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Estimating Total Mortality among Fisheries Affecting Porbeagle Shark (*Lamna nasus*) in Atlantic Canadian Waters

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Foreword

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

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ABSTRACT

Porbeagle Sharks (*Lamna nasus*) in the northwest Atlantic are currently being considered for listing under the Canadian *Species at Risk Act* (SARA), and Fisheries and Oceans Canada (DFO) Science was asked to estimate total annual fishing mortality. This would come from landings, and at-vessel mortality (AVM) or post-release mortality (PRM) of discards from fisheries in the Maritimes (MAR), Gulf (GULF), Quebec (QC) and Newfoundland and Labrador (NL) Regions. This evaluation considers 2015 to 2021, representing a time period following the closure of the commercial Porbeagle fishery.

Total landings remained low from Atlantic Canadian fisheries, dropping from 3.8 mt in 2015 to less than 200 kg in 2021. The vast majority of landings in 2015–2021 came from longline gear in MAR, primarily benthic longline in the Atlantic Halibut fishery with lower amounts from the pelagic longline fishery for Swordfish and Other Tunas.

At-sea observer (ASO) coverage was variable among different fisheries and could not be estimated for fisheries in NL, GULF or QC. When coverage was low (< 5% annually), fisheries observed discards of Porbeagle substantially underestimated fishery-wide totals and needed to be scaled up to annual discard estimates. Also, several fisheries that would be expected to interact with Porbeagle had no ASO coverage and thus could not be considered in this assessment. A suite of statistical estimators was evaluated to model fishery-wide discards for pelagic longline in MAR. However, the data were not sufficient for quantitative models and thus these approaches were not applied. Simple scalars of either the proportion of observed trips (MAR) or proportion of observed target catch (NL) were used to approximate annual fishery-wide bycatch from individual fisheries.

Although estimates of total mortality were derived from scenarios assuming different AVM and PRM rates for various fisheries, they lacked precision and were predicated on numerous assumptions. Also, there were several factors that would have caused annual mortality to be underestimated but could not be corrected in advance of this assessment, so the magnitude of underestimation was unknown. Given demonstrated challenges and limitations of the available data, it is not possible to derive meaningful estimates of total annual fishing mortality of Porbeagle throughout Atlantic Canadian waters. Interpretation of the implications of observed increases or decreases in annual fishing mortality is not possible without information on underlying abundance and status of infrequently observed, discarded bycatch species (such as Porbeagle). This limits the utility of estimates of fishing mortality to address conservation or management goals and warrants consideration of an alternate framework to quantify threats to bycatch species from fisheries.

INTRODUCTION

The population of Porbeagle Shark (*Lamna nasus*) in the northwest Atlantic Ocean was assessed as Endangered by the Committee on the Status of Endangered Wildlife in Canada in 2014 (COSEWIC 2014). The subsequent Recovery Potential Assessment (RPA) in 2015 identified fishing mortality related to bycatch as the main anthropogenic threat to Porbeagle Sharks (Campana et al. 2015). The associated assessment of allowable harm determined that total mortality must not exceed 185 mt annually to allow abundance to increase (DFO 2015). Porbeagle are distributed throughout Atlantic Canada and interact with a variety of fishing activities in the four Atlantic regions: Maritimes (MAR), Gulf (GULF), Quebec (QC), and Newfoundland and Labrador (NL).

Porbeagle in the northwest Atlantic are currently being considered for listing under the Canadian *Species at Risk Act* (SARA). Regardless of any listing decision, quantifying bycatch and total fishing mortality will be necessary to implement and monitor management measures for the species, inform fisheries management decisions, and to track recovery. Thus, Fisheries and Oceans Canada (DFO) Science was asked to estimate total annual fishing mortality on Porbeagle Sharks. Specifically, the request was to:

- Estimate the total commercial catches of Porbeagle Shark in the Maritimes, Gulf, Newfoundland and Labrador, and Quebec Regions, in both tonnage and number of animals.
- Determine the proportion of Porbeagle bycatch attributed to specific fisheries and retained by each.
- Evaluate the spatial and temporal distribution of bycatch and estimate how it has changed over time.
- When bycatch is discarded, estimate post-release mortality for each fishery/gear type.
- Describe uncertainties in the estimates of bycatch and mortality and identify gaps in available data sources.
- Explore various methods to address the above objectives, including approaches used in other jurisdictions (e.g., International Commission for the Conservation of Atlantic Tunas [ICCAT], United States of America [USA]).

The request did not specifically speak to the condition of the species when intercepted (i.e., alive or dead), but consideration of at-vessel mortality was included for completeness when evaluating post-release mortality. The terms of reference (TORs) have been addressed to the extent possible with the available time and data, but the numerous limitations affecting these analyses have been documented and discussed.

HISTORICAL CONTEXT

Commercial fishing on Porbeagle Sharks in the northwest Atlantic (Northwest Atlantic Fisheries Organization [NAFO] Subareas 3–6) began in 1961 when Norwegian vessels started an exploratory fishery (Campana et al. 2003). They were joined by other foreign fisheries (notably from the Faroe Islands) in subsequent years. Total landings were unrestricted and sharply increased from 1,900 mt in 1961 to over 9,000 mt in 1964. By 1970, the fishery collapsed, and landings dropped to less than 500 mt per year between 1971 and 1989. Canadian participation in the fishery started in 1991 and continued until the directed fishery closed in 2013 (Campana et al. 2015).

During the Canadian commercial fishery, the majority of Porbeagle catches came from pelagic longline (Campana et al. 2015). Two factors contributed to the fishery closure and a subsequent shift to the majority of Porbeagle Sharks being discarded at sea: (1) the original COSEWIC status designation of Endangered in 2004, which was re-affirmed in 2014 (COSEWIC 2014) and (2) an associated Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) listing of Porbeagle Sharks on Appendix 2 in 2014, which placed restrictions on international trade.

In response to the original status determination in 2004 by COSEWIC, the total allowable catch (TAC) for Porbeagle was reduced from 250 mt (200 directed, 50 bycatch) in 2002 to 185 mt (135 directed, 50 bycatch) in 2006 (DFO 2007). However, fishing practices markedly changed after the CITES listing in 2014. The requirement to apply for and then provide a non-detriment finding when Porbeagle Sharks or shark products were shipped internationally became too logistically difficult and effectively eliminated the market in Canada.

These analyses are specific to the years following the CITES listing and closure of the directed fishery (2015 onwards). This represents a time period when Porbeagle Sharks were considered bycatch and there was little incentive to land the species due to its low economic value and poor conservation status. There is no expectation that these conditions will change in the short-term, so the current data sources and characteristics are expected to be representative of future years.

COMPONENTS OF MORTALITY

Total fishing mortality is made up of landings as well as at-vessel mortality (AVM) and post-release mortality (PRM) of discards (Campana et al. 2016). At-vessel mortality is also called capture or hooking mortality and represents the number or weight of animals dead upon retrieval of the fishing gear. Note that during the directed fishery, the majority of animals dead at vessel would also have been landed. Post-release mortality occurs when animals are discarded alive yet subsequently die due to injuries sustained during the capture process (Bowlby et al. 2021).

Other potential sources of human-caused mortality were not quantified (e.g., entanglements in garbage, mortalities from tagging) or considered further in these analyses. In addition, there is currently no evidence that natural mortality rates for Porbeagle have changed due to human-caused threats (e.g., climate change, prey/predator redistribution, etc.).

LANDINGS

Commercial landings of Porbeagle Sharks from Canadian fisheries began to decline well before the closure of the directed fishery (Campana et al. 2001). By 2011, there were essentially no reported landings in international waters of NAFO Divisions 3KLNOP by foreign fisheries (Simpson and Miri 2014). Total landings were consistently < 1 mt annually from all fisheries in NL and QC, and < 0.1 mt annually in the GULF from 2007 until 2014 (Campana et al. 2015). Even in MAR, landings dropped from 83 mt in 2010 to 8 mt in 2014 (Campana et al. 2015).

For this assessment, landings data from all regions were extracted from the Zonal Interchange File Format (ZIFF) database, which contains all commercial logbook reports by Canadian fisheries (Simpson and Miri 2014). It should be noted that discards are rarely reported in ZIFF, so total commercial catch (landings + discards at sea) cannot be determined from this database.

Many Canadian fisheries require 100% dockside monitoring of landings. However, even in these fisheries, all landings are not necessarily monitored by a dockside observer. In some cases, an authorization form is submitted by a dispatcher, which represent self-reported copies of captain's logbooks. In 2019, only 54% of recorded landings in NL were reported through the dockside monitoring program, of which a further 21% were completed by authorization forms. Similar analyses have not been done for other regions, so it is unknown how prevalent industry-reported (self-reported) data are in the commercial records. International fleets fishing in Canadian waters had 100% at-sea fisheries observer (ASO) coverage from 1987 onwards (Campana et al. 2001, Campana et al. 2015).

Porbeagle can be landed in various conditions (e.g., whole; head off, gutted; head off, tail off, gutted) and conversion factors are applied to go from landed state to whole-fish weights. To be consistent with previous analyses (e.g., Campana et al. 2015), post-processing edits made to the data prior to annual submission to ICCAT were not incorporated (Bowlby et al. 2022). Notably, these use a length-based function rather than a single conversion factor to convert from dressed to round (whole-fish) weights. Thus, there are minor differences between the annual ICCAT submission of total landings from Canadian fisheries versus the data extracted from the national database. In addition, errors in specific records may be corrected in regional databases after the original upload to the national database. These updates are not necessarily reflected in ZIFF data. For this assessment, there are minor discrepancies between Porbeagle landings from the Maritimes Region reported in regional versus national databases, particularly in 2018.

Throughout 2015–2021, total landings remained low from Atlantic Canadian fisheries (Table 1). Total landings from bycatch by all commercial fisheries in the Maritimes Region dropped from approximately 4 mt in 2015 to less than 200 kg in 2021. Landings were sporadic in all other Regions, only occurring in one or two years. In general, landings make up a small component of total fishing mortality as the majority of Porbeagle are discarded.

Maritimes Region

To partition both landings and discards by fishery and/or gear type, this report makes use of the Mar.fleets R package (McMahon and Bowlby 2021). This package contains functions to identify specific fisheries, extract commercial catch data from the Maritimes Fisheries Information System (MARFIS) database, and match it to ASO records archived in the Industry Surveys Database (ISDB; McMahon and Bowlby 2021). This package is specific to fisheries in the Maritimes Region and has been previously applied in a framework assessment for Atlantic Halibut (*Hippoglossus hippoglossus*; Bowlby et al. 2024) and in a management strategy evaluation (MSE) framework assessment for Pollock (*Pollachius pollachius*; Andrushchenko et al. In press).

The main benefits of Mar.fleets for this assessment is that it facilitates the calculation of observer coverage through a 1:1 match between commercial and ASO records from the same trip. Rather than taking the common approach of extracting data on a species-by-species basis or specific to a particular gear, Mar.fleets identifies a directed fishery based on licence conditions. This means that it considers both gear type (e.g., longline, otter trawl) and fishing strategy (e.g., small-mesh versus large-mesh cod ends).

Although the vast majority of Porbeagle were landed from pelagic longline by the Swordfish and Other Tunas fishery in the years prior to 2014 (Campana et al. 2015), this is no longer the case in the Maritimes Region. It is important to remember that MARFIS has a single code for longline gear, rather than separate codes for pelagic versus benthic longlines. Previous evaluations of landings by gear type from commercial fisheries reported totals for both types of longline combined. Using Mar.fleets, the Atlantic Halibut trips using benthic longline could be separated from Swordfish and Other Tunas trips using pelagic longline to quantify the amount of landed Porbeagle from the two gear types.

The vast majority of landings in 2015–2021 came from longline gear, primarily benthic longline in the Atlantic Halibut fishery with lower amounts from the pelagic longline fishery for Swordfish and Other Tunas. No Porbeagle Shark were landed from other gear types in 2020 or 2021. Landings from otter trawl, set gillnet and handline combined were consistently below 1 mt per year, with the exclusion of 2015 (Table 2).

Newfoundland and Labrador Region

Similar to MARFIS, the DFO Newfoundland and Labrador Region's ZIFF database was created in 1985 to compile commercial landings reported by Canadian fish harvesters (as recorded in their logbooks and on fish plants' purchase slips. As per licence conditions, up to a maximum of 500 kg (or 10% of the total round weight of authorized groundfish caught) of shark bycatch can be legally retained in groundfish-directed fisheries (except for White Shark [*Carcharodon carcharias*] and Shortfin Mako Shark [*Isurus oxyrinchus*]).

Landings in the ZIFF database over 2001–2003 averaged 1,250 kg per year but have rarely exceeded 150 kg since then. In 2015, total landed weight was 167 kg from longline, and 10 kg from handline in 2018 (Table 2). These landings came from NAFO Subdivision 3Ps in 2015 and Division 3L in 2018 (Table 3). Although no landings were reported in more recent years, records of Porbeagle bycatch did occur (i.e., ZIFF records of 0 kg weight).

Commercial landings data are also reported in the NAFO STATLANT 21A database from NAFO Subareas, as reported annually by NAFO-member countries (including Canada) from 1961 to 2021. Similar to ZIFF, reporting in this database also does not include discards at sea. While previous analyses indicated that combined Porbeagle landings in NL had declined to approximately 1 mt in 2011, total reported landings in 2012 rose to an estimated 23 mt. In 2014, landings totaled approximately 1 mt, and have remained zero since then. This means that landings have remained zero from 2015 onwards.

Gulf and Quebec Regions

Historical landings data strongly suggest that Porbeagle were rarely encountered by fisheries in the Gulf and Quebec Regions. When gear type was recorded, landings in 2015–2021 came exclusively from longline (pelagic + benthic longline combined). Total landings were low in all years considered in this assessment (Table 2).

DISCARDS

Quantifying mortality of discards relies on two components: (1) fishery-wide estimates of the magnitude of discarded catches and (2) gear-specific estimates of AVM and PRM rates. Information on the species composition and weight of discards from Canadian fisheries comes from ASO programs (Beauchamp et al. 2019). In relation to discards, it is important to recognize that not all types of fishing activity are subject to ASO coverage. Also, monitoring protocols differ in terms of the specific information that must be collected from each observed trip. Finally, depending on the fishery, observers may not be able to watch every set on an observed trip (e.g., while sleeping). In advance of this assessment, it was not possible to prorate the observed weight of Porbeagle by the proportion of the sets that were monitored due to the diversity and amount of data considered. This means some of the ASO data were transcribed from industry logbooks (i.e., industry self-reporting) and likely underestimate bycatch.

The most common monitoring protocols record shark catches by species and weight (in kilograms), with an optional field for the number of animals. Species identification is considered to be fairly accurate from 2001 onwards, following the development and distribution of training materials for various fisheries (Bowlby et al. 2022). There is currently no representative information on the length-frequency distribution of Porbeagle Shark bycatch from any fleet. Historically, length-frequency distributions would have been derived from landings data. Thus, it is not possible to document the life history characteristics (e.g., life stages) of Porbeagle bycatch intercepted by various fleets. As with landings, all values are estimates because crew had no ability to weigh individual sharks.

Maritimes Region

To identify the fisheries that potentially interact with Porbeagle, ASO data from all years (1979–2021) were originally queried for captures of Porbeagle Shark. Records were organized by species sought and gear type. There was a single record (2016) of a Porbeagle caught in the Northern Shrimp (*Pandalus borealis*) fishery, five records (prior to 1994) of discards from the Shortfin Squid (*Illex illecebrosus*) fishery, and two records (1993, 2005) of discards from handline while targeting Bluefin Tuna (*Thunnus thynnus*). These fisheries were not considered further in this assessment, mainly because discards would have been zero from 2015 to 2021 for Shortfin Squid and Bluefin Tuna, and the record from the shrimp fishery appeared to represent a rare event (i.e., no other ASO records before or since; no landings ever). Similarly, there have been Porbeagle Shark caught on the summer Research Vessel (RV) survey, but at exceptionally low rates so the research survey was not considered further in this assessment. The five records from the offshore scallop (*Placopecten magellanicus*) fishery were determined to be data entry errors in the species code associated with the catch record.

For each fleet, the total number of commercial trips was compared with the total number of observed trips (i.e., trips observed/total trips) to calculate annual observer coverage. Observer coverage estimates were calculated individually for each gear type contributing to catches by a specific fleet. Although this may not be consistent with stock assessments that calculate coverage relative to target species weight, it is more useful to understand the potential for Porbeagle interactions by gear type and fishing strategy. The total number of observed trips was compared with the number of observed trips that encountered Porbeagle to calculate relative interception rates (i.e., observed trips catching Porbeagle/trips observed; Bowlby et al. 2022).

Discard weights are totals from the ASO-monitored trips exclusively, and values are estimates because industry participants have no ability to weigh animals prior to discarding. We did not report discards as a number of animals because this is an optional data field in the ISDB and values were commonly missing. Data are summarized by fishery in Appendix 1.

The majority of groundfish fisheries have a quota year that does not correspond to the calendar year. Data are presented relative to calendar year because that seemed most consistent with the requested TORs for this assessment. However, ASO coverage and the number of commercial and ASO trips will not correspond with other assessment documents due to the differences in time period.

Mar.fleets was used to extract data for the multi-species groundfish fisheries (fixed and mobile) targeting Haddock (*Melanogrammus aeglefinus*) and Pollock with bycatch of Atlantic Cod (*Gadus morhua*) (hereafter, the Cod/Haddock/Pollock fleet), the multi-species Unit 2 and Unit 3 redfish (*Sebastes* spp.) fleets, the Silver Hake (*Merluccius bilinearis*) fleet, and the Atlantic Halibut fishery. Mar.fleets has not yet been extended to include functions to extract data for fisheries targeting flatfish, or small and large pelagics.

Because of generalities related to licensing (e.g., benthic longline can be fished under a multispecies groundfish licence to target Cod/Haddock/Pollock or Atlantic Halibut), specific trips could belong to multiple fisheries if a large suite of species was caught. We removed instances where specific trip IDs were duplicated to better represent observer coverage in specific fishery components and so that Porbeagle bycatch weight could be summed across fleets. This necessitated several assumptions: (1) benthic longline that intercepted Atlantic Halibut was part of the Atlantic Halibut fishery and not the fixed gear Groundfish fishery for Cod/Haddock/Pollock, (2) mobile gear for Cod/Haddock/Pollock that also caught Atlantic Halibut were part of the Cod/Haddock/Pollock fleet, (3) mobile gear catching Cod/Haddock/Pollock in addition to Winter or Witch Flounder were also part of the Cod/Haddock/Pollock fishery and (4) set or drift gillnets catching flatfishes were part of the small pelagics fleet.

Unit 2 and Unit 3 redfish

Redfish are targeted primarily using otter trawl with smaller cod-end mesh sizes than other groundfish fisheries in Maritimes Region. The fishery is broken into two units, with Unit 2 including NAFO Subdivisions 3Pn, 3Ps, 4Vn, 4Vs and DFO statistical unit areas 4Wfgj. Unit 3 comprises DFO statistical unit areas 4Xumnopqrs, 4Wdehkl and NAFO Division 5Y. The mesh size used in Unit 2 ranges from 90 to 120 diamond or square, and in Unit 3 is 110–120 diamond or square. In Unit 2, there are temporal changes in management where NAFO Subdivisions 3Pn and 4Vn belong to Unit 2 during June to December and Unit 1 (Gulf Region) for the remainder. The data presented here are only from effort by vessels licenced in the Maritimes Region (Table A1, Appendix 1).

Relatively few commercial otter trawl trips from the Maritimes Region targeted redfish during 2015–2021, with the total number ranging from 50 to 71 in Unit 2 and from 121 to 250 in Unit 3 (Table A1, Appendix 1). ASO coverage was variable, ranging from 1.8 to 22% of trips in Unit 2, and 4.6 to 17.4% in Unit 3 (Table A1, Appendix 1). Porbeagle were rarely intercepted on ASO trips, particularly in Unit 2. When they were caught, interception rates were variable because of the low number of observed trips, ranging from 9 to 50% in Unit 2 and 5 to 25% in Unit 3 (Table A1, Appendix 1). Observed discard weights of Porbeagle from each Unit remained below 1 mt annually, often substantially below (Table A1, Appendix 1).

Multispecies groundfish

The major multispecies groundfish fisheries in the Maritimes Region target Haddock and Pollock, with bycatch of Atlantic Cod, using a variety of gear types. The fixed gear component fishes primarily with benthic longline using smaller hook sizes than trips targeting Atlantic Halibut, although hook sizes are not recorded in commercial data and are inconsistently recorded in ASO data (Themelis and den Heyer 2015). The mobile gear component fishes with otter trawl and licence conditions stipulate that otter trawl cannot be used to target Atlantic Halibut. When gear characteristics are recorded in the commercial data, the cod-end mesh is typically 120 mm. Effort is widely distributed on the Scotian Shelf.

For the component of the fishery using fixed gear, there tended to be more trips in a year using benthic longline than other fixed gear types in both 4X5Y and 5Z (Table A2, Appendix 1). There were large discrepancies in observer coverage between 4X5Y versus 5Z, with < 5% of trips observed irrespective of gear type in 4X5Y, and coverage ranging between 6.7 and 33% for benthic longline and 0 to 12% for set gillnet in 5Z. Note that the total number of observed trips for the component of the fishery using fixed gear is quite low, with a maximum of 15 in a single year and most values < 10 (Table A2, Appendix 1). There were no observed handline trips. Discard weights and interception rates of Porbeagle from handline and set gillnet are relatively unknown, in that most years had no observed trips and others had a maximum of two observed trips (Table A2, Appendix 1). Interception rates for the fixed gear fisheries are essentially unknown, as there was only one observation (from one observed trip) of Porbeagle bycatch, leading to 54 kg of observed discards.

The mobile gear component of the fishery fishes with otter trawl, and observation rates were much higher in NAFO Division 5Z (34–79.8%) than in 4X5Y (3.9–10.3%; Table A2, Appendix 1). The interception rate for Porbeagle was slightly lower in 4X5Y (6.7–32%) as compared with 5Z (16.1–35%). It is likely that the estimates for 5Z are more accurate given the higher level of observation effort. Observed discard amounts were extremely variable in 4X5Y (47–4,853 kg) and were substantially higher in 5Z (4,344–23,134 kg), reflecting the higher observer coverage (Table A2, Appendix 1).

Silver Hake

The directed fishery for Silver Hake is active in LaHave Basin, Emerald Basin and small mesh management areas, and uses otter trawl with 55–65 mm square cod-end mesh. Such small mesh cannot be used outside of these areas by other multispecies groundfish fleets. From 2015 to 2021, the number of commercial trips undertaken annually ranged from 152 to 400, with 1.4 to 5.3% being observed (Table A3, Appendix 1). There was only one observed record of discards, 40 kg in 2019 (Table A3, Appendix 1).

Atlantic Halibut

The Atlantic Halibut fishery uses benthic longline (2,763–3,464 trips annually) and has observer coverage ranging from 1.5 to 4.2% (Table A4, Appendix 1). From 2015 to 2021, the estimated interception rate for Porbeagle on benthic longline was low, at 1.3–10.3%. Total weights of observed discarded Porbeagles have ranged from 92 to 2,513 kg (Table A4, Appendix 1).

Multispecies Flatfish

The multispecies flatfish fishery predominantly catches Greenland Halibut/Turbot (*Reinhardtius hippoglossoides*), American Plaice (*Hippoglossoides platessoides*), Witch Flounder/Greysole (*Glyptocephalus cynoglossus*), Winter Flounder (*Pseudopleuronectes americanus*), Yellowtail Flounder (*Pleuronectes ferruginea*), and unspecified flounders. Winter Flounder and Witch Flounder are considered the two main target species. The mobile gear component of the fishery uses a larger cod–end mesh size than is typical for other groundfish fleets, with a minimum of 155 mm square for otter trawl and a minimum of 145 mm diamond for Danish/Scottish seiners. Unlike purse seine, Danish or Scottish seines use weighted ropes to deploy the net on the sea floor.

From 2015–2021, there were no observed trips for Danish/Scottish seines or the set gillnet components of this fishery (Table A5, Appendix 1). The majority of commercial flatfish trips use otter trawl yet had exceptionally low observer coverage (< 1% in all years). There were 60 kg of observed discards from the single observed trip in 2015. The only other year with discarded Porbeagle was 2018, where a total of 250 kg of discards were observed from one of the seven observed trips. Interception rates for Porbeagle were not meaningful given the low observer coverage, being 100% in 2015 and 14.3% in 2018 (Table A5, Appendix 1).

Swordfish and Other Tunas

The Swordfish and Other Tunas fishery uses pelagic longline, with effort concentrated within deep basins off Nova Scotia and along the edge of the continental shelf. The fishery targets Swordfish (*Xiphias gladius*) or tuna species, including Albacore (*Thunnus alalunga*) and Yellowfin (*Thunnus albacares*). From 2015 to 2021, a relatively small number of commercial trips were undertaken annually (216–307), with observer coverage ranging from 2.6 to 13.9% (Table A6, Appendix 1). The low value in 2021 (2.6%) occurred because at-sea observers were not available for deployment. Porbeagle were intercepted on 11.1–40% of observed trips, with total observed discard weights ranging from 76 to 3,783 kg (Table A6, Appendix 1).

Small pelagics

There are several components to the small pelagics fishery, with Atlantic Herring (*Clupea harengus*) and Atlantic Mackerel (*Scomber scombrus*) landings derived from otter trawl, purse seine, set or drift gillnets, handline, weirs and trapnets (Table A7, Appendix 1). From 2015 to 2021, only purse seine trips were observed, with coverage estimates below 5% annually (0–4.7%). Notably, there was no observer coverage for the gillnet, handline, weir and trapnet components of this fleet. Two observed purse seine trips had Porbeagle discards, with interception rates estimated as 3.9% (2015) and 5.9% (2019; Table A7, Appendix 1). Observed discarded weights were negligible on both trips (8 and 34 kg, respectively).

Regional summary

Across all fisheries in the Maritimes Region, there were a total of 677 ASO trips from 2015 to 2021 that captured Porbeagle (20% of all observed trips), leading to 146 mt of observed discards. Discards were observed from diverse fisheries using a variety of gear types, including benthic and pelagic longline, otter trawl, gillnet and purse seine (Appendix 1, Appendix 2). Nearly 100% of benthic and pelagic longline sets were monitored on an observed trip, but Porbeagle bycatch weights from other gear types were underestimated by an unknown degree. There was a substantial amount of fishing effort (e.g., multispecies flatfish, small pelagics) that had no ASO coverage or no observed Porbeagle discards on observed trips (Appendix 2). Only the mobile gear fishery for Cod/Haddock/Pollock in NAFO Division 5Z had observer coverage in excess of 25% annually, so the observed discard total represents a substantial underestimate of Porbeagle bycatch by fisheries in the Maritimes Region.

Median observer coverage was 0.5% if the components of each fishery having zero observer coverage were included, and 5.9% if excluded (Appendix 2). Interception rates for Porbeagle from fisheries in MAR ranged from 0 to 100%, with the most variable estimates for fishery components with few observed trips (e.g., 10 or less annually). For the majority of fisheries, it was difficult to determine how often a particular gear type would be expected to intercept Porbeagle while fishing.

Even when using the same general gear type, there could be marked differences in total bycatch weight among fleets. For example, benthic longline targeting Atlantic Halibut had higher bycatch than benthic longline targeting Cod/Haddock/Pollock, even though observer coverage rates were comparable. It is possible that this is due to differences in the hook sizes used between the fisheries (Themelis and den Heyer 2015). Similarly, otter trawl targeting Cod/Haddock/Pollock in 4X5Y had higher bycatch than otter trawl targeting redfish or Silver Hake.

Newfoundland and Labrador Region

The Newfoundland and Labrador Region maintains an ASO database, which contains set-by-set information collected at sea in a standardized format by DFO-trained Canadian ASOs. This database provides a reliable source of information on total catches and discarding at sea from a subset of fishing trips in various NL commercial fisheries. However, it must be noted that the representativeness of these data by fishery depends on annual ASO coverage levels (i.e., the percentage of commercial trips observed in specific fisheries). The percentage of trips observed is not tracked by DFO-NL Conservation and Protection within the Resource Management Branch. In addition, some fisheries that are known sources of mortality for Porbeagles, such as small-boat inshore gillnet fisheries, have no ASO coverage.

To identify current fisheries that encounter Porbeagle Sharks, ASO data from 2015 to 2021 were queried by directed species and gear type. The vast majority of observed Porbeagle catches in 2015–2021 came from otter trawl gear, primarily in the NAFO Division 3NO Yellowtail Flounder fishery (Table 4) that had 25–60% ASO coverage over this time frame. Lesser amounts were also recorded in trawl fisheries that targeted redfish, Atlantic Cod, and Witch Flounder. Porbeagles were also reported in gillnet fisheries targeting Greenland Halibut/Turbot and Atlantic Cod, but with the caveat that only NL vessels greater than 100 feet had some ASO coverage (averaging 12% over those years) when using gillnet. Porbeagle bycatch was also recorded by ASOs aboard several longline vessels targeting Atlantic Halibut (Table 4).

Regional summary

Overall, discards of Porbeagle from ASO-monitored trips in NL were typically an order of magnitude lower than in MAR from 2015 to 2021. Annual ASO coverage varies in NL commercial fisheries, with the majority in the range of 0–5%, yet there are examples of very high coverage (e.g., 3LNO Yellowtail). Similar to MAR, observed discards of Porbeagle were substantially lower than fishery-wide bycatch when ASO coverage was low.

Gulf and Quebec Regions

ASO data from the Gulf and Quebec Regions indicated very low levels of Porbeagle discards in any year from 2015 to 2021 (Table 5). Also, none of the gear types were consistently associated with Porbeagle bycatch during all years. Given the scarcity of interactions, it was not practical to assign captures to individual fisheries and calculate observer coverage for these analyses.

Fishery-independent surveys

In 2017, a fishery-independent fixed-station shark survey was conducted throughout Atlantic Canada, using pelagic longline gear (Figure 1). This was the third attempt at a shark survey in Canadian waters, the previous two occurred in 2007 and 2009 (Campana et al. 2015). A total of 47 stations were fished between June 27 and July 12, and a total of 253 Porbeagle Shark were caught (168 alive, 85 dead; 34% AVM). Based on the length distribution of the catches and a length-weight relationship (Kohler et al. 1995), total fishing mortality from the survey was 10,296 kg (10.3 mt).

The surveys were originally done to track changes in relative abundance and status of Porbeagle. A comparison of the results from the three surveys demonstrated obvious violations of assumptions for a fixed station design (e.g., a lack of persistence in the spatial pattern of catches; Figure 2). Spatiotemporal analyses that incorporated several environmental covariates were evaluated to try to account for the influence of environmental conditions on catches. Such standardization is commonly done to reduce noise in an abundance index to better track changes in status (Maunder and Punt 2004, Gwinn et al. 2019).

Incorporating environmental predictors accounted for some of the observed variability in catch rates, yet none of the models could account for a high outlier in 2007. Also, residual patterns were inverted for stations along the shelf edge in 2007 as compared to 2009 (indicative of the lack of persistence). The predicted abundance index remained inconsistent with projections from fisheries assessment models (Campana et al. 2013, Anon. 2020) and suggested precipitous decline (63%) from 2007 to 2017. The extent of variability in the spatial distribution of catches among years was too high to make the argument that the surveys resulted in a representative abundance index for Porbeagle. Targeted surveys no longer contribute to total annual mortality of Porbeagle Shark.

Recreational fishery

Recreational shark fisheries in Atlantic Canada use rod and reel, and as of 2023, are exclusively catch and release (Bowlby et al. 2023). Even when shark landings were permitted in a small number of tournaments in Maritimes Region, Porbeagle were voluntarily excluded from 2006 onwards due to conservation concerns (Campana et al. 2015).

Recreational fisheries are not monitored (no ASO coverage) and mandatory logbook reporting is not strictly enforced. It is not possible to determine the magnitude of bycatch of Porbeagle within the Canadian recreational and shark charter fishery. At-vessel mortality and post-release mortality rates from captures on rod and reel are expected to be very low (Anderson et al. 2021). Thus, recreational and shark charter fishing is expected to have minimal contribution to annual Porbeagle mortality.

FISHERY-WIDE ESTIMATES OF BYCATCH

In a multi-species or multi-fishery context, simple ratios with effort or target species catches tended to be used as universal bycatch estimators (e.g., Gavaris et al. 2010, Campana et al. 2011, Themelis and den Heyer 2015). While simple to apply consistently to various fleets, these estimators have multiple analytical drawbacks. Potential issues could arise from non-linear relationships with effort or target species catches, excess zeros, and/or a spatially or temporally variable correlation structure in the catches. Excellent recent progress has been made applying more sophisticated spatiotemporal modeling or machine learning approaches to estimate bycatch of specific species from specific fisheries (e.g., Stock et al. 2019). Adequate data are expected when the majority of the total fishing effort is observed (e.g., Cosandey-Godin et al. 2015) or when the fishery undertakes a very large number of annual trips (e.g., Benoît and Allard 2009). The appropriate methodology to use to scale up observed bycatch to fishery-wide totals will depend on the amount of data (the annual number of ASO trips) as well as on the characteristics of the data (e.g., the number of zero catches, spatial and temporal variability, measured covariates).

ANALYTICAL OPTIONS

This assessment identified a suite of analytical approaches that could be applied to set-level data and used to estimate fishery-wide bycatch (Hastie et al. 2009, Gavaris et al. 2010, Themelis and den Heyer 2015, Stock et al. 2019). These included simple approaches such as means, stratified means and catch ratios, as well as more complex methods such as nearest neighbour interpolation, random forests, generalized linear mixed models (GLMMs), and spatiotemporal models (Table 6). These represent a suite of commonly used approaches (nationally or internationally) to estimate fishery-wide bycatch.

The directed fishery (1991–2013) for Porbeagle Shark used pelagic longline gear, so preliminary model evaluation was conducted using ASO data from the Swordfish and Other Tunas fishery which also uses pelagic longline gear. To increase the amount of information available, nearly all years following the implementation of an expanded ASO shark monitoring protocol were included (2011–2020). Data from 2021 were limited and not considered.

Mean estimator

The selection of trips for at-sea observation is intended to be random. If so, ASO data are random samples from all commercial trips, meaning that the sample mean from ASO can be used to infer the overall mean for the commercial data. Bycatch weight on unobserved commercial sets can be predicted by mean bycatch weight on observed sets.

Stratified mean estimator

Stratification is commonly used in fisheries science to partition a study area into regions with homogeneous density within, and heterogeneous density among, strata. In designed research surveys, strata are typically defined relative to depth, temperature, or bottom type. Bycatch weight from unobserved sets can be predicted by the average bycatch weight of observed sets within the same year and stratum.

Catch ratio

Ratio methods assume that the magnitude of bycatch will be proportional to effort. The metric used for effort must be recorded or have the potential to be derived for all commercial and observed trips. Thus, landed weight of target species is typically used as a proxy (e.g., Gavaris et al. 2010, Campana et al. 2011, Themelis and den Heyer 2015). Predicted bycatch weight becomes the weight of target species multiplied by the ratio between bycatch and target catch for each year.

Nearest neighbours

The k-nearest neighbors (k-NN) is a simple non-parametric model and a generalization of the stratified mean estimator. Rather than assuming homogeneous density within relatively large spatial strata, k-NN restricts the assumption of similarity to a limited number of nearby data points (i.e., locally). When applied to bycatch analyses, these would represent nearby observed sets. Bycatch on a commercial set could be calculated as a weighted average of neighbouring observations, where the weights were inversely proportional to the Euclidean distance from the observed sets.

Generalized linear mixed model

Parametric models such as GLMM generally assume a consistent relationship between predictors and the response variable, where numerous environmental predictors are evaluated (e.g., year, day, depth, season, etc.). Models can also allow for sources of variation on these relationships with random effects, accounting for potential variations related to different grouping variables, including space and time.

Random forest

Tree-based regression models extend the idea of data partitioning (e.g., stratified estimator, k-NN) by recursively finding the best partitioning regime within a feature space to predict a response variable from simple averaging or regression. Each predictor corresponds to a dimension in the feature space that are analogous but not limited to Euclidean space (as in the stratified estimator). Predictions from an individual tree model can have variations related to randomness in the partitioning regime, so bootstrap aggregation is typically used to average among the large number of randomized trees (i.e., random forest) and to optimize final predictions.

Spatiotemporal model

The spatiotemporal model is a specific GLMM which incorporates a random spatiotemporal effect, where the distribution of bycatch in space and time is typically modeled by an auto-regressive (more specifically, an AR1 process) Gaussian random Markov field (GRMF). The strength of spatial autocorrelation in the GRMF is modeled by a Matérn function, which attenuates as distance between two locations increases.

DATA CHARACTERISTICS AND PRELIMINARY EVALUATION

Annual sample sizes were small (i.e., a low number of observed sets per year) and positive catches of Porbeagle were sparse, sporadic over space and had a large number of zero observations (Figure 3). The number of sets observed each year (51–155) was small relative to the spatial region used by the commercial fishery. In addition, greater than 75% of observed sets in each year did not catch Porbeagle. These two characteristics indicate limited and highly zero-inflated data.

Meaningful predictions of bycatch magnitude and spatial distribution might be expected when:

- Interaction rates are high with the bycatch species of interest (i.e., the species is caught on the majority of observed trips).
- The majority of commercial sets are observed.
- Observed sets are known to be representative of the commercial fishery.
- There is relatively low spatial and/or temporal variability in bycatch events (high signal-to-noise ratio).
- Correlations between bycatch and target species catches are high (for catch ratio methods).
- Bycatch magnitude is related to measured covariates (for complex modeling approaches).
- Independent data exists for comparison (e.g., fishery-independent sampling).

Evaluation of the Porbeagle data from pelagic longline captures and preliminary model fits from each analytical approach did not meet any of these criteria, so statistical modeling was not pursued.

To demonstrate some of the points above, the data inputs were summarized in multiple ways. Comparing the spatial extent of commercial fishing activity in each year (Figure 4) with observed fishing events (Figure 5) demonstrates the paucity of sampling over the spatial domain of the commercial fishery. Of the locations sampled, the vast majority had zero catches of Porbeagle (Figure 3). There were essentially no correlations between Porbeagle bycatch and target species (Swordfish, tunas) and low correlation between Porbeagle and Blue Shark (*Prionace glauca*) (both are bycatch species; Figure 6). The absence of correlation with target species suggests that ratio methods using target species catch as a proxy for effort (Campana et al. 2011) would be inappropriate for estimating Porbeagle bycatch.

As a preliminary evaluation of predictive performance, fits from each modeling framework were compared using cross-validated root mean square errors. These comparisons indicated highly variable predictive performance among years for all models, with no indication of strong relationships with spatial, temporal, or environmental covariates. There was no attempt to actually use any statistical modeling approach to predict fishery-wide commercial bycatch from the observed data. To be clear, limitations did not relate to any one analytical approach, but were inherent to ASO data characteristics in terms of: (1) the amount of information, (2) signal-to-noise ratio or the information content of the data, and (3) data quality.

Although the approaches were fit to the observed data in preliminary analyses, none of these analytical approaches were used to estimate Porbeagle bycatch on unobserved sets for the pelagic longline fleet (i.e., predict fishery-wide bycatch).

EXTENSION TO MULTIPLE FLEETS

As an alternative, the simplest metric that can be used to estimate fishery-wide bycatch scales up the summed discarded weights on all observed trips by the proportion of observed effort.

Unlike the statistical approaches discussed above, this estimator represents data at a trip level rather than a set level and was straightforward to apply to all fisheries. Unlike a mean estimator, this method does not provide a measure of variability. Similar to a mean estimator, it assumes that the observed trips are representative of the catch profiles from the entire fleet.

Maritimes Region

For fisheries in MAR, Porbeagle bycatch on observed trips (N_{obs}) was scaled up to a fishery-wide estimate ($N_{fishery}$) based on the proportion of observed trips (p_{obs}):

$$(1) \qquad N_{fishery} = N_{obs}/p_{obs}$$

Fishery-wide estimates of Porbeagle bycatch were very low from purse seine for small pelagics and set gillnet for Cod/Haddock/Pollock, with all positive estimates below 1 mt and the majority of values being zero (representing years with no observed bycatch; Table 7). The most substantial estimates came from otter trawl for Cod/Haddock/Pollock in NAFO Division 5Z, benthic longline for Atlantic Halibut, and pelagic longline for Swordfish. Of these, only the 5Z Cod/Haddock/Pollock component had appreciable observer coverage (averaging 60.6% from 2015 to 2021). When ASO coverage was exceptionally low (e.g., < 1% multispecies flatfish otter trawl; Appendix 2), single sporadic captures scaled up to large annual totals. Although there were no observed Porbeagle captures from the set gillnet component of the Cod/Haddock/Pollock fishery in NAFO Divisions 4X5Y because only one trip was observed (Table 7), there were landings recorded in the commercial data, suggesting that fishery-wide estimates of zero were not representative. Total annual estimates ranged from 23 mt to 189 mt of Porbeagle discards among fisheries (Table 7).

Newfoundland and Labrador Region

The proportion of observed trips could not be calculated for fisheries in NL because commercial data stored in ZIFF-NL does not have a variable that identifies unique trips. For fisheries in NL, p_{obs} represented the weight of target species kept for processing on observed trips divided by total commercial landings of the target species from the ZIFF database (representing trips that landed their catches in Newfoundland region). This provides a fraction of how much of the target species' catch was observed by an ASO. However, a lack of comparable data between ZIFF-NL and NL-ASO for each fishery in some years restricted the application of this method: the ZIFF-NL database either had no reported landings of the target species in those fisheries or contained landings of said target species in years other than those covered by NL-ASOs. Furthermore, using this ratio assumes that the probability of Porbeagle bycatch will be the same on all trips targeting a specific species.

During 2015–2021, annual bycatch estimates of Porbeagle from all NL fisheries varied from 77.5 mt in 2017 to 4.1 mt in 2018, with an average of 26.0 mt/year (Table 8). As mentioned previously, these estimates are greatly dependent on the proportion of target species catch that was observed. For example, while the NAFO Division 3NO Yellowtail Flounder trawl fishery was observed to have the most bycatch of Porbeagle (ranging from 0 to 7.6 mt per year), fishery-wide bycatch estimates were relatively similar (0–7.9 mt) because a high proportion of target species catch was observed. In contrast, the NAFO Division 3L and Subdivision 3Ps Atlantic Cod gillnet fisheries contributed very little to the observed Porbeagle bycatch (i.e., less than 0.3 mt in any particular year), yet were estimated to account for 73 mt of fishery-wide discards in 2017 (Table 8).

Summary

Scaling up discards by an annual estimate of observer coverage for MAR and by the catch ratio in NL resulted in a high degree of variability in annual discard totals among fleets. As would be expected from small sample sizes, many annual values were zero yet chance captures of Porbeagle on one or two observed trips could scale up to multiple metric tonnes of discards. A good example is from the multispecies flatfish fishery in MAR, where fishery-wide Porbeagle discard estimates went from zero in 2017 to 35.7 mt in 2018 and back to zero thereafter (Table 7). Changes are more pronounced in the gillnet fishery for Atlantic Cod in NAFO Divisions 3LPs, changing from zero in 2018, to 56.8 mt in 2019 and zero again thereafter (Table 8). It is exceptionally unlikely that discards vary so widely among years. Also, this extent of variability means that bycatch trends in individual fisheries are not representative of any underlying patterns.

Bycatch weight on observed trips from fisheries in QC and GULF were not scaled up to fishery-wide totals due to the scarcity of data and unknown ASO coverage. The extent to which Porbeagle bycatch is underestimated from fisheries in these regions is unknown.

TOTAL FISHING MORTALITY

Recall that quantifying total mortality of discards relies on two components: (1) fishery-wide estimates of the magnitude of bycatch and (2) gear-specific estimates of AVM and PRM rates.

In 2010, an expanded shark monitoring protocol was implemented by at-sea observers in the Maritimes Region in order to characterize the condition of shark captures, intended predominantly for the pelagic longline fishery. Kept catches (i.e., landings) were characterized as either alive or dead upon gear retrieval, while discarded catches were categorized as dead, injured, healthy, sharkbit, or unknown (Bowlby et al. 2022). The same protocol was followed by observers in the mobile gear otter trawl fishery for Cod/Haddock/Pollock. Shark condition was not available from other fisheries in MAR, or any NL, GULF or QC fishery for this assessment.

AT-VESSEL MORTALITY

The proportion of captures released alive was calculated as the sum of all healthy and injured releases, divided by the total number released from all condition categories, excluding ‘unknown’. In the Maritimes Region during 2015–2021, there were a total of 277 discarded Porbeagles that were scored for condition from observed trips by the Swordfish fishery using pelagic longline and a total of 809 from otter trawl trips directing for Cod/Haddock/Pollock (Table 9). From pelagic longline, the proportion of captures released alive each year was quite variable (mean = 64%; range = 0–100%), with several years having very few animals sampled. Prior to 2015, there were several years where the majority of captures from pelagic longline were categorized as ‘unknown’, leading to essentially no information on shark condition at capture or release from 2012 to 2014. From the 3375 captures during 2001–2011, the average proportion alive was very similar at 61% (range = 28–94%). The AVM rate used for this assessment was 36% for pelagic longline. This value is similar to global analyses for the species, where AVM was estimated to range between 21 and 44% (reviewed in Ellis et al. 2017), with the higher end of the range being more likely (Gilman et al. 2022).

From otter trawl, a greater proportion was released alive (mean = 80%; range = 72–84%) and there was much less variability in the estimates as compared to pelagic longline. Lower variability likely occurred because a greater number of animals were sampled. Also, condition could be more accurately assessed because animals were released following boarding, rather than cut off the gear while still in the water. Anecdotal information from NL supports the conclusion that survival is high following capture by otter trawl. The AVM rate used in this assessment was 20% for otter trawl.

Mortality was assumed to be 100% from gillnet captures because Porbeagle are ram ventilators and need to keep swimming to prevent suffocation (Campana et al. 2015).

POST-RELEASE MORTALITY

Quantifying post-release mortality from fish released alive requires tagging with pop-up archival satellite tags (PSATs) to determine the fate of each released fish. If the tagging includes both healthy and injured animals, estimates specific to each injury category can be prorated by the proportion of each in the captures to better estimate overall PRM.

The initial PRM estimates for Porbeagle discarded from pelagic longline were 27% (10% for healthy sharks, 75% for injured; Campana et al. 2016). Given that sample size was very low on injured animals (n = 4), additional tagging was done in 2017 and 2018, where an additional 8 healthy and 10 injured animals were tagged. PRM was re-estimated from a total of 48 and 14 tag deployments on healthy and injured animals, respectively, using a survival mixture model (Bowlby et al. 2020). Values were 0.06 (CI = 0.02, 0.17) for healthy and 0.40 (CI = 0.19, 0.65) for injured animals. Accounting for the relative frequency of the condition categories in the commercial catches at the time of the assessment gave a weighted mean PRM mortality rate of 0.15 (Bowlby et al. 2020). This means that there was an expectation that 15% of the animals released alive would be expected to subsequently die from injury sustained during capture.

In a more recent assessment for the entire Atlantic (multiple pelagic longline fleets), the overall PRM rate was estimated at 36% (95% CI = 26–48%) using a larger dataset and accounting for natural mortality and condition (Bowlby et al. 2021). However, this updated analysis used data from international fishing fleets that have different gear characteristics and handling practices for sharks, which explained the increase in PRM.

There were no PRM estimates from any other Canadian fishery and/or gear type.

MORTALITY OF DISCARDS

Mortality of discards (i.e., dead discards) becomes the sum of AVM and PRM from all fisheries. Two mortality scenarios were compared in this assessment.

The first scenario incorporated an AVM rate of 36% for all types of longline, 20% for all types of otter trawl, and 100% from gillnet. The PRM rate of 15% was applied to releases from all types of longline. PRM from gillnet was zero because AVM was 100%. All other captures were from otter trawl, and the condition monitoring from otter trawl in the Cod/Haddock/Pollock fishery suggested that 80% of releases were healthy and 20% were injured. To approximate PRM for all otter trawl fisheries, the condition-specific PRM rates of 6% for healthy and 40% for injured were applied to the proportion of discards that were healthy and injured, respectively. The weighted mean PRM rate applied to discards from otter trawl was 16%.

The second mortality scenario used the 75th quantile of the estimates of AVM rather than the mean value, which was 49% from pelagic longline in the Swordfish fishery and 24% from otter trawl in the Cod/Haddock/Pollock fishery. All PRM rates were the same as described in the first scenario. The decision was made to vary AVM because this component of mortality contributes more than PRM to the total and there was observed data that could be used to calculate variability.

The combined annual estimates of dead discards from MAR and NL were 6–20% higher in scenario 2 compared to scenario 1 (Table 10).

TOTAL FISHING MORTALITY

Total annual mortality was calculated as the sum of landings, plus AVM and PRM from the two scenarios described above, applied to: (1) the fishery-wide estimate of discards for MAR and NL, and (2) observed discards in GULF and QC. Mortality associated with a fishery-independent Porbeagle survey in 2017 was also included (Table 11). When gear type was not specified for discards in GULF and QC, AVM was assumed to be 0.36 and 0.49 in the two scenarios, respectively (the values used for longline). For scenario 1, total fishing mortality ranged between 11.1 mt and 136.9 mt. For scenario 2, total fishing mortality ranged between 12.9 mt and 147.3 mt.

SOURCES OF UNCERTAINTY

Several limitations inherent to data collection prevent rigorous science advice on total fishing mortality for Porbeagle Sharks. These are particularly important in the context of SAR permitting and future Fisheries Management where the intention is to use 185 mt as a maximum acceptable amount of mortality.

FACTORS AFFECTING MONITORING DATA

For both landed and released sharks, observers use a visual assessment of shark length to approximate its weight because there is no equipment onboard to weigh individual sharks. For sharks that were landed, the accuracy of weight estimates depends on the estimation ability of the individual observer. For sharks released in the water, accuracy additionally depends on how long the shark was visible and how close it was to the vessel when released. From the available data, it is not possible to determine how close weight estimates were to the actual weight of each captured shark.

When data are subsequently archived in catch databases, conversion factors are embedded in ZIFF to calculate round (whole) weight from sharks that were landed dressed (e.g., gutted). These were developed in the early 2000s and cannot be updated because Porbeagle are now rarely landed (developing conversion factors necessitates killing the sharks). Similarly, it is increasingly difficult to update size- or age-at-maturity relationships for Porbeagle in the Northwest Atlantic, given the lack of sampling opportunities. This means that there is very limited potential to evaluate changes in morphology that may be linked to human activity.

When shark condition was being scored by at-sea observers, data were more variable from pelagic longline than from otter trawl. When captured on longline, sharks are often not moving when they come to the surface and observers may not have a clear view as the gangion is cut to release the shark, making it very difficult to categorize condition. For this assessment, lower certainty in AVM for pelagic longline also affected fisheries using benthic longline when calculating fishery-wide mortality. Additionally, AVM and PRM rates would vary among fisheries, even those using the same gear general type (e.g., Gilman et al. 2022). The amount of variability in AVM or PRM from captures on different types of otter trawl or longline could not be determined.

In addition to unquantified variability, several sources of errors in data could not be corrected in advance of this assessment. In general, the reporting accuracy of positional data in commercial logbooks is poor. This can result from missing and/or incorrect information on latitude and longitude or NAFO Division (see the detailed example for the Atlantic Halibut fishery in Bowlby et al. 2024). When visualizing data from different fisheries in MAR for this assessment, there were points on land (all fisheries), instances where fishing effort apparently occurred in an incorrect NAFO Division (e.g., Unit 2 and Unit 3 redfish), at locations that are well away from the bulk of the effort (e.g., multispecies flatfish), or outside of Canadian territorial waters in US waters (e.g., Atlantic Halibut). Additionally, there were recorded Porbeagle weights that were obvious errors (e.g., < 1 kg). These types of errors can only be corrected by comparisons with paper copies of logbooks, which was a quality control exercise that was impossible to undertake for all fisheries contributing to this assessment, particularly across regions.

FACTORS CONTRIBUTING TO BIAS

There were several fisheries or components of fisheries identified in this assessment that did not have any ASO coverage, but used gear types that would be expected to catch Porbeagle (Appendix 2). Total bycatch was underestimated from those fisheries. Additionally, observed bycatch in GULF and QC was not scaled up to fishery-wide estimates due to a lack of information on ASO coverage, and was thus underestimated. Compounding the significant monitoring gaps was the absence of coordination among regional ASO programs. This becomes particularly important when fisheries are active in multiple regions, such as the Atlantic Halibut benthic longline fleet. Commercial trips that land catch in a different region (e.g., Nova Scotian vessels fishing off the coast of Newfoundland) would be erroneously excluded from the total number of commercial trips, which would cause ASO coverage to be overestimated and bycatch to be underestimated.

All ASO data records from a trip were summed regardless of whether each set was witnessed by the observer. Several fleets fish over a 24-hour period or set multiple nets at the same time, yet only a single observer is on the vessel. Porbeagle bycatch was therefore underestimated for fleets in which it was logistically impossible to monitor all sets (e.g., while an observer was sleeping), such as otter trawl fisheries for groundfish.

In MAR, the method used to scale up observed discards to fishery-wide estimates relied on being able to accurately calculate ASO coverage by fishery. Partitioning data among fisheries for MAR was intended to give more detailed information on the gear types and gear characteristics that had higher potential for interaction with Porbeagle. However, the manner in which fisheries are licenced in MAR means that specific trips have the potential to belong to multiple fisheries based on licence type, gear type, gear characteristics, and landed species. Removing duplicated trips necessitated subjective decisions on which fishery the trip belonged to. Stock assessments typically include all trips that intercept a particular species to represent the commercial fishery because they require information on total landings. A preliminary evaluation of Porbeagle bycatch using this method for data extraction suggested that specific trips would commonly belong to three or more fisheries, where such duplication caused underestimation of ASO coverage and overestimation of Porbeagle bycatch weight and interception rates. Attempting to partition commercial trips on the basis of catches had similar issues, where many trips had roughly similar proportions of multiple species (e.g., redfish, Pollock), and the assignment given to the commercial trip on the basis of catches often would not have matched the observer's determination of target species. There was no purely objective way to calculate ASO coverage and quantify bycatch for multispecies fisheries. Duplicated trips were removed, after making somewhat subjective determinations of the target species. If specific trips were wrongly ascribed to a specific fishery, ASO coverage would be overestimated, and bycatch underestimated.

In NL, the method used to scale up observed Porbeagle discards to fishery-wide estimates relied on being able to appropriately quantify the amount of target landings that were observed relative to the total target species landings from commercial fisheries. However, this proportion could exhibit a high degree of variability among years (e.g., changing from 0.64 in 2016 to 0.023 in 2017 for redfish in NAFO Subdivision 3Ps), and there were several instances where the estimate was greater than one (suggesting more was observed than was landed in a particular year). For NL fisheries with low ASO coverage targets (0–5%), it is likely that total landings of the target species in ZIFF-NL are underestimated when proportions are greater than 0.05. As with data from MAR, underestimating commercial effort means that bycatch is also underestimated.

CONCLUSIONS

There is no expectation that total fishing mortality of Porbeagle Shark from Canadian fisheries can be estimated with sufficient precision on an annual basis to manage relative to the estimate of allowable harm (185 mt). The available data allow for a limited understanding of the magnitude of mortality attributable to specific fisheries in a given year, largely due to limited ASO monitoring, low data quality, and challenges related to describing the extent of commercial fishing activity. ASO coverage across fleets would need to increase substantially, and in advance of future analyses, to generate sufficient data to obtain relatable estimates of fishing mortality.

TOR 1: TOTAL COMMERCIAL CATCHES

TOR 1: Estimate the total commercial catches of Porbeagle Shark in the Maritimes, Gulf, Newfoundland and Labrador, and Quebec regions, in both tonnage and number of animals.

The annual estimates of total commercial catches of Porbeagle Shark in MAR, GULF, QC, and NL could only be derived as a tonnage. Catch number is an optional field in ASO data and there is no representative length-frequency information from Porbeagle commercial catches from any fishery during 2015–2021 that could be used to transform tonnage into a number of animals.

For the years considered in this assessment (2015–2021), recorded data led to commercial catch estimates that were imprecise and underestimated by an unknown degree due to:

- Partial reliance on industry self-reporting in both the commercial landings data and ASO records (commercial data in logbooks are not always verified by dockside monitoring, and logbook records are used by an ASO when a specific set could not be monitored on an observed trip).
- Low and/or non-existent ASO coverage in numerous fisheries that have the potential to intercept Porbeagle.
- Annual Porbeagle discards from specific fisheries were extremely variable with a high number of zeros; interception rates on observed trips were similarly variable.
- Relative to other years in this assessment, ASO coverage in 2021 tended to be particularly low. Starting in 2020, restrictions related to the COVID-19 pandemic would have influenced data collection. Data from 2021 were not comparable to other years.

Total commercial catches include all landings and discards from all regions, without consideration of whether the animal was alive or dead at capture or release (i.e., these values represent all bycatch from fisheries, not only the proportion contributing to total mortality estimates). For each year, the fishery-wide discard estimates from MAR (Table 7) and NL (Table 8), the observed discards from QC and GULF (Table 5) and all landings (Table 1) were summed to get an annual estimate. Captures from the fishery-independent shark survey in 2017 were not included, because these were not from commercial fisheries. Note that the survey was included in the annual mortality estimates under TOR 4. Excluding 2021, values ranged between 74.7 mt (2020) and 203.3 mt (2017) per year and these should be considered minimum estimates, given the caveats above.

TOR 2: BYCATCH FROM SPECIFIC FISHERIES

TOR 2: Determine the proportion of Porbeagle bycatch attributed to specific fisheries and retained by each.

Similar to the outcomes of TOR 1, it was difficult to accurately attribute the proportion of annual Porbeagle bycatch to specific fisheries, due to:

- Landings could only be evaluated by gear type rather than fishery given the structure of the national ZIFF database.
- There was no purely objective way to assign commercial trips to specific fisheries for multispecies groundfish licences in MAR that used the same gear, yet interception rates for Porbeagle differed among them.
- There were examples of fisheries with landings but no observed discards, due to low/non-existent ASO coverage.
- Observed catches (landings or discards) of Porbeagle were sporadic from numerous regions (particularly GULF and QC) and from different fisheries in MAR and NL.

Porbeagle bycatch was consistently observed in the majority of years from the Atlantic Halibut fishery (benthic longline) and the Swordfish and Other Tunas fishery (pelagic longline) in MAR Region. From 2015–2021, benthic longline used in the Atlantic Halibut fishery was associated with the highest bycatch of Porbeagle, considering both landings and discard information. High amounts of observed bycatch in the otter trawl component of the Cod/Haddock/Pollock fishery were associated with high ASO coverage in comparison with other fisheries, resulting in fishery-wide discard estimates that were more similar to observed bycatch. Conversely, there was an absence of monitoring or limited monitoring in fisheries using gear types that would be expected to have high mortality for Porbeagle (e.g., set or drift gillnets) in both MAR and NL.

TOR 3: SPATIAL AND TEMPORAL DISTRIBUTION

TOR3: Evaluate the spatial and temporal distribution of bycatch and estimate how it has changed over time.

It was not possible to address this TOR with the data available.

The reporting accuracy of set-level positional data in commercial logbooks can be poor (Bowlby et al. 2024). Points on land were excluded from the data used in this assessment, but other types of positional errors remained (e.g., incorrect NAFO Divisions, points outside Canadian waters). These types of errors can only be corrected by comparisons with paper copies of logbooks, which was a quality control exercise that was not possible to undertake for all fisheries contributing to this assessment, particularly across regions.

Positional errors influence our understanding of the spatial distribution of effort in particular fisheries, by including locations that are not actually being fished. If bycatch at these erroneous locations were to be predicted from a statistical model, positional errors would also influence the spatial distribution of bycatch. This is why our assessment did not show the spatial distribution of observed Porbeagle bycatch relative to the extent of each commercial fishery.

Statistical models must be fit to observed data to predict bycatch magnitude at unobserved locations. These models can be spatially implicit (e.g., stratified means, nearest neighbour interpolation) or spatially explicit (e.g., spatiotemporal models). Combining predictions with the locations of the observed catches gives information on the spatial distribution of bycatch throughout a commercial fishery. For this assessment, statistical modeling could only be explored for one fishery given time constraints.

None of the identified analytical approaches were pursued, due to:

- High spatial and temporal variability in Porbeagle catches in the pelagic longline data coupled with low sampling and a very high proportion of zeros.
- Poor data quality, in that Porbeagle weights are estimated from the approximate length of each animal and then summed to a total discard weight per set.
- No correlation between Porbeagle bycatch and target species catches, invalidating catch ratio methods.
- Preliminary comparison of multiple modeling frameworks demonstrated similar predictive power from simple and complex approaches, suggesting weak/non-existent relationships with covariate predictors.

Furthermore, the inability to develop robust, model-based predictors for fishery-wide bycatch also prevented the evaluation of spatial patterns in catches from individual fleets. While not shown here, there were large differences in spatial predictions from the different types of analytical methods, reflecting different model assumptions. For example, using a Guassian Markov Random Field to describe correlations in bycatch over space (spatiotemporal model) introduced relatively smooth declines in density from areas of higher concentration. Conversely, local estimation from k-NN (nearest neighbours) produced a much more patchy distribution of fishery-wide bycatch.

Other research has combined all observed data on a particular species to describe spatial patterns in bycatch, irrespective of fishery that it came from (e.g., Jubinville et al. 2021). This assessment showed distinct differences in Porbeagle catchability by different fisheries using the same general gear type (e.g., high interception rates from benthic longline for Atlantic Halibut in comparison with benthic longline for groundfish). These differences in catchability would bias spatial pattern in a combined analysis, overestimating density in the areas targeted by fisheries with high catchability. An excellent example of how catchability can influence apparent distribution patterns was recently explored for the Pollock fishery (Andrushenko et al. 2024), where changes in the manner that otter trawls were set essentially determined the main species intercepted within a small spatial area. For the same reason that differences in catchability cannot be ignored when evaluating bycatch magnitude, they cannot be ignored relative to spatial patterns. It would not be advisable to combine all ASO information in an integrated analysis, unless the distinct differences in apparent catchability among fisheries for Porbeagle (as approximated by interception rates) were accounted for. This could be explored in future work.

The trends in annual bycatch were not meaningful because of the predominance of zeros in the ASO data. Porbeagle were captured sporadically on observed trips from the majority of fisheries, and it is not possible to scale up a zero. Fishery-wide estimates of Porbeagle bycatch could go from zero to multiple tonnes and back to zero over the course of three years. Such high variability resulted from low ASO coverage as well as the methods used to scale up observed catches to fishery-wide totals in MAR and NL.

Even if a trend could have been described, there is no clear interpretation of what increasing or decreasing bycatch trends in particular fisheries might signify about Porbeagle Shark abundance. This makes it difficult to infer the overall risk posed by individual fisheries to Porbeagle from fishery-wide estimates of bycatch. There is a tendency to view positive trends in bycatch as a negative characteristic (indicating increased mortality on a population), yet increased bycatch might signify increased abundance and thus be a positive instead of a negative sign (Minami et al. 2007).

On the other hand, the magnitude of discarded bycatch is expected to be related to fishery characteristics that influence catchability. If operational characteristics of the fisheries (e.g., spatial distribution, seasonality) and/or changes in the abundance of the target species (via hook exclusion) lead to lower catchability, bycatch can decline without a change in the underlying abundance of Porbeagle. The lack of catch per unit effort (CPUE) indices for the 2020 Northwest Atlantic Porbeagle assessment by ICCAT is a good example, where operational characteristics of fisheries had changed so dramatically, it was not possible to develop standardized indices where catchability of Porbeagle was roughly constant over time (Anon. 2020). A second example relates to the Atlantic Halibut fishery in MAR, where increasing abundance of the target species lead to hook exclusion (Luo 2020). As more and more hooks were occupied by Atlantic Halibut, the number available for bycatch declined, potentially leading to lower catchability for numerous species of bycatch (Bowlby et al. 2024).

TOR 4: MORTALITY OF DISCARDS

TOR 4: When bycatch is discarded, estimate post-release mortality for each fishery/gear type.

It is unrealistic to assume that a commercial fishery would cause no mortality during capture and release of bycatch. However, assumed AVM and PRM rates were applied to captures by the same general gear type (longline, otter trawl, gillnet, etc.) when fishery-specific data were unavailable. This meant that the magnitude of annual discard mortality was highly uncertain for the majority of fisheries. Condition monitoring to assess AVM occurred in two fisheries in MAR; rates were assumed for 18 other fisheries in MAR and NL plus all observed discards in QC and GULF. PRM has been estimated for one fishery in MAR; rates were assumed for all others. It is critical to consider the number of assumptions contributing to information from a specific fishery in future work.

Annual estimates of dead discards from MAR and NL varied by 6–20% between the two mortality scenarios considered in this assessment (Table 10). The higher scenario would be more precautionary. If the same mortality assumptions (AVM and PRM rates for each gear type) were applied to observed discards in GULF and QC and added to the values in Table 10, total dead discards ranged from 10.9 to 125.0 mt in Scenario 1 and 12.6 to 135.4 mt in Scenario 2. These totals represent the sum of AVM and PRM mortality (dead discards) for all regions. The lowest values in both scenarios were in 2021 and the highest in 2017.

TOR 5: UNCERTAINTIES AND GAPS

TOR 5: Describe uncertainties in the estimates of bycatch and mortality and identify gaps in available data sources.

Correctly propagating the numerous sources of uncertainty and bias affecting these analyses was not possible from the available data. There is cumulative variability associated with all aspects of this assessment. Most often, the magnitude of uncertainty was unknown and logistically impractical to estimate. For example, there would be the potential to explore the influence of conversion factors (i.e., constant values versus a length-based relationship) when going from dressed to round weight when evaluating the magnitude of observed Porbeagle discards or when summing commercial landings (see a rough comparison in Table 1 between recorded landings and ICCAT data submissions). However, without current morphological monitoring (from landings or lethal sampling), it would be difficult to determine which option would generate more accurate values.

The greatest source of potential variability would arise from the method used to go from observed Porbeagle discards to fishery-wide total estimates. This was apparent in the annual estimates of fishery-wide discards from MAR and NL, where small catch amounts (10s of kg) could become multiple tonnes of discards when the effort ratio was low (e.g., multispecies flatfish in MAR), or observed discards could remain similar to fishery-wide estimates if the effort ratio was high (e.g., the 3OPs Witch Flounder fishery in NL).

The major gaps in available data sources related to ASO monitoring, which was very low or non-existent for several components of several fisheries, particularly those using gear types that would be expected to cause higher Porbeagle mortality (e.g., gillnets). Another major gap resulted from the inconsistencies in databases and data archival. The data formats were not standardized amongst Regions, resulting in difficulties extracting and summarizing the commercial and ASO records used in this assessment and inconsistencies in results. For example, landings from all regions could only be partitioned relative to gear type rather than assigned to a particular fishery.

TOR 6: ALTERNATIVE METHODS

TOR 6: Explore various methods to address the above objectives, including approaches used in other jurisdictions.

An attempt was made to address this TOR by identifying and evaluating multiple statistical modeling approaches to estimate bycatch magnitude on unobserved commercial sets in the Swordfish and Other Tunas pelagic longline fishery. These methods represented a range of approaches that varied in complexity, used previously in Canadian assessments of bycatch (e.g., Gavaris et al. 2010) or used internationally (e.g., Stock et al. 2019). However, the quality and characteristics of the data precluded the use of statistical models for bycatch prediction.

ADDITIONAL CONSIDERATIONS

Evaluating bycatch across diverse fisheries is a very complex process and there are numerous factors that influence whether the attempt will result in meaningful advice relative to management goals. Some of these considerations are outlined here for Porbeagle but may also influence similar processes for other widely distributed and rarely intercepted bycatch.

RELEVANCE OF MAXIMUM LEVEL (185 MT)

The threshold for allowable harm (185 mt) represented an exploitation rate of approximately 4% on the estimate of exploitable Porbeagle biomass from 2009 (4,700–5,100 mt; Campana et al. 2013). The population viability analysis (PVA) that was used to evaluate allowable harm projected the northwest Atlantic Porbeagle population into the future, starting from the terminal year biomass prediction from a stock assessment model (2009) and assumed a constant exploitation rate for each projection (Gibson and Campana 2005, Campana et al. 2013). The exploitation rates were a constant proportion of biomass, and values ranged from 0 to 10% annually in individual projections. The projection that was chosen as the basis for the allowable harm threshold used an exploitation rate of 4%, where the population was predicted to reach maximum sustainable yield (MSY) for spawning stock number (SSN_{msy}) between 2040 and 2060 from two model variants, and as early as 2028 from the other two that assumed higher productivity.

It is important to recognize that the results of the PVA were conditional on the underlying population model (four variants), the abundance value used to represent exploitable biomass (4,700–5,100 mt in 2009; Campana et al. 2013) as well as the length-weight relationship and average Porbeagle weight used to convert numbers to biomass (to get 185 mt). If any of those components changed, abundance would have changed, and an exploitation rate of 4% would have given a different threshold value for the reference point. The main sensitivity would be to population size. If abundance is currently less than approximately 5,000 mt, the 185 mt threshold for total mortality would represent a higher exploitation rate and thus could be too high relative to the assessment of allowable harm, and vice versa if abundance is currently greater.

It is difficult to determine the current population size of Porbeagle Shark in the northwest Atlantic and consequently how close 185 mt is to the 4% exploitation rate from the allowable harm assessment. No CPUE abundance indices could be derived for the most recent stock assessment by ICCAT (from any country) because of substantial changes in fishing practices since approximately 2015 in the north Atlantic (Anon. 2020). CPUE indices are used to scale biomass in stock assessment to predict annual population size (Quinn and Deriso 1999). Because there were no indices, abundance was scaled from the terminal year biomass from Campana et al. (2013) to predict population response to observed total removals. Although the stock assessment predicts that Porbeagle abundance has been increasing since 2001 and that current abundance should be larger than in 2009 (Anon. 2020), this result is partially dependent on using 2009 biomass as a model input (in addition to assuming that the removals series represents total annual mortality). If exploitable biomass has increased by approximately 30% since 2009 (as predicted by the assessment), it would suggest abundance is approximately 6,500 mt in 2021. A 4% exploitation rate would represent a threshold of 260 mt for allowable harm.

The only other source of information on relative abundance of Porbeagle in the north Atlantic is the index derived from the fishery-independent Canadian shark surveys. Contrary to the stock assessment, this index suggested precipitous decline in Porbeagle Shark abundance from 2007 to 2017 (63% reduction). As previously discussed, there were clear violations to survey assumptions that would have impacted the index, making it uncertain how well it tracks changes in relative abundance. To get a decline of this magnitude, unreported mortality would have to have been very high. In other words, the data provided to ICCAT would have needed to be a substantial underestimate of Porbeagle removals in the Northwest Atlantic. If exploitable biomass has declined by approximately 60%, it would suggest abundance is approximately 2,000 mt in 2021. A 4% exploitation rate would represent a threshold of 80 mt for allowable harm.

Given that there is uncertainty on whether the population has been increasing or decreasing since 2009, it is not possible to determine how well 185 mt approximates a 4% exploitation rate.

PRACTICALITIES

The main sources of uncertainty identified in the 2015 Recovery Potential Assessment related directly to monitoring deficiencies affecting future ability to assess population status and evaluate the magnitude of total catch (Campana et al. 2015). When trying to quantify total fishing mortality, low and/or non-existent observer coverage as well as unreported bycatch were highlighted as key data gaps (Campana et al. 2015). It has long been recognized that NAFO-reported landings from Canadian harvesters do not represent the extent of Porbeagle bycatch, and removals continue to be substantially higher than the totals from official statistics. This ongoing impediment to the assessment of Porbeagle Sharks in Atlantic Canadian waters is a global problem in other regional assessments. Some regions in the Atlantic are hypothesized to have bycatch mortalities of Porbeagle and other large pelagic sharks at least twice as high as what reported landings indicate (Cosandey-Godin and Worm 2010, ICES 2013, Worm et al. 2013, Campana et al. 2016).

There are several fisheries or components of fisheries that do not require ASO coverage. In MAR, examples include commercial handlining, recreational fishing in the marine environment for sharks and/or groundfish, as well as brush weirs and trapnets for small pelagics. In NL, notable examples include inshore Atlantic Cod gillnet and herring nets, which are known to interact with Porbeagle Sharks because of reporting through harvester outreach programs. The extent that unmonitored fisheries may interact with Porbeagle and the magnitude of any associated mortality from these interactions are unknown. It is important to recognize that our current and future understanding of Porbeagle Shark interactions with commercial fisheries relies entirely on ASO data collection. While alternate monitoring tools (SARA logbooks and supplementary bycatch logbooks) may be introduced for various fleets, auditing these reporting mechanisms will also be needed to ensure congruence between industry-reported data and independent monitoring (e.g., Lewison et al. 2004, Emery et al. 2019). This means that ASO data will continue to be critical to: (1) identify the fisheries that potentially interact with Porbeagle Sharks (e.g., identify when supplementary logbooks or SARA logbooks are needed) and (2) monitor the magnitude of discarding by those fleets.

The way that fishing data are collected and archived in Atlantic Canada greatly complicated these analyses. In situations where model-based estimators of bycatch might be appropriate, they may become logistically impossible to implement because they require set-level data (including positional information) from all commercial trips and all ASO trips. From a practical standpoint, statistical model development would only be possible for a limited number of fisheries on an annual basis, given complexities related to data extraction and model development and optimization.

Identifying fisheries and scaling up observed discards by the proportion of commercial effort that was observed represented a large amount of work. For ASO data from MAR, substantial effort was expended to assign specific trips to unique fisheries. This was done to ensure that observer coverage could be calculated reliably and Porbeagle bycatch could be ascribed to the correct fishery. The reason this took so much time is that multiple fisheries (e.g., small pelagics, flatfishes, redfish) have not been assessed recently, so there is limited knowledge about fishery characteristics (e.g., number of trips, spatial distribution of effort). Other errors in data (e.g., impossible geographical locations) could not be corrected in advance of this assessment, as this would require comparison of thousands of catch records with paper copies of logbooks. These analyses also required input and time from numerous assessment units who were not directly involved in this process. Moving forward, such logistical considerations should be weighted against the potential utility of the analyses for future questions on bycatch.

MONITORING FISHERY INTERACTIONS

There is an important distinction between using ASO programs as a monitoring tool for directed fisheries and using ASO to quantify bycatch of a specific species. While it was not evaluated in this assessment, the level of ASO coverage that may be appropriate in the former instance may be insufficient for the latter (Collins et al. 2015). In Collins et al. (2015), ASO coverage levels in excess of 25% were required to accurately monitor the bycatch of wolffish species in some NL fisheries. This is a level of ASO monitoring that is not achieved in NL fisheries, with the exception of offshore shrimp fisheries that have a target of 100% ASO coverage, and NAFO Division 3NO Yellowtail Flounder trawl fishery with 25–50% target ASO levels. Similarly, monitoring coverage in excess of 25% is rarely achieved in other regions.

Simulation studies are often suggested to determine how high ASO coverage would need to be in order to reliably estimate a specific parameter (Babcook et al. 2003). In developing such a simulation, it would be necessary to make assumptions about whether current monitoring is representative. For example, should the observed temporal and spatial patterns in Porbeagle bycatch be used to develop the underlying hypothetical abundance distribution of Porbeagle that will be sampled during the simulation? If not, how will a realistic and biologically-meaningful distribution be determined so that we have accurate and precise estimates of necessary ASO coverage levels? Unlike teleosts that are intercepted by research surveys, there is no fishery-independent information on Porbeagle density or distribution. Therefore, assumptions made in setting up the simulation would largely determine the results.

For any rarely-intercepted SAR, a high level of at-sea monitoring may be required in order to precisely estimate annual bycatch of rarely-intercepted species. In terms of improving data collection, electronic monitoring with sensors and cameras is often suggested as an avenue to address limitations inherent in ASO programs. Benefits include complete coverage (100%) that could be subsampled following a true randomized design to eliminate spatial and temporal biases as well as deployment and observer effects (Benoît and Allard 2009). Electronic monitoring also has the potential to change behavior and ensure fishing practices conform to licence conditions (van Helmond et al. 2020). Relative to shark bycatch, numerous practical challenges and some inherent limitations with that may never be overcome. The most important challenges are related to the placement of cameras so that catches are visible, recording and archival of the video, and the development of artificial intelligence algorithms to identify species and estimate catch magnitude. For the fisheries in which pelagic sharks are released in the water (e.g., benthic and pelagic longline), these practical challenges become more onerous. Electronic monitoring precludes data collection on morphological characteristics (e.g., sex) and condition (e.g., dead or alive) and limits the potential for biological sampling (e.g., vertebral sampling for aging). Finally, trials of electronic monitoring systems in NL demonstrate instances of deliberate alteration or disconnection of the system.

RESEARCH RECOMMENDATIONS

It would be beneficial to improve standardization among the data sources contributing to assessments of bycatch for wide-ranging species that inhabit multiple regions. An initial step could be to incorporate an identifier for unique trips in the ZIFF-NL database. This would allow ASO coverage to be calculated at a trip level, similar to the method used in MAR for this assessment.

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TABLES

Table 1. Total landings (kg) of Porbeagle Shark from all fisheries and fisheries in the Maritimes, Gulf, Quebec and Newfoundland and Labrador Regions during 2015–2021, as reported through the national Zonal Interchange File Format (ZIFF) database. Totals reported to the International Commission for the Conservation of Atlantic Tunas (ICCAT) include landings from vessels fishing in international waters. Data were extracted November 17, 2022.

Region	2015	2016	2017	2018	2019	2020	2021
Maritimes	3,599	1,652	1,511	670	304	126	198
Gulf	0	107	0	0	0	0	0
Quebec	0	227	0	0	0	108	0
Newfoundland and Labrador	167	0	0	10	0	0	0
Total	3,766	1,986	1,511	680	304	234	198
ICCAT submission	4,164	1,884	1,781	785	338	148	207

Table 2. Commercial landings (kg) by gear type of Porbeagle Shark in the Maritimes (MAR), Gulf (GULF), Quebec (QC) and Newfoundland and Labrador (NL) Regions during 2015–2021, as reported through the national Zonal Interchange File Format (ZIFF) database. The Mar.fleets R package (McMahon and Bowlby 2021) was used to split the longline category into surface (pelagic) and bottom-set (benthic) components for the Maritimes Region.

Region	Gear	2015	2016	2017	2018	2019	2020	2021
GULF	Longline	0	107	0	0	0	0	0
NL	Longline	167	0	0	0	0	0	0
NL	Handline	0	0	0	10	0	0	0
QC	Longline	0	0	0	0	0	108	0
QC	Not reported	0	227	0	0	0	0	0
MAR	Otter trawl	351	210	127	92	0	0	0
MAR	Set gillnet	741	199	391	30	202	0	0
MAR	Pelagic longline	503	107	27	0	0	0	0
MAR	Benthic longline	2,004	967	927	506	102	126	198
MAR	Handline	0	169	39	42	0	0	0

Table 3. Landings (kg) by Northwest Atlantic Fisheries Organization (NAFO) Division and Subdivision in Newfoundland and Labrador Region from the regional Zonal Interchange File Format (ZIFF) database. Stars (*) identify years in which Porbeagle Shark bycatch did occur but was not landed; thus, not having a recorded weight. Zeros represent no data on landings or discards.

Year	3L	3N	3O	3Pn	3Ps	Total
2015	0	0	0	0	167	167
2016	0	0	0	0	*	*
2017	0	*	0	0	0	*
2018	10	*	*	0	*	10
2019	0	0	0	0	*	*
2020	*	*	0	0	0	*
2021	0	*	*	0	0	*

Table 4. Total discard weight (kg) of Porbeagle Shark by fishery from at-sea observer data collected in the Newfoundland and Labrador Region, from 2015 to 2021. Gear types include benthic longline (BLL), otter trawl (trawl) and set gillnet (gillnet). Zeros indicate years in which no Porbeagle discards were observed by at-sea observers.

Year	Atlantic Halibut 3NOPs (BLL)	Yellowtail Flounder 3NO (trawl)	Witch Flounder 3OPs (trawl)	Atlantic Cod 3Ps (trawl)	Atlantic Cod 3L+3Ps (gillnet)	Greenland Halibut 3L (gillnet)	Redfish 3L (trawl)	Redfish 3Ps (trawl)	Total (kg)
2015	0	850	159	0	80	0	0	0	1,089
2016	200	214	665	45	45	0	125	0	1,294
2017	159	985	60	0	212	45	631	0	2,092
2018	406	990	420	182	0	0	0	0	1,998
2019	360	0	68	695	295	0	0	181	1,599
2020	0	5,741	0	0	0	0	525	0	6,266
2021	0	7,617	0	0	0	0	0	0	7,617

Table 5. Total discard weight (kg) by gear type of Porbeagle Shark from at-sea observer data collected in the Gulf and Quebec Regions from 2015 to 2021.

Year	Not Specified	Longline	Pelagic Longline	Otter Trawl	Total (kg)
2015	0	0	0	0	0
2016	0	0	90	0	90
2017	110	0	175	0	285
2018	0	0	300	0	300
2019	0	0	0	75	75
2020	0	12.7	240	615	867.7
2021	0	0	288	362	650

Table 6. A comparison of analytical approaches that can be used to estimate bycatch. (NP = non-parametric, P = parametric). Complexity is a general description of how difficult the analyses would be to implement, considering model specification, selection, and diagnostics.

Model	Type	Complexity	Model Platform	Premise	Limitations
Mean estimator	NP	Easy	Self-coded	Central tendency is representative of all commercial trips (Law of large numbers).	Ignores fine-scale variations that may be further explained by available variables; estimator usually of high uncertainty and is subject to sampling bias.
Stratified mean	NP	Easy	Self-coded	Central tendency of each spatial group is representative (Law of large numbers, homogeneity within group, heterogeneity between groups).	Ignores fine-scale variations as above; inefficient spatial stratification may even reduce precision, making stratification counterproductive.
Ratio estimator	NP	Easy	Self-coded	Bycatch is a constant ratio of effort/target species catch (Linear association between target species and Porbeagle bycatch weights).	Relationship between distributions of target species and Porbeagle are often anecdotal and unreliable; commercial data does not record catch of all potentially associated species, further reducing reliability of the estimator.
Nearest neighbours	NP	Medium	gstat (Pebesma 2004, Gräler et al. 2016); knn (Venables and Ripley 2002, Beygelzimer et al. 2023)	Catches on nearby trips predict catches on unobserved trips (Bycatch from nearby locations are similar).	Sensitive to sparseness of sampled locations and quickly declining similarity.
GLMM	P	Medium	glmmTMB (Brooks et al. 2017); lme4 (Bates et al. 2015); self-coded in template model builder (TMB; Kristersen 2016)	Bycatch can be predicted from a set of covariates with a parametric relationship, e.g., effort, environment.	Relationship with covariates may not be consistent over time or space, and easily overshadowed by noise such as random measurement errors.
Random forest	NP	Medium	randomForest (Liaw and Wiener 2002)	Observations can be distinguished (branched) by a set of covariates where bycatch weights within each branch are similar (similarity in bycatch relates to similarity in certain set characteristics).	Dependent on the effectiveness of covariates, and similar to M5, the relationship may not be consistent in all cases.

Model	Type	Complexity	Model Platform	Premise	Limitations
Spatiotemporal model	P	Difficult	sdmTMB (Anderson et al. 2022); VAST (Thorson 2019); self-coded in TMB (Kristersen 2016)	Bycatch from nearby locations are more similar than distant locations, but more specifically, this similarity can be described from a parametric function.	Spatial and temporal variations are often difficult to accurately quantify especially with small sample size and may cause bias in estimation.

Table 7. Fishery-wide discard estimates (kg) for fisheries in the Maritimes Region. All years in which there were no observed discards of Porbeagle Shark are shown by zeros. Years in which there was no at-sea observer (ASO) coverage in a particular fishery are not available (NA). CHP stands for Cod/Haddock/Pollock, BLL is benthic longline. The at-vessel mortality (AVM) rate for scenario 1 and post-release mortality (PRM) rate used in both scenarios to calculate dead discards from each fleet are also shown. Dashes (-) indicate not applicable.

Fleet	2015	2016	2017	2018	2019	2020	2021	AVM Rate	PRM Rate
Redfish (Unit 2; Trawl)	0	0	0	1,136	0	5,741	1,551	0.2^	0.16^
Redfish (Unit 3; Trawl)	1,348	7,513	932	729	4,530	14,138	625	0.2^	0.16^
CHPs Fixed 4X5Y (Gillnet)*	NA	NA	NA	0	NA	NA	NA	1^	0
CHPs Fixed 5Z (Gillnet)	0	0	0	0	594	NA	0	1^	0
CHPs Mobile 4X5Y (Trawl)	10,052	8,956	13,811	6,301	86,383	8,952	12,22	0.2	0.16^
CHPs Mobile 5Z (Trawl)	20,889	24,601	31,968	36,147	27,175	21,061	12,776	0.2	0.16^
Silver Hake (Trawl)	0	0	0	0	1,000	0	0	0.2^	0.16^
Atlantic Halibut (BLL)	56,839	8,363	66,744	93,009	4,034	15,661	7,555	0.36^	0.15^
Multispecies Flatfish (Trawl)**	60,000	0	0	35,714	0	0	0	0.2^	0.16^
Swordfish (PLL)	35,962	31,525	10,773	10,237	14,377	962	0	0.36	0.15
Small pelagics (Purse seine)	200	0	0	0	895	0	NA	1^	0
Annual Total	185,290	80,958	124,228	183,273	138,988	66,515	23,729	-	-

*This fishery component had landings of Porbeagle but no observed discards.
**Extremely low ASO coverage (see Appendix 2); small observed weights lead to substantial fishery-wide estimates.
^Assumed rate.

Table 8. Fishery-wide discard estimates (kg) for fisheries in Newfoundland and Labrador (NL) Region, identified by target species and Northwest Atlantic Fisheries Organization (NAFO) subdivisions. Years in which the catch ratio used to scale up observed discards to fishery-wide totals was > 1 are identified in bold red font, and cells are outlined with a black border. These values are observed discards from Table 4 rather than scaled values. All years in which there were no observed discards of Porbeagle are shown by zeros. BLL stands for benthic longline. The at-vessel mortality (AVM) rate for scenario 1 and post-release mortality (PRM) rate used in both scenarios to calculate dead discards from each fleet are also shown. Dashes (-) indicate not applicable..

Fleet	2015	2016	2017	2018	2019	2020	2021	AVM Rate	PRM Rate
Atlantic Halibut 3NOPs (BLL)	0	1,464	1,135	1,886	2,193	0	0	0.36^	0.15^
Yellowtail Flounder 3NO (Trawl)	1,102	349	1,283	1,562	0	6,531	7,885	0.2^	0.16^
Witch Flounder 3OPs (Trawl)	159	842	66	422	68	0	0	0.2^	0.16^
Atlantic Cod 3Ps (Trawl)	0	84	0	225	880	0	0	0.2^	0.16^
Atlantic Cod 3L+3Ps (Gillnet)	8,622	11,922	72,830	0	56,783	0	0	1^	0
Greenland Halibut 3L (Gillnet)	0	0	1473	0	0	0	0	1^	0
Redfish 3L (Trawl)	0	125	749	0	0	525	0	0.2^	0.16^
Redfish 3Ps (Trawl)	0	0	0	0	618	0	0	0.2^	0.16^
Annual Total	**9,883**	**14,786**	**77,536**	**4,095**	**60,542**	**7,056**	**7,885**	**NA**	**NA**

^Assumed rate

Table 9. Condition of Porbeagle Shark discards and the percentage of captures that were alive from observed trips by the Swordfish fishery (pelagic longline) and from the mobile component of the Cod/Haddock/Pollock (CHP) fishery (otter trawl) from 2015 to 2021. When no animals were observed, the percentage alive was not available (NA).

Fleet	Year	Unknown	Healthy	Injured	Dead	Shark bit	Moribund	Alive %
Swordfish	2015	0	1	0	0	0	0	100.0
Swordfish	2016	51	66	21	51	0	0	46.0
Swordfish	2017	0	11	2	7	0	0	65.0
Swordfish	2018	8	28	5	1	1	0	76.7
Swordfish	2019	0	19	0	1	0	0	95.0
Swordfish	2020	0	0	0	4	0	0	0.0
Swordfish	2021	0	0	0	0	0	0	NA
CHP mobile	2015	2	64	8	14	0	2	80.0
CHP mobile	2016	1	97	19	13	3	5	84.1
CHP mobile	2017	1	103	27	19	1	4	83.9
CHP mobile	2018	3	90	33	16	0	7	82.6
CHP mobile	2019	1	116	28	42	0	7	74.2
CHP mobile	2020	0	45	15	22	0	1	72.3
CHP mobile	2021	0	0	0	0	0	0	NA

Table 10. A comparison of two mortality scenarios of discards from the Maritimes and Newfoundland and Labrador Regions, representing the summed weight in kg of at-vessel and post-release mortality from all fisheries in each year. The fishery-wide estimate of total bycatch (kg) and the percentage that mortality differs between the scenarios are also shown.

Year	Total bycatch	Scenario 1	Scenario 2	Difference
2015	195,173	79,409	92,928	17%
2016	95,744	43,612	49,664	14%
2017	201,764	124,918	135,312	8%
2018	187,368	72,791	87,277	20%
2019	199,530	104,128	110,614	6%
2020	73,571	24,789	28,613	15%
2021	31,614	10,715	12,390	16%

Table 11. Annual total mortality estimates (kg) of Porbeagle Shark from fisheries in the Maritimes (MAR), Gulf (GULF), Quebec (QC), and Newfoundland and Labrador (NL) Regions, showing landings and estimated dead discards (sum of at-vessel and post-release mortality from all fisheries) for the two mortality scenarios.

Scenario	Region	Source	2015	2016	2017	2018	2019	2020	2021
1	MAR	landings	3,599	1,652	1,511	670	304	126	198
1	MAR	dead discard	61,185	26,612	45,244	63,113	33,871	18,118	6,680
1	MAR	survey	0	0	10,296	0	0	0	0
1	GULF	landings	0	107	0	0	0	0	0
1	GULF + QC	dead discard	0	41	130	137	15	238	204
1	QC	landings	0	227	0	0	0	108	0
1	NL	landings	167	0	0	10	0	0	0
1	NL	dead discard	17,748	12,869	75,240	1,302	58,096	1,253	1,577
1	MAR	total mortality	64,784	28,264	57,051	63,783	34,175	18,244	6,878
1	GULF + QC	total mortality	0	375	130	137	15	346	204
1	NL	total mortality	17,915	12,869	75,240	1,312	58,096	1,253	1,577
1	All	Atlantic total	82,700	41,508	132,421	65,231	92,286	19,844	8,659
2	MAR	landings	3,599	1,652	1,511	670	304	126	198
2	MAR	dead discard	61,185	26,612	45,244	63,113	33,871	18,118	6,680
2	MAR	survey	0	0	10,296	0	0	0	0
2	GULF	landings	0	107	0	0	0	0	0
2	GULF + QC	dead discard	0	41	130	137	15	238	204
2	QC	landings	0	227	0	0	0	108	0
2	NL	landings	167	0	0	10	0	0	0
2	NL	dead discard	17,748	12,869	75,240	1,302	58,096	1,253	1,577
2	MAR	total mortality	64,784	28,264	57,051	63,783	34,175	18,244	6,878
2	GULF + QC	total mortality	0	375	130	137	15	346	204
2	NL	total mortality	17,915	12,869	75,240	1,312	58,096	1,253	1,577
2	All	Atlantic total	82,700	41,508	132,421	65,231	92,286	19,844	8,659

FIGURES

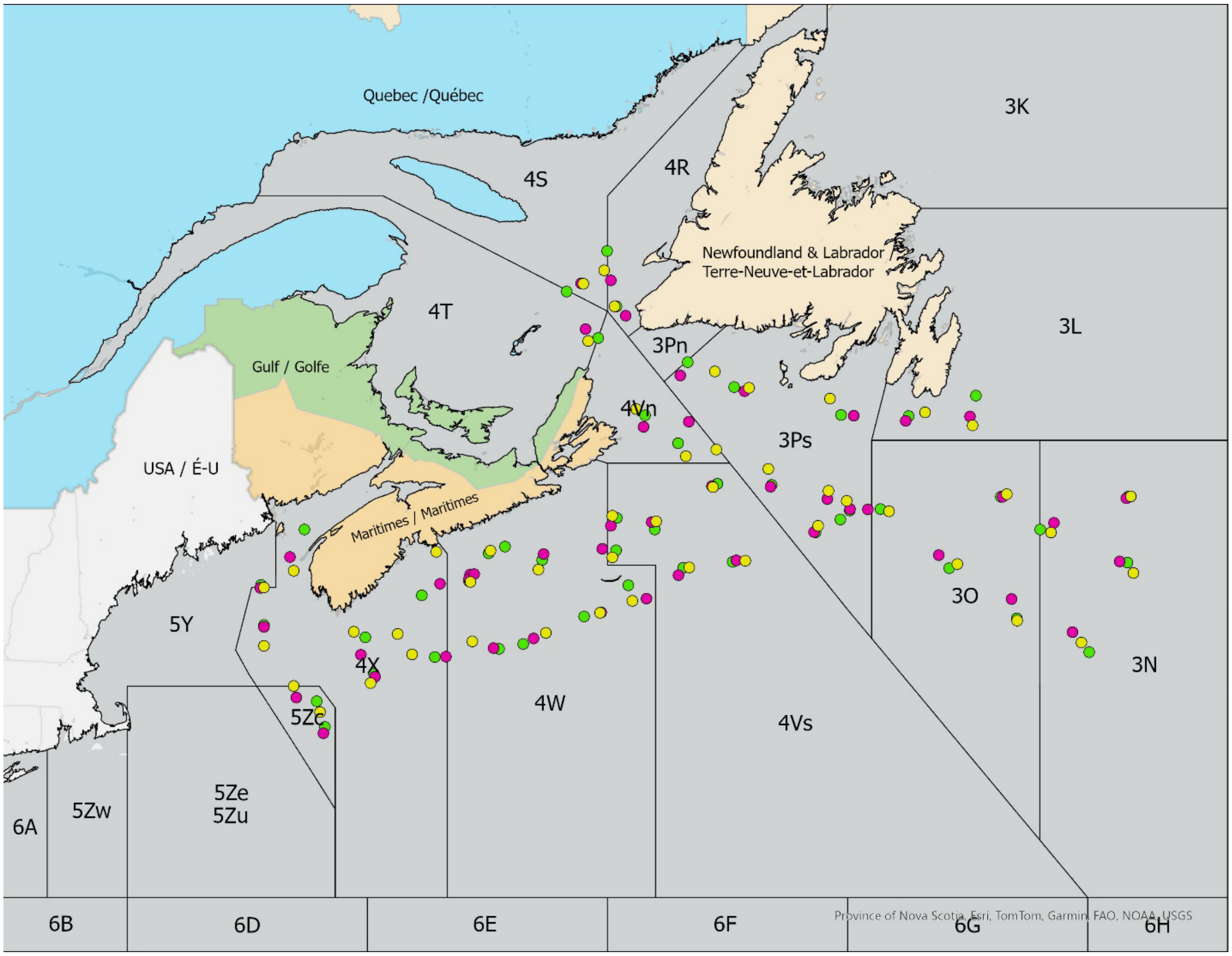

Figure 1. Distribution of the survey stations sampled in 2007 (red dots), 2009 (yellow dots) and 2017 (purple dots) for the three fishery-independent longline surveys conducted in Atlantic Canada. NAFO divisions are labeled and identified by black polygons.

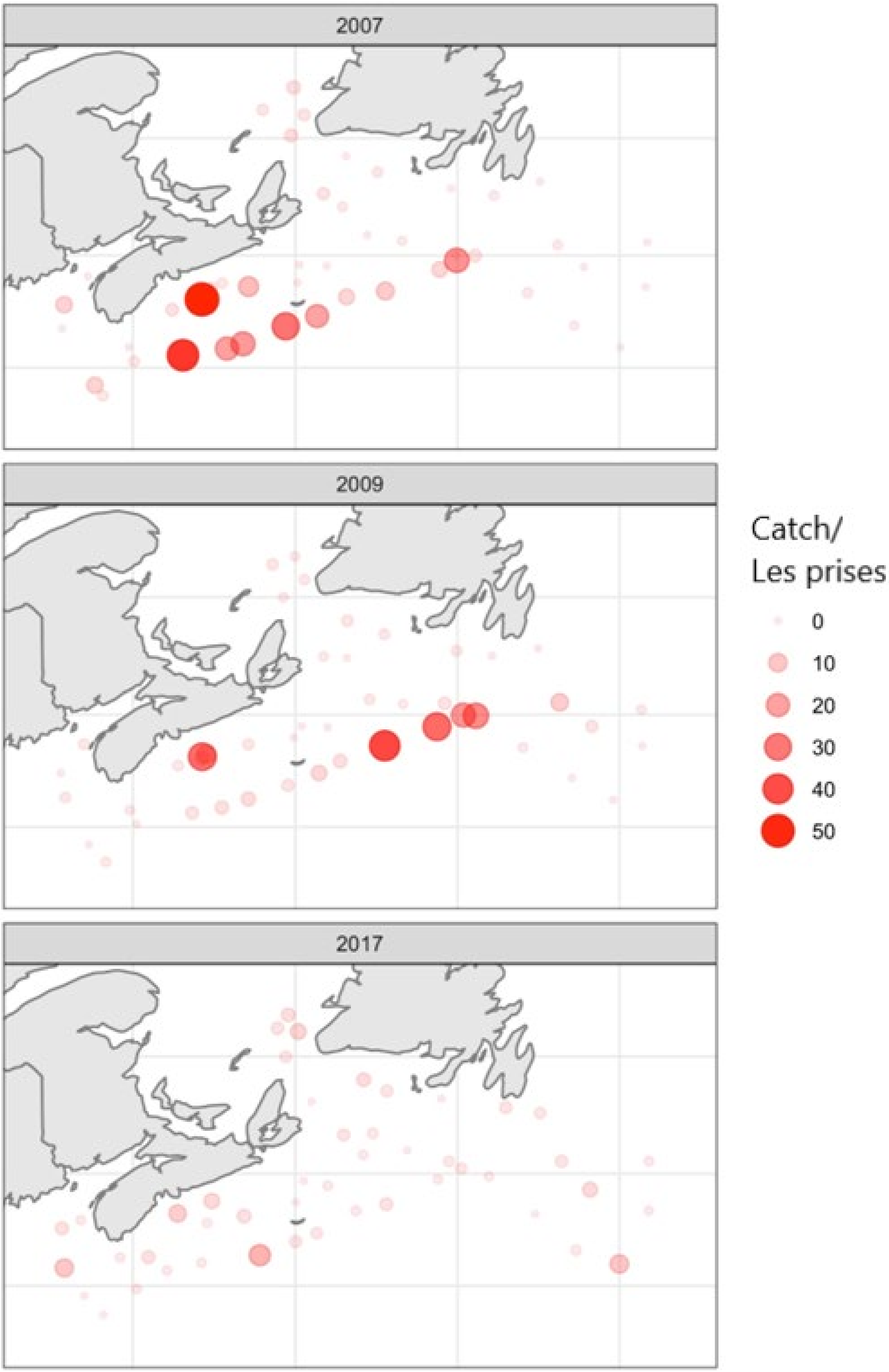

Figure 2. Catch per unit effort (CPUE) of Porbeagle Shark at each of the sampled locations in the 2007, 2009 and 2017 research surveys. Catch number was scaled by number of hooks (thousands) and soak time to calculate CPUE. The size and colour of the dot are proportional to magnitude.

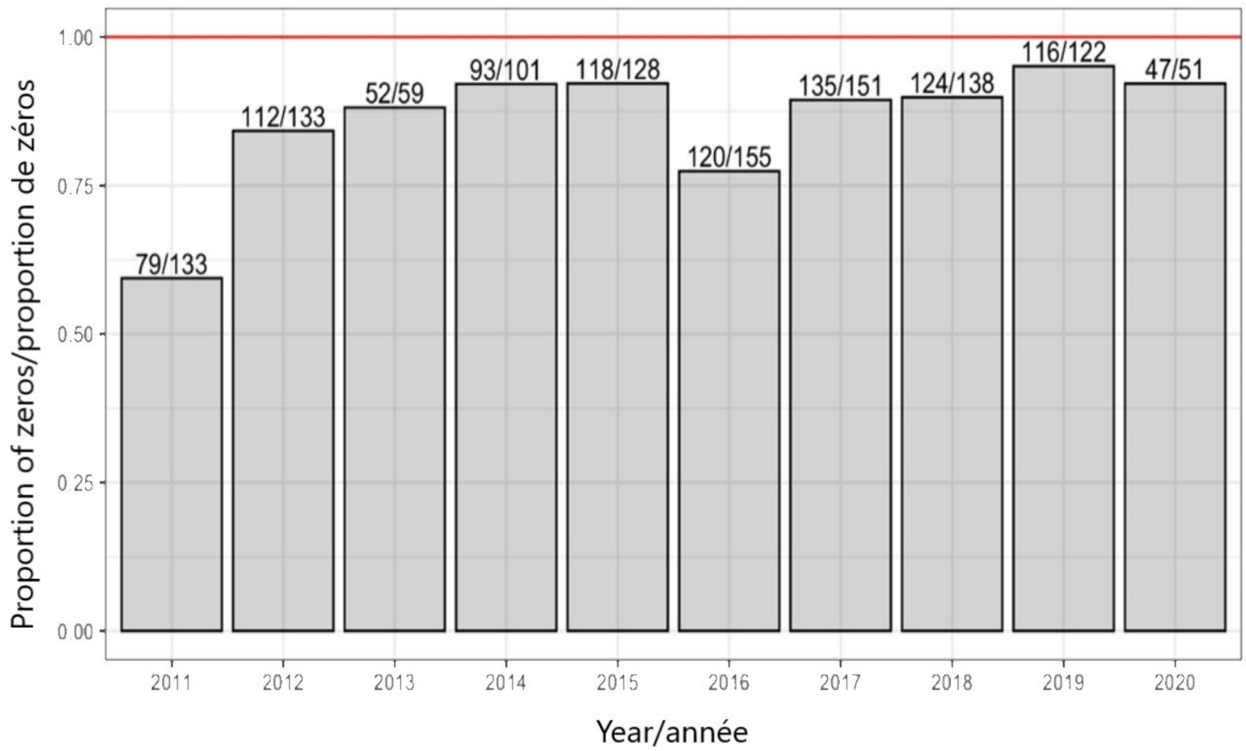

Figure 3. Barplot of the proportion of zeros for Porbeagle Shark catches on observed sets from the pelagic longline fishery for Swordfish and Other Tunas from 2011 to 2020, with the values that the proportion is calculated from above each bar. The red horizontal line represents 100% of the sets.

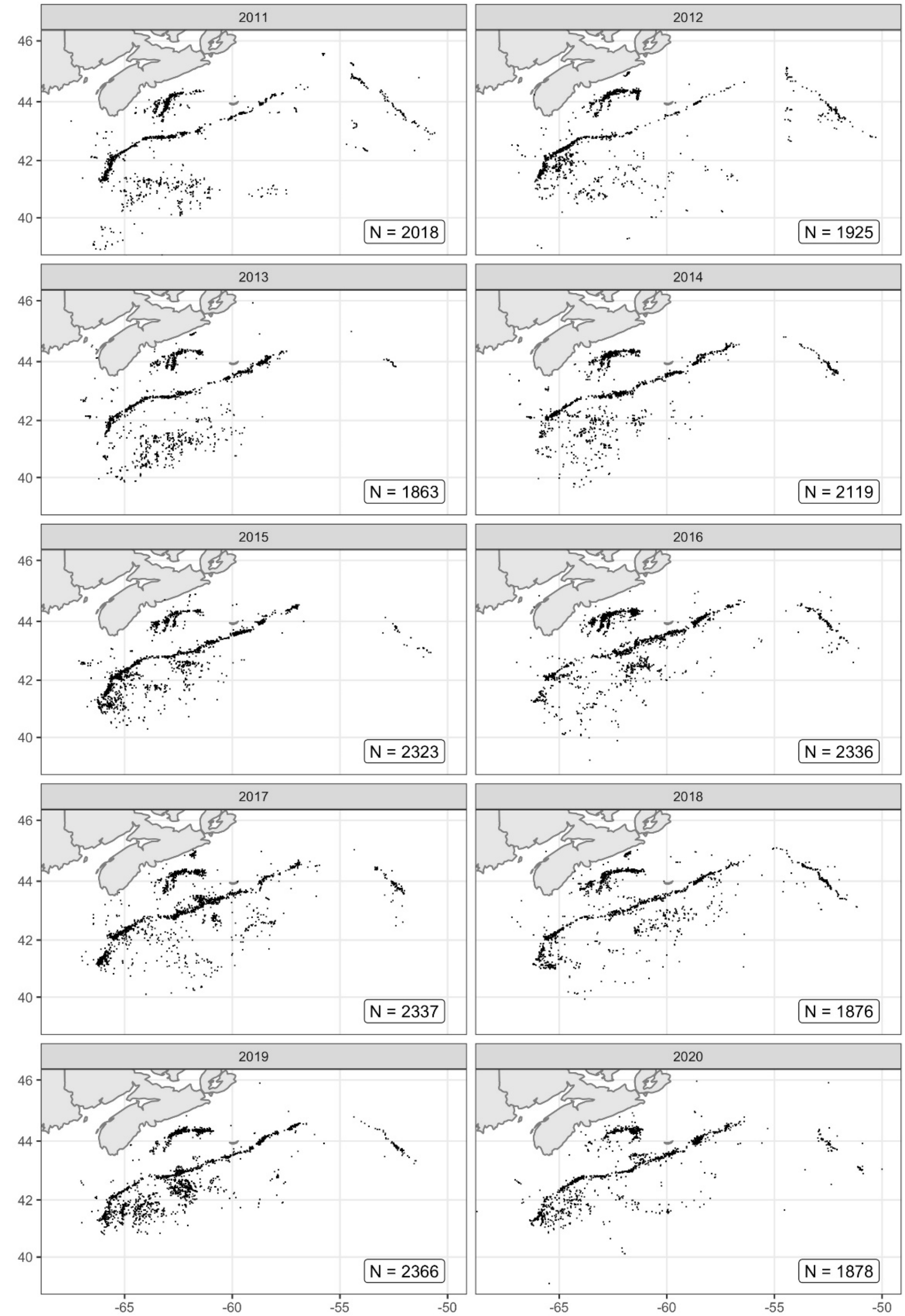

Figure 4. Locations of commercial sets from the pelagic longline fishery targeting Swordfish and Other Tunas from 2011 to 2020. The total number of sets (N) in each year is given by the inset values.

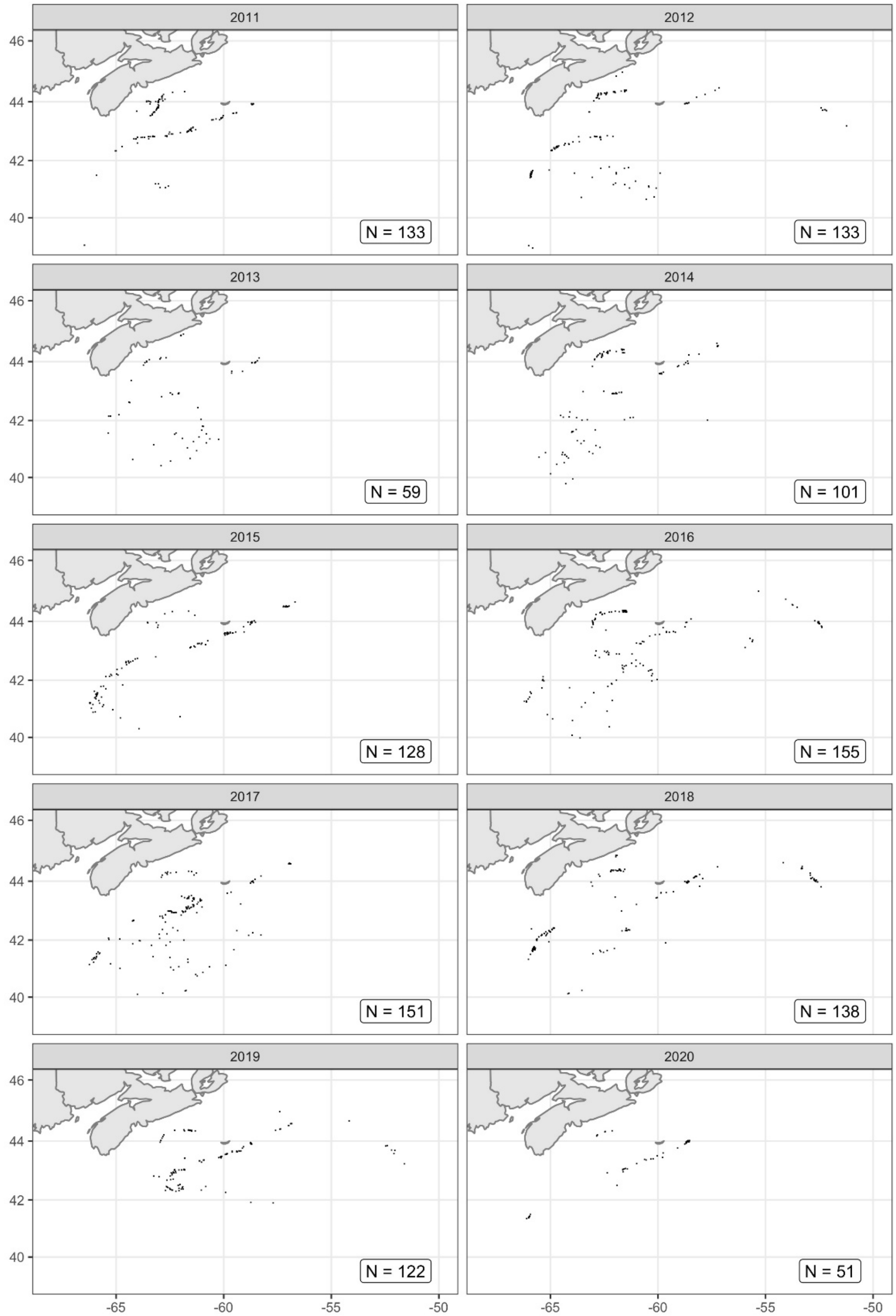

Figure 5. Locations of the observed sets from the pelagic longline fishery targeting Swordfish and Other Tunas from 2011 to 2020. The total number of sets (N) each year is given by the inset values.

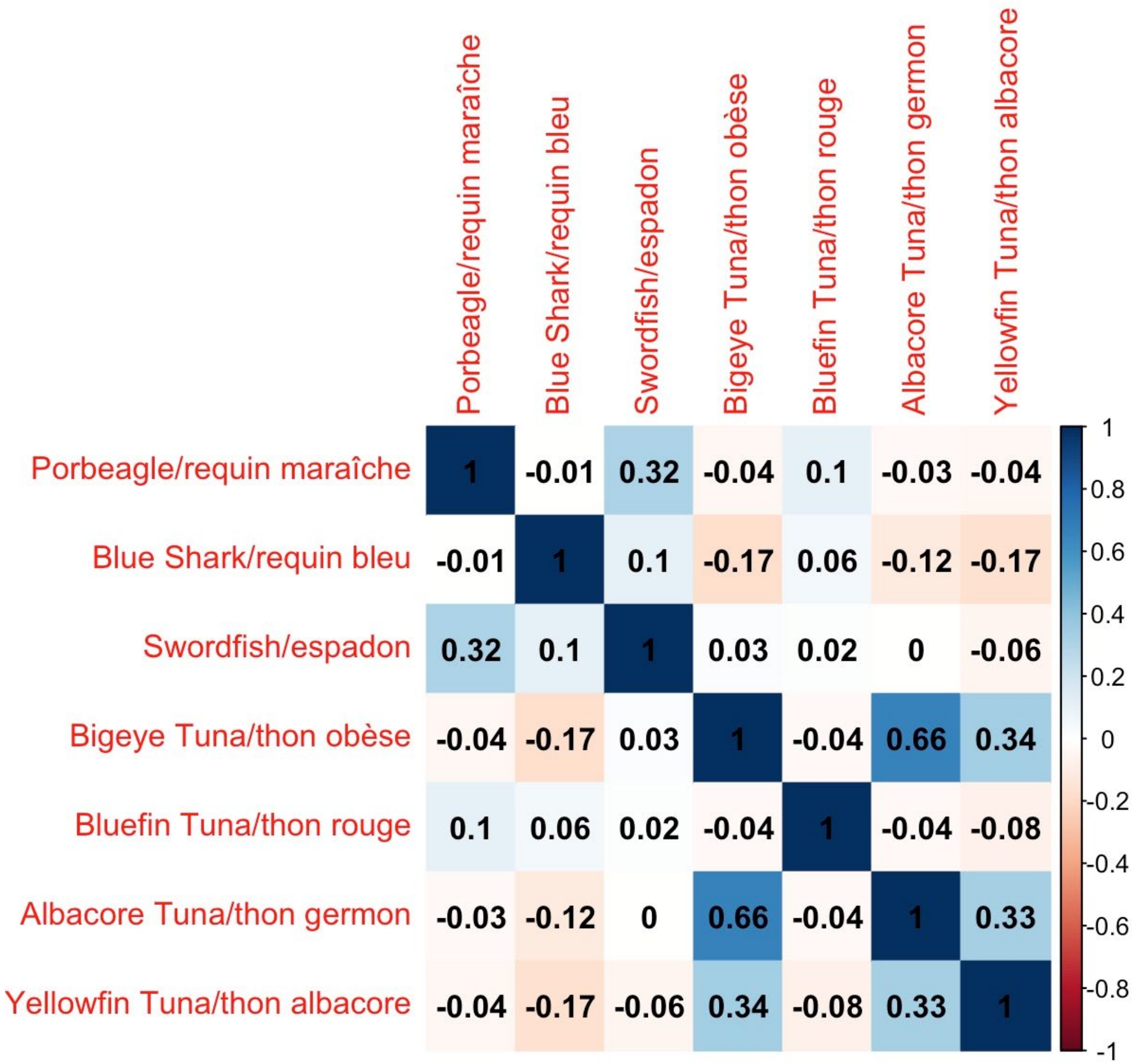

Figure 6. Correlation matrix among pelagic species catches from observed sets undertaken by the Swordfish and Other Tunas pelagic longline fishery in the Maritimes Region during 2011–2020. The value and colour represent the strength of the Pearson correlation of pairwise observations.

APPENDIX 1

UNIT 2 AND UNIT 3 REDFISH

Table A1. Characteristics of the multispecies Unit 2 and Unit 3 redfish fisheries in the Maritimes Region. Landed weight of Porbeagle Shark (POR) was summed from all commercial trips, yet discarded weight represents only observed trips. When no Porbeagle were caught on observed trips, interception rates were zero. ASO: at-sea observer.

Fishery	Year	Gear	Commercial Trips (#)	Observed Trips (#)	Observer Coverage (%)	ASO Trips with POR (#)	Landed Weight (kg)	Discarded Weight (kg)	Interception Rate on ASO Trips (%)
Redfish Unit 2	2015	Otter trawl	68	4	5.9	0	0	0	0
Redfish Unit 2	2016	Otter trawl	56	1	1.8	0	0	0	0
Redfish Unit 2	2017	Otter trawl	52	2	3.9	0	0	0	0
Redfish Unit 2	2018	Otter trawl	50	11	22.0	1	0	250	9.1
Redfish Unit 2	2019	Otter trawl	63	6	9.5	0	0	0	0
Redfish Unit 2	2020	Otter trawl	71	7	9.9	1	0	566	14.3
Redfish Unit 2	2021	Otter trawl	66	2	3.0	1	0	47	50.0
Redfish Unit 3	2015	Otter trawl	121	21	17.4	3	0	234	14.3
Redfish Unit 3	2016	Otter trawl	189	16	8.5	3	0	636	18.8
Redfish Unit 3	2017	Otter trawl	222	20	9.0	1	0	84	5.0
Redfish Unit 3	2018	Otter trawl	193	18	9.3	1	0	68	5.6
Redfish Unit 3	2019	Otter trawl	224	18	8.0	3	0	364	16.7
Redfish Unit 3	2020	Otter trawl	174	8	4.6	2	0	650	25.0
Redfish Unit 3	2021	Otter trawl	250	16	6.4	1	0	40	6.3

MULTISPECIES GROUNDFISH

Table A2. Characteristics of the multispecies groundfish fisheries for Cod, Haddock and Pollock (CHP) in the Maritimes Region from either fixed or mobile gear. Landed weight was summed from all commercial trips yet discarded weight represents only observed trips. When there were no observed trips, at-sea observer (ASO) trips with Porbeagle Shark (POR), discarded weights and interception rates are not available (NA). When no Porbeagle Shark were caught on observed trips, interception rates were zero.

Fishery	Year	Gear	Commercial Trips (#)	Observed Trips (#)	Observer Coverage (%)	ASO Trips with POR (#)	Landed Weight (kg)	Discarded Weight (kg)	Interception Rate on ASO Trips (%)
CHP Fixed 4X5Y	2015	Benthic longline	264	7	2.7	0	0	0	0.0
CHP Fixed 4X5Y	2016	Benthic longline	178	6	3.4	0	0	0	0.0
CHP Fixed 4X5Y	2017	Benthic longline	163	7	4.3	0	0	0	0.0
CHP Fixed 4X5Y	2018	Benthic longline	135	1	0.7	0	0	0	0.0
CHP Fixed 4X5Y	2019	Benthic longline	104	0	0.0	NA	0	NA	NA
CHP Fixed 4X5Y	2020	Benthic longline	129	0	0.0	NA	0	NA	NA
CHP Fixed 4X5Y	2021	Benthic longline	100	0	0.0	NA	0	NA	NA
CHP Fixed 5Z	2015	Benthic longline	52	15	28.8	0	0	0	0.0
CHP Fixed 5Z	2016	Benthic longline	36	10	27.8	0	0	0	0.0
CHP Fixed 5Z	2017	Benthic longline	24	7	29.2	0	0	0	0.0
CHP Fixed 5Z	2018	Benthic longline	21	7	33.3	0	0	0	0.0
CHP Fixed 5Z	2019	Benthic longline	23	6	26.1	0	0	0	0.0
CHP Fixed 5Z	2020	Benthic longline	23	3	13.0	0	0	0	0.0
CHP Fixed 5Z	2021	Benthic longline	15	1	6.7	0	0	0	0.0
CHP Fixed (4X5Y)	2015	Set gillnet	111	0	0.0	NA	434	NA	NA
CHP Fixed (4X5Y)	2016	Set gillnet	114	0	0.0	NA	198	NA	NA
CHP Fixed (4X5Y)	2017	Set gillnet	106	0	0.0	NA	391	NA	NA
CHP Fixed (4X5Y)	2018	Set gillnet	68	1	1.5	0	30	0	0.0
CHP Fixed (4X5Y)	2019	Set gillnet	41	0	0.0	NA	202	NA	NA
CHP Fixed (4X5Y)	2020	Set gillnet	54	0	0.0	NA	0	NA	NA
CHP Fixed (4X5Y)	2021	Set gillnet	60	0	0.0	NA	0	NA	NA
CHP Fixed (5Z)	2015	Set gillnet	16	2	12.5	0	0	0	0.0
CHP Fixed (5Z)	2016	Set gillnet	16	2	12.5	0	0	0	0.0
CHP Fixed (5Z)	2017	Set gillnet	21	2	9.5	0	0	0	0.0
CHP Fixed (5Z)	2018	Set gillnet	16	2	12.5	0	0	0	0.0
CHP Fixed (5Z)	2019	Set gillnet	11	1	9.1	1	0	54	100.0
CHP Fixed (5Z)	2020	Set gillnet	11	0	0.0	NA	0	NA	NA
CHP Fixed (5Z)	2021	Set gillnet	13	1	7.7	0	0	0	0.0

Fishery	Year	Gear	Commercial Trips (#)	Observed Trips (#)	Observer Coverage (%)	ASO Trips with POR (#)	Landed Weight (kg)	Discarded Weight (kg)	Interception Rate on ASO Trips (%)
CHP Fixed	2015	Handline	25	0	0.0	NA	0	NA	NA
CHP Fixed	2016	Handline	35	0	0.0	NA	169	NA	NA
CHP Fixed	2017	Handline	15	0	0.0	NA	38	NA	NA
CHP Fixed	2018	Handline	12	0	0.0	NA	42	NA	NA
CHP Fixed	2019	Handline	51	0	0.0	NA	0	NA	NA
CHP Fixed	2020	Handline	25	0	0.0	NA	0	NA	NA
CHP Fixed	2021	Handline	6	0	0.0	NA	0	NA	NA
CHP Mobile (4X5Y)	2015	Otter trawl	312	32	10.3	6	83	1,031	18.8
CHP Mobile (4X5Y)	2016	Otter trawl	382	27	7.1	5	210	633	18.5
CHP Mobile (4X5Y)	2017	Otter trawl	419	27	6.4	7	127	890	25.9
CHP Mobile (4X5Y)	2018	Otter trawl	447	31	6.9	3	91	437	9.7
CHP Mobile (4X5Y)	2019	Otter trawl	445	25	5.6	8	0	4,853	32.0
CHP Mobile (4X5Y)	2020	Otter trawl	469	23	4.9	4	0	439	17.4
CHP Mobile (4X5Y)	2021	Otter trawl	390	15	3.9	1	0	47	6.7
CHP Mobile (5Z)	2015	Otter trawl	524	386	73.7	62	0	15,458	16.1
CHP Mobile (5Z)	2016	Otter trawl	545	435	79.8	110	0	19,681	25.3
CHP Mobile (5Z)	2017	Otter trawl	477	301	63.1	87	0	20,140	28.9
CHP Mobile (5Z)	2018	Otter trawl	492	317	64.4	111	0	23,134	35.0
CHP Mobile (5Z)	2019	Otter trawl	470	299	63.6	97	0	17,392	32.4
CHP Mobile (5Z)	2020	Otter trawl	441	201	45.6	44	0	9,688	21.9
CHP Mobile (5Z)	2021	Otter trawl	291	99	34.0	32	0	4,344	32.3

SILVER HAKE

Table A3. Characteristics of the Silver Hake fishery in the Maritimes Region. Landed weight was summed from all commercial trips yet discarded weight represents only observed trips. When no Porbeagle Shark (POR) were caught on observed trips, interception rates were zero. ASO: at-sea observer.

Fishery	Year	Gear	Commercial Trips (#)	Observed Trips (#)	Observer Coverage (%)	ASO Trips with POR (#)	Landed Weight (kg)	Discarded Weight (kg)	Interception Rate on ASO Trips (%)
Silver Hake	2015	Otter trawl	332	12	3.6	0	0	0	0.0
Silver Hake	2016	Otter trawl	333	7	2.1	0	0	0	0.0
Silver Hake	2017	Otter trawl	400	8	2.0	0	0	0	0.0
Silver Hake	2018	Otter trawl	317	8	2.5	0	0	0	0.0
Silver Hake	2019	Otter trawl	225	9	4.0	1	0	40	11.1
Silver Hake	2020	Otter trawl	152	8	5.3	0	0	0	0.0
Silver Hake	2021	Otter trawl	219	3	1.4	0	0	0	0.0

ATLANTIC HALIBUT

Table A4. Characteristics of the Atlantic Halibut fishery in the Maritimes Region, with information aggregated by year. Landed weight of Porbeagle Shark (POR) was summed from all commercial trips, yet discarded weight represents only observed trips. ASO: at-sea observer.

Fishery	Year	Gear	Commercial Trips (#)	Observed Trips (#)	Observer Coverage (%)	ASO Trips with POR (#)	Landed Weight (kg)	Discarded Weight (kg)	Interception Rate on ASO Trips (%)
Atlantic Halibut	2015	Benthic longline	2,763	112	4.1	10	1,978	1,433	7.1
Atlantic Halibut	2016	Benthic longline	2,892	120	4.2	7	967	242	5.8
Atlantic Halibut	2017	Benthic longline	2,967	107	3.6	11	927	2,293	10.3
Atlantic Halibut	2018	Benthic longline	3,294	89	2.7	9	855	2,513	10.1
Atlantic Halibut	2019	Benthic longline	3,464	79	2.3	1	102	92	1.3
Atlantic Halibut	2020	Benthic longline	3,328	51	1.5	2	124	240	3.9
Atlantic Halibut	2021	Benthic longline	3,228	47	1.5	2	198	110	4.3

MULTISPECIES FLATFISH

Table A5. Characteristics of the multispecies flatfish fisheries in the Maritimes Region. Landed weight was summed from all commercial trips yet discarded weight represents only observed trips. When there were no observed trips, at-sea observer (ASO) trips with Porbeagle Shark (POR), discarded weights and interception rates are not available (NA). When no Porbeagle Shark were caught on observed trips, interception rates were zero.

Fishery	Year	Gear	Commercial Trips (#)	Observed Trips (#)	Observer Coverage (%)	ASO Trips with POR (#)	Landed Weight (kg)	Discarded Weight (kg)	Interception Rate on ASO trips (%)
Multispecies flatfish	2015	Otter trawl	960	1	0.1	1	0	60	100.0
Multispecies flatfish	2016	Otter trawl	971	3	0.3	0	0	0	0.0
Multispecies flatfish	2017	Otter trawl	997	4	0.4	0	0	0	0.0
Multispecies flatfish	2018	Otter trawl	971	7	0.7	1	0	250	14.3
Multispecies flatfish	2019	Otter trawl	905	3	0.3	0	0	0	0.0
Multispecies flatfish	2020	Otter trawl	860	1	0.1	0	0	0	0.0
Multispecies flatfish	2021	Otter trawl	781	1	0.1	0	0	0	0.0
Multispecies flatfish	2015	Danish/Scottish seine	32	0	0.0	NA	0	NA	NA
Multispecies flatfish	2016	Danish/Scottish seine	11	0	0.0	NA	0	NA	NA
Multispecies flatfish	2017	Danish/Scottish seine	15	0	0.0	NA	0	NA	NA
Multispecies flatfish	2018	Danish/Scottish seine	14	0	0.0	NA	0	NA	NA
Multispecies flatfish	2019	Danish/Scottish seine	10	0	0.0	NA	0	NA	NA
Multispecies flatfish	2020	Danish/Scottish seine	7	0	0.0	NA	0	NA	NA
Multispecies flatfish	2021	Danish/Scottish seine	6	0	0.0	NA	0	NA	NA
Multispecies flatfish	2015	Set gillnet	154	0	0.0	NA	0	NA	NA
Multispecies flatfish	2016	Set gillnet	182	0	0.0	NA	0	NA	NA
Multispecies flatfish	2017	Set gillnet	154	0	0.0	NA	0	NA	NA
Multispecies flatfish	2018	Set gillnet	117	0	0.0	NA	0	NA	NA
Multispecies flatfish	2019	Set gillnet	171	0	0.0	NA	0	NA	NA
Multispecies flatfish	2020	Set gillnet	171	0	0.0	NA	0	NA	NA
Multispecies flatfish	2021	Set gillnet	215	0	0.0	NA	0	NA	NA

SWORDFISH AND OTHER TUNAS

Table A6. Characteristics of the Swordfish and Other Tunas fishery in the Maritimes Region. Landed weight of Porbeagle Shark (POR) was summed from all commercial trips yet discarded weight represents only observed trips. ASO: at-sea observer.

Fishery	Year	Gear	Commercial Trips (#)	Observed Trips (#)	Observer Coverage (%)	ASO Trips with POR (#)	Landed Weight (kg)	Discarded Weight (kg)	Interception Rate on ASO Trips (%)
Swordfish	2015	Pelagic longline	270	21	7.8	4	503	2,805	19.1
Swordfish	2016	Pelagic longline	259	31	12.0	11	107	3,783	35.5
Swordfish	2017	Pelagic longline	268	20	7.5	8	27	808	40.0
Swordfish	2018	Pelagic longline	237	33	13.9	8	0	1,423	24.2
Swordfish	2019	Pelagic longline	235	18	7.7	2	0	1,107	11.1
Swordfish	2020	Pelagic longline	216	17	7.9	2	0	76	11.8

SMALL PELAGICS

Table A7. Characteristics of the small pelagics fishery in the Maritimes Region. Landed weight was summed from all commercial trips yet discarded weight represents only observed trips. When there were no observed trips, at-sea observer (ASO) trips with Porbeagle Shark (POR), discarded weights and interception rates are not available (NA). When no Porbeagle Shark were caught on observed trips, interception rates were zero.

Fishery	Year	Gear	Commercial Trips (#)	Observed Trips (#)	Observer Coverage (%)	ASO Trips with POR (#)	Landed Weight (kg)	Discarded Weight (kg)	Interception Rate on ASO Trips (%)
Small pelagics	2015	Purse seine	656	26	4.0	1	0	8	3.9
Small pelagics	2016	Purse seine	691	28	4.1	0	0	0	0.0
Small pelagics	2017	Purse seine	600	18	3.0	0	0	0	0.0
Small pelagics	2018	Purse seine	538	25	4.7	0	0	0	0.0
Small pelagics	2019	Purse seine	443	17	3.8	1	0	34	5.9
Small pelagics	2020	Purse seine	493	8	1.6	0	0	0	0.0
Small pelagics	2021	Purse seine	465	0	0.0	NA	0	NA	NA
Small pelagics	2015	Otter trawl	266	0	0.0	NA	0	NA	NA
Small pelagics	2016	Otter trawl	296	0	0.0	NA	0	NA	NA
Small pelagics	2017	Otter trawl	226	0	0.0	NA	0	NA	NA
Small pelagics	2018	Otter trawl	187	0	0.0	NA	0	NA	NA
Small pelagics	2019	Otter trawl	122	0	0.0	NA	0	NA	NA

Fishery	Year	Gear	Commercial Trips (#)	Observed Trips (#)	Observer Coverage (%)	ASO Trips with POR (#)	Landed Weight (kg)	Discarded Weight (kg)	Interception Rate on ASO Trips (%)
Small pelagics	2020	Otter trawl	68	0	0.0	NA	0	NA	NA
Small pelagics	2021	Otter trawl	55	0	0.0	NA	0	NA	NA
Small pelagics	2015	Set gillnet	276	0	0.0	NA	0	NA	NA
Small pelagics	2016	Set gillnet	447	0	0.0	NA	0	NA	NA
Small pelagics	2017	Set gillnet	705	0	0.0	NA	0	NA	NA
Small pelagics	2018	Set gillnet	945	0	0.0	NA	0	NA	NA
Small pelagics	2019	Set gillnet	1,407	0	0.0	NA	0	NA	NA
Small pelagics	2020	Set gillnet	1,771	0	0.0	NA	0	NA	NA
Small pelagics	2021	Set gillnet	1,720	0	0.0	NA	0	NA	NA
Small pelagics	2015	Drift gillnet	859	0	0.0	NA	0	NA	NA
Small pelagics	2016	Drift gillnet	1,258	0	0.0	NA	0	NA	NA
Small pelagics	2017	Drift gillnet	976	0	0.0	NA	0	NA	NA
Small pelagics	2018	Drift gillnet	1,298	0	0.0	NA	0	NA	NA
Small pelagics	2019	Drift gillnet	1,530	0	0.0	NA	0	NA	NA
Small pelagics	2020	Drift gillnet	1,404	0	0.0	NA	0	NA	NA
Small pelagics	2021	Drift gillnet	764	0	0.0	NA	0	NA	NA
Small pelagics	2015	Handline	102	0	0.0	NA	0	NA	NA
Small pelagics	2016	Handline	161	0	0.0	NA	0	NA	NA
Small pelagics	2017	Handline	534	0	0.0	NA	0	NA	NA
Small pelagics	2018	Handline	604	0	0.0	NA	0	NA	NA
Small pelagics	2019	Handline	215	0	0.0	NA	0	NA	NA
Small pelagics	2020	Handline	117	0	0.0	NA	0	NA	NA
Small pelagics	2021	Handline	197	0	0.0	NA	0	NA	NA
Small pelagics	2015	Weir/trapnet	53	0	0.0	NA	0	NA	NA
Small pelagics	2016	Weir/trapnet	157	0	0.0	NA	0	NA	NA
Small pelagics	2017	Weir/trapnet	119	0	0.0	NA	0	NA	NA
Small pelagics	2018	Weir/trapnet	253	0	0.0	NA	0	NA	NA
Small pelagics	2019	Weir/trapnet	116	0	0.0	NA	0	NA	NA
Small pelagics	2020	Weir/trapnet	239	0	0.0	NA	0	NA	NA
Small pelagics	2021	Weir/trapnet	77	0	0.0	NA	0	NA	NA

APPENDIX 2

The following table is a partial reproduction of Table 4, but gives a more detailed summary of the characteristics of fisheries in the Maritimes Region. For each fishery and gear type associated with Porbeagle Shark bycatch, the amount of Porbeagle discards (kg) observed in 2015–2021 is shown, along with the percentage of at-sea observer (ASO) coverage associated with each value in brackets. Instances where there was no ASO coverage are identified by NA (0%) and bold type. Zeros show instances where there was ASO coverage but no observed Porbeagle discards. CHP: Cod, Haddock and Pollock.

Fishery	Gear Type	2015	2016	2017	2018	2019	2020	2021
Redfish Unit 2	Otter trawl	0 (5.9%)	0 (1.8%)	0 (3.9%)	250 (22%)	0 (9.5%)	566 (9.9%)	47 (3%)
Redfish Unit 3	Otter trawl	234 (17.4%)	636 (8.5%)	84 (9%)	68 (9.3%)	364 (8%)	650 (4.6%)	40 (6.4%)
CHP Fixed 4X5Y	Benthic longline	0 (2.7%)	0 (3.4%)	0 (4.3%)	0 (0.7%)	NA (0%)	NA (0%)	NA (0%)
CHP Fixed 5Z	Benthic longline	0 (28.8%)	0 (27.8%)	0 (29.2%)	0 (33.3%)	0 (26.1%)	0 (13.0%)	0 (6.7%)
CHP Fixed (4X5Y)*	Set gillnet	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)
CHP Fixed (5Z)	Set gillnet	0 (12.5%)	0 (12.5%)	0 (9.5%)	0 (12.5%)	54 (9.1%)	NA (0%)	0 (7.7%)
CHP Fixed	Handline	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)
CHP Mobile (4X5Y)	Otter trawl	1,031 (10.3%)	633 (7.1%)	890 (6.4%)	437 (6.9%)	4853 (5.6%)	439 (4.9%)	47 (3.9%)
CHP Mobile (5Z)	Otter trawl	15,458 (73.7%)	19,681 (79.8%)	20,140 (63.1%)	23,134 (64.4%)	17,392 (63.6%)	9,688 (45.6%)	4,344 (34.0%)
Silver Hake	Otter trawl	0 (3.6%)	0 (2.1%)	0 (2.0%)	0 (2.5%)	40 (4.0%)	0 (5.3%)	0 (1.3%)
Atlantic Halibut	Benthic longline	1,433 (4.1%)	242 (4.2%)	2,293 (3.6%)	2,513 (2.7%)	92 (2.3%)	240 (1.5%)	110 (1.5%)
Multispecies Flatfish	Otter trawl	60 (0.1%)	0 (0.3%)	0 (0.4%)	250 (0.7%)	0 (0.3%)	0 (0.1%)	0 (0.1%)
Multispecies Flatfish	Danish/Scottish seine	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)
Multispecies Flatfish	Set gillnet	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)
Swordfish	Pelagic longline	2,805 (7.8%)	3,783 (12.0%)	808 (7.5%)	1,423 (13.9%)	1,107 (7.7%)	76 (7.9%)	0 (2.6%)
Small pelagics	Purse seine	8 (4.0%)	0 (4.1%)	0 (3.0%)	0 (4.7%)	34 (3.8%)	0 (1.6%)	NA (0%)
Small pelagics	Otter trawl	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)
Small pelagics	Set gillnet	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)
Small pelagics	Drift gillnet	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)
Small pelagics	Handline	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)	NA (0%)

* This fishery component had Porbeagle landings but no observed discards.