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Data Inputs for the Assessment Framework Review of Atlantic Halibut on the Scotian Shelf and Southern Grand Banks in Northwest Atlantic Fisheries Organization Divisions 3NOPs4VWX5Zc

L. Li[1], B. Hubley[1], D.L. Harper[1], G. Wilson[2], and C.E. den Heyer[1]

[1]Population Ecology Division
Bedford Institute of Oceanography
PO Box 1006
Dartmouth, Nova Scotia, B2Y 4A2

[2]Atlantic Halibut Council
1326 Revell Drive
Manotick, Ontario, K4M 1K8

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Canada

Foreword

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

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TABLE OF CONTENTS

ABSTRACT

Atlantic Halibut (*Hippoglossus hippoglossus*) is a large, sexually dimorphic flatfish and currently the most valuable groundfish fishery in Atlantic Canada. The Atlantic Halibut fishery was unregulated until 1988, at which time a total allowable catch was implemented for the Scotian Shelf and southern Grand Banks management unit (Northwest Atlantic Fisheries Organization [NAFO] Divisions 3NOPs4VWX5Zc). In 1994, a minimum legal size limit of 81 cm was adopted. Longline and otter trawl are the two major fishing gears used in this fishery. This paper is a review of the data inputs including biological parameters, ecosystem considerations, landings, indices of abundance, catch composition and mortality estimates used in fitting a statistical catch-at-length model. The length-weight relationship was updated using a new model and new data. Halibut abundance indices remain above long-term averages and the landings are among the highest on record. Rising ocean temperatures may have contributed to the increasing Halibut population since the early 2000s. Hundreds of Halibut stomachs collected in the Maritimes Summer Ecosystem Research Vessel (RV) Survey in NAFO Divisions 4VWX were analyzed and the occurrence rates of different prey were estimated. Halibut are landed with a number of other groundfish species including White Hake *(Urophycis tenuis)*, Haddock (*Melanogrammus aeglefinus*), Pollock (*Pollachius virens)*, and Atlantic Cod *(Gadus morhua)*. Multiple indices of abundance have been estimated. The Maritimes Ecosystem RV surveys provide fisheries-independent indices of abundance of small Halibut. The Maritimes Summer Ecosystem RV Survey stratified mean number of Halibut per tow peaked in 2011, but remains well above the long-term mean. The stratified mean number of Halibut per tow from the Newfoundland and Labrador Spring Ecosystem RV Survey in 3NOPs has been generally increasing since early 2000s. In 1998, the Industry-DFO Halibut Longline Survey was established to provide an additional fishery-independent index of exploitable biomass throughout the management unit. A new Stratified Random Industry-DFO Halibut Longline Survey was introduced in 2017 and has been run concurrently with the Fixed Station Halibut Survey. The longline Halibut survey biomass index increased steadily since the mid-2000s, but in recent years has plateaued. An industry-DFO tagging program began in 2006. The multiyear mark-recapture model provides estimates of natural mortality (M) at 0.10 and fishing mortality (F) between 2007 and 2020. The peak estimated fishing mortality was 0.2 in 2008 and has since declined to between 0.03 and 0.04 since 2017. The data inputs will be used to fit an update of the statistical catch-at-length model previously accepted in 2014.

INTRODUCTION

Atlantic Halibut (*Hippoglossus hippoglossus*) is the largest of the flatfishes and ranges widely over the northern Atlantic and Arctic Ocean, from depths less than 50 m to more than 1,250 m. They are long-lived and sexually dimorphic, with females reaching lengths of approximately 200 cm and males approximately 125 cm. Atlantic Halibut is the most valuable groundfish species per unit weight landed on the Atlantic coast, and in recent years has become the most valuable groundfish fishery in Atlantic Canada.

This document focuses on the Atlantic Halibut management unit in Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NOPs4VWX5Zc on the Scotian Shelf and southern Grand Banks (Figure 1). In 1987, two management units, 4RST and 3NOPs4VWX5Zc, were defined for Atlantic Halibut in Canadian waters, based primarily on tagging studies (McCracken 1958, Bowering 1986, Stobo et al. 1988) and differences in growth rates between fish caught on the Scotian Shelf and in the Gulf of St. Lawrence (Neilson and Bowering 1989). Evidence from genetics studies (Kess et al. 2021), conventional tagging (McCracken 1958, Bowering 1986, Stobo et al. 1988, Kanwit 2007, den Heyer et al. 2012), and recent satellite tagging (Le Bris et al. 2018, James et al. 2019) continues to support the separation. A recent review of the spatial ecology of Atlantic Halibut in the context of climate change summarizes this work, as well as the evidence for subpopulation structure within the existing management units (Shackell et al. 2022).

The Halibut fishery was unregulated until 1988 and a legal size of 81 cm was fully established in 1995. The first total allowable catch (TAC) of 3,200 t was not captured for several years. In 1994, the TAC was reduced to 1,500 t, and was further reduced to 850 t in 1995 in response to a protracted decline in landings. In 1999, recommendations made by the Fisheries Resource Conservation Council (FRCC) resulted in an increase in the TAC from 850 to 1,000 t. Since that time, both the TAC and landings have been increasing (Figure 2). The TAC in 2021 was 5,445 t.

Prior to 2010, science advice was provided based on the Fisheries and Oceans Canada (DFO) Ecosystem Research Vessel (RV) Survey abundance indices and catch per unit effort (e.g., Perley et al. 1985, Zwanenburg et al. 1997). In 1998, industry, in conjunction with DFO, initiated a Fixed Station Halibut Survey to provide a fishery-independent index of exploitable biomass throughout the management unit. In 2010, a length-based, age-structured assessment model was adopted for the Scotian Shelf and southern Grand Banks Atlantic Halibut (Trzcinski et al. 2011a, Trzcinski and Bowen 2016). This model was replaced by a statistical catch-at-length model in 2014 and a closed loop simulation was used to inform harvest strategies and interim assessment procedures (Cox et al. 2016). Since 2014, the TAC had been set based on a fishing mortality of 0.14 (F = 0.14) strategy and the index of exploitable biomass from the Industry-DFO Halibut Longline Survey.

Notable changes to the data preparation for the framework review include, consideration of ecosystem changes, updated information on the biology, new methodology for the estimation of the length-weight relationship, a new growth model fit to recent data (Zheng et al. in prep.[1]), changes to landings by gear over the time series, and new indices of abundance from the Industry-DFO Halibut Longline Survey data. As with the previous assessment, incidental catch

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[1] Zheng, N., Perreault, A.M.J., Li, L., Hubley, B., den Heyer, C.E., and N.G. Cadigan. In preparation. A Spatiotemporal Richards-Schnute Growth Model for Atlantic Halibut (*Hippoglossus hippoglossus*) on the Scotian Shelf and Southern Grand Banks (fit to preliminary data). DFO Can. Sci. Advis. Sec. Res. Doc.

of non-target species from the commercial fishery for Atlantic Halibut is presented in a separate document (Bowlby et al. 2024).

HABITAT

Atlantic Halibut are demersal flatfish, living on or near the seafloor. Halibut commercial landings and catches in the Maritimes Ecosystem Research Vessel (RV) surveys, find a higher proportion of smaller Halibut in NAFO Division 4X around Browns Bank (McCracken 1958, Neilson et al. 1993, Boudreau et al. 2017). Boudreau et al. (2017) completed a spatiotemporal model of RV Survey Halibut catches throughout Atlantic Canada and found areas of high juvenile Halibut abundance connected at a spatial scale of 250 km. Two areas of high juvenile abundance, one in the Gully and the other in southwest Nova Scotia, persisted since the mid-1970s, while areas of high juvenile abundance in Newfoundland disappeared over time. Again, using the RV Survey data, French et al. (2018) investigated habitat suitability for juvenile Halibut across the management area and found that high levels of suitable habitat exist in 4Vs, 4W and especially 4X. These areas of high habitat suitability are consistent with high landings from the commercial fishery, both current and historical.

Larger Halibut are found deeper than smaller Halibut (McCracken 1958, Bowering 1986, Sigourney et al. 2006, Trzcinski et al. 2009). Pop-up satellite archival transmitting (PSAT) tags show that larger Halibut maintain a narrow temperature range around 4–6°C, and may have a seasonal pattern of movement from deeper water (>500 m) in winter to shallower water (between 200 and 400 m) in May and June. Similar seasonal movement patterns and temperature ranges were seen for PSAT-tagged Halibut in the Gulf of St. Lawrence (Le Bris et al. 2018, James et al. 2019). The archival tagging shows how Halibut used the water column, which was possibly associated with spawning between October and January (Armsworthy et al. 2014, Le Bris et al. 2018, James et al. 2019).

MOVEMENT

Atlantic Halibut ranges widely over the northwest Atlantic, from the coast of Virginia in the south to the waters off northern Greenland in the north. A small number of Halibut tagged on the Scotian Shelf and in the Gulf of St. Lawrence have been captured off of Iceland (McCracken 1958, den Heyer et al. 2012) and those tagged in Iceland have been recaptured off of Newfoundland (Bowering 1986). Despite these remarkable movements, Halibut are generally recaptured within 30 km of the point of release (Kanwit 2007, den Heyer et al. 2012, Shackell et al. 2022). Archival electronic tagging in the Gulf of St. Lawrence and the Gulf of Maine shows that Halibut exhibit both homing and residency behaviours (Le Bris et al. 2018, James et al. 2019, Liu et al. 2019, Gatti et al. 2020). While earlier tagging work supported a hypothesis of compensatory movement, counter to the drift of eggs and larvae from spawning areas (Stobo et al. 1988), the new data from archival and conventional tags show there is considerable variation in movement throughout the range, which has been attributed to migratory contingents (Shackell et al. 2022).

GROWTH

Atlantic Halibut are sexually dimorphic (Figure 3). The largest female recorded in the Industry Survey Database (ISDB) was caught in 1992, in NAFO Division 3N, and measured 278 cm in length. More than 4,500 Halibut otoliths were collected from both otter trawl and longline catches, and were aged to develop age-length keys and fit growth models (Armsworthy and Campana 2010). Armsworthy and Campana (2010) selected otoliths from a broad range of fish lengths collected on DFO Ecosystem RV Surveys and on commercial trips from two periods: historic (1964–1974) and recent (1997, 2001 and 2007). The age estimates from otolith thin sections were validated with bomb-radiocarbon dating and used to develop a reference collection for Halibut aging. Although this work identified the importance of gear type and region in estimation of growth rate, the von Bertalanffy growth model was fit to all males and females. These parameters, L_∞ = 134, k = 0.18, for males, and L_∞ = 205, k = 0.12, for females, were used in the 2014 assessment. A recent analysis of growth estimated from tagged fish that were released and recaptured in the same NAFO Divisions, found higher growth rates for both males and females in the warmer southwest (Shackell et al. 2019). In 2018, aging of an additional 2,628 Halibut otoliths, selected from fish caught throughout the management unit, was completed. The new growth estimates accounting for gear type and spatial correlation will be presented in Zheng et al. (in prep.1 above).

LENGTH-WEIGHT RELATIONSHIP

The length and weight of individual Halibut have been measured on Maritimes Summer Ecosystem RV Survey in 4VWX and 5Zc and by at-sea observers (ASO) on the Industry-DFO Halibut Longline Survey and commercial trips directing for Halibut and other species in NAFO Subareas 3 (Divisions 3NOPs), 4 (Divisions 4VWX), and 5 (Divisions 5Zc) (Table 1). Data queries on September 14, 2021, returned 59,435 fish sampled for length and weight between 1970 and 2020. Of these, 59,109 samples were used for further analyses and 326 samples were excluded. These fish were excluded because either the length or weight of the fish was deemed improbable (i.e., the recorded weight exceeded 175% of the predicted weight or was less than 25% of predicted weight for curve fit to entire data set using the length-weight relationship from the previous assessment set). The number of samples from the ASO Program has been declining in recent years, with no weights of Halibut measured in 3NOPs in 2013 and 2014. Additionally, there have been little to no individual weight measurements recorded by ASO in the entire management area (3NOPs4VWX5Zc) since 2017, due to changes in the measurement protocol for the Industry-DFO Halibut Longline Survey. The number of fish sampled on the Maritimes Summer Ecosystem RV Surveys in NAFO Divisions 4VWX+5Zc was very sparse between 1985 and 1994, with no fish sampled in six of those years. Prior to 1988, there were almost no Halibut length and weight data collected by ASO on Halibut-directed trips; however, some were observed in other fisheries (Table 2). There were 87% of the samples identified as male or female and 74% of the samples were collected in May, June, and July (Table 3).

A linear mixed effects model was fit to log-transformed weight as a function of log-transformed length accounting for fixed and random effects. Three factors were considered as the fixed effects: sex (male and female), NAFO Division (factor with two levels: NAFO Subarea 3 (including NAFO Divisions 3NOPs) and NAFO Subarea 4 (including NAFO Divisions 4VWX+5Zc), and quarter of the year (factor with four levels: 1 [January–March], 2 [April–June], 3 [July–September], 4 [October–December]). Both year and trip type (Table 2) were included as random effects on the intercept. All samples of unknown sex (n = 7,651) were removed from model selection as sex was considered a fixed effect, leaving a sample size of 51,458. Results from eleven models with all possible combinations of factors were compared (Appendix Table A1). The model with the lowest Akaike information criterion (AIC) had sex and quarter of the year as fixed effects and was closely followed by the model including all possible parameters. After evaluating the model predictions, neither sex nor NAFO Division contributed to the explained variance of the model and were therefore removed. The model with quarter of the year as a fixed effect had the next lowest AIC. Predictions for the different levels of quarter indicated that it did contribute to the explained variance (Appendix Figure A1), but because of the uneven spread of the data throughout the year and Subarea (Figure 4), and to limit complications in the overall assessment model, quarter was also removed as a fixed effect from the final model. The results from both models (i.e., with and without quarter as a fixed effect), are presented in Appendix Table A2. The final model represents log-weight as a function of log-length with year and trip type as random effects. Since sex did not appear to have a significant impact on the model, all samples (i.e., male, female, and unknown) were included in the final model (n = 59,109).

NATURAL MORTALITY, MATURITY, AND GENERATION TIME

For long-lived fish, natural mortality (M) is typically assumed to be less than 0.2. Yield models to assess the impact of changes in minimum legal size, considered both 0.1 and 0.175 to be plausible values (Neilson and Bowering 1989). In the 2014 stock assessment framework review for the Scotian Shelf and the southern Grand Banks, M was assumed to be 0.14. Because of the similarity between Pacific (*Hippoglossus stenolepis*) and Atlantic Halibut, and the extensive research program on Pacific Halibut, Pacific Halibut are thought to provide important context. For recent assessment models of Pacific Halibut, the International Pacific Halibut Commission (IPHC) estimated M to be between 0.173 and 0.213 for females and 0.155 to 0.199 for males, although in the 1990s, M was estimated to be 0.15 for females and 0.14–0.155 for males (Stewart and Hicks 2019). A review of indirect estimates of natural mortality for Atlantic Halibut ranged from 0.02 to 0.34 for males and between 0.09 and 0.29 for females (den Heyer et al. 2013).

Generation time can be estimated from the age at 50% maturity (A50) of the population and natural mortality. Length at maturity varies throughout the geographic range of Atlantic Halibut (reviewed in Shackell et al. 2022). For Atlantic Halibut in Newfoundland, females reached 50% maturity at about 119 cm (total length) at age 12, while males reached 50% maturity at about 77 cm at age 8 (Trumble et al. 1993). Armsworthy and Campana (2010) re-estimated the ages for these length at 50% maturity coming from Trumble et al. (1993) as 5–6 for males and 9–10 for females. In the Gulf of Maine, females reached 50% maturity at 103 cm total length at age 7 and males reached 50% maturity at 80 cm total length at age 6 (Sigourney et al. 2006). A recent modelling study estimated a similar length at 50% maturity for females based on growing degree days (Shackell et al. 2019). According to Haug (1990), there is more variation in the age at first sexual maturity for Atlantic Halibut than length at maturity, and to the extent that growth may be variable over time or throughout the management unit, these estimates should be used with caution. Considering all the variations, A50 for females at 11.5 and A95 (age at 95% maturity) at 14.5 has been applied to the assessment model. The generation time (A50 + 1/M) is estimated to between 16.5 (M = 0.2) and 21.5 years (M = 0.1).

DISCARD MORTALITY

In addition to the direct impact of the fishery on the stock, discarding may also be a significant source of mortality for Atlantic Halibut. Since 1995, all Halibut less than 81 cm are required to be discarded in NAFO Divisions 3NOPs4VWX5Zc. Illegal discarding of large ‘whale’ Halibut, which have a lower value per pound, also occurs. Additionally, Atlantic Halibut are caught and landed with other commercially valuable groundfish species. Halibut caught may be illegally discarded by fisheries directing for other species without Halibut quota.

Generally, Halibut are thought to be robust to handling, relative to other groundfish. Neilson et al. (1989) found that 35% of otter trawl caught Halibut and 77% of longline caught Halibut survived 48 hours in holding tanks. The first deployments of pop-up satellite archival tags suggested that survival of larger Halibut caught by longline gear could be 100% (Armsworthy et al. 2014). Kaimmer and Trumble (1998) found that careful handling of Pacific Halibut can increase discard survival and that 69% of Pacific Halibut with moderate injuries and 43% with severe injuries survived. More recent work on Pacific Halibut, using accelerometer-equipped satellite tags on fish caught in trawl fisheries, suggests that survivability increases with larger fish size and decreases with longer tow duration and handling time (Rose et al. 2019).

ECOSYSTEM CONSIDERATION

OCEANOGRAPHIC CONDITIONS

Warming ocean temperatures have been recognized as a significant contributor to the increasing population of Atlantic Halibut in recent decades (Czich et al. 2023). Both sea surface temperature and bottom temperature have increased in most areas of 3NOPs4VWX5Zc since the late 1990s (DFO 2020, Hebert et al. 2020). Consequently, both growing degree days and available thermal habitat increased (Shackell et al. 2019, Shackell et al. 2022, Czich et al. 2023). Both factors may have contributed to the increasing Halibut population and its expanding distribution.

Increasing temperatures may not always result in an increase in fish abundance. Generally, within normal temperature ranges, fish growth increases with increasing temperature until the optimum temperature, after which fish growth decreases with increasing temperature (Pörtner et al. 2008, Neuheimer et al. 2011). It remains unknown if the recent high temperature has exceeded the optimal temperature range, leading to slower growth and lower survival. Additionally, high temperatures can exacerbate the impacts of acidification (Di Santo 2015, Gobler et al. 2018) and hypoxia (Stortini et al. 2016, Li et al. 2019). However, neither acidification nor hypoxia have been reported for the area of 3NOPs4VWX5Zc.

With the increasing temperature and other changes in the oceanographic conditions, there have been shifts in zooplankton communities. The total zooplankton biomass decreased; nutrition-poor warm water copepods replaced nutrition-rich cold water copepods dominating the zooplankton communities from 2014 to 2018 (Casault et al. 2020).These changes at lower trophic levels may have impacts on the productivity of the entire ecosystem. A lag between environmental change impacting the larval to juvenile stages of Atlantic Halibut.

After several years of high abundance of Atlantic Halibut, the Maritimes Ecosystem Summer RV Survey index of recruitment, indicated a decreasing trend (see Indices of Abundance section below). A decline in juvenile Atlantic Halibut abundance could be linked to thermal stress and changes in food availability.

DIETS

The diet of Atlantic Halibut changes with size as well as with space and time. Kohler (1967) reported the diet of Halibut up to 30 cm consisted of invertebrates almost exclusively and that consumption of fish increased as the size of Halibut increased, switching to a fish-dominated diet around 80 cm in size. Based on data from the Northeast Fisheries Science Center (NEFSC) bottom trawl survey in the Gulf of Maine: crustaceans (mostly decapods) dominated the diet of smaller Halibut (i.e., <31 cm), Halibut 31–80 cm in length fed on decapods, fish (including gadids and clupeids), and mollusks, and fish contributed to 80% of the diet of Halibut 81–134 cm in length (Cargnelli et al. 1999).

Data records from the DFO Maritimes Food Habits Database for Atlantic Halibut show a similar ontogenetic shift in the diet of Atlantic Halibut based on stomachs collected during the Maritimes Ecosystem RV surveys and other research programs on the Scotian Shelf. Halibut stomach content was analyzed between 1999 and 2019. Thirty-seven percent of stomachs were empty and 120 prey species were identified in the remaining 683 stomachs of Halibut that ranged in length from 18 cm to 203 cm. Shrimp and crab had the highest occurrence rates (i.e., >50%) in the stomach contents of fish smaller than 30 cm (n = 41). The occurrence of crab decreased and shrimp and mollusks were the highest, 30% in total, in the diets of fish 31–80 cm. Also, the occurrence of fish greatly increased as size increased. Unlike in the other areas, the occurrence of invertebrates dominated by mollusks was still high, nearly 40%, in the diets of fish larger than 81 cm (n = 120). Atlantic Herring (*Clupea harengus*) and Silver Hake (*Merluccius bilinearis*) had the highest occurrence rates among fish prey in the diets of medium (46–81 cm) and large >82 cm) size groups of Halibut. In an ecosystem model for the Bay of Fundy, Western Scotian Shelf and 4X, Halibut was split into three size groups: <46 cm, 46–81 cm, and >82 cm with at least 50% fish in the diet composition coming from the medium group (Araújo and Bundy 2011). Due to the low number of stomachs collected from small fish, it is difficult to examine whether 46 cm would be a better cutoff for ontogenetic shifts in Halibut diets. Combined stomach content and stable isotope analyses may provide a better approach to estimate a more accurate diet composition for Atlantic Halibut in the Scotian Shelf and southern Grand Banks.

PREDATORS

Small Halibut are preyed upon by Greenland Sharks (*Somniosus microcephalus*), seals, and Spiny Dogfish (*Squalus acanthus*) (Cargnelli et al. 1999). Predators are rare for large Halibut because of their large size. Additionally, depredation by seals when fish are caught on fishing gear has been reported by the fishing industry. However, without ASO data or directed research, it is difficult to incorporate the impacts of Grey Seals *(Halichoerus grypus)* into the framework.

Grey Seal abundance has been increasing on the Scotian Shelf since the 1960s (Hammill et al. 2017, Rossi et al. 2021). Most of this increase is associated with the Sable Island breeding colony, but since the 1990s, smaller breeding colonies along coastal Nova Scotia have also been increasing rapidly (den Heyer et al. 2020). Outside of the breeding season, Grey Seals disperse and forage throughout the northwest Atlantic from Cape Cod to the Labrador coast.

DESCRIPTION OF THE FISHERY

On the Scotian Shelf and the southern Grand Banks, most of the landed Halibut is from a directed longline Halibut fishery. Halibut is also landed by other longline, trawl, gill net, and handline fisheries. Halibut is primarily caught in deep channels and areas along the edge of the continental shelf, but in southwest Nova Scotia (4X) the catch is more broadly distributed (Figure 6). The spatial and temporal distribution of the Halibut catch is further displayed by quarter in five year blocks for the period 2001–2020 (Figures 7a–h). These data are obtained from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region (NL) landing data, representing catch (from 4VWX3NOPs) that was landed in the Maritimes and Newfoundland and Labrador Regions, respectively. The spatial distribution of fishing effort follows seasonal patterns, where more fishing on the shelf edge occurs in the first three months of the year (i.e., January to March; Q1) and July to September (Q3), and most of the fishing in 4X occurs in April to June (Q2) and July to September (Q3). These seasonal patterns are influenced by Halibut movement, but also effort being directed in other fisheries, particularly the lobster fishery in 4X. Over time, as the stock has increased, fishing effort has expanded in the inshore areas of 4VW.

There are restrictions on fishing for Halibut in the haddock spawning area (4W) and in the Gully (4VsW) and St. Anns Bank (4Vn) Marine Protected Areas. As well, Halibut fishing is not permitted in the Lophelia Coral Conservation Area (4Vs), the Northeast Channel Coral Conservation Area (4X), and the Laurentian Channel MPA (3P). There are also seasonal closures in other areas as well as trip limits and bycatch restrictions.

The North American Atlantic Halibut fishery began in coastal New England in the early 1800s. The fishery expanded to deeper waters and eastward as far as Iceland, as the easy-to-access stocks became depleted (Grasso 2008). Atlantic Halibut landings have been recorded since 1867, initially by province, and then by statistical area (SA). From 1920 to the late 1930s, United States vessels, fishing off the coast of New England, landed about half of the Halibut caught in NAFO Subareas 3 and 4 (McCracken 1958). Since that time, Halibut landings have been primarily Canadian. Nonetheless, NAFO statistics are used to describe removals because landings occur in two DFO Regions (Maritimes and Newfoundland), as well as by other countries including Portugal, Spain, and France.

Off the coast of Nova Scotia and Newfoundland, landings rose steadily for the first half of the 20th century and nearly tripled from 1911 to 1949 (Figure 8). The dramatic increase in landings in 1950 and 1951 is believed to have resulted from increased fishing effort post-war and harvesting of an accumulated biomass of large Halibut, although the possibility of increased recruitment could not be eliminated as there were limited data on the size composition of landings (McCracken 1958). Current landings on the Scotian Shelf and southern Grand Banks (3NOPs4VWX5Zc) are above the historic peak landings (Table 4).

Historically, the price of Halibut per unit weight was based on the size of the fish (McCracken 1958, Neilson and Bowering 1989). Medium to large Halibut (5.4–27.2 kg) commanded a higher value than small (known as snapper [0.5–3.2 kg] or chicken [3.2–5.4 kg]) and extra-large Halibut (known as whales: >56.7 kg).

LANDINGS BY GEAR

All countries

The Halibut landings for 1970–2016 by gear type were pulled from NAFO STATLANT 21B (herein referred to as 21B), which provides monthly catch by gear for each country in each NAFO Division (NAFO 2021a). As otter trawl (OT) and longline (LL) are the two dominant gears, gears in 21B were combined into three types: OT, LL, and Other. OT included bottom otter trawl, bottom otter trawl (charters), bottom otter trawl (side or stern not specified), and bottom otter trawl (side). LL included longlines (charters), longlines (not specified), set lines, and drift lines (drifting longlines). The remaining gears were merged into an “Other” category. NAFO Divisions were constrained to 3N, 3O, 3Ps, 4Vn, 4Vs, 4W, and 4X. Specifically, 5Zc, 5Ze, 5Z, and 5Y were constrained to Canadian catch only and assigned to 4X; very few trips of low catch in unknown divisions of Subarea 3 (3NK) were assigned to Division 3N. The annual catch by gear and division was estimated as the sum of monthly catch.

Missing data in 21B between 2001 and 2016 were estimated using NAFO STATLANT 21A (herein 21A; NAFO 2021b) and MARFIS. 21A presents annual landings from each country in each Division from 1970 to 2019; MARFIS contains gear information, mainly for the Maritimes Region, since 2000. Gear was aggregated in MARFIS: all otter trawl were merged into “OT”; longline was kept as “LL”; the remaining 6 gears were combined into “Other”. The same gear aggregations were applied to the 21A (NAFO Divisions 5Zc, 5Ze, 5Z, and 5Y, including Canadian landings only, were assigned to 4X) and MARFIS data (NAFO Divisions 5Ze and 5Y assigned to 4X) as in 21B. Inconsistent landings were found between 21A and 21B (Figure 9). Particularly, since 2001, 21B landings were considerably lower than 21A in both NAFO Subareas 3 and 4; 21B was missing for several years and divisions. To fill in the missing landings in Subarea 3 (NAFO Divisions 3N, 3O, and 3Ps) in 21B, the annual proportion of landing by gear in each division was first estimated in 21B; for each missing year, the division-specific gear proportion was calculated as an average of previous three years. The division-specific gear proportion was then scaled to 21A as total landing. The updates increased the total landing from 21B in Subarea 3 to the same as 21A from 2001 to 2016. To fill in the missing landings in Subarea 4 (NAFO Divisions 4Vn, 4Vs, 4W, and 4X) from 21B for 2001 to 2016, the proportion of landing by gear in each division was estimated annually using MARFIS and also scaled to 21A as total landing. OT catch was occasionally missing in some divisions of Subarea 4 before 2001 including 1994, 1996, 1998, and 2000, and directly replaced with zero because of the lack of data to estimate the proportion and the high possibility of true zeros.

Landings by gear data were further updated to 2020. As the last year in 21B was 2016 and the last year in 21A was 2020, landing by gear for years 2017–2020 was added to 21B as the sum of Canadian landing and foreign landing by gear for each year and division. MARFIS and NL commercial landings were summed as Canadian landings by gear for Subarea 3; MARFIS provides Canadian landings by gear for Subarea 4. The Canadian landings based on MARFIS and NL landings were very similar to those in 21A (difference <24 t per year). This validated the Canadian landings by gear for 21B. For foreign landings by gear and division, the annual division-specific gear proportion was estimated from NL landings and MARFIS, respectively for Subareas 3 and 4. The total foreign landings was the result of extracting Canadian landings from landings of all countries in 21A.

The updated 21B landings by gear represent the best available landings data from 1970 to 2020 (Figure 10). Longline is a dominant gear in each division of Subarea 4 with an increase in 4X in recent years. In divisions of Subarea 3, landings are relatively low with more variability in gears; however, both LL and OT are the dominant gears in most years. In 3Ps particularly, LL has been increasing greatly since late 1990s; there was also an increase in OT in the last few years after low landings for about two decades. The landings of LL and OT were further merged into Subarea 3 and 4 (Table 5) to be used as an input for the stock assessment model. Landings in Subarea 4 are greater than those in Subarea 3 and LL is the dominant gear in Subarea 4 (Figure 11).

Landings data varied over time (Figure 12, Figure 13). The historic landings data appear to have been updated in the NAFO database after the last Halibut framework assessment in 2014, creating different total landings in the online 21B in 2021 (Figure 12). The 2021 version of total landings were generally higher before the mid-1980s and lower after that. Additionally, landings by gear and Subarea were compared between the different versions of model input data, the previous version for the 2014 assessment vs the current (Figure 13). In most years, previous LL landings were higher than the current in both Subareas except a few recent years in the 2000s. For the dominant gear LL, absolute differences from 2021 landings were small with a mean of 11% and standard deviation of 9% in Subarea 3 and a mean of 3% and standard deviation of 4% in Subarea 4. By contrast, OT landing differences were larger in 1970s and 1980s compared to more recent years in both Subareas. However, as the OT landings were generally low, the percentage of absolute differences (mean ± standard deviation: 41% ± 49% in Subarea 3 and 16% ± 14% in Subarea 4) were much higher.

Canada

The Canadian landings by gear include landings from 21B with recent years filled in with a combination of MARFIS and NL commercial landing data. The same divisions and gear types (LL, OT, and Others) as in the all-country landings were applied to the Canadian data. Compared to landings by Subarea in 21A, 21B landings were substantially lower in Subarea 3 in most years since 2000 and were also lower in Subarea 4 in 1990s (Figure 14). Because the percent difference was lower in Subarea 4 (<7.7% per year) and there were no data in MARFIS for this time period, the gear landings before 2001 were from 21B and used MARFIS data for divisions of Subarea 4 and a combination of MARFIS and NL commercial landing data for divisions of Subarea 3 since 2001.

Gear contribution to the Canadian landings from 1970 to 2020 varied over time and space (Figure 15). Historically, a large portion of landings came from otter trawl, but more recently landings are dominated by longline fishing. Particularly, since 2011, more than 91% of the Canadian landings were from the longline fishery, with NAFO Division 4X accounting for the largest portion of the catch.

Longline Landings in the Maritimes Region

Commercial Halibut longline landings between 2002 and 2020 were extracted from MARFIS for 3NOPs and 4VWX (see also Bowlby et al. 2024). In general, Halibut are landed head on and gutted. The round weight, adjusted using weight to live-weight conversion factors (Zwanenburg and Wilson 1999), are reported in MARFIS. Halibut landings for the period from 2002 to 2011 were 12,272 t (Table 6), while landings for the period from 2012 to September 2021 were 29,366 t (Table 7). The percent of landed Halibut (by weight) is 42% from 4VW, 38% from 4X, and 18% from 3NOPs for the period 2002–2011. For 2012 to 2021, the percent of landed Halibut (by weight) is 42% from 4VW, 41% from 4X, and 15% from 3NOPs. The Halibut fishery on the Scotian Shelf is a small boat (<45 ft) fishery. From 2002 to 2011, 92% of the landings in 4VWX were from vessels <35 and 35–45 ft. In contrast, in 3NOPs, 78% of the landings were from vessels >45 ft for this period. This trend remains but less so in the recent period from 2012 to 2021, where 76% of the landings in 4VWX were from vessels <35 ft and 35–45 ft and 54% of the landings were from vessels >45 ft in 3NOPs.

CATCH LENGTH COMPOSITION

Despite the increase in ASO and shore sampling associated with the Halibut survey, ASO and port sampling of Halibut-directed trips have been sparse.

PORT SAMPLING

The groundfish port sampling program started in 1948, but Halibut were not measured because, at that time, most fish were landed without a head. The first Halibut length in our port sampling database was in 1989 (Table 8). Halibut have only been sampled from landings from longline and otter trawl gear. All samples are unculled samples (no size grading). In total, 927 trips were accessed from the database. When the Halibut Commercial Index shore sampling began in 1999, an average of 31 additional trips were sampled until 2015 when Commercial Index samples were linked to the corresponding sets and entered into the ISDB. The proportion at length was generated separately for otter trawl and longline gear for trips that occurred in 4VWX5Zc only (Figure 16, Figure 17). There were insufficient data on trips in 3NOPs. While collecting samples by sex is not regular protocol for port sampling, there were occasions where fish were landed whole and the sample sex and length were recorded (e.g., 1994 and 1997). Halibut landed as part of the Commercial Index shore sampling (1999–2015) were marked at sea to indicate sex. Thus, port samples from the otter trawl fishery were unsexed and port samples of the longline fishery were sexed when they were harvested as part of the Halibut Survey Commercial Index. Sample size is presented for each length frequency and indicates that up until 2015 the data came largely from the Commercial Index (Figure 16). Port sampling in the regular commercial longline fishery has increased since 2018 but these Halibut were not sampled for sex information (Figure 16).

AT-SEA OBSERVERS

ASO monitor and record fishing activities in greater detail than can be obtained from fishery monitoring documents submitted by fishermen. The catches of all species are recorded, whether retained or discarded. In addition to the information on the catch, ASO also record information on the fishing practices, including nature and location of the fishing activity, and may sample fish to assess sex, weight, and maturity, and collect otoliths and other samples or data. The ASO data were maintained by the DFO Maritimes Region within the ISDB. ASO data from the DFO Newfoundland and Labrador (NL) Region were provided by DFO Science in NL Region.

ASO data on Halibut catch by otter trawl and longline gear were used to characterize the length composition of the commercial fishery. A number of fisheries that catch small amounts of Halibut incidentally (Silver Hake, mackerel, shrimp, squid, and Silver Hake/squid/argentine) were excluded. Industry-DFO surveys, such as the 4VN & 4VSW Sentinel, 4X Mobile Gear, 4X Monkfish, and 5Z Fixed Gear, as well as, Fixed Station Halibut Survey and Stratified Random Halibut Survey stations were excluded. Halibut Survey Commercial Index sets sampled by ASO were included.

Prior to 1988, there were a small number of sets sampled by ASO (Table 9). ASO coverage increased in 1988, and again in 1999 with the beginning of the Halibut Survey Commercial Index (CI). The number of sets observed in the otter trawl fleet peaked during the collapse of the cod fishery, and then rapidly declined, averaging 61 sets per year since 1994. From 2007 to 2013, the longline fleet averaged 463 observed sets; this has declined to an average of 267 observed sets between 2014 to 2020. There has been an average of 271 observed sets in the CI since 1999.

The proportion at length was generated separately for otter trawl and longline gear (Figures 18–21). The length composition is presented separately for 3NOPs and 4VWX5Zc, as there is a difference in the size composition of the landings across the management unit and the proportion of the fishery observed at sea varies, with a greater proportion of the landings observed in 3NOPs. Overall, the sampling of otter trawl has been quite variable (Figure 20, Figure 21), while the number of fish caught by longline and sampled by ASO has been in the thousands since the late 1990s (Figure 19, Figure 20). As the sex of the fish cannot be assessed until a fish is gutted, sub-legal fish are usually thrown back without being sexed. Samples observed in 3NOPs reveal that relatively more large females make up the catch in that area (Figure 18). Generally, smaller Halibut comprise a larger portion of the catch of male Halibut than female and 4VWX had more small Halibut than 3NOP. All data are from ISDB, except the NL ASO data, which are included in Figures 18 and 20. The NL data from the NL ASO program are available upon request (contact person: Carol Ann Peters, DFO).

INDICES OF ABUNDANCE

The Maritimes Summer Ecosystem RV survey in 4VWX and the NL Spring Ecosystem RV Survey in 3NOPs provide long-term fisheries-independent indices of abundance. The Fixed Station Halibut Survey, initiated in 1998, provides a fishery-independent index of exploitable biomass throughout the management unit. A new stratified random survey design was initiated in 2017, which extends the longline survey into areas that were not previously covered by the Fixed Station Halibut Survey. One hundred of the original Halibut Survey fixed stations continue to be fished along with the Stratified Random survey stations to calibrate the new survey design.

RESEARCH VESSEL SURVEYS

The longest and most comprehensive fisheries-independent data on the distribution and abundance of Halibut are from DFO Ecosystem RV Surveys. Here, we present the NL Spring Ecosystem RV Survey in 3NOPs, and the Maritimes Summer Ecosystem RV Survey.

Maritimes Summer Ecosystem Research Vessel Survey

The Maritimes Summer Ecosystem RV Survey has low catchability for larger (>81 cm) Halibut, and does not provide a good index of exploitable biomass. The median size of Halibut caught in the Maritimes Summer Ecosystem RV surveys is between 40 and 50 cm. The growth model presented by Armsworthy and Campana (2010) suggests that these fish may enter the fishery in two to four years; therefore, the RV survey data have been used as an index of recruitment.

The Maritimes Summer Ecosystem RV Survey in 4VWX has been completed every July–August since 1970, with the exception of 2018 and 2021. In 2018, the survey was only completed in 4X due to mechanical issues. Each year, about 231 stations are sampled by the Maritimes Summer Ecosystem RV Survey, which covers the area from the Upper Bay of Fundy to the northern tip of Cape Breton and from the 20 m depth contour to 500 m depth (Branton and Black 2004). The number of strata covered and the survey duration vary from year to year. There have also been changes to the ship and gear used. From 1970 to 1981 the survey was conducted by the *A.T. Cameron* using a Yankee 36 trawl. Since 1982, Western IIA trawl gear was used with a variety of boats. In 1982 the survey was completed by the *Lady Hammond*, in 1983–2004, 2006 and 2009–2013 by the *Alfred Needler*, in 2004, 2005, and 2007 by the *Teleost*, and in 2008 by the *Wilfred Templeman*. In 2005, some stations were surveyed by both the *Teleost* and the *Alfred Needler*. The change of fishing gear in 1982 is known to have had important effects on the catchability of cod and haddock, but appears to have had little effect on Halibut (Trzcinski et al. 2011b). Almost all Halibut caught on the Maritimes Summer Ecosystem RV Surveys have been measured and the sex was assessed and reported, except in 2000, when the sex was not recorded. Correction factors for gear changes have been applied for similarly-sized flatfish (e.g., plaice; COSEWIC 2009); however, they were not calculated for the index of abundance (Figure 22) or the length frequency (Figure 23a–b).

Index of Abundance

There was a moderate increase in the abundance (mean number per tow) of Halibut caught in the Maritimes Summer Ecosystem RV Survey in the 1970s, followed by a sharp decline in the early 1980s (Figure 22). The abundance increased again in the late 1980s and early 1990s, but remained low until the early 2000s. Since 2004, the mean number per tow has been above the long-term average. The peak number per tow occurred in 2011, and has remained above the long-term mean since. The mean number per tow in 2020 was the lowest since 2011, but still above the long-term mean. The mean numbers of Halibut per tow for 2018 in Figure 22 is for 4X only and cannot be estimated in the full area of 4VWX.

Catch Composition

The Maritimes Summer Ecosystem RV Survey is the main indicator of recruitment evident by the relatively large number of small fish in the catch composition (Figure 23a–b). Although the 2017 Maritimes Summer Ecosystem RV Survey did not catch Halibut under 38 cm in length, roughly 20% of the 2020 catch was under 38 cm, indicating that some of the youngest cohorts are still present in the survey.

Newfoundland and Labrador Spring Ecosystem Research Vessel Survey

DFO has been conducting research surveys to monitor groundfish resources off of Newfoundland and Labrador in the spring since 1946. Although these surveys are conducted to monitor Canadian resources, they extend beyond the Canadian exclusive economic zone (i.e., outside Canada’s 200 nautical mile limit). From 1946 to 1970, groundfish abundance was estimated using line transect surveys over a range of depths. Between 1971 and 1982, the *A.T. Cameron* with a Yankee-41.5 otter trawl completed an annual stratified-random survey in the spring in 3LNO. The survey was stratified based on depth, with the allocation of sets proportional to the stratum area (Doubleday and Rivard 1981). In 1983 the Yankee trawl was replaced with an Engels-145 high-lift otter trawl. In 1984, the *A.T. Cameron* was replaced by the *Alfred Needler.* From 1996 to 2013, the NL Spring Ecosystem RV Survey was conducted using a Campelen-1800 shrimp trawl. The NL Spring Ecosystem RV Surveys were also conducted in 3Ps and 3Pn since 1972. Mechanical problems in 2006 prevented the sampling of 3Ps, and allowed only minimal coverage of 3NO. Survey coverage has been relatively constant in recent years, with a slight decrease in the number of stations since 2014.

Conversion factors during periods of comparative tows between different survey trawls were not derived for many fish species. Plots of the raw length frequency of Atlantic Halibut with male and female combined for 1972–1982 (Yankee), 1983–1995 (Engels-145), and 1996–2019 (Campelen-1800) suggest a broader size selectivity of the Campelen-1800 shrimp trawl than the Yankee or Engels-145 trawls (Figure 24, Table 10, Table 11). This is consistent with the change in mesh size, but should be interpreted with caution as changes in the size composition in the population could also contribute to the change in the length composition of the survey catch. Further, the length frequencies are not weighted by the stratification scheme. Notably the mean length of Halibut caught by each of the gears used for the NL Spring Ecosystem RV Survey was between 81.9–90.5 cm (Table 11). Therefore, much of the catch in the survey is of sufficient size (>81 cm) to be available to the fishery, and unlike the Maritimes Summer Ecosystem RV Survey, the NL Spring Ecosystem RV Survey may not provide an of index of the abundance of recruits.

The time series is divided into three periods to reflect the different survey gear: 1971–1982 (Yankee trawl), 1983–1995 (Engel), and 1996–2019 (Campelen). We use numbers of fish per tow rather than weight of catch as an index because the catch of large Halibut can inflate the variance in the index, particularly when small numbers of fish are caught. During the first 10 years (Yankee) of the survey, the catch of Halibut increased (Figure 25). Between the mid-1980s to mid-1990s, the catch declined. After the Campelen gear was introduced in 1996, there was little change in the mean number per tow until 2007. Since 2007, the number per tow has generally been increasing. There was one set in the 2016 survey with a very high catch resulting a high mean number of fish per tow for that year that may not be representative of the trend in the population.

INDUSTRY-DFO HALIBUT LONGLINE SURVEY

On the Scotian Shelf and southern Grand Banks, a collaborative Industry-DFO Halibut Longline Survey, with fixed stations and directed fishing, has been conducted since 1998 to monitor the abundance and distribution of a broad size range of Halibut (50–230 cm) over a wide range of depths (50–800 m) (Zwanenburg and Wilson 2000, Zwanenburg et al. 2003, Trzcinksi et al. 2009). Commercial fishermen complete the survey following established protocols and data are collected by ASO and stored in the ISDB (Zwanenburg and Wilson 2000). The Halibut Commercial Index fishery is completed in conjunction with the Halibut survey (Table 12). The Halibut survey has been reviewed in previous assessment documents (Zwanenburg et al. 2003, Trzcinski et al. 2009). Since 2009, the survey protocols have been reviewed and documented, and data management has been improved with enhanced quality control and changes to the handling of replicate survey sets.

Fixed Station Halibut Survey

An initial 222 predetermined stations were identified when the survey started in 1998. Thirty stations were reserved for 3NOPs and the remainder were allocated proportionally over 4Vn, 4VsW, and 4X based on areas of low, medium, and high historic catch rates. Stations were allocated at a ratio of 5:7:10 (i.e., 50 stations in low catch areas, 70 stations in medium catch areas, and 100 in high catch areas). In 1999, stations were rearranged and reallocated, and in 2005, 2006, 2007, and 2008, 4, 51, 8, and 10 new fixed stations were added, respectively, to increase coverage in the Bay of Fundy, north of Cape Breton and Georges Bank. In 2005, one station (Station 46) was relocated a short distance to avoid fishing in a newly protected sensitive habitat. In 2017, a Stratified Random Halibut Survey, described below, was implemented to extend the longline survey coverage into areas and depths that were poorly sampled by the Fixed Station Halibut Survey (Cox et al. 2018). Calibration of the new survey was required to allow for maximal use of data from the whole time series. As a result,100 of the most frequently fished fixed stations in the time series (1998–2015) that also provided good coverage of the survey area have continued to be fished alongside the new Stratified Random Halibut Survey stations (Figure 26).

The protocol for the Fixed Station Halibut Survey is 1,000 hooks set for 10 hours with Mustad circle hooks size #14 or greater with gear set between 4 am and 12 pm. A small number of stations (247 of 4,388 stations fished since 1998) have been fished with two sets of roughly 500 hooks. For these split sets, the catch from the two sets is summed, and the soak time is estimated by a number-of-hooks weighted average. There is some variation in soak time, which is to be expected. Notably, there is also variation in the size of hooks used during the survey, as the minimum required hook size for longline fishing varies across the management unit. There has also been a change over time in the hook size used, with size #16 hooks becoming more common between 2014 and 2017. However, since 2017, when the Stratified Random Halibut Survey (which requires size #15 hooks) was introduced, size #15 hooks have become the more common hook size in the Fixed Station Halibut Survey (Table 13, Table 14). Either the start or end of a gear set is usually within three nautical miles of the station, although some set locations are further from the planned station location. Early in the survey, it was not uncommon for more than one string of gear to be fished at a station by more than one boat in a year. Where there were replicate sets by different boats, the first set that followed the protocol is considered the Fixed Station Halibut Survey set, and the other sets are assigned to the CI survey.

The number of boats involved in the Fixed Station Halibut Survey has ranged between 11 and 17 (Table 12). With the implementation of the Stratified Random Halibut Survey and reduction of the Fixed Station Halibut Survey to only 100 stations, the number of stations completed annually since 2017 has stabilized with Halibut catch ranging from 20 to 25 t (Table 12, Table 15). In 2005 and 2006, there were fewer stations completed in 3NOP, but since 2017 the distribution of stations has remained stable. In the first few years of the Fixed Station Halibut Survey, there was variable survey coverage, particularly in the Southern Grand Banks (3NOPs). Nova Scotia-based participants face a high cost to access these areas, and cod bycatch limits in 3Ps limit the number of fixed stations that can be conducted and preclude fishing CI sets. For all but three years, the majority of stations were fished in June, with a smaller number of stations fished in May and July. In 2007, 2013, 2017, 2018, and 2020 the survey was delayed by roughly a month, leading to a small number of stations being completed in August of those years.

Index of Abundance

In the early years of the survey, the assessment of the stock used Halibut catches from the most consistently sampled stations (known as the golden stations) as the biomass index (Figure 27). As the survey time series grew, and the distribution of sampling effort became more constant, there were a larger number of stations that had been consistently fished (Table 15). A generalized linear model (GLM) approach was introduced to the assessment in 2008 to address the issue of variable station coverage (Trzcinski et al. 2009). For the index of abundance, only stations with soak times greater than three hours and with more than 500 hooks were included (210 of 3,299 [6%] sets excluded; n = 3,089). Further, only stations fished in four or more years (n = 287) were retained for the model of abundance. The catch rate ranged from 0 to 1,205 kg. The GLM used a negative binomial error distribution where year (unordered factor) and station (unordered factor) effects were estimated and the response variable (weight in kg) was offset by the log number of hooks (Trzcinski et al. 2009). Other effects, such as area and vessel, were not considered. No effort was made to account for gear saturation. Further, differences in bait, vessel or hook size were not addressed.

This model has been used as part of the harvest control rule to set TAC in the years since the last assessment. The re-estimation of the index each year does produce a small retrospective effect (Figure 28) and has lead to confusion when providing advice (DFO 2020). With the establishment of the Stratified Random Halibut Survey, a sub-sample of 100 of the most frequently fished stations would serve to calibrate the new Stratified Random Halibut Survey during the transition period (Cox et al. 2018). With the sub-sample of 100 stations, a simple mean of the catch (kg) per 1,000 hooks, can be used as an effective index and replace the GLM model that was addressing variability in the stations fished each year (Figure 27).

The Halibut survey biomass index (mean catch from 100 stations) for 3NOPs4VWX5Zc Atlantic Halibut in 2020 was more than double the index in 2013 (Figure 27). The index continued to decline in 2021 after a peak in 2018.

Catch Composition

The proportion at length by year and sex were calculated using all stations in each year (Figure 29). Sex information is available for retained fish only (>81 cm; Figure 29). As with the commercial longline fishery, the proportion of small Halibut was higher in the male catch versus the female catch, with some indication of cohorts recruiting to the survey gear (as with fishery >81 cm) and moving through in subsequent years.

Stratified Random Halibut Survey

In 2017, a Stratified Random Halibut Survey with standardized fishing protocols, expanded geographic coverage, and increased data collection, was initiated. The Stratified Random Halibut Survey area is divided into five (NAFO Divisions 4X5YZc, 4W, 4V, 3P, 3NO) area strata each with three depth zones (30–130 m, 131–250 m, 251–750 m) (Figure 30). The depth stratification may be considered a proxy for temperature and some bottom habitat information (Cox et al. 2018) and were based on exploratory analyses of catch rates by depth using fixed-station and Commercial Index sets from the Atlantic Halibut survey (Smith 2016). Stations are randomly assigned to the 15 strata (Figure 30, Table 16), and allocated proportionally by the size of each strata. A number of areas closed to fishing for conservation and the French waters around St. Pierre and Miquelon are excluded from the survey. A total of 150 stations were allocated in 2017 and 153 stations were allocated each year in 2018–2021. The extra stations were added to strata with only two stations in an effort to reduce the probability of unfished strata or strata with only one station fished.

For each set, there were 1,000 baited hooks. Gear design and fishing procedures are standardized. Gangions are spaced 4.6–5.5 m apart with total length of gear between 4.6 and 5.5 km. Size #15 circle hooks are baited with herring (125–200 g) and set for a duration between 6 and 12 hours. In strata 1–3 (4VWX5YZc), a sinking mainline is used, while in strata 4 and 5 (3NOP), buoyant polypropylene rope with 1–4 lb weights is used. All catch (by weight) from each set is monitored and every Halibut caught is enumerated and measured (Figure 31). For each set, there are 10 hook condition samples of 30 hooks and for each sample of hook condition, we obtain counts of empty-unbaited hooks, empty-baited hooks, broken hooks, and the number of fish caught by species. To avoid data loss caused by zeros in the hook condition sample, if there are no baited hooks in any of the 10 hook condition samples, captains are asked to fish the set again at an alternate station. Although seven sets were fished between 2017 and 2020 with no baited hooks in the hook condition sample, to date (November 2021) this protocol has not been used. Notably, there is variability in the number of stations that were successfully completed per year (Table 16, Table 17).

Traditional catch per unit effort (CPUE) standardization of number- or weight-per-hook considers soak time only, but ignores factors that can contribute to gear saturation, such as competition for baited hooks within and between species (Etienne et al. 2010). For example, bait loss could occur because of physical disturbance or variation in bait. Gear saturation effectively decreases fishing effort (Beverton and Holt 1957) and could result in catch rates that are not proportional to the target species abundance. Smith (2016) recommended using a multinomial exponential model to account for the number of Halibut caught, the number of hooks occupied by other species as well as empty-baited and empty-unbaited hooks and developed a package (llsurv) using the software R. A general-purpose optimizer using Template Model Builder (Kristensen et al. 2016) for model implementation of the multinomial model is in peer review (Luo et al. 2022). Here, we show the stratified mean of the catch (kg) per 1,000 hooks (Figure 32) which will be used in the assessment. The mean of the catch (kg) per 1,000 hooks from the Stratified Random Halibut Survey is lower than the mean of the catch (kg) per 1,000 hooks from the Fixed Station Halibut Survey because it covers the entire stock area, while the Fixed Station Halibut Survey is concentrated in areas with generally higher Halibut catch rates.

Commercial Index

Commercial vessels that complete the Fixed Station and Stratified Random Halibut Survey sets also conduct CI sets. The annual number of CI sets is approximately three times that of the Halibut Survey. The greatest number of CI sets completed was in 2008 (1,016 sets). On average, 50% of these sets are completed with ASO (Table 18, Table 19). Notably, almost 100% of the CI sets in 3NOP are completed with ASO (Table 18, Table 19). For the other 50% of CI sets, ASO meet the vessel at port and collect detailed length frequency data on the Halibut catch. While most Halibut are landed gutted, Halibut are marked at sea so that the length frequencies can be completed by sex. Up until 2014, these length frequencies were entered in the port sampling database, but since then they have been associated with the appropriate set information and stored in the ISDB. Captains also collect information at sea that allows for a set by set analysis of the catch rate (numbers of fish and estimated weight in kg). There are minimal CI data available for the year 2020 due to restrictions implemented on the ASO program as a result of the COVID-19 pandemic.

As with the Fixed Station Halibut Survey, the number of vessels involved has varied from year to year (Table 12). Further, with few exceptions, the CI was conducted primarily in June and July, with some additional sets in May and August. There is more variation in the fishing protocols with the CI than the Fixed Station and Stratified Random Halibut Surveys, with longer soak times on average (mean = 695 min, median = 539 min) but the number hooks per set has been similar (mean = 987, median = 1,000) to the Fixed Station protocol. Recording of fishing effort data is not consistent, which limits how these data can be used. As with the Fixed Station Halibut Survey, the use of #16 hooks was becoming more common; however, since 2017 with the implementation of gear restrictions for the Stratified Random Halibut Survey, that is conducted concurrent with the Fixed Station and CI surveys, hook size #15 has become the most commonly used (Table 20, Table 21). The CI provides a significant portion of the length samples that make up the catch composition of the longline fishery.

Index of Abundance

The CI catch rate is presented as the weight of Halibut (kg) caught per 1,000 hooks. No stratification scheme or model was used (Figure 33). This index is more difficult to interpret than the Fixed Station/Stratified Random Halibut survey biomass indices because of variation in fishing practices. Notably, this is an index from Halibut-directed commercial fishing and as a result, the CI is generally higher than the Fixed Station and Stratified Random Halibut Survey indices, though it still follows a similar trend compared to the survey. Both the CI and the Fixed Station Halibut Survey abundance increased in the late 2000s and peaked in 2017 (Figure 33).

Length frequency

CI length frequencies are included in the ASO and port sampling data.

4Vn Sentinel Survey

The joint Industry-DFO Sentinel Survey has been conducted annually since 1993 in September in 4Vn (Lambert 2019). It is a stratified random longline survey with a #12 hook. Halibut caught in the survey are presented in terms of biomass (kg per 1,000 hooks) and numbers (per 1,000 hooks) in Figure 34. This index only covers 4Vn and shows an increase in Halibut abundance and biomass beginning in 2010 to levels that were approximately five times larger than previous to 2010. Levels have since declined to about twice the pre-2010 mean, with numbers dropping off earlier than biomass. This index has not been used in assessment of the Halibut stock, as the survey coverage is limited to a relatively small portion of the stock, but it does indicate that the recent increase in Halibut happened later and more suddenly in 4Vn than in the overall stock area.

MULTI-YEAR TAGGING MODEL TO ESTIMATE NATURAL MORTALITY AND FISHING MORTALITY

In 2006, DFO and the Atlantic Halibut Council (AHC) began the Halibut All Sizes Tagging (HAST) program to estimate the population size, exploitation rate, and to evaluate the distribution of Halibut within the Scotian Shelf southern Grand Banks management unit. More than 6,000 Halibut have been double tagged with T-bar anchor tags during the Industry-DFO Halibut Longline Surveys since 2006. Tagged Halibut were released throughout the management unit. Prior to 2018, the proportion of tags allocated to each NAFO Division was proportional to the abundance estimated from 1995 to 1997 (Table 22). In 2019, the tagging program was switched to the Stratified Random Halibut Survey stations. The Halibut tagged and released in NAFO Subarea 3 were larger than the Halibut released in NAFO Subarea 4 (Figure 35). Most Halibut were recaptured in the NAFO Division where they were released (Table 23, Table 24).

The HAST program is an industry support tagging program with high monetary rewards for tag reporting. Fishermen are asked to report the recapture of tagged Halibut with the date, location, length and sex. For each fish recaptured (one or both tags returned), fishermen are rewarded with $100 from the AHC and their name is entered in the pool for the four lotteries per year offering a prize of $1,000. Despite these rewards, there may be recaptured tags that are not reported. A social science project is being undertaken to estimate non-reporting rate and identify methods to improve tag reporting. From the tag reports themselves, we see some evidence of non-reporting as the pink tags are sometimes reported by dockside monitors, buyers, and on one occasion a chef. As of October 21, 2021, 993 of the 1,218 (82%) tag reports provided sufficient information for the multi-year mark-recapture model.

A substantial number of fish below the legal size limit (81 cm) were tagged and released (Figure 35). Only fish that were of legal size at time of release were analyzed in the 2010 stock assessment (den Heyer et al. 2011); in this assessment framework review all tagged fish are included, as most of the undersized fish would have been available to the fishery during later years. Further work could explore the implications of both upper and lower size limits on the estimate of fishing and natural mortality (M).

The HAST program is an example of a band-recovery experiment as exemplified by Brownie et al. (1985). Following the methods of Hoenig et al. (1998), the expected number of fish released and recaptured can be expressed as a function of the expected number of recoveries given a constant instantaneous M, year-specific instantaneous fishing mortality (F_i), constant initial-tagging survival rate (ITS) and constant tag-reporting rate (RR), assuming that fishing takes place uniformly over the entire year with tagged-fish released at the start of each year (den Heyer et al. 2013). There are two extensions to Hoenig et al. (1998) in the Atlantic Halibut multiyear mark-recapture model. First, as the majority of tagging takes place in June and July, fish tagged and released in the first year are only subject to half a year of fishing and apparent natural mortality. Second, tag-loss is considered in the model and described with two parameters (R_1 and R_2). The incomplete mixing model estimates fishing mortality (F*) in the first six months of release, when fish behavior might be altered and would bias estimates of F. This model was chosen because it fit the data better than a complete mixing model (den Heyer et al. 2013). Unfortunately, there is no information in the data that allows for identifying the best ITS or RR, so these value are fixed based on other information. Neilson et al. (1989) found that ITS for Halibut caught on longlines ranged from 80% to near 100% depending on handling time, total catch, fish length, depth fished, etc. Subsequent to this work, additional PSAT tagging has been completed both in the Gulf of St. Lawrence and on the Scotian Shelf, demonstrating that the assumption of 90% survival is conservative. In previous work, an ITS of 0.9 and 1.0 was used for model fitting (den Heyer et al. 2011, den Heyer et al. 2012). Here, the model is fit with a range of ITS from 0.8 to 1.0 (Table 25). As roughly 15–20% of tag reports are incomplete because of lack of data on recapture location and date information, the model was also fit to a range of reporting rates from 0.6 to 0.9 (Table 25).

The model selection criteria provides no information on the assumptions of ITS and RR, but based on the discussion above, 70% tag reporting and 100% survival from tagging, was chosen as the preferred model (Table 25). The updated multiyear mark-recapture model estimates natural mortality (M) at 0.10 and fishing mortality (F) between 2007 and 2020 ranging from 0.20 to 0.04 (Figure 36). The declining F is consistent with the capped increases in F during a period of high recruitment, but the F estimate is roughly one-third of the management objective of F = 0.14. New information on tag reporting rate will help to inform the multi-year mark-recapture model, but there may be other issues with model assumptions, such as the assumed fixed M or initial tag survival. A retrospective pattern was observed in M (Table 26), which is not unexpected with an assumption of fixed M. Notably, Halibut are long-lived fish with high tag retention. It is possible that size-selectivity of the fishery, and unaccounted spatial variation in fishing effort could also impact the estimate of F. An integrated population model that fits to the fishery and fishery-independent data and the mark-recapture data could help to reconcile the differences in the indices of F from mark-recapture and the population model.

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TABLES

Table 1. Sample size for Atlantic Halibut length and weight by Northwest Fisheries Organization (NAFO) Subareas (3, 4, and 5) and year; data collected by the At-Sea Observer (ASO) Program and the Fisheries and Oceans Canada Ecosystem Research Vessel (RV) Surveys.

Year	ASO Program NAFO 3	ASO Program NAFO 4	ASO Program NAFO 5	RV Survey NAFO 3	RV Survey NAFO 4	RV Survey NAFO 5
1970	0	0	0	0	23	0
1971	0	0	0	0	38	0
1972	0	0	0	0	25	0
1973	0	0	0	0	37	0
1974	0	0	0	0	45	0
1975	0	0	0	0	58	0
1976	0	0	0	0	69	0
1977	0	0	0	0	109	0
1978	0	0	0	0	195	0
1979	0	0	0	0	277	0
1980	0	22	0	0	294	1
1981	0	16	0	0	237	0
1982	0	0	0	0	182	0
1983	0	0	0	0	136	0
1984	0	21	0	0	109	0
1985	37	0	0	0	25	0
1986	0	0	0	0	4	2
1987	6	66	7	0	0	0
1988	387	179	3	0	0	0
1989	589	1,876	3	0	14	2
1990	515	2,577	32	0	0	0
1991	549	3,109	11	0	0	0
1992	652	1,292	6	0	0	0
1993	292	456	0	0	0	0
1994	2	170	0	0	44	0
1995	316	91	0	0	43	0
1996	150	433	0	0	79	1
1997	326	49	0	0	107	0
1998	131	4,508	0	0	59	0
1999	459	2,158	1	0	78	0
2000	392	1,309	1	0	77	3
2001	346	1,272	2	0	76	0
2002	378	1,442	5	0	87	0
2003	318	1,856	2	0	78	0
2004	670	558	2	0	59	0
2005	658	1,080	1	0	221	1
2006	161	547	0	0	181	0
2007	427	930	15	0	122	1
2008	205	625	3	0	140	1
2009*	1320	2,873	24	0	98	2
2010	603	2,531	5	0	219	0
2011	746	2,399	3	0	229	9
2012	247	1,219	0	0	174	5
2013	0	608	0	0	118	7
2014	0	908	7	0	187	0
2015	60	1,790	133	0	176	2
2016	365	2,079	66	0	246	6
2017	0	135	1	0	119	10
2018	0	43	1	0	56	4
2019	0	886	22	0	142	5
2020	0	42	0	0	128	9

*ASO data may have derived weights.

Table 2. Table of trip types where Atlantic Halibut have been measured for length and weight. The type "other" refers to the combination of all measured Atlantic Halibut from trips where there were less than 30 fish sampled per type. All trip types were used to model the length-weight relationship.

Trip Type	Number of Halibut
HALIBUT LONGLINE SURVEY	33,898
SILVER HAKE	8,129
HALIBUT	5,913
RESEARCH VESSEL SURVEY	5,291
COD, HADDOCK, POLLOCK	2,615
OTHER	789
4V SW SENTINEL PROGRAM	757
WHITE HAKE	573
4X MOBILE GEAR SURVEY	529
REDFISH	296
FLATFISH	114
SQUID	114
SKATE	46
SILVERHAKE, SQUID, ARGENTINE	45
Overall	59,109

Table 3. The number of Atlantic Halibut from observed sets and Maritimes Summer Ecosystem Research Vessel Survey sets with length and weight measurements by sex and month, excluding outliers (i.e., removed due to improbable length or weight measurements). All includes all fish measured: females, males, and unsexed individuals.

Sex	Total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Male	26,156	684	997	1,770	2,240	5,658	8,207	5,106	568	126	291	279	250
Female	25,302	609	847	1,564	1,746	5,118	9,562	4,291	511	200	318	313	223
All	59,109	1,395	2,106	3,482	4,134	11,687	20,849	11,307	1,192	826	911	701	519

Table 4. Total reported Canadian and foreign landings (tonnes) of Atlantic Halibut from Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NOPs4VWX5Zc[a]. Ten-year annual average landings are presented for 1960 to 2009. The NAFO STATLANT 21A table of landings by country are reported by calendar year; however, the total allowable catch (TAC) for the stock is set for the period of April–March. Dash (-) indicates data not available. NA indicates no set TAC.

Year	Canada			Foreign			3NOPs4VWX5Z	
	3NOPs	4VWX5Z	Total	3NOPs	4VWX5Z	Total	Total	TAC
1960–1969	638.4	1,520.9	2,159.3	492.2	62	554.2	2,713.5	NA
1970–1979	427.8	874	1,301.8	73.7	15.4	89.1	1,390.9	NA
1980–1989[b,c]	738.2	1,624.6	2,362.8	217	13.8	230.8	2,593.6	NA
1990–1999	323.2	815.4	1,138.6	179.6	4.3	183.9	1,322.5	1,855
2000–2009	460.9	878.1	1,339	147.8	0.1	147.9	1,486.9	1,340
2010	464	1,296	1,760	131	1	132	1,892	1,850
2011	373	1,346	1,719	218	1	219	1,938	1,850
2012	531	1,491	2,022	200	1	201	2,223	2,128
2013	562	1,836	2,398	205	1	206	2,604	2,447
2014	839	1,811	2,650	312	1	313	2,963	2,563
2015	693	2,174	2,867	395	1	396	3,263	2,738
2016	626	2,186	2,812	393	1	394	3,206	3,149

Year	Canada			Foreign			3NOPs4VWX5Z	
	3NOPs	4VWX5Z	Total	3NOPs	4VWX5Z	Total	Total	TAC
2017	759	2,353	3,112	403	1	404	3,516	3,621[d]
2018	699	3,171	3,870	343	0	343	4,213	4,164[d]
2019	841	3,414	4,255	480	0	480	4,735	4,789[d]
2020	1,142	3,692	4,834	465	0	465	5,299	5,507[d]
2021	1,472[e]	3,894[e]	5,366[e]	-	-	-	-	5,445[d]

[a]Canadian landings in NAFO Division 5Y are assumed to have been in the Canadian portion and are included in the 4VWX+5Zc value. Foreign/US landings in 5Y are not included.
[b]Landings were first listed in NAFO Division 5Zc in 1986; 5Zc and 5Ze are used to indicate same area.
[c]Prior to 1988, the Atlantic Halibut catch was unregulated.
[d]For 2017, 2018 and 2019, 100 t of the Canadian TAC were set aside to cover catches by US and France within the stock area.
[e]Landings from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region landing data for 2021 are preliminary as of January 18, 2022.

Table 5. Longline landing (tonnes) in Northwest Atlantic Fisheries Organization (NAFO) Subareas 3 (LL3) and 4 (LL4), and otter trawl landing in NAFO Subareas 3 (OT3) and 4 (OT4) for all countries in 3NOPs4VWX5Zc.

Year	LL3	LL4	OT3	OT4
1970	249	603	440	270
1971	319	676	244	399
1972	172	716	319	154
1973	206	722	287	117
1974	147	600	287	78
1975	150	563	255	145
1976	107	567	238	175
1977	89	503	500	188
1978	73	709	256	306
1979	52	856	365	329
1980	71	1,050	218	443
1981	61	1,100	172	359
1982	74	1,414	417	383
1983	136	1,597	137	312
1984	600	1,826	323	204
1985	906	1,772	951	231
1986	904	1,467	752	140
1987	582	1,070	799	103
1988	763	1,216	259	131
1989	600	1,136	164	70
1990	603	1,017	487	132
1991	278	802	801	138
1992	284	875	166	105
1993	252	758	112	140
1994	127	856	97	36
1995	139	520	86	47
1996	118	581	51	37

Year	LL3	LL4	OT3	OT4
1997	152	692	75	34
1998	201	564	90	18
1999	186	585	148	27
2000	254	509	92	7
2001	394	722	159	44
2002	348	721	199	53
2003	442	779	312	50
2004	349	800	129	82
2005	334	766	69	65
2006	339	872	35	50
2007	489	899	37	88
2008	363	960	53	59
2009	297	1,180	510	73
2010	421	1,241	118	67
2011	419	1,265	133	94
2012	539	1,377	139	131
2013	520	1,757	213	99
2014	756	1,729	314	106
2015	613	2,093	414	107
2016	366	2,116	634	110
2017	649	2,251	490	127
2018	585	2,993	452	191
2019	727	3,184	586	202
2020	1,196	3,458	398	198

Table 6. Weight of Atlantic Halibut landed (tonnes) by Northwest Atlantic Fisheries Organization (NAFO) Division and vessel class (VC) from 2002 to 2011 from the Maritimes Fisheries Information System (MARFIS).

NAFO Division	VC <35 ft	VC 35–45 ft	VC 45–65 ft	VC >65 ft	VC Mobile gear	Total Weight
3N	0	96	125	306	0	527
3O	0	31	63	120	2	216
3Ps	5	314	101	996	25	1,441
4Vn	131	277	18	0	39	465
4Vs	6	872	586	189	92	1,745
4W	222	2,193	483	71	12	2,981
4X	471	3,604	108	9	477	4,669
5Y	2	24	1	0	17	44
5Z	0	141	4	0	39	184
Total	837	7,552	1,489	1,691	703	12,272

Table 7. Weight of Atlantic Halibut landed (tonnes) by Northwest Atlantic Fisheries Organization (NAFO) Division and vessel class from 2012 to 2021 from the Maritimes Fisheries Information System (MARFIS) (Note: data from 2021 are incomplete as data were compiled in September 2021).

NAFO Division	<35 ft	35–45 ft	45–65 ft	>65 ft	Mobile gear	Total
3N	0	470	208	191	0	869
3O	0	387	268	316	83	1,054
3PS	0	998	87	1,351	118	2,554
4VN	371	1,227	82	21	68	1,769
4VS	152	2,715	921	539	403	4,730
4W	759	4,134	615	148	79	5,735
4X	692	10,577	80	0	741	12,090
5Y	2	88	0	0	10	100
5Z	0	360	0	0	105	465
Total	1,976	20,956	2,261	2,566	1,607	29,366

Table 8. The number of trips sampled by shore sampled Commercial Index longline, port sampling commercial fishing longline, and port sampling commercial otter trawl.

Year	Longline Commercial Index	Longline Commercial	Otter Trawl Commercial
1989	0	0	2
1990	0	1	0
1991	0	1	1
1992	0	0	1
1993	0	1	1
1994	0	6	2
1995	0	10	1
1996	0	12	0
1997	0	11	2
1998	0	11	2
1999	20	15	12
2000	25	16	2
2001	23	15	5
2002	23	19	3
2003	20	10	3
2004	33	8	8
2005	25	12	5
2006	31	14	1
2007	57	8	6
2008	47	5	1
2009	23	14	3
2010	27	8	3
2011	36	7	4
2012	32	11	17
2013	38	23	1
2014	34	7	6
2015	1	7	7
2016	3	8	0

Year	Longline Commercial Index	Longline Commercial	Otter Trawl Commercial
2017	0	3	0
2018	0	8	0
2019	0	19	1
2020	0	31	0

Table 9. The number of observed sets that caught Atlantic Halibut by fishery by year. Numbers along the top row refer to the trip type codes: 12 = White Hake, 23 = Redfish, 30 = Halibut, 31 = Turbot, 49°=°Flatfish, 211 = Skate, 230 = Porbeagle, 312 = Sculpin, 7001 = Cod, Haddock, Pollock, 7057°=°Halibut Commercial Index, 7099 = other.

Year	12	23	30	31	49	211	230	312	7001	7057	7099
1979	0	0	0	0	0	0	0	0	1	0	0
1980	0	2	0	0	0	0	0	0	2	0	0
1981	0	0	0	0	0	0	0	0	2	0	0
1982	0	0	0	0	0	0	0	0	1	0	0
1984	0	0	0	0	0	0	0	0	4	0	0
1985	0	1	19	0	0	0	0	0	14	0	0
1986	0	1	0	0	0	0	0	0	3	0	0
1987	0	19	0	0	0	0	0	0	84	0	0
1988	0	8	0	0	0	0	0	0	263	0	13
1989	0	29	21	0	0	0	0	0	205	0	6
1990	34	121	0	0	23	0	0	0	398	0	56
1991	13	60	47	0	7	0	4	0	305	0	22
1992	40	77	19	1	16	0	0	0	429	0	13
1993	0	84	10	6	6	3	1	0	137	0	25
1994	46	64	7	0	3	0	0	0	34	0	13
1995	144	19	84	0	0	16	0	0	42	0	55
1996	136	1	277	0	3	4	0	0	49	0	12
1997	47	4	200	0	0	76	0	0	67	0	0
1998	44	11	216	14	0	0	0	0	10	569	0
1999	25	8	193	0	0	12	0	0	36	162	38
2000	0	13	339	0	0	0	0	0	113	228	0
2001	11	11	492	0	0	0	0	2	93	90	3
2002	0	29	327	0	0	0	1	0	26	161	2
2003	0	6	416	2	0	0	0	1	20	162	0
2004	0	24	54	1	6	0	0	0	87	142	0
2005	0	9	228	0	0	0	0	2	40	205	0
2006	0	0	138	0	0	10	0	1	40	127	0
2007	16	12	581	0	0	0	0	0	101	101	0
2008	10	0	481	0	0	0	0	0	49	347	0
2009	0	7	420	0	0	0	0	0	11	317	0
2010	0	10	457	0	3	0	0	0	115	349	0
2011	0	25	423	0	0	0	0	0	69	256	0
2012	0	3	404	0	3	0	0	0	84	203	0
2013	0	13	474	0	0	0	0	0	56	217	0
2014	0	1	307	0	0	0	0	0	86	188	0
2015	0	10	329	0	0	0	0	0	109	459	0
2016	0	3	293	0	1	0	0	0	52	497	0
2017	28	26	296	0	3	0	0	0	83	448	0
2018	0	28	274	0	10	0	0	2	35	267	0
2019	0	40	161	0	0	0	0	0	57	548	0
2020	0	50	207	0	0	0	0	0	59	196	0

Table 10. Number of male, female, unknown sex and total Atlantic Halibut measured during the Newfoundland and Labrador Spring Ecosystem Research Vessel Survey in the Northwest Atlantic Fisheries Organization Divisions 3NOPs.

Year	Male	Female	Unknown	Total
1973	8	3	0	11
1974	8	4	0	12
1975	2	7	0	9
1976	15	13	0	28
1977	19	18	0	37
1978	22	17	0	39
1979	19	19	0	38
1980	44	32	0	76
1981	9	9	0	18
1982	19	15	0	34
1983	9	11	0	20
1984	15	9	0	24
1985	20	19	0	39
1986	18	22	0	40
1987	16	13	0	29
1988	7	3	0	10
1989	9	7	0	16
1990	4	3	0	7
1991	9	10	0	19
1994	7	6	0	13
1995	11	11	0	22
1996	2	6	0	8
1997	16	14	0	30
1998	6	9	0	15
1999	6	4	0	10
2000	9	3	0	12
2001	3	10	1	14
2002	8	5	0	13
2003	9	6	0	15
2004	3	4	4	11
2005	1	3	0	4
2006	2	0	0	2
2007	16	7	0	23
2008	9	7	0	16
2009	14	7	0	21
2010	16	13	0	29
2011	12	10	1	23
2012	9	17	2	28
2013	31	13	0	44
2014	22	17	0	39
2015	20	18	0	38
2016	29	43	6	78
2017	24	23	0	47
2018	30	27	1	58
2019	29	27	2	58

**LF (length frequencies) files missing for 1971, 1992 and 1993; no Halibut lengths for Spring 1972.*
**Experiment type 1 (survey) only; species code 893 (Atlantic Halibut); month 3,4,5,6; NAFO Divisions 3N, 3O and 3Ps only; there were no Halibut lengths in 4Vn, 4Vs.*

Table 11. Summary of the distribution of the length of Atlantic Halibut caught in Northwest Atlantic Fisheries Organization Divisions 3NOPs during the Newfoundland and Labrador Spring Ecosystem Research Vessel Survey for each trawl gear.

Gear	1st Quarter	Median	Mean	3rd Quarter
Yankee	68.0	80	81.9	89.0
Engel	71.0	89	90.5	106.2
Campelen	63.0	81	82.2	98.0

Table 12. Total number of boats that participated in the Fixed Station Halibut Survey, Stratified Random Halibut Survey, and Commercial Index. Note that the Stratified Random Halibut Survey began in 2017. NA indicates not applicable.

Year	Fixed Station Halibut Survey			Stratified Random Halibut Survey			Commercial Index		
	# of Boats	# of Stations	Halibut catch (t)	# of Boats	# of Stations	Halibut catch (t)	# of Boats	Number of sets	Halibut catch (t)
1998	17	175	7	NA	NA	NA	17	669	84
1999	13	167	8	NA	NA	NA	13	568	75
2000	14	217	12	NA	NA	NA	21	809	93
2001	11	190	9	NA	NA	NA	14	583	83
2002	12	200	9	NA	NA	NA	14	707	84
2003	12	189	8	NA	NA	NA	13	696	83
2004	11	215	10	NA	NA	NA	11	906	90
2005	12	164	9	NA	NA	NA	11	548	59
2006	11	163	7	NA	NA	NA	12	588	71
2007	17	241	13	NA	NA	NA	17	647	87
2008	17	283	15	NA	NA	NA	20	1,016	133
2009	14	214	18	NA	NA	NA	14	673	103
2010	17	215	18	NA	NA	NA	18	707	101
2011	14	217	24	NA	NA	NA	15	882	116
2012	15	217	21	NA	NA	NA	16	728	128
2013	14	233	24	NA	NA	NA	14	784	109
2014	15	233	26	NA	NA	NA	15	619	127
2015	14	232	33	NA	NA	NA	14	619	140
2016	14	227	25	NA	NA	NA	14	621	122
2017	13	99	20	21	149	11	19	489	130
2018	14	100	25	20	153	16	21	459	149
2019	12	100	21	17	127	14	15	629	177
*2020	11	99	20	16	151	13	8	145	49

**In the year 2020, there is less available data for Commercial Index sets due to limited at-sea observer coverage resulting from the COVID-19 pandemic.*

Table 13. The number of stations fished by hook size (#14, #15 or #16) and by Northwest Atlantic Fisheries Organization (NAFO) division in the Fixed Station Halibut Survey.

NAFO Division	Hook size #14	Hook size #15	Hook size #16
3N	18	34	48
3O	73	138	146
3P	102	79	64
4V	385	201	233

NAFO Division	Hook size #14	Hook size #15	Hook size #16
4W	703	300	42
4X	811	592	22
5Y	0	4	0
5Z	2	12	0

Table 14. The number of stations fished by hook size (#14, #15, or #16) and by year in the Fixed Station Halibut Survey. Note: in the first two years of the survey (1998 and 1999), hook size was not recorded.

Year	Hook size #14	Hook size #15	Hook size #16
2000	217	0	0
2001	174	16	0
2002	157	26	17
2003	138	51	0
2004	175	40	0
2005	61	94	0
2006	110	53	0
2007	174	47	0
2008	195	44	34
2009	78	136	0
2010	105	74	36
2011	100	34	83
2012	98	34	85
2013	89	76	68
2014	78	68	87
2015	62	97	73
2016	50	105	72
2017	19	80	0
2018	14	86	0
2019	0	100	0
2020	0	99	0

Table 15. The number of stations fished by year and Northwest Atlantic Fisheries Organization division in the Fixed Station Halibut Survey.

Year	3N	3O	3P	4V	4W	4X	5Y	5Z	Total
1998	1	3	8	44	57	59	0	3	175
1999	5	20	14	27	54	47	0	0	167
2000	6	24	20	45	68	54	0	0	217
2001	6	11	22	31	68	51	0	1	190
2002	0	7	17	47	65	63	0	1	200
2003	0	4	18	45	59	63	0	0	189
2004	6	26	15	46	60	62	0	0	215
2005	6	14	0	33	44	67	0	0	164
2006	0	0	9	29	52	73	0	0	163
2007	6	18	12	33	56	116	0	0	241
2008	6	20	12	61	59	115	0	10	283
2009	6	20	12	50	53	71	1	0	213
2010	6	20	12	48	53	75	1	0	215
2011	6	20	8	47	52	84	0	0	217
2012	6	20	10	47	51	83	0	0	217

Year	3N	3O	3P	4V	4W	4X	5Y	5Z	Total
2013	6	20	13	46	58	89	0	1	233
2014	6	20	9	51	52	94	0	1	233
2015	6	20	12	49	55	88	2	0	232
2016	6	20	12	48	54	87	0	0	227
2017	4	18	9	19	24	25	0	0	99
2018	4	18	9	19	24	26	0	0	100
2019	4	18	7	21	24	26	0	0	100
2020	4	19	7	19	24	26	0	0	99
Total	106	380	267	905	1,166	1,544	4	17	4,389

Table 16. Number of stations fished by year and strata in the Stratified Random Halibut Survey. The strata numbers refer to area (1: 4X, 2: 4W, 3: 4V, 4: 3P, 5: 3NO) and depth (1: 30–130 m, 2: 131–250 m, 3: 251–750 m). For example, Strata 1.3 represents the area of 4X and depth range of 251–750 m.

Strata	2017	2018	2019	2020	Total
1.1	16	16	16	16	64
1.2	11	11	11	11	44
1.3	2	3	3	3	11
2.1	15	15	15	15	60
2.2	7	7	7	7	28
2.3	2	3	3	3	11
3.1	11	11	11	11	44
3.2	5	5	5	5	20
3.3	8	8	8	7	31
4.1	13	13	10	13	49
4.2	8	8	5	8	29
4.3	7	8	4	8	27
5.1	39	39	25	39	142
5.2	2	3	2	3	10
5.3	3	3	2	2	10
Total	149	153	127	151	580

Table 17. The number of stations fished by year and Northwest Atlantic Fisheries Organization division in the Stratified Random Halibut Survey.

Year	3N	3O	3P	4V	4W	4X	5Y	5Z	Total
2017	26	18	28	24	24	24	0	5	149
2018	20	25	29	24	25	26	0	4	153
2019	13	16	18	25	25	27	0	3	127
2020	24	20	29	23	25	23	2	5	151
Total	83	79	104	96	99	100	2	17	580

Table 18. Number of Commercial Index sets in each Northwest Atlantic Fisheries Organization (NAFO) division by year for sets observed at sea.

Year	3N	3O	3P	4T	4V	4W	4X	5Z
1998	0	20	0	0	257	272	120	0
1999	0	39	3	0	94	36	8	0
2000	0	95	0	0	155	14	16	0
2001	0	1	0	0	81	12	1	0
2002	0	0	1	0	137	29	6	0

Year	3N	3O	3P	4T	4V	4W	4X	5Z
2003	0	0	0	0	164	26	3	0
2004	21	40	0	0	44	25	1	0
2005	59	58	0	0	50	10	27	0
2006	21	8	7	0	75	15	9	0
2007	41	5	10	0	40	10	3	0
2008	52	22	0	0	127	93	13	65
2009	105	25	57	0	114	19	15	0
2010	75	2	37	1	139	14	44	0
2011	94	9	9	0	65	15	88	0
2012	84	14	6	1	62	1	11	0
2013	21	72	18	0	55	18	45	0
2014	63	26	1	0	43	20	42	0
2015	3	42	59	0	91	9	27	0
2016	5	38	41	0	75	28	54	0
2017	44	48	29	0	44	16	44	1
2018	18	14	44	0	61	20	33	0
2019	30	36	74	2	101	10	10	0
*2020	32	3	11	1	66	0	30	0
Total	768	617	407	5	2,140	712	650	66

**In the year 2020 there is less available data for Commercial Index sets due to limited at-sea observer coverage resulting from the COVID-19 pandemic.*

Table 19. Number of Commercial Index sets in each Northwest Atlantic Fisheries Organization (NAFO) division by year for port-sampled sets.

Year	3N	3O	3P	4RT	4V	4W	4X	5Z
1998	0	0	0	0	0	0	0	0
1999	0	0	0	0	152	200	36	0
2000	0	0	0	0	148	343	38	0
2001	0	0	0	0	153	235	100	0
2002	0	0	1	0	229	198	106	0
2003	0	0	0	0	251	166	86	0
2004	0	0	0	0	302	240	233	0
2005	0	0	0	0	181	59	104	0
2006	0	0	0	0	134	62	257	0
2007	0	0	0	1	38	61	438	0
2008	0	0	0	0	151	44	449	0
2009	0	0	0	0	0	20	318	0
2010	0	0	0	0	0	10	385	0
2011	0	0	0	2	70	30	500	0
2012	0	0	0	2	21	50	476	0
2013	0	0	0	1	22	40	492	0
2014	0	0	0	1	70	10	343	0
2015	0	0	0	0	0	11	377	0
2016	0	0	0	0	20	12	348	0
2017	0	0	0	0	35	15	213	0
2018	8	0	17	1	2	3	229	9
2019	0	0	2	0	0	0	364	0
*2020	0	0	0	0	0	0	0	0
Total	8	0	20	8	1,979	1,809	5,892	9

**In the year 2020, there are less data available for Commercial Index sets due to limited at-sea observer coverage resulting from the COVID-19 pandemic.*

Table 20. The number of observed (at-sea and port-sampled) commercial sets fished by hook size (#12, #14, #15, or #16) and by year for sets where hook size data was available. Note: in the first two years of the survey (1998 and 1999), hook size was not recorded.

Year	Hook size #12	Hook size #14	Hook size #15	Hook size #16
2000	0	280	0	0
2001	0	88	7	0
2002	0	167	2	4
2003	0	63	130	0
2004	0	132	38	0
2005	0	23	175	0
2006	0	44	91	0
2007	0	24	59	0
2008	0	87	125	112
2009	0	41	294	0
2010	2	55	148	107
2011	0	161	73	216
2012	0	58	90	154
2013	0	93	84	144
2014	0	101	30	153
2015	0	126	344	149
2016	0	116	277	126
2017	0	18	191	17
2018	0	15	195	0
2019	0	0	263	0
2020	0	12	133	0

Table 21. The number of observed (at-sea and port-sampled) commercial sets fished by hook size (#12, #14, #15, or #16) and by Northwest Atlantic Fisheries Organization (NAFO) division for sets where hook size data was available. Note: in the first two years of the survey (1998 and 1999), hook size was not recorded.

NAFO Division	Hook size #12	Hook size #14	Hook size #15	Hook size #15
3N	0	45	336	307
3O	0	158	198	96
3P	0	14	257	33
4R	0	0	1	0
4T	0	4	3	0
4V	0	761	758	372
4W	0	215	220	51
4X	2	507	908	28
5Y	0	0	2	0
5Z	0	0	66	0

Table 22. The number of Atlantic Halibut tagged and released as part of the Halibut all-sizes tagging (HAST) program by Northwest Fisheries Atlantic Organization (NAFO) division between 2006 and 2021 (n = 6,020).

NAFO Division	2006	2007	2008	2010	2012	2014	2016	2018	2019	2020	Total
3N	93	54	54	55	54	54	35	53	37	54	543
3O	32	57	58	71	71	71	76	68	37	63	604
3P	30	236	143	134	134	131	134	71	18	74	1,105
4V	103	116	185	126	171	170	173	80	86	105	1,315
4W	165	132	166	141	171	164	164	115	89	144	1,451
4X	103	84	102	109	101	109	116	119	95	28	966
5Z	0	0	0	0	0	0	0	7	16	13	36
Total	526	679	708	636	702	699	698	513	378	481	6,020

Table 23. The number of Atlantic Halibut recaptured by Northwest Atlantic Fisheries Organization (NAFO) division of release and recapture, as part of the Halibut All Sizes Tagging program (2006 and 2021).

Release NAFO	Recapture NAFO												
	0B	3L	3N	3O	3P	4R	4S	4T	4V	4W	4X	5Y	5Z
3N	0	0	36	50	7	0	0	0	0	0	2	0	0
3O	0	0	8	52	13	1	0	0	3	1	0	0	0
3P	0	0	5	12	140	0	0	0	18	5	3	0	0
4V	1	0	0	0	12	2	1	7	120	26	1	0	1
4W	0	1	4	0	11	0	0	0	15	95	17	0	0
4X	0	0	2	2	8	0	0	0	11	24	103	3	0
5Z	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1	1	55	116	191	3	1	7	167	151	126	3	1

Table 24. The number of Atlantic Halibut recaptured as part of the Halibut All-Sizes Tagging program between 2006 and 2020 (top row), reported by the year released (first column). NA indicates not applicable.

Release year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2006	16	40	23	18	15	8	10	6	3	4	4	3	2	0	1
2007	NA	13	93	40	24	11	12	10	9	6	2	0	1	0	0
2008	NA	NA	20	50	33	13	22	16	9	13	7	1	1	1	0
2010	NA	NA	NA	NA	16	38	42	18	13	7	4	1	2	1	2
2012	NA	NA	NA	NA	NA	NA	12	29	16	19	7	4	11	1	3
2014	NA	NA	NA	NA	NA	NA	NA	NA	14	31	18	13	6	4	2
2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6	16	12	8	13
2018	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	5	15	10
2019	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2	8
2020	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4

Table 25. Parameter estimates for incomplete mixing models fit to the recapture of tagged Atlantic Halibut. A range of initial tagging mortality (ITS) and tag reporting rates (RR) were used in the models. All models were fit with two parameters to describe tag loss: for complete mixing model, $R_1$is estimated to be 0.77, and R_2, the subsequent annual tag retention rate, is 0.95. F, fishing mortality in the year of release is not reported. The preferred model is in bold. NA indicates not applicable.*

Model	M	F_{2007}	F_{2008}	F_{2009}	F_{2010}	F_{2011}	F_{2012}	F_{2013}	F_{2014}	F_{2015}	F_{2016}	F_{2017}	F_{2018}	F_{2019}	F_{2020}
ITS = 0.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RR = 0.6	0.053	0.213	0.282	0.188	0.16	0.112	0.17	0.118	0.089	0.107	0.07	0.053	0.054	0.042	0.054
RR = 0.7	0.075	0.183	0.243	0.161	0.136	0.096	0.146	0.101	0.077	0.093	0.062	0.047	0.048	0.038	0.049
RR = 0.8	0.092	0.16	0.213	0.14	0.118	0.084	0.128	0.089	0.068	0.082	0.055	0.042	0.043	0.035	0.045
RR = 0.9	0.105	0.142	0.19	0.124	0.105	0.075	0.114	0.079	0.061	0.073	0.049	0.038	0.04	0.032	0.041
RR = 1.0	0.116	0.127	0.171	0.111	0.094	0.067	0.103	0.071	0.055	0.067	0.045	0.034	0.036	0.029	0.038
ITS = 0.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RR = 0.6	0.07	0.19	0.252	0.167	0.141	0.1	0.152	0.105	0.08	0.096	0.064	0.048	0.049	0.039	0.05
RR = 0.7	0.09	0.163	0.217	0.142	0.12	0.086	0.13	0.09	0.069	0.083	0.056	0.042	0.044	0.035	0.046
RR = 0.8	0.105	0.142	0.19	0.124	0.105	0.075	0.114	0.079	0.061	0.073	0.049	0.038	0.04	0.032	0.041
RR = 0.9	0.117	0.126	0.169	0.11	0.093	0.066	0.101	0.07	0.054	0.066	0.044	0.034	0.036	0.029	0.038
RR=1.0	0.126	0.113	0.152	0.099	0.083	0.06	0.091	0.063	0.049	0.06	0.04	0.031	0.033	0.026	0.035

Model	M	F_{2007}	F_{2008}	F_{2009}	F_{2010}	F_{2011}	F_{2012}	F_{2013}	F_{2014}	F_{2015}	F_{2016}	F_{2017}	F_{2018}	F_{2019}	F_{2020}
ITS = 1.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RR = 0.6	0.084	0.171	0.227	0.15	0.127	0.09	0.136	0.094	0.072	0.087	0.058	0.044	0.046	0.036	0.047
RR = 0.7	**0.102**	**0.146**	**0.195**	**0.128**	**0.108**	**0.077**	**0.117**	**0.081**	**0.062**	**0.075**	**0.051**	**0.039**	**0.041**	**0.032**	**0.042**
RR = 0.8	0.116	0.127	0.171	0.111	0.094	0.067	0.103	0.071	0.055	0.067	0.045	0.034	0.036	0.029	0.038
RR = 0.9	0.126	0.113	0.152	0.099	0.083	0.06	0.091	0.063	0.049	0.06	0.04	0.031	0.033	0.026	0.035
RR = 1.0	0.135	0.101	0.136	0.089	0.074	0.054	0.082	0.057	0.044	0.054	0.037	0.028	0.03	0.024	0.032

[1] F_{2020} is based on tags recovered up to October 21, 2021.

Table 26. Natural mortality (M) and fishing mortality (F_i) estimates for incomplete mixing models, assuming initial tagging mortality = 1.0 and tag reporting rates = 0.7, fit to subsets of the Halibut tagging data with maximum year. All models were fit with two parameters (R_1 and R_2) to describe tag loss. The F, fishing mortality in the year of release, is not reported. NA indicates not applicable.*

Year	M	F_{2007}	F_{2008}	F_{2009}	F_{2010}	F_{2011}	F_{2012}	F_{2013}	F_{2014}	F_{2015}	F_{2016}	F_{2017}	F_{2018}	F_{2019}	F_{2020}
2010	0.204	0.163	0.227	0.16	0.159	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2011	0.174	0.157	0.216	0.15	0.142	0.087	NA	NA	NA	NA	NA	NA	NA	NA	NA
2012	0.201	0.16	0.225	0.159	0.155	0.108	0.191	NA	NA	NA	NA	NA	NA	NA	NA
2013	0.174	0.156	0.217	0.15	0.14	0.099	0.169	0.14	NA	NA	NA	NA	NA	NA	NA
2014	0.11	0.151	0.201	0.133	0.115	0.08	0.125	0.085	0.066	NA	NA	NA	NA	NA	NA
2015	0.1	0.151	0.199	0.13	0.11	0.078	0.118	0.081	0.062	0.074	NA	NA	NA	NA	NA
2016	0.094	0.148	0.196	0.127	0.106	0.075	0.114	0.078	0.06	0.072	0.048	NA	NA	NA	NA
2017	0.094	0.147	0.195	0.127	0.106	0.075	0.114	0.078	0.06	0.072	0.048	0.035	NA	NA	NA
2018	0.092	0.147	0.194	0.126	0.105	0.075	0.112	0.077	0.058	0.071	0.047	0.036	0.038	NA	NA
2019	0.092	0.147	0.194	0.126	0.105	0.075	0.113	0.078	0.059	0.071	0.047	0.037	0.038	0.022	NA

Year	M	F_{2007}	F_{2008}	F_{2009}	F_{2010}	F_{2011}	F_{2012}	F_{2013}	F_{2014}	F_{2015}	F_{2016}	F_{2017}	F_{2018}	F_{2019}	F_{2020}
2020	0.103	0.146	0.195	0.128	0.108	0.077	0.118	0.081	0.062	0.076	0.051	0.039	0.041	0.032	0.045

FIGURES

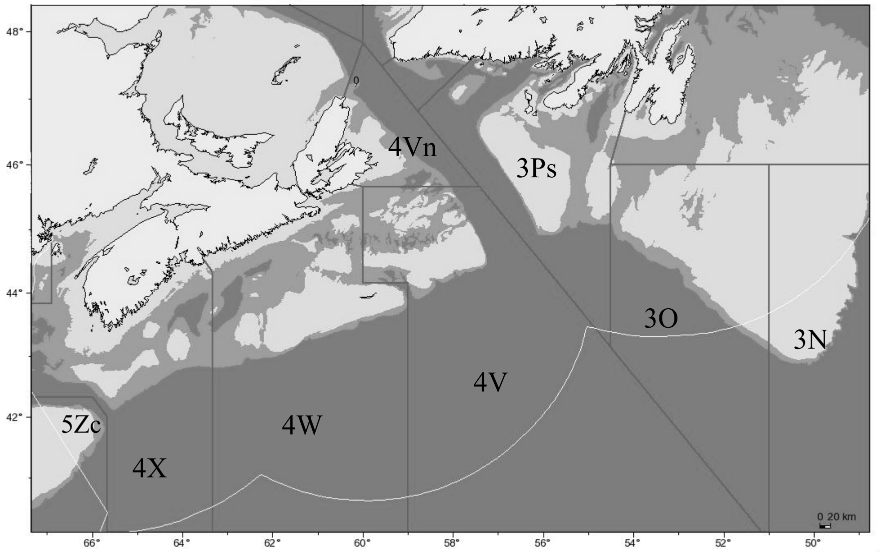


Figure 1. Northwest Atlantic Fisheries Organization management unit 3NOPs4VWX5Zc.

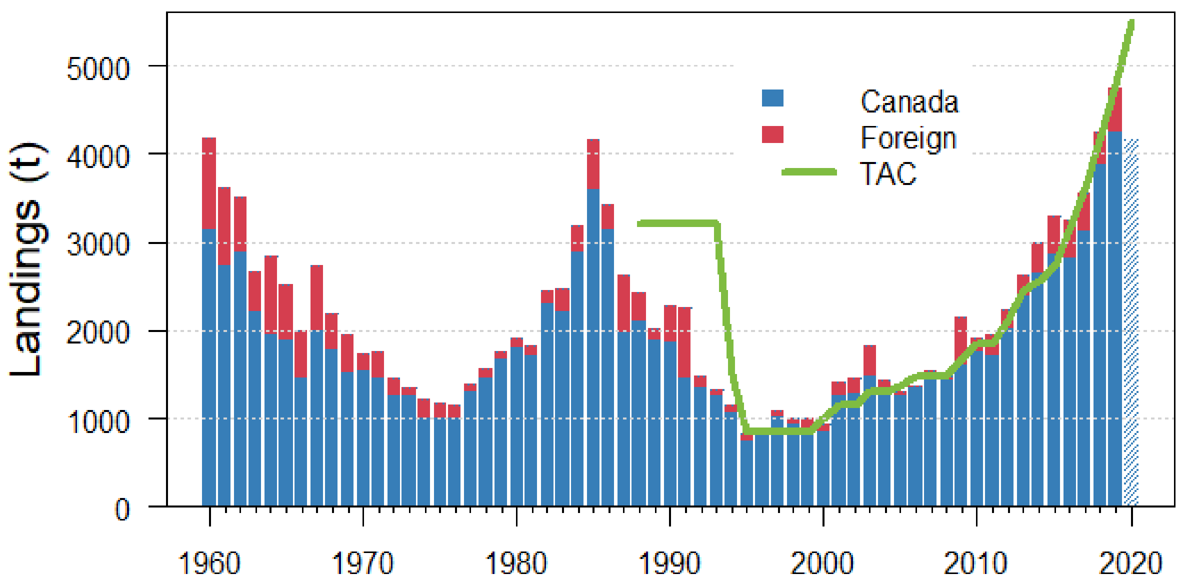


Figure 2. Northwest Atlantic Fisheries Organization (NAFO) reported Canadian (blue) and foreign (red) landings (tonnes) for the Atlantic Halibut management unit (3NOPs4VWX5Zc). Landings for 2021 (hashed bar) are preliminary, and were obtained from the Maritimes Fisheries Information System (MARFIS) on November 18, 2020. The solid green line represents the Canadian total allowable catch (TAC). The NAFO STATLANT 21A table of landings by country are reported by calendar year; however, the TAC for the stock is set for the period of April–March.

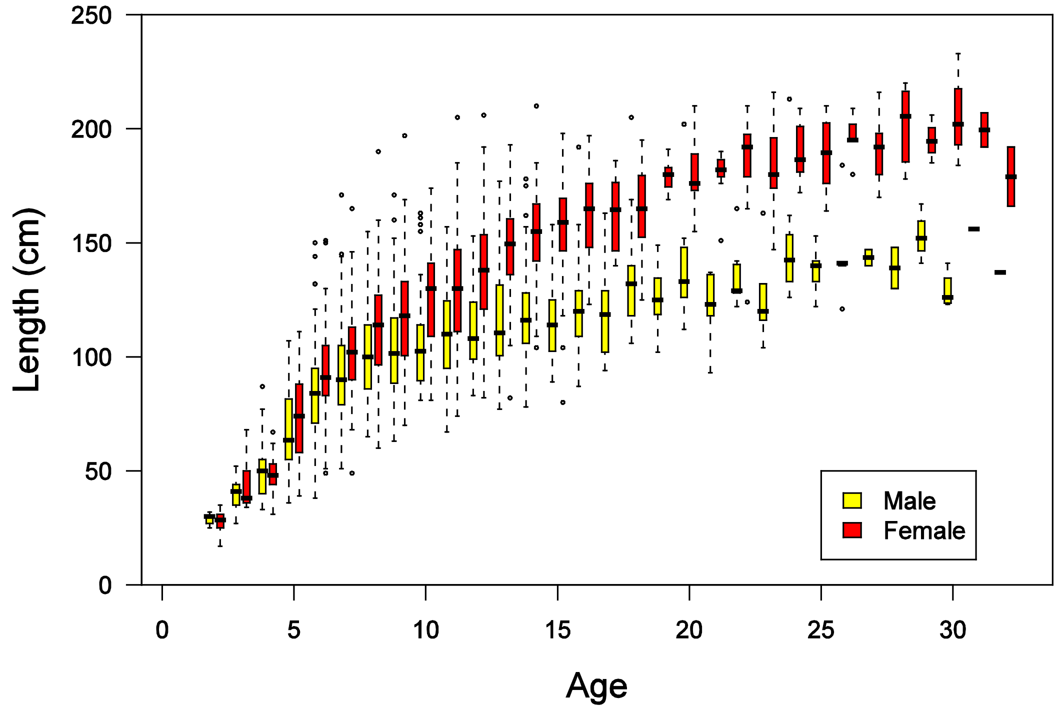


Figure 3. Length at age for male and female Atlantic Halibut (from Trzcinski et al. 2011a).

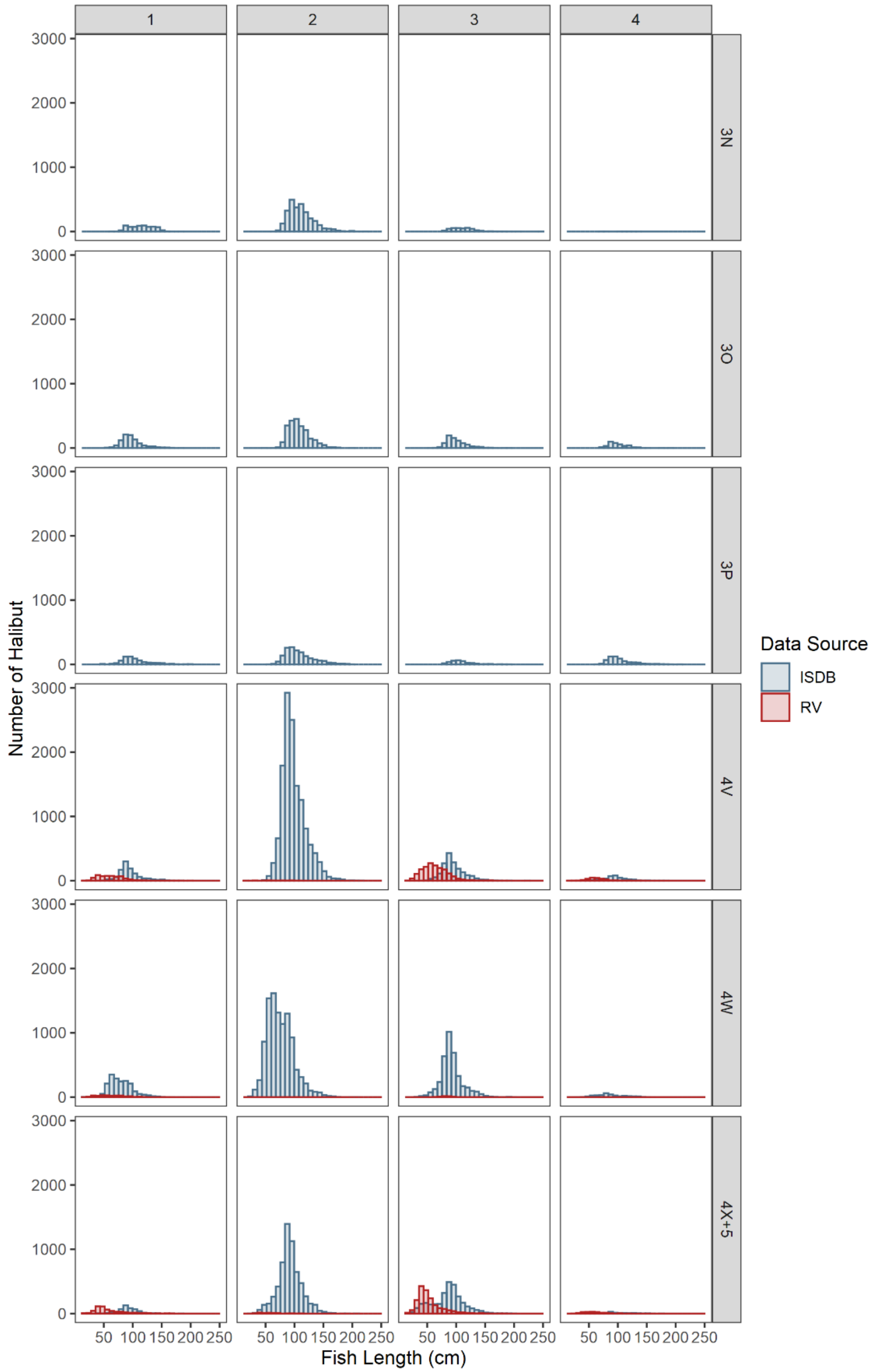


Figure 4. Number of Atlantic Halibut measured for length and weight by length bin (8 cm bins). Panels are arranged by columns for each quarter of the year (i.e., 1: January–March, 2: April–June, 3: July–September, 4: October–December) and the rows for the Northwest Atlantic Fisheries Organization divisions where samples were measured. Data were collected by at-sea observers on Industry-DFO Halibut Survey and commercial sets (Industry Surveys Database [ISDB], blue bars) and the Fisheries and Oceans Canada Ecosystem Research Vessel Surveys (RV, red bars).

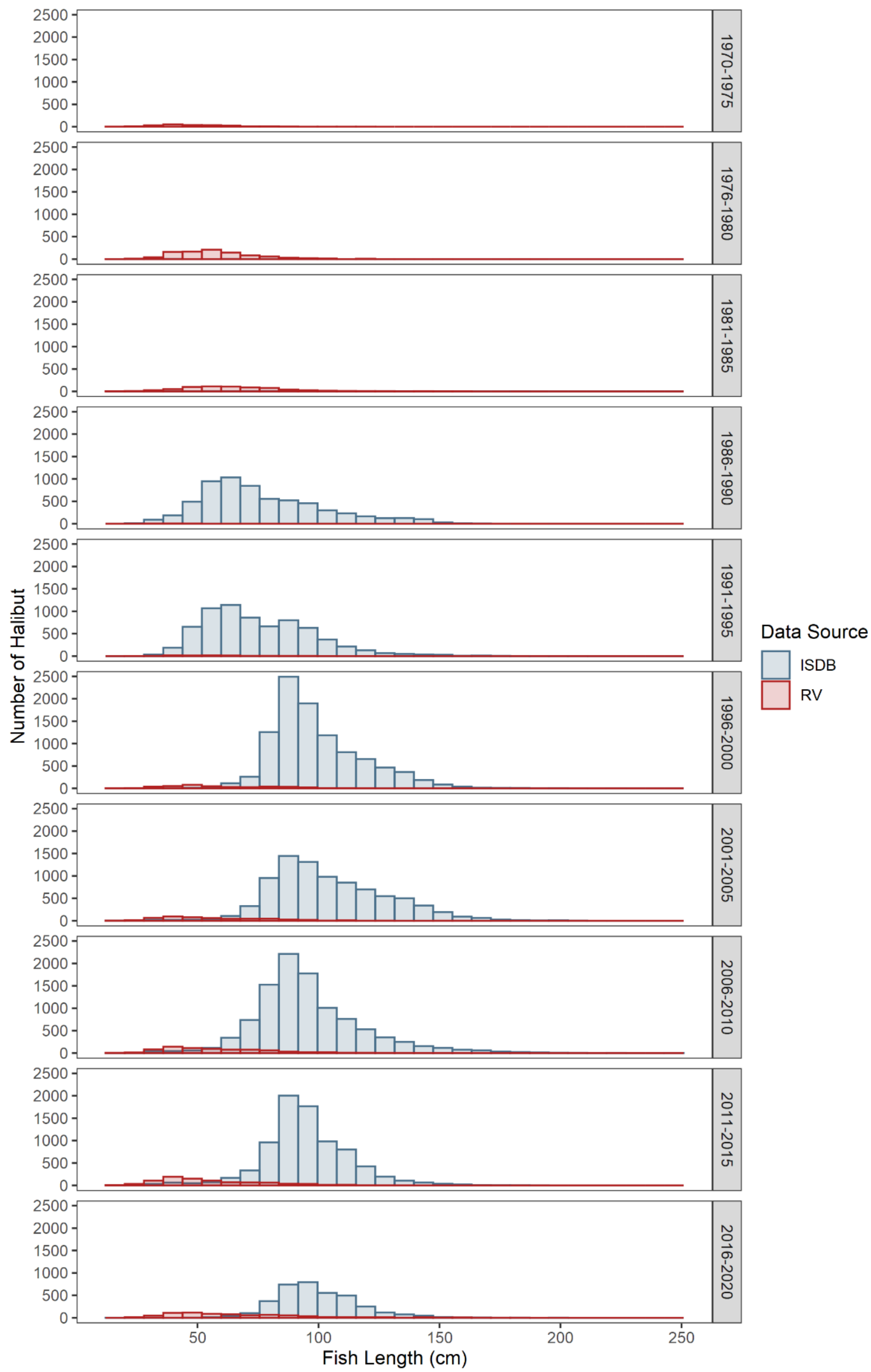


Figure 5. Number of Atlantic Halibut throughout the available time series by length (8 cm bins). Data were collected by at-sea observers on industry survey and commercial sets (Industry Surveys Database [ISDB], blue bars) and the Fisheries and Oceans Canada Ecosystem Research Vessel Surveys (RV, red bars).

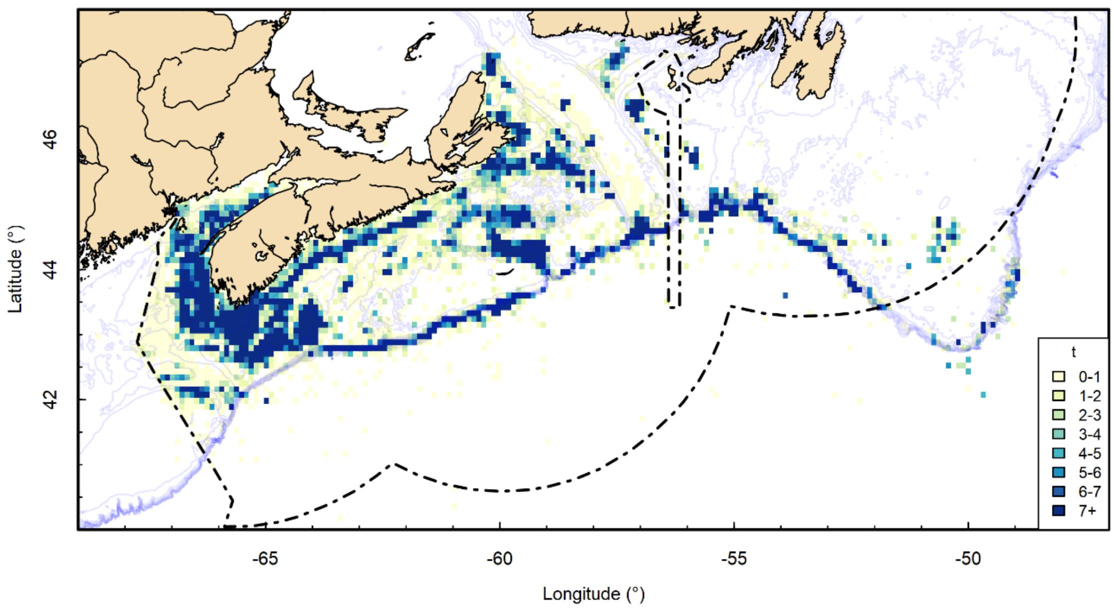
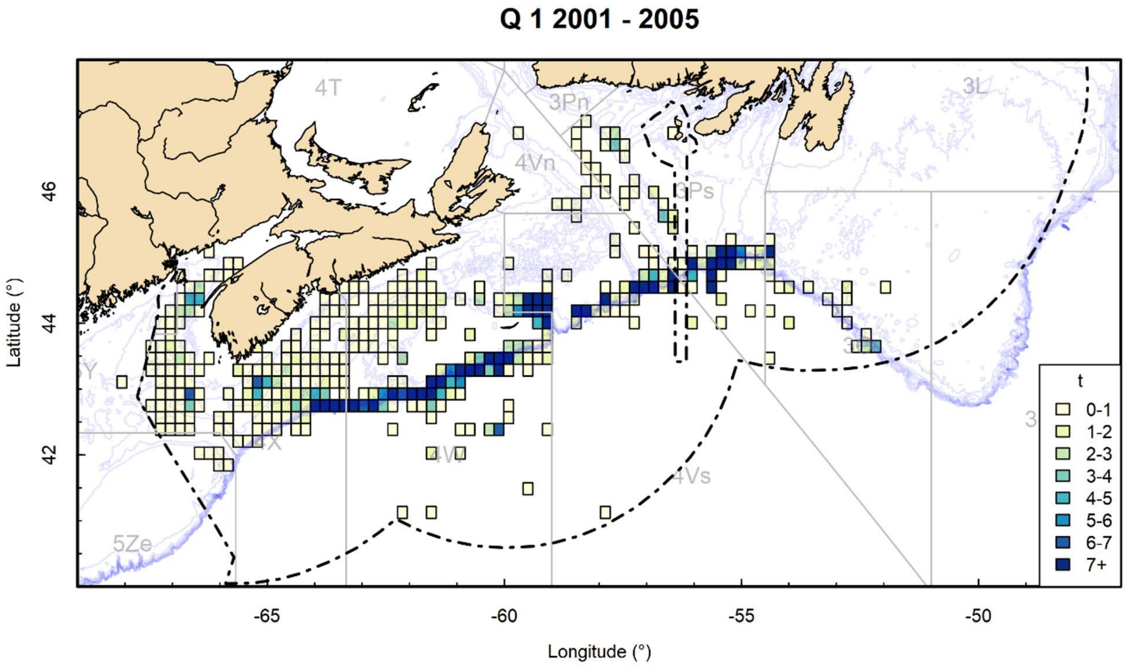


Figure 6. Distribution of Atlantic Halibut catch, by 20 km grid cells, from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region landing data for the period of 2016–2020. The dashed line indicates the Canadian exclusive economic zone.



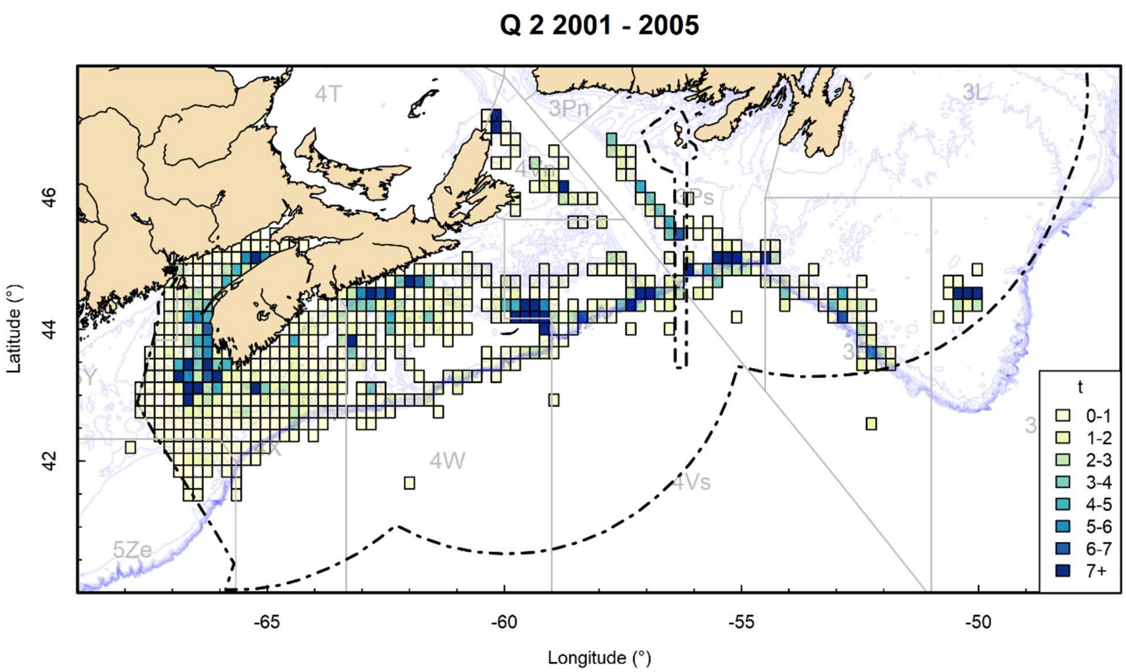


Figure 7a. Distribution of Atlantic Halibut catch, by 20 km grid cells, from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region landing data for quarter 1 (January–March; top) and quarter 2 (April–June; bottom) for the period of 2001–2005. The dashed line indicates the Canadian exclusive economic zone.

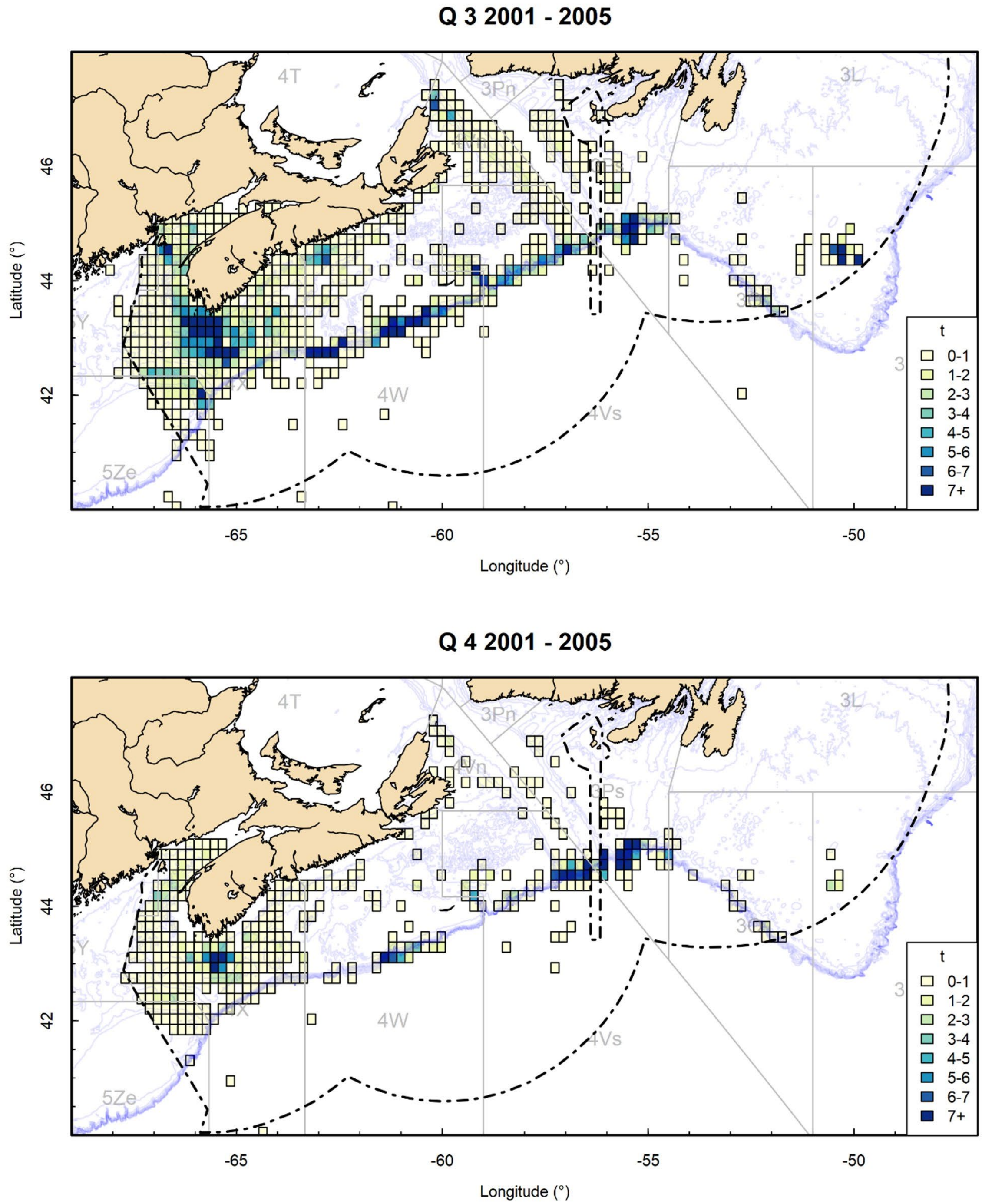
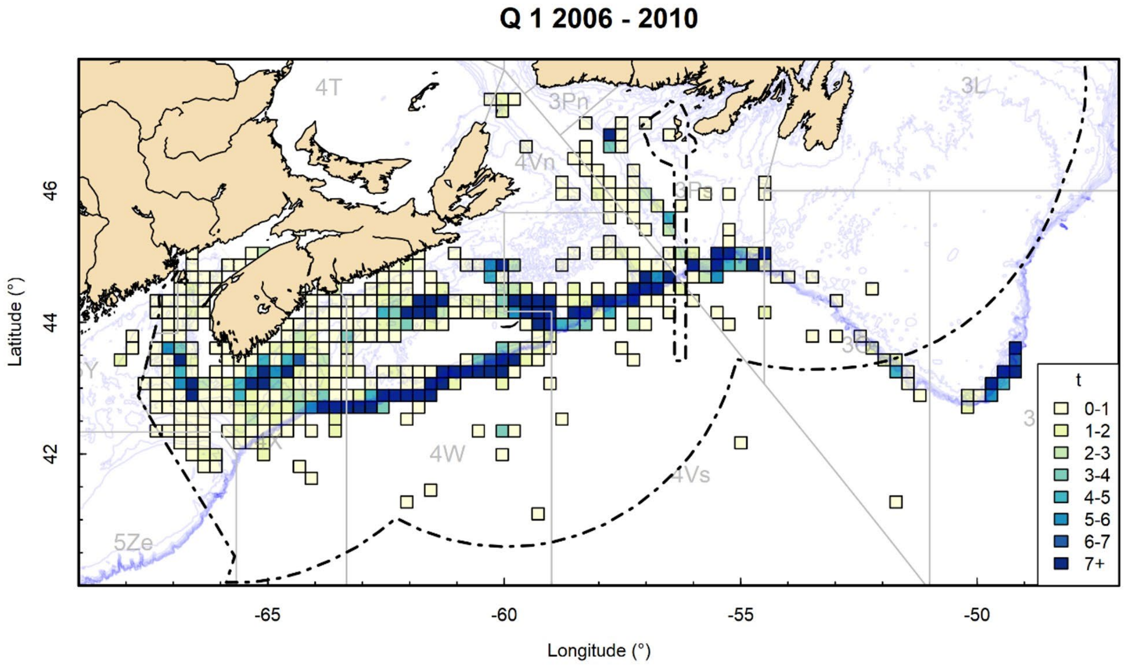


Figure 7b. Distribution of Atlantic Halibut catch, by 20 km grid cells, from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region landing data for quarter 3 (July–September; top) and quarter 4 (October–December; bottom) for the period of 2001–2005. The dashed line indicates the Canadian exclusive economic zone.



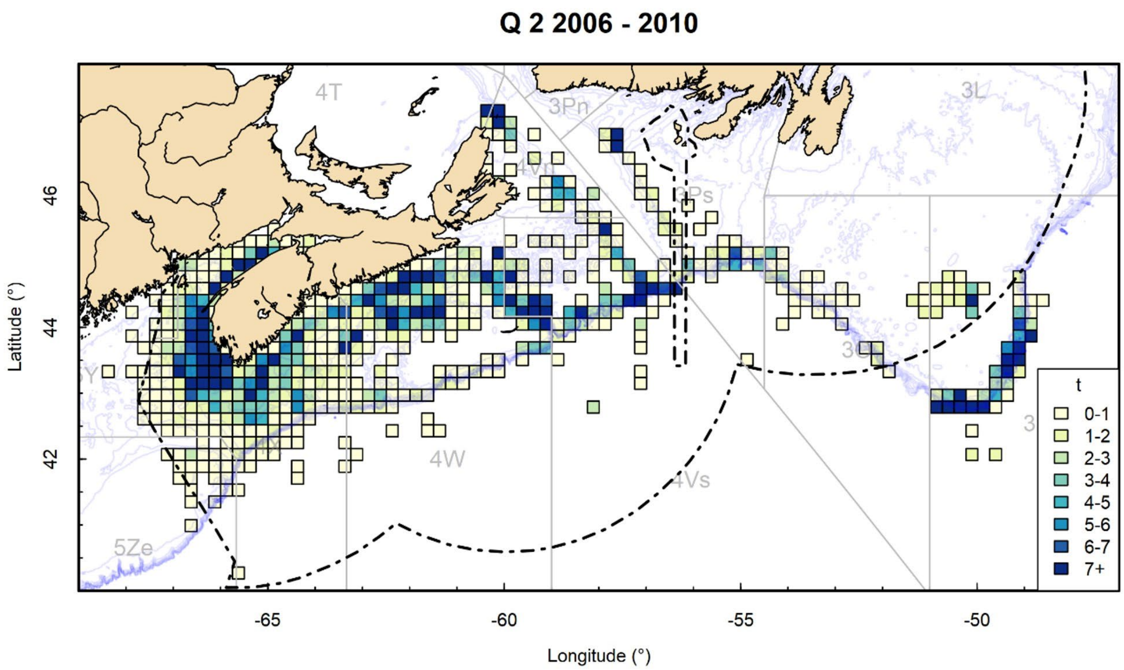


Figure 7c. Distribution of Atlantic Halibut catch, by 20 km grid cells, from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region landing data for quarter 1 (January–March; top) and quarter 2 (April–June; bottom) for the period of 2006–2010. The dashed line indicates the Canadian exclusive economic zone.

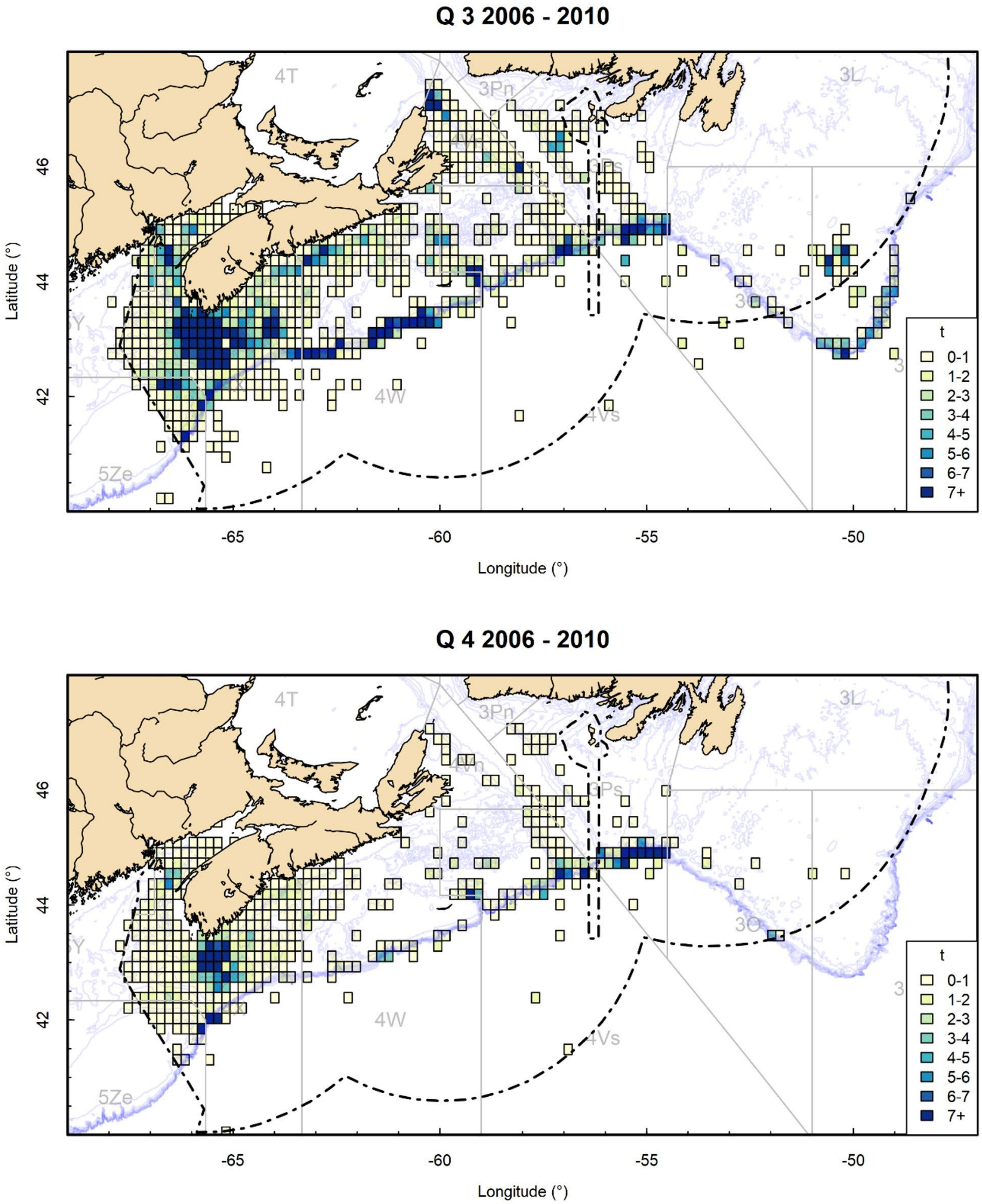
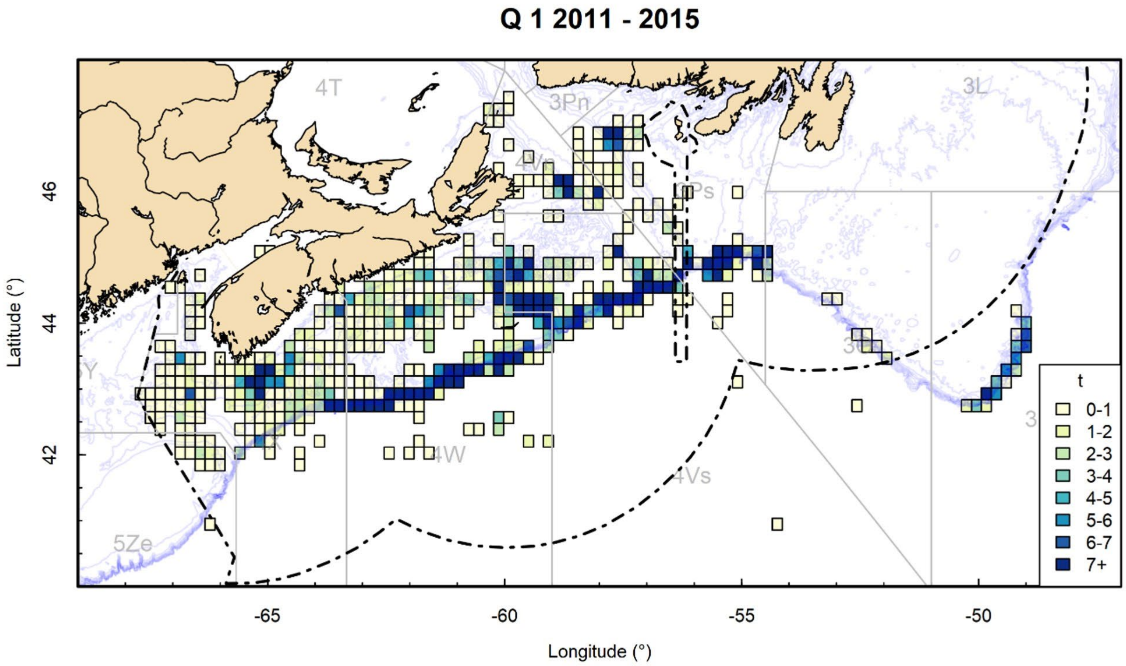


Figure 7d. Distribution of Atlantic Halibut catch, by 20 km grid cells, from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region landing data for quarter 3 (July–September; top) and quarter 4 (October–December; bottom) for the period of 2006–2010. The dashed line indicates the Canadian exclusive economic zone.



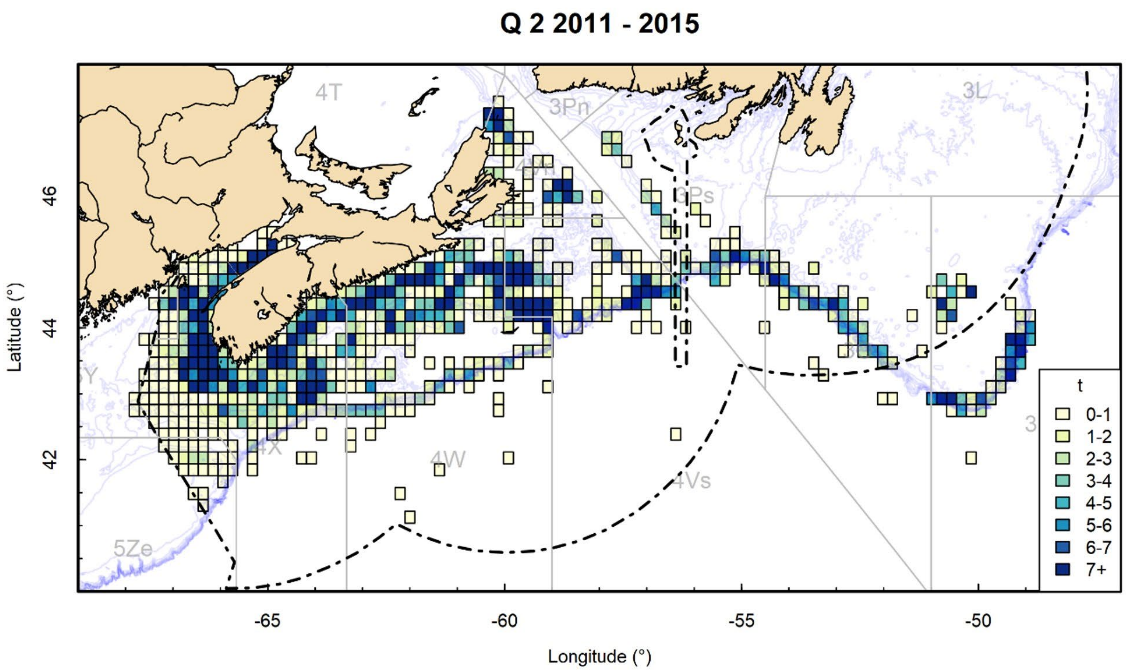


Figure 7e. Distribution of Atlantic Halibut catch, by 20 km grid cells, from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region landing data for quarter 1 (January–March; top) and quarter 2 (April–June; bottom) for the period of 2011–2015. The dashed line indicates the Canadian exclusive economic zone.

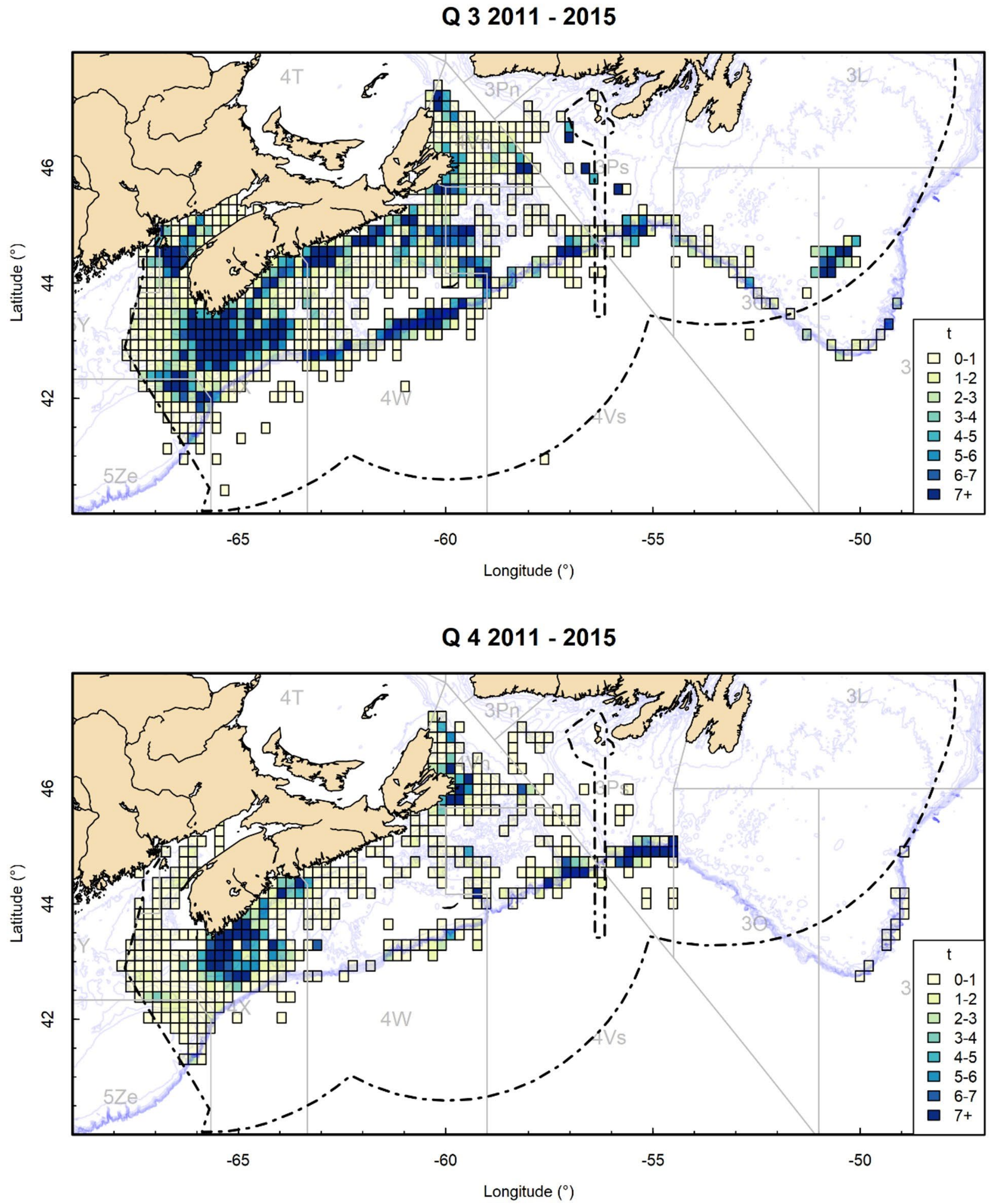


Figure 7f. Distribution of Atlantic Halibut catch, by 20 km grid cells, from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region landing data for quarter 3 (July–September; top) and quarter 4 (October–December; bottom) for the period of 2011–2015.

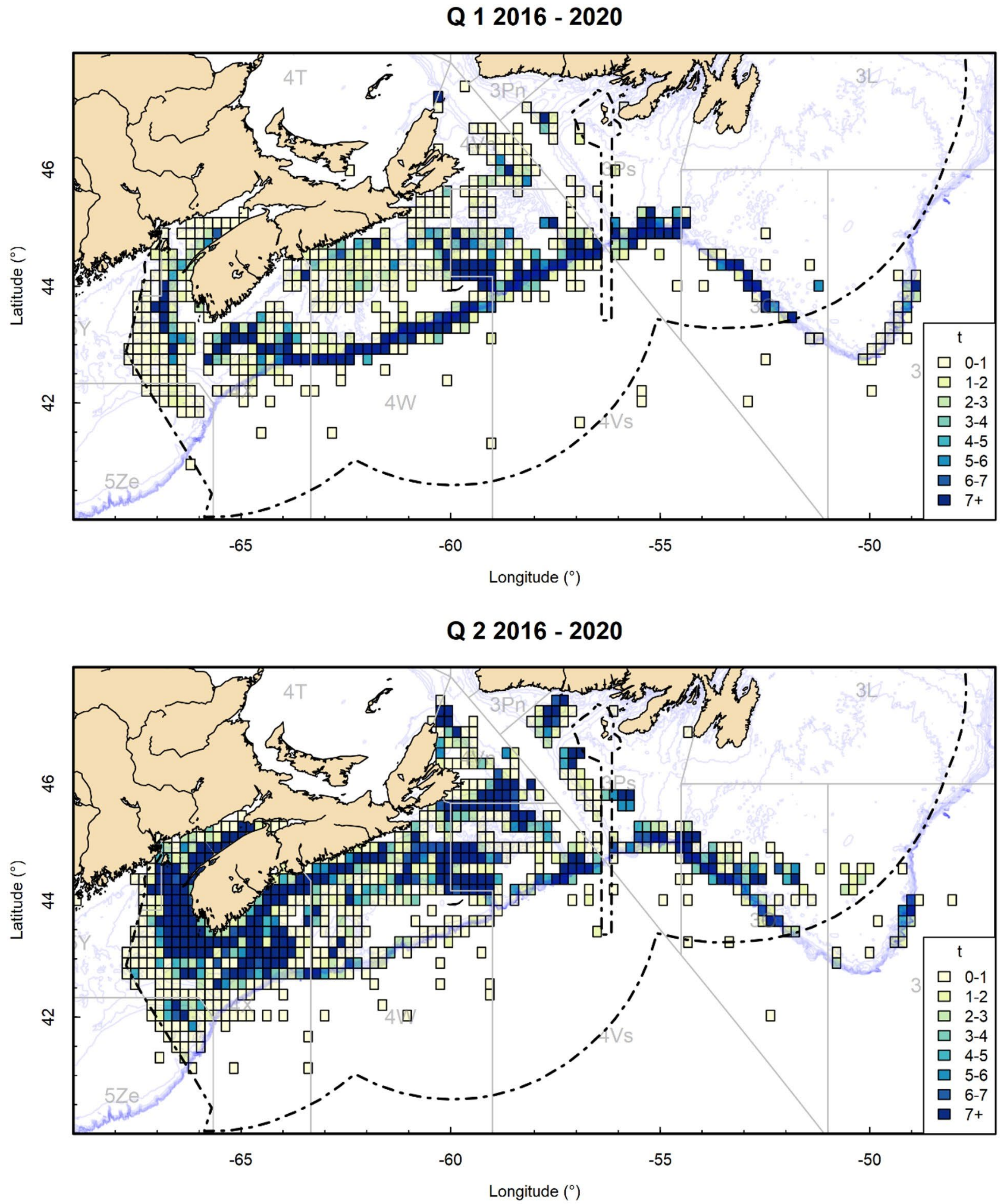
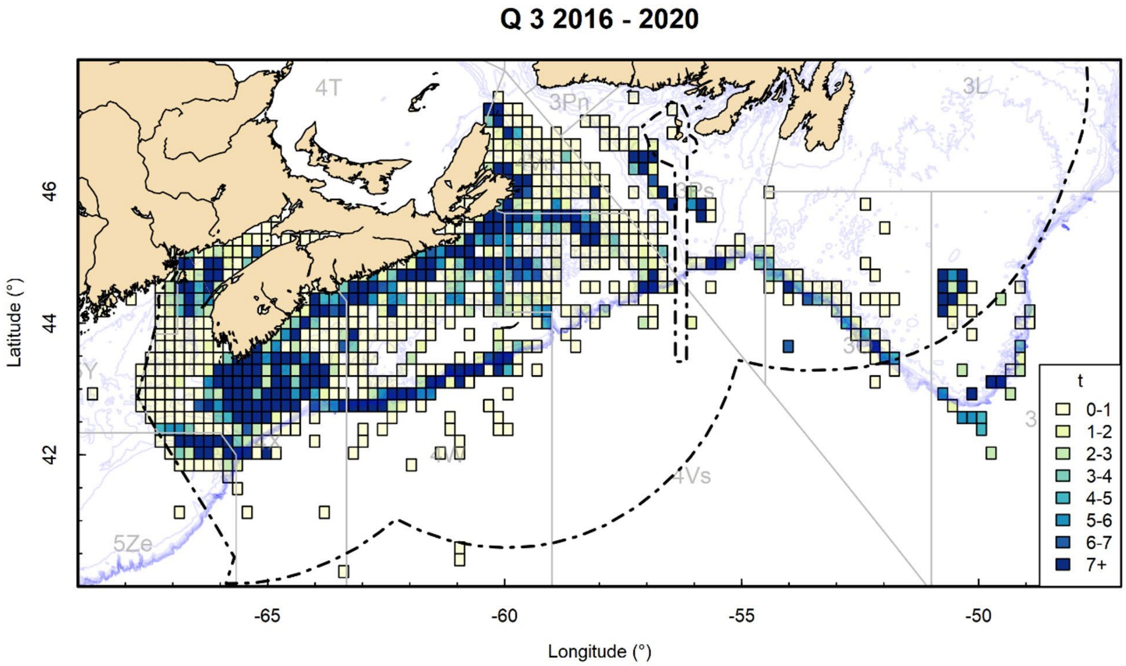


Figure 7g. Distribution of Atlantic Halibut catch, by 20 km grid cells, from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region landing data for quarter 1 (January–March; top) and quarter 2 (April–June; bottom) for the period of 2016–2020. The dashed line indicates the Canadian exclusive economic zone.



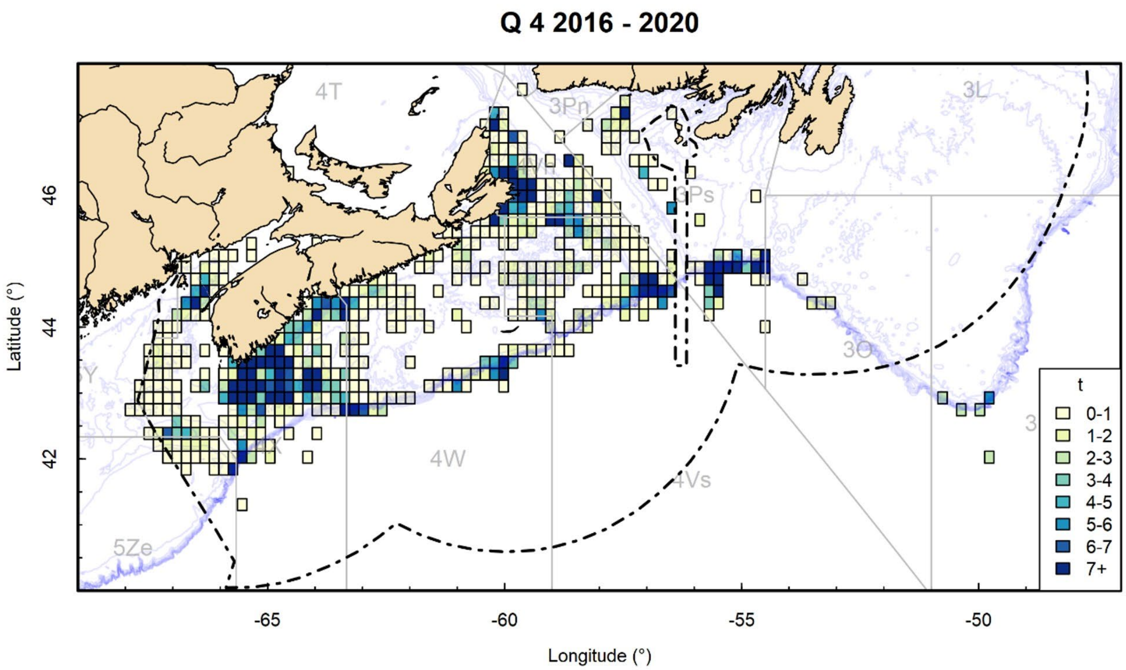


Figure 7h. Distribution of Atlantic Halibut catch, by 20 km grid cells, from the Maritimes Fisheries Information System (MARFIS) and the Newfoundland and Labrador Region landing data for quarter 3 (July–September; top) and quarter 4 (October–December; bottom) for the period of 2016–2020. The dashed line indicates the Canadian exclusive economic zone.

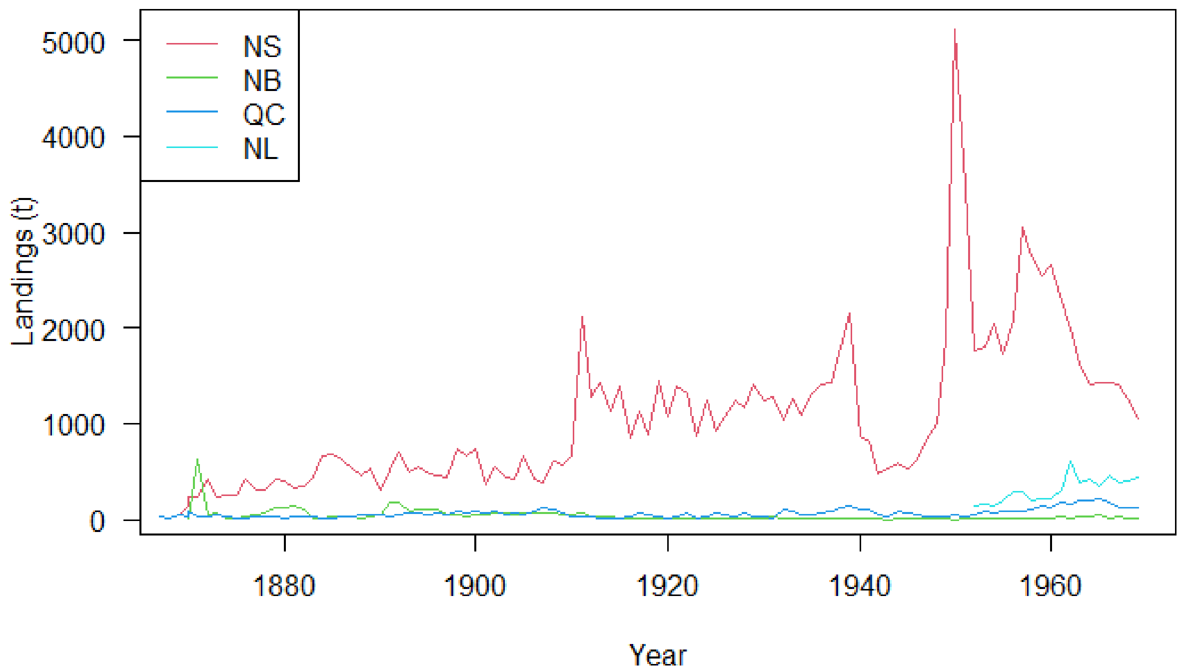


Figure 8. Historical Atlantic Halibut landings in Nova Scotia (NS), New Brunswick (NB), Quebec (QC) and Newfoundland (NL).

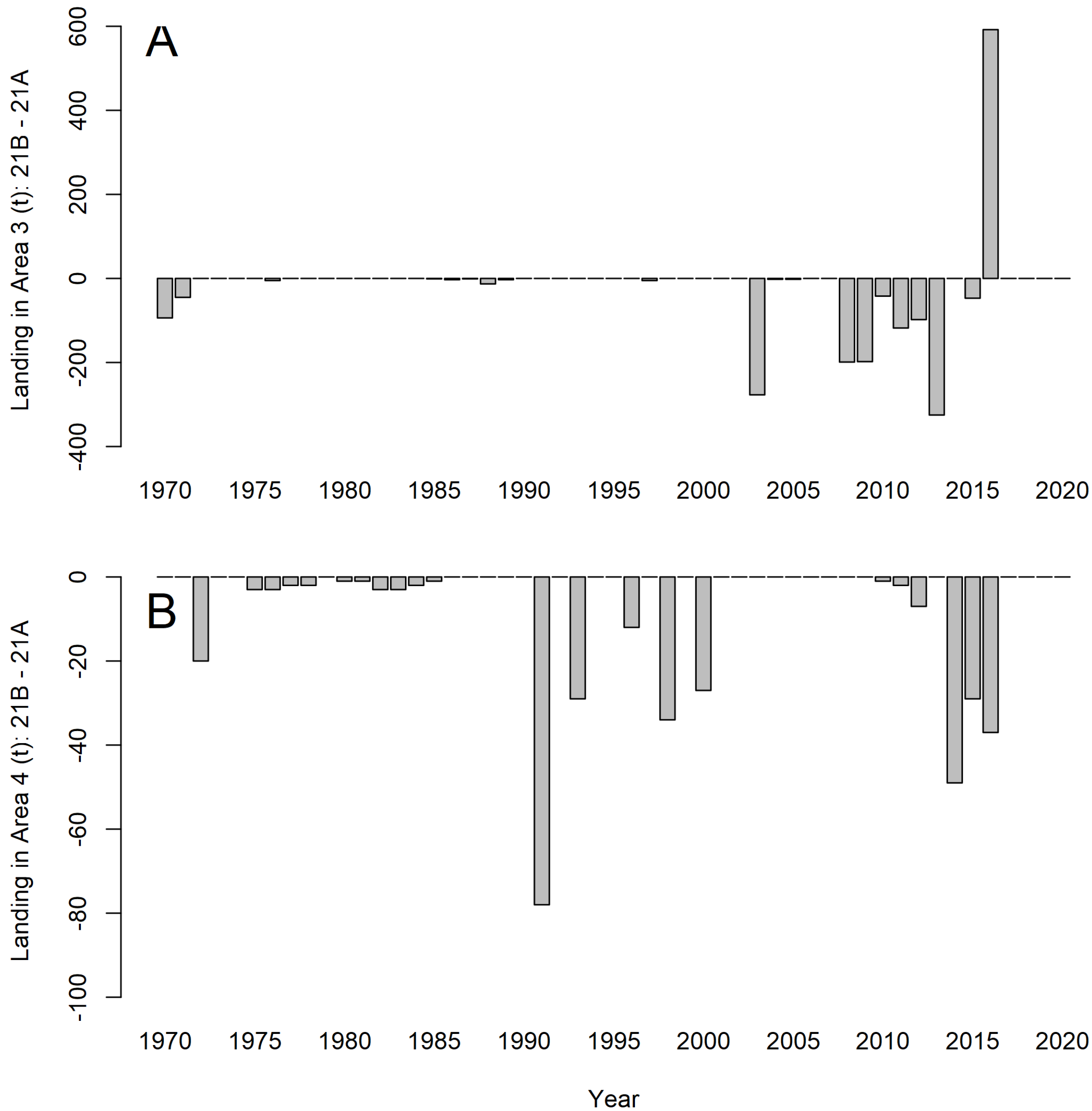


Figure 9. Landing differences (t) for Atlantic Halibut in Subareas 3 (A) and 4 (B) between Northwest Atlantic Fisheries Organization (NAFO) STATLANT 21A and 21B. Both datasets were downloaded from the NAFO website in 2021 (NAFO 2021a,b). Subarea 3 includes NAFO Divisions 3N, 3O, 3Ps and Subarea 4 includes NAFO Divisions 4Vn, 4Vs, 4X, 4W, 5Zc, 5Ze, 5Z, and 5Y.

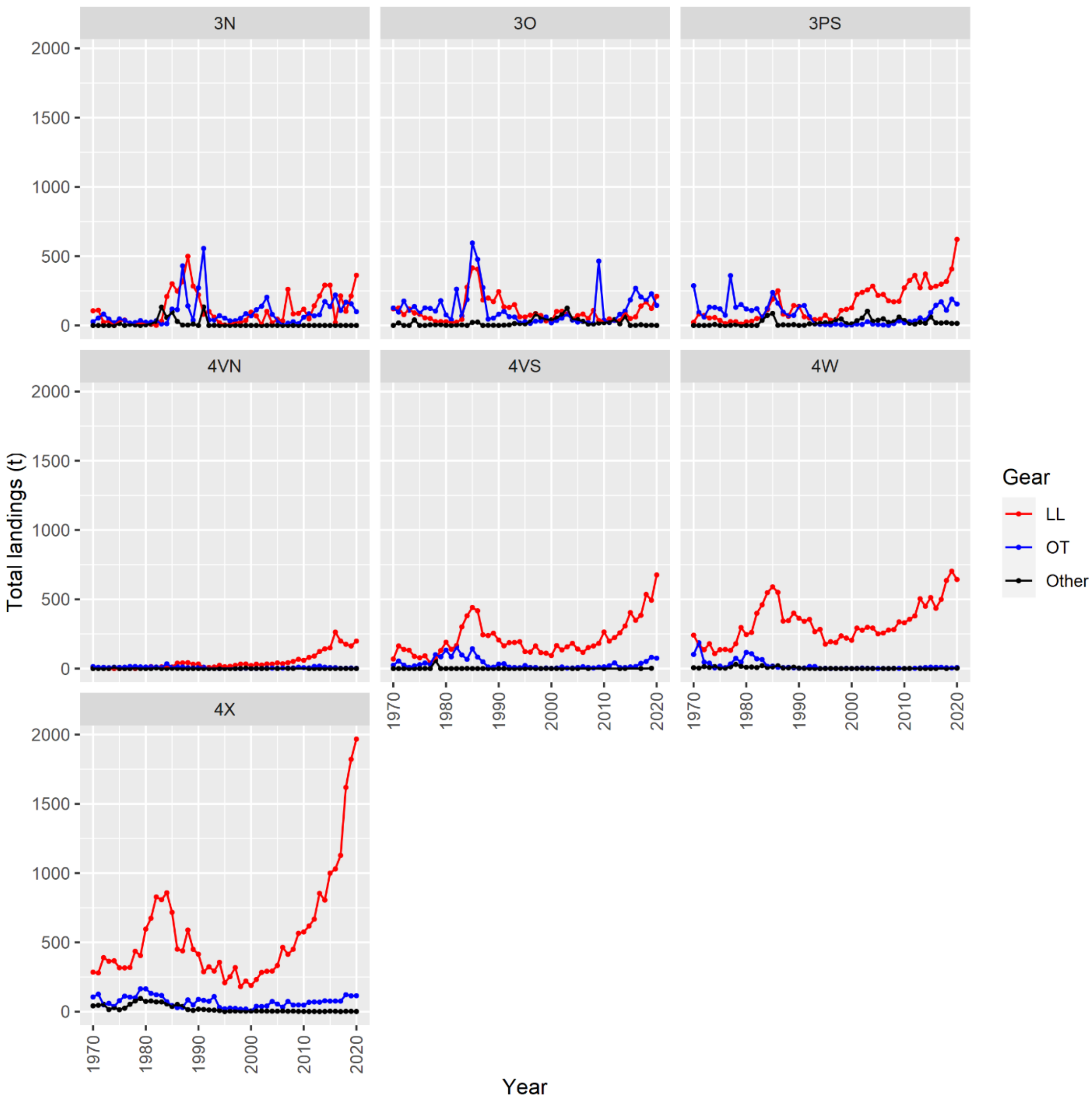


Figure 10. Updated landings from 1970 to 2020 in all countries by otter trawl (OT), longline (LL), and other gears (Other) based on Northwest Atlantic Fisheries Organization (NAFO) STATLANT 21B. Missing data were filled from NAFO STATLANT 21A, the Maritimes Fisheries Information System (MARFIS) and Newfoundland and Labrador Region commercial landings. NAFO divisions 5Zc, 5Ze, 5Z, and 5Y were assigned to 4X and very few 3 Unknown (3NK) were assigned to 3N. OT includes bottom otter trawl, bottom otter trawl (charters), bottom otter trawl (side or stern not specified), and bottom otter trawl (side). LL includes longlines (charters), longlines (not specified), set lines, and drift lines (drifting longlines). The remaining gears were merged into the category "Other".

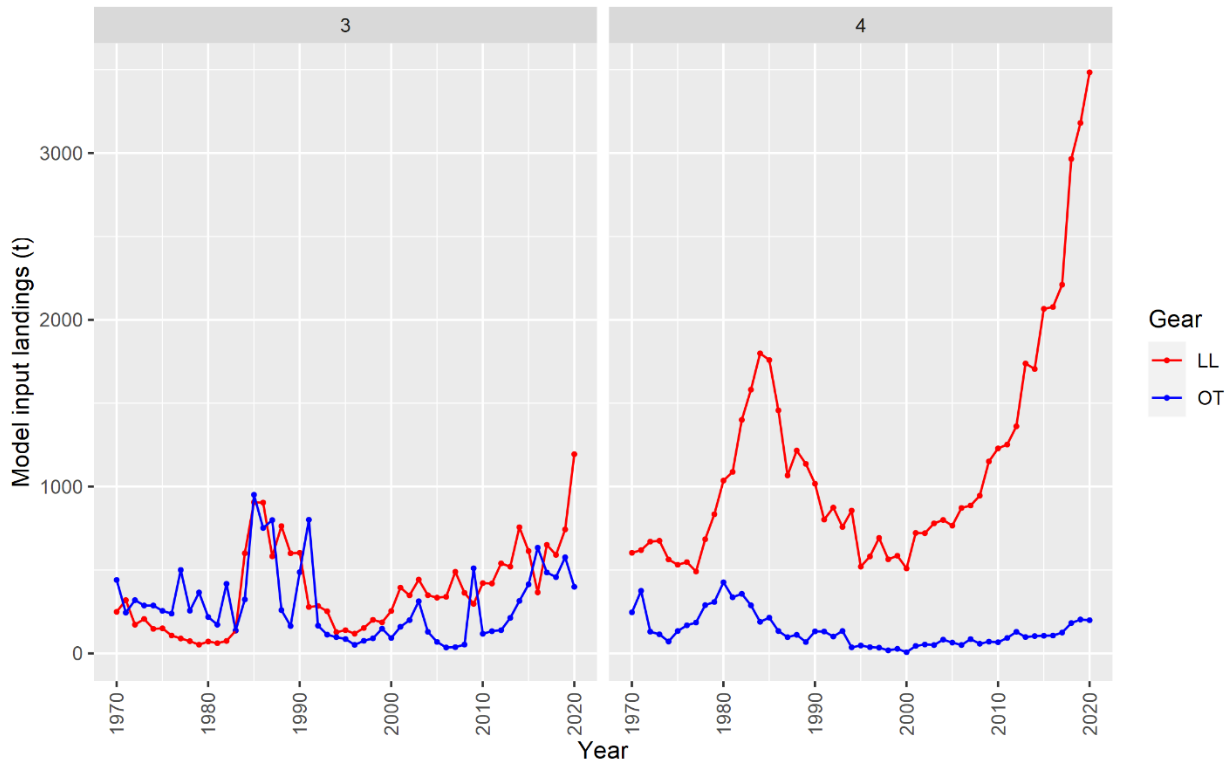


Figure 11. Statistical catch-at-length input data of updated landings (t) for Atlantic Halibut from 1970 to 2020. Subarea 3 includes Northwest Atlantic Fisheries (NAFO) Divisions 3N, 3O, 3Ps and Subarea 4 includes NAFO Divisions 4Vn, 4Vs, 4X, 4W, 5Zc, 5Ze, 5Z, and 5Y. Otter trawl (OT) includes bottom otter trawl, bottom otter trawl (charters), bottom otter trawl (side or stern not specified), and bottom otter trawl (side); longline (LL) includes longlines (charters), longlines (not specified), set lines, and drift lines (drifting longlines). Data from all other gears types were excluded.

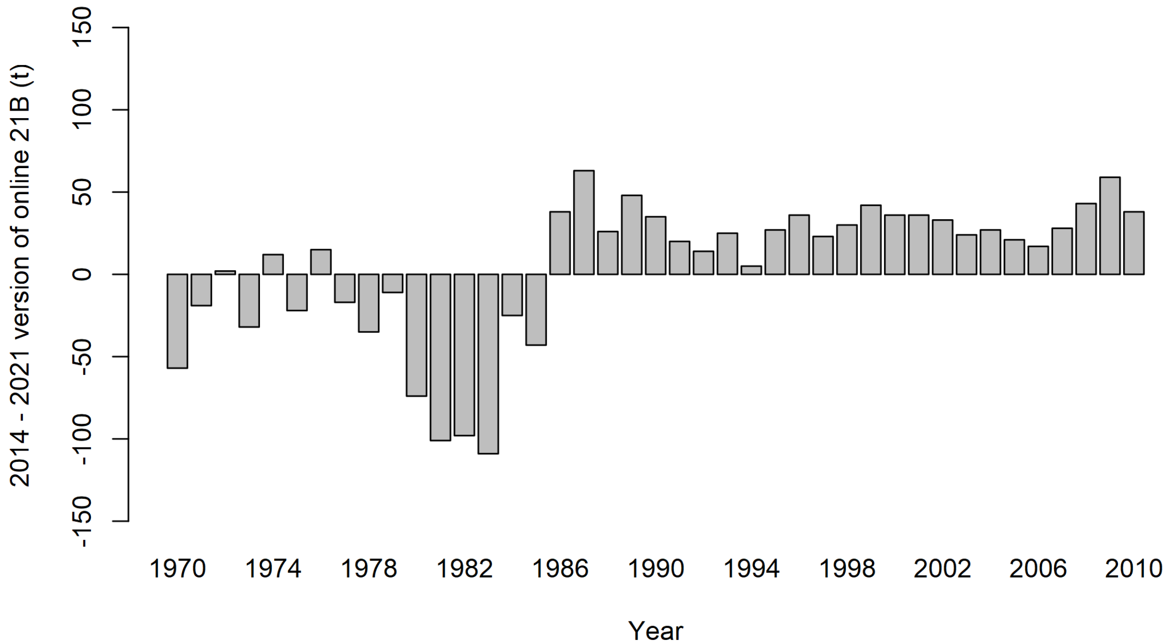


Figure 12. Differences in annual Atlantic Halibut landings (t) in all countries between different versions (downloaded in 2021 vs 2014) of Northwest Atlantic Fisheries Organization (NAFO) online landing data (i.e., NAFO STATLANT 21B; NAFO 2021a).

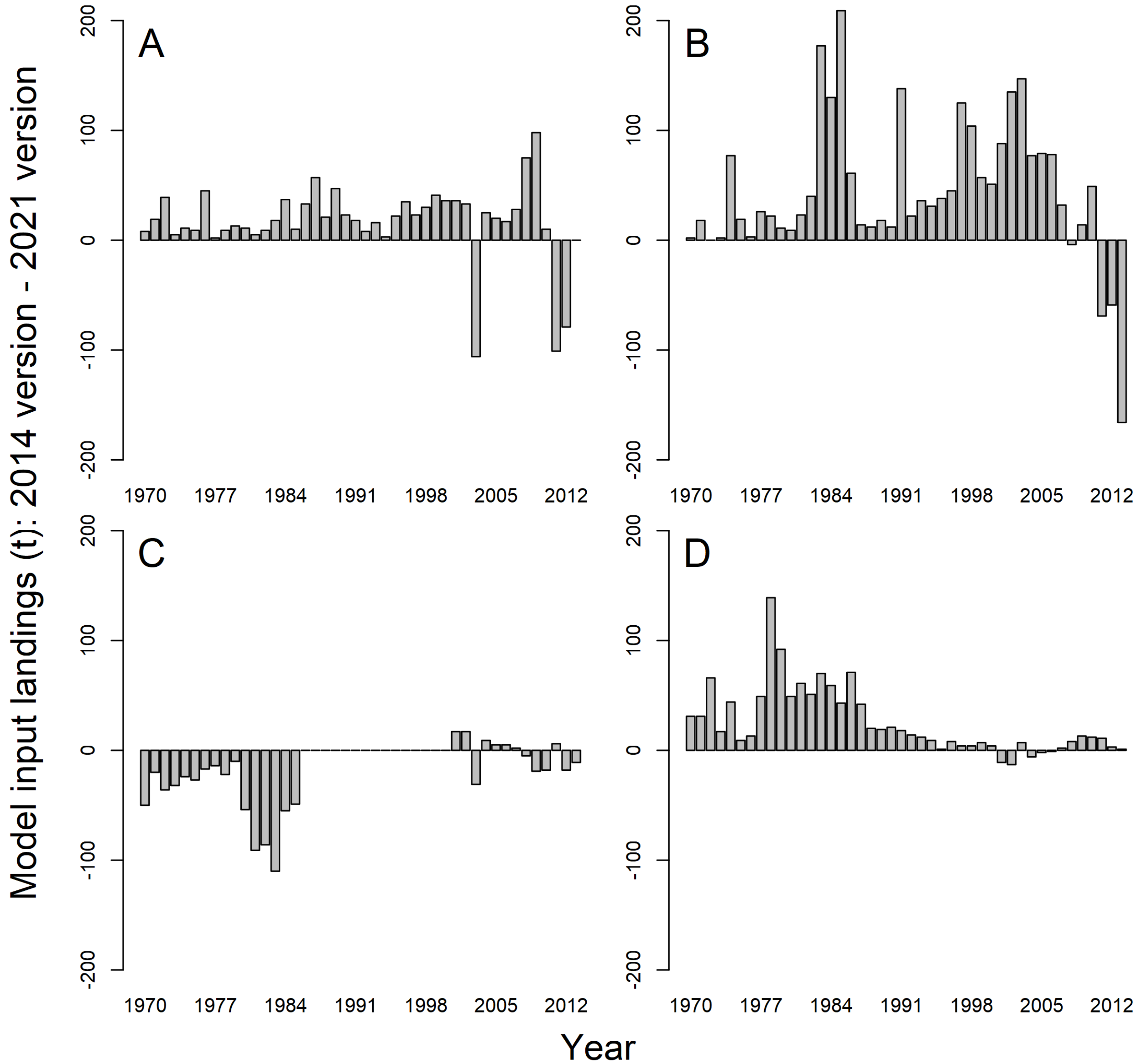
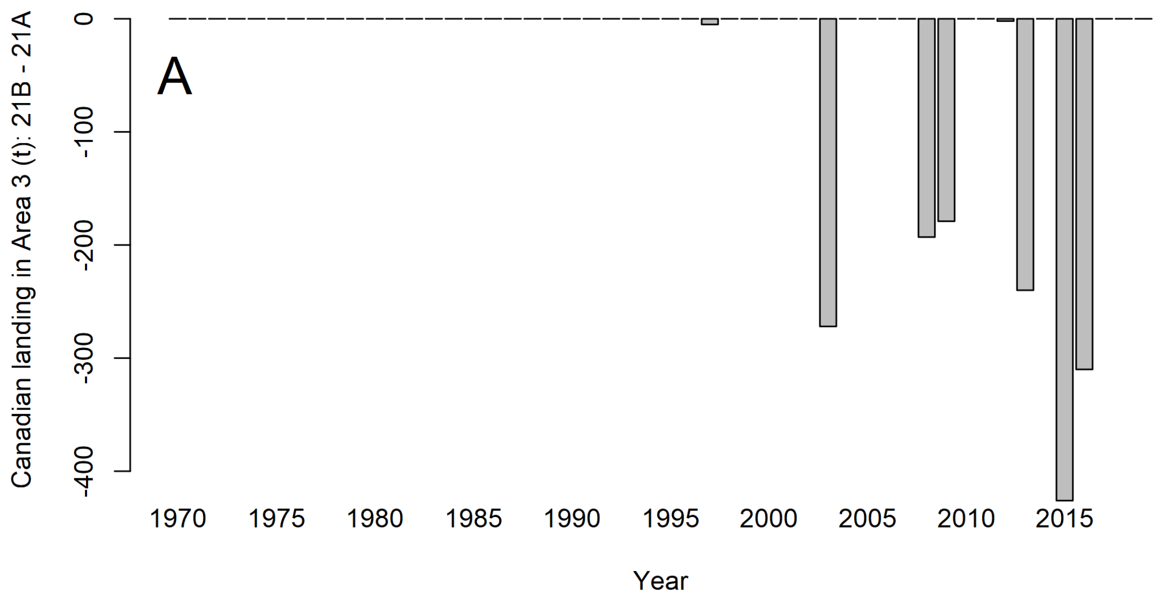


Figure 13. Differences in Atlantic Halibut landings statistical catch-at-length input data between the current assessment framework review (2021) and the previous review (2014). A: longline (LL) in North Atlantic Fisheries Organization (NAFO) Subarea 3; B: otter trawl (OT) in Subarea 3; C: LL in Subarea 4; D: OT in Subarea 4. Both datasets are based on NAFO STATLANT 21B (NAFO 2021a). No changes were made to the 2021 version of NAFO STATLANT 21B data.



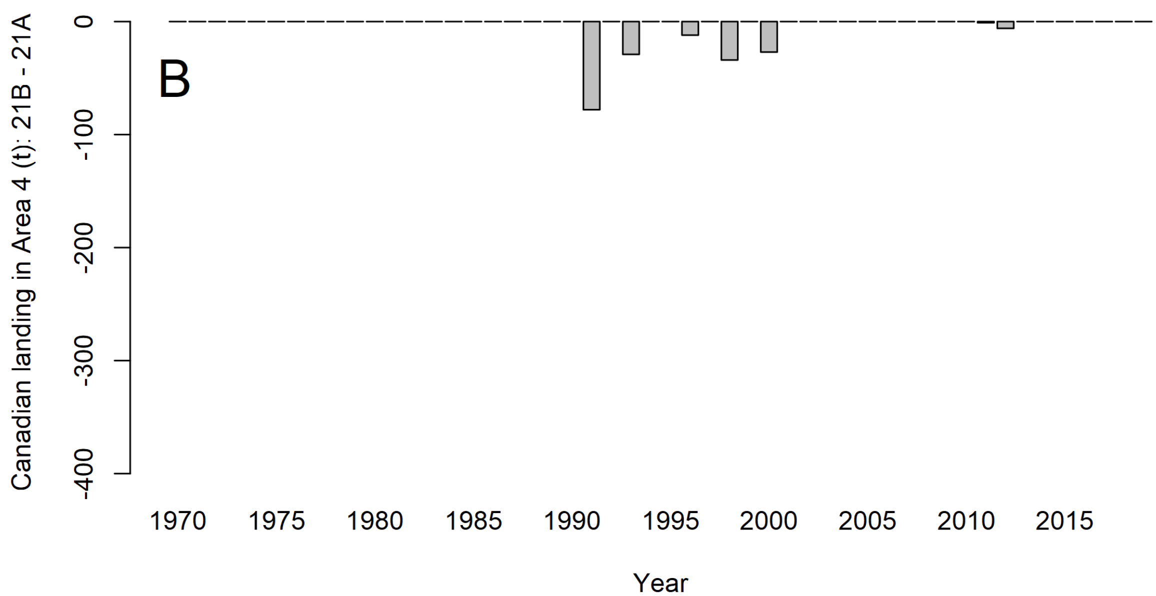


Figure 14. Differences in Canadian Atlantic Halibut landings (t) in Northwest Atlantic Fisheries Organization (NAFO) Subarea 3 (A) and Subarea 4 (B) between online data from NAFO STATLANT 21A and 21B (NAFO 2021a,b). Subarea 3 includes NAFO divisions 3N, 3O, 3Ps and Subarea 4 includes 4Vn, 4Vs, 4X, 4W, 5Ze, and 5Y.

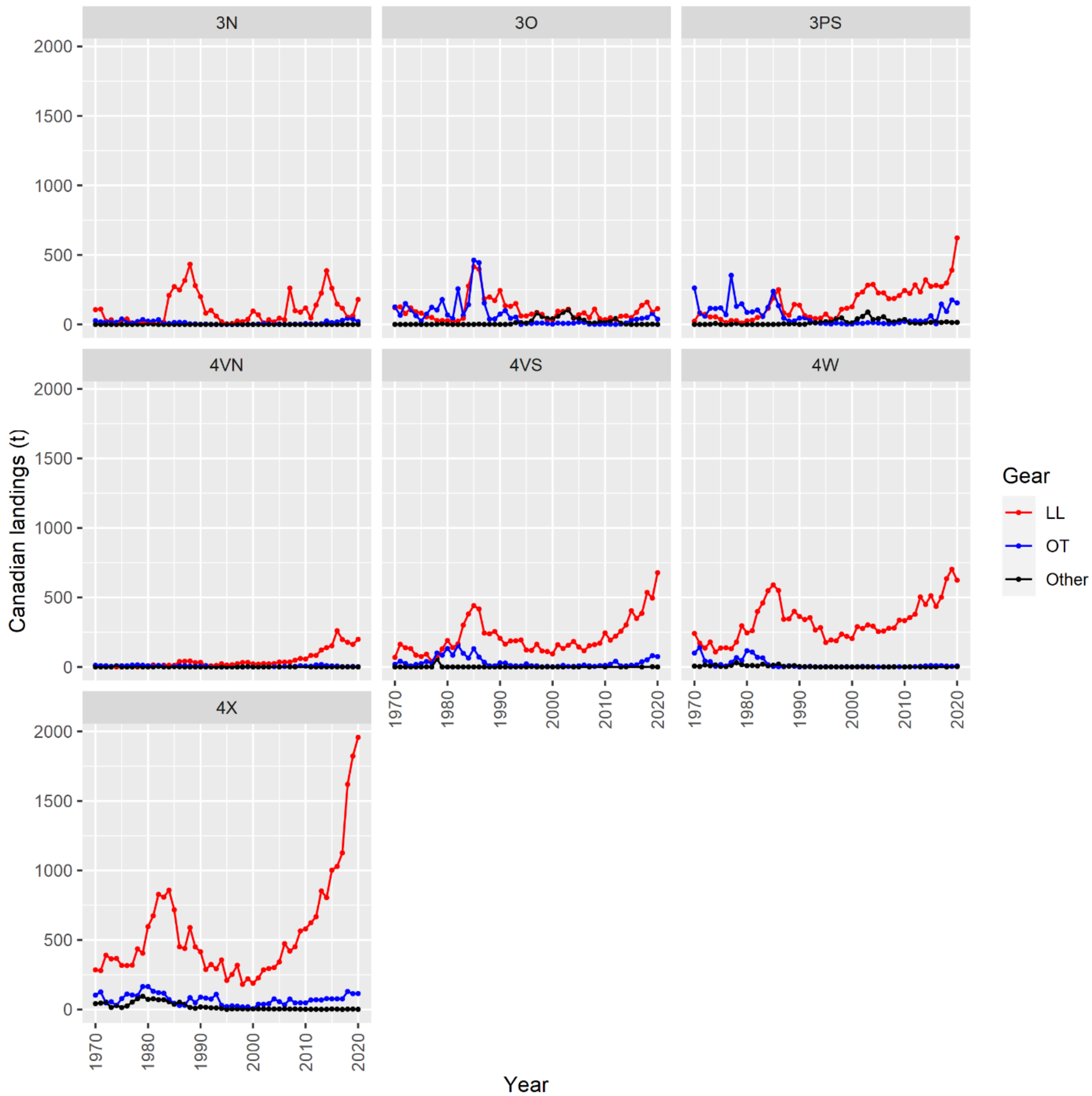


Figure 15. Canadian landings of Atlantic Halibut (1970–2020) by otter trawl (OT), longline (LL), and other gears (Other) based on the Maritimes Fisheries Information System (MARFIS) and Newfoundland and Labrador Region commercial landing data. Northwest Atlantic Fisheries Organization divisions 5Zc, 5Ze, 5Z, and 5Y were assigned to 4X. OT includes otter trawl stern and otter trawl pair; longline is the only gear for LL; the remaining gears were aggregated into the category "Other".

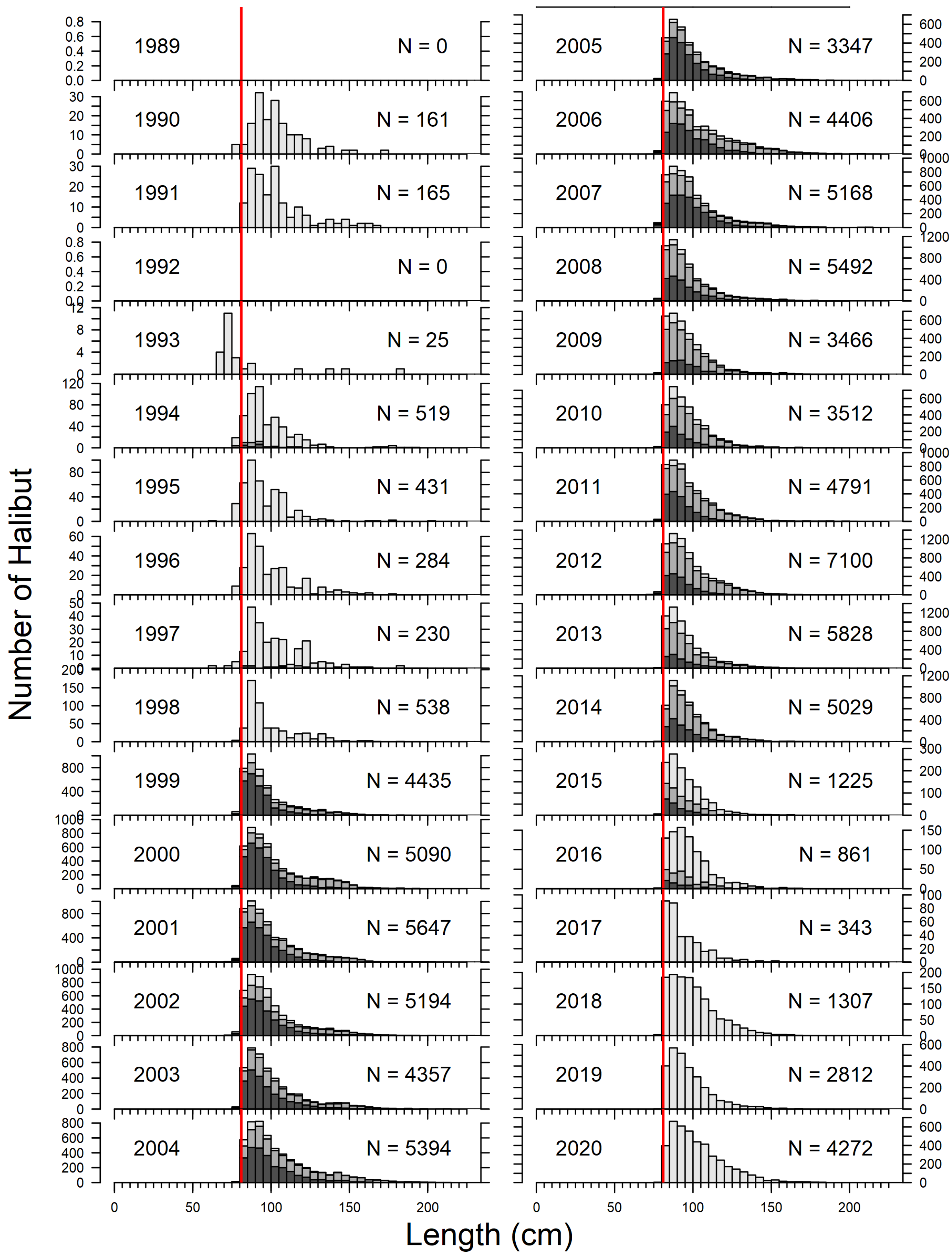


Figure 16. Length frequency samples of Atlantic Halibut from port samples of the longline fishery in Northwest Atlantic Fisheries Organization Subarea 4. Dark grey bars represent male Atlantic Halibut, medium grey indicates females and light grey are unsexed. The vertical red lines represent the legal size of Atlantic Halibut (81 cm).

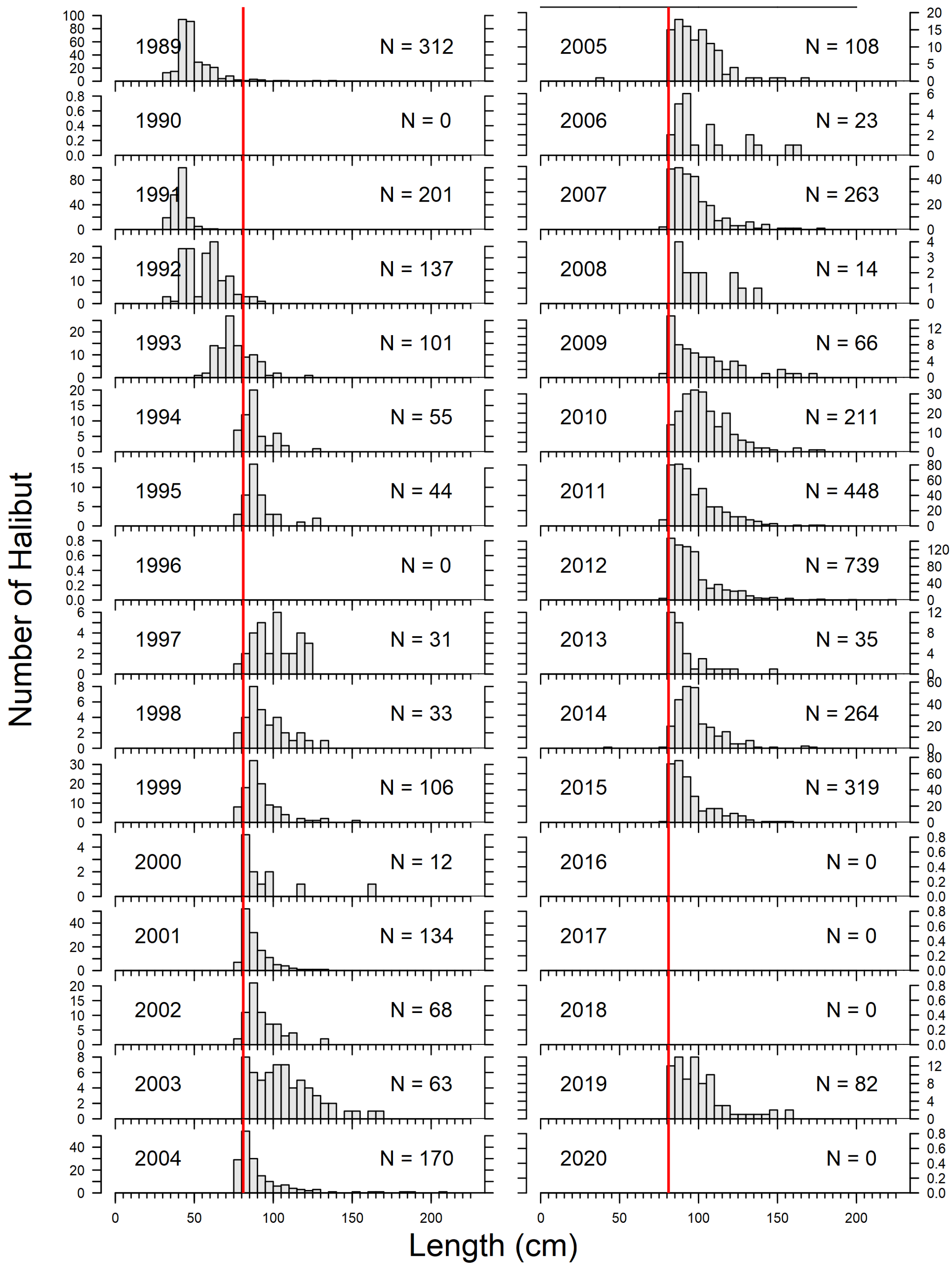


Figure 17. Length samples of Atlantic Halibut from port samples of the otter trawl fishery in the Northwest Atlantic Fisheries Organization Subarea 4. Dark grey bars represent male Atlantic Halibut, medium grey indicates females and light grey are unsexed. The vertical red lines represent the legal size of Atlantic Halibut (81 cm).

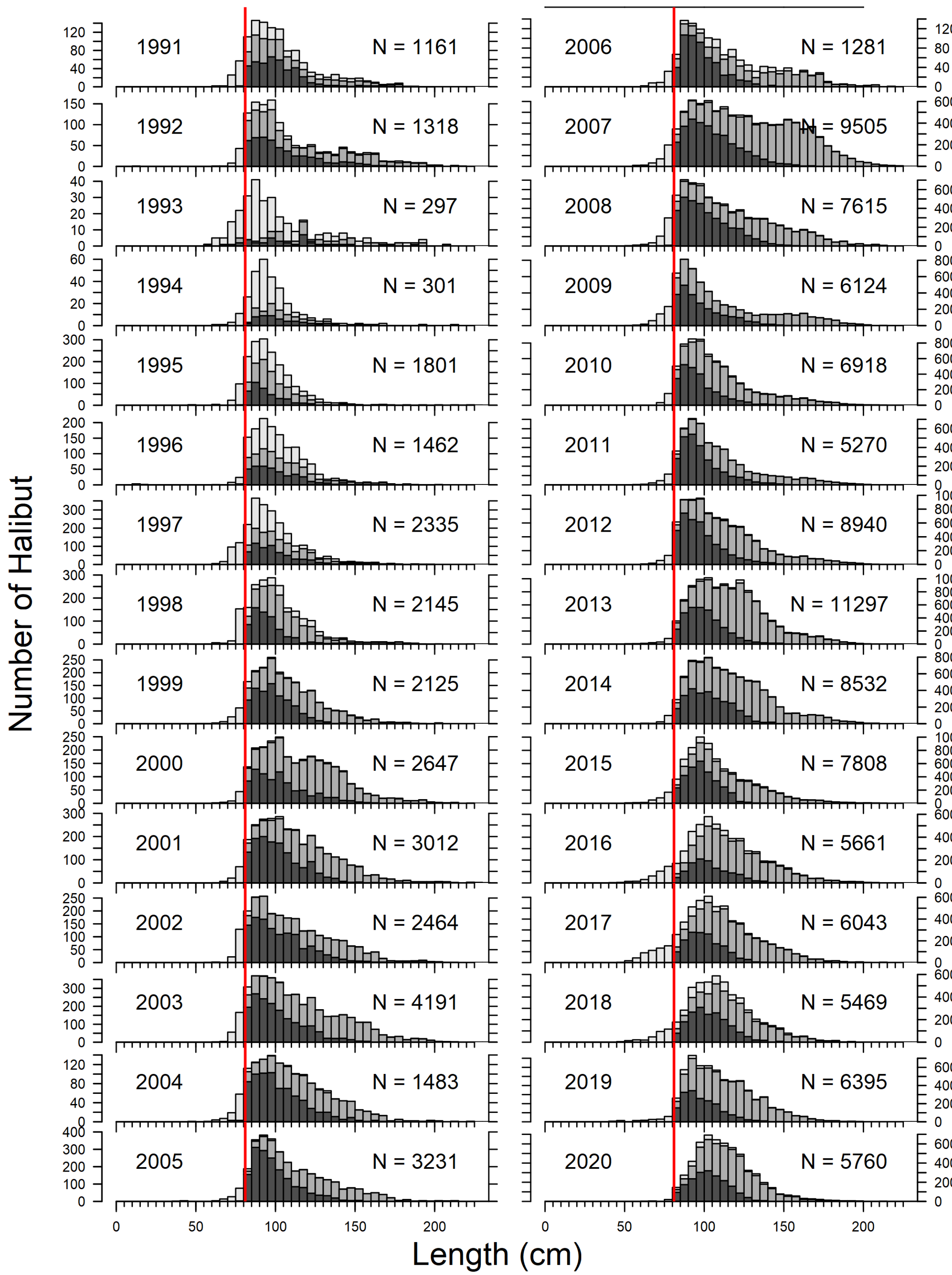


Figure 18. Length samples of Atlantic Halibut from at-sea observers of the longline fishery in Northwest Atlantic Fisheries Organization Subarea 3. Dark grey bars represent male Atlantic Halibut, medium grey indicates females and light grey are unsexed. The vertical red lines represent the legal size of Atlantic Halibut (81 cm).

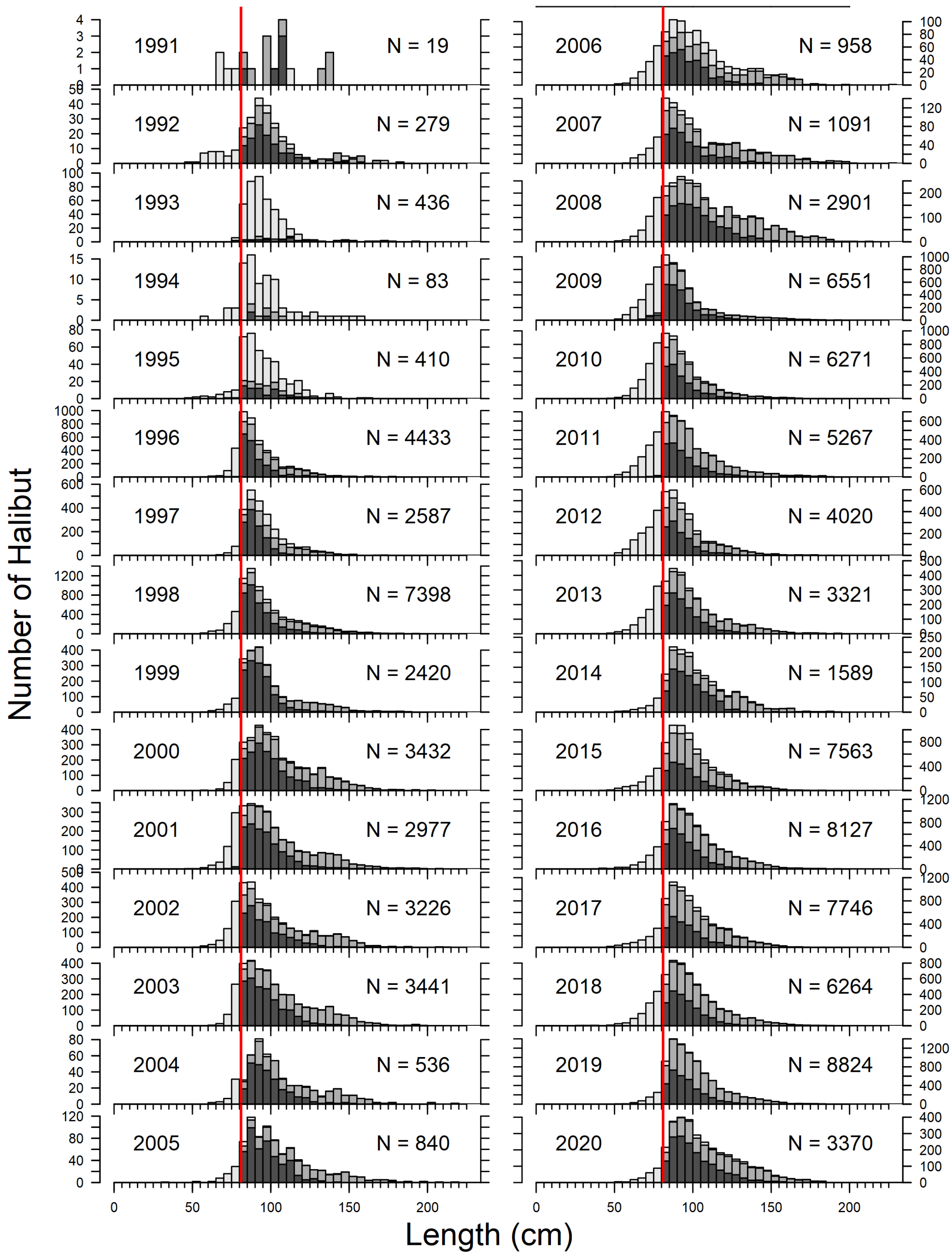


Figure 19. Length samples of Atlantic Halibut from at-sea observers of the longline fishery in Northwest Atlantic Fisheries Organization Subarea 4. Dark grey bars represent male Atlantic Halibut, medium grey indicates females and light grey are unsexed. The vertical red lines represent the legal size of Atlantic Halibut (81 cm).

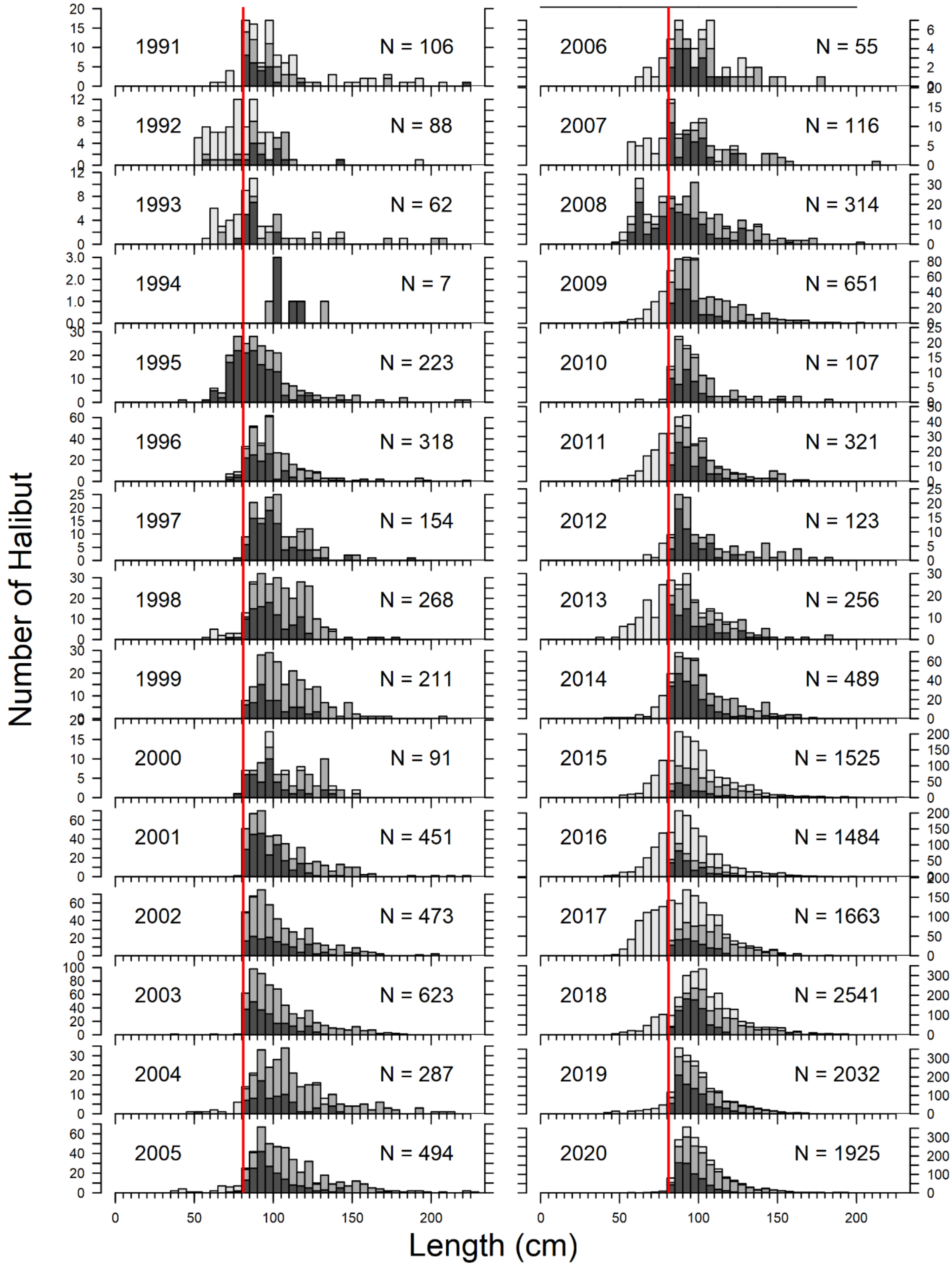


Figure 20. Length samples of Atlantic Halibut from at-sea observers of the otter trawl fishery in Northwest Atlantic Fisheries Organization Subarea 3. Dark grey bars represent male Atlantic Halibut, medium grey indicates females and light grey are unsexed. The vertical red lines represent the legal size of Atlantic Halibut (81 cm).

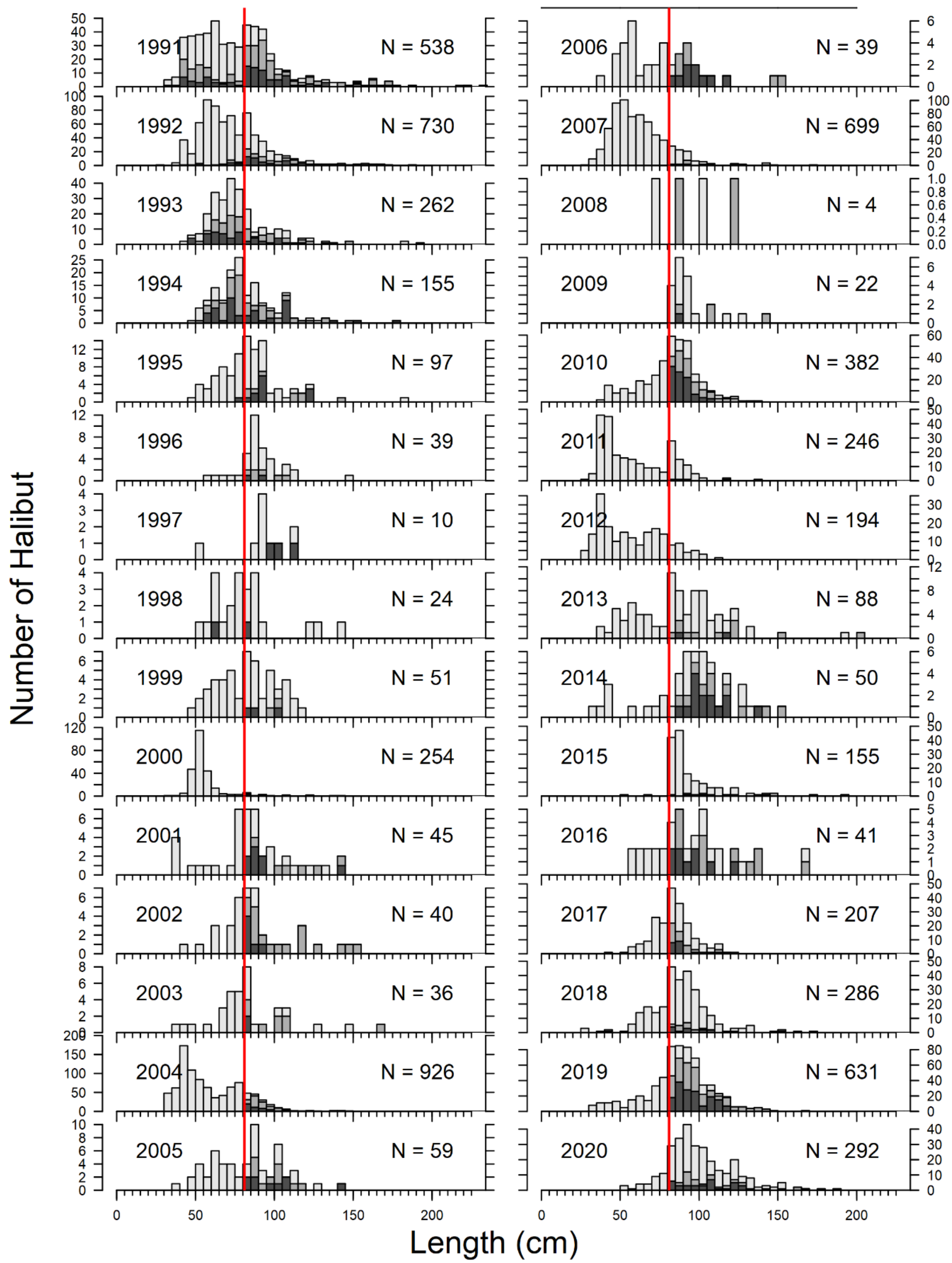


Figure 21. Length samples of Atlantic Halibut from at-sea observers of the otter trawl fishery in Northwest Atlantic Fisheries Organization Subarea 4. Dark grey bars represent male Atlantic Halibut, medium grey indicates females and light grey are unsexed. The vertical red lines represent the legal size of Atlantic Halibut (81 cm).

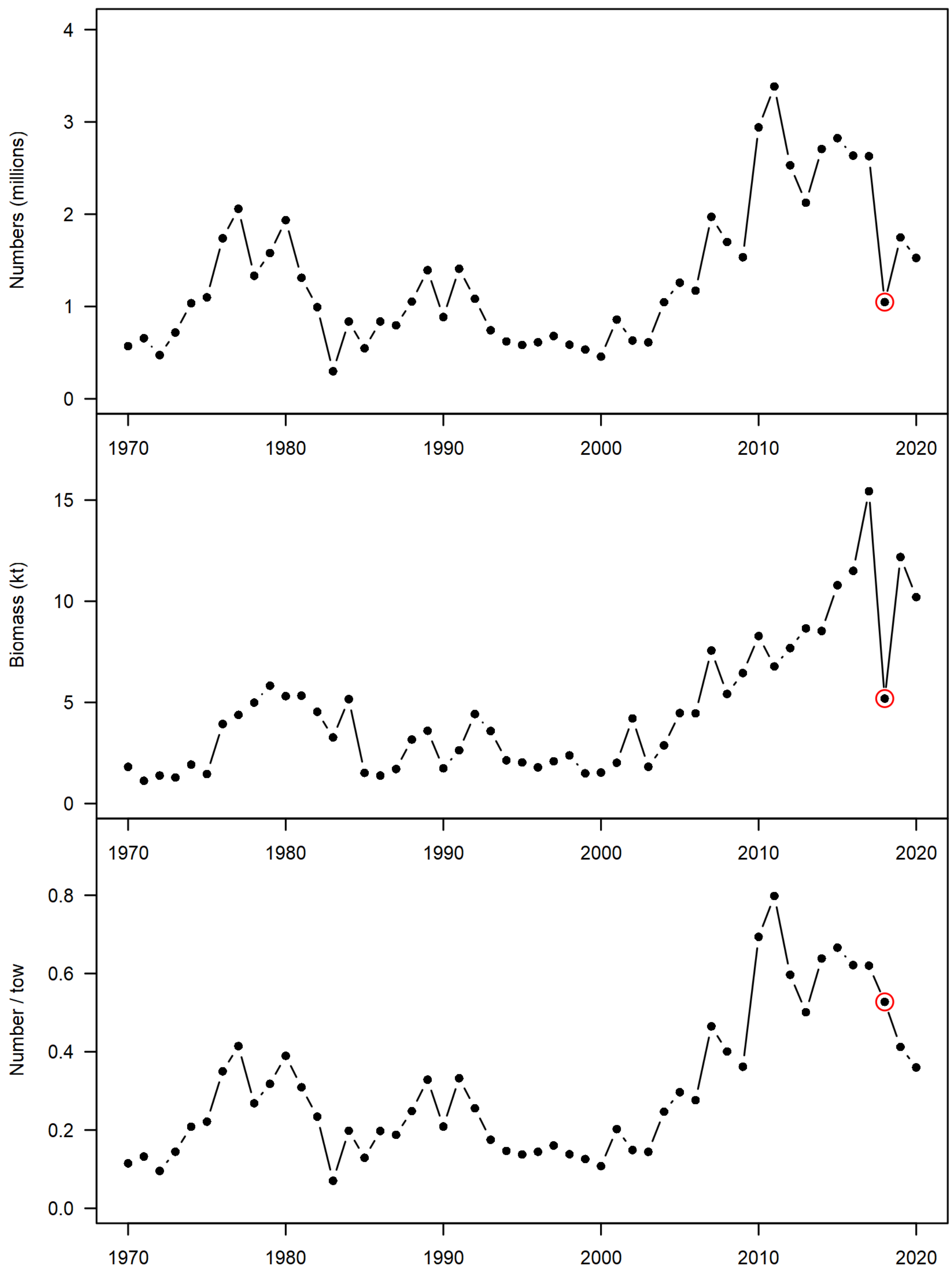


Figure 22. Plot of the extrapolated number of Atlantic Halibut (top), extrapolated biomass (middle) and mean number per tow (bottom) for the Maritimes Summer Ecosystem Research Vessel Survey sets in Northwest Atlantic Fisheries Organization (NAFO) Divisions 4VWX from 1970 to 2020. Red circles indicate where the survey only covered 4X in 2018.

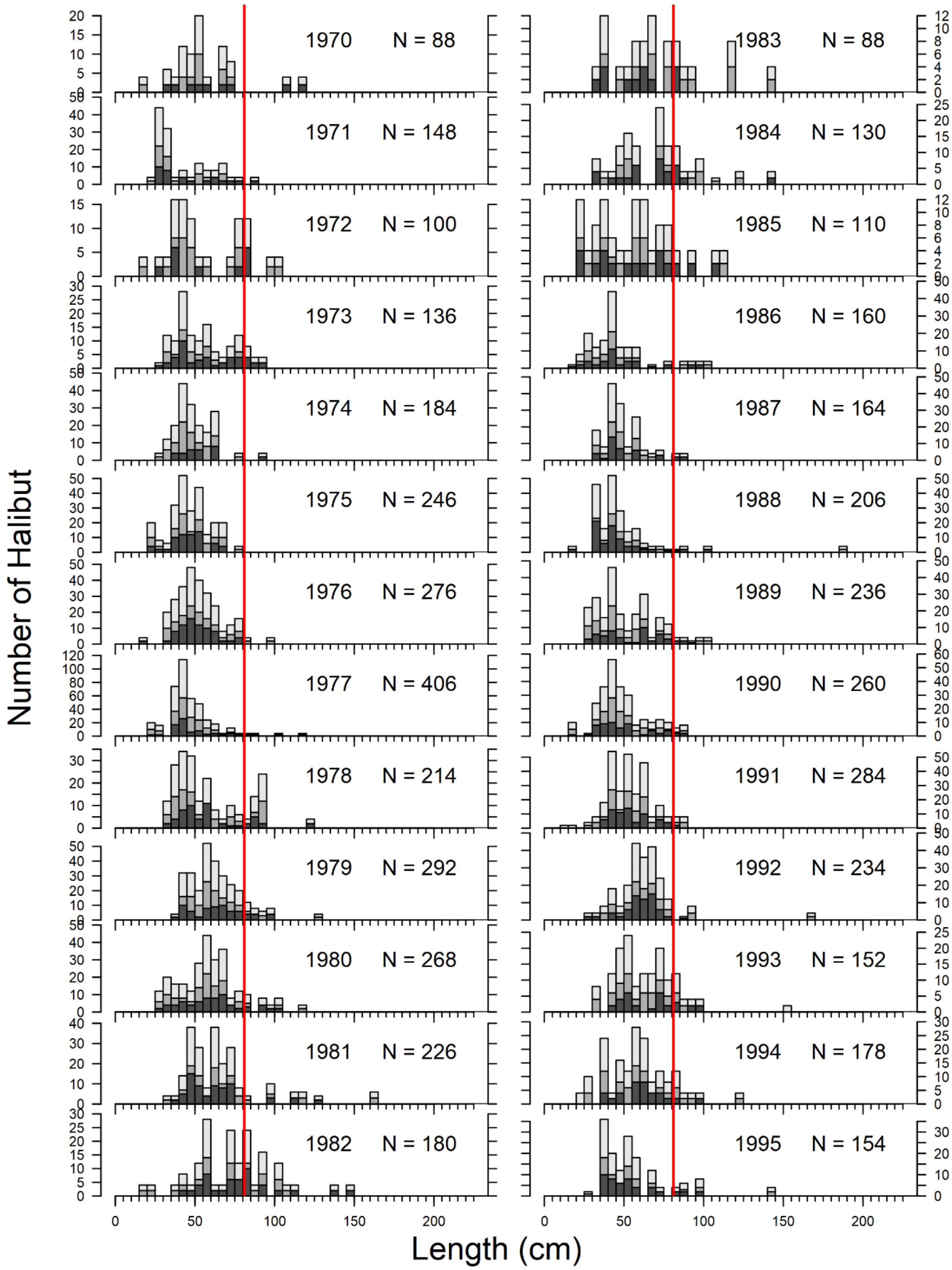


Figure 23a. Length frequency samples at Atlantic Halibut from the Maritimes Summer Ecosystem Research Vessel Surveys for Northwest Atlantic Fisheries Organization Divisions 4VWX, 1970 to 1995. Dark grey bars represent male Atlantic Halibut, medium grey indicates females and light grey are unsexed. The vertical red lines represent the legal size of Atlantic Halibut (81 cm).

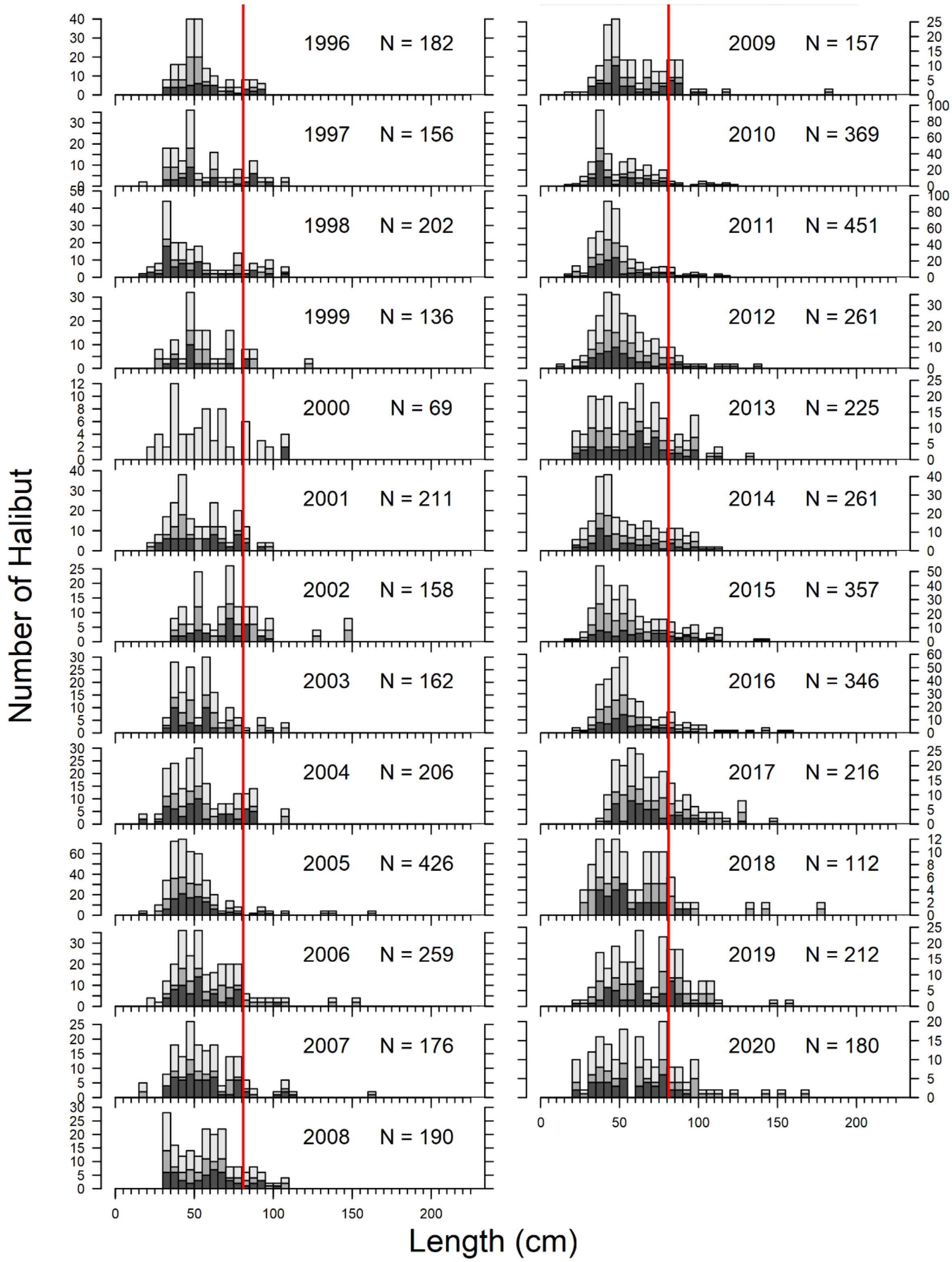


Figure 23b. Length frequency samples at Atlantic Halibut from the Maritimes Summer Ecosystem Research Vessel Surveys for Northwest Atlantic Fisheries Organization Divisions 4VWX, 1996 to 2020. Dark grey bars represent male Atlantic Halibut, medium grey indicates females and light grey are unsexed. The vertical red lines represent the legal size of Atlantic Halibut (81 cm).

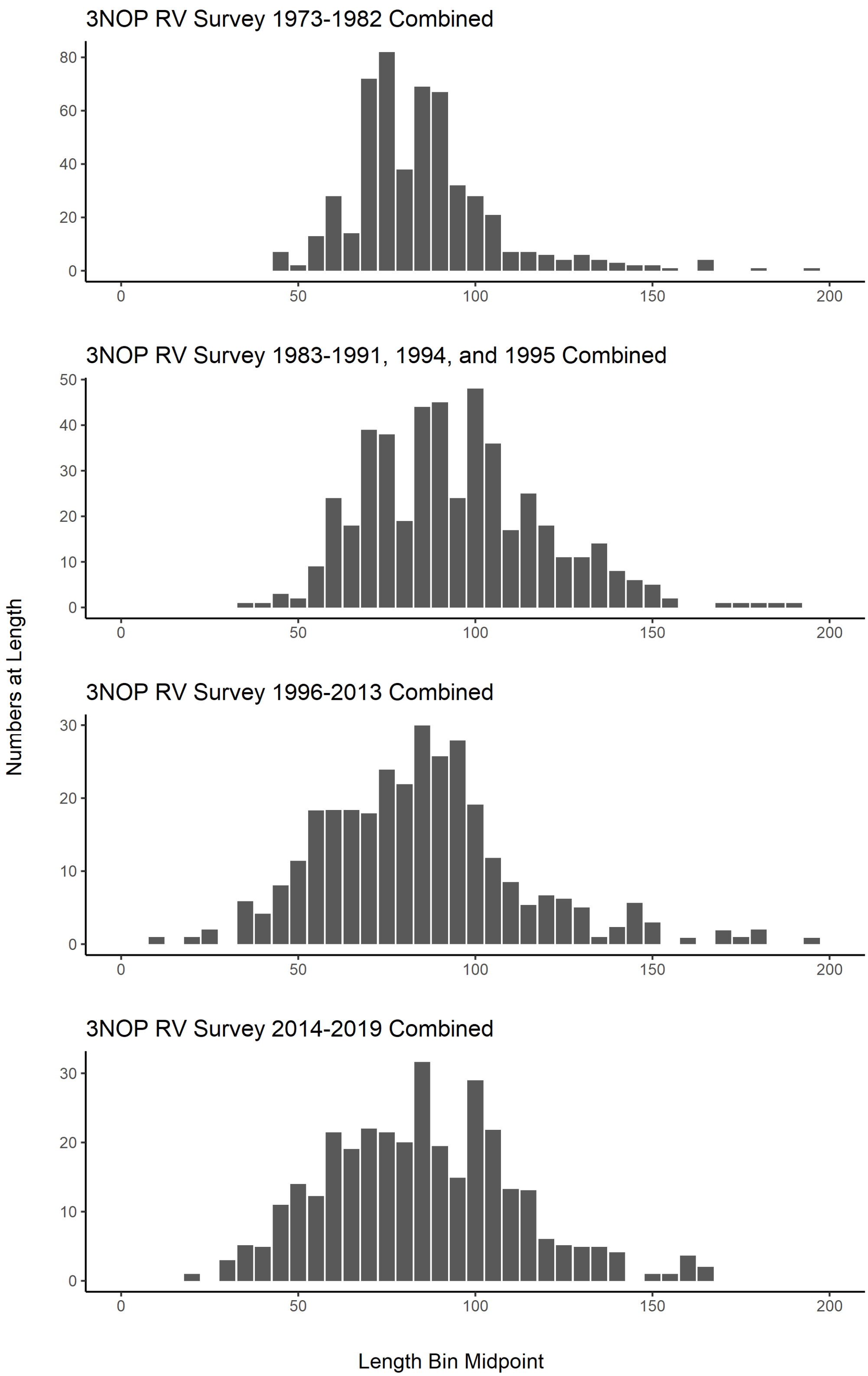


Figure 24. The number of Atlantic Halibut caught during the Newfoundland and Labrador Spring Ecosystem Research Vessel Survey in Northwest Atlantic Fisheries Organization divisions 3NOPs between 1972–1982, 1983–1995, 1996–2013, and 2014–2019 (5 cm length bins).

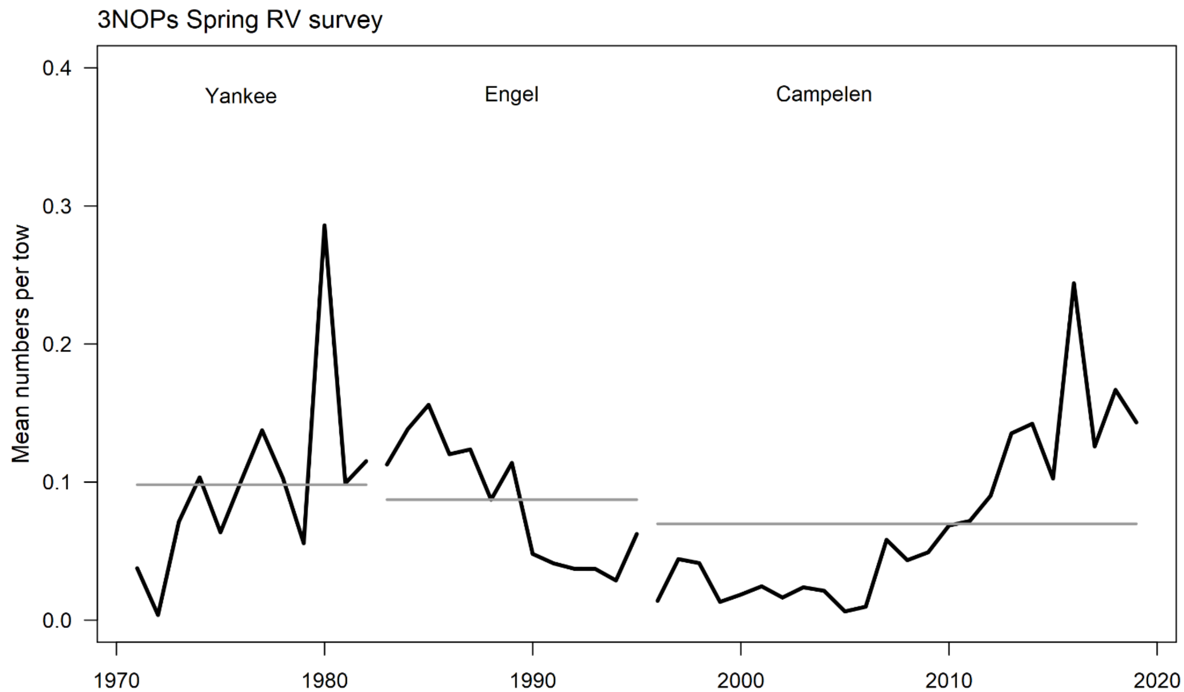


Figure 25. The standardized mean number of Atlantic Halibut per tow for the Newfoundland and Labrador Spring Ecosystem Research Vessel surveys in Northwest Atlantic Fisheries Organization Divisions 3NOPs between 1971 and 2013. The grey horizontal lines represent the means for the Yankee trawl (1971–1982), Engel trawl (1983–1995) and Campelen trawl (1996–2019).

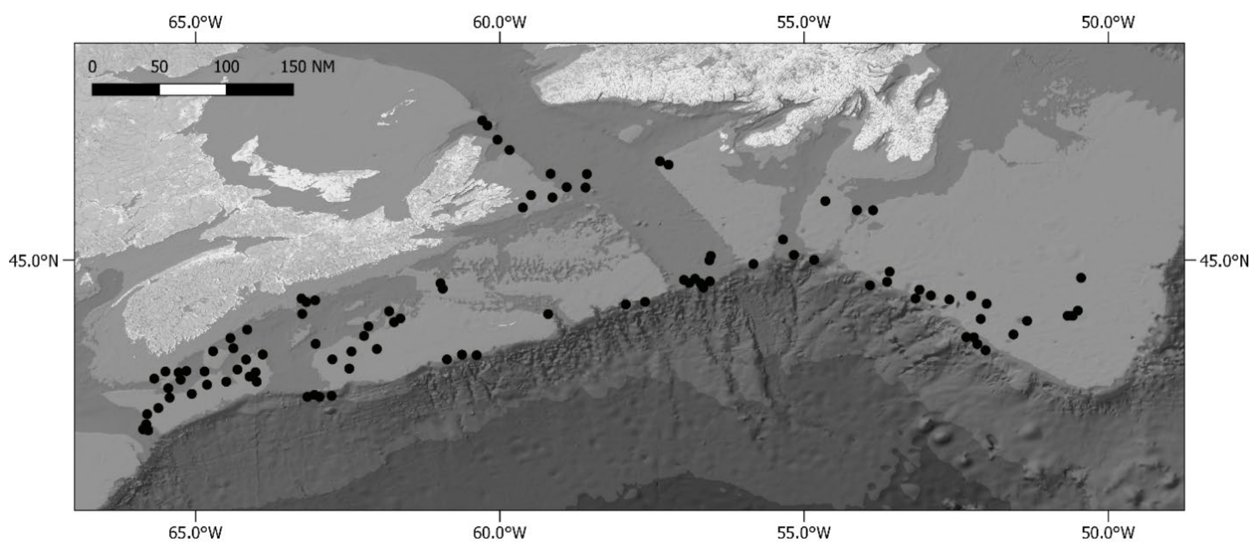


Figure 26. Map of the 100 stations that have been consistently fished throughout the timeframe of the Fixed Station Halibut Survey and continue to be fished alongside the Stratified Random Halibut Survey.

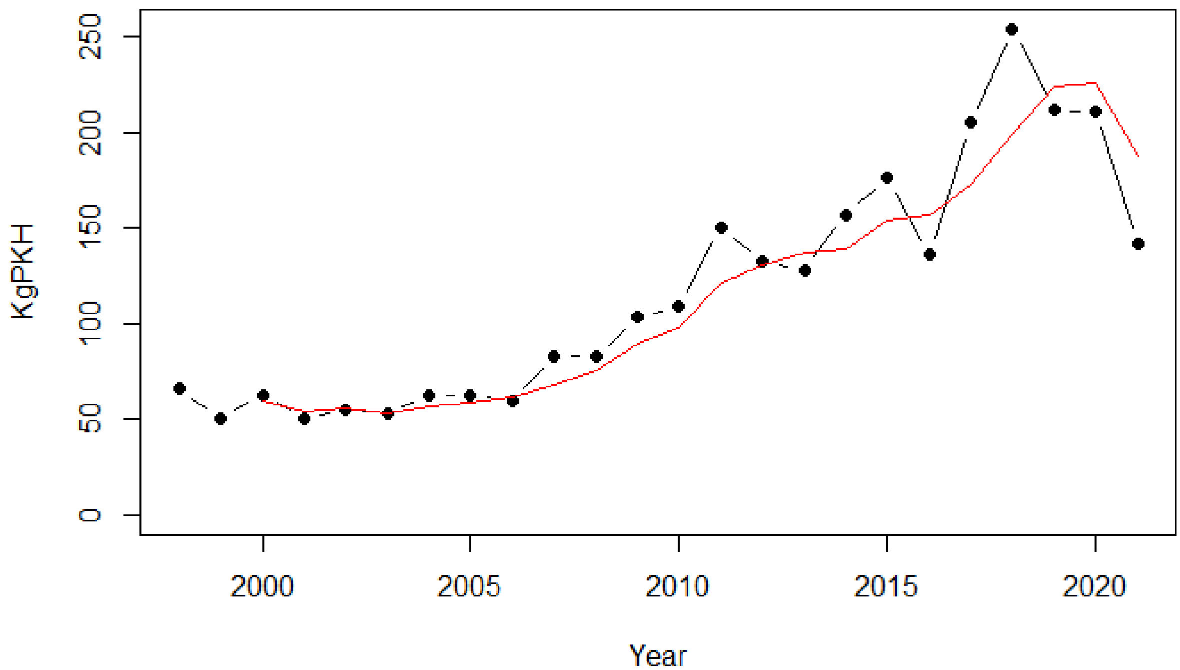


Figure 27. The Fixed Station Halibut Survey index in kg of Atlantic Halibut per 1,000 hooks hauled for the 100 frequently-sampled stations. The red line represents the three-year mean.

Figure 28. Retrospective pattern of the generalized linear model used to standardize the 3NOPs4VWX Halibut survey 100 index stations.

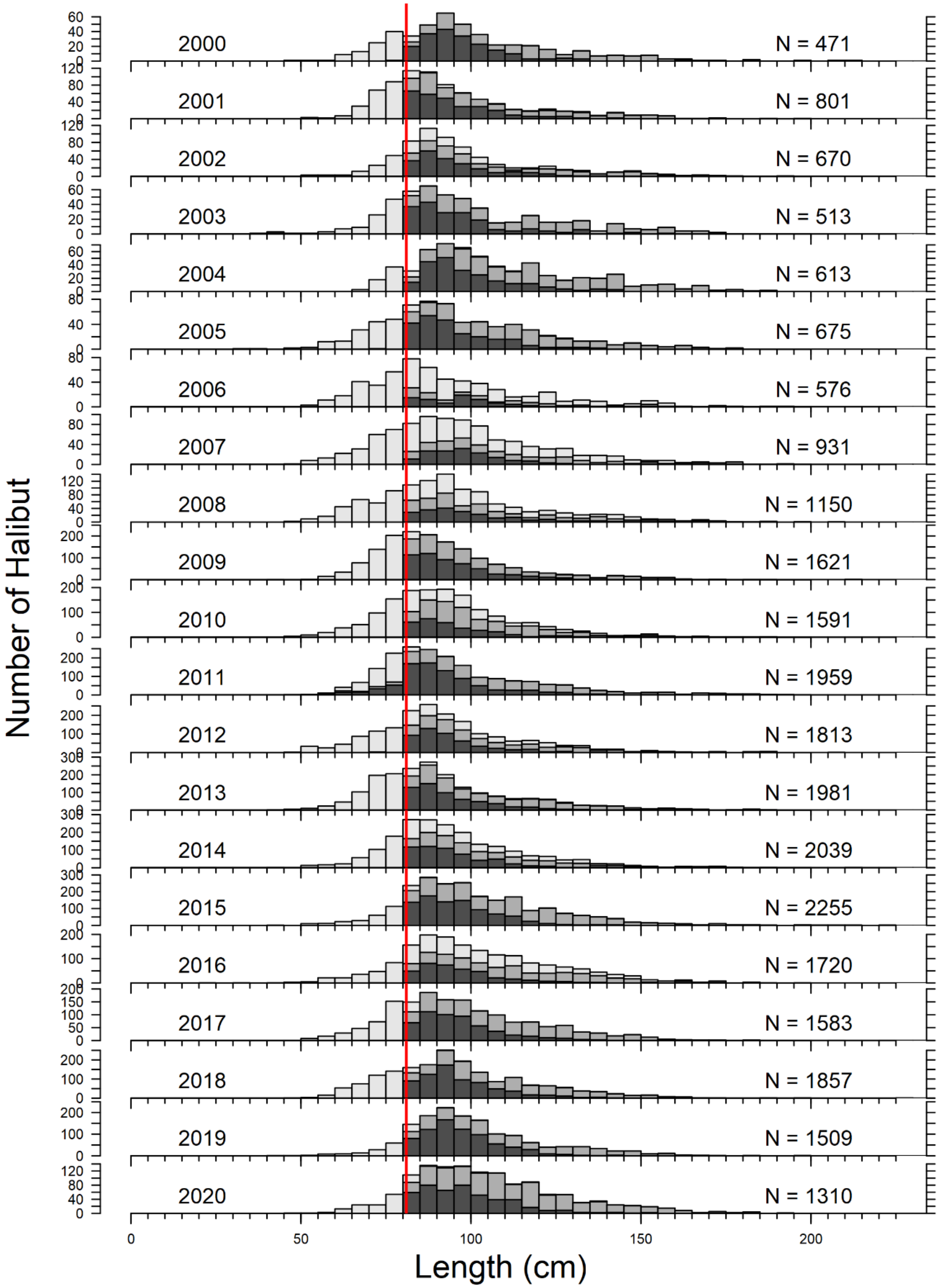


Figure 29. Length (cm) samples of Atlantic Halibut from the Northwest Atlantic Fisheries Organization Divisions 3NOPs4VWX Fixed Station Halibut Survey. Dark grey bars represent male Atlantic Halibut, medium grey indicates females and light grey are unsexed. The vertical red lines represent the legal size of Atlantic Halibut (81 cm).

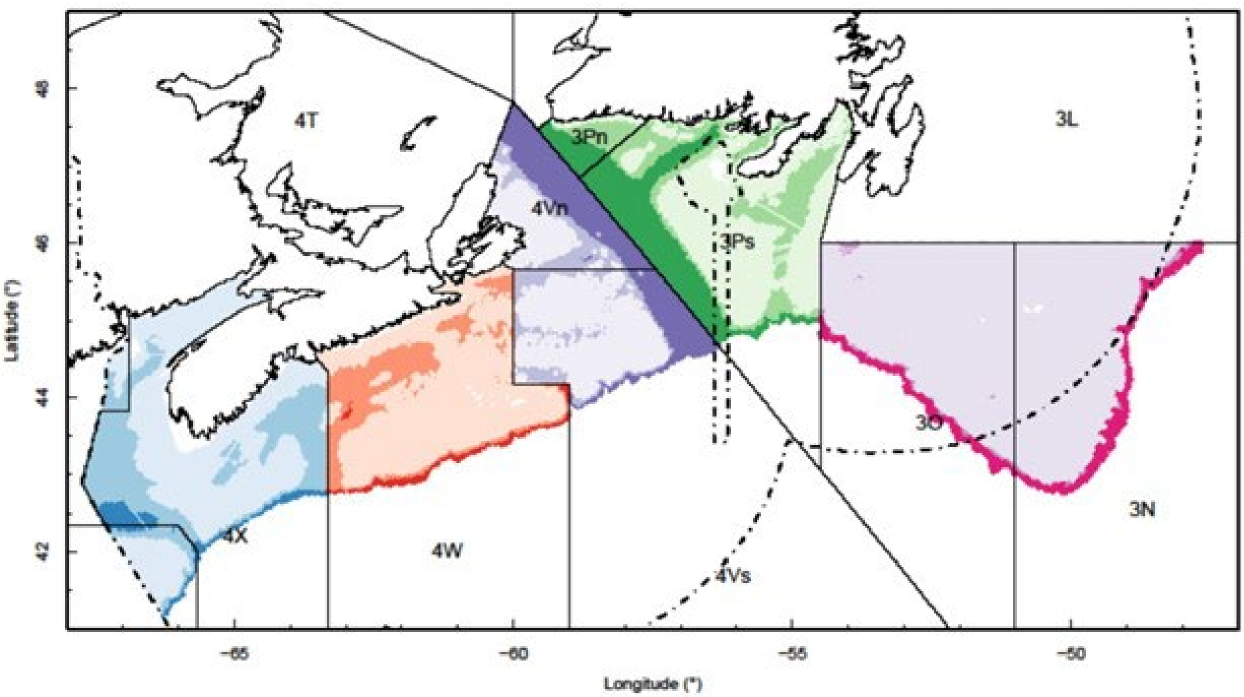


Figure 30. Map of the stratification scheme of the survey area for the Northwest Atlantic Fisheries Organization Divisions 3NOPs4VWX5Zc Atlantic Halibut stock, with survey area strata 4X5YZ (blues), 4W (oranges), 4V (purples), 3P (greens) and 3NO (reds) and three depth strata 30–130 m (light colour), 131–250 m (medium colour), 251–750 m (dark colour).

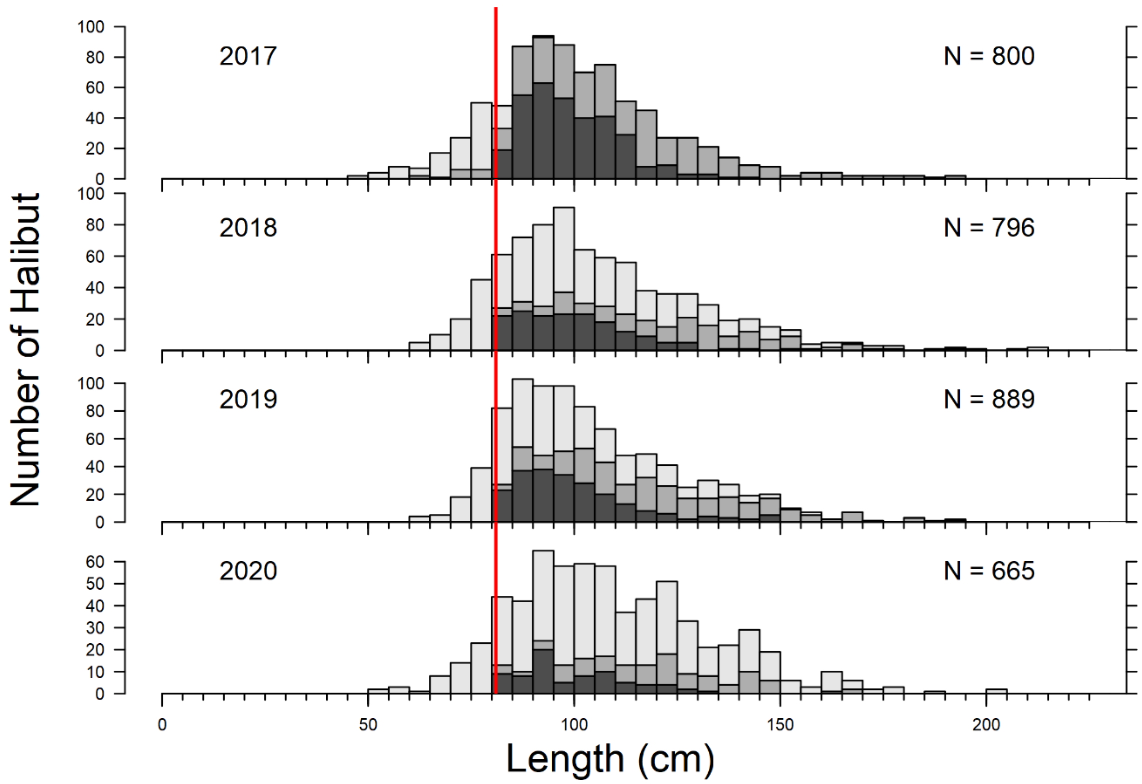


Figure 31. Length (cm) samples of Atlantic Halibut from the Stratified Random Halibut Survey. Dark grey bars represent male Atlantic Halibut, medium grey indicates females and light grey are unsexed. The vertical red lines represent the legal size of Atlantic Halibut (81 cm).

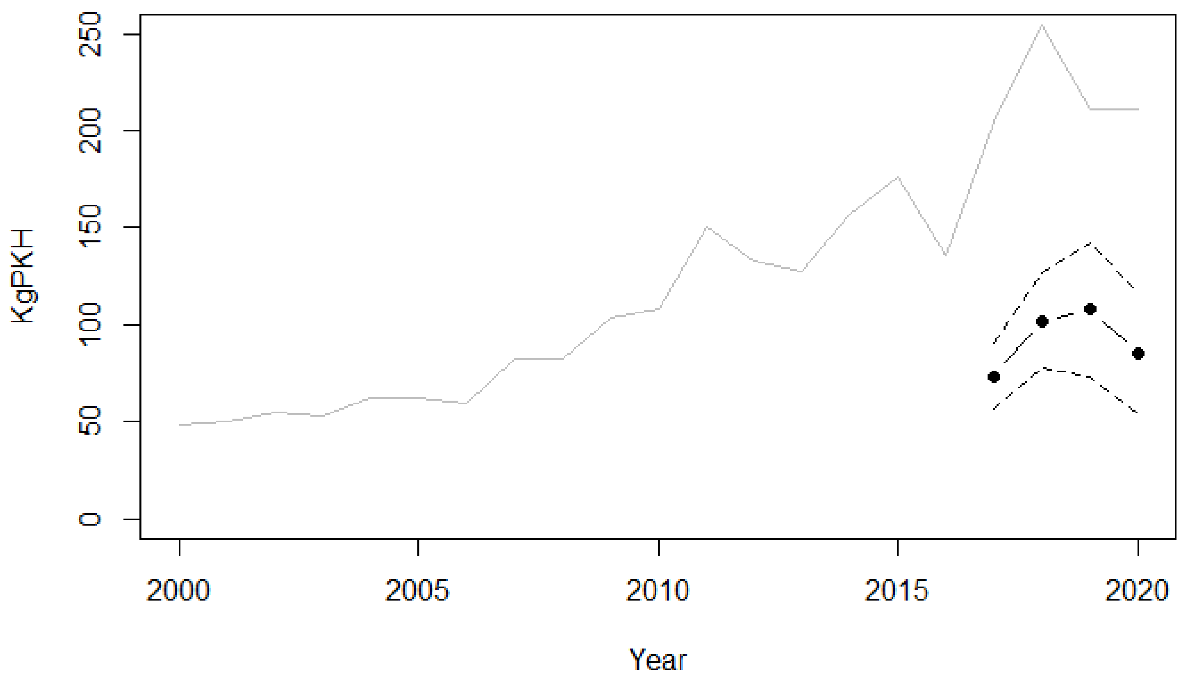


Figure 32. Stratified mean weight (kg) of Atlantic Halibut per 1,000 hooks (KgPKH, black line with points) and 95% confidence intervals (dashed black lines) from the Stratified Random Halibut Survey from 2017 to 2020. The Fixed Station Halibut Survey index is shown for reference in grey.

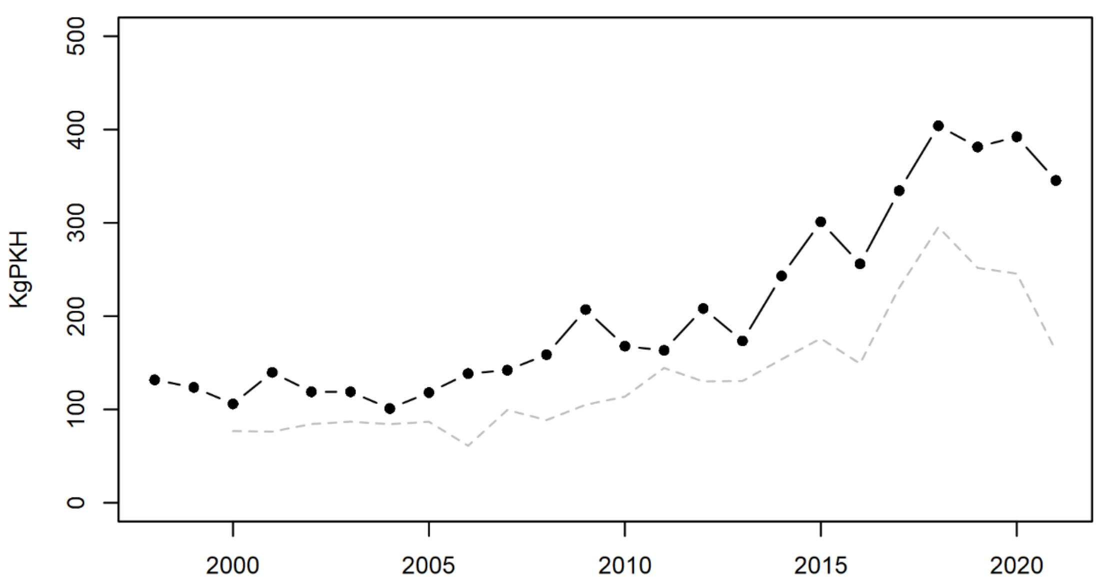


Figure 33. Mean weight (kg) of Atlantic Halibut caught per 1,000 hooks (KgPKH, black line with points) from the 3NOPs4VWX Halibut Survey Commercial Index sets. Fixed Station Halibut Survey is shown for comparison (grey dashed line).

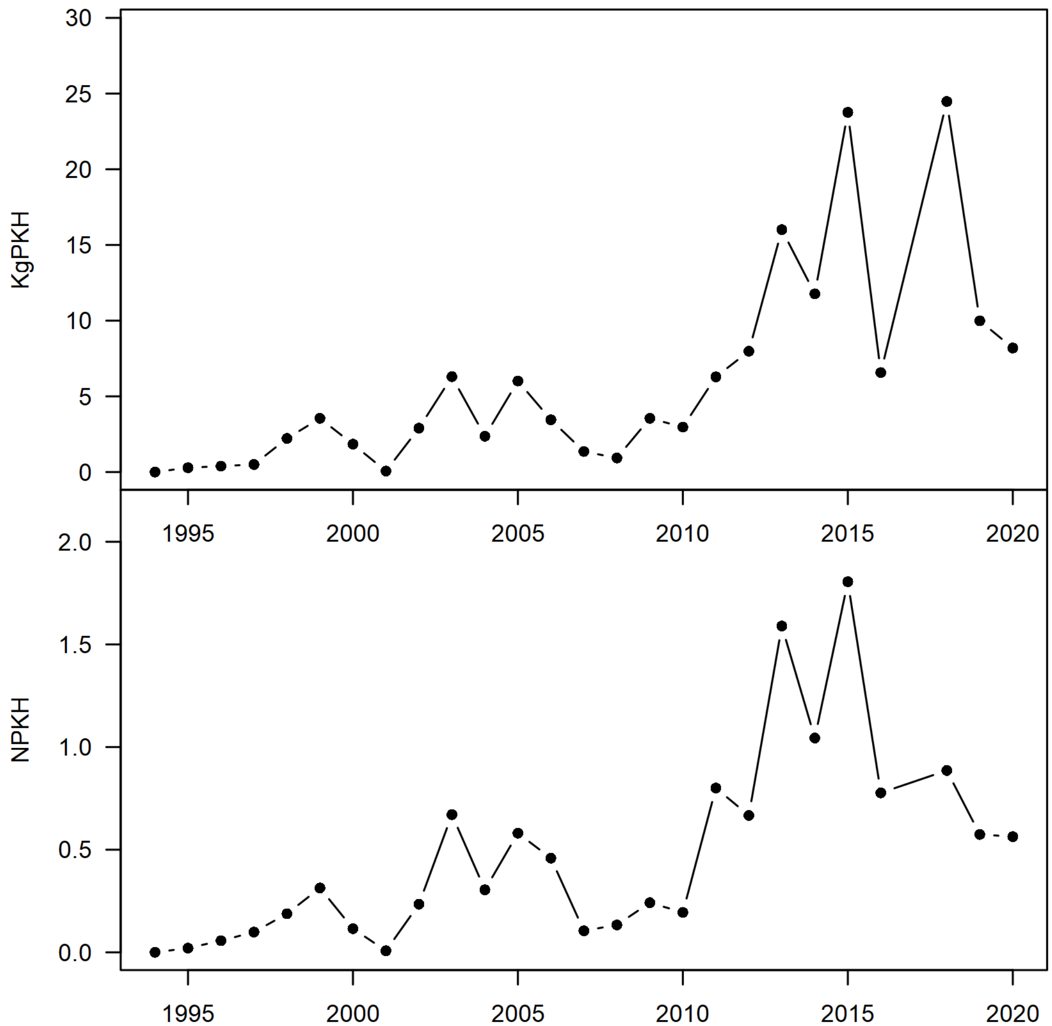


Figure 34. Weight (kg) of Atlantic Halibut per 1,000 hooks (KgPKH, top panel) and number of Atlantic Halibut per 1,000 hooks (NPKH, bottom panel) from the 4Vn Sentinel Survey.

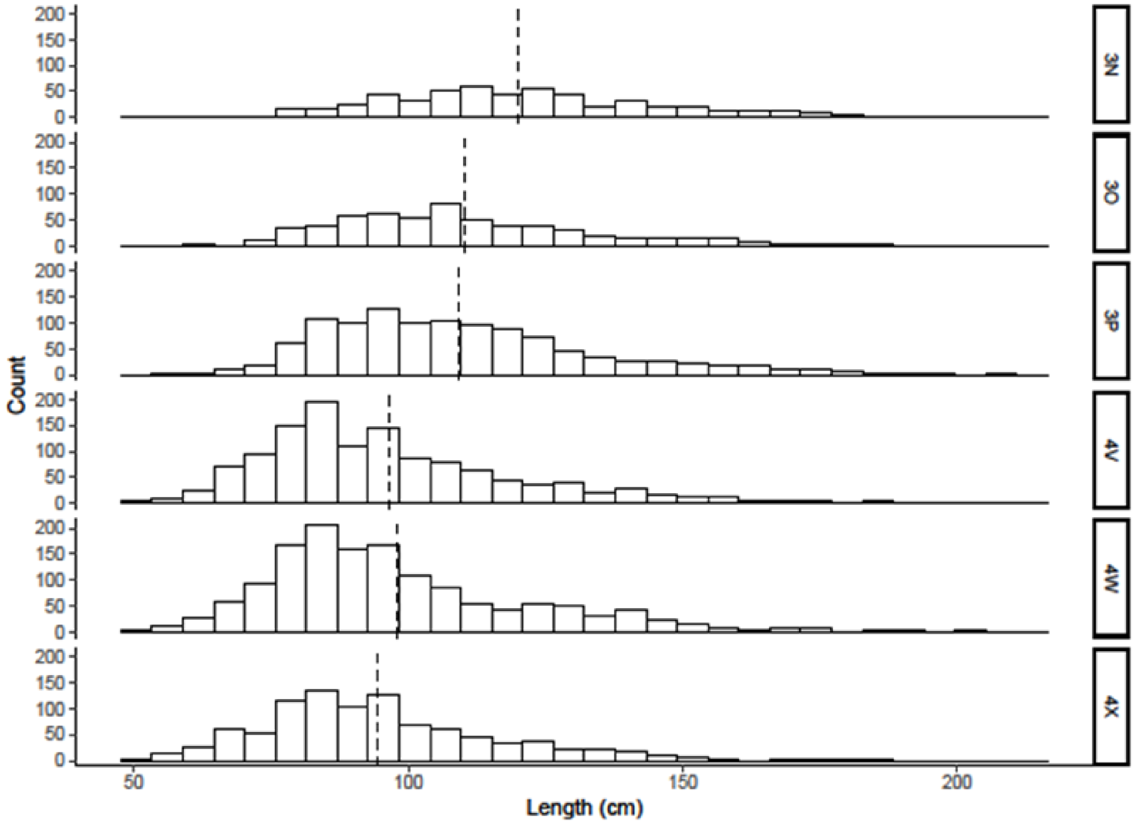


Figure 35. Frequency histograms of length at time of release for Atlantic Halibut by Northwest Atlantic Fisheries Organization (NAFO) divisions (as labelled along right side of figure). Twenty-four fish from NAFO Division 5Z are not shown. Dashed lines represent the mean values of released fish in each Division.

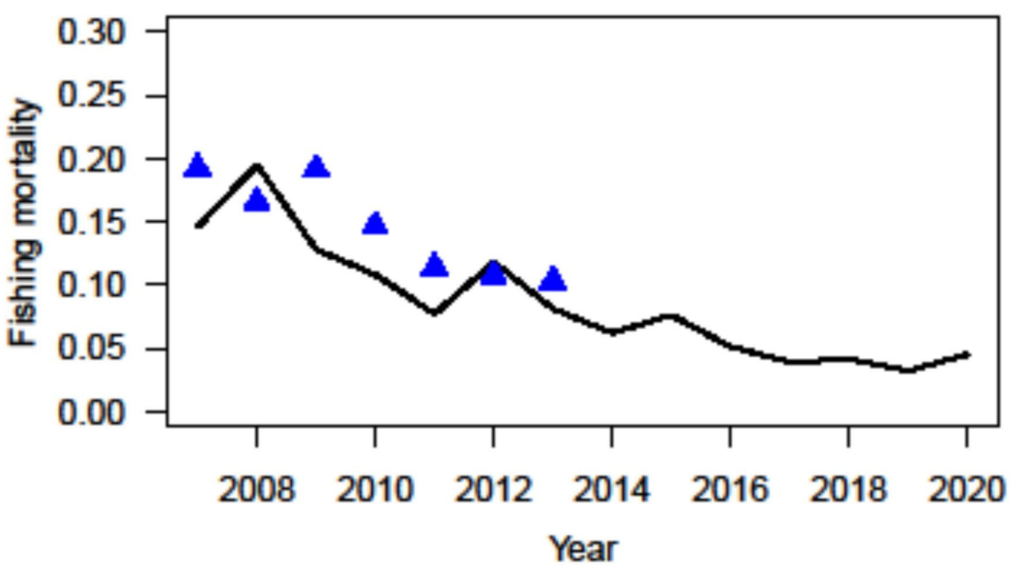


Figure 36. Plot of instantaneous fishing mortality for Atlantic Halibut estimated from the multi-year tagging model (solid black line) and the 2014 assessment model (blue triangles).

APPENDICES

Table A1. Models tested for evaluating the length-weight relationship for Atlantic Halibut. Data from observed commercial and survey fishing as well as from the Fisheries and Oceans Canada Ecosystem Research Vessel (RV) surveys (n = 51,458). The difference column refers to the difference in Akaike information criterion (AIC) between the lowest AIC and each other model. The lowest AIC is bolded.

Model	AIC	Difference
log(W) ~ log(L)	-59,092	5,710
log(W) ~ log(L) + (1 | YR)	-62,282	2,520
log(W) ~ log(L) + (1 | TRIP)	-60,101	4,701
* log(W) ~ log(L) + (1 | YR) + (1 | TRIP)	-63,244	1,558
log(W) ~ log(L) + SEX + (1 | YR) + (1 | TRIP)	-63,260	1,542
log(W) ~ log(L) + NAFO + (1 | YR) + (1 | TRIP)	-63,242	1,560
log(W) ~ log(L) + SEX + NAFO + (1 | YR) + (1 | TRIP)	-63,258	1,544
log(W) ~ log(L) + QUARTER + (1 | YR) + (1 | TRIP)	-64,792	10
log(W) ~ log(L) + SEX + QUARTER + (1 | YR) + (1 | TRIP)	**-64,802**	0
log(W) ~ log(L) + QUARTER + NAFO + (1 | YR) + (1 | TRIP)	-64,790	12
log(W) ~ log(L) + QUARTER + NAFO + SEX + (1 | YR) + (1 | TRIP)	-64,800	2

*Final model that was selected based on reasoning in the main text.

Table A2. Summary of model outputs from the linear mixed effects models of log weight as a function of log length with and without quarter as a fixed effect. Year (factor: 1970–2020) and trip type (factor with 14 levels) were both included as random effects in the two models. Quarter of the year included 4 levels: 1 (January–March), 2 (April–June), 3 (July–September), 4 (October–December). The model outputs without quarter were used in the weight estimation in the assessment model (n = 59,109). NA indicates not applicable.

Predictors	*log(W) ~ log(L) + QUARTER + (1 | YR) + (1 | TRIP)*			*log(W) ~ log(L) + (1 | YR) + (1 | TRIP)*		
	Estimates	CI	*p*	Estimates	CI	*p*
(Intercept)	-5.07	-5.10–5.04	**<0.001**	-4.99	-5.03–4.96	**<0.001**
log(L)	3.12	3.12–3.13	**<0.001**	3.12	3.11–3.12	**<0.001**
Quarter(2)	0.03	0.03–0.04	**<0.001**	NA	NA	NA
Quarter(3)	0.09	0.08–0.09	**<0.001**	NA	NA	NA
Quarter(4)	0.08	0.07–0.08	**<0.001**	NA	NA	NA
SD (Intercept)	0.04	NA	NA	0.04	NA	NA
SD (Intercept)	0.04	NA	NA	0.05	NA	NA
SD (Intercept)	0.04	NA	NA	0.04	NA	NA
SD (Intercept)	0.04	NA	NA	0.05	NA	NA
SD (Observations)	0.37	NA	NA	0.37	NA	NA
			Random Effects			
σ^2	0.02	NA	NA	0.02	NA	NA
τ_{00}	0.00_{YEAR}	NA	NA	0.00_{YEAR}	NA	NA
	0.00_{TRIP}	NA	NA	0.00_{TRIP}	NA	NA
ICC	0.13	NA	NA	0.16	NA	NA
N	51_{YEAR}	NA	NA	51_{YEAR}	NA	NA
	14_{TRIP}	NA	NA	14_{TRIP}	NA	NA
Observations	59,109	NA	NA	59,109	NA	NA
Marginal R^2/Conditional R^2	0.978/0.981	NA	NA	0.977/0.980	NA	NA

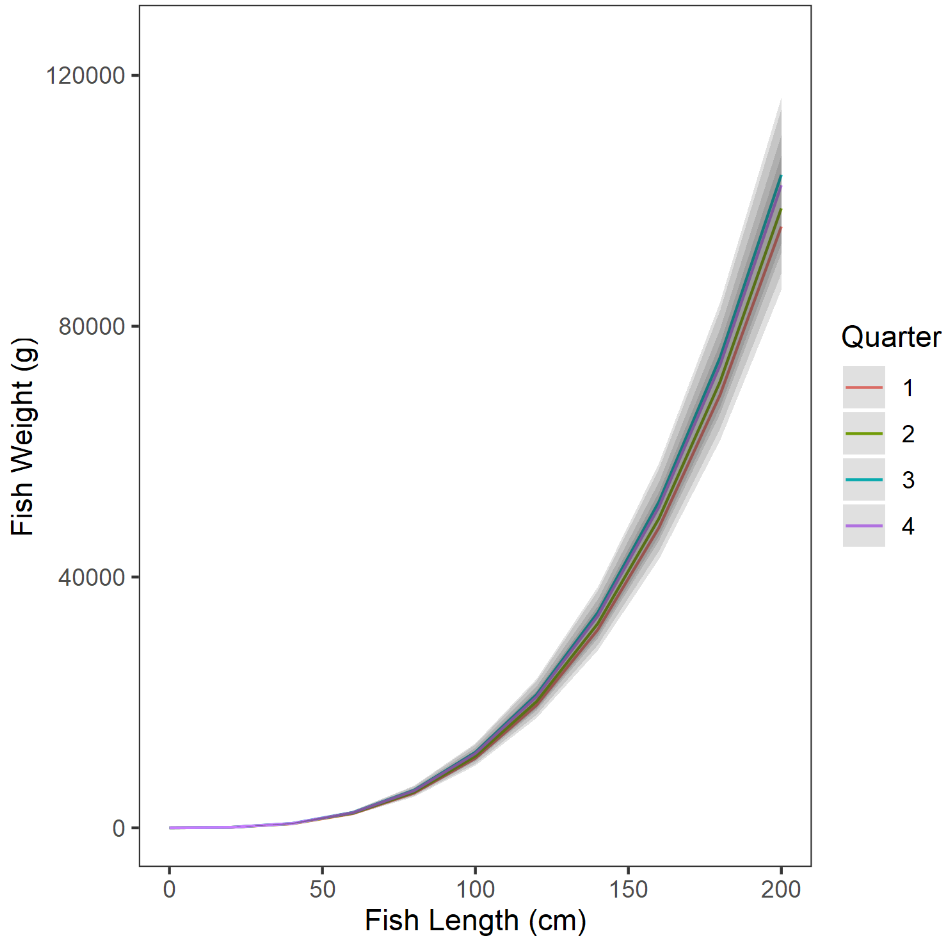


Figure A1. Predictions of fish weight (g) from fish length (cm) for different quarters of the year (1: January–March, 2: April–June, 3: July–September, 4: October–December) for Atlantic Halibut caught on surveys and observed commercial trips within the Scotian Shelf and southern Grand Banks management unit (3NOP4VWX5Zc).