F.P., Scales, K.L., Miller, P.I., Sousa, L.L., Seabra, R., and Sims, D.W. 2016. Ocean-wide tracking of pelagic sharks reveals extent of overlap with longline fishing hotspots. PNAS. vol. 113(6):1582–1587.

Reinhardt, J.F., Weaver, J., Latham, P.J., Dell'Apa, A., Serafy, J.E., Browder, J.A., Christman, M., Foster, D.G., and Blankinship, D.R. 2017. Catch rate and at-vessel mortality of circle hooks versus J-hooks in pelagic longline fisheries: A global meta-analysis. Fish Fish. 19:413–430.

Ribot-Carballal, M.C., Galván-Magaña, F., and Quiñónez-Velázquez, C. 2005. Age and growth of the Shortfin Mako shark, Isurus oxyrinchus, from the western coast of Baja California Sur, Mexico. Fish. Res. 76:14–21.

Rigby, C.L., Barreto R., Carlson J., Fernando D., Fordham S., Francis M.P., Jabado R.W., Liu K.M., Marshall A., Pacoureau N., Romanov E., Sherley R.B. & Winker H. 2019. *Isurus paucus*. The IUCN Red List of Threatened Species 2019 e.T60225A3095898.

Rigg, D.P., Peverell, S.C., Heardon, M., and Seymour, J.E. 2009. Do elasmobranch reactions to magnetic fields in water show promise for bycatch mitigation? Mar. Freshwater Res. 60:942–948.

Rogers, P.J., Corrigan, S., and Lowther, A. 2015. Using satellite tagging and molecular techniques to improve the ecologically sustainable fisheries management of Shortfin Makos (*Isurus oxyrinchus*) in the Australasian region. Final Report FRDC Tactical Research Fund Project No. 2011/077.

Semba, Y., Nakano, H., and Aoki, I. 2009. Age and growth analysis of the Shortfin Mako, *Isurus oxyrinchus*, in the western and central North Pacific Ocean. Environ. Biol. Fish. 84:377–391.

Semba, Y, Aoki, I., and Yokawa, K. 2011. Size at maturity and reproductive traits of Shortfin Mako, *Isurus oxyrinchus*, in the western and central North Pacific. Mar. Freshwater Res. 62:20–29.

Semba, Y., Kai, M., Oshima, K., Ouchi, D., and Honda, H. 2018. Trial evaluation of the effectiveness of the use of circle hooks to reduce mortality of Shortfin Mako shark in pelagic longline fisheries. Vol. Sci. Pap. ICCAT, 75(3):435–439.

Sepulveda, C.A., Kohin, S., Chan, C., Vetter, R., and Graham, J.B. 2004. Movement patterns, depth preferences, and stomach temperatures of free-swimming juvenile mako sharks, *Isurus oxyrinchus*, in the Southern California Bight. Mar. Biol. 145:191–199.

Sepulveda, C.A., Heberer, C., Aalbers, S.A., Spear, N., Kinney, M., Bernal, D., and Kohin, S. 2015. Post-release survivorship studies on common thresher sharks (*Alopias vulpinus*) captured in the southern California recreational fishery. Fish. Res. 161:102–108.

Showell, M.A., Fowler, G.M., Joyce, W., McMahon, M., Miri, C.M., and Simpson, M.R. 2017. Current Status and Threats to the North Atlantic Shortfin Mako Shark (*Isurus oxyrinchus*) Population in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/039. v + 45 p.

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

Stevens, J.D. 1983. Observations on Reproduction in the Shortfin Mako *Isurus oxyrinchus*. Copeia 1:126–130.

Stevens, J.D., Bonfil, R., Dulvy, N.K., and Walker, P.A. 2000. The effects of fishing on sharks, rays, and chimaeras (Chondrichthyans), and the implications for marine ecosystems. ICES. J. Mar. Sci. 57:476–494.

Stillwell, C.E., and Kohler, N.E. 1982. Food, Feeding Habits, and Estimates of Daily Ration of the Shortfn Mako (*Isurus oxyrinchus)* in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 39:407-414.

Stock, B.C., Ward, E.J., Thorson, J.T., Jannot, J.E., and Semmens, B.X. 2019. The utility of spatial model-based estimators of unobserved bycatch. ICES J. Mar. Sci. 76:255-267.

Taguchi, M., Kitamura, T., and Yokawa, K. 2011. Genetic population structure of shortfin mako (*Isurus oxyrinchus*) inferred from mitochondrial DNA on inter-oceanic scale. WP ISC Shark Working Group Workshop, 19-21 July 2011. (Cited with Permission of Author).

Tsai, W-P, Sun C-L, Punt A.E., and Liu K-M. 2014. Demographic analysis of the Shortfin Mako Shark, *Isurus oxyrinchus*, in the Northwest Pacific using a two-sex stage-based matrix model. ICES Journal of Marine Science. 71:1604-1618.

Vaudo J.J., Wetherbee B.M., Wood A.D., Weng K., Howey-Jordan L.A., Harvey G.M., and Shivji M.S. 2016. Vertical movements of Shortfin Mako sharks *Isurus oxyrinchus* in the western North Atlantic Ocean are strongly influenced by temperature. Mar. Ecol. Prog. Ser. 547:163–175.

Vaudo J.J., Byrne M.E., Wetherbee B.M., Harvey G.M., and Shivji M.S. 2017. Long-term satellite tracking reveals region-specific movements of a large pelagic predator, the Shortfin Mako shark, in the western North Atlantic Ocean. J. Appl. Ecol. 54:1765–1775.

Vetter, R., Kohin, S., Preti, A., McClatchie, S., and Dewar, H. 2008. Predatory interactions and niche overlap between mako shark, *Isurus oxyrinchus*, and jumbo squid, *Dosidicus gigas*, in the California current. CalCOFI Rep., Vol. 49/2008.

Visser, I.N., Berghan, J., van Meures, R., and Fertl, D. 2000. Killer whale (*Orcinus orca*) predation on a Shortfin Mako shark (*Isurus oxyrinchus*) in New Zealand waters. Aquat. Mamm. 26(3):229–231.

Wakefield, C.B., Santana-Garcon, J., Dorman, S.R., Blight, S., Denham, A., Wakeford, J., Molony, B.W., Newman, S.J. 2017. Performance of bycatch reduction devices varies for chondrichthyan, reptile, and cetacean mitigation in demersal fish trawl: assimilation subsurface interactions and unaccounted mortality. ICES J. Mar. Sci. 74:343–358.

Walsh, W.A., Bigelow, K.A., and Sender, K.L. 2009. Decreases in Shark Catches and Mortality in the Hawaii-Based Longline Fishery as Documented by Fishery Observers. Mar. Coast. Fish. Dyna., Man. Eco. Sci.1(1):270–282.

Ward , P., Myers, R.A., and Blanchard, W. 2004. A Fish lost at sea: the effect of soak time on pelagic longline catches. Fish. Bull. 102(1):179–195.

Ward, P., Lawrence, E., Darbyshire, R., and Hindmarsh, S. 2008. Large-scale experiment shows that nylon leaders reduce shark bycatch and benefit pelagic longline fishers. Fish. Res. 90:100–108.

Watson, J.W., Epperly, S.P., Shah, A.K., and Foster, D.G. 2005. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. Can. J. Fish. Aquat. Sci. 62:965–981.

Wells, R.J.D., Smith, S.E., Kohin, S., Freund, E., Spear, N. and Ramon, D.A. 2013. Age Validation of Juvenile Shortfin Mako (*Isurus oxyrinchus*) Tagged and Marked with Oxytetracycline off Southern California. Fish. Bull. 111:147–160.

Wilson, B., and Dill, L.M. 2002. Pacific herring respond to simulated odontocete echolocation sounds. Can. J. Fish. Aquat. Sci. 59:542–553.

Wood, A.D., and Wetherbee, B.M. 2009. Recalculated diet and daily ration of the Shortfin Mako (*Isurus oxyrinchus*), with a focus on quantifying predation on bluefish (*Pomatomus saltatrix*) in the northwest Atlantic Ocean. Fish. Bull. 107(1):76–88.

TABLES

Table 1. Basic biology and current life history parameters. Acronyms: NP = North Pacific, SP = South Pacific, NA = North Atlantic.

	Life history parameter	Female	Male	References
Growth and Aging	Parturition size (cm)	60–70 up to 88.7	60–70 up to 81.2	Mollet et al. 2000, Joung and Hsu 2005, Dono et al. 2015
	Growth rate (k) ($year^{-1}$)*	0.09 NP, 0.076 SP, 0.087 NA	0.16 NP, 0.087 SP, 0.125 NA	Natanson et al.2020, Cerna and Licandeo 2009, Semba et al. 2009
	Maximum length (cm)	339 NP, 300 SP, 336 NA	254 NP, 272 SP, 253 NA	Natanson et al.2020, Cerna and Licandeo 2009, Semba et al. 2009
	Longevity (years)	31–41 NP, 38 NA	24–31 NP, 21 NA	Tsai et al. 2014, Natanson et al. 2006
Maturity	Age (A_{50})	18 years	8 years	Natanson et al. 2006
	Length (L_{50})	280cm	182cm	Natanson et al.2020, Francis and Duffy 2005, Semba et al. 2011
	Weight (W_{50})	275kg	64kg	Natanson et al. 2020
Reproduction	Gestation (Months)	19–20 NA, 9–13 NP, 21 SP	-	Mollet et al. 2000, Semba et al. 2011, Duffy and Francis 2001
	Parturition	winter–spring, possibly into summer	-	Pratt and Casey 1983, Semba et al. 2011, Duffy and Francis 2001
	# of Pups	4–16	-	Mollet et al. 2000, Stevens 1983, Duffy and Francis 2001, Joung and Hsu 2005, Semba et al. 2011, Mollet et al. 2002
	Reproductive cycle	2–3 years	-	Mollet et al. 2000
Diet	Teleost fish, cephalopods, marine mammals, elasmobranchs. With increasing size, a trophic shift to larger prey likely occurs. Unlikely any sex specific diet, with the exception of possible size dependent diet shifts in mature females.			Stillwell and Kohler 1982, Wood et al. 2009, MacNeil et al. 2005, Logan et al. 2013, Maia et al. 2006, Harford 2013, Porsmoguer et al. 2015a, Monteiro et al. 2006, Vetter et al. 2008, Preti et al. 2012, Groeneveld et al. 2014, Cliff et al. 1990, Malpica-Cruz et al. 2013
Distribution and habitat	Circumglobal in all tropical to temperate seas between 50°N (60°N in NA) and 50°S. Preferred temperature range: 17–22°C. Majority of time spent in mixed layer with feeding dives down to 888m. Some age/size dependent habitat use may be present. Sex-specific distribution likely with males undertaking infrequent long migrations between ocean basins and females likely remaining within one basin			Compagno 2001, Abascal et al. 2011, Holts and Bedford 1993, Sepulveda et al. 2004, Francis et al. 2019, Byrne et al. 2019, Corrigan et al. 2018

** Parturition size and maximum length measures have been converted to FL for ease of comparison but reported growth rates from the same sources have not been converted. Consult referenced literature for original measurements.*

Table 2. Summary of long-term archival tag deployments on Shortfin Mako. When fork length could not be measured, an approximate value is given (*). Two tags were physically recovered (**) rather than transmitting data remotely.

Tag #	FL (cm)	Sex	Date Deployed	Release Lat. (N)	Release Lon. (W)	Pop-up Date	Pop-up Lat. (N)	Pop-up Lon. (W)	Days at Liberty	Onboard/ In water	Injury Status	Tag Type
09A0466	148	M	11-Aug-11	42.7002	63.2657	15-Aug-11	42.7350	-63.3620	4	on board	healthy	PAT MK10
08A1057	123	M	14-Aug-11	42.9232	62.3877	21-Aug-11	42.9310	-62.3850	7	on board	healthy	PAT MK10
10A1067	127	M	17-Aug-11	44.0833	58.4167	21-Aug-11	44.0900	-58.4140	4	on board	healthy	PAT MK10
08A1000	99	M	17-Aug-11	44.1833	58.2000	5-Sep-11	41.8960	53.8500	19	on board	healthy	PAT MK10
08A0999	127	M	17-Aug-11	43.9000	58.5833	11-Dec-11	38.7300	-42.6550	116	on board	healthy	PAT MK10
11A0430	210	M	25-Sep-11	42.1167	65.5500	24-Dec-11	39.7570	42.4300	90	on board	healthy	PAT MK10
11A0420	88	F	31-Jul-12	42.8177	62.5598	4-Aug-12	41.9190	62.2570	6	on board	healthy	PAT MK10
11A0419	81	F	29-Jul-12	42.8170	62.5478	5-Aug-12	42.3140	-61.8950	7	on board	healthy	PAT MK10
11A0432	80	M	30-Jul-12	42.9065	62.3017	7-Aug-12	42.9360	62.0800	8	on board	healthy	PAT MK10
11A0330	81	M	30-Jul-12	42.9128	62.3262	13-Aug-12	43.3130	60.3200	14	on board	healthy	PAT MK10
11A0434	118	M	29-Jul-12	42.6923	62.4122	15-Aug-12	41.7690	63.1400	17	on board	healthy	PAT MK10
11A0438	118	M	28-Jul-12	42.8502	62.5875	7-Sep-12	42.4640	62.8900	41	on board	healthy	PAT MK10
08A1056	152*	U	5-Aug-12	44.2950	62.1833	26-Sep-12	43.9040	36.5300	52	in water	healthy	PAT MK10
10A1068	127	F	28-Aug-12	44.4167	54.1000	27-Sep-12	45.9770	41.2700	30	on board	healthy	PAT MK10
11A0174	229*	M	18-Jul-13	41.3833	64.0167	22-Jul-13	41.0010	64.5300	1	in water	healthy	PAT MK10
08A1055	152*	F	18-Jul-13	41.8333	63.9333	9-Aug-13	42.8690	57.1720	5	in water	healthy	PAT MK10
13P0089	137*	M	15-Sep-13	42.5817	64.4283	27-Sep-13	40.5860	65.6000	13	in water	healthy	Mini-PAT
11A0431	110*	U	16-Aug-13	41.4000	62.0000	5-Oct-13	40.9800	66.0630	54	in water	healthy	PAT MK10
23494	88	F	7-Oct-13	42.9535	62.2773	13-Oct-13	42.9480	62.2880	7	on board	injured	X-Tag
13P0083	203*	F	25-Aug-13	42.9233	62.4317	15-Nov-13	39.4290	66.9200	80	in water	healthy	Mini-PAT
13P0080	152*	M	19-Aug-13	41.6337	62.3933	19-Nov-13	44.6810	-43.2660	94	in water	healthy	Mini-PAT
11A0435	166*	M	21-Sep-13	44.3683	61.8433	20-Nov-13	39.4440	68.2520	61	in water	healthy	PAT MK10
13P0087	92*	U	2-Sep-13	42.5833	64.6333	8-Dec-13	40.2410	59.0000	100	on board	healthy	Mini-PAT
13P0090	122*	M	16-Sep-13	42.5100	64.5950	10-Dec-13	38.8330	65.4300	88	in water	healthy	Mini-PAT
13P0085	122*	U	1-Sep-13	42.5000	64.5833	18-Dec-13	40.24	49.5100	111	on board	healthy	Mini-PAT
23501	175	F	5-Oct-13	40.9827	62.8493	14-Jan-14	33.7250	48.4090	102	on board	injured	X-Tag
11A0316	152*	F	18-Jul-13	41.3667	64.0500	19-Jan-14	25.9250	-49.6440	183	in water	healthy	PAT MK10
13P0088	183*	F	25-Aug-13	42.9433	62.2733	17-Feb-14	35.7560	-74.6630	179	in water	healthy	Mini-PAT
23502	90	U	11-Oct-13	43.6083	59.3503	20-Feb-14	39.6820	49.3010	133	on board	healthy	X-Tag
23499	100	M	11-Oct-13	43.5852	59.4240	**21-Feb-14	35.1000	46.6667	-	on board	healthy	X-Tag
13P0092	122*	M	19-Sep-13	42.5367	64.5250	21-Mar-14	36.8680	55.3080	185	in water	healthy	Mini-PAT
13P0024	122*	U	8-Sep-13	42.5367	64.5250	21-Apr-14	24.4840	-74.0580	-	in water	healthy	Mini-PAT
09A0465	112	F	14-Aug-11	42.8598	62.5090	**01-Sep-11	43.6190	59.2720	18	on board	injured	PAT MK10

Table 3. Lotek tagging summary. Tags that did not report (DNR) are identified in grey.

Tag #	FL (cm)	Sex	Date Deployed	Release Lat. (N)	Release Lon. (W)	Pop-up Date	Pop-up Lat. (N)	Pop-up Lon. (W)	Days at Liberty	Onboard/ in water	Injury status	Tag comment
1567	160	F	11-Sep-18	44.02283	-58.86867	9-Oct-18	41.32478	-45.01397	28	in water	injured	-
1588	158	M	23-Sep-17	42.85342	-62.57117	-	-	-	-	on board	moribund	DNR
1593	86	M	9-Sep-18	43.94200	-58.84483	-	-	-	-	on board	injured	DNR
1891	150	M	15-Oct-17	42.79933	-62.70983	12-Nov-17	38.17506	-61.15204	28	in water	healthy	-
1893	85	M	9-Sep-18	43.91030	-58.72733	7-Oct-18	43.28922	-58.71620	28	on board	injured	-
1894	170	M	9-Jul-18	41.84596	-65.35467	-	-	-	-	on board	healthy	DNR
1895	156	F	9-Jul-18	41.90891	-65.31948	-	-	-	-	on board	healthy	DNR
1897	93	M	12-Sep-18	44.03733	-58.63283	4-Oct-18	41.73749	-62.14722	22	on board	injured	-
1898	165	F	9-Jul-18	41.91291	-65.29633	6-Aug-18	41.55211	-60.50619	28	on board	healthy	-
1900	290	M	3-Jul-18	41.75205	-65.14163	-	-	-	-	on board	healthy	DNR
1901	183	M	8-Jul-18	41.82379	-64.99710	5-Aug-18	44.05171	-46.99350	28	in water	healthy	-
1902	120	F	15-Aug-19	42.86483	-62.47483	12-Sep-19	43.39959	-57.73531	28	in water	injured	-
1904	175	M	24-Sep-17	42.87898	-62.48003	22-Oct-17	40.12384	-72.50217	28	in water	healthy	-
1906	95	F	16-Sep-17	42.26353	-65.14952	14-Oct-17	41.57566	-62.53241	28	on board	healthy	-
1907	145	F	17-Sep-17	42.43333	-64.82817	15-Oct-17	38.70133	-71.22035	28	in water	healthy	-
1908	80	F	24-Sep-17	42.82647	-62.20697	20-Oct-17	39.49708	-52.36344	26	on board	healthy	-
2295	140	U	18-Sep-17	42.51783	-64.59704	16-Oct-17	38.38792	-70.78753	28	in water	healthy	-
2296	85	F	20-Sep-17	42.80170	-63.89002	18-Oct-17	40.29036	-68.92819	28	on board	healthy	-
2297	145	M	23-Sep-17	43.00152	-62.24893	-	-	-	-	in water	healthy	DNR
2299	102	M	25-Sep-17	42.86597	-62.22225	-	-	-	-	on board	moribund	DNR
2301	96	F	22-Sep-17	42.95477	-62.42352	7-Oct-17	42.67218	-61.65444	15	on board	healthy	-
2304	131	M	16-Sep-17	42.35193	-64.91108	-	-	-	-	on board	injured	DNR
2400	105	F	16-Jul-18	42.99650	-68.80067	-	-	-	-	on board	healthy	DNR
2405	137	F	14-Sep-18	43.98583	-58.87217	12-Oct-18	41.63615	-65.55949	28	on board	healthy	-
2419	140	M	17-Sep-18	43.64600	-59.60350	-	-	-	-	on board	healthy	DNR
2423	93	F	12-Sep-18	43.98983	-58.66267	16-Sep-18	43.959930	-58.66783	4	on board	injured	-

Table 4. Task 1 data representing annual landings and dead discards (metric tonnes) as reported to ICCAT. Data from ICCAT 2020.

Year	Canada	Japan	U.S.A.	European Union	Morocco	Mexico	Other Nations	Total
1994	0	214	574	2,813	0	0	58	3,659
1995	111	592	1658	2,866	0	10	69	5,306
1996	67	790	400	3,985	0	0	64	5,306
1997	110	258	345	2,770	0	0	51	3,534
1998	69	892	296	2,530	0	0	58	3,845
1999	70	120	198	2,380	0	0	90	2,858
2000	78	138	414	1,882	0	10	65	2,587
2001	69	105	350	2,064	0	16	73	2,677
2002	78	438	372	2,463	0	0	75	3,426
2003	73	267	106	3,318	147	10	66	3,987
2004	80	572	477	2,562	169	6	134	4,000
2005	91	0	422	2,860	215	9	98	3,695
2006	71	0	353	2,869	220	5	56	3,574
2007	72	82	319	3,354	151	8	172	4,158
2008	43	131	296	2,929	283	6	112	3,800
2009	53	98	314	3,415	476	7	178	4,541
2010	41	116	350	3,525	636	8	106	4,782
2011	37	53	332	2,712	420	8	158	3,720
2012	29	56	371	3,331	406	8	236	4,437
2013	35	33	363	2,329	667	4	172	3,603
2014	55	69	961	1,701	624	4	53	3,467
2015	85	45	572	1,585	947	4	43	3,281
2016	82	74	271	1,840	1,050	3	36	3,356
2017	109	89	302	2,061	450	5	103	3,119
2018	53	20	165	1,437	594	2	102	2,373
2019*	63	4	57	1,156	501	2	80	1,863

*10 countries out of 27 did not report data for 2019; catches from these countries would be very small

Table 5. Landings (mt) of Shortfin Mako by region, extracted from the Zonal Interchange File Format (ZIFF) database. Grey shading was added to aid interpretability. Other includes Trap Net and Miscellaneous Fixed Gears (1994 and 1995), Pot (2002), and Trap (2013).

Year	Region	Troll line, angling and handline	Otter trawl	Gillnets	Harpoon	Benthic and pelagic longline	Seine	Other	Regional total	Annual total
1994	Gulf	0	0	0	0	0	0	0	0	142.4
1994	Maritimes	2.324	1.654	9.523	0	117.603	0.075	0.051	131.23	-
1994	Newfoundland	0	0	4.53	0	6.461	0	0	10.991	-
1994	Quebec	0.225	0	0	0	0	0	0	0.225	-
1995	Gulf	0	0	0	0	0	0	0	0	111.0
1995	Maritimes	0.177	0.677	13.421	0.047	87.968	0.071	0.396	102.757	-
1995	Newfoundland	0	0	2.362	0	5.871	0	0	8.233	-
1995	Quebec	0	0	0	0	0	0	0	0	-
1996	Gulf	0	0	0	0	0	0	0	0	67.4
1996	Maritimes	0.287	0.978	7.782	0	50.468	0	0	59.515	-
1996	Newfoundland	0	0	2.297	0	5.601	0	0	7.898	-
1996	Quebec	0	0	0	0	0	0	0	0	-
1997	Gulf	0	0	0	0	0.19	0	0	0.19	109.5
1997	Maritimes	0.266	1.521	9.322	0	90.208	0	0	101.317	-
1997	Newfoundland	0	0.07	3.968	0	3.968	0	0	8.006	-
1997	Quebec	0	0	0	0	0	0	0	0	-
1998	Gulf	0	0	0	0	0.213	0	0	0.213	70.8
1998	Maritimes	0.205	2.184	7.971	0.561	46.172	0	0	57.093	-
1998	Newfoundland	0	0	4.004	0	9.483	0	0	13.487	-
1998	Quebec	0	0	0	0	0	0	0	0	-
1999	Gulf	0.039	0	0	0	0.351	0	0	0.39	70.7
1999	Maritimes	0.005	1.757	4.833	0.658	45.775	0	0.109	53.137	-
1999	Newfoundland	0.11	0.106	9.157	0	7.759	0	0	17.132	-
1999	Quebec	0	0	0	0	0	0	0	0.014	-
2000	Gulf	0	0	0	0	0.059	0	0	0.059	79.1

Year	Region	Troll line, angling and handline	Otter trawl	Gillnets	Harpoon	Benthic and pelagic longline	Seine	Other	Regional total	Annual total
2000	Maritimes	0.301	0.42	5.285	0.619	48.157	0	0	54.782	-
2000	Newfoundland	0.474	0.142	12.923	0	10.745	0	0	24.284	-
2000	Quebec	0	0	0	0	0.017	0	0	0.017	-
2001	Gulf	0	0	0	0	0.029	0.064	0	0.093	69.5
2001	Maritimes	0.543	0.205	5.168	0	51.044	0	0	56.96	-
2001	Newfoundland	0	0.077	3.478	0	8.613	0	0	12.168	-
2001	Quebec	0.088	0	0.151	0	0.043	0.04	0	0.322	-
2002	Gulf	0	0	0.261	0	0.775	0.097	0	1.133	79.1
2002	Maritimes	0.517	0.798	9.77	1.077	54.271	0	0	66.433	-
2002	Newfoundland	0.063	0	4.153	0	6.958	0	0.166	11.34	-
2002	Quebec	0	0	0.092	0	0.075	0.026	0	0.193	-
2003	Gulf	0	0	0	0	0.041	0	0	0.041	60.0
2003	Maritimes	0.344	0.471	6.12	1.253	44.908	0	0	53.096	-
2003	Newfoundland	0	0.02	1.08	0	5.651	0.07	0	6.821	-
2003	Quebec	0	0	0	0	0.031	0	0	0.031	-
2004	Gulf	0	0	0	0	0.17	0	0	0.17	81.9
2004	Maritimes	0.286	0.122	6.828	0.858	62.115	0	0	70.209	-
2004	Newfoundland	0	0	3.54	0	7.986	0	0	11.526	-
2004	Quebec	0	0	0	0	0	0	0	0	-
2005	Gulf	0.099	0	0	0	0.257	0	0	0.356	95.8
2005	Maritimes	0.469	0.941	11.91	0.875	71.309	0	0	85.504	-
2005	Newfoundland	0	0.141	4.517	0	5.309	0	0	9.967	-
2005	Quebec	0	0	0	0	0	0	0	0	-
2006	Gulf	0.09	0	0	0	0.211	0	0	0.301	71.3
2006	Maritimes	0.104	0.305	4.994	0.464	61.5	0	0	67.367	-
2006	Newfoundland	0	0	1.153	0	2.445	0	0	3.598	-
2006	Quebec	0	0	0	0	0	0	0	0	-

Year	Region	Troll line, angling and handline	Otter trawl	Gillnets	Harpoon	Benthic and pelagic longline	Seine	Other	Regional total	Annual total
2007	Gulf	0.166	0	0	0	0.544	0	0	0.71	72.5
2007	Maritimes	0.02	0.833	6.011	0.591	61.296	0	0	68.751	-
2007	Newfoundland	0.031	0	1.008	0	1.92	0	0	2.959	-
2007	Quebec	0	0	0	0	0.055	0	0	0.055	-
2008	Gulf	0	0	0	0	0.023	0	0	0.023	45.9
2008	Maritimes	1.293	0.693	2.345	0.041	39.273	0	0	43.645	-
2008	Newfoundland	0	0	0.129	0	2.021	0	0	2.15	-
2008	Quebec	0	0	0	0	0.052	0	0	0.052	-
2009	Gulf	0	0	0	0	0.249	0	0	0.249	53.2
2009	Maritimes	0	0.232	1.669	0	46.636	0	0	48.537	-
2009	Newfoundland	0	0	0.909	0	3.456	0	0	4.365	-
2009	Quebec	0	0	0	0	0	0	0	0	-
2010	Gulf	0	0	0.164	0	0.173	0	0	0.337	41.1
2010	Maritimes	0.304	0.09	0.467	0	36.979	0	0	37.84	-
2010	Newfoundland	0	0	1.484	0	1.472	0	0	2.956	-
2010	Quebec	0	0	0	0	0	0	0	0	-
2011	Gulf	0	0	0	0	0.208	0.058	0	0.266	37.7
2011	Maritimes	0.141	0	0.141	0.011	35.599	0	0	35.892	-
2011	Newfoundland	0	0	0	0	1.348	0	0	1.348	-
2011	Quebec	0	0	0	0	0.174	0	0	0.174	-
2012	Gulf	0	0	0	0	0.116	0	0	0.116	29.7
2012	Maritimes	0	0.502	0.214	0	28.412	0	0	29.128	-
2012	Newfoundland	0	0	0.378	0	0	0	0	0.378	-
2012	Quebec	0	0.077	0	0	0	0	0	0.077	-
	Gulf	0	0	0	0	0.113	0	0	0.113	35.7
2013	Maritimes	0	0	0.367	0.316	34.412	0	0.442	35.537	-
2013	Newfoundland	0	0	0	0	0	0	0	0	-

Year	Region	Troll line, angling and handline	Otter trawl	Gillnets	Harpoon	Benthic and pelagic longline	Seine	Other	Regional total	Annual total
2013	Quebec	0	0	0	0	0.057	0	0	0.057	-
2014	Gulf	0	0	0	0	0	0	0	0	54.9
2014	Maritimes	0.057	0	1.459	0	53.176	0	0	54.692	-
2014	Newfoundland	0	0	0	0	0.05	0	0	0.05	-
2014	Quebec	0	0	0	0	0.112	0	0	0.112	-
2015	Gulf	0	0	0	0	0.009	0	0	0.009	84.6
2015	Maritimes	0	0.334	0.012	0.042	84.101	0	0	84.489	-
2015	Newfoundland	0	0	0.109	0	0	0	0	0.109	-
2015	Quebec	0	0	0	0	0	0	0	0	-
2016	Gulf	0	0	0	0	0	0	0	0	82.5
2016	Maritimes	0	0	0.419	0.116	80.056	0	0	80.591	-
2016	Newfoundland	0.027	0	0.015	0	1.837	0	0	1.879	-
2016	Quebec	0	0	0	0	0.05	0	0	0.05	-
2017	Gulf	0	0	0	0	0.09	0	0	0.09	96.5
2017	Maritimes	0	0.097	0	0.01	88.051	0	0	88.158	-
2017	Newfoundland	0	0	0.068	0	8.176	0	0	8.244	-
2017	Quebec	0	0	0	0	0	0	0	0	-
2018	Gulf	0	0	0	0	0	0	0	0	48.7
2018	Maritimes	0	0	0.015	0	48.491	0	0	48.506	-
2018	Newfoundland	0	0	0	0	0	0	0	0	-
2018	Quebec	0	0	0	0	0.204	0	0	0.204	-
2019	Gulf	0	0	0	0	0	0	0	0	53.6
2019	Maritimes	0	0	0.371	0	53.25	0	0	53.621	-
2019	Newfoundland	0	0	0	0	0	0	0	0	-
2019	Quebec	0	0	0	0	0	0	0	0	-

Table 6. Total observed discards (live + dead) of Shortfin Mako by weight (mt) from fisheries in Maritimes Region.

Year	Trawl fisheries	Unspecified Longline	Benthic Longline	Pelagic Longline	Other Fisheries	Total
1994	0.27	1.995	0	0	0	2.265
1995	0.07	0.282	0	0	0	0.352
1996	0.85	0.599	0	0	0	1.449
1997	0	0.165	0	0	0	0.165
1998	0	1.42	0	0	0	1.42
1999	0.5	0.7896	0	3.896	0	5.1856
2000	0.02	0.0109	0.009	0.509	0.206	0.7549
2001	0.25	0.014	0	1.299	0.05	1.613
2002	0.568	0.125	0.009	0.673	0.056	1.431
2003	0	0.0095	0.046	0.692	0	0.7475
2004	0.025	0	0.017	0.478	0.39	0.91
2005	0.363	0	0	0.801	0.573	1.737
2006	1.393	0.116	0.01	0.92	0	2.439
2007	7.959	0	0	1.073	0	9.032
2008	0.45	0	0	0.856	0	1.306
2009	0.689	0	1.05	1.251	0	2.99
2010	0.948	0.0545	0.011	1.694	0	2.7075
2011	0.612	0.0909	0.35	1.252	0.225	2.5299
2012	1.391	0.081	0.134	2.928	0	4.534
2013	0.49	0	0.056	0.768	0	1.314
2014	0.495	0.091	0.014	0.795	0	1.395
2015	0.818	0	0.338	0.971	0	2.127
2016	0.726	0.016	0.351	1.262	0.2	2.555
2017	0.859	0	0	0.294	0	1.153
2018	0.61	0	0	2.142	0	2.752
2019	0.193	0	0	0.579	0	0.772

Table 7. The number of sets that caught Mako (SMA), the total number of observed sets using the same gear type (N) and the proportion of observed sets that caught Mako (Prop.) for longline and otter trawl from ASO data in the Maritimes Region. Dash (-) = No data

	Bottom Otter and Midwater trawl			**Longline (unspecified)**			**Bottom Longline**			**Pelagic Longline**		
Year	**SMA**	**N**	**Prop.**	**SMA**	**N**	**Prop.**	**SMA**	**N**	**Prop.**	**SMA**	**N**	**Prop.**
1994	9	6,834	0.001	324	1,554	0.209	0	37	0	5	21	0.238
1995	8	8,469	0.001	100	1,212	0.083	2	63	0.032	7	28	0.25
1996	16	11,950	0.001	73	2,081	0.035	-	-	-	-	-	-
1997	2	8,174	> 0.001	123	1,802	0.068	-	-	-	-	-	-
1998	1	4,369	> 0.001	107	2,243	0.048	-	-	-	-	-	-
1999	2	4,129	0.001	25	1,891	0.013	0	157	0	81	319	0.254
2000	1	2,906	> 0.001	4	705	0.006	6	1,815	0.003	39	61	0.639
2001	4	2,389	0.002	5	430	0.012	4	1,544	0.003	109	204	0.534
2002	3	2,939	0.001	9	436	0.021	5	1,458	0.003	109	238	0.458
2003	0	1,630	0	1	534	0.002	2	1,787	0.001	33	77	0.429
2004	2	1,747	0.001	6	324	0.019	6	1,848	0.003	26	48	0.542
2005	2	1,905	0.001	2	356	0.006	6	1,245	0.005	34	79	0.43
2006	13	4,363	0.003	3	296	0.01	3	1,333	0.002	46	83	0.554
2007	46	6,842	0.007	0	53	0	5	1,282	0.004	35	76	0.461
2008	7	2,763	0.003	0	53	0	4	2,373	0.002	28	43	0.651
2009	5	1,817	0.003	0	53	0	6	1,886	0.003	50	119	0.42
2010	6	2,956	0.002	1	118	0.009	10	1,877	0.005	50	110	0.455
2011	4	2,950	0.001	1	109	0.009	9	2,258	0.004	67	133	0.504
2012	7	4,015	0.002	1	135	0.007	9	1,988	0.005	86	125	0.688
2013	4	3,732	0.001	0	24	0	2	1,702	0.001	22	58	0.379
2014	3	4,164	0.001	1	74	0.014	1	1,243	0.001	57	100	0.57
2015	7	6,068	0.001	0	73	0	2	1,181	0.002	74	128	0.578
2016	5	6,837	0.001	1	91	0.011	5	1,210	0.004	70	132	0.53
2017	7	4,314	0.002	0	24	0	0	936	0	100	151	0.662
2018	4	5,302	0.001	0	24	0	0	879	0	59	114	0.518
2019	3	3,997	0.001	0	32	0	1	969	0.001	39	104	0.375
Total/Ave	171	117,561	0.002	787	14,727	0.025	88	31,071	0.004	1,226	2,551	0.483

Table 8. The number of sets that caught Mako (SMA), the total number of observed sets using that gear type (N) and the proportion of observed sets that caught Mako (Prop.) for other gear types from ASO data in the Maritimes Region. Dash (-) = data not available

	Purse Seine			**Set Gillnets**			**Hand lines**			**Troll lines**		
Year	**SMA**	**N**	**Prop.**	**SMA**	**N**	**Prop.**	**SMA**	**N**	**Prop.**	**SMA**	**N**	**Prop.**
1994	0	5	0	1	67	0.015	0	3	0	0	12	0
1995	0	236	0	-	-	-	-	-	-	1	26	0.039
1996	0	90	0	0	186	0	0	9	0	0	28	0
1997	0	36	0	0	130	0	0	21	0	0	12	0
1998	0	53	0	0	60	0	0	11	0	0	18	0
1999	0	85	0	0	59	0	0	12	0	0	5	0
2000	4	122	0.033	0	52	0	0	41	0	0	53	0
2001	2	105	0.019	0	51	0	0	4	0	0	68	0
2002	0	106	0	1	78	0.013	2	102	0.02	2	150	0.013
2003	0	67	0	0	128	0	0	77	0	0	114	0
2004	5	74	0.068	0	156	0	1	11	0.091	0	28	0
2005	0	24	0	8	349	0.023	0	80	0	0	41	0
2006	0	18	0	0	8	0	0	53	0	0	47	0
2007	0	7	0	0	1	0	0	19	0	0	1	0
2008	0	19	0	5	98	0.051	0	44	0	0	56	0
2009	0	27	0	0	51	0	0	51	0	0	1	0
2010	0	39	0	0	192	0	-	-	-	-	-	-
2011	1	32	0.031	7	96	0.073	0	45	0	0	10	0
2012	0	56	0	0	207	0	0	39	0	0	27	0
2013	0	11	0	0	160	0	0	14	0	-	-	-
2014	0	10	0	0	105	0	0	3	0	-	-	-
2015	0	50	0	0	29	0	0	17	0	0	7	0
2016	5	40	0.125	0	47	0	0	22	0	0	4	0
2017	0	36	0	0	64	0	0	8	0	-	-	-
2018	0	35	0	0	78	0	0	19	0	0	1	0
2019	0	31	0	0	47	0	0	5	0	-	-	-
Total/Ave	17	1,414	0.011	22	2,499	0.007	3	710	0.005	3	709	0.003

Table 9. The number of sets that caught Mako (SMA), the total number of observed sets using that gear type (N) and the proportion of observed sets that caught Mako (Prop.) for longline and otter trawl from ASO data in the Maritimes Region, separated by fishing quarter: 1. January to March, 2. April to June, 3. July to September and 4. October to December. Grey shading was added to aid interpretability. NA = data not available

Year	Quarter	Bottom Otter and Midwater Trawl			Longline (unspecified)			Bottom Longlines			Pelagic Longlines		
		SMA	N	Prop.	SMA	N	Prop.	SMA	N	Prop.	SMA	N	Prop.
1994	1	2	1,160	0.002	28	200	0.14	NA	NA	NA	NA	NA	NA
	2	2	3,410	0.001	1	198	0.005	0	21	0	NA	NA	NA
	3	1	1,415	0.001	118	756	0.156	0	8	0	5	21	0.238
	4	4	849	0.005	177	400	0.443	0	8	0	NA	NA	NA
1995	1	3	1,457	0.002	0	148	0	2	41	0.049	NA	NA	NA
	2	2	5,453	>0.001	33	287	0.115	0	16	0	5	6	0.833
	3	2	1,027	0.002	38	345	0.11	0	6	0	NA	NA	NA
	4	1	532	0.002	29	432	0.067	NA	NA	NA	2	22	0.091
1996	1	13	1,608	0.008	5	394	0.013	NA	NA	NA	NA	NA	NA
	2	2	6,989	>0.001	7	54	0.13	NA	NA	NA	NA	NA	NA
	3	1	2,843	>0.001	35	1,015	0.035	NA	NA	NA	NA	NA	NA
	4	0	510	0	26	618	0.042	NA	NA	NA	NA	NA	NA
1997	1	2	1,538	0.001	2	277	0.007	NA	NA	NA	NA	NA	NA
	2	0	5,352	0	0	221	0	NA	NA	NA	NA	NA	NA
	3	0	866	0	107	976	0.11	NA	NA	NA	NA	NA	NA
	4	0	418	0	14	328	0.043	NA	NA	NA	NA	NA	NA
1998	1	0	246	0	14	156	0.09	NA	NA	NA	NA	NA	NA
	2	0	2,106	0	1	446	0.002	NA	NA	NA	NA	NA	NA
	3	0	1,201	0	79	1,208	0.065	NA	NA	NA	NA	NA	NA
	4	1	816	0.001	13	433	0.03	NA	NA	NA	NA	NA	NA
1999	1	0	869	0	0	129	0	NA	NA	NA	NA	NA	NA
	2	2	1,827	0.001	1	336	0.003	NA	NA	NA	NA	NA	NA
	3	0	934	0	18	1,259	0.014	0	18	0	NA	NA	NA
	4	0	499	0	6	167	0.036	0	139	0	81	319	0.254
2000	1	0	637	0	0	51	0	0	214	0	NA	NA	NA
	2	1	864	0.001	0	63	0	3	740	0.004	1	1	1
	3	0	1,030	0	3	479	0.006	1	669	0.002	28	36	0.778
	4	0	375	0	1	112	0.009	2	192	0.01	10	24	0.417
2001	1	1	364	0.003	0	3	0	2	225	0.009	NA	NA	NA
	2	0	772	0	0	22	0	1	483	0.002	3	17	0.176
	3	1	766	0.001	4	195	0.021	0	632	0	59	110	0.536
	4	2	487	0.004	1	210	0.005	1	204	0.005	47	77	0.61
2002	1	1	777	0.001	0	45	0	1	169	0.006	NA	NA	NA
	2	2	1,134	0.002	0	16	0	3	457	0.007	24	70	0.343
	3	0	829	0	1	180	0.006	1	743	0.001	80	128	0.625
	4	0	199	0	8	195	0.041	0	89	0	5	40	0.125
2003	1	0	341	0	0	13	0	0	249	0	NA	NA	NA
	2	0	673	0	0	21	0	2	600	0.003	2	3	0.667
	3	0	503	0	1	387	0.003	0	665	0	29	47	0.617
	4	0	113	0	0	113	0	0	273	0	2	27	0.074
2004	1	0	334	0	NA	NA	NA	0	58	0	NA	NA	NA
	2	0	594	0	NA	NA	NA	3	550	0.006	2	6	0.333
	3	1	579	0.002	4	232	0.017	2	972	0.002	23	39	0.59
	4	1	240	0.004	2	92	0.022	1	268	0.004	1	3	0.333
2005	1	0	398	0	NA	NA	NA	0	63	0	NA	NA	NA
	2	2	636	0.003	NA	NA	NA	1	417	0.002	7	13	0.539
	3	0	760	0	0	238	0	5	708	0.007	27	62	0.436
	4	0	111	0	2	118	0.017	0	57	0	0	4	0
2006	1	3	516	0.006	NA	NA	NA	0	27	0	NA	NA	NA
	2	5	1,324	0.004	0	19	0	0	531	0	9	10	0.9
	3	1	1,749	0.001	3	232	0.013	2	716	0.003	31	55	0.564
	4	4	774	0.005	0	45	0	1	59	0.017	6	18	0.333
2007	1	8	1,108	0.007	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	11	1,455	0.008	NA	NA	NA	0	37	0	9	10	0.9
	3	27	3,401	0.008	0	41	0	4	1,056	0.004	23	49	0.469
	4	0	878	0	0	12	0	1	189	0.005	3	17	0.177
2008	1	1	882	0.001	NA	NA	NA	0	24	0	NA	NA	NA
	2	4	869	0.005	NA	NA	NA	1	753	0.001	4	4	1
	3	1	665	0.002	0	18	0	1	1,350	0.001	23	36	0.639
	4	1	347	0.003	0	35	0	2	246	0.008	1	3	0.333
2009	1	0	309	0	NA	NA	NA	0	213	0	NA	NA	NA
	2	3	477	0.006	NA	NA	NA	0	479	0	2	10	0.2
	3	1	693	0.001	0	53	0	5	1,083	0.005	45	104	0.433
	4	1	338	0.003	NA	NA	NA	1	111	0.009	3	5	0.6
2010	1	1	510	0.002	NA	NA	NA	0	88	0	NA	NA	NA

Year	Quarter	Bottom Otter and Midwater Trawl			Longline (unspecified)			Bottom Longlines			Pelagic Longlines		
		SMA	N	Prop.	SMA	N	Prop.	SMA	N	Prop.	SMA	N	Prop.
	2	2	898	0.002	NA	NA	NA	2	640	0.003	15	24	0.625
	3	4	1,007	0.004	1	114	0.009	7	1,047	0.007	31	61	0.508
	4	0	541	0	0	4	0	1	102	0.01	4	25	0.16
2011	1	0	880	0	NA	NA	NA	0	220	0	NA	NA	NA
	2	1	469	0.002	NA	NA	NA	1	757	0.001	4	8	0.5
	3	3	1,071	0.003	1	109	0.009	8	1,110	0.007	57	101	0.564
	4	0	530	0	NA	NA	NA	0	171	0	6	24	0.25
2012	1	0	490	0	NA	NA	NA	0	130	0	NA	NA	NA
	2	3	882	0.003	NA	NA	NA	6	692	0.009	7	9	0.778
	3	2	1,808	0.001	1	135	0.007	1	946	0.001	70	97	0.722
	4	2	835	0.002	NA	NA	NA	2	220	0.009	9	19	0.474
2013	1	0	827	0	0	10	0	0	69	0	NA	NA	NA
	2	2	724	0.003	NA	NA	NA	1	105	0.01	1	8	0.125
	3	0	1,297	0	0	5	0	1	1,428	0.001	17	36	0.472
	4	2	884	0.002	0	9	0	0	100	0	4	14	0.286
2014	1	1	940	0.001	NA	NA	NA	0	13	0	NA	NA	NA
	2	2	980	0.002	NA	NA	NA	0	324	0	11	21	0.524
	3	0	1,734	0	1	74	0.014	1	850	0.001	41	50	0.82
	4	0	510	0	NA	NA	NA	0	56	0	5	29	0.172
2015	1	0	681	0	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	0	1,349	0	NA	NA	NA	0	565	0	6	12	0.5
	3	0	2,711	0	0	55	0	1	551	0.002	61	84	0.726
	4	7	1,327	0.005	0	18	0	1	65	0.015	7	32	0.219
2016	1	0	938	0	NA	NA	NA	0	74	0	NA	NA	NA
	2	0	1,133	0	NA	NA	NA	3	567	0.005	9	23	0.391
	3	5	3,649	0.001	1	74	0.014	1	466	0.002	57	81	0.704
	4	0	1,117	0	0	17	0	1	103	0.01	4	28	0.143
2017	1	0	731	0	NA	NA	NA	0	66	0	NA	NA	NA
	2	1	1,109	0.001	0	6	0	0	451	0	31	34	0.912
	3	1	1,634	0.001	NA	NA	NA	0	362	0	58	82	0.707
	4	5	840	0.006	0	18	0	0	57	0	11	35	0.314
2018	1	0	543	0	NA	NA	NA	0	26	0	NA	NA	NA
	2	2	1,387	0.001	0	3	0	0	284	0	8	11	0.727
	3	2	2,411	0.001	NA	NA	NA	0	458	0	44	80	0.55
	4	0	961	0	0	21	0	0	111	0	7	23	0.304
2019	1	0	702	0	0	15	0	0	99	0	NA	NA	NA
	2	1	857	0.001	0	17	0	0	464	0	11	19	0.579
	3	1	1,619	0.001	NA	NA	NA	1	352	0.003	27	53	0.509
	4	1	819	0.001	NA	NA	NA	0	54	0	1	32	0.031

Table 10. Condition of landed Shortfin Mako by the pelagic longline fishery from ASO data in Maritimes Region. Values represent the number of individuals.

Year	Unknown	Live	Dead	Total	%Dead
2010	2	69	25	96	26.04
2011	3	48	11	62	17.74
2012	0	211	73	284	25.7
2013	0	14	9	23	39.13
2014	0	96	43	139	30.94
2015	0	161	56	217	25.81
2016	5	101	27	133	20.3
2017	11	201	55	267	20.6
2018	1	6	81	88	92.05
2019	0	0	43	43	100

Table 11. Condition of released discards by the pelagic longline fishery from ASO data in Maritimes Region. Values represent the number of individuals.

Year	Unknown	Healthy	Injured	Dead	Total	% Dead	% Injured
2010	5	64	13	19	101	18.81	12.87
2011	1	56	8	18	83	21.69	9.64
2012	2	102	86	89	279	31.9	30.82
2013	0	28	8	5	41	12.2	19.51
2014	0	31	10	13	54	24.07	18.52
2015	3	59	8	16	86	18.6	9.3
2016	0	48	5	8	61	13.11	8.2
2017	1	21	0	6	28	21.43	0
2018	0	72	4	8	84	9.52	4.76
2019	0	19	0	0	19	0	0

Table 12. Combined total number and percentage of animals dead at vessel from pelagic longline based on ASO data in Maritimes Region. Values represent the number of individuals.

Year	Dead	Total	Hooking Mortality (%)
2010	44	197	22.34
2011	29	145	20.00
2012	162	563	28.77
2013	14	64	21.88
2014	56	193	29.02
2015	72	303	23.76
2016	35	194	18.04
2017	61	295	20.68
2018	89	172	51.74
2019	43	62	69.35

Table 13. Number of landed Shortfin Mako by year from recreational fishing tournaments in Nova Scotia.

Year	Captures
1994	0
1995	0
1996	1
1997	0
1998	0
1999	0
2000	3
2001	0
2002	4
2003	3
2004	6
2005	2
2006	5
2007	3
2008	0
2009	3
2010	3
2011	2
2012	5
2013	2
2014	3
2015	2
2016	3
2017	2
2018	0
2019	0
Total	**52**

Table 14. Threat assessment of international fisheries as compared to Canadian fisheries. The rankings given to Causal Certainty (e.g., (1) = Very High), are given in DFO 2014. The rank for Causal Certainty combines with the Threat Frequency, Extent and Level of Impact to determine the Overall

Activity	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Occurrence	Threat Frequency	Threat Extent	Overall Risk
International Fisheries	Known	Extreme	Very High (1)	Historical, Current, Anticipatory	Continuous	Extensive	High (1)
Canadian Fisheries	Known	Low	Very High (1)	Historical, Current, Anticipatory	Recurrent	Broad	Low (1)

Table 15. Threat assessment of Canadian fisheries. The rankings given to Causal Certainty (e.g., (1) = Very High), are given in DFO 2014. The rank for Causal Certainty combines with the Threat Frequency, Extent and Level of Impact to determine the Overall Risk.

Region	Activity	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Occurrence	Threat Frequency	Threat Extent	Overall Risk
Maritimes	pelagic longline	Known (100%)	Low	Very High (1)	Historical, Current, Anticipatory	Recurrent	Broad	Low (1)
	otter trawl	Known (100%)	Very Low	Very High (1)	Historical, Current, Anticipatory	Recurrent	Narrow	Very Low (1)
	bottom longline	Likely (80%)	Very Low	Very High (1)	Historical, Current, Anticipatory	Recurrent	Narrow	Very Low (1)
	purse seine	Remote (20%)	Negligible	Very High (1)	Historical, Current, Anticipatory	Single	Restricted	Negligible (1)
	fixed gillnet	Remote (20%)	Negligible	Very High (1)	Historical, Current, Anticipatory	Single	Restricted	Negligible (1)
	handlines	Unknown (0% currently)	Negligible	Very High (1)	Historical	Single	Restricted	Negligible (1)
	troll lines	Unknown (0% currently)	Negligible	Very High (1)	Historical	Single	Restricted	Negligible (1)
Newfoundland			Very Low	Very High (1)	Historical, Current, Anticipatory	Recurrent	Narrow	Very Low (1)
Gulf			Negligible	Very High (1)	Historical, Current, Anticipatory	Single	Restricted	Negligible (1)
Quebec			Negligible	Very High (1)	Historical, Current, Anticipatory	Single	Restricted	Negligible (1)

Table 16. Probability that SSF > SSF_{MSY} at different levels of removals (TAC) from population projects of the age-structured assessment model. Reprinted from the 2019 ICCAT assessment (Anon 2020).

TAC (t)	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	46	42	24	14	11	33	53	60	63	67	72	81
100	46	42	24	13	10	29	49	56	59	61	66	73
200	46	42	24	13	9	26	47	54	55	57	61	66
300	46	42	24	12	9	22	42	50	52	53	56	60
400	46	42	24	12	8	19	39	47	49	50	52	55
500*	46	42	24	12	7	17	34	42	45	47	49	52
600	46	42	24	12	7	14	28	37	40	41	43	47
700	46	42	24	11	6	11	23	31	34	35	37	41
800	46	42	23	11	6	10	19	26	27	28	30	32
900	46	42	23	11	5	8	16	20	21	21	23	24
1000	46	42	23	11	5	7	12	16	16	15	15	17
1100	46	42	23	10	5	6	10	12	12	11	10	10

Table 17. A multi-stage process for using the mitigation hierarchy to make science-based management decisions for sharks. Reprinted from Booth et al. (2020).

Stage in the assessment	Key questions/considerations
1. Define the problem	
1.1 Understand the fishery	Fishery footprint, market-type, target species, targeting of sharks
1.2 Define the species of management concern	Single species, taxonomic group or species complex
1.3 Assess the risks	
1.3.1. Biological (species)	Size, fecundity, biological reference points, extinction risk
1.3.2. Technical (fishery)	Encounterability, catchability and survivability of species in fishery
1.3.3. Socioeconomic (context)	Uses and values of sharks, target markets
1.3.4. Constraints (context)	Budget for monitoring, enforcement and implementation. Societal limits on acceptable damage to species or costs to people
1.4. Set goals and quantitative targets	
1.4.1. Goal	Desired change in biodiversity (e.g., no net loss, net gain, population recovery, mortality minimization, population stability, fishery sustainability).
1.4.2. Target	Quantitative target which operationalizes the goal
1.4.3. Metric	Units to measure gains and losses in biodiversity to evaluate progress (e.g., population growth, total mortality, number of animals).
1.4.4. Baseline	Reference point against which progress is assessed.
1.4.5. Counterfactual	Projected change in metric in business-as-usual scenario.
2. Explore management measures	Which management options are available for achieving the target at each step? What data are available for estimating their impact on the target? What are the uncertainties?
2.1. Avoid	Options for avoiding encounters (i.e., reducing EX)
2.2. Minimize	Options for minimizing capture, given *EX* is present (i.e., reducing CPUEX)
2.3. Remediate	Options for minimizing mortality, given sharks are captured (i.e., reducing MPUEX)
2.4. Compensate	Options to compensate for residual mortality (i.e., increasing *CX*)
3. Assess hypothetical effectiveness of management measures	
3.1. Technical assessment	To what degree could management measures reduce risks to the species, based on biophysical and operational factors?
3.2. Feasibility assessment	To what degree could management measures be feasibly implemented, given costs, benefits, social context and resources for implementation? Is there scope for incentives to address gaps?
4. Make a management decision	Which mix of measures and instruments is likely to have the greatest impact?
5. Implement, monitor and adapt	Implement measures and encourage uptake. Monitor progress towards target. Adapt management.

FIGURES

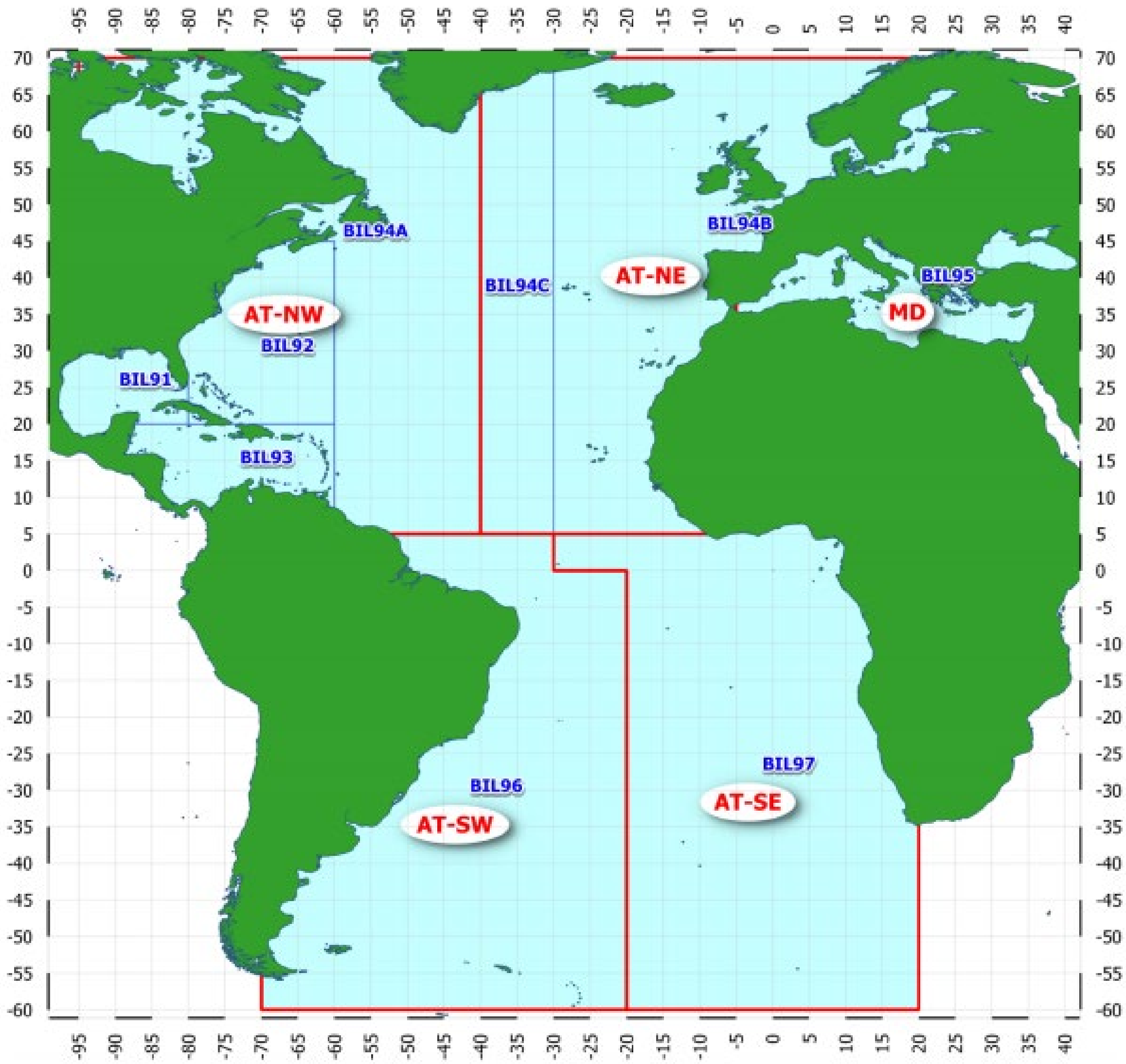

Figure 1. ICCAT sampling areas for large pelagic fish species, including Shortfin Mako Shark. AT-NW and AT-NE combined (BIL91, BIL92, BIL93 and BIL94A-C) are considered to represent the North Atlantic.

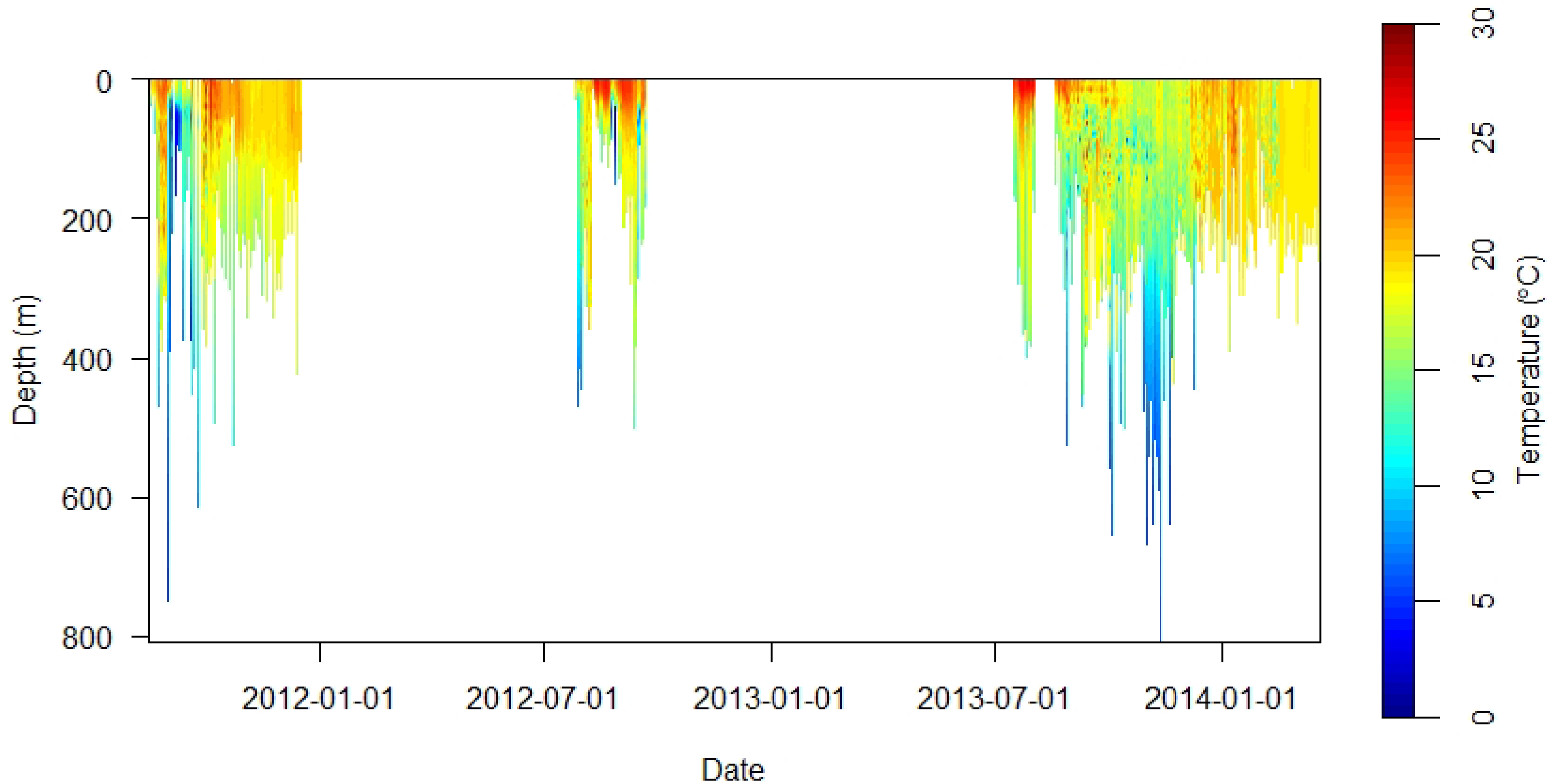

Figure 2. Interpolated temperature profiles and dive depths from 16 Shortfin Mako tagged with archival satellite tags. Empty space represents time periods where there were no tagged individuals.

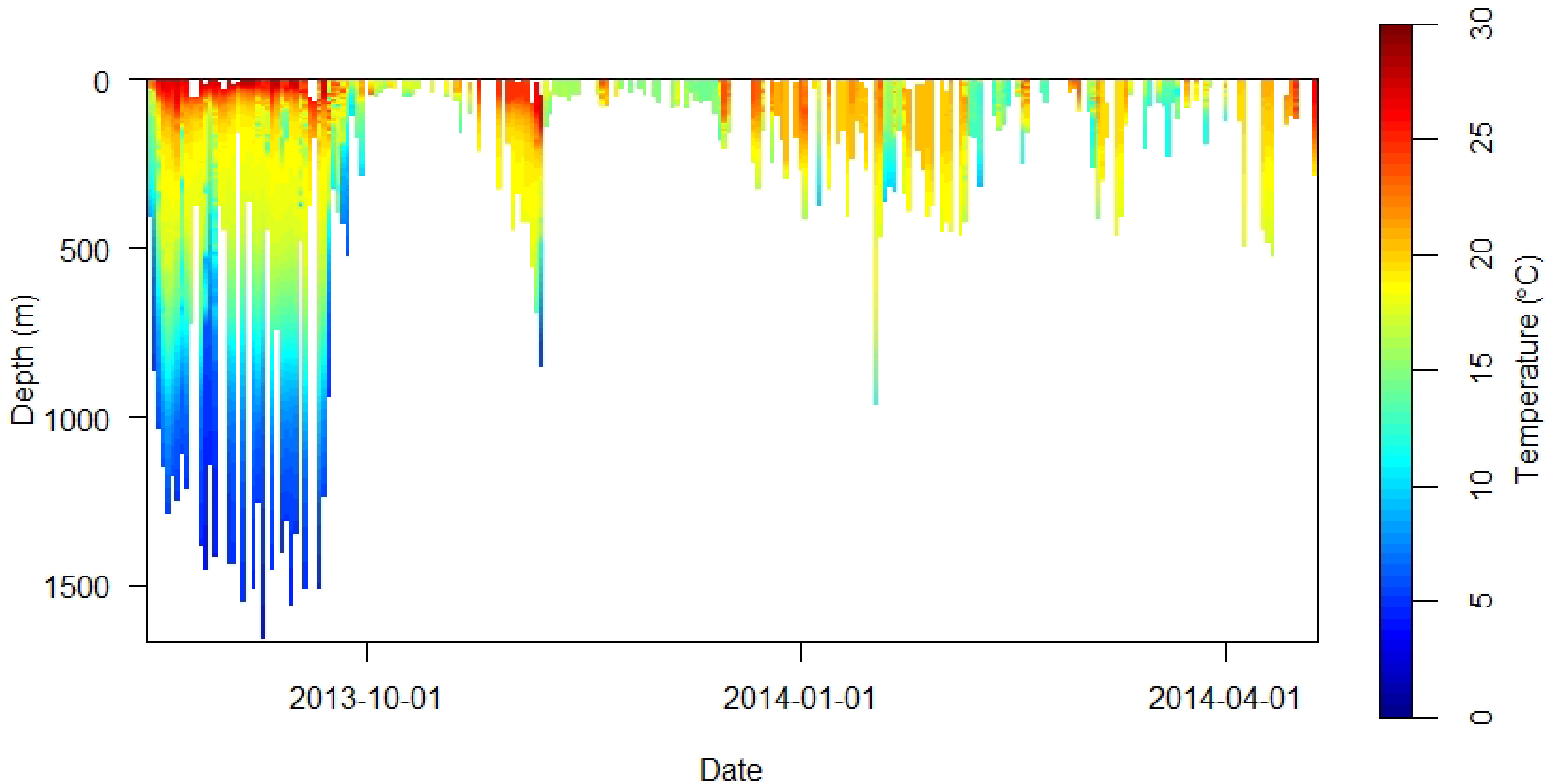

Figure 3. Interpolated temperature profiles and dive depths of 2 Shortfin Mako tagged with archival satellite tags, which exhibit diving behaviour to maximum depths in excess of those previously reported for this species.

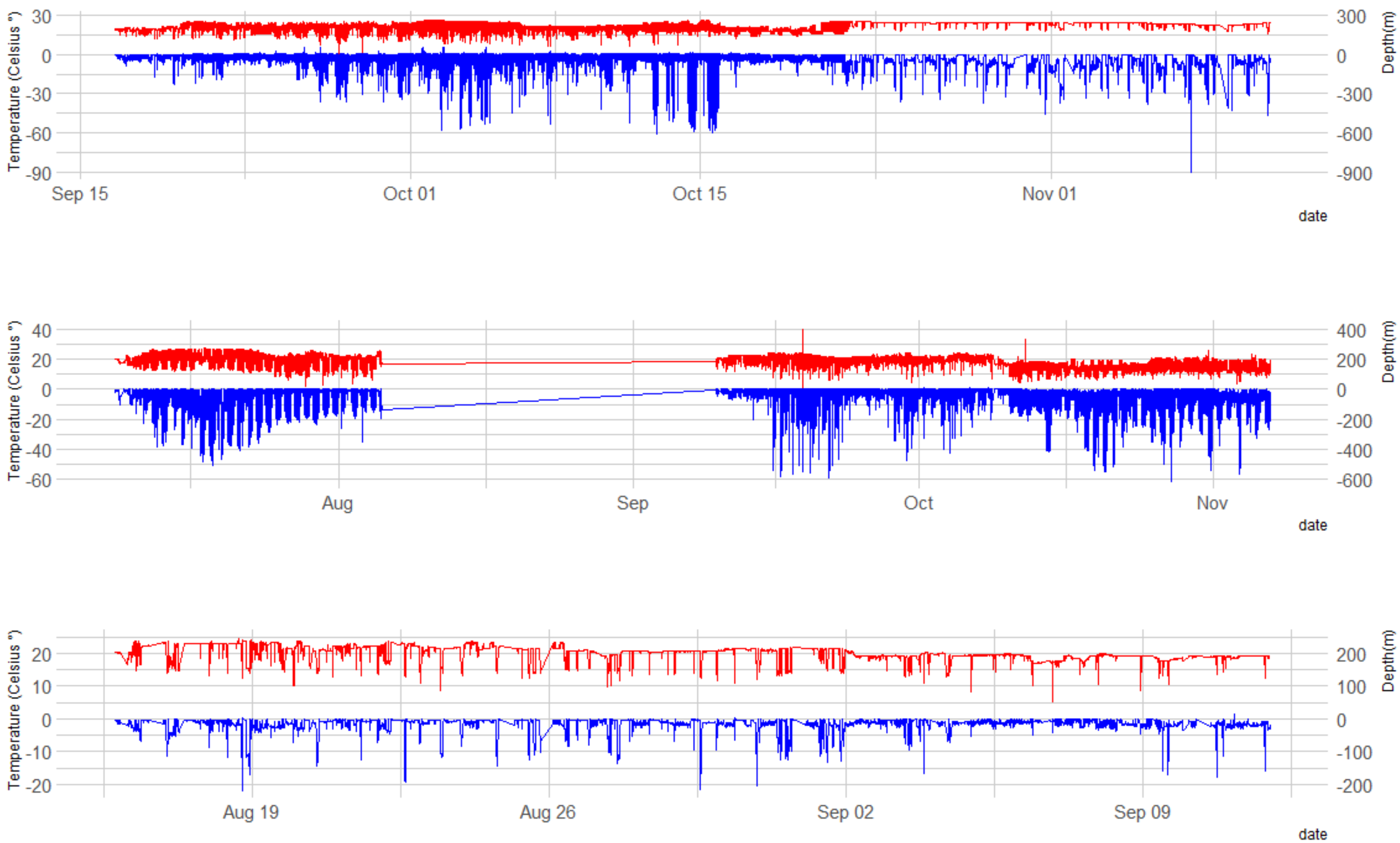

Figure 4. Dive depth in meters (blue lines) and temperature profiles in degrees Celsius (red lines) of Shortfin Mako tagged with Lotek survival tags in 2017 (top panel), 2018 (middle panel), and 2019 (lower panel). Note that data are collected at 5-minute intervals over a maximum 28-day deployment from this type of tag.

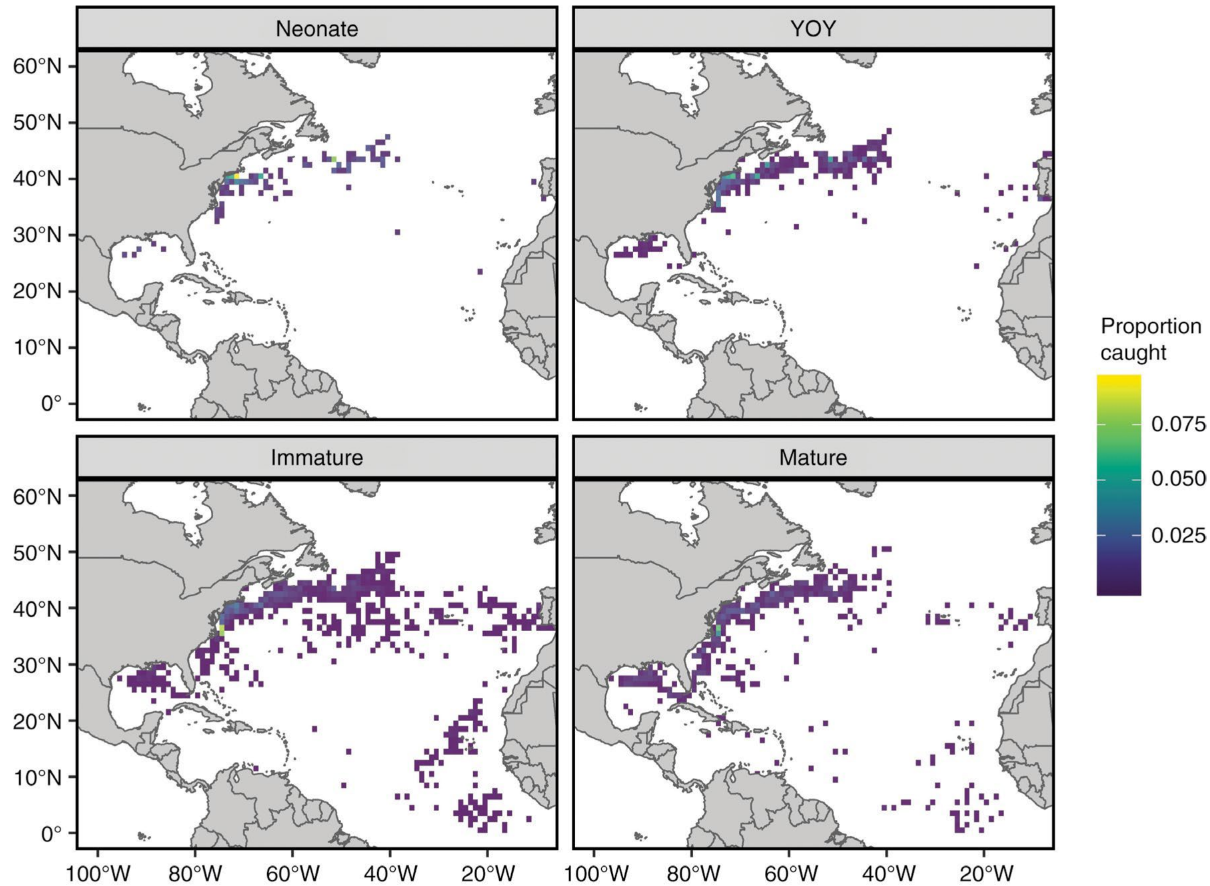

Figure 5. Maps showing the distribution of male Shortfin Mako Sharks (Isurus oxyrinchus) caught in the western North Atlantic Ocean during 1962–2018, by maturity status. Data are presented as proportion caught in 1° squares. YOY = Young Of the Year. Figure and caption taken from Natanson et al. 2020. Refer to the publication for the equivalent figure for females.

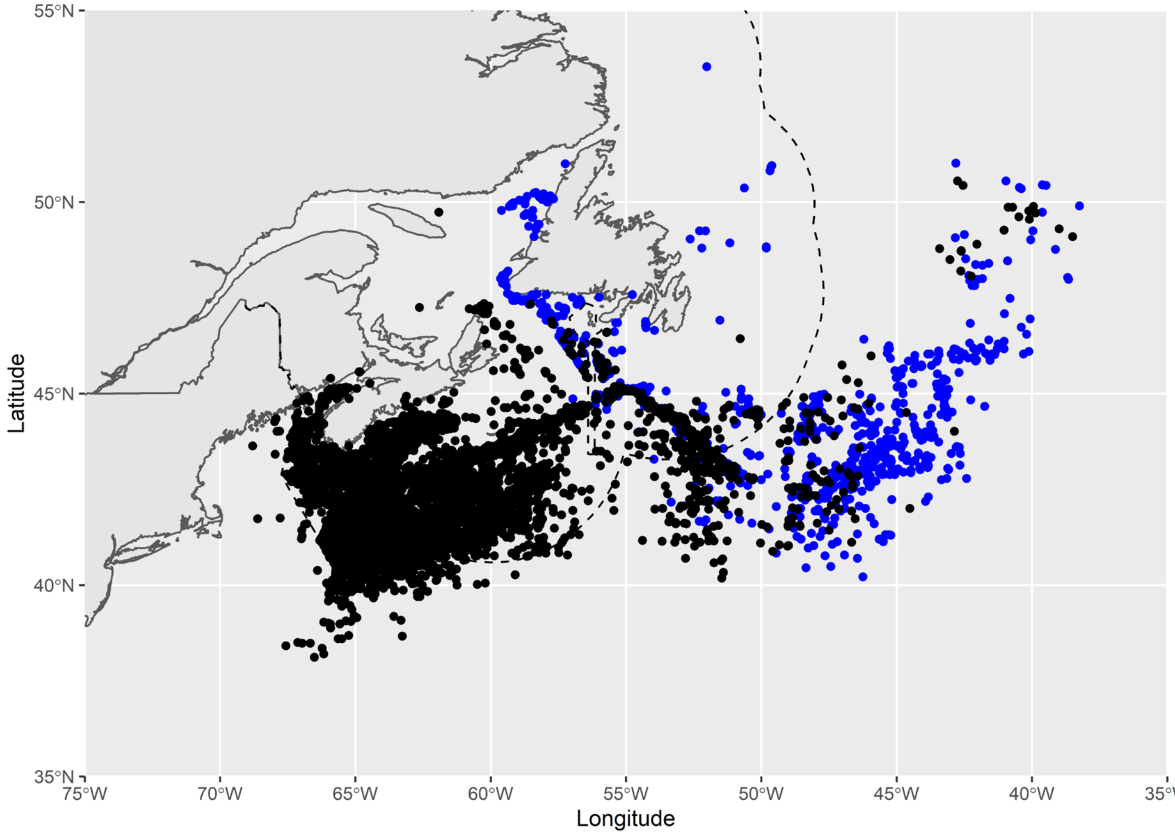

Figure 6. Logbook recorded captures of Shortfin Mako Shark by fisheries from Maritimes Region (black points) and Newfoundland Region (blue points) from 2001–2019.

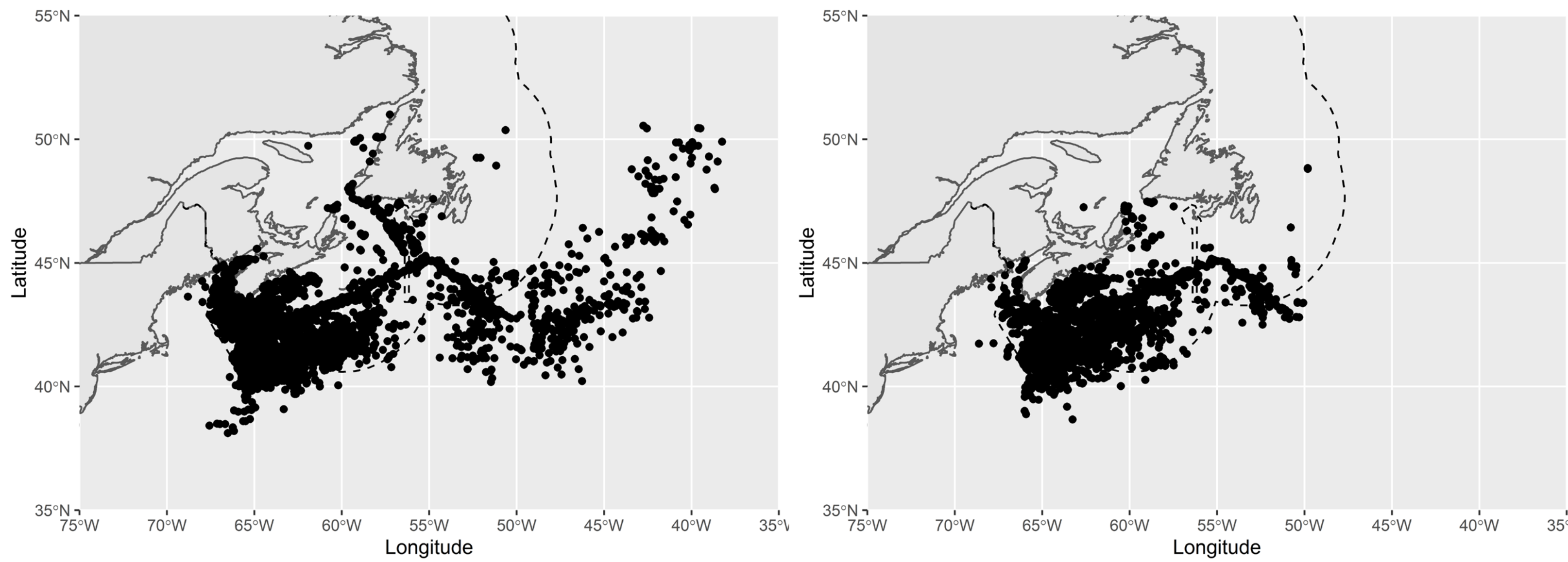

Figure 7. Logbook recorded captures of Shortfin Mako Shark by fisheries from Maritimes and Newfoundland regions binned by decade: 2001–2009 (left panel) and 2010–2019 (right panel).

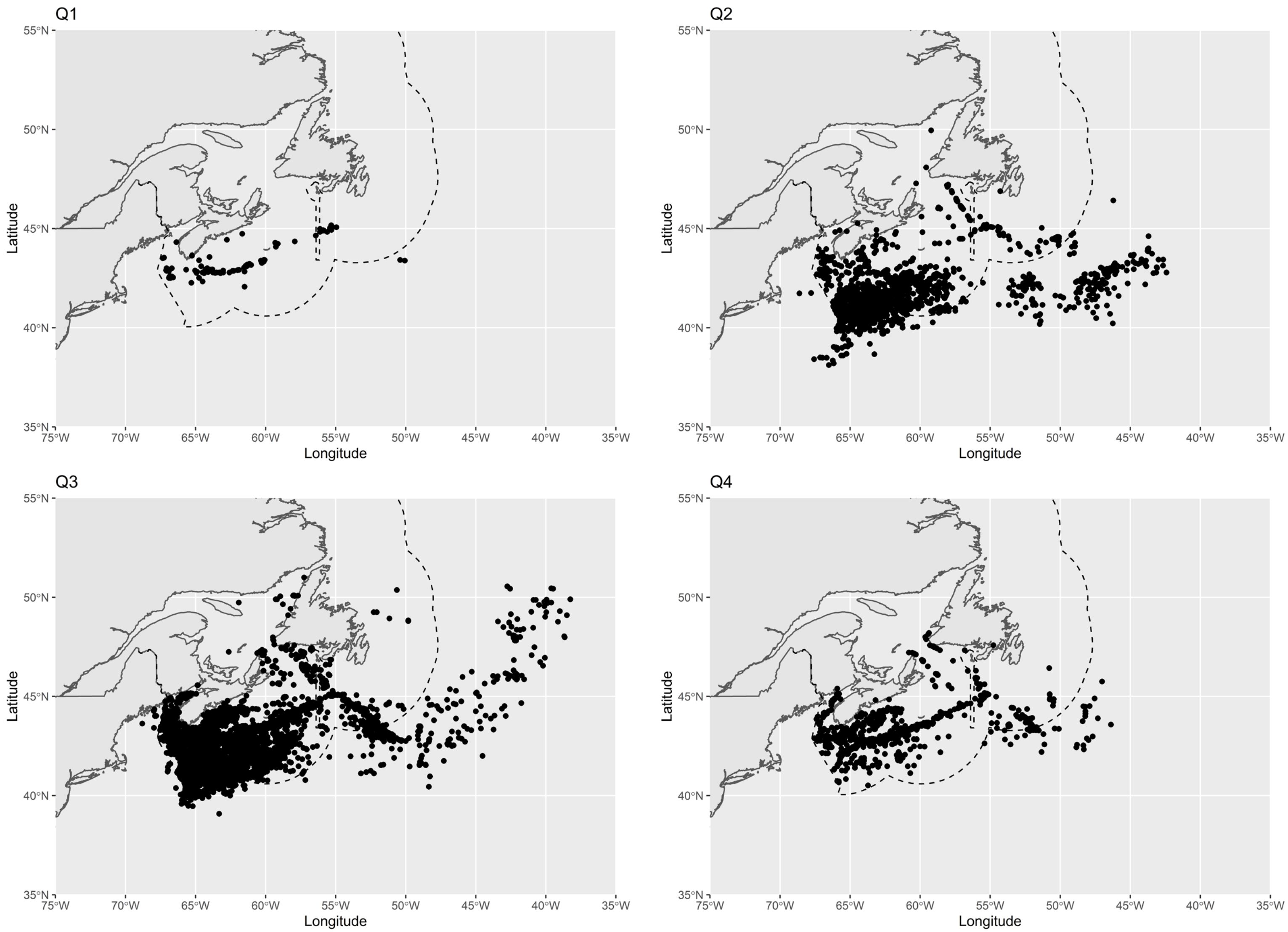

Figure 8. Logbook recorded captures of Shortfin Mako Shark by fisheries from Maritimes and Newfoundland regions during 2001–2019, binned by fishing quarter: 1. January to March, 2. April to June, 3. July to September, and 4. October to December.

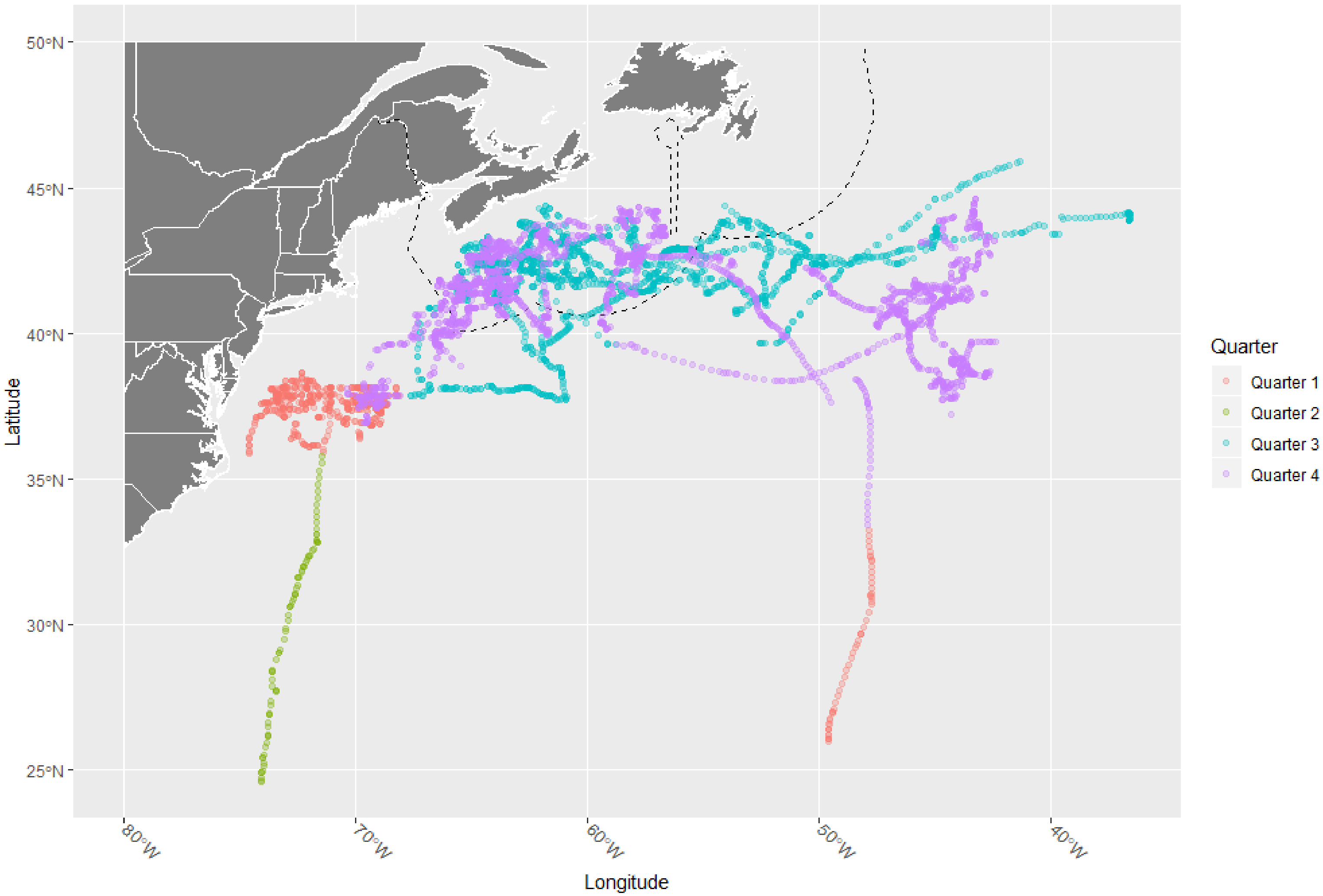

Figure 9. Satellite tracks of tagged Shortfin Mako in the Northwest Atlantic Ocean with positions binned by fishing quarter: 1. January to March, 2. April to June, 3. July to September, and 4. October to December.

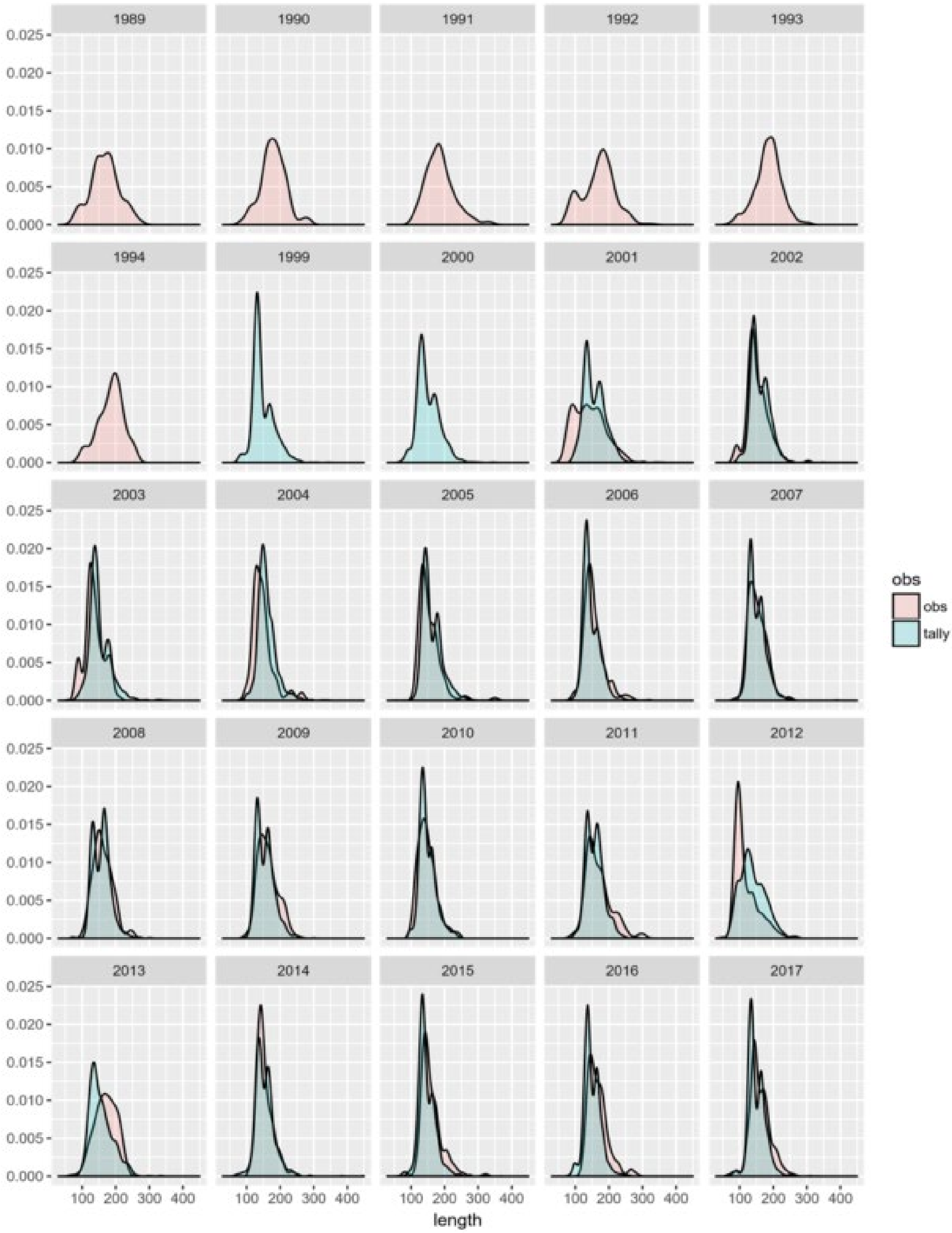

Figure 10. Length Frequency of Shortfin Mako captures (males and females combined) from Maritimes ASO data (obs: landings and discards) and dockside monitoring data (tallies: landings) from pelagic longline. Originally submitted to ICCAT and the sex-specific observed data was used in the 2017 assessment (Anon 2018).

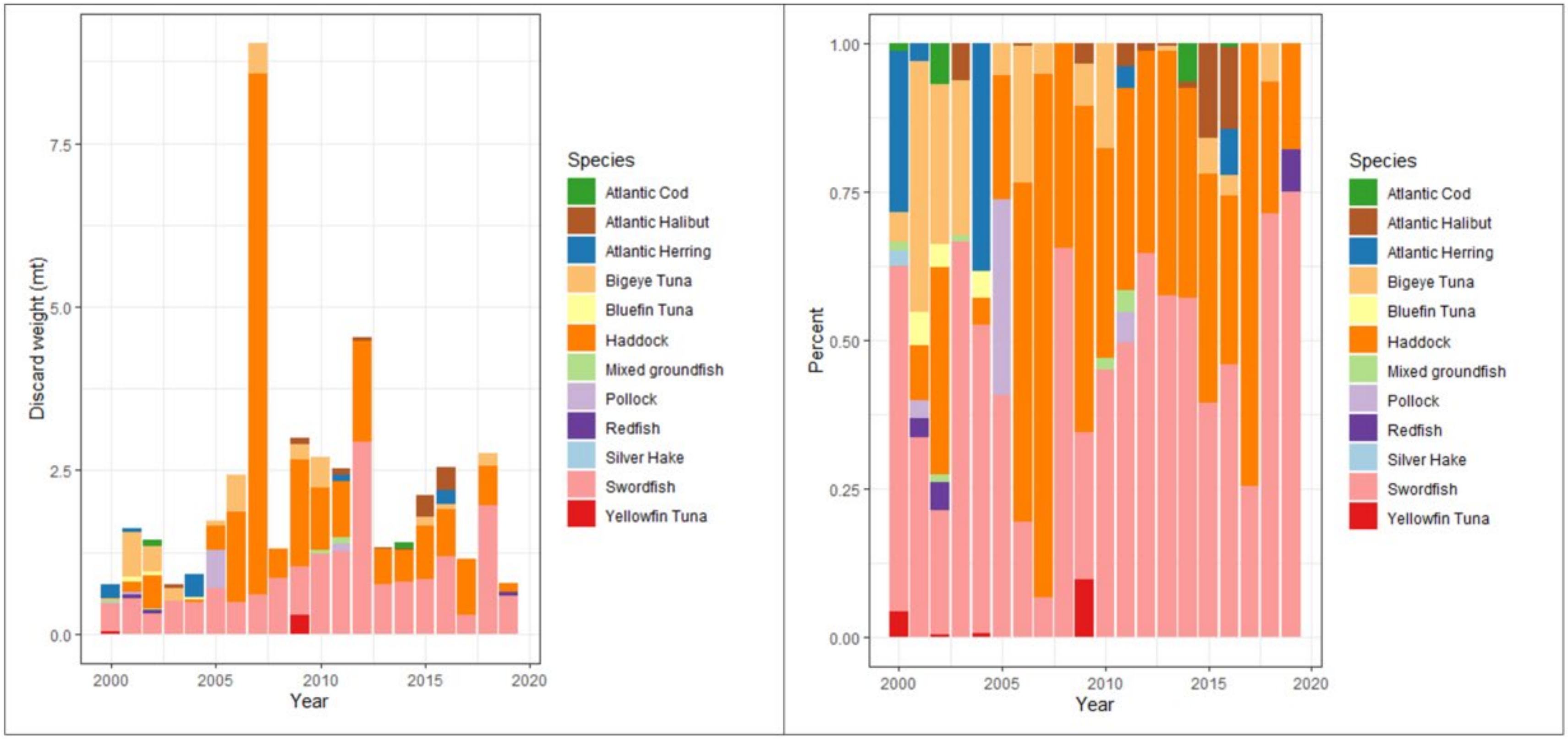

Figure 11. ASO-recorded discards of Shortfin Mako from Maritimes Region (Divs. 4VWX5YZ) for 2000–2019, by directed species.

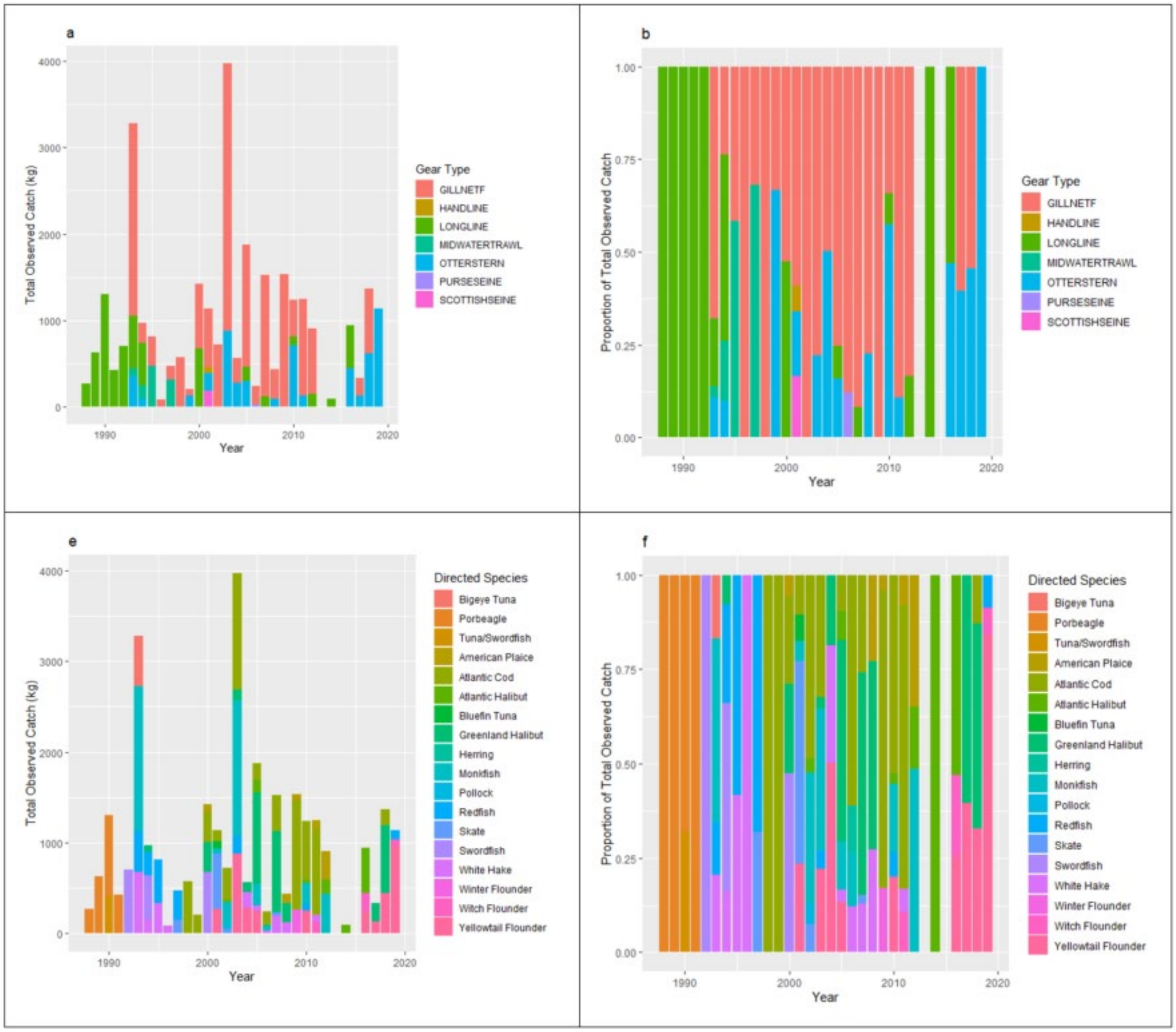

Figure 12. ASO-recorded catches (landings + discards) of Shortfin Mako from Newfoundland Region (Divisions 3KLMNOP4R) by gear type and directed species, 1988–2019.

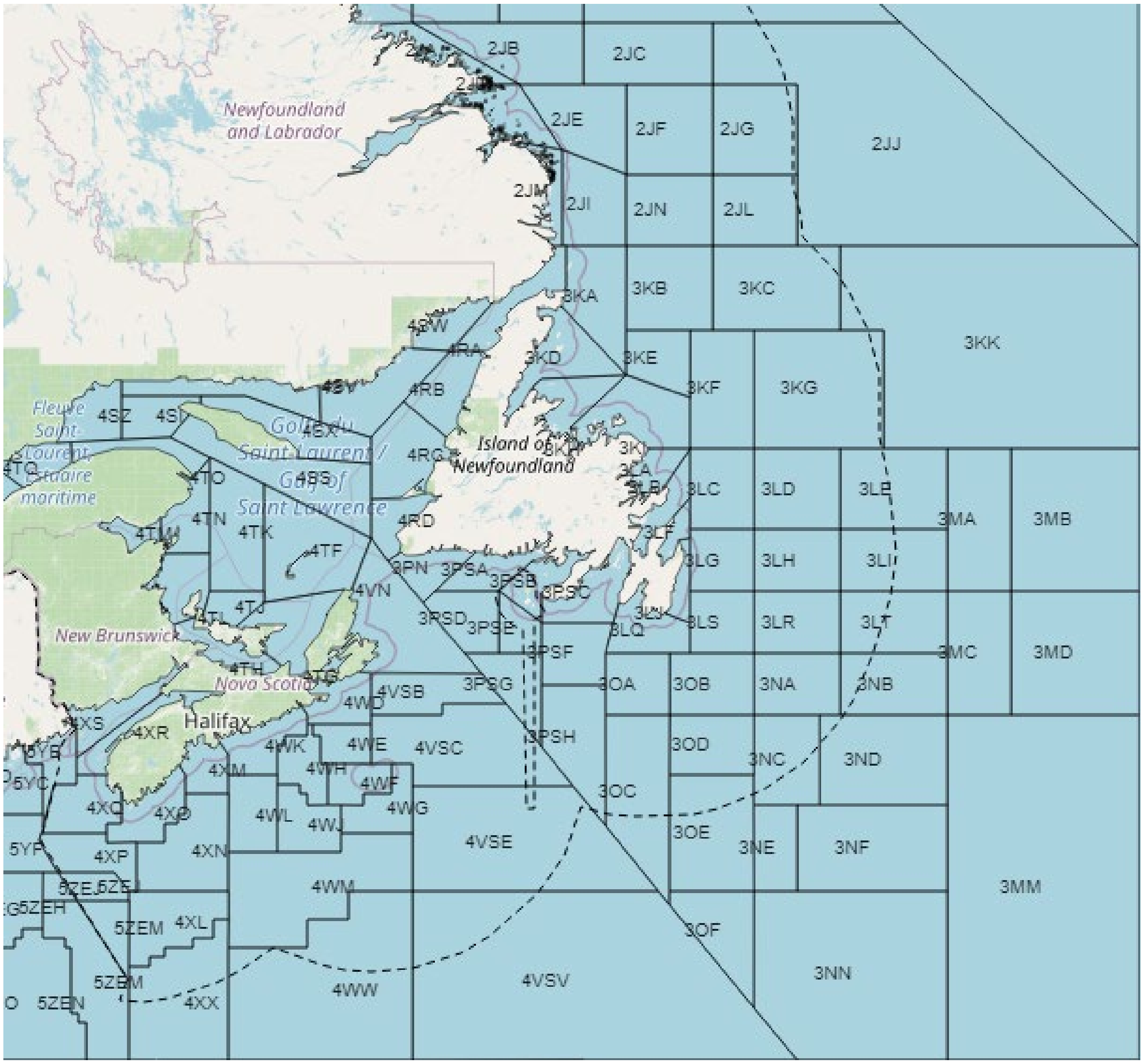

Figure 13. NAFO Divisions and Subdivisions referred to in this document.

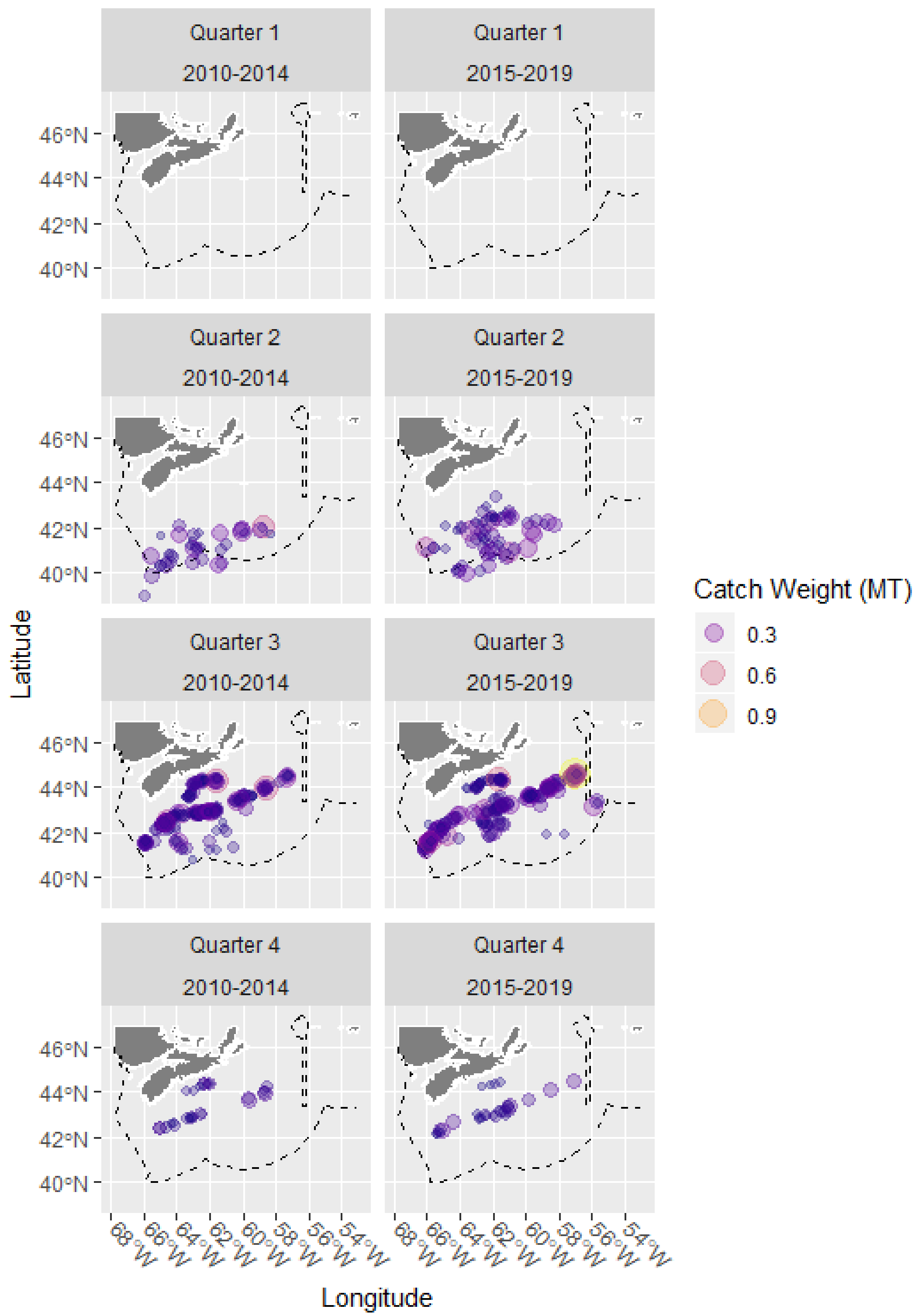

Figure 14. Catch weight (kg) of kept and discarded Shortfin Mako from pelagic longline based on Maritimes Region ASO data, binned by time period: 2010–2014 (left panels) and 2015–2019 (right panels) and by fishing quarter.

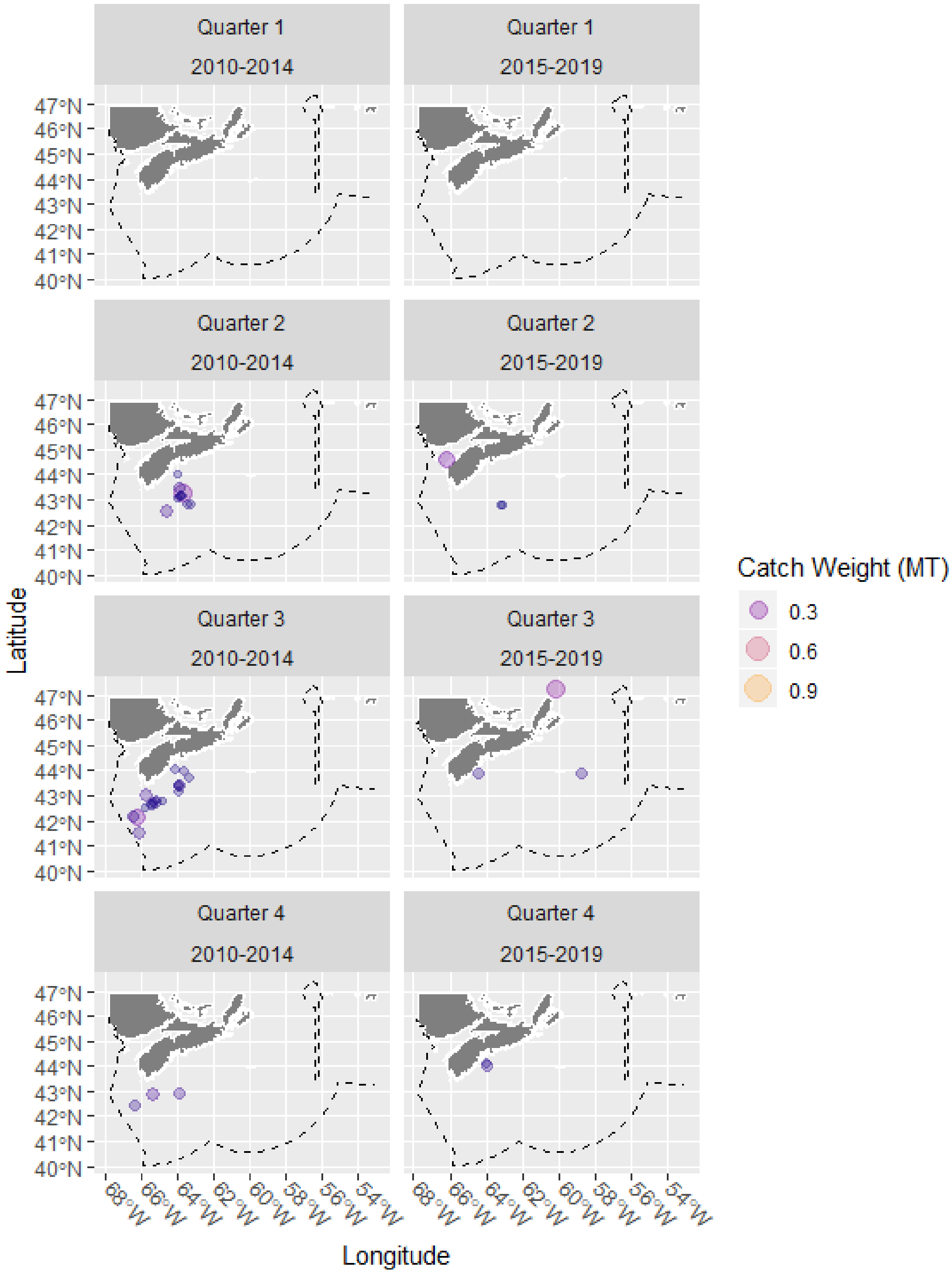

Figure 15. Catch weight (kg) of kept and discarded Shortfin Mako from benthic longline based on Maritimes Region ASO data, binned by time period: 2010–2014 (left panels) and 2015–2019 (right panels) and by fishing quarter.

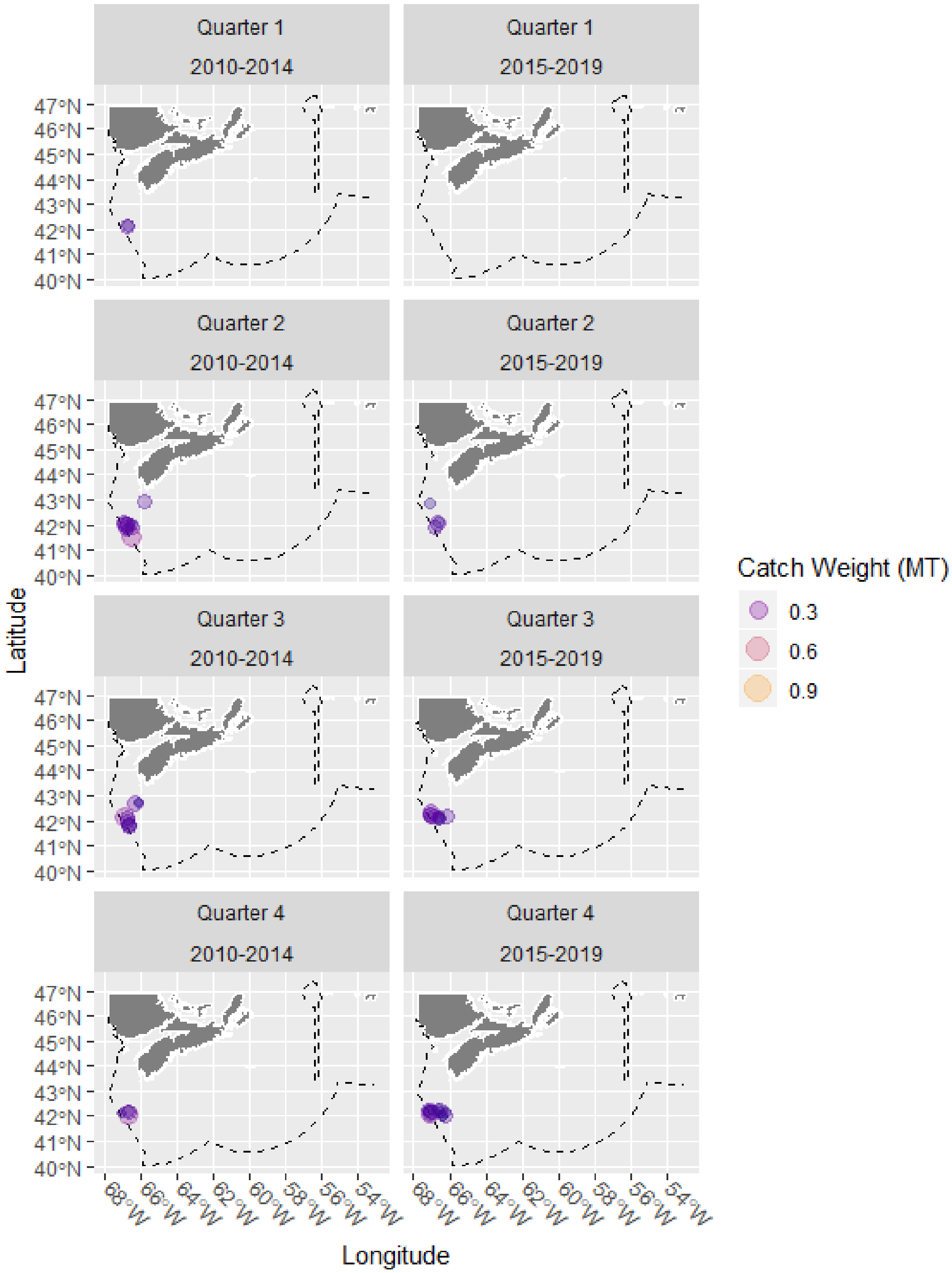

Figure 16. Catch weight (kg) of kept and discarded Shortfin Mako from Otter trawl based on Maritimes Region ASO data, binned by time period: 2010–2014 (left panels) and 2015–2019 (right panels) and by fishing quarter.

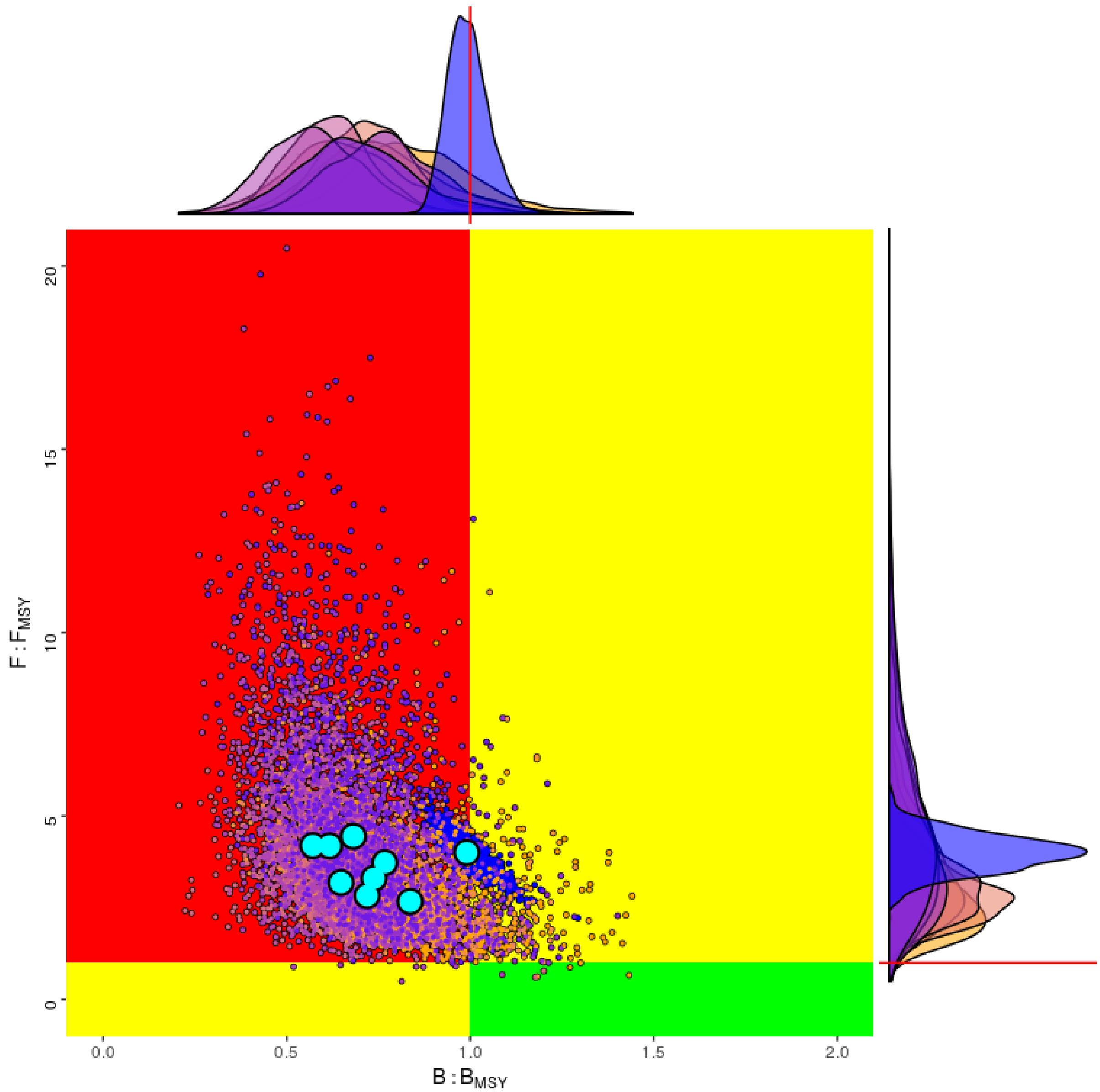

Figure 17. Example of a Kobe phase plot from the 2017 assessment of Shortfin Mako in the North Atlantic (reprinted from Anon 2018). The probability mass (points) and model means (large light blue points) from the combined model outputs suggest that the population is overfished and overfishing is occurring (red quadrant).