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Atlantic Halibut (*Hippoglossus hippoglossus*) in the Estuary and Gulf of St. Lawrence (NAFO 4RST) in 2022: Data Review

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Foreword

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

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ABSTRACT

This research document presents updated data on the Atlantic halibut stock in NAFO Divisions 4RST. These data provide a more accurate picture of current trends and potential changes in the status of the halibut stock. Although this update does not provide a definitive stock status assessment, it is a crucial step in the assessment process. The information gathered will be critical in informing future stock assessments and in helping to develop evidence-based management recommendations. Collecting accurate, up-to-date data is indeed an essential part of effective fish stock management and the document also emphasizes the importance of ongoing Atlantic halibut stock monitoring and regular data updates.

INTRODUCTION

The Atlantic halibut (*Hippoglossus hippoglossus*, hereinafter referred to as “halibut”) occurs in the northern Atlantic Ocean and the Arctic Ocean. It is the largest species of flatfish and has been fished commercially in Canadian waters since the late 19th century. In 1987, two management units were created in these waters, mainly on the basis of tagging studies showing that halibut are highly mobile (Neilson et al. 1987). One management unit covers North Atlantic Fisheries Organization (NAFO) Divisions 4RST (Figures 1 and 2), i.e. the Estuary and the Gulf of St. Lawrence (EGSL). The other management unit covers NAFO Divisions 3NOPs4VWX5Zc, i.e. the Scotian Shelf and southern Grand Banks (SSSGB). DFO Fisheries Management introduced a total allowable catch (TAC) in 1988, followed by a minimum legal size in 1997. Today, the directed halibut fishery is carried out by longliners on a competitive basis or by individual transferable quota (ITQ).

Bottom trawl surveys conducted by Fisheries and Oceans Canada (DFO) research vessels in the estuary and the northern St. Lawrence Gulf (nGSL) and southern Gulf of St. Lawrence (sGSL), as well as bottom trawl surveys from the sentinel fishery program, provide indices of long-term abundance independent of the fishery. Beginning in 2017, a collaboration between DFO and the fishing industry allows for an annual longline survey to be conducted to provide a fishery independent index of fishable biomass throughout the management unit.

The assessment of the status of the resource aims to highlight changes in the status of the stock that would justify adjustments to the conservation measures and the management plan. An advice on the status of the resource is prepared based on the various indicators from the commercial fishery and research surveys. This document presents the updated data on landings and indicators and the methods used to produce them.

BIOLOGY

HABITAT

Halibut occur in the Northwest Atlantic from Virginia in the south to the waters off northern Greenland (Trumble et al. 1993). Tagging studies using pop-up satellite archival tags (PSATs) have shown that the EGSL halibut stock also overwinters in deep channels (200 to 500 m) in the Estuary and Gulf, moving to shallower habitats in spring and remaining there until autumn (Le Bris et al. 2018; Gatti et al. 2020). Summer site fidelity, revealed by mark-recapture studies using conventional tags, has been confirmed using PSAT tagging.

Fishery-independent bottom trawl surveys in NAFO Divisions 4RST show that, from July to September, halibut range throughout the Gulf (Figure 3). Halibut depth preferences are detailed in Figure 4, which shows the two ranges of depths preferred by the species: between 20 m and 50 m and a wider range between 100 m and 300 m. Halibut are rarely found at temperatures below 2 °C, and extremely rarely at those below 0 °C (Figure 5). Only a few stations with temperatures above 7 °C are sampled, but halibut are regularly found there, at temperatures at least as high as 12 °C. There is a correlation between depth and temperature in the EGSL, and Figure 6 shows that halibut catches are much less frequent in the cold intermediate layer (CIL), usually situated between the depths of 50 m and 100 m, where temperatures remain below 2 °C from July to September. The preference of halibut for waters warmer than 2 °C has also been observed through PSAT tagging (Murphy et al. 2017), showing that they move quickly through the CIL during what may be seasonal migrations between deep channels and shallow coastal waters.

The use of PSATs has also revealed patterns of rapid, abrupt ascent (of 100 to 200 m) in the water column by halibut, which is possibly associated with spawning, which occurs between December and April and peaks in mid-February (Le Bris et al. 2018; Gatti et al. 2020). Potential spawning areas have been identified through geolocation by modelling the locations where tagged fish have made rapid vertical migrations likely associated with spawning. This research suggests that halibut spawn over a vast area in all the deep channels of the EGSL.

GROWTH

Halibut are sexually dimorphic, and females grow to a larger maximum size than do males. The largest female ever recorded in the DFO database for the EGSL stock was 272 cm in length and was caught in 2004 in NAFO Unit Area 4Tn. The largest male was 207 cm in length and was caught in 1996 in NAFO Unit Area 4Rc. Growth studies based on readings of otoliths in fish from the SSSGB stock (Armsworthy and Campana 2010) show that males and females grow at a similar rate of around 10 cm per year until age 5, when the growth of males then slows. Males can live to the age of 50, while the age of the oldest females has been estimated at 38.

To determine ESGL-specific growth rates in halibut, 168 otolith pairs collected in 2021 were aged, 96 of which were obtained from trawl research surveys in the nGSL and sGSL and 72 from commercial sampling in the longline fishery by at-sea observers (Figure 7). The otoliths of 55 males (24 to 144 cm) and 41 females (28 to 178 cm) from the research survey were analyzed, as well as those of 24 males (86 to 153 cm) and 46 females (87 to 175 cm) obtained in commercial sampling. Photographs of the distal side of whole otoliths were taken using reflected light (Figure 8). The otoliths had been previously immersed in water for 24 h to make the growth increments easier to distinguish (Karlson et al. 2013). In general, the left sagittal otolith, which is on the blind (lower) side of the fish, has clearer growth increments than the right one in halibut.

The otoliths collected by the at-sea observers came exclusively from halibut larger than 85 cm, as, legally, smaller specimens must be released back into the water alive. To prevent the sampling of larger fish from skewing the growth curve, only halibut aged 14 years and over were selected as a data source. The von Bertalanffy growth curve fit

$$L(a) = L_\infty \left(1 - exp\left(-\kappa(a - t_0)\right)\right)$$

where L_∞ = 180.5, κ = 0.076 and t_0 = 0.44, is shown for all individuals in Figure 9A and by sex in Figure 9B.

LENGTH-WEIGHT

The length-weight relationship (Figure 10) was calculated from the data from 2,031 halibut measured and weighed in DFO trawl surveys (nGSL and sGSL, Figure 11) between 2013 and 2022. The length-weight model fit is

$$weight = 4.931 \times 10^{-6} * length^{3.183} * \varepsilon$$

for $weight$ in kilograms and $length$ in centimetres, with a lognormal distribution of residuals (ε). The weights observed in halibut caught in shallow water, which were generally above the estimated values (Figure 12), could be interpreted as an indication that they are in better condition. Further research is needed to identify factors that may explain this observation.

MATURITY

Studies in the SSSGB region have found that 50% of females reach maturity at around 119 cm, and males, at around 77 cm (Trumble et al. 1993), with estimated ages at maturity of 5 to

9 years for males and 9 to 15 years for females. The preliminary results of studies in the EGSL (D. Archambault, pers. comm.) suggest larger sizes at maturity, namely 130 cm for females and 92 cm for males.

DIET

The analysis of stomach contents collected during the scientific survey of the nGSL from 2015 to 2017 identified 63 taxa in the diet of the 346 halibut sampled (Ouellette-Plante et al. 2020). In general, fish made up 66% of food intake, with redfish (*Sebastes* spp.) accounting for one third of these, followed by fourbeard rockling (*Enchelyopus cimbrius*), Atlantic cod (*Gadus morhua*), pricklebacks and blennies (*Lumpenus* spp.) and skates (family Rajidae). The main invertebrates were snow crab (*Chionoecetes opilio*), which accounted for 8% of the diet, and striped shrimp (*Pandalus montagui*), which accounted for 7%.

Diet varies depending on the size of the individual (Figure 13). Stomachs removed from halibut smaller than 50 cm contained mainly pandalid shrimps, fourbeard rockling and hermit crabs (*Pagurus* sp.), while halibut larger than 50 cm fed primarily on redfish, followed by cod, fourbeard rockling and snow crab.

The massive arrival of redfish (Senay et al. 2021) over the past 14 years has changed the EGSL ecosystem. In 2020, the two redfish species combined accounted for 81% of the trawlable biomass, whereas it averaged 15% between 1995 and 2012 (Bourdages et al. 2021).

Figures 13 and 14, from Ouellette-Plante et al. (2020), can be used to compare the diet of halibut with that of the redfish group. Zooplankton was virtually absent from the stomach contents of halibut, but was the main contributor to the filling index of redfish smaller than 25 cm. The shrimp group was predominant in the stomach contents of redfish larger than 25 cm and accounted for 15% to 30% of the stomach contents of halibut measuring between 25 cm and 45 cm. However, the species of shrimp consumed differed, with mainly northern shrimp (*Pandalus borealis*) and pink glass shrimp (*Pasiphaea multidentata*) found in redfish stomach contents and striped shrimp in halibut stomach contents. This was also true of the fish species consumed. The main species in redfish stomach contents, apart from redfish themselves, were white barracudina (*Arctozenus risso*) and Krøyer's lanternfish (*Notoscopelus kroyeri*). These observations indicate that, in terms of the type of prey that they consume, halibut and redfish do not compete with each other significantly at any life stage.

COMMERCIAL FISHERY

FISHING STATISTICS

Since 1960, the EGSL halibut stock has supported average annual landings of 505 t (Figure 15). Annual landings are currently at the highest levels observed, at approximately 1,500 t. They were around 600 t in the early 1960s and fell to 91 t in 1982, the lowest value in the series. In 1995, annual landings began to gradually increase to their recent peak values, and in response to increased quotas beginning in 2005. Total allowable catches (TACs) were introduced in 1988 and, as of 2004, had been reached on only four occasions. They are revised every year at the start of the season to take into account management measures, such as quota carry-forward or reconciliation, when applicable. TACs have been reached each year since 2004.

In recent years, the TAC has been distributed among 12 fleets in Quebec and the four Maritime provinces, including 9 fixed gear fleets and 3 mobile gear fleets (Management plan for Atlantic halibut in the Gulf of St. Lawrence). Longlines are the only gear authorized in the directed fixed gear fishery for halibut; catches by fleets using other fixed gear (gillnets) and mobile gear are considered bycatch.

In addition to TACs, a number of other measures have been put in place over the years to manage the fishery. In 1997, a minimum legal size (MLS) of 81 cm was incorporated in the commercial fishing licence conditions. The MLS was increased to 85 cm in 2010. Halibut under this size must be released back into the water. In addition to the MLS, the following management measures have been introduced:

- dockside monitoring program for commercial catches (100%)
- at-sea observer coverage (percentage varies by fleet)
- mandatory logbooks (except for vessels < 10.67 m in the Newfoundland and Labrador region)
- predetermined fishing periods
- limits on the size and maximum number of hooks allowed per line
- small-fish and bycatch protocols
- vessel monitoring system (VMS) (for most Quebec fleets).

Lastly, quota reconciliation has been in effect since the 2011 fishing season. Any quota overrun in a given year, whether under an individual quota system or a competitive system, is deducted from the quota for the next season on a one-for-one basis. The carry-forward of uncaught quotas of halibut from the previous year may be authorized for up to 15% of the initial quotas.

Official statistics on halibut landings in the EGSL have been available since 1960, compiled from data collected from Canadian and foreign fishing fleets and recorded by NAFO. The Gulf Quota Reports have provided breakdowns of landings by fleet since 1998. These reports are produced by DFO. Significant discrepancies have been observed between the NAFO data and the Gulf Quota Reports since 2010. For the years in which data are available from both sources, the Gulf Quota Reports have been used in this document. Since 1985, DFO has been compiling detailed fishing statistics (in Zonal Interchange File Format [ZIFF] files) on halibut, using data from logbooks maintained by fishers, which are validated using purchase slips from processing plants, and from the Dockside Monitoring Program. The data usually collected include the fishing date and location, type of gear used, fishing effort and total catch weight. Under the dockside monitoring program, all fishers must have their landings weighed by species at designated ports. Halibut that is landed is normally gutted, and sometimes headed. Reported weights are adjusted using conversion factors to estimate the round (or whole) weight.

Landings calculated from detailed fishing statistics (ZIFF files) and disaggregated by NAFO division (Table 1, Figure 16) and fishing gear (Table 2, Figure 18) show that, since 1996, an average of 87% of the landed biomass of Atlantic halibut has come from longline fishing, a proportion that increased to 95% between 2015 and 2022. Gillnets accounted for an average of 13% of halibut landings between 2006 and 2013, and less than 8% since then. Other gear, in particular bottom trawls, accounted for up to 45% of landings in the 1980s, but less than 5% since 2000. According to the same data (ZIFF files) disaggregated by main target species (Table 3 and Figure 18), most landings of Atlantic halibut since 1996 have resulted from trips targeting this species (generally using longlines). Atlantic halibut landings from trips targeting Greenland halibut (*Reinhardtius hippoglossoides*, hereafter referred to as “turbot”) peaked between 2006 and 2013. The two main fisheries generating halibut bycatch are the directed turbot and cod fisheries. Target species were not documented for most landings before 1995. In the directed halibut fishery (Figure 19), the main bycatch is cod, while turbot made up a significant, but smaller, proportion of bycatch in the 2000s, as did white hake in the 1990s.

The geographical distribution of halibut catches (Figures 20 and 21) shows their main locations along the Esquiman, Anticosti and Laurentian channels, off the North Coast of Prince Edward Island, on Miscou Bank and around the Magdalen Islands. Over the last five years, in some NAFO sub-divisions, up to 120 t of halibut (the annual average) could not be associated with a geographic location. As a result, the precise locations of catches by some fleets may be entirely absent from the maps, particularly along the west coast of Newfoundland. The absence of precise location data was commonplace during the 1980s.

Since 2000, the fishing season has started on May 15 and ended on May 14 of the following year. Before 1998, the fishing season began on January 1 and ended on December 31; the transition took place in the management year of 1999, when the season began on January 1, 1999, and ended on May 14, 2000. The daily distribution of landings according to ZIFF file data is shown in Figure 21. Between May 15, 2021, and May 14, 2022, 33% of landings came from Division 4R, 37% from Division 4S and 30% from Division 4T. Landings in NAFO Divisions 4R and 4S occurred later in the season in 2022 than they did in the early 2000s (Figure 21). Landings before May 15 occurred in divisions 4S and 4T, coinciding with the end of the management year. Daily landings for the two adjacent NAFO sub-divisions, 3Pn and 4Vn, are also presented for comparison purposes (Figure 22).

STANDARDIZATION OF CATCHES PER UNIT OF EFFORT

The standardized catch rate in the commercial longline fishery, i.e. the catch per unit effort (CPUE) measured in weight per 1,000 hooks, is calculated using ZIFF file data. Since the directed halibut fishery uses longlines, the number of hooks deployed is used to quantify the effort. Fishing activities for which values (catch or effort) are missing or incorrect are excluded from the analyses. A number of these excluded fishing activities are concentrated in certain areas in certain years (Table 4 and Figure 23), which can make it difficult to identify trends, given that the stock may not be evenly distributed across the different sectors of the EGSL, its distribution may vary in relation to density, or changes in environmental conditions may have altered the species' use of the habitat. In NAFO Division 4R, less than 20% of landings from 2013 onward can be used to calculate the CPUE and, in NAFO Division 4T, none of the data before 2003 are usable.

Standardized annual CPUE values are calculated to take into account changes in fishing capacity and seasonal fishing patterns (Gavaris 1980). Multiple linear regression was performed between the logarithm of the CPUE values and the variables of month, NAFO division, vessel size, and year, in order to isolate the annual effect from the effects of the other variables. The analyses were carried out using the *lm()* function in the R software package (R Core Team 2022).

The CPUE values for NAFO Divisions 4RST as a whole from 2003 to 2022 (Figure 24) represent the average reference fishing activity. Non-standardized CPUE values correspond to the annual average of the individual CPUE values observed, i.e. each individual landing divided by the effort required to obtain it. CPUE values increase steadily throughout the series, with one of the highest values recorded in 2022. The contribution of the various factors considered in standardizing the CPUE is shown in Figure 25. These factors (and the values retained) include the calendar year (2003 to 2022), fishing month (March to December, or 3 to 12), NAFO division (4R, 4S and 4T) and size class of the vessel (under 35 ft., 35 to 45 ft. and 45 to 65 ft.).

The following potential biases may affect the interpretation of standardized CPUEs for the commercial fishery:

- The price paid per unit of weight is higher for small halibut, which may encourage operators with individual quotas to avoid concentrations of larger halibut in order to maximize the value of the landed biomass.
- Fisheries in NAFO Division 4R have been under-represented in the calculations, in particular since 2013.
- Some operators have fishing quotas for various groundfish species and are authorized to land bycatch within the limit of each quota. It is therefore conceivable that some operators will target fishing sites that maximize the value of landings of all species combined, settling for lower yields of halibut that are disproportionate to the species' abundance.
- The attractiveness of baited gear can be expected to decrease with soak time. A common practice in the analysis of longline catch rates is to consider only fishing activities with a soak time between two predefined values. Soak time is often poorly documented and, when available in the data consulted, varies greatly; therefore, this factor has not been included in the standardized CPUE calculation.
- In some regions, large numbers of predators are reportedly present and may attack halibut caught on longlines, forcing fishers to shorten the soak time in order to avoid losses and waste from depredation. Fishers have observed seal bites on fish, rendering it unfit for sale or significantly reducing the price that buyers are willing to pay. To prevent this, fishers have changed their practices, remaining near their longlines to monitor the situation and reducing the soak time before they haul in the gear. As a result, yields tend to be underestimated when expressed in kilograms per number of hooks.
- When individual quotas are in place, the amount allocated to each fisher can vary greatly. It has been reported that some fleets with lower individual quotas prefer to fish sites that are less productive but involve lower travel costs, which affects the calculated yields for these activities.
- In 2010, the MLS increased from 81 to 85 cm, reducing the quantity of halibut landed per given amount of effort and resulting in changes in operators' behaviour in terms of fishing locations.

All these factors create uncertainties over the usefulness of the standardized commercial CPUE indicator for monitoring changes in the abundance of the resource, suggesting that this metric should be considered at best an indicator of fishing performance, rather than of abundance.

SAMPLING OF COMMERCIAL CATCHES

A program in which DFO samplers collect biological data on commercial landings dockside or at the plant has been providing data on halibut since 1990. A second sampling campaign, conducted under the at-sea observers program, is carried out on board vessels at sea and has been providing data since 1996. At-sea observers monitor and record fishing activities in greater detail than can be obtained in fishery monitoring documents submitted by fishers. Catches of all species, whether retained or discarded, are recorded. In addition to catch data, at-sea observers record information on fishing practices, including the nature and location of fishing activities, and may sample fish to determine sex and collect otoliths. The coverage rate in the two programs varies between years and between fleets.

The proportion of landings for which an at-sea observer or dockside sampler measured the size of the halibut caught is shown in Figure 26. The level of sampling under both programs is similar in NAFO Divisions 4S and 4T, but lower in NAFO Division 4R. Temporal coverage by at-sea observers and dockside samplers is shown by NAFO division in Figure 27. Apart from

NAFO Division 4R, where the sampling rate is lower, the temporal distribution of samples during the fishing season generally corresponds to the distribution of landings. The spatial distribution of halibut catches sampled by at-sea observers, shown in Figure 28, indicates that some regions are sampled more often than others, especially in recent years.

Figures 29 and 30 show the size of halibut caught in the commercial fishery and sampled at sea or at dockside, respectively, by size class (in 3 cm increments). The presumed trajectory of six cohorts (1992, 1994, 2003, 2005, 2011 and 2017) is also illustrated (see GROWTH section for details on the growth curve used). According to the sizes of halibut sampled at dockside, fish smaller than the current MLS are virtually absent from the samples once catches are landed.

The average size and average estimated weight of halibut caught with longlines have been increasing since 2005 (Figure 31). The increase in the MLS in 2010 may have contributed to the increase in average size by encouraging fishers to operate in areas frequented by larger halibut. Aside from changes in fishing practices, this could also be explained by an increased abundance of larger halibut.

The total number of halibut caught per year (Figure 32) is estimated by dividing the reported landings by average estimated individual weight. Linear regressions are presented to track the trends in different size classes. The regressions are segmented into two parts to cover the periods when release measures were in effect, i.e. an MLS of 81 cm between 1997 and 2009, and 85 cm between 2010 and 2022. The total number of halibut landed tripled between 2000 and 2022, from 20,000 halibut over 81 cm to about 65,000 halibut over 85 cm. Between 1997 and 2009, the numbers of halibut landed in the three size classes (81 to 85 cm, 85 to 100 cm, and over 100 cm) were similar, with an increasing trend found for all three size classes. Since 2010, the 81 to 85 cm size class has almost disappeared from landings, the 85 to 100 cm size class has remained steady at 15,000 to 20,000 individuals, and the over 100 cm size class has tripled in abundance, from 15,000 to 45,000 individuals. The differences between classes become more pronounced when the landed biomass (Figure 33) is considered. Although annual landings of the 85 to 100 cm size class remained at around 150 t during the 2010s, those of halibut larger than 100 cm rose to approximately 1,300 t between 2020 and 2022.

SCIENTIFIC SURVEYS

DESCRIPTION OF MOBILE GEAR SURVEYS

Four mobile-gear scientific surveys that are independent of commercial fishery activities provide information on the status of the Gulf of St. Lawrence halibut stock. The four surveys are conducted between July and September using a stratified random sampling plan (Figure 34), with a common area present on the southern slope of the Laurentian Channel (Figure 35). The two sampling plans together provide almost complete coverage of the stock (Figure 36). Two surveys are conducted by DFO (one in the sGSL and one in the nGSL), and the other two under the sentinel fisheries program (one in the sGSL and the other in the nGSL). The vessels used, number of vessels, gear type, tow duration and tow speed differ between the four surveys. The four surveys are described in detail in Savoie (2014a), Bourdages et al. (2021), Savoie (2014b) and Brassard et al. (2020), respectively. At each station, the total catch of halibut is weighed and counted, and the fish are measured, sexed and, depending on the survey, weighed individually.

Catch distribution

Figures 37 and 38 show the geographic distribution of catches in the four scientific surveys. As these surveys use different sampling protocols, Figure 3 aggregates the data according to the presence or absence of halibut. For each 5-minute quadrilateral, the proportion of stations where at least one fish was caught is indicated, in all four surveys and during all available years. The size of the symbols indicates the total number of stations sampled per quadrilateral. The species' depth and temperature preferences have already been discussed in the subsection on habitat in the BIOLOGY section (Figures 4, 5 and 6).

Yields

The average catch rates by weight and by number of individuals (Figures 39 to 42) are calculated taking into account the stratification used in allocating the fishing stations (see Bourdages et al. 2021 for details). At each station sampled, the halibut catch is adjusted according to the area covered by the trawl (swept area). A multiplicative model (Gavaris 1980) is used to assign catch rate indices (by number and weight) to strata not sampled by at least two tows in a given year. The value predicted by the model for strata covered by fewer than two tows is calculated using data from the current year, if available, and the previous three years. Consequently, the indicators presented for the series are representative of a standard total area, the sum of the area of all strata sampled. The variance of the indicator is generally greater when weight is considered (rather than numbers), because the occasional capture of very large specimens can result in increased data dispersion.

Halibut catch rates are disaggregated by size class in Figure 43 by number and in Figure 44 by weight. The size classes used make it possible to differentiate the fishable component (over 85 cm) and short-term recruitment (65 to 85 cm), from smaller halibut (under 65 cm). The recent abundance values for halibut over 85 cm were among the highest in the series in all the surveys, although a significant decline was observed in 2022 in the nGSL sentinel survey. In 2022, values for short-term recruitment (65 to 85 cm) in the sGSL were among the lowest observed in the past 15 years, but higher than the values seen between 1990 and 2003. In the nGSL, recruitment values were among the four highest in the available series.

Size frequency distribution

The size distribution of the catches in all the surveys is shown in Figure 45 (DFO surveys) and Figure 46 (sentinel fisheries program), weighted according to the stratification scheme and aggregated in 3-cm size classes. Although limited numbers of fish were caught during these surveys, increases in certain larger or smaller cohorts can be discerned. The presumed trajectories of six cohorts (1992, 1994, 2003, 2005, 2011 and 2017) are presented, and descriptions of these trajectories can be found in the section on commercial catch sampling. The last cohort seen in high abundance in the surveys is likely the 2017 one, which should reach commercial size in 2025. In 2022, this cohort was prominent in the nGSL survey but less visible in the sGSL survey.

Minimum trawlable biomass and exploitation rate

The minimum trawlable biomass of commercial-size halibut is calculated by multiplying the average annual yields for the over-85 cm size class (Figure 44) by the number of trawlable units in each of the DFO surveys of the nGSL and sGSL. The number of trawlable units is obtained by dividing the study area by the area swept by the fishing gear during a standard fishing activity. The study area of the nGSL survey is 117,914 km², and the swept area of a standard fishing activity is 23,572 m², for a total of 5,011,210 trawlable units. The study area of the sGSL survey is 73,138 km², and the swept area of a standard fishing activity is 39,033 m², for a total of 1,873,705 trawlable units. The two surveys overlap (Figure 35) in an area of 5,623 km², or 4.77% of the nGSL survey and 7.69% of the sGSL survey.

Using spatiotemporal overlap analyses, Yin and Benoît (2022) inter-calibrated halibut catchability in the two surveys. They found that the sGSL survey was 2.438 times more efficient in catching this species than the nGSL survey. Figures 47 to 49 show that the estimated minimum trawlable biomass for the overlap area follows similar trajectories for both surveys once this adjustment factor has been applied. The average minimum trawlable biomass adjusted for the overlap area of the two surveys is used to calculate the total minimum trawlable biomass. As shown in Figures 50 to 52, the total minimum trawlable biomass is obtained by adding the average for the overlap area and the values obtained for each of the surveys outside the overlap area.

The relative exploitation rate is calculated by dividing the recorded landings by the total minimum trawlable biomass in the same year, as shown in Figure 53. The average exploitation rate for the last 15 years is estimated at 6.7% if the Yin and Benoît (2022) adjustment is applied to the sGSL data, and at 2.7% if it is applied to the nGSL data (not shown here).

DESCRIPTION OF FIXED GEAR SURVEY

A longline scientific survey for halibut, independent of commercial fishing activities, has been in place since 2017. This survey is a collaboration between DFO and various partners in the commercial halibut fishery. It is funded under section 10 of the *Fisheries Act*, “National Policy for Allocating Fish for Financing Purposes,” commonly referred to as “use of fish” or “utilisation du poisson.” The allocation associated with the project was 50 t of halibut in 2017 and 2018 and 60 t of halibut from 2019 to 2022. Six fishers’ associations are partners in the project, namely the Association des Capitaines-Propriétaires de la Gaspésie (ACPG); Lower North Shore Fishermen’s Association (LNSFA); Fish, Food and Allied Workers Union (FFAW-Unifor); Gulf Nova Scotia Fleet Planning Board (GNSFPB); Prince Edward Island Fishermen’s Association (PEIFA) and Regroupement des palangriers et pétoncliers uniques madelinots (RPPUM). The distribution of responsibilities and allocation of fish vary among the partners and have been determined by mutual agreement.

The project involves the annual sampling of 125 stations located in NAFO Divisions 4RST. These stations are randomly distributed in proportion to the area of each stratum. Strata are determined on the basis of depth and NAFO sub-division (Figure 54). Sampling is done between mid-August and mid-October and covers the known distribution of this stock at that time of year (Figure 55).

The fishing gear used in the survey is the same as that used in the commercial halibut fishery (the total number of hooks may vary). The length of each halibut caught is recorded, and the distribution of these is shown in Figure 56. Changes in preferred depth as a function of size and, presumably, the age of the halibut can be seen in Figure 57, which details the distribution of catches according to the depth of the station for each 5-cm size class.

Halibut catches are distributed throughout the study area and characterized by a small number of high-yield stations and a large number of stations with more moderate yields (Figure 58). Each year, no halibut are caught at around 40% of stations (Figures 59 and 60). Among the commercially valuable species caught, cod, redfish and turbot are also observed in the longline survey.

The catch per unit effort (CPUE), expressed as the number or biomass of halibut per 500 hooks, is affected by interspecific competition, and the failure to take this into account may introduce bias in the values obtained for the abundance indicators (Etienne et al. 2010, Smith 2016). Disregarding hooks that have not caught the target species implicitly assumes that those hooks remain available to catch new individuals, should there be any in the fished area. Clark (2009) proposes an approach to Pacific halibut that provides a relative estimate of the effect of competition on halibut catch rates. The stratified random mean NUE and CPUE values for halibut larger than 85 cm, taking the correction factor into account, are shown in Figure 61.

DESCRIPTION OF TAGGING PROJECT

Since 2014, 5,351 halibut have been marked, usually with two T-bar anchor tags each. Of these individuals, 3,887 were tagged in proportion to stratum density, i.e. (1) the fishing effort was proportional to the area of the stratum; and (2) the same proportion of halibut caught at each station (40% in 2017, 100% since then) were tagged and released. Only the latter halibut are used to calculate the instantaneous exploitation rate (F). Fishers send information to DFO on tagged fish that they recapture in return for $100 per halibut. As of February 27, 2023, information on 269 recaptures has been sent to DFO for this project (Table 5), including 120 individuals used to calculate F (Table 6). Tagging is carried out after the bulk of the landings have taken place, which allows the sampled fish to disperse in the population before they become available to be recaptured. The tag return model developed by Hoening et al. (1998) is used to estimate annual F values. The model assumes that fish tagged in year *t* are unavailable to the fishery until year *t* + 1, and that fishing mortality and natural mortality are distributed over year *t* + 1. Assumptions about tagging mortality and the rate of information return by fishers are informed by similar research on the 3NOPs4VWX5Zc halibut stock. The cumulative tag loss rate is estimated using the approach developed by Seber and Felton (1981), based on the time spent at sea before recapture and the number of halibut recaptured with both tags or with one tag missing. The estimated cumulative tag loss rate for the 4RST stock (Figure 62) is approximately 5% after the first year and stabilizes at around 13% from the fourth year onward. For the 3NOPs4VWX5Zc stock, the estimated tag loss rate is much higher, between 20% and 25% during the first three years. The low loss rate observed in the GSL means that halibut are unlikely to lose both tags in the five years used to calculate the instantaneous mortality rate. Therefore, the tag loss rate has not been included in the estimation model for F.

The *F* values were estimated using the “irm_h” function in the “fishmethods” package (Nelson 2023) of the R software package, which incorporates the tag return model of Hoening et al. (1998). A natural mortality value of 0.10 was applied to the model. Table 7 summarizes the results for different tagging mortality values and tag return rates for halibut caught by fishers.

CONCLUSION

This data update on the Atlantic halibut stock in NAFO Divisions 4RST provides a solid basis for future analyses. The updated data provide a better understanding of current trends and potential changes in the halibut stock.

This information will be critical in informing future stock status assessments and in helping to develop evidence-based management recommendations. Although this data update does not provide a definitive stock status assessment, it is a crucial step in the assessment process.

Note that collecting accurate and up-to-date data is an essential part of effective fish stock management. The Atlantic halibut stock requires continued close monitoring, regular updating of data and the adaptation of management strategies in response to new information.

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TABLES

Table 1. Total declared landings (tonnes) of halibut for NAFO areas of the management unit (4R, 4S and 4T) and adjacent to it (3Pn and 4Vn). Ten-year average annual landings are presented from 1960 to 2009. Data for 2017 to 2022 are preliminary. The values are taken from NAFO (Table 21A) up to 1992 and from ZIFF files thereafter.

Year(s)	Division 4R	Division 4S	Division 4T	Division 3Pn	Division 4Vn
1960-1969	293.0	190.9	113.7	69.3	50.3
1970-1979	136.2	81.1	78.8	22.4	14.2
1980-1989	51.6	68.8	78.9	29.9	34.2
1990-1999	87.5	77.8	93.9	27.2	24.3
2000-2009	144.2	130.0	133.7	31.5	44.0
2010	192.6	233.7	256.2	64.6	68.1
2011	179.5	271.5	286.0	41.5	125.4
2012	278.3	233.9	219.1	48.7	95.8
2013	244.6	207.4	357.3	59.5	102.2
2014	262.2	268.2	340.2	79.4	138.1
2015	292.2	313.4	411.7	59.6	243.5
2016	289.3	370.6	359.1	115.0	268.8
2017	319.9	453.1	534.7	39.4	162.0
2018	333.7	466.5	454.5	92.2	168.8
2019	405.4	494.1	506.7	48.2	153.5
2020	377.5	453.4	578.7	125.8	308.9
2021	451.6	504.1	648.2	75.0	361.5
2022	468.5	519.7	421.6	39.1	143.7

Table 2. Reported halibut landings by fishing gear calculated from ZIFF files. Data from 2017 to 2022 are preliminary. The start and end dates of management cycles are described in section FISHING STATISTICS.

Management cycle	Longline	Gillnet	Other	Unknown	Total
1985	96.0	13.1	92.1	1.0	202.2
1986	171.2	70.7	93.8	0.0	335.7
1987	110.1	40.1	126.7	0.0	276.9
1988	140.6	42.8	72.4	0.0	255.8
1989	124.3	64.7	65.1	0.1	254.2
1990	225.5	60.2	156.9	0.2	442.7
1991	265.1	51.1	64.3	1.1	381.6
1992	88.9	19.2	56.1	0.1	164.2
1993	98.2	23.0	24.9	0.0	146.1
1994	91.3	19.7	13.9	56.6	181.4
1995	34.0	24.2	14.7	33.4	106.3
1996	154.4	14.2	44.8	22.5	235.9
1997	230.7	32.8	24.4	9.6	297.6
1998	270.5	21.7	13.4	0.0	305.6
1999	290.8	33.1	20.4	0.0	344.4
2000	248.7	24.1	14.5	0.0	287.2
2001	258.4	25.8	14.8	0.0	299.0
2002	253.7	16.9	10.2	1.5	282.4
2003	277.3	24.1	12.1	0.0	313.4
2004	393.2	20.9	10.9	0.0	424.9
2005	364.3	28.7	17.2	0.0	410.1
2006	328.7	44.2	14.8	0.0	387.8
2007	358.9	60.9	19.2	0.0	439.1
2008	476.2	106.5	12.7	0.0	595.4
2009	541.9	77.8	20.0	0.0	639.7
2010	587.6	82.6	12.3	0.0	682.5
2011	641.9	84.1	11.0	0.0	737.0
2012	613.8	104.3	13.1	0.0	731.3
2013	688.7	109.8	10.8	0.0	809.4
2014	797.0	65.7	7.7	0.1	870.5
2015	963.5	42.6	10.9	0.3	1 017.3
2016	967.6	37.2	13.7	0.6	1 018.9
2017	1 238.1	56.2	13.4	0.0	1 307.7
2018	1 180.0	63.9	10.8	0.0	1 254.7
2019	1 327.8	59.2	17.1	2.1	1 406.1
2020	1 374.7	22.9	11.8	0.2	1 409.6
2021	1 547.8	28.0	26.6	1.4	1 603.9
2022	1 393.6	7.2	9.1	0.0	1 409.9

Table 3. Reported halibut landings by fishing gear calculated from ZIFF files. Data from 2017 to 2022 are preliminary. The start and end dates of management cycles are described in section FISHING STATISTICS.

Management cycle	Atlantic halibut	Greenland halibut	Cod	Other	Unknown	Total
1985	0.2	0.0	34.2	18.4	149.4	202.2
1986	1.2	0.0	36.0	31.0	267.5	335.7
1987	0.0	1.7	26.8	54.4	194.0	276.9
1988	4.5	0.4	82.4	30.9	137.7	255.8
1989	0.0	4.0	71.6	25.5	153.2	254.2
1990	18.9	7.5	56.6	18.2	341.6	442.7
1991	47.0	7.4	47.8	18.5	260.8	381.6
1992	11.8	2.5	37.2	23.4	89.3	164.2
1993	11.5	4.6	29.2	16.9	83.9	146.1
1994	65.8	2.5	0.0	7.7	105.4	181.4
1995	22.3	0.1	0.0	1.2	82.6	106.3
1996	138.2	3.3	0.0	9.5	85.0	235.9
1997	163.0	3.6	6.2	23.0	101.9	297.6
1998	188.7	10.3	9.7	10.0	87.0	305.6
1999	207.4	18.6	15.9	11.9	90.5	344.4
2000	202.2	23.2	33.4	4.2	24.3	287.2
2001	157.6	24.4	82.5	6.1	28.4	299.0
2002	183.6	11.3	61.8	6.6	19.1	282.4
2003	218.1	33.5	2.1	6.7	53.0	313.4
2004	296.7	17.9	84.2	7.7	18.4	424.9
2005	278.8	20.7	67.0	8.8	34.9	410.1
2006	287.8	27.3	40.5	13.9	18.2	387.8
2007	322.1	45.7	41.7	15.1	14.4	439.1
2008	398.2	88.2	81.9	18.8	8.3	595.4
2009	502.3	70.0	45.2	21.9	0.4	639.7
2010	553.7	75.2	34.0	18.4	1.3	682.5
2011	581.4	79.1	58.8	17.0	0.6	737.0
2012	576.5	105.7	33.1	15.8	0.1	731.3
2013	665.5	110.9	22.1	10.7	0.1	809.4
2014	760.7	63.7	38.8	7.2	0.1	870.5
2015	941.7	40.2	19.8	11.3	4.4	1 017.3
2016	946.7	34.9	20.1	15.5	1.7	1 018.9
2017	1 206.3	49.9	38.7	12.9	0.0	1 307.7
2018	1 155.6	59.9	28.3	10.0	0.9	1 254.7
2019	1 328.8	58.4	5.8	12.9	0.2	1 406.1
2020	1 366.6	23.1	8.4	11.1	0.4	1 409.6
2021	1 549.5	17.7	13.6	22.0	1.1	1 603.9
2022	1 393.3	6.0	0.1	10.3	0.3	1 409.9

Table 4. Data available to calculate commercial CPUE, as a percentage of longline landings targeting Atlantic halibut, by NAFO zone.

Management cycle	4R	4S	4T
1998	22.4	15.9	0.0
1999	51.7	12.4	0.0
2000	47.5	3.7	0.0
2001	49.8	1.5	0.0
2002	30.2	6.6	0.0
2003	57.5	94.0	72.9
2004	42.8	81.8	93.0
2005	44.3	96.9	44.9
2006	32.2	87.3	89.1
2007	34.6	86.6	97.1
2008	37.5	88.5	94.6
2009	30.0	82.3	86.6
2010	32.4	78.1	89.2
2011	39.8	85.3	72.4
2012	30.5	99.1	93.7
2013	17.2	85.3	91.6
2014	11.7	85.5	89.2
2015	10.6	94.4	91.8
2016	18.2	89.3	94.6
2017	13.6	99.8	87.2
2018	12.8	91.7	92.4
2019	18.5	97.0	91.6
2020	14.6	95.7	88.6
2021	13.6	91.0	80.4
2022	2.4	80.8	82.0

Table 5. Number of halibut tagged and number recaptured. The first and second values represent the number of halibut recaptured with two tags or one tag, respectively.

Tagging Year	Number tagged	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
2014	224	0 - 0	7 - 1	9 - 0	4 - 0	8 - 1	1 - 1	1 - 0	2 - 0	1 - 0	36
2015	753	0 - 0	0 - 0	9 - 1	15 - 3	14 - 3	6 - 3	4 - 3	7 - 2	3 - 0	73
2016	321	0 - 0	0 - 0	0 - 0	10 - 0	8 - 0	5 - 0	5 - 1	0 - 1	0 - 0	30
2017	444	0 - 0	0 - 0	0 - 0	0 - 0	7 - 0	7 - 2	1 - 0	0 - 0	0 - 1	18
2018	540	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	6 - 1	7 - 3	5 - 1	5 - 1	29
2019	753	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	2 - 0	18 - 2	14 - 1	8 - 0	45
2020	781	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	10 - 1	12 - 3	26
2021	861	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	10 - 1	11
2022	674	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	1 - 0	1

Table 6. Number of halibut tagged and number recaptured. Only halibut affixed with two tags and sampled proportionally to density are shown. The first and second values represent the number of halibut recaptured with two tags or one tag, respectively.

Tagging Year	Number tagged	2017	2018	2019	2020	2021	2022	Total
2017	420	0 - 0	7 - 0	4 - 2	1 - 0	0 - 0	0 - 1	15
2018	531	0 - 0	0 - 0	5 - 1	6 - 3	5 - 1	5 - 1	27
2019	685	0 - 0	0 - 0	2 - 0	15 - 2	13 - 0	8 - 0	40
2020	740	0 - 0	0 - 0	0 - 0	0 - 0	10 - 1	12 - 3	26
2021	852	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	10 - 1	11
2022	659	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	1 - 0	1

Table 7. Input parameters and estimates obtained by adjusting the model for recaptures of tagged halibut. A range of values for the tag return rate (TR) and the post-tagging survival rate (SSM) were used in the models. M = natural mortality; F = fishing mortality.

Model	M	F 2018	F 2019	F 2020	F 2021	F 2022
TR=0,5; SSM=0,9	0.12	0.04161908	0.03296557	0.04512206	0.03659025	0.03891889
TR=0,5; SSM=1	0.12	0.03714153	0.02949170	0.04040066	0.03273047	0.03476177
TR=0,6; SSM=0,9	0.12	0.03419706	0.02719661	0.03728097	0.03018290	0.03202477
TR=0,6; SSM=1	0.12	0.03055670	0.02433392	0.03340077	0.02702157	0.02863558
TR=0,7; SSM=0,9	0.12	0.02902143	0.02314098	0.03175797	0.02568898	0.02720723
TR=0,7; SSM=1	0.12	0.02596427	0.02073684	0.02847776	0.02302320	0.02435830
TR=0,8; SSM=0,9	0.12	0.02520492	0.02013833	0.02766078	0.02236048	0.02365082
TR=0,8; SSM=1	0.12	0.02257713	0.01805714	0.02481232	0.02005383	0.02118999
TR=0,9; SSM=0,9	0.12	0.02226684	0.01782742	0.02449092	0.01978759	0.02091841
TR=0,9; SSM=1	0.12	0.01996829	0.01598431	0.02199030	0.01775529	0.01875530
TR=1; SSM=0,9	0.12	0.01996829	0.01598431	0.02199030	0.01775529	0.01875530
TR=1; SSM=1	0.12	0.01788967	0.01435035	0.01974099	0.01593795	0.01681442

FIGURES

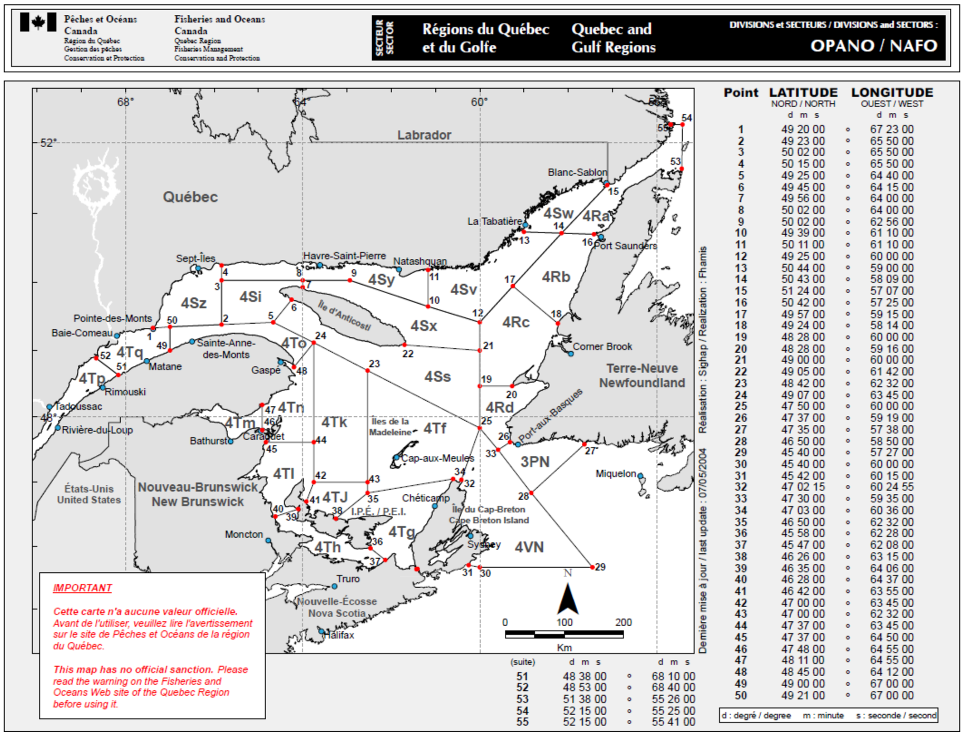

Figure 1. Map of the NAFO divisions and sectors of the St. Lawrence estuary and gulf. The stock management unit includes divisions 4R, 4S and 4T.

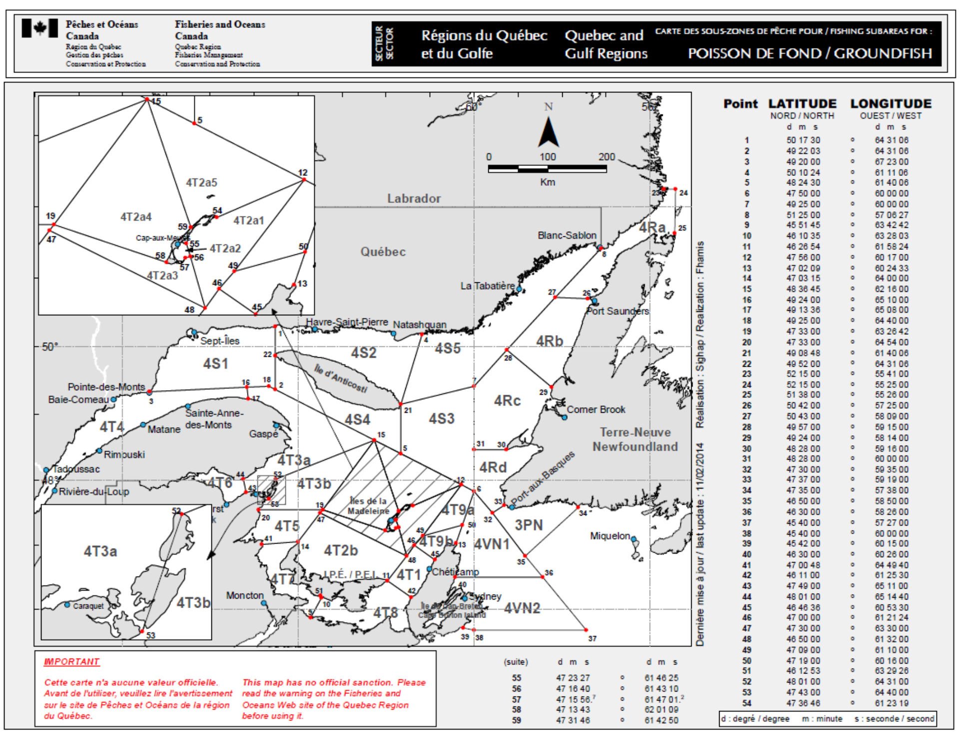

Figure 2. Map of groundfish fishing subareas of the St. Lawrence estuary and gulf. The stock management unit includes divisions 4R, 4S and 4T.

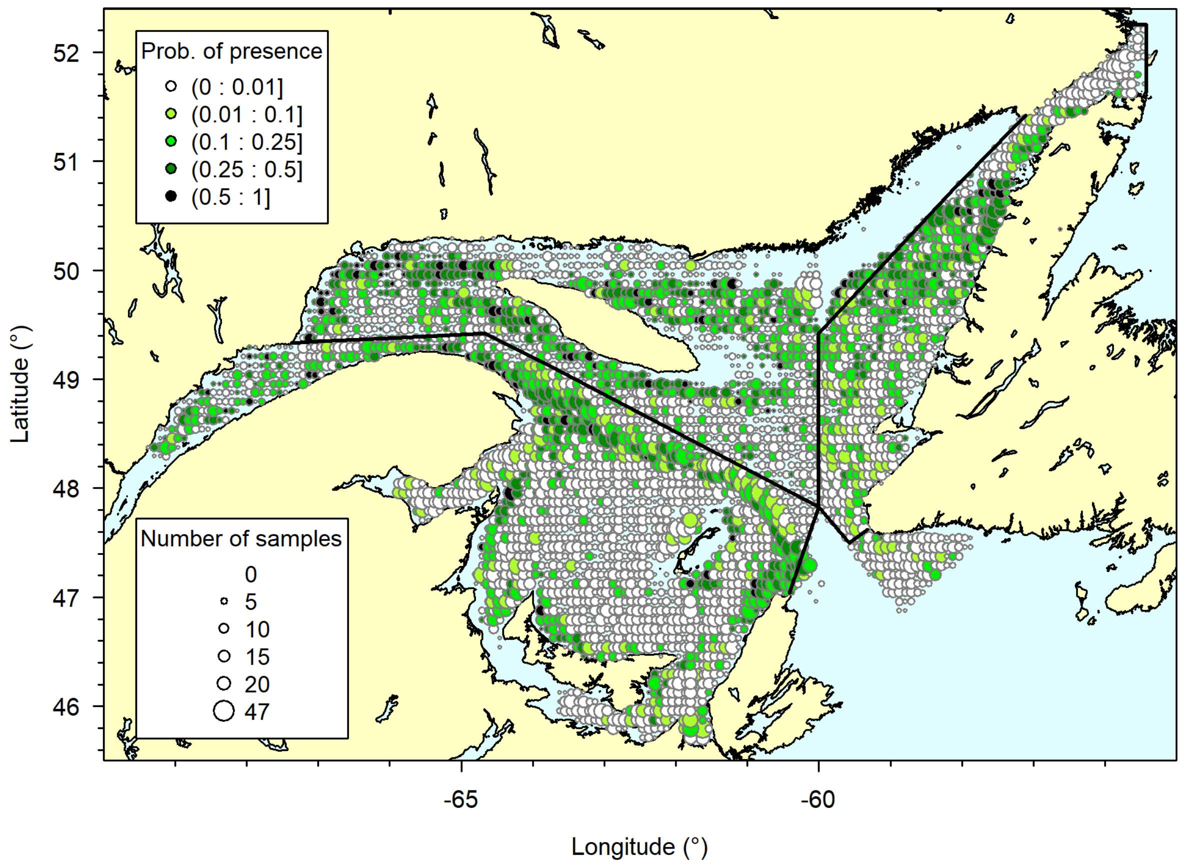

Figure 3. Distribution of the probabilities of catching halibut in scientific bottom trawl surveys, by 5-minute quadrilateral, during the years 1985 to 2022.

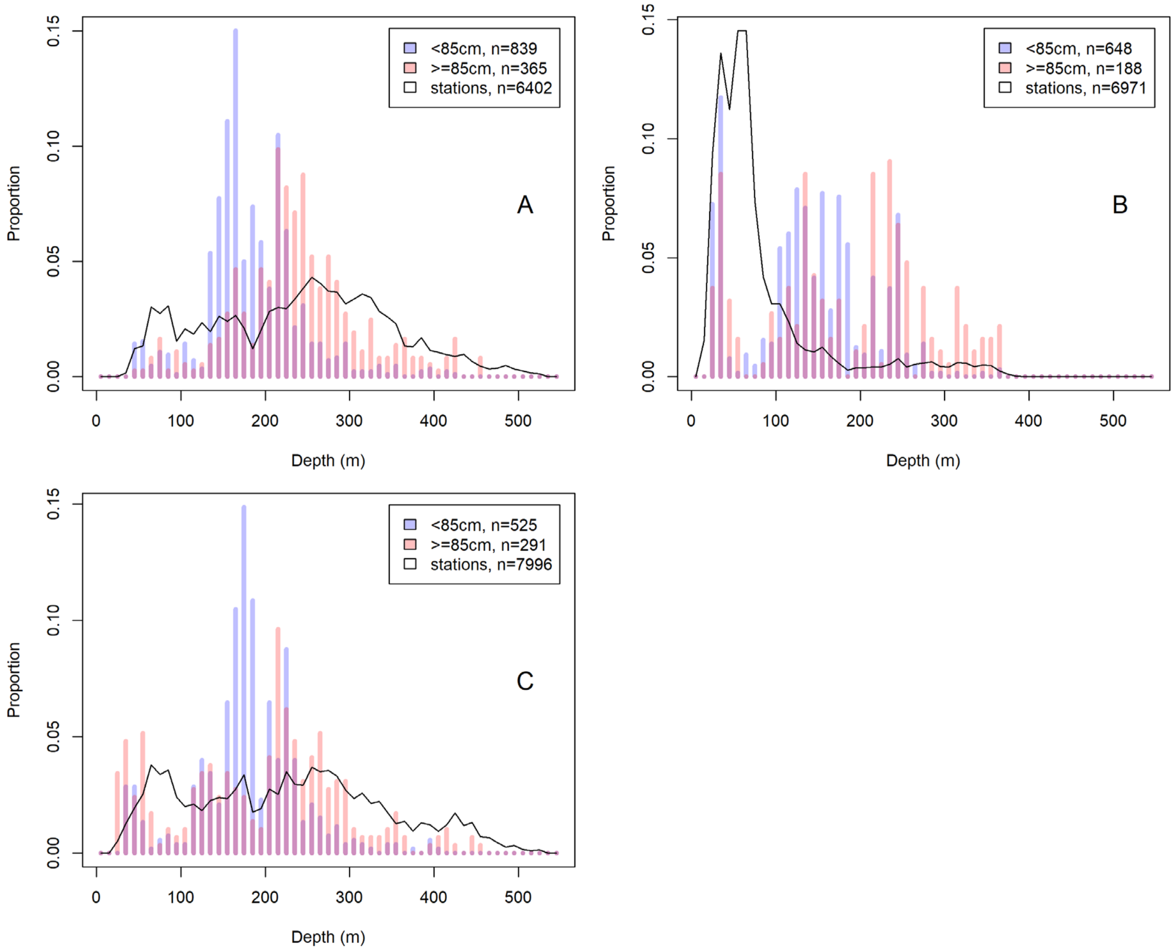

Figure 4. Proportion of catches by depth and size class, between 1985 and 2022. The depth classes cover 10 m, and the black line indicates the proportion of stations carried out by depth class. Data are from the DFO nGSL (A) and sGSL (B) surveys, as well as those from the nGSL (C) sentinel survey.

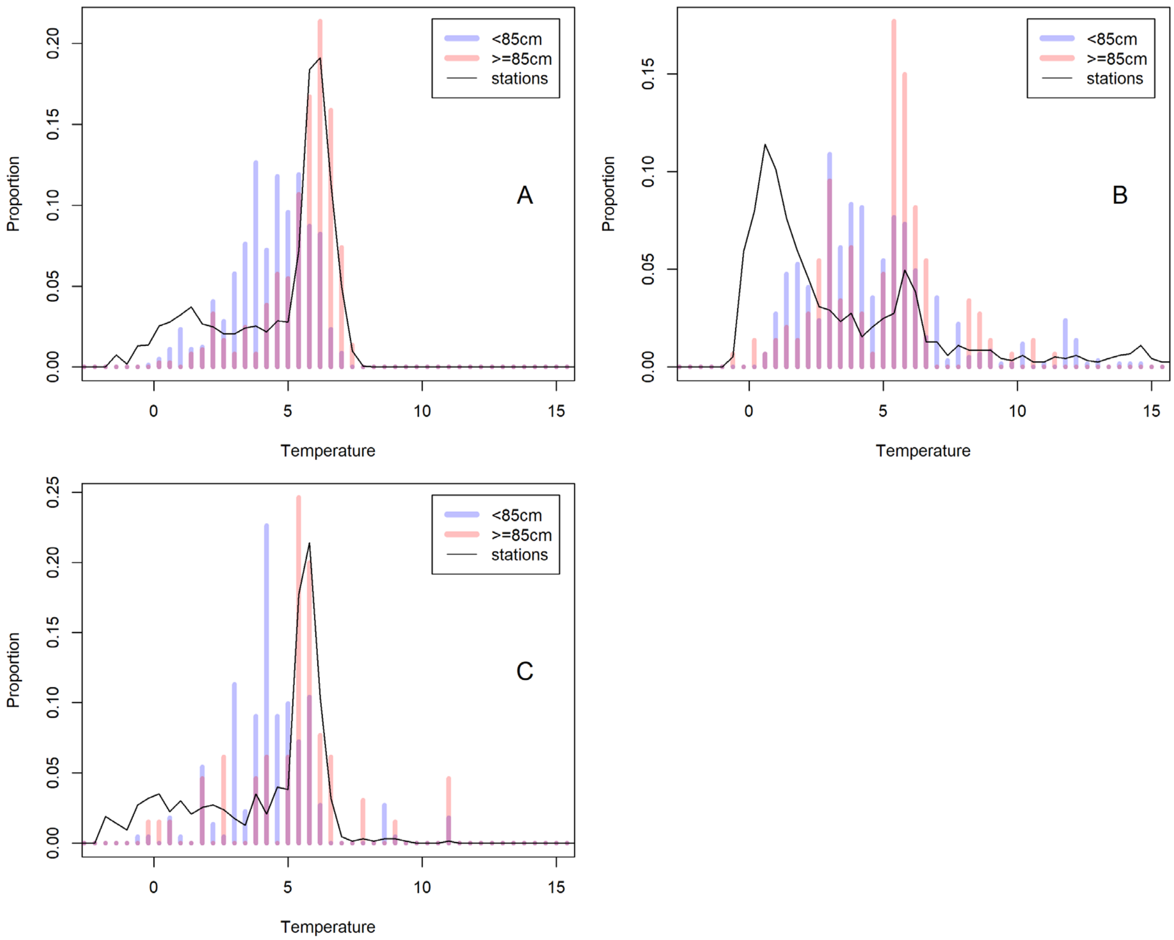

Figure 5. Proportion of catches by bottom temperature and size class, between 1985 and 2022. The temperature classes cover 0.4 degrees, and the black line indicates the proportion of stations carried out by depth class. Data are from the DFO nGSL (A) and sGSL (B) surveys, as well as those from the nGSL (C) sentinel survey.

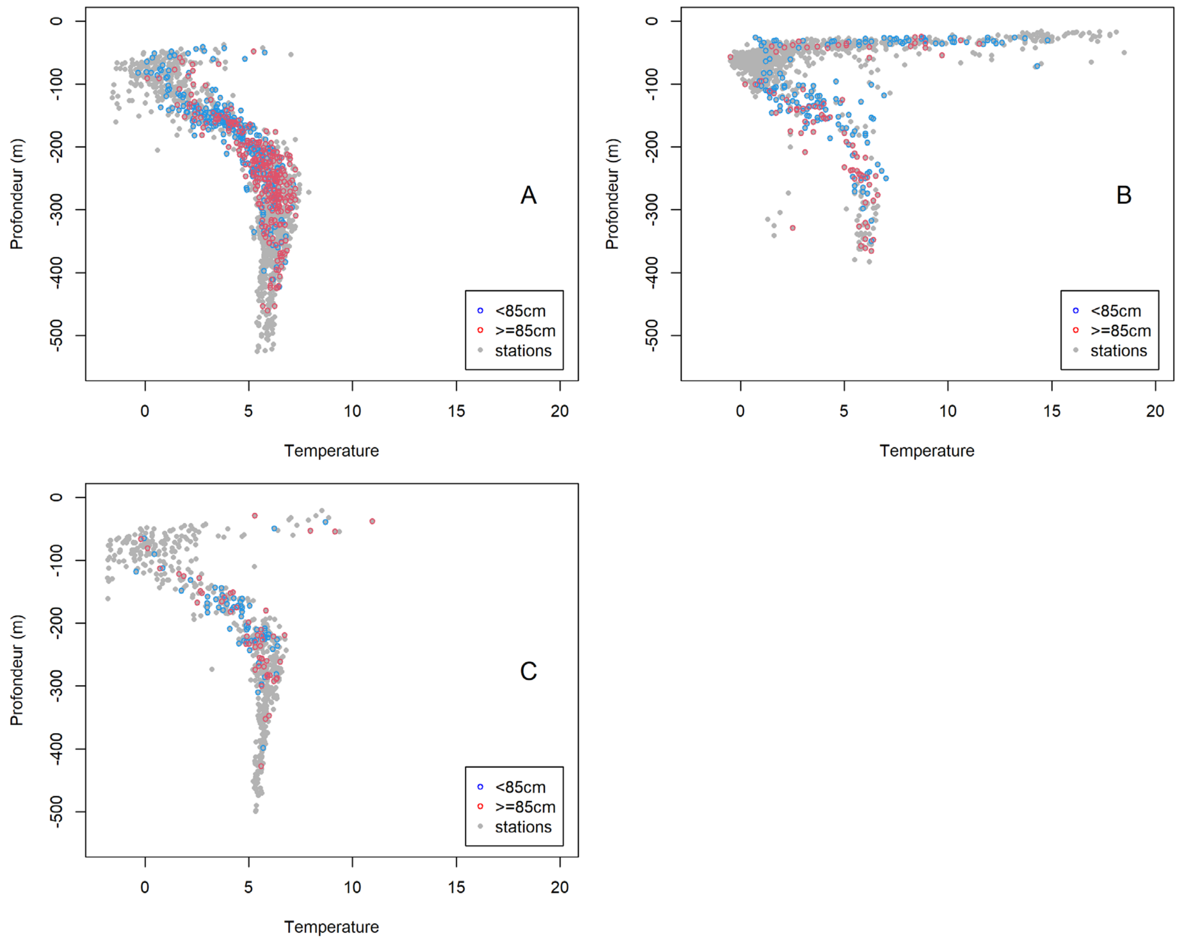

Figure 6. Depth and temperature at the bottom of scientific bottom trawl survey stations and catches by size class, between 2011 and 2020. Data are from the DFO nGSL (A) and sGSL (B) surveys, as well as those from the nGSL (C) sentinel survey.

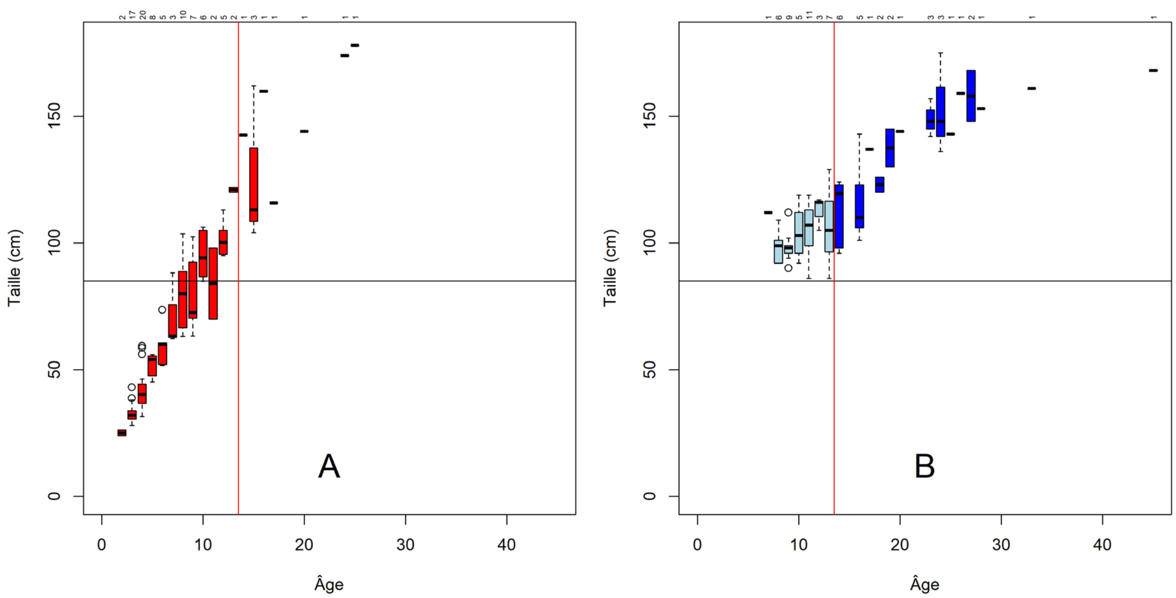

Figure 7. Age of halibut caught by trawl (A) and longline (B). The horizontal black line is the minimum legal size in force (85 cm) and the vertical red line indicates the minimum age (14 years) of halibut caught by longline and retained for analysis. The numbers observed for each age are shown at the top of the graph.

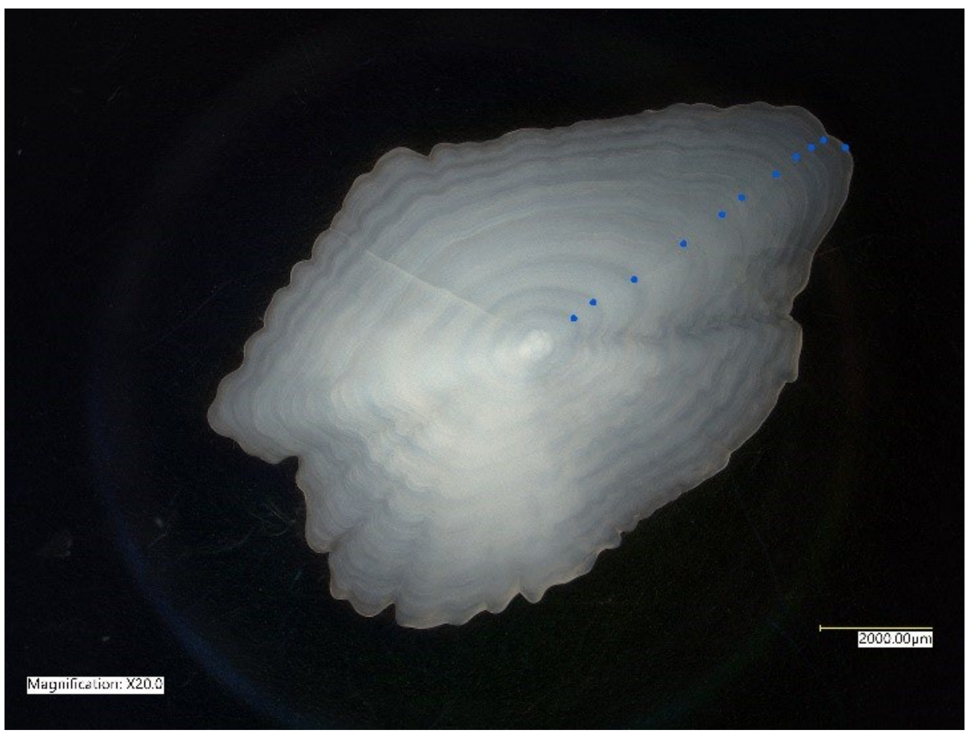

Figure 8. Image of the distal surface of a left sagitta from a 118 cm female halibut, taken with a Keyence microscope using reflected light.

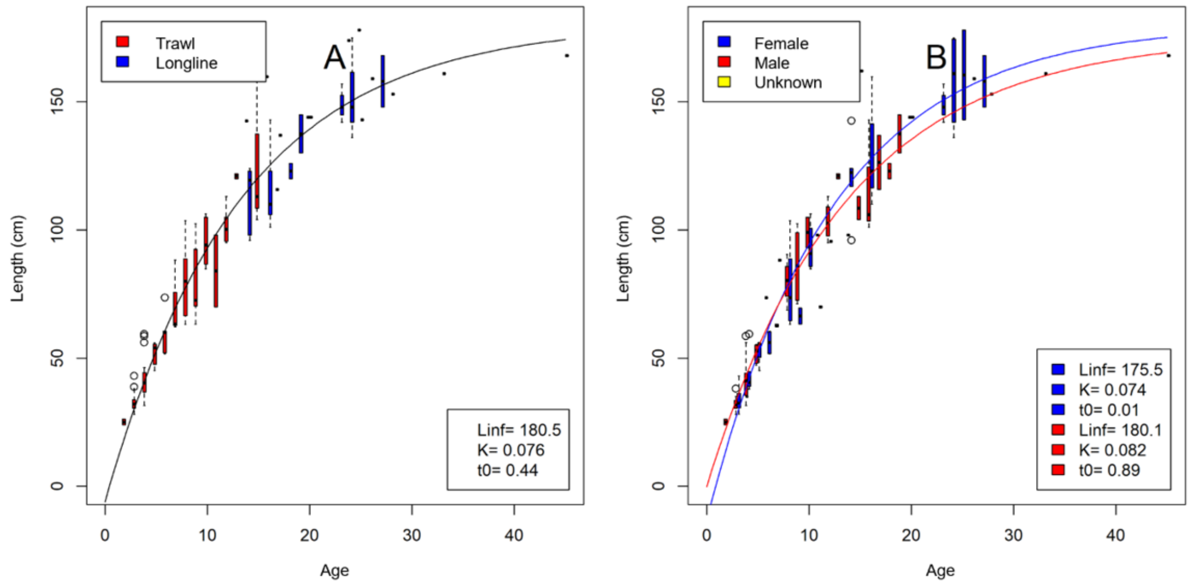

Figure 9. Fitting a von Bertalanffy growth curve to the data set (A) and by sex (B).

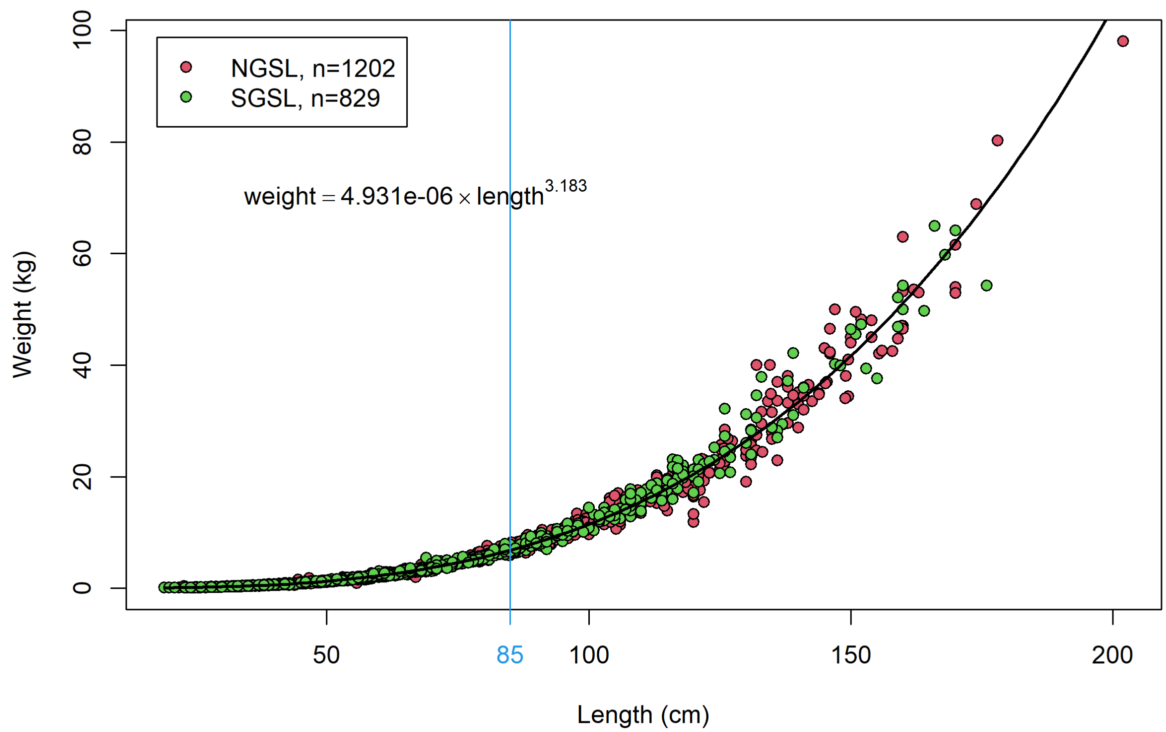

Figure 10. Adjustment of a length-weight correspondence relationship to DFO surveys data, sexes combined. The vertical line represents the current minimum legal size.

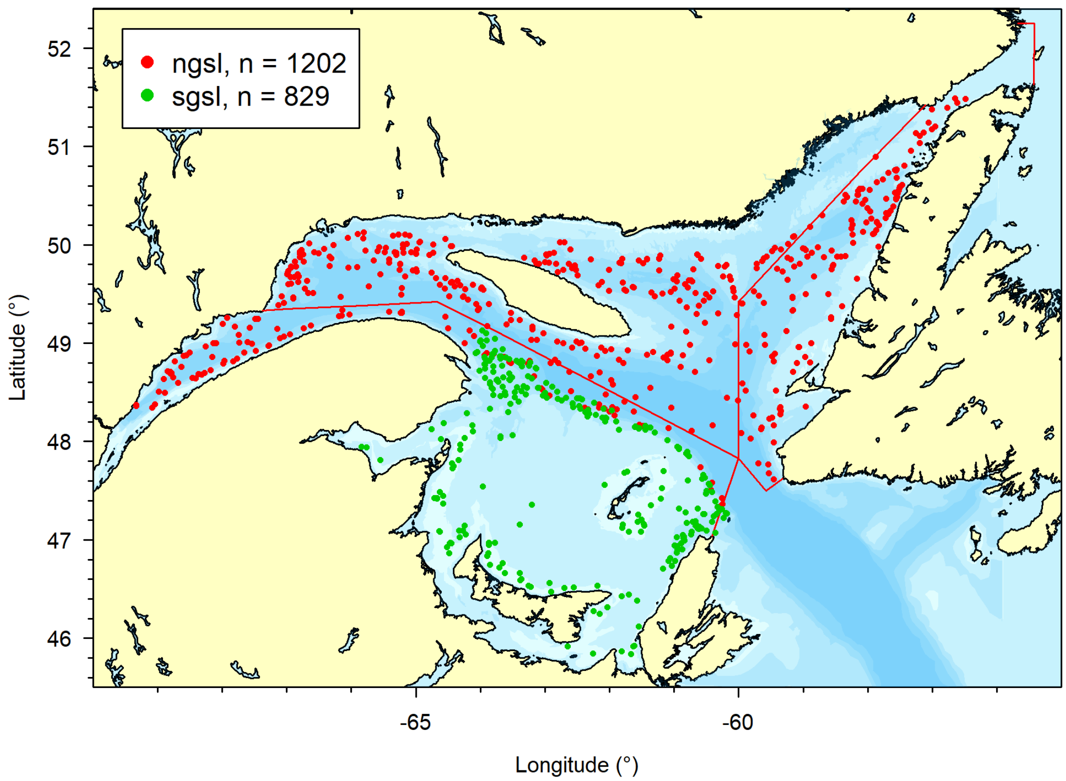

Figure 11. Distribution of halibut caught over the past 10 years during DFO science bottom trawl surveys and used to calculate a length-weight correspondence relationship.

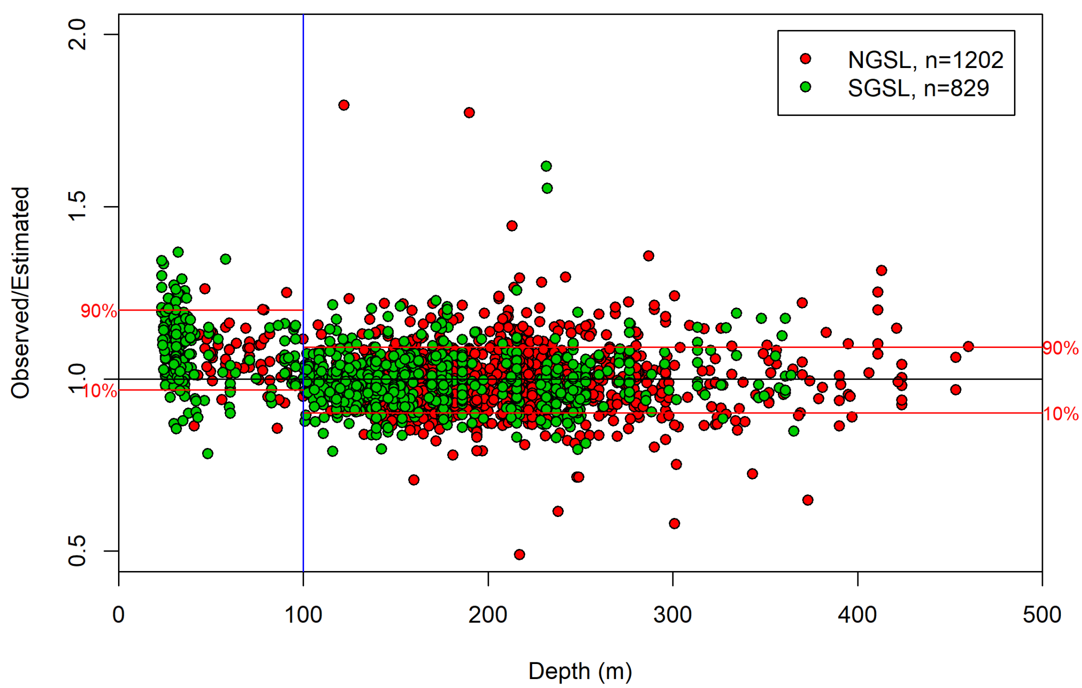

Figure 12. Distribution of residuals from the fit of a length-weight correspondence relationship as a function of depth of capture of halibut. The red lines delimit quantiles for the component at less than 100 m and more than 100 m.

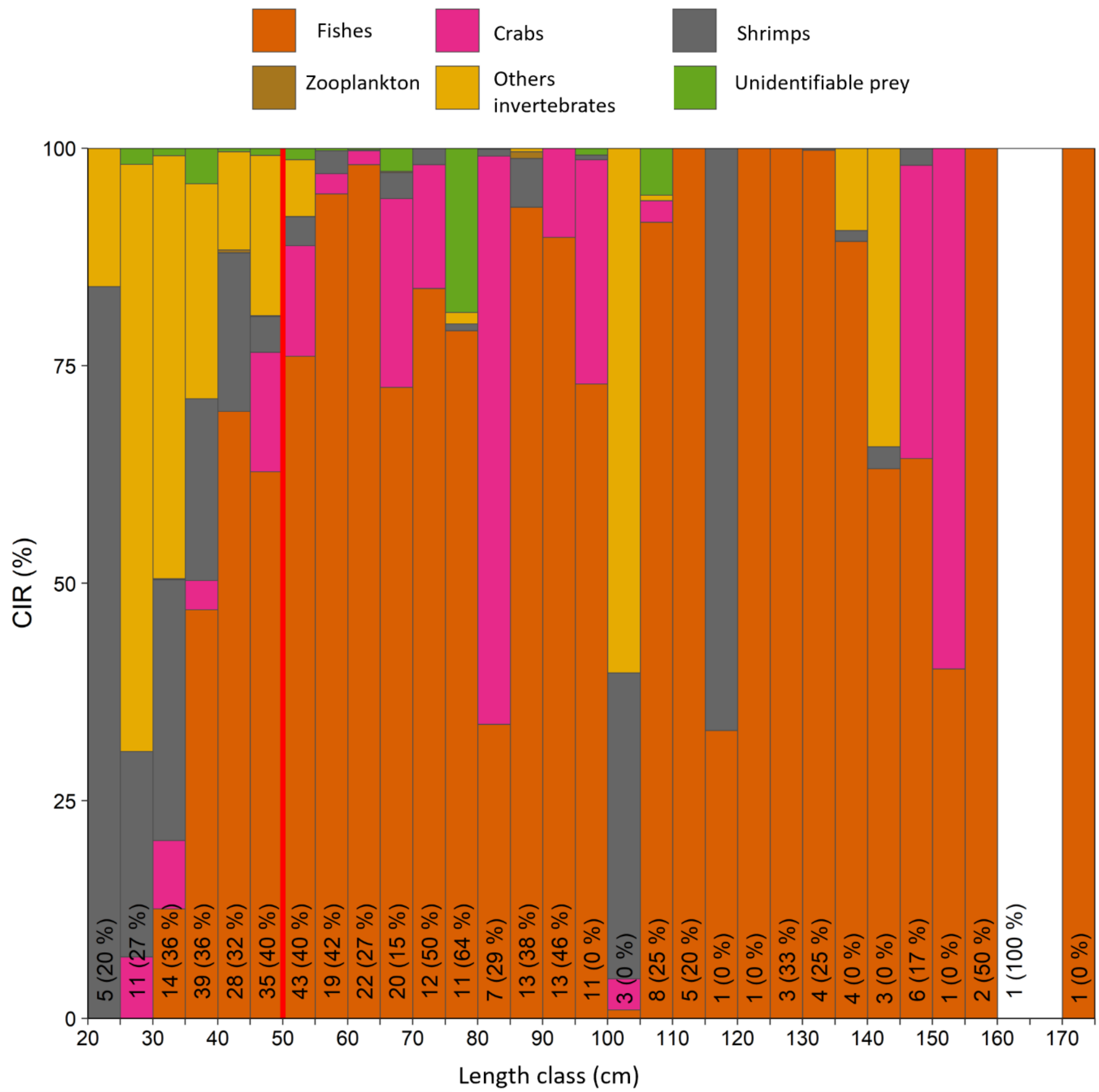

Figure 13. Contribution of the filling index (CIR) of prey groups to the total filling index of halibut stomachs. from Ouellette-Plante et al. (2020). Numbers and percentages of empty stomachs are provided for each size class. The vertical red line separates halibut into two classes: those smaller than 50 cm and those larger than 50 cm.

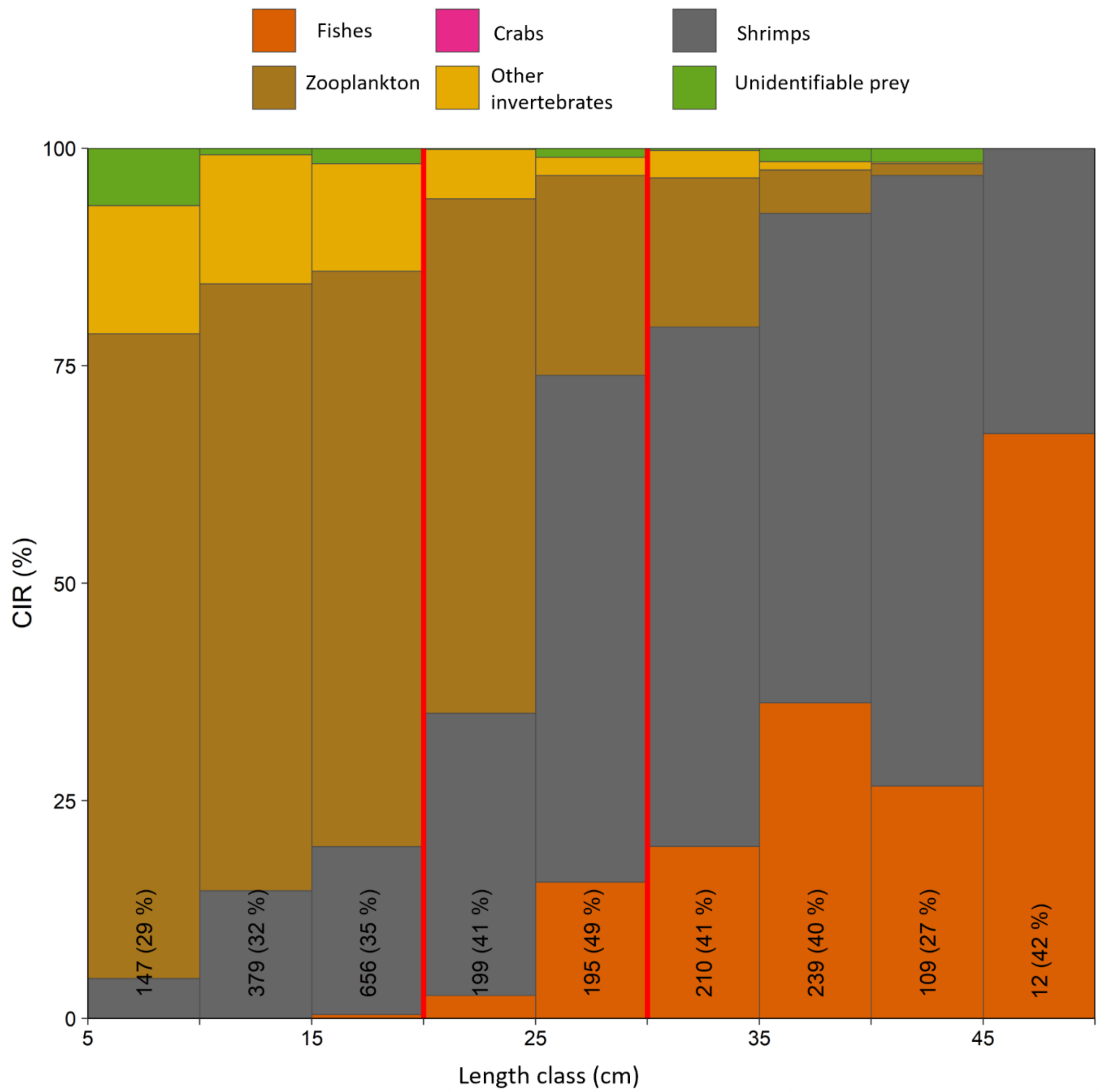

Figure 14. Contribution of the filling index (CIR) of prey groups to the total filling index of redfish stomachs. from Ouellette-Plante et al. (2020). Numbers and percentages of empty stomachs are provided for each size class. The vertical red line separates redfish into three classes: those smaller than 20 cm, between 20 and 30 cm, and those larger than 30 cm.

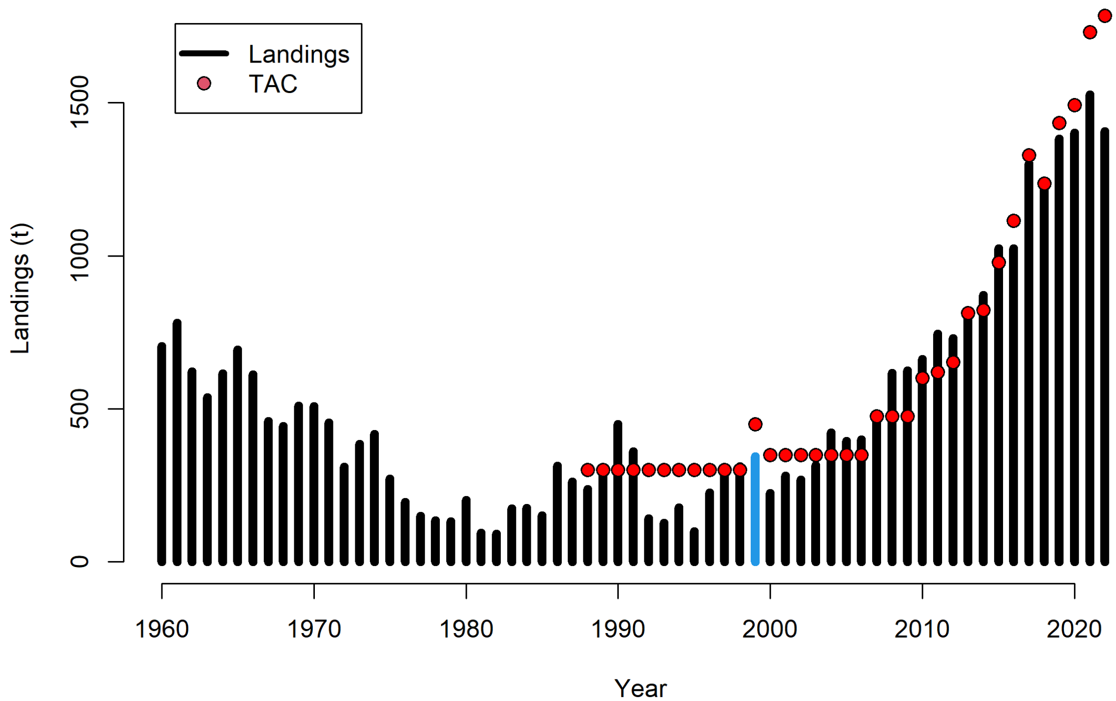

Figure 15. Halibut landings and TAC (after revision) by management cycle for NAFO Divisions 4RST. The landings reported for the year 1999 (in blue) exceptionally took place over a period of one year and 135 days due to a change in the definition of the management year. Landings between 2017 and 2022 are preliminary.

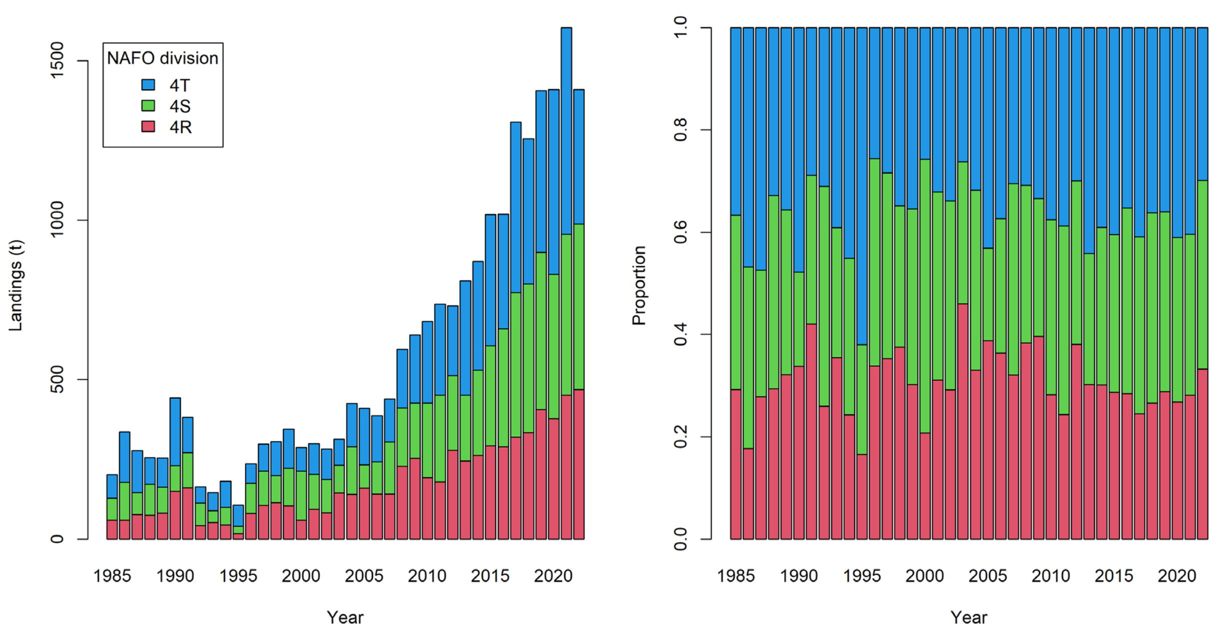

Figure 16. Halibut landings by NAFO division. Data from 2017 to 2022 are preliminary.

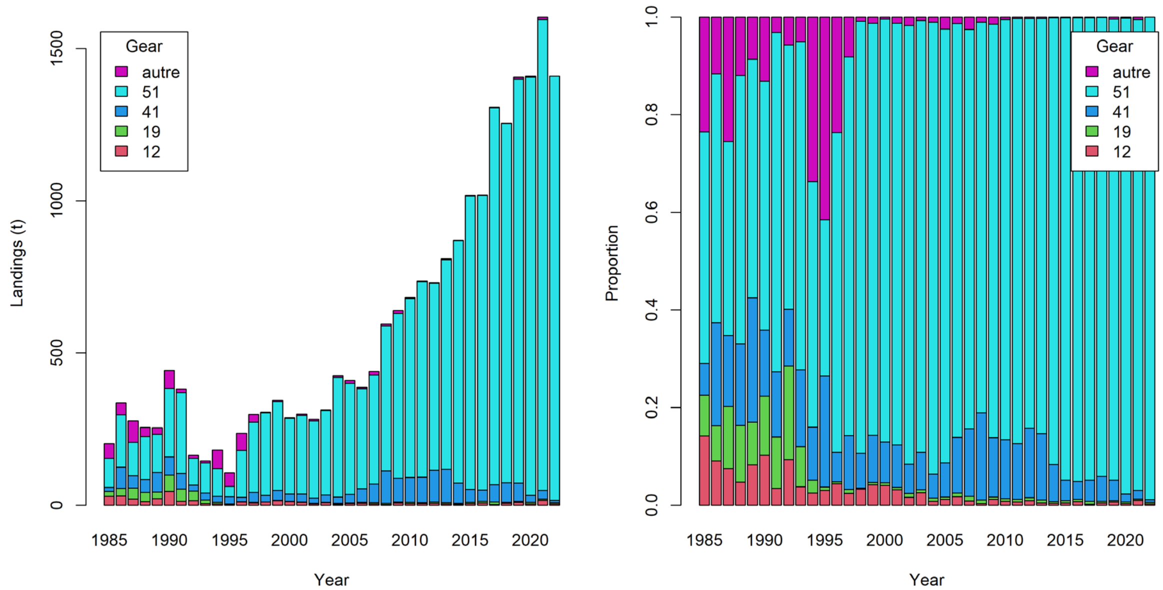

Figure 17. Halibut landings by gear (12=Bottom otter trawl (stern). 19=Shrimp trawl. 41=Gillnet. 51=Longline). Data from 2017 to 2022 are preliminary.

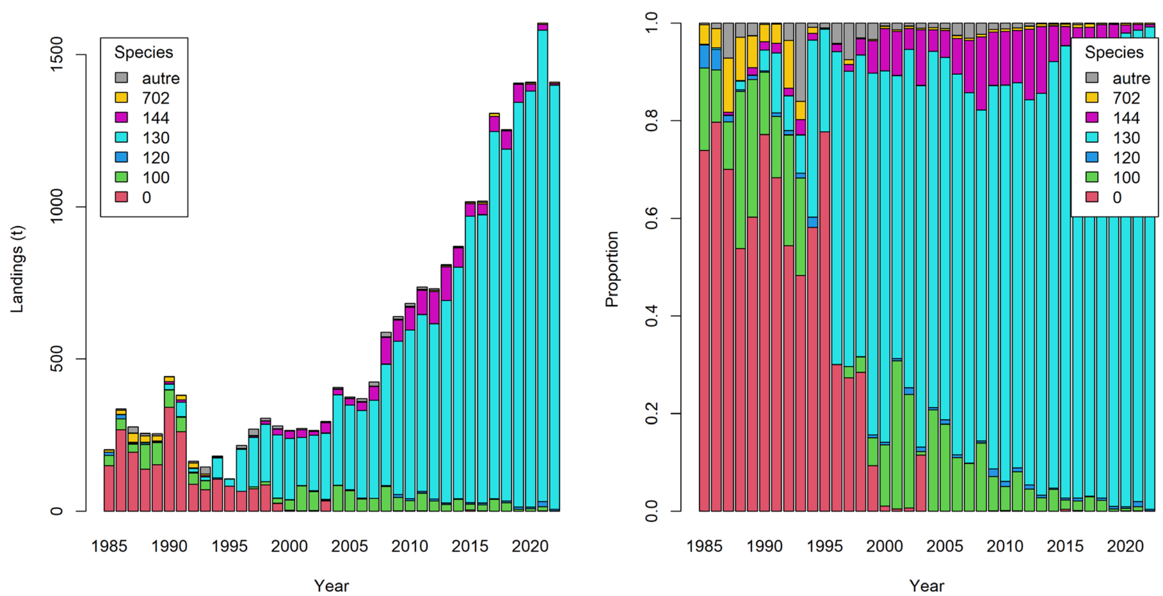

Figure 18. Proportion of halibut landings by target species (0=not specified, 100=Cod, 120=Redfish, 130=Atlantic halibut, 144=Greenland halibut, 702=Shrimp). Data from 2017 to 2022 are preliminary.

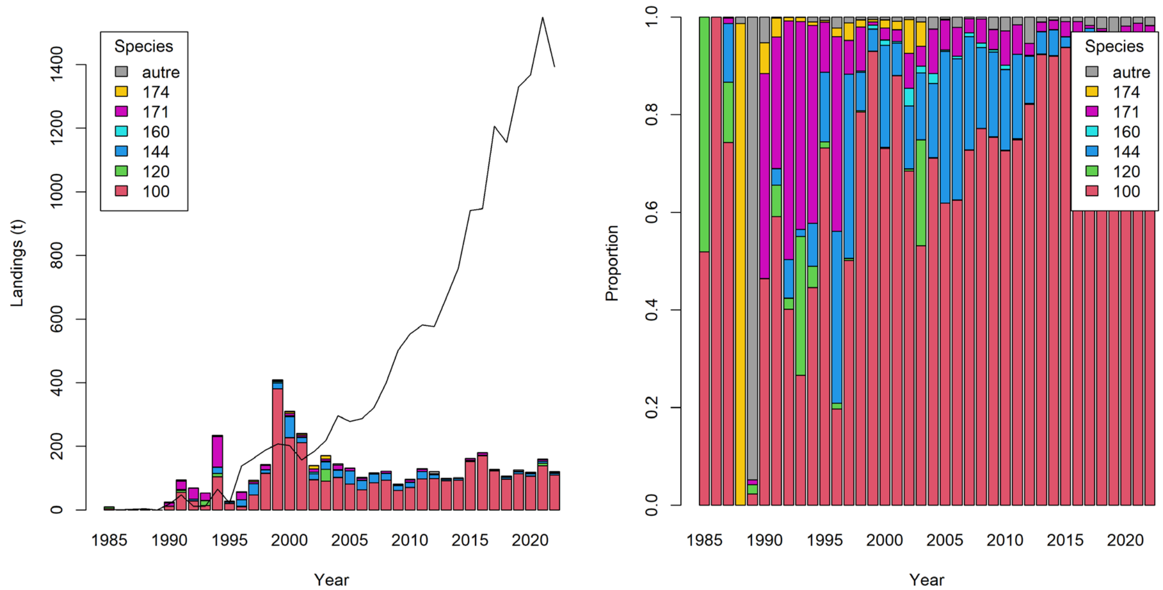

Figure 19. Proportion of bycatch landings where halibut is the target species (100=Cod, 120=Redfish, 144=Greenland halibut, 160=Skates, 171=White hake, 174=Wolffish). The black line represents halibut landings when halibut is targeted. Data from 2017 to 2022 are preliminary.

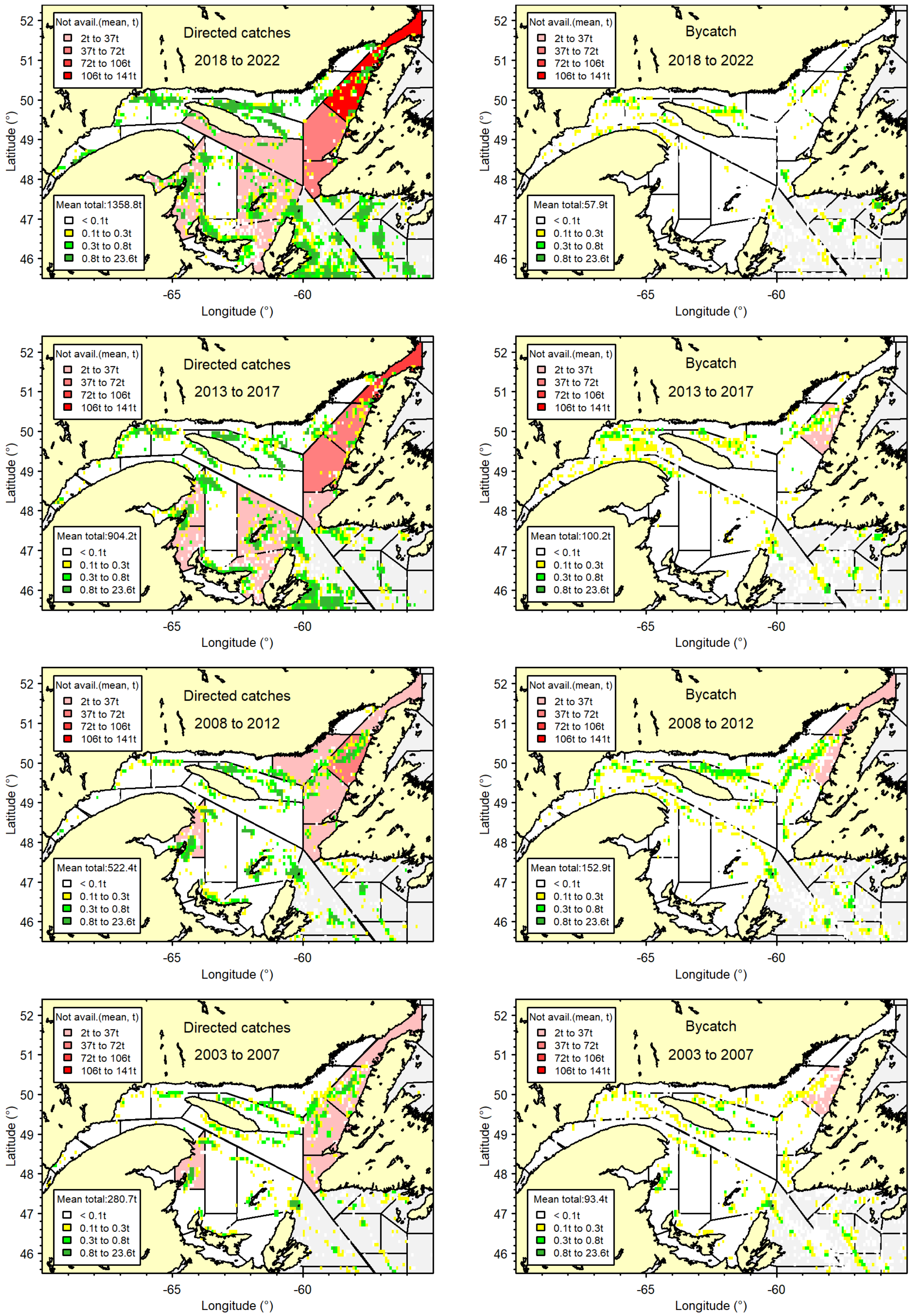

Figure 20. Spatial distribution of halibut catches in directed fishing and bycatch, by 5-minute square. Landings without associated geographic coordinates are reported to the NAFO sub-division and the average annual quantity is indicated as "Not avail.". Data from 2017 to 2022 are preliminary.

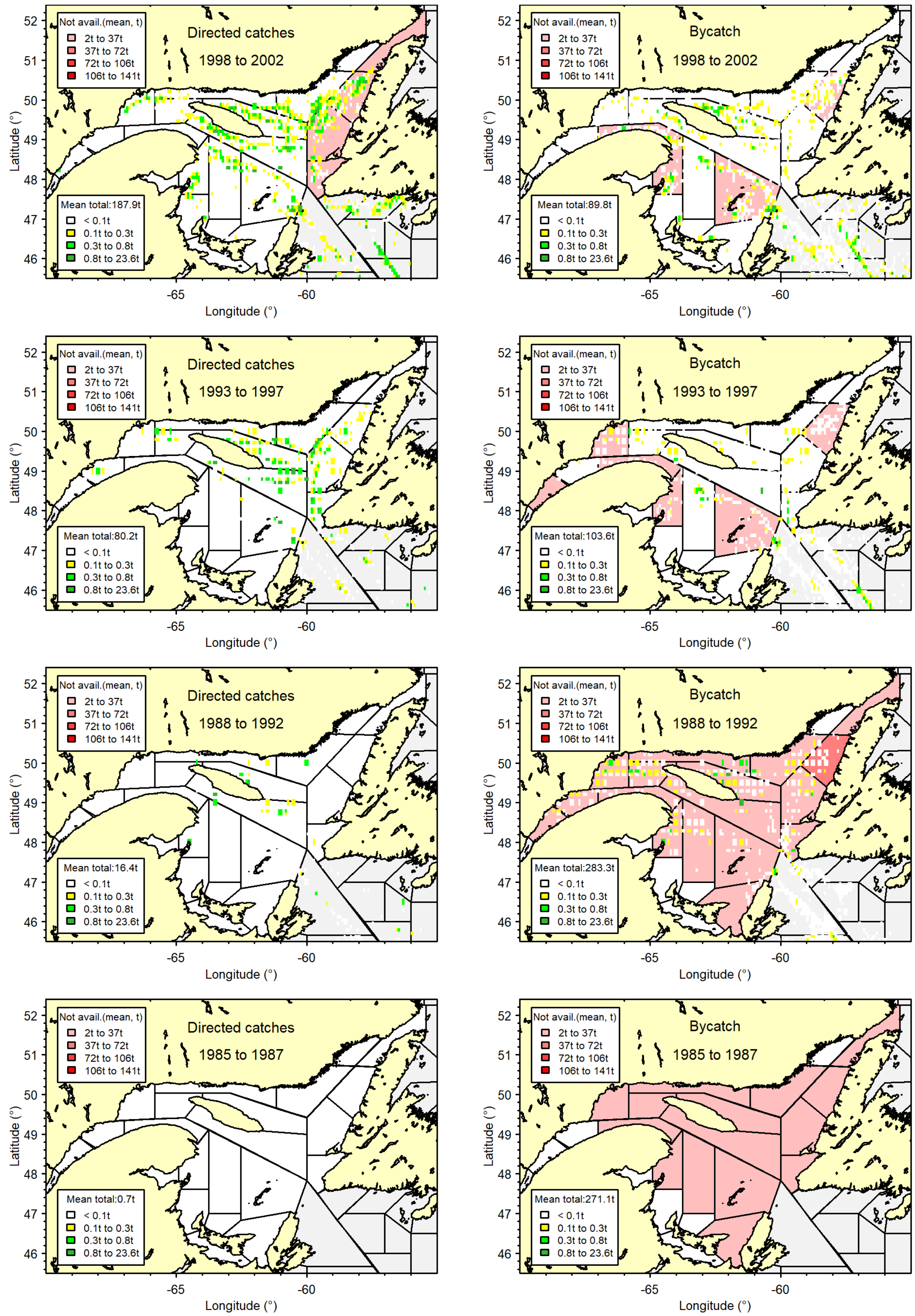

Figure 20. (Continued) Spatial distribution of halibut catches in directed fishing and bycatch, by 5-minute square. Landings without associated geographic coordinates are reported to the NAFO sub-division and the average annual quantity is indicated as "Not avail.". Data from 2017 to 2022 are preliminary.

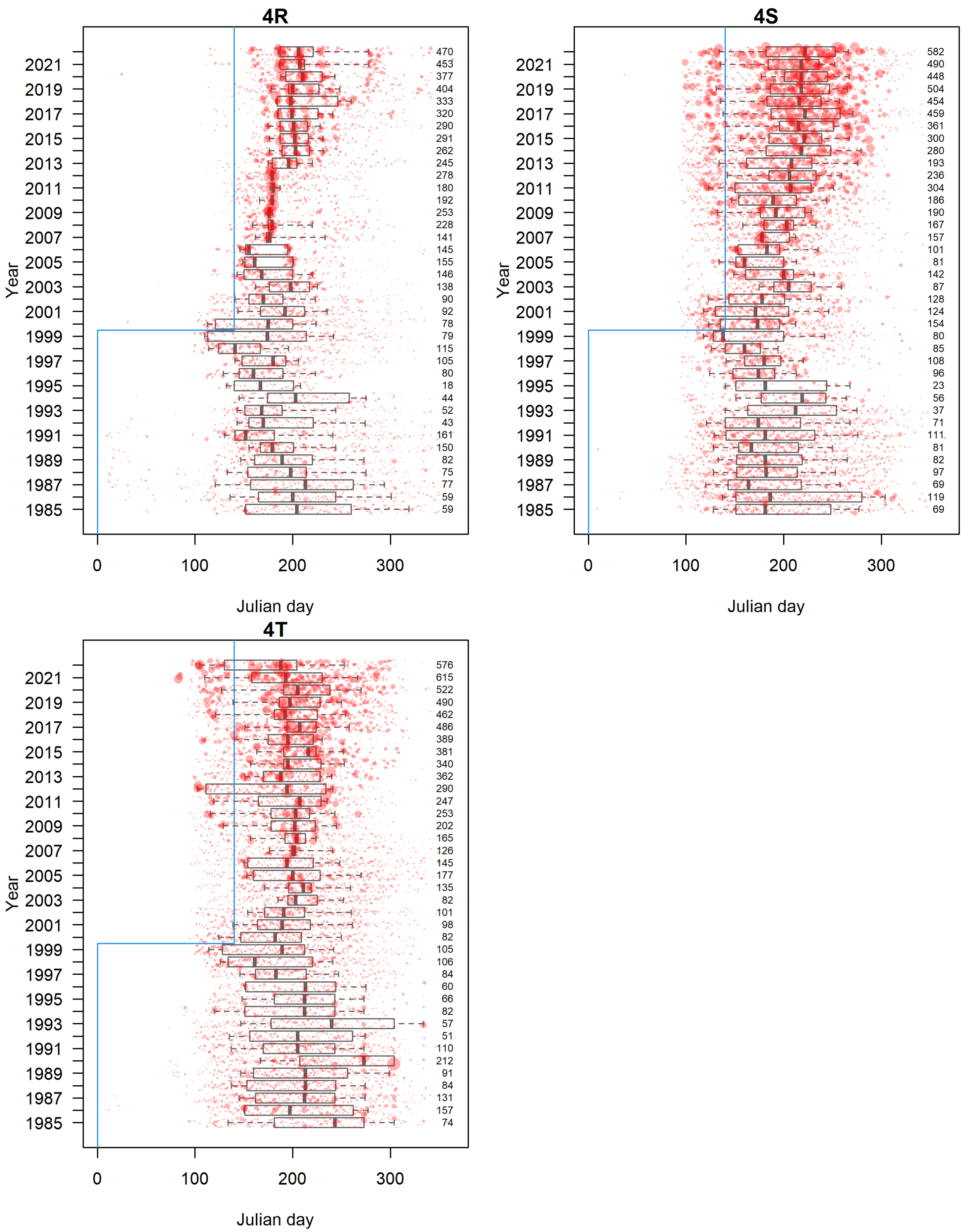

Figure 21. Daily distribution of landings for NAFO areas 4R, 4S and 4T. The size of the points varies according to the total daily landings. Boxplots show the 10, 25, 50, 75, and 90 percentiles of cumulative landings and annual totals (t) are shown to the right of the graph. The blue line separates two successive management cycles. Data from 2017 to 2022 are preliminary.

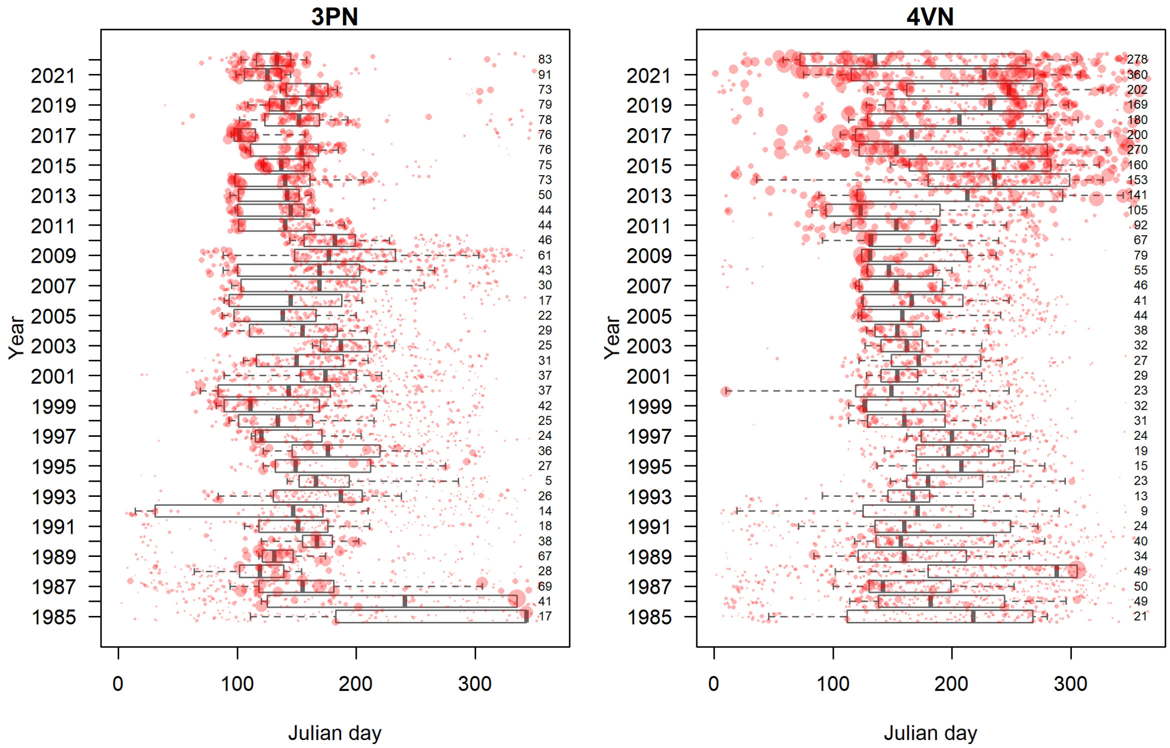

Figure 22. Daily distribution of landings for NAFO areas 3Pn and 4Vn, adjacent to management unit 4RST. The size of the points varies according to the total daily landings. Boxplots show the 10, 25, 50, 75, and 90 percentiles of cumulative landings and annual totals (t) are shown to the right of the graph. Data from 2017 to 2020 are preliminary.

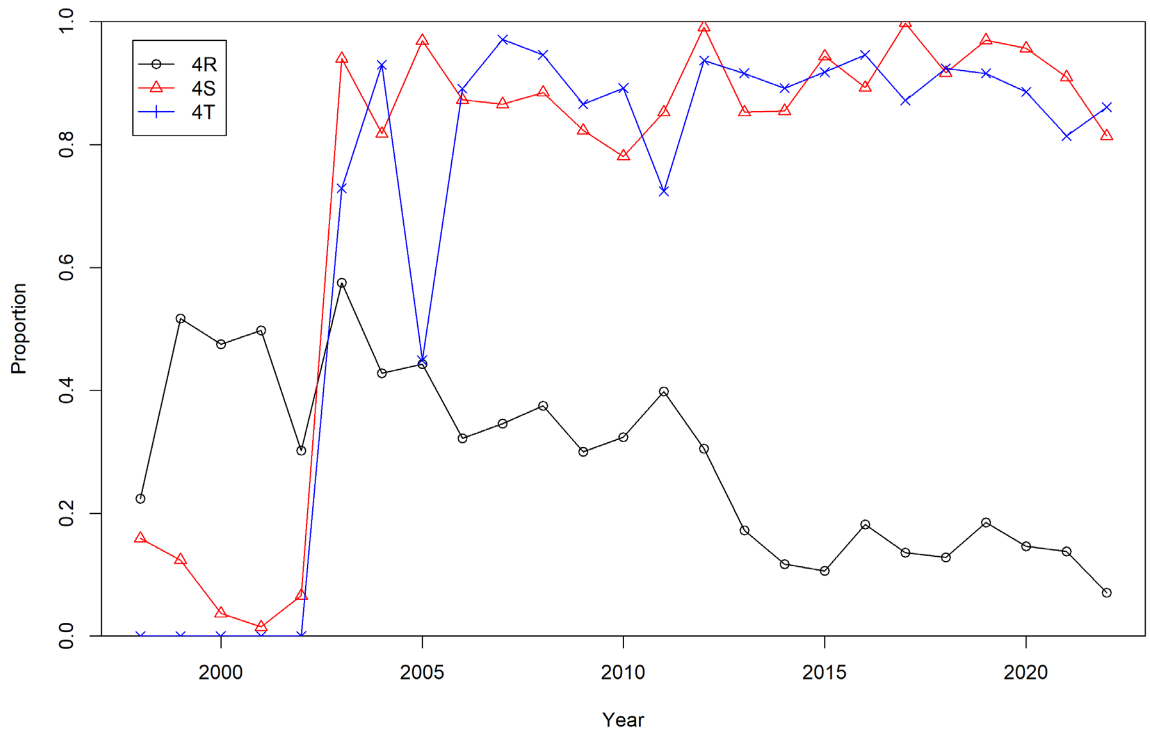

Figure 23. Proportion of directed longline halibut landings with a valid effort measure associated with it, by NAFO area. Data from 2017 to 2022 are preliminary.

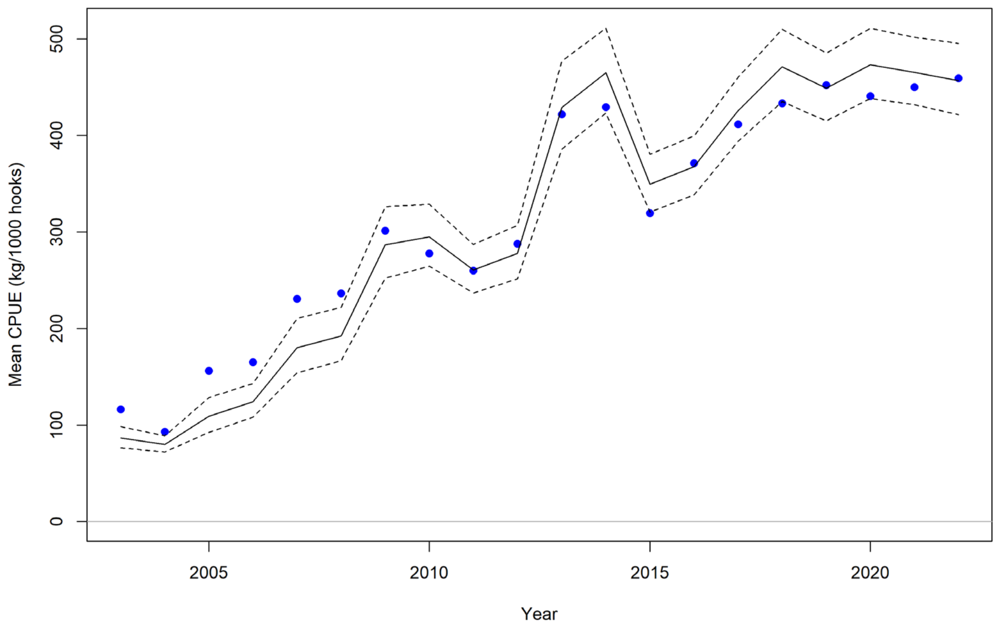

Figure 24. Commercial longline catch per unit effort (CPUE) targeting Atlantic halibut. The blue points are the average of the observed values (before standardization) and the solid line indicates the predicted values after standardization. Dashed lines describe the 95% confidence interval.

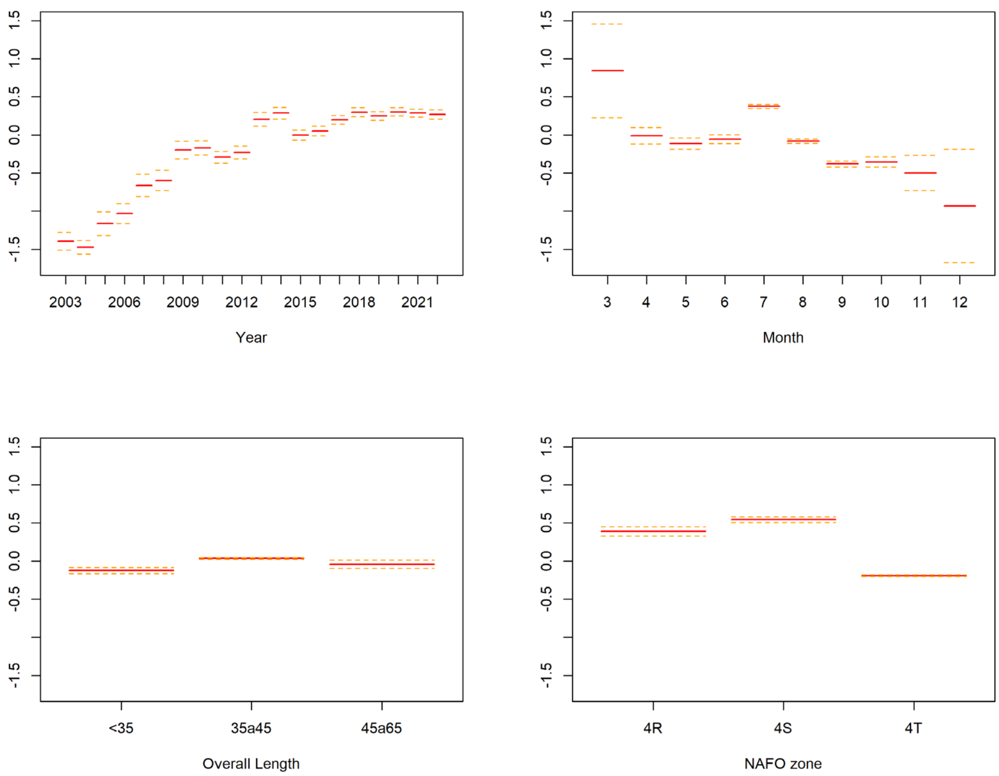

Figure 25. Regression terms against their predictors, with standard errors.

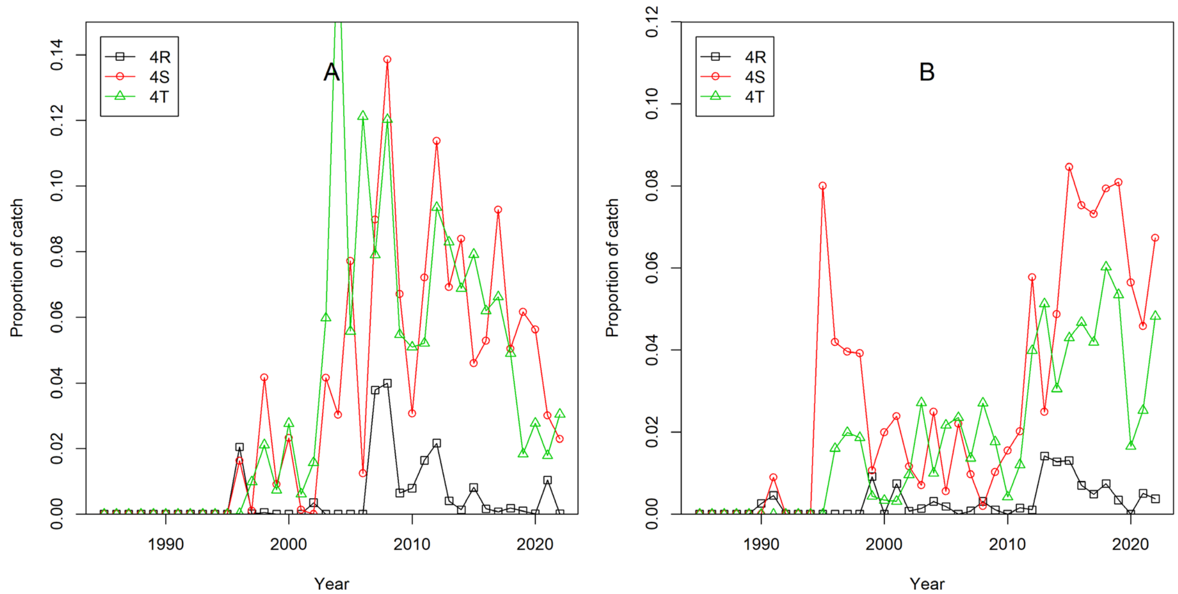

Figure 26. Proportion of landings (by weight) for which an at-sea observer (A) or a dockside sampler (B) measured the size of halibut caught. In the case of at-sea observers, the measured halibut include released halibut.

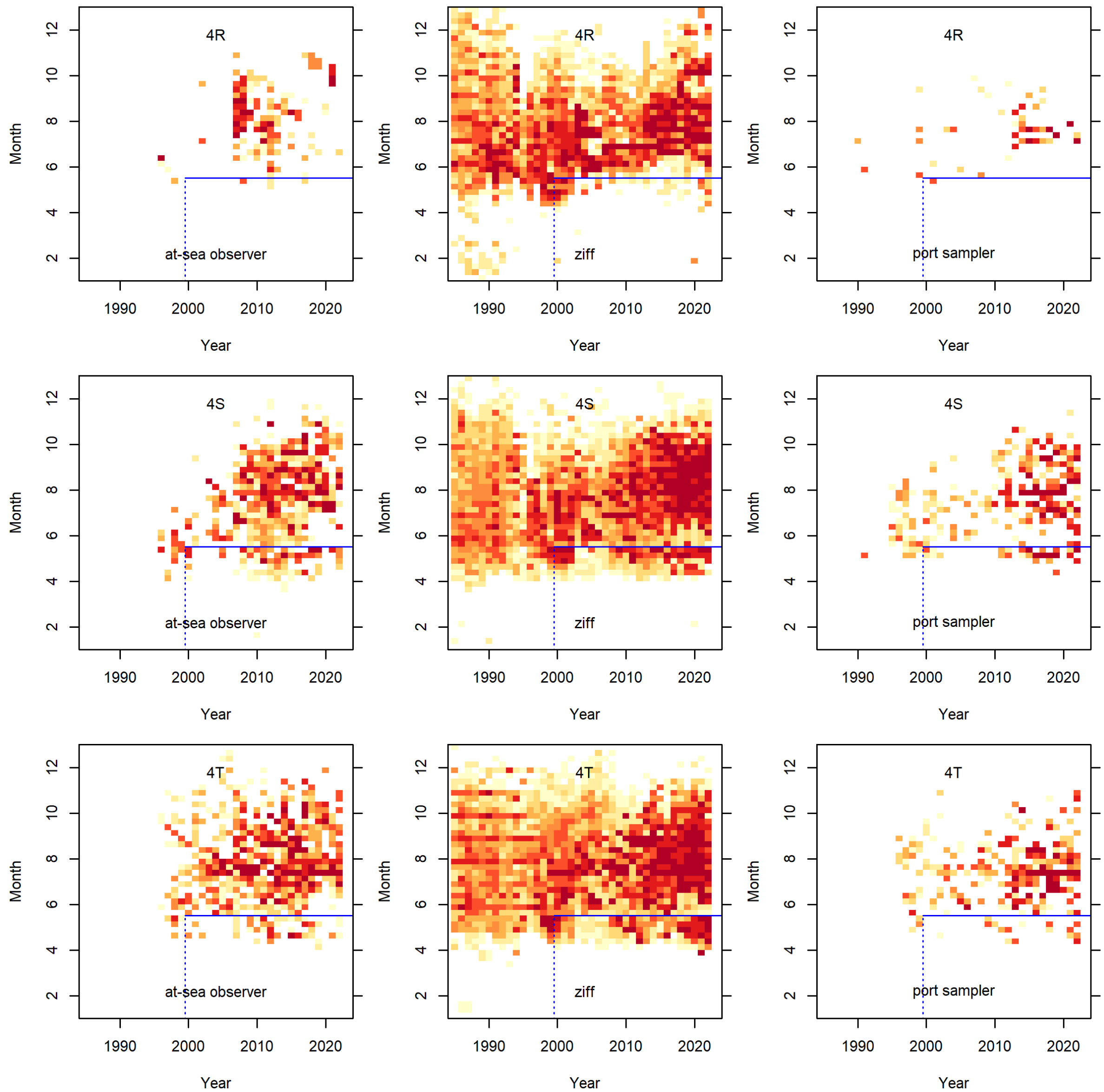

Figure 27. Weekly distribution of landings (from ZIFF files) and quantities of fish measured (at-sea observers and dockside samplers), by NAFO division. The blue line separates two successive management cycles. ZIFFiff data from 2017 to 2022 are preliminary.

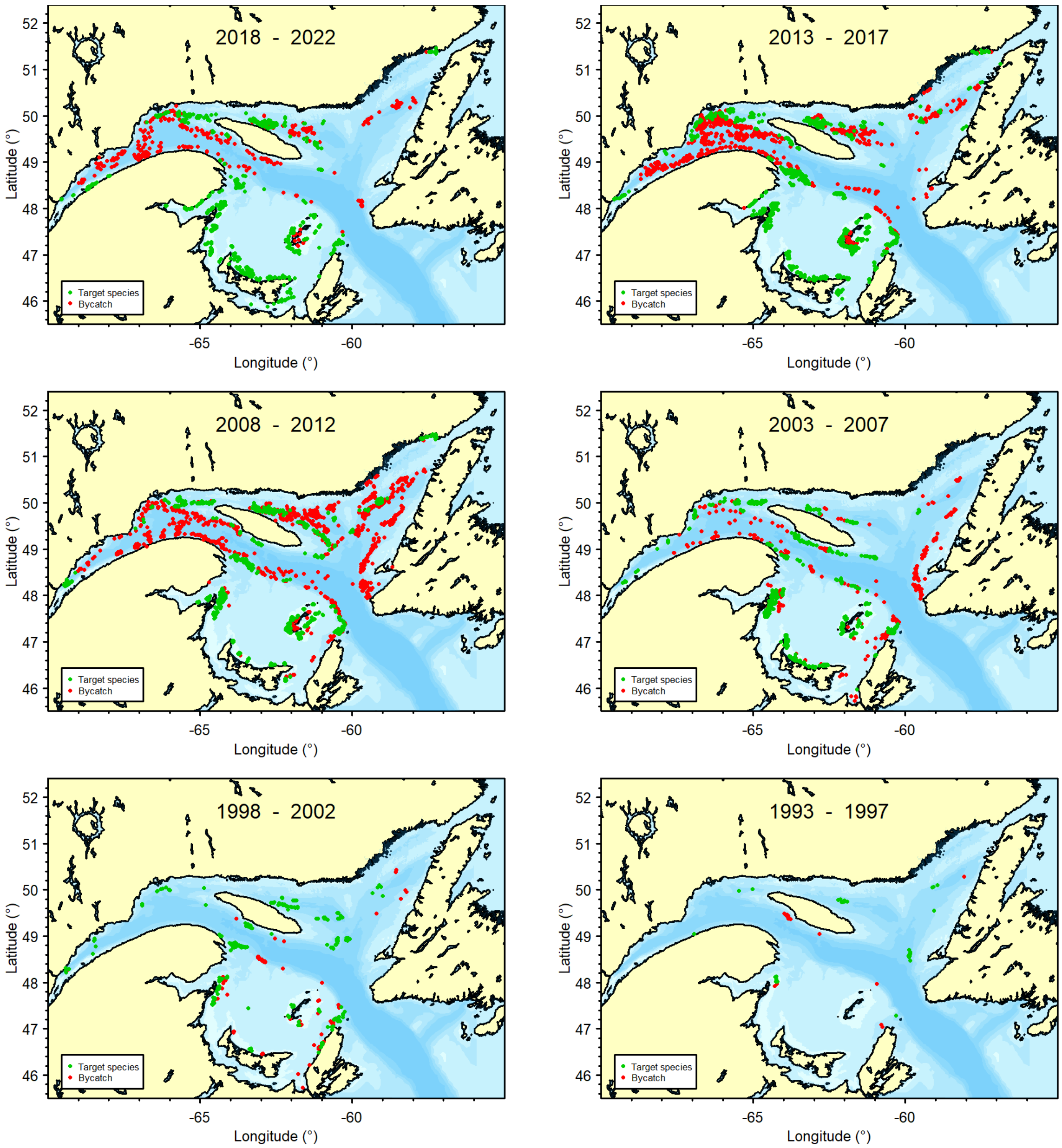

Figure 28. Spatial distribution of halibut catches sampled by an at-sea observer.

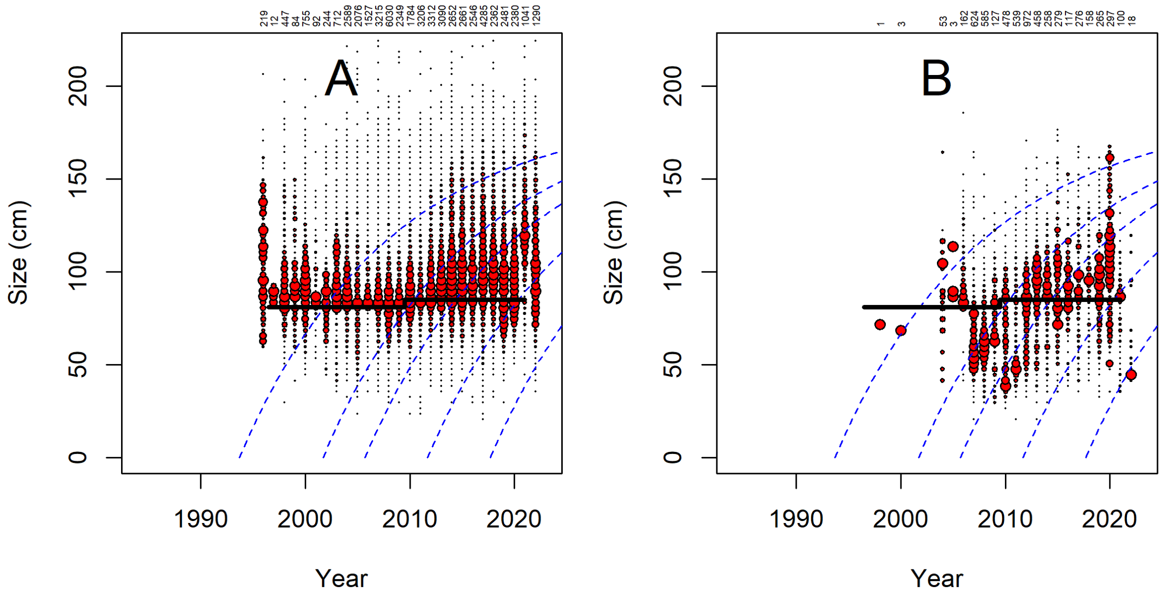

Figure 29. Halibut size frequency distribution for at-sea sampling from longline (A) and gillnet (B) fisheries. The diameter of each bubble is proportional to the number of individuals sampled for the size class and relative to the mode of the year concerned. The total number of individuals sampled per year is shown at the top of the graph. The dotted lines highlight the presumed trajectory of certain cohorts and the minimum landing size is presented by a black line when in force.

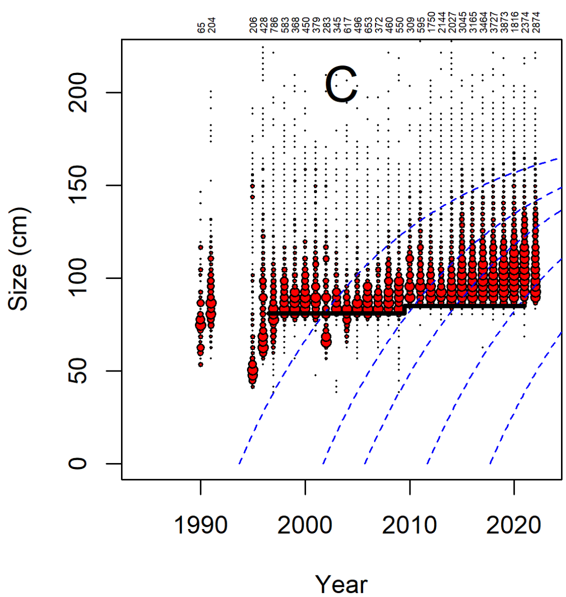

Figure 30. Halibut size frequency distribution for dockside sampling, all fisheries combined. The diameter of each bubble is proportional to the number of individuals sampled for the size class and relative to the mode of the year concerned. The total number of individuals caught per year is shown at the top of the graph. The dotted lines highlight the presumed trajectory of certain cohorts and the minimum landing size is presented by a black line when in force.

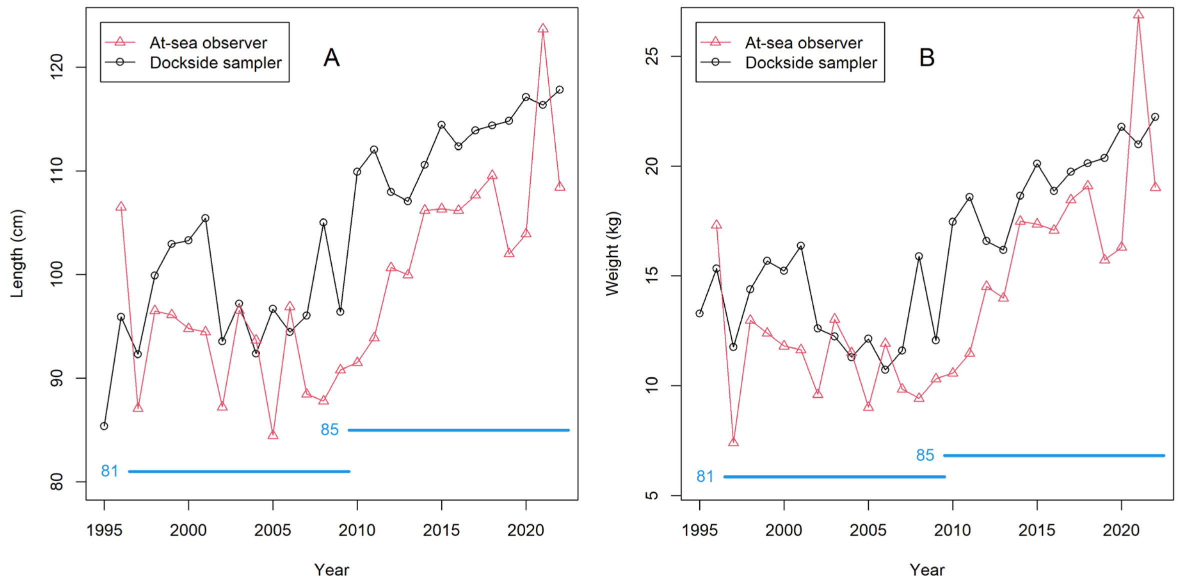

Figure 31. Average size (A) and average weight (B) of halibut caught commercially with longlines, measured by at-sea observers and dockside samplers. Periods characterized by a minimum landing size are indicated by a blue line accompanied by the current value.

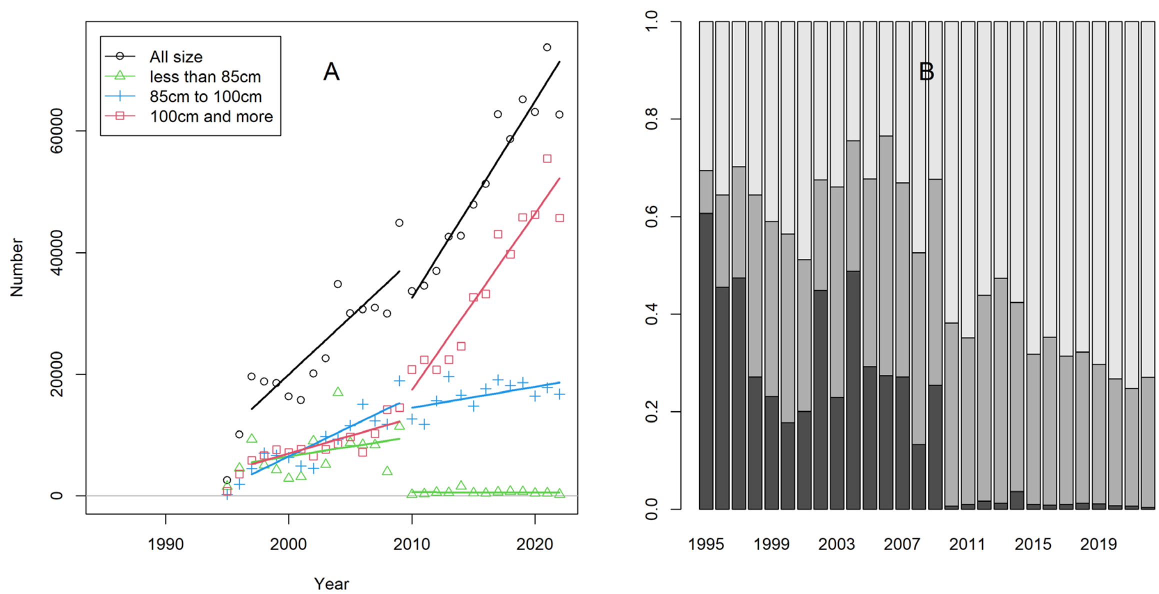

Figure 32. Estimated total number (A) and proportion (B) of halibut landed by size class, for longline fishing. The regression lines are segmented according to the two periods when a minimum landing size was in effect (81 cm between 1997 and 2009, and 85 cm between 2010 and today).

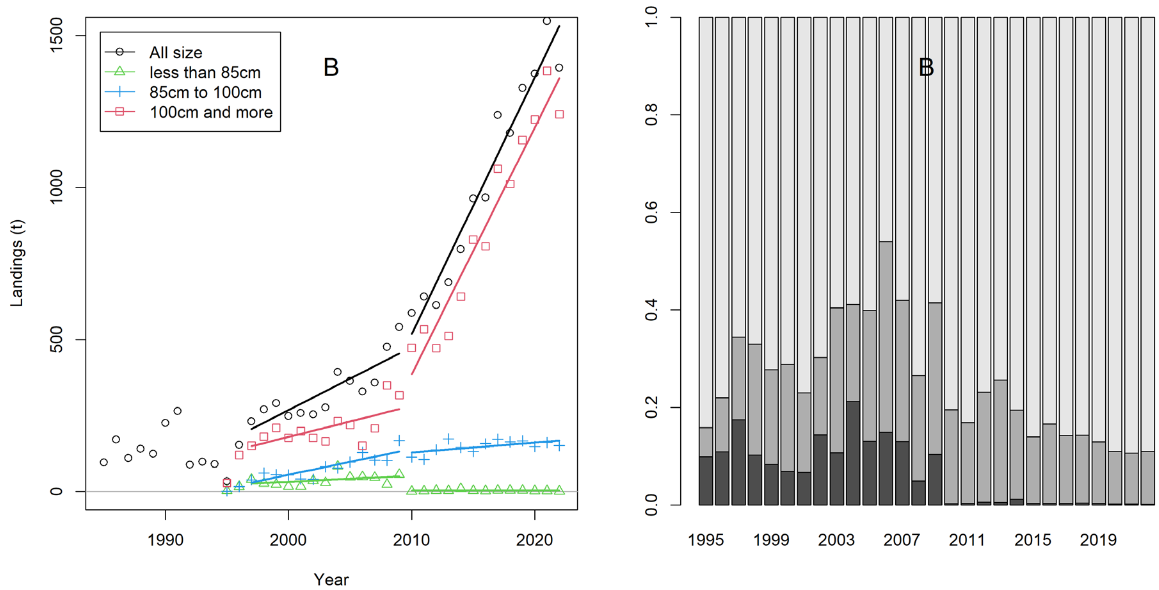

Figure 33. Annual landings (A) and proportion of landings (B) by size class, for longline fishing. The regression lines are segmented according to the two periods when a minimum landing size was in effect (81 cm between 1997 and 2009, and 85 cm between 2010 and today).

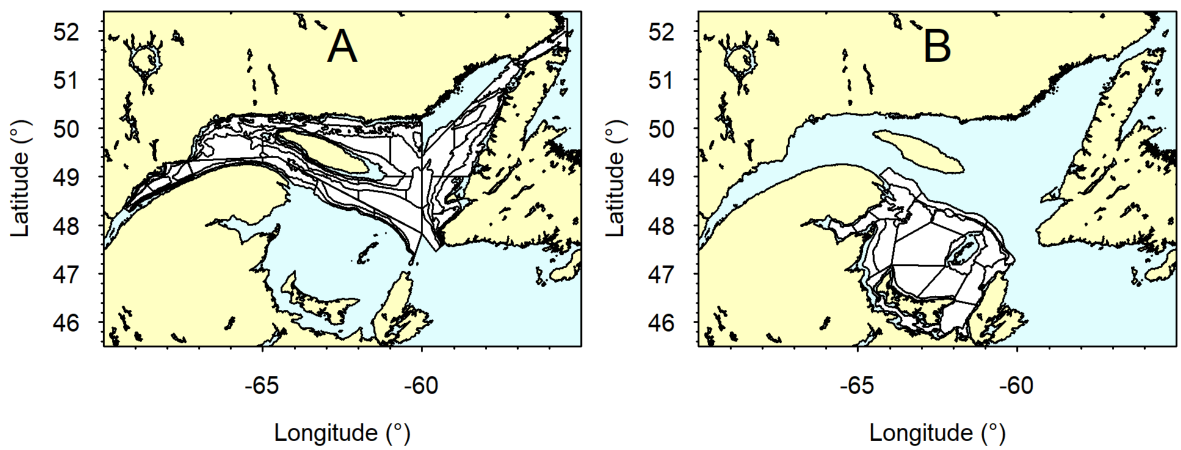

Figure 34. Maps of the strata covered in the scientific surveys of nGSL (A) and sGSL (B).

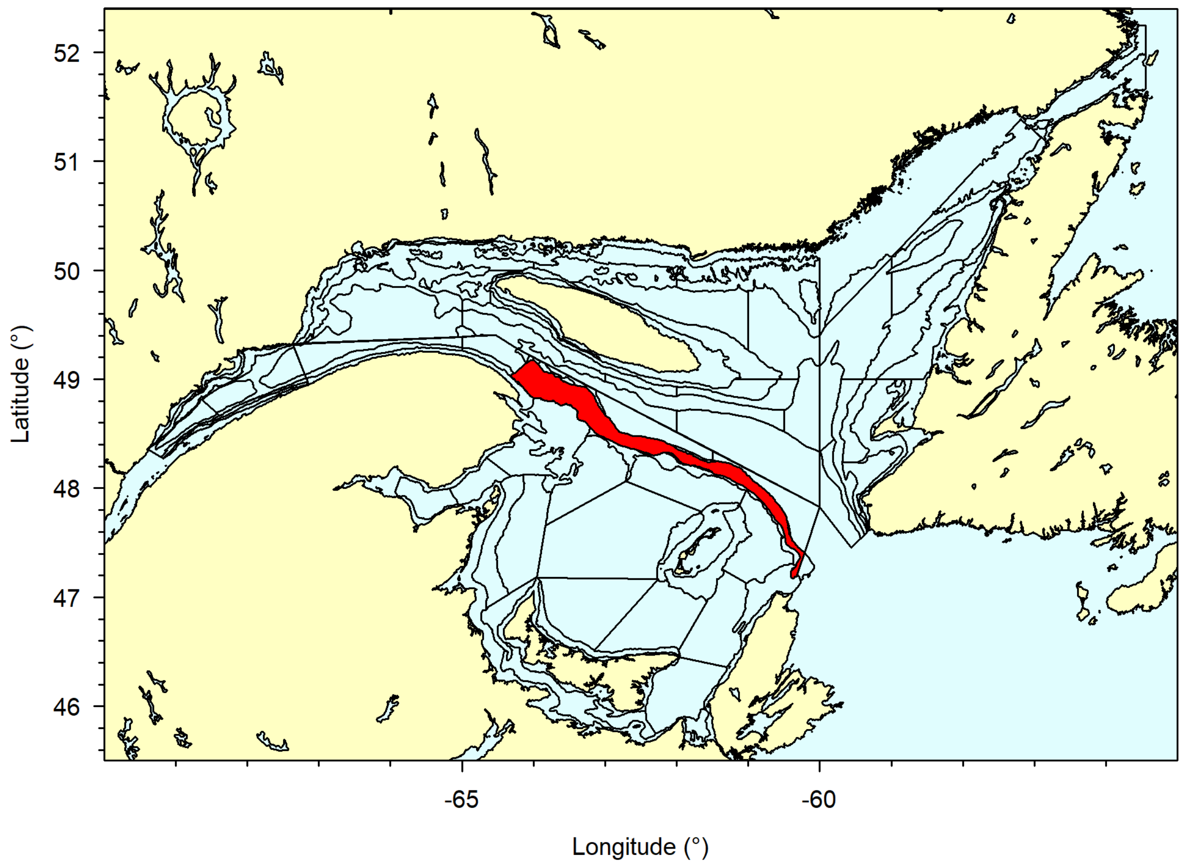

Figure 35. Map showing the common area (in red) of the stratification of the nGSL and sGSL mobile scientific surveys.

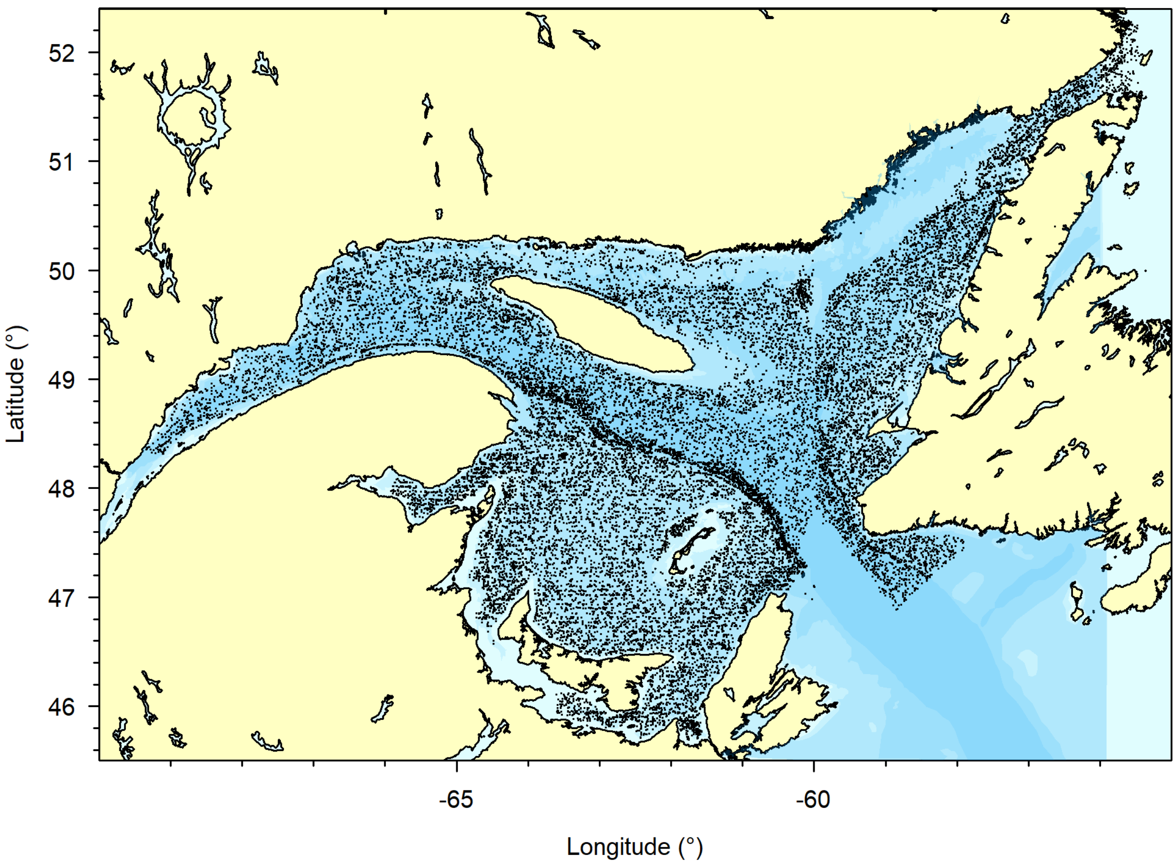

Figure 36. Distribution of sampling stations for 4 fishery-independent scientific mobile gear surveys. All the available years are presented and they vary according to the survey considered.

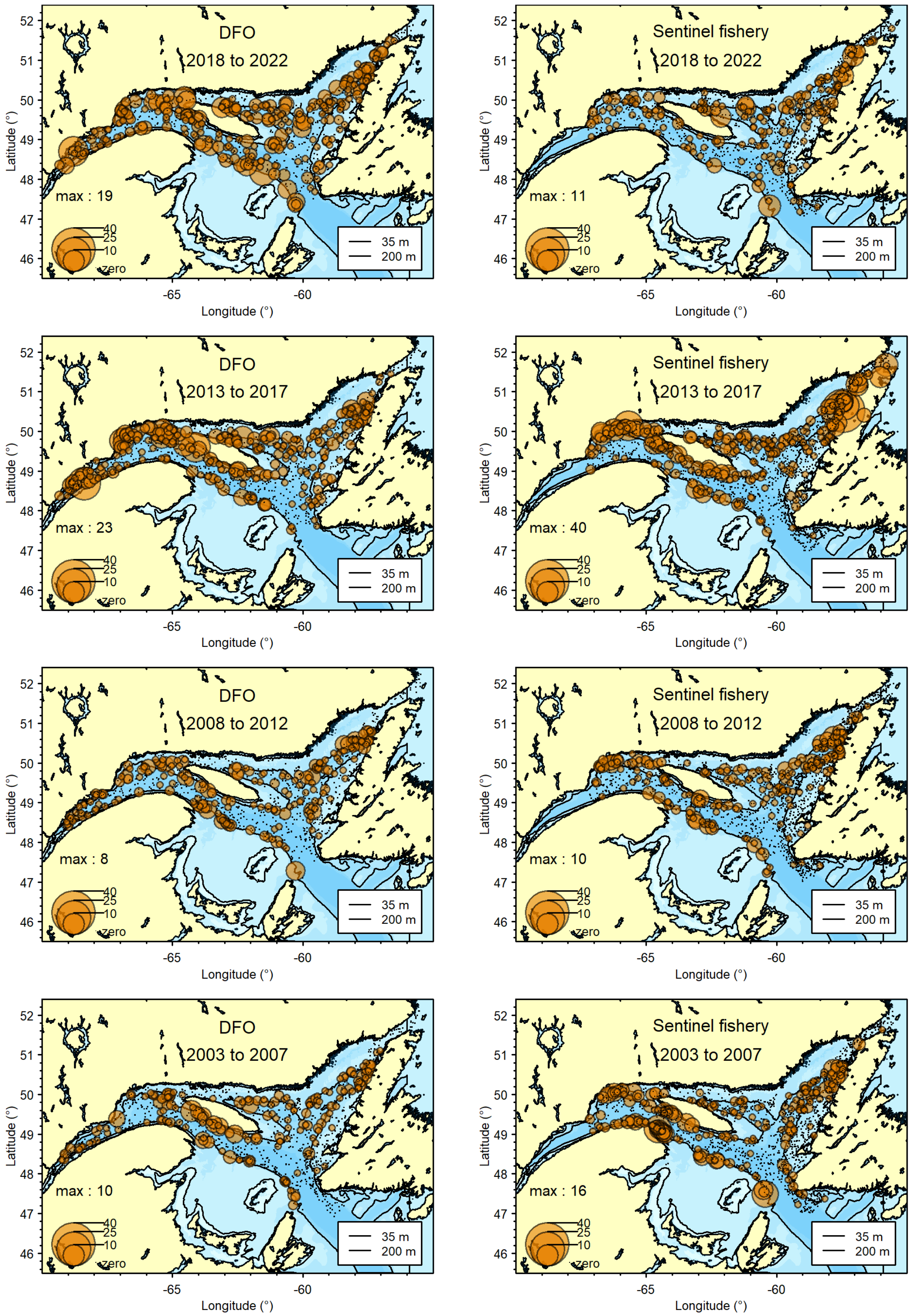

Figure 37. Distribution of catches (by number) in nGSL fishery independent bottom trawl surveys.

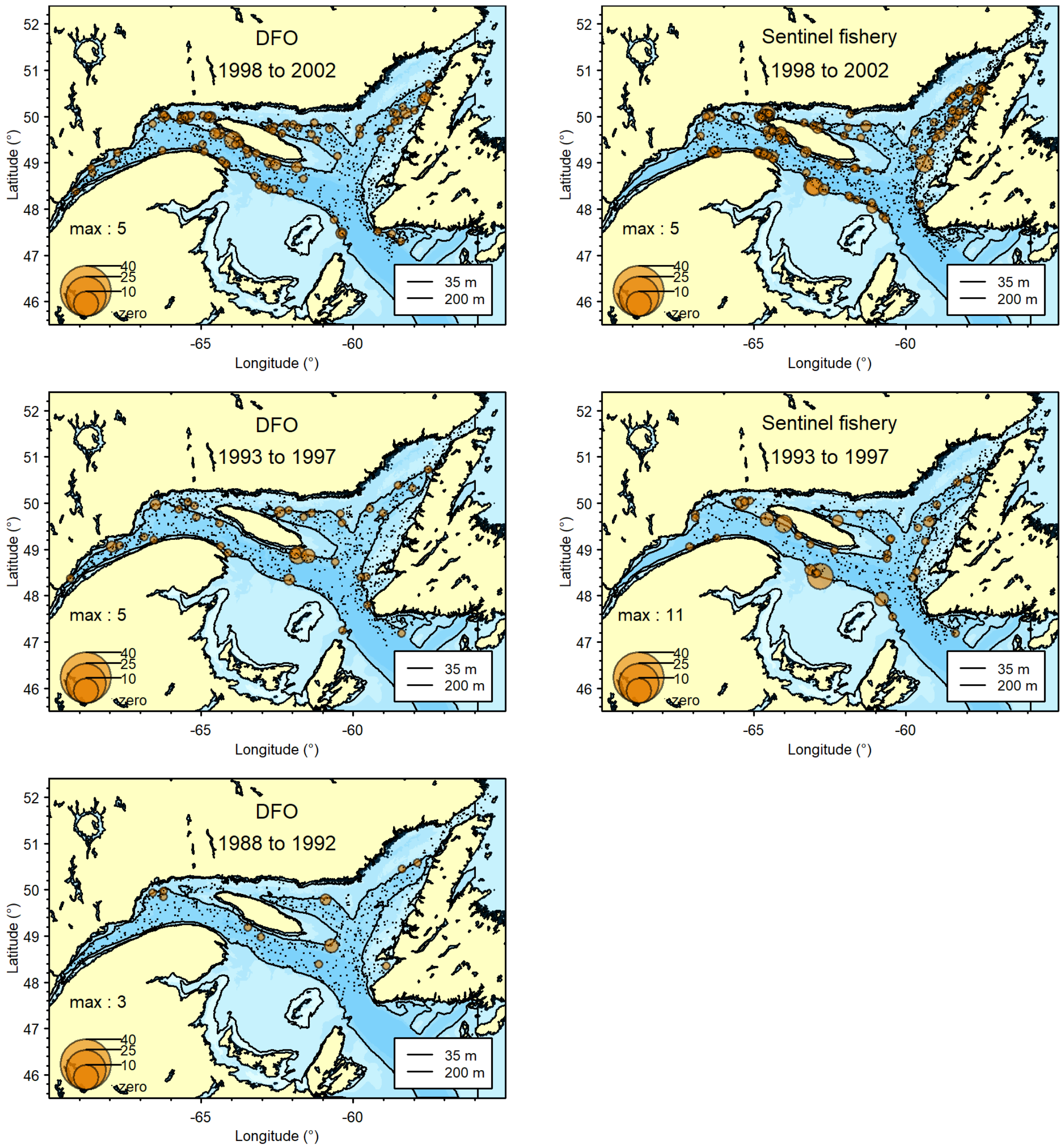

Figure 37. (Continued) Distribution of catches (by number) in nGSL fishery independent bottom trawl surveys.

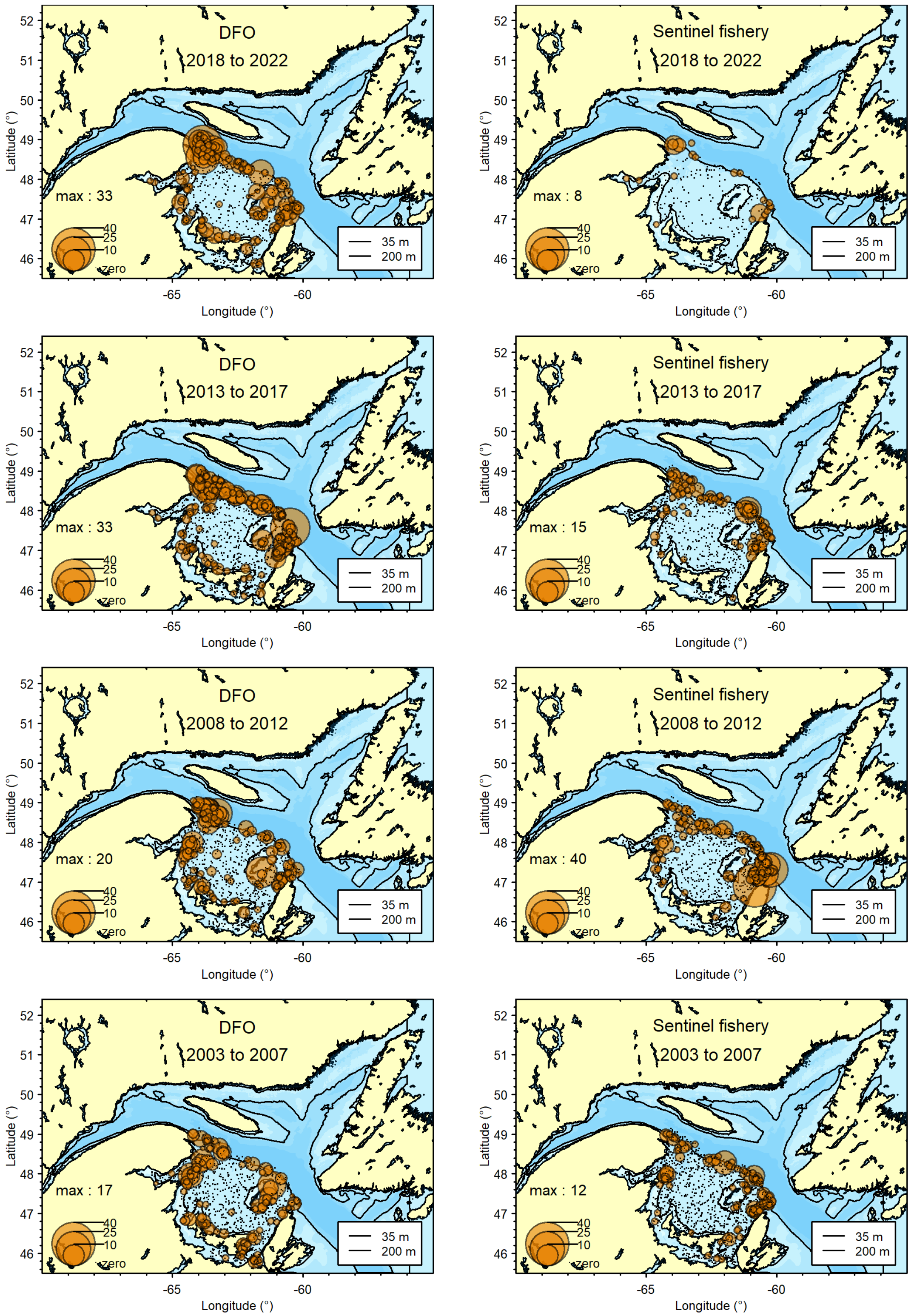

Figure 38. Distribution of catches (by number) in sGSL fishery independent bottom trawl surveys.

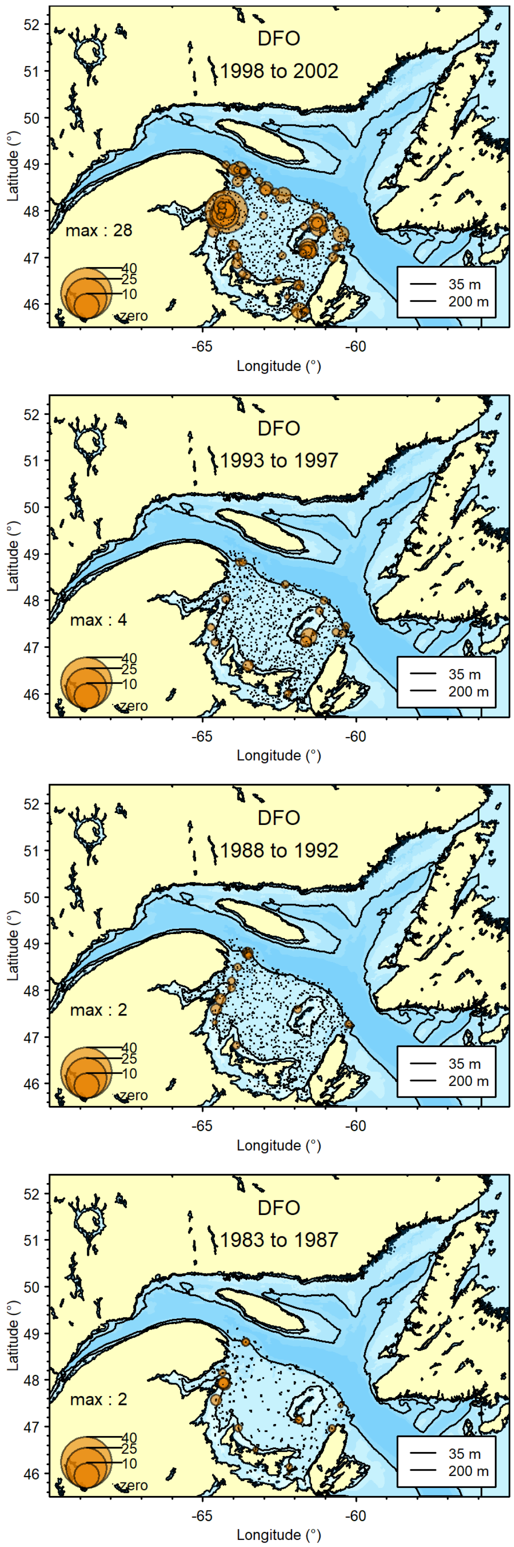

Figure 38. (Continued) Distribution of catches (by number) in sGSL fishery independent bottom trawl surveys.

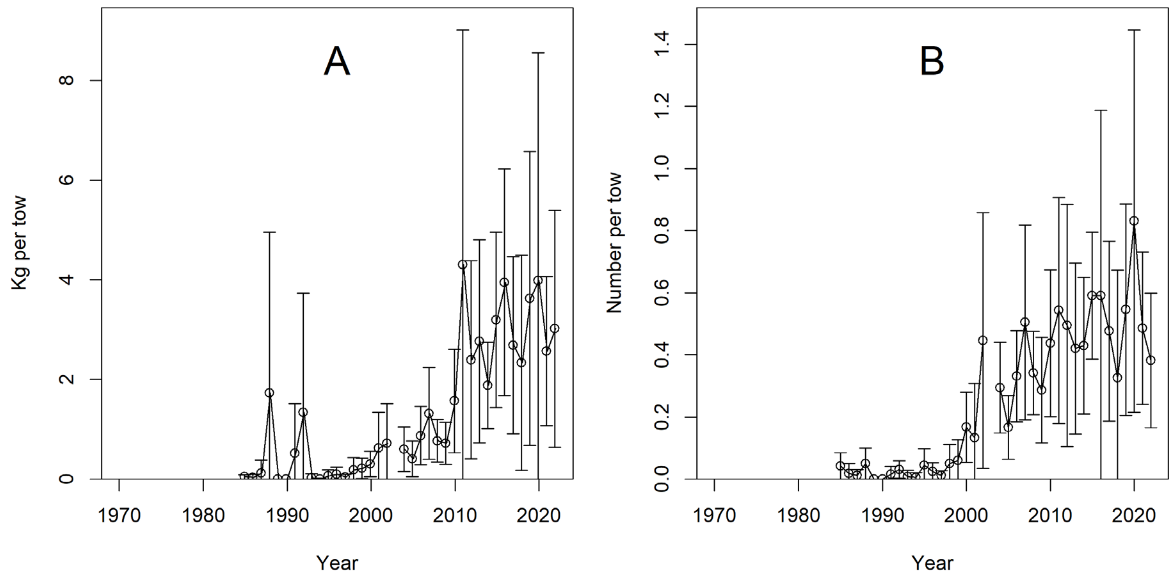

Figure 39. Catch rate by weight (A) and number (B) from the sGSL DFO bottom trawl survey. The 95% confidence interval is shown.

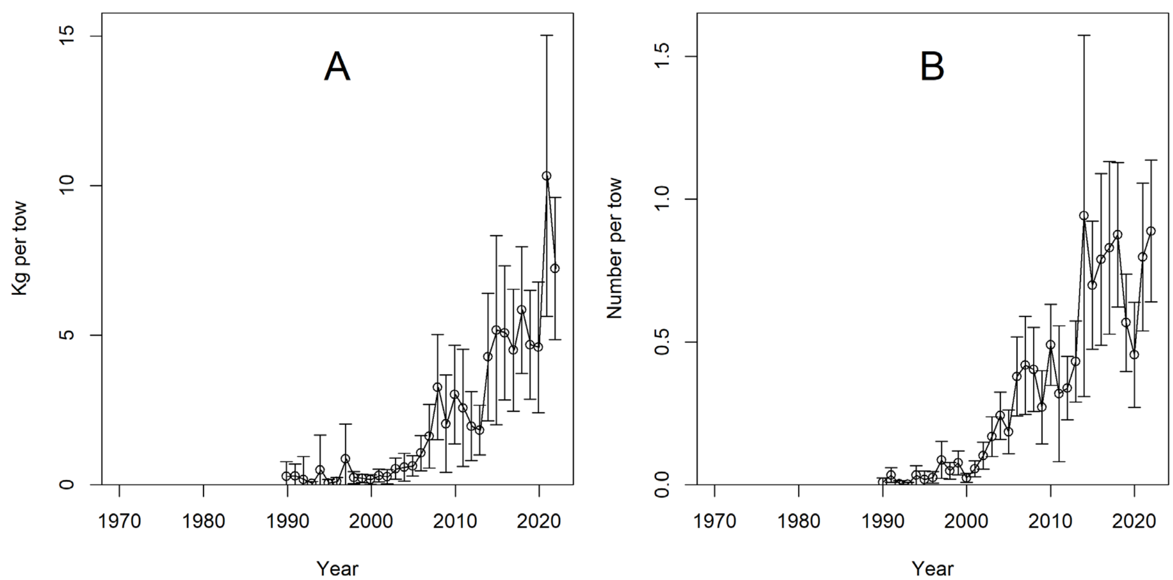

Figure 40. Catch rate by weight (A) and number (B) from the nGSL DFO bottom trawl survey. The 95% confidence interval is shown.

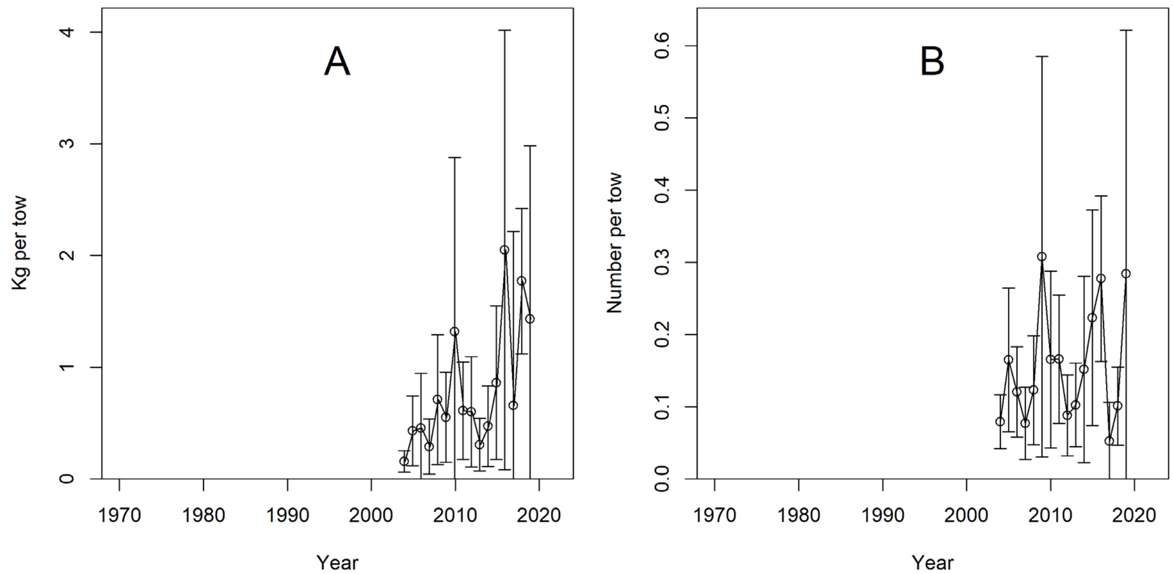

Figure 41. Catch rate by weight (A) and number (B) from the sGSL Sentinel bottom trawl survey. The 95% confidence interval is shown.

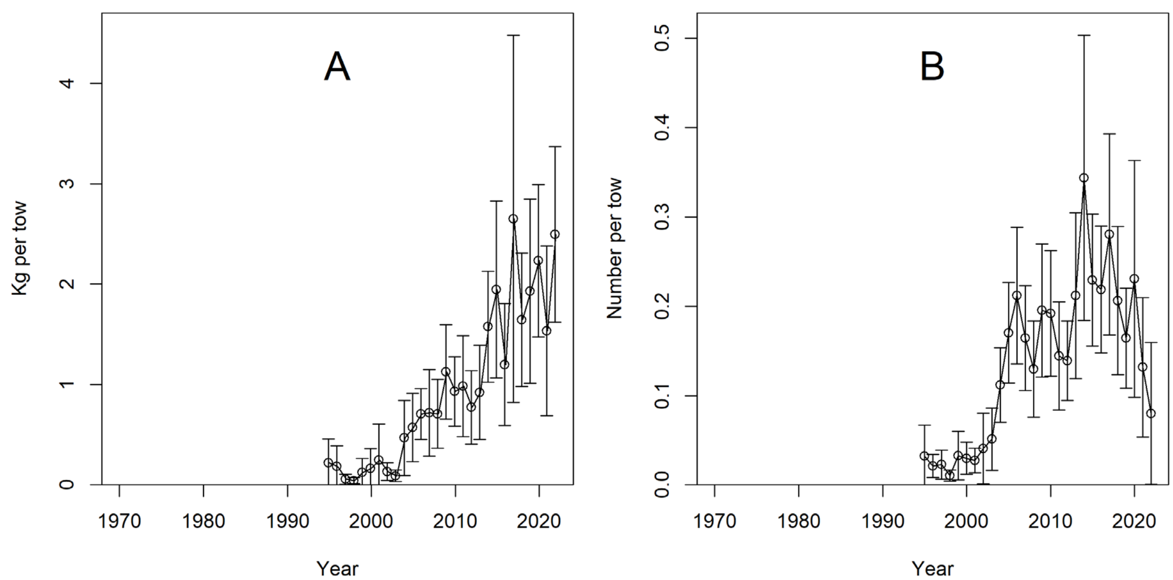

Figure 42. Catch rate by weight (A) and number (B) from the nGSL Sentinel bottom trawl survey. The 95% confidence interval is shown.

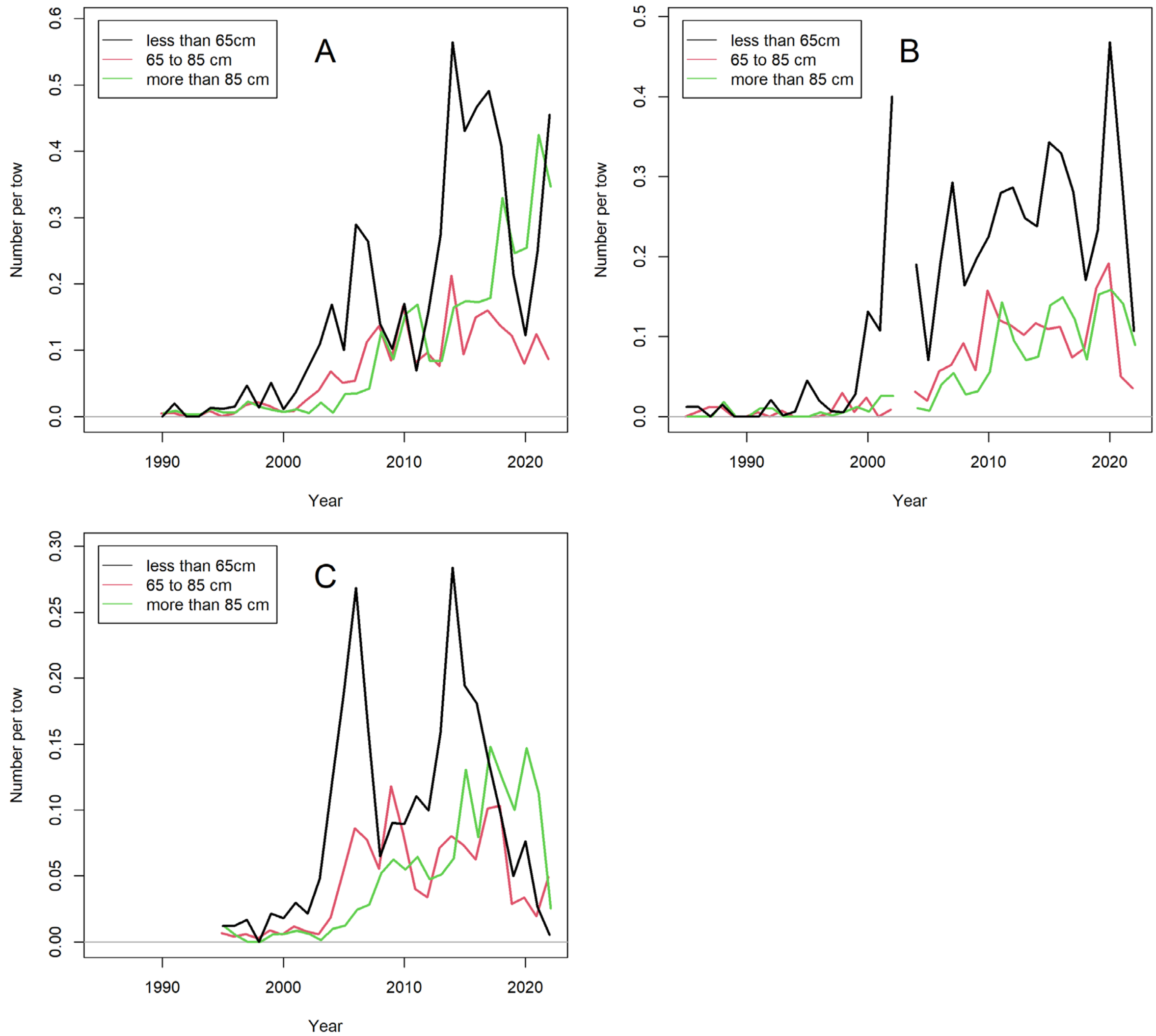

Figure 43. Catch rate in number per unit of effort by size class for DFO bottom trawl surveys for nGSL (A) and sGSL (B) as well as for the sentinel program of nGSL (C).

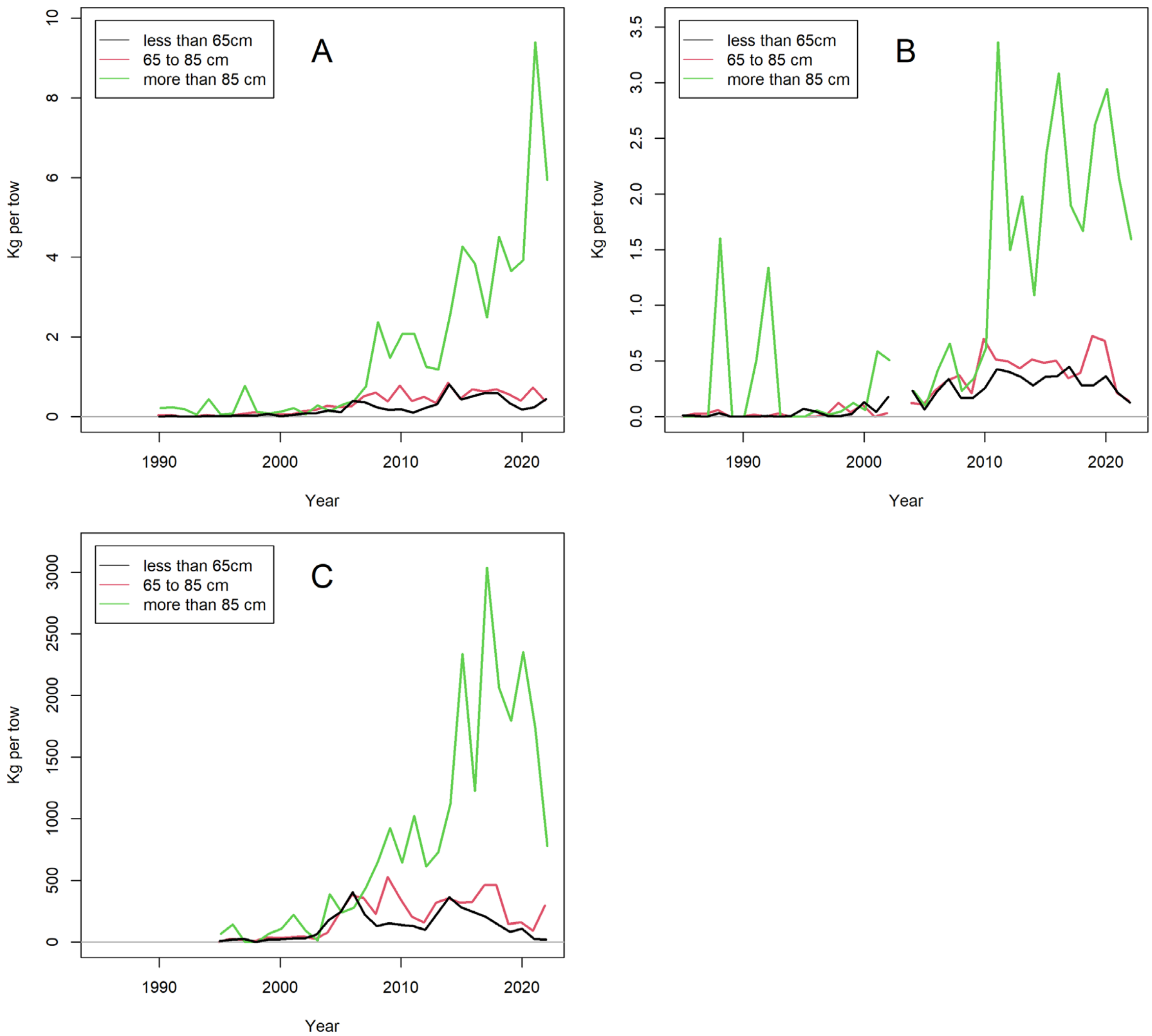

Figure 44. Catch rate in weight per unit of effort by size class for DFO bottom trawl surveys for nGSL (A) and sGSL (B) as well as for the sentinel program of nGSL (C).

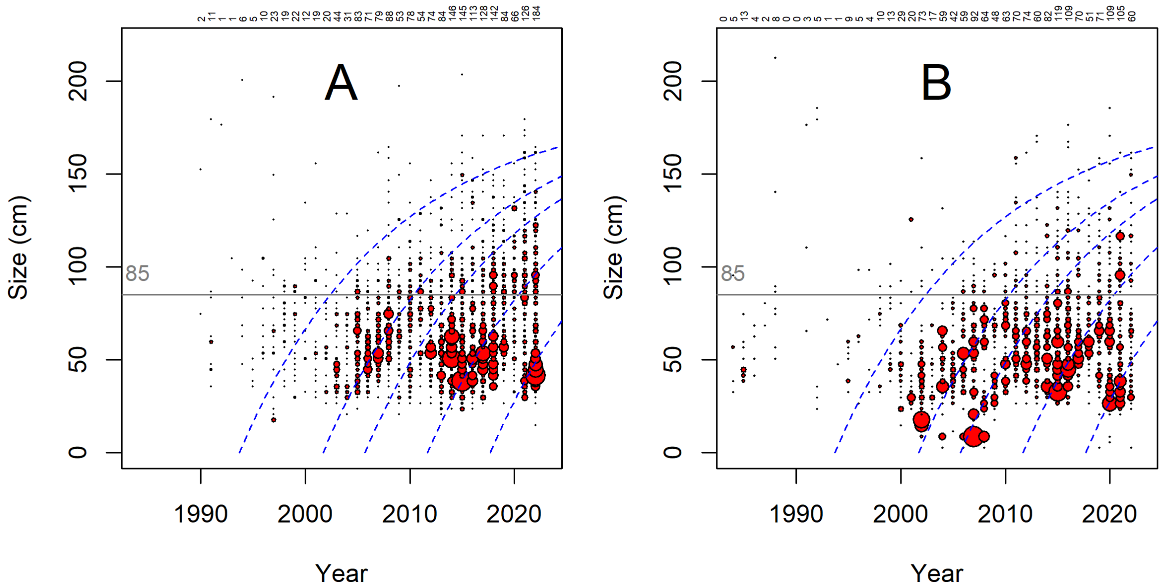

Figure 45. Size frequency distribution for DFO trawl surveys in nGSL (A) and sGSL (B). The diameter of each bubble is proportional to the number of individuals captured for the size class. The total number of individuals caught per year is shown at the top of the graph. The dotted lines highlight the presumed trajectory of certain cohorts and the minimum landing size in effect since 2010, i.e. 85 cm, is presented in grey.

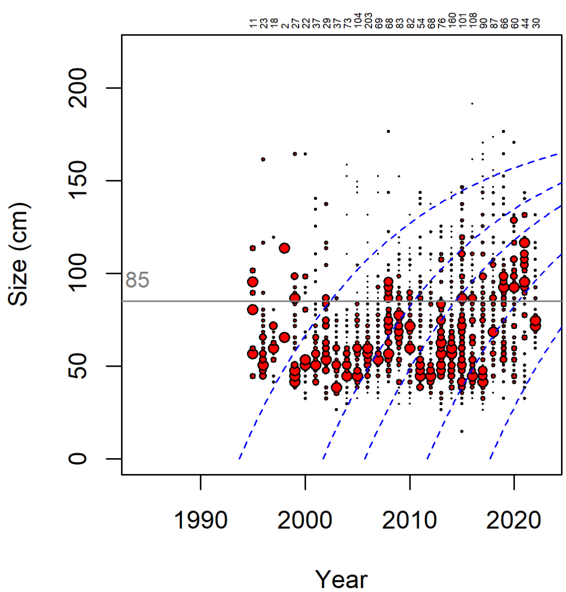

Figure 46. Size frequency distribution for bottom trawl surveys of the sentinel fishery program for nGSL. The diameter of each bubble is proportional to the number of individuals captured for the size class and relative to the mode of the year concerned. The total number of individuals caught per year is shown at the top of the graph. The dotted lines highlight the presumed trajectory of certain cohorts and the minimum landing size in effect since 2010, i.e. 85 cm, is presented in gray.

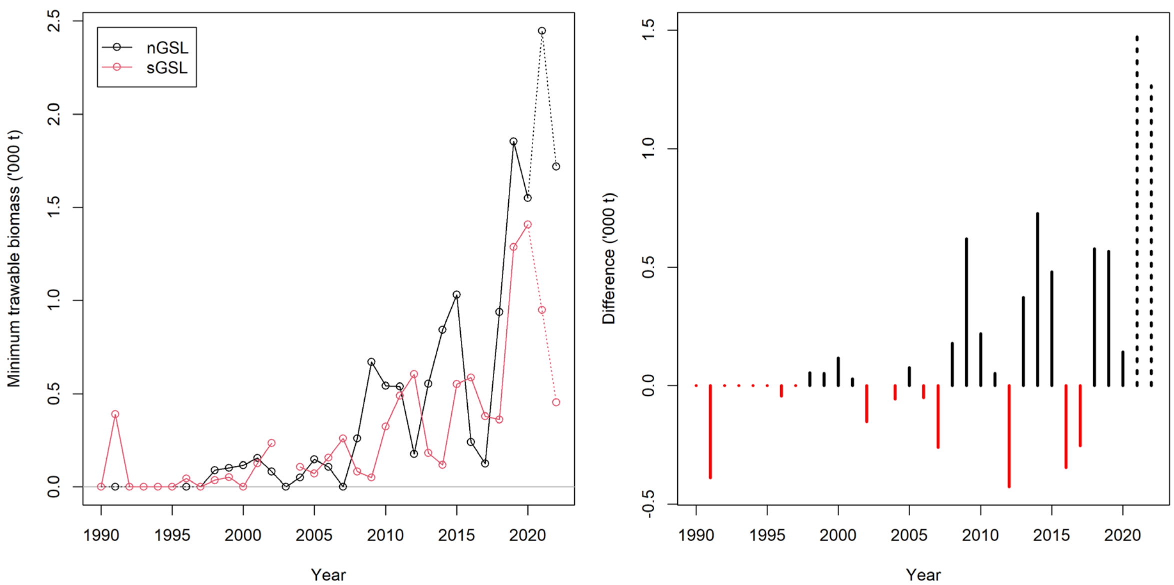

Figure 47. Comparison of minimum trawlable biomass of halibut larger than 85 cm caught in the overlapping portion of the study area during DFO bottom trawl surveys of the nGSL and sGSL. Results for the sGSL are adjusted using the correspondence factor calculated by Yin and Benoît (2022). Dotted lines are used for 2021 and 2022 to indicate that these years were not considered in the adjustment factor calculation.

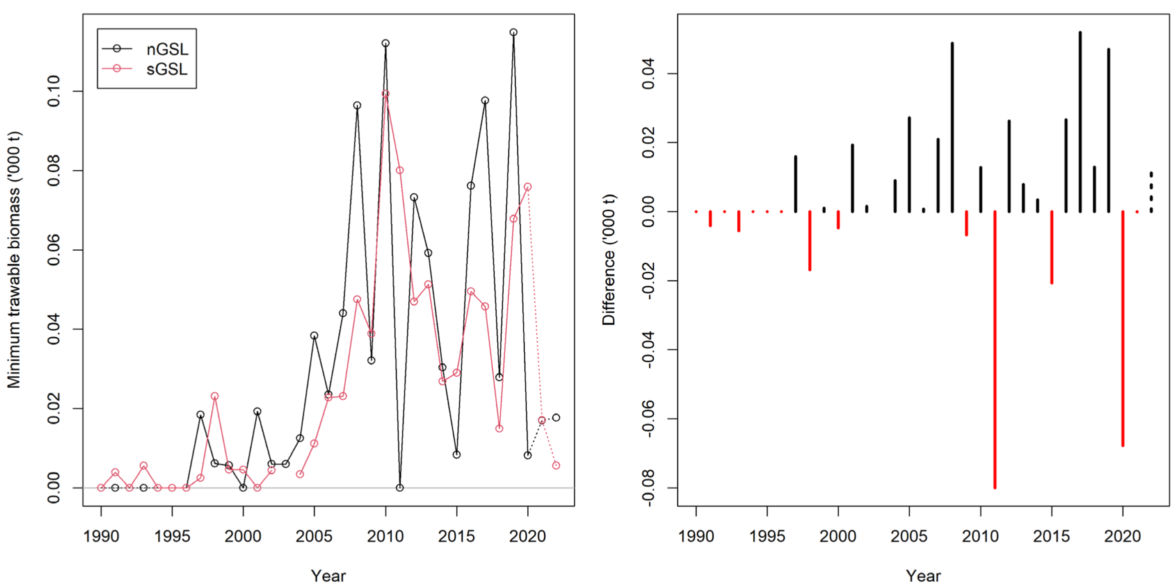

Figure 48. Comparison of minimum trawlable biomass of halibut between 65 and 85 cm caught in the overlapping portion of the study area during DFO bottom trawl surveys of the nGSL and sGSL. Results for the sGSL are adjusted using the correspondence factor calculated by Yin and Benoît (2022). Dotted lines are used for 2021 and 2022 to indicate that these years were not considered in the adjustment factor calculation. The adjustment factor is applied to the sGSL data.

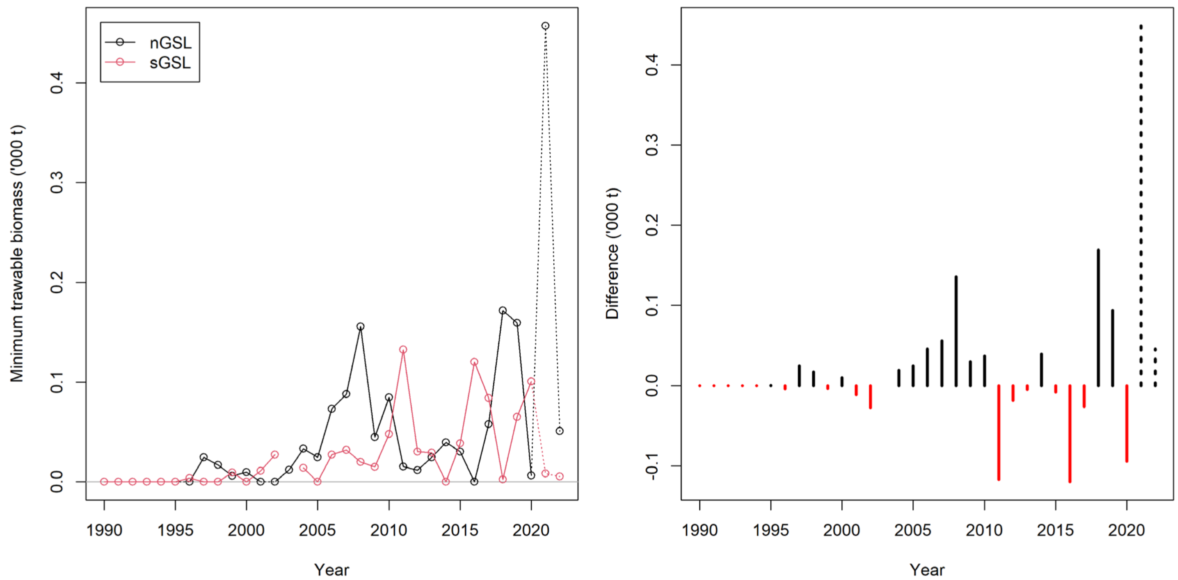

Figure 49. Comparison of minimum trawlable biomass of halibut smaller than 65 cm caught in the overlapping portion of the study area during DFO bottom trawl surveys of the nGSL and sGSL. Results for the sGSL are adjusted using the correspondence factor calculated by Yin and Benoît (2022). Dotted lines are used for 2021 and 2022 to indicate that these years were not considered in the adjustment factor calculation. The adjustment factor is applied to the sGSL data.

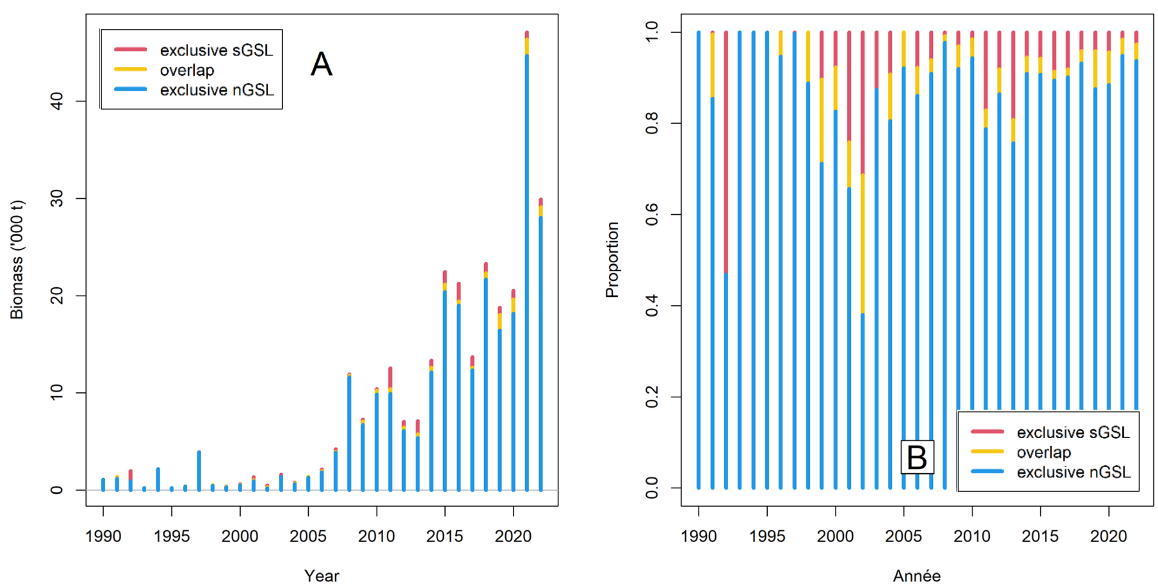

Figure 50. Breakdown of the minimum trawlable biomass (t) of halibut larger than 85 cm estimated using data from DFO trawl surveys, by location of observations (area exclusive to sGSL, common to both surveys or exclusive to nGSL). The adjustment factor is applied to the sGSL data.

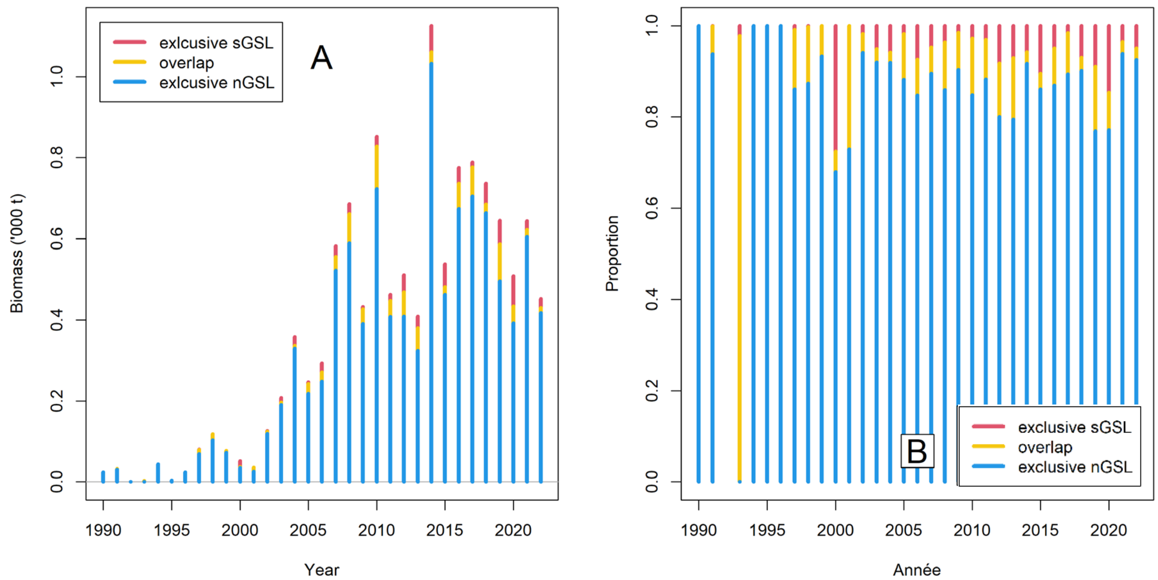

Figure 51. Breakdown of the minimum trawlable biomass of halibut between 65 and 85 cm estimated using data from DFO trawl surveys, by location of observations (area exclusive to sGSL, common to both surveys or exclusive to nGSL). The adjustment factor is applied to the sGSL data.

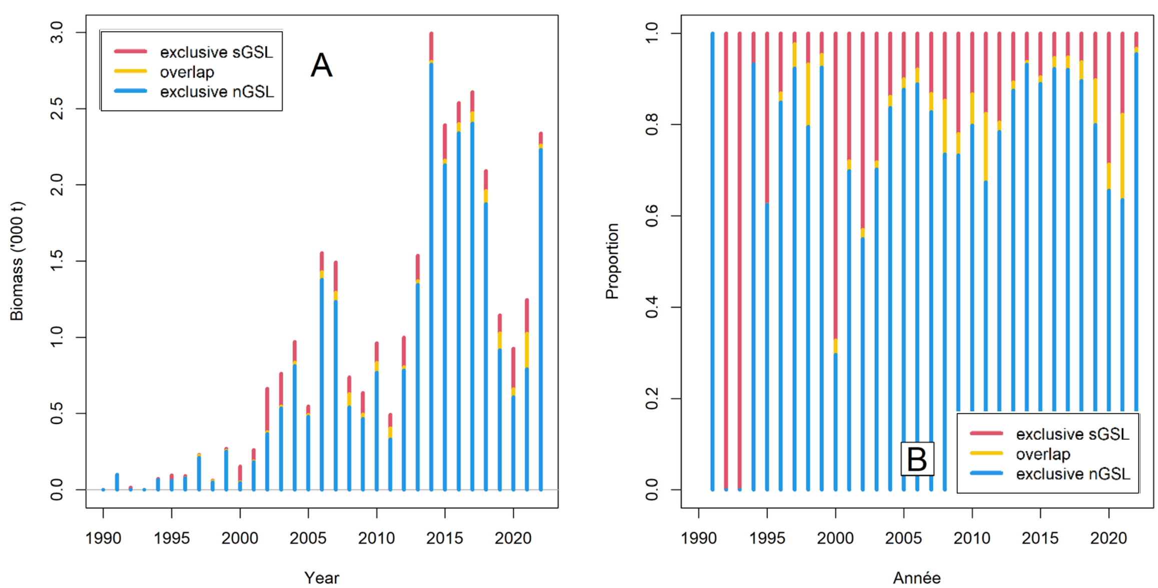

Figure 52. Breakdown of the minimum trawlable biomass of halibut smaller than 65 cm estimated using data from DFO trawl surveys, by location of observations, including area exclusive to sGSL, common to both surveys or exclusive to nGSL. The adjustment factor is applied to the sGSL data.

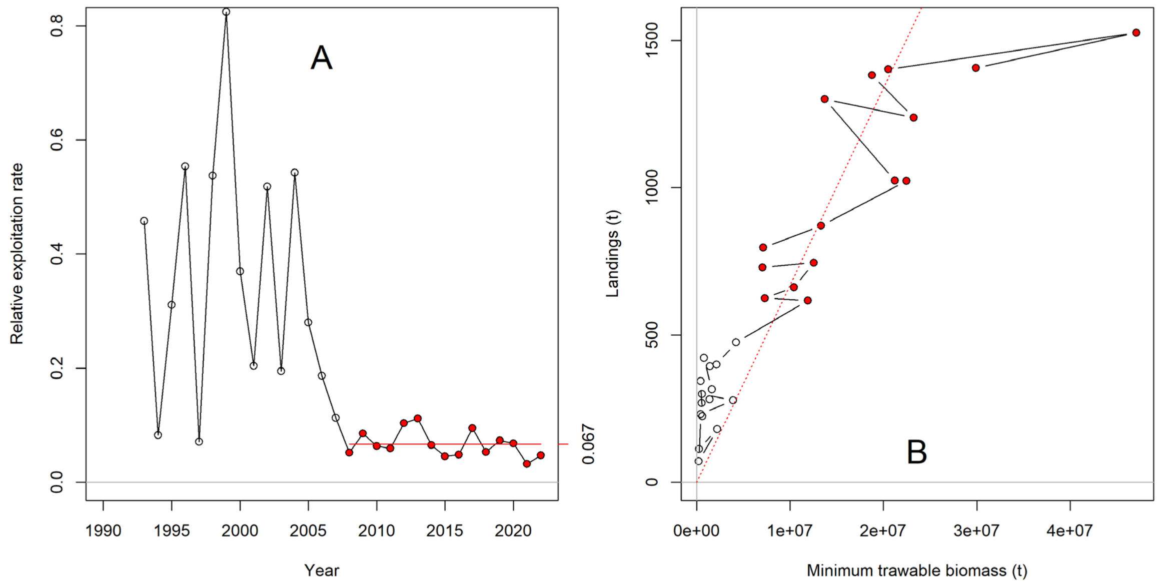

Figure 53. Relative exploitation rate calculated from landings and minimum trawlable biomass (85 cm or more) (A) and the relation between landings and minimum trawlable biomass (85 cm or more) (B). The average exploitation rate for the last 15 years is represented by the red line. The adjustment factor is applied to the sGSL data.

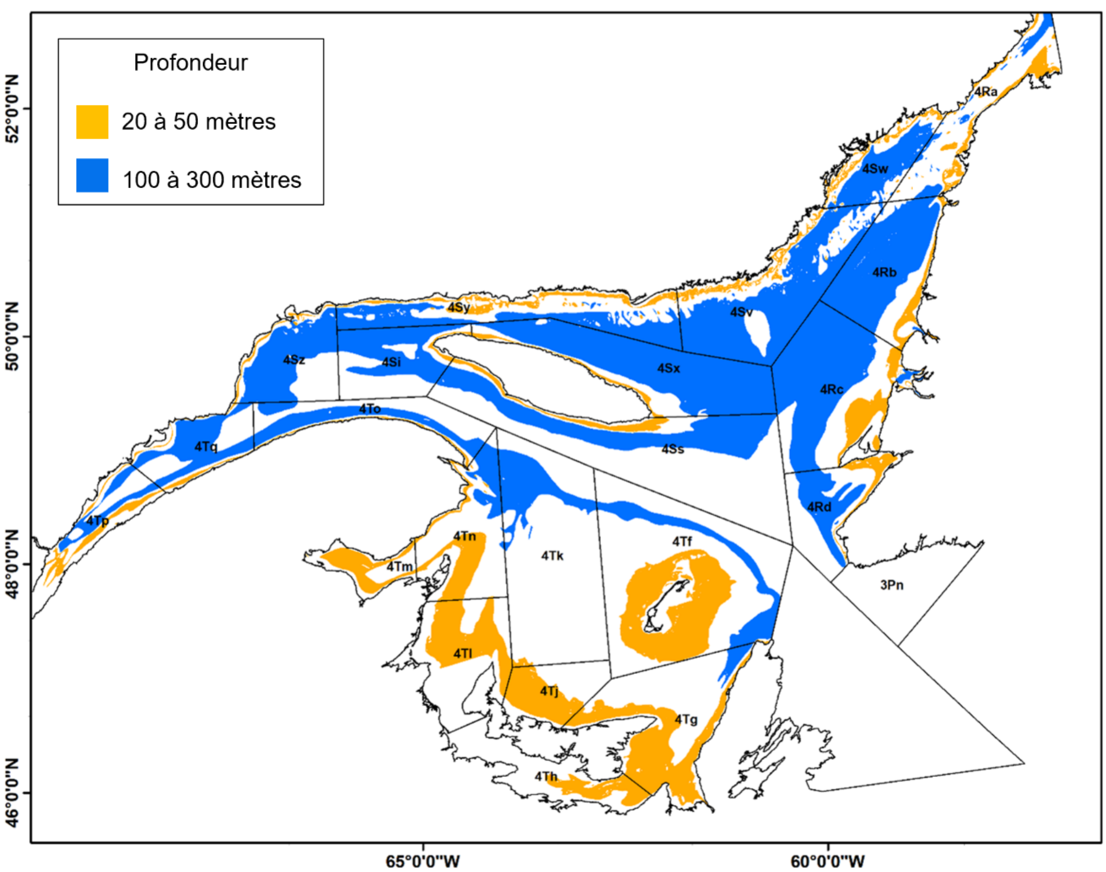

Figure 54. Sampling strata for the longline halibut survey.

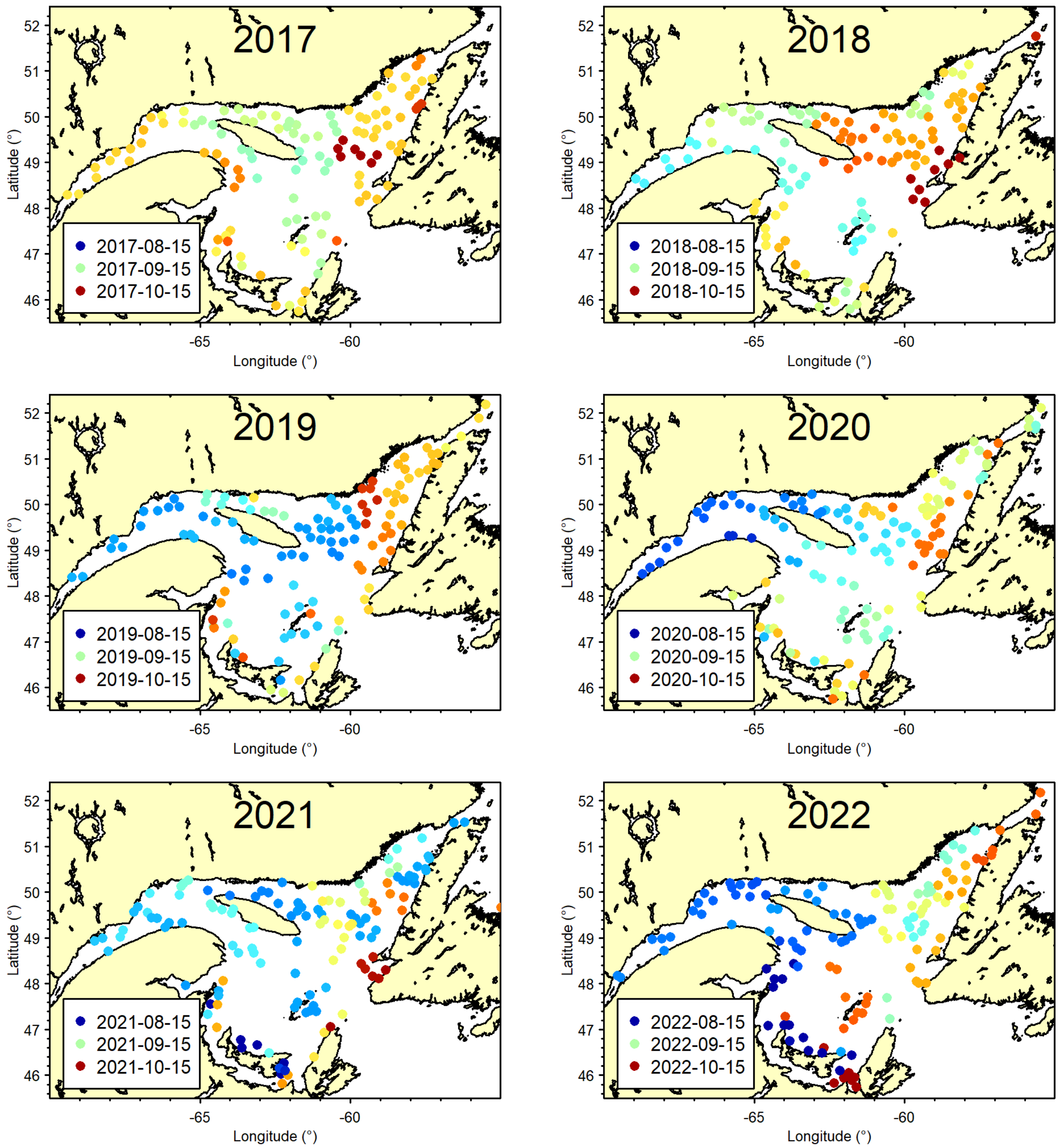

Figure 55. Location of stations in the scientific longline survey for halibut, by sampling date.

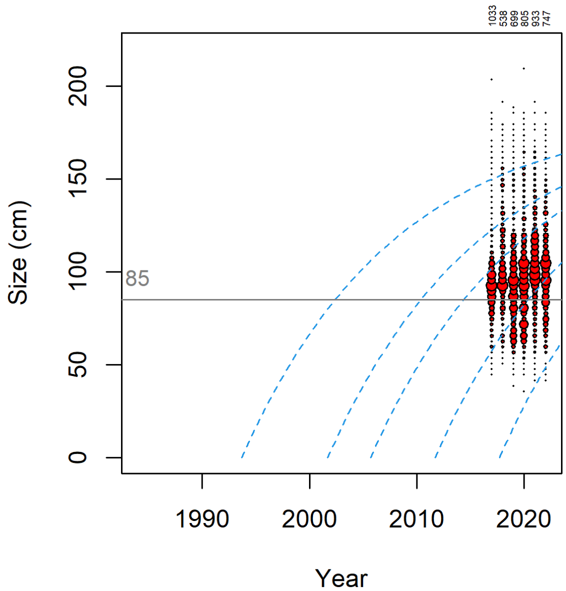

Figure 56. Size frequency distribution for the longline halibut survey. The diameter of each bubble is proportional to the number of individuals captured in that the size class. The total number of individuals caught per year is shown at the top of the graph. The dotted lines highlight the presumed trajectory of some cohorts. The minimum legal size in force in 2022, 85 cm, is shown in grey.

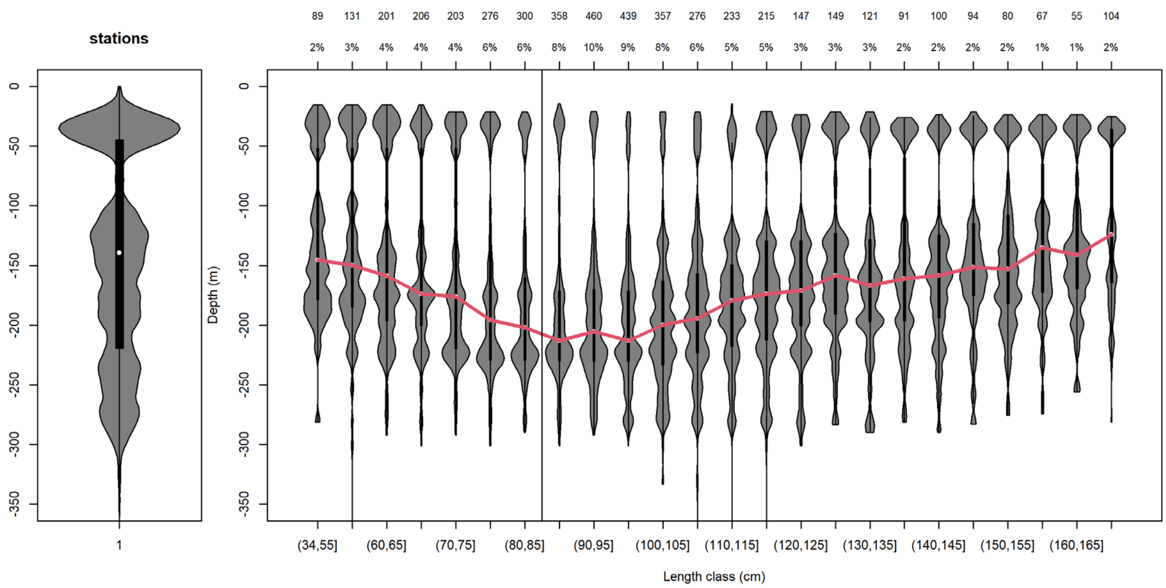

Figure 57. Halibut capture depth by 5-cm size class. The red line connects the median values. The number of individuals by size class and the proportion of the total number that they represent are shown at the top of the graph.

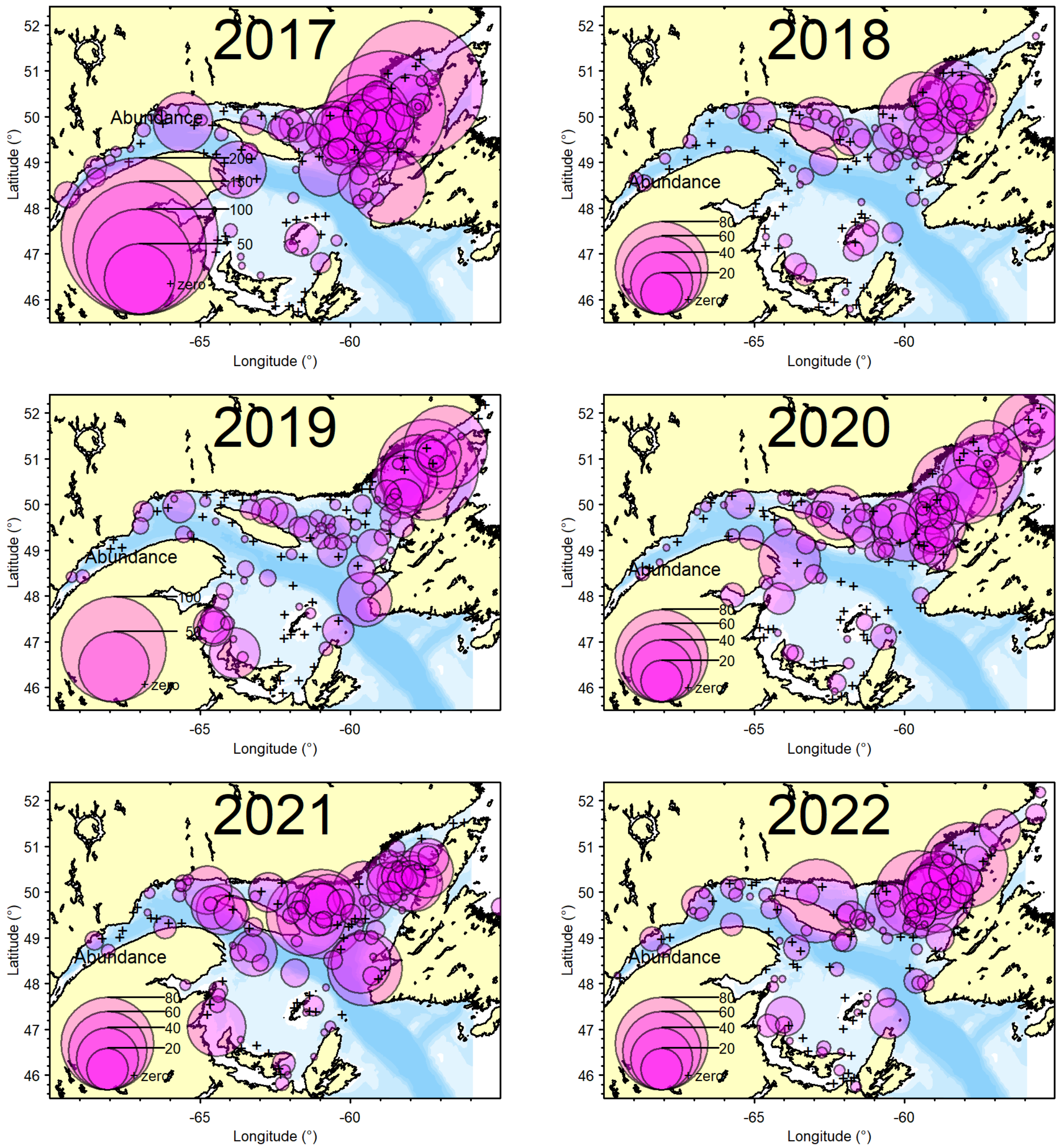

Figure 58. Location of halibut catches (diameter of the circles is proportional to the number of individuals) in the scientific longline survey for halibut.

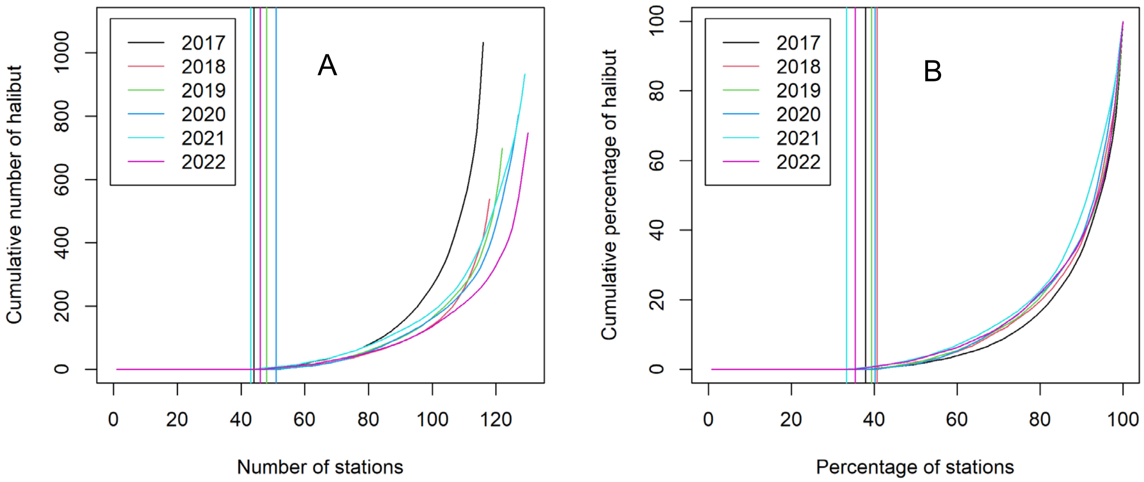

Figure 59. Cumulative catches by number in relation to the number of stations sampled per year (A) and cumulative catches by percentage in relation to the percentage of stations sampled per year (B) in the longline survey. Stations are shown in ascending order of yield. Vertical lines indicate stations where no halibut were caught.

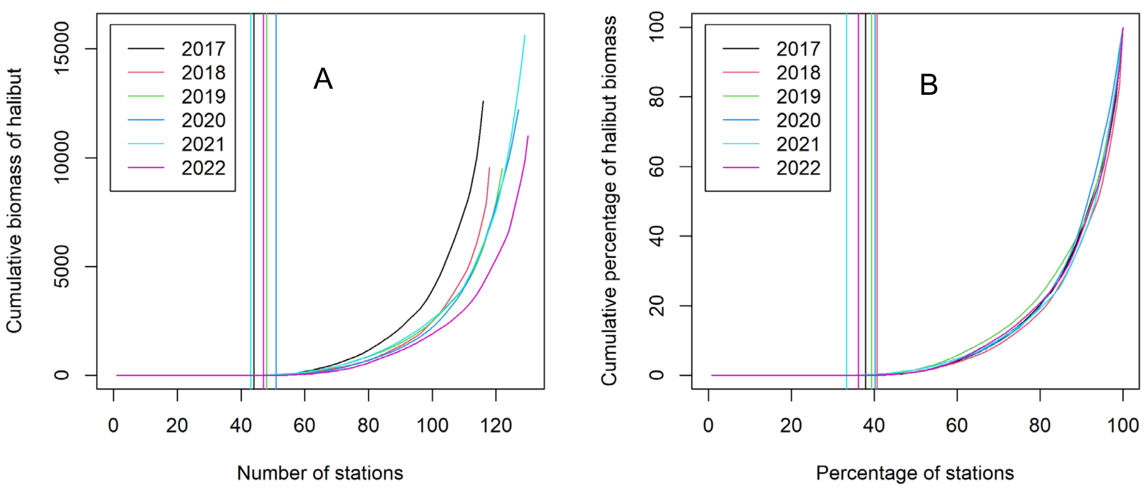

Figure 60. Cumulative catches by biomass in relation to the number of stations sampled per year and cumulative catches by percentage in relation to the percentage of stations sampled per year in the longline survey. Stations are shown in ascending order of yield. Vertical lines indicate stations where no halibut were caught.

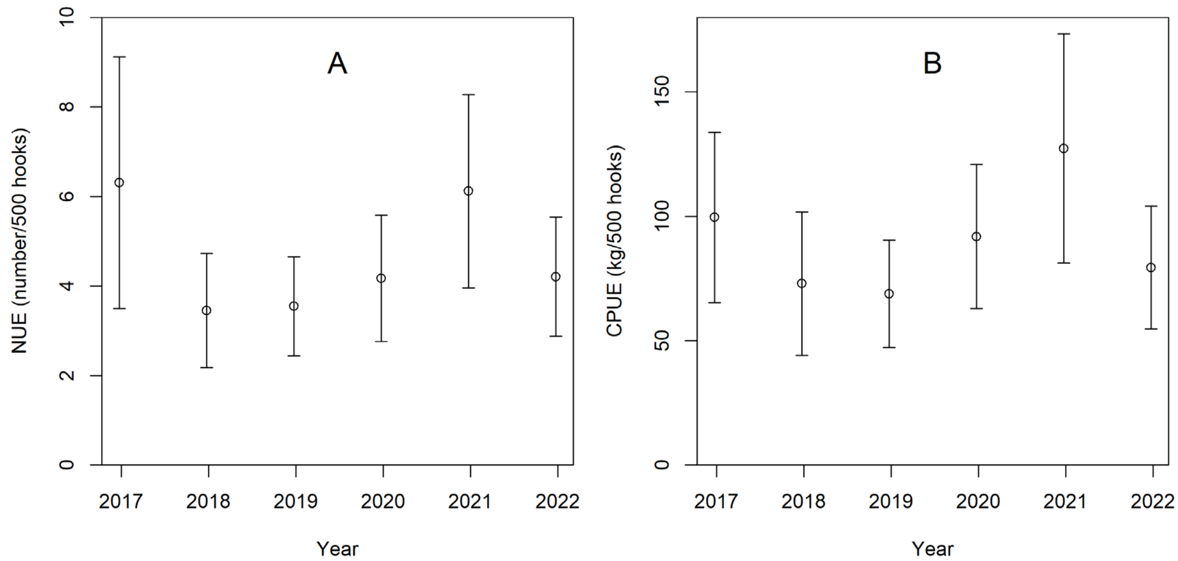

Figure 61. Stratified random mean values of NUE (A) and CPUE (B) for halibut larger than 85 cm.

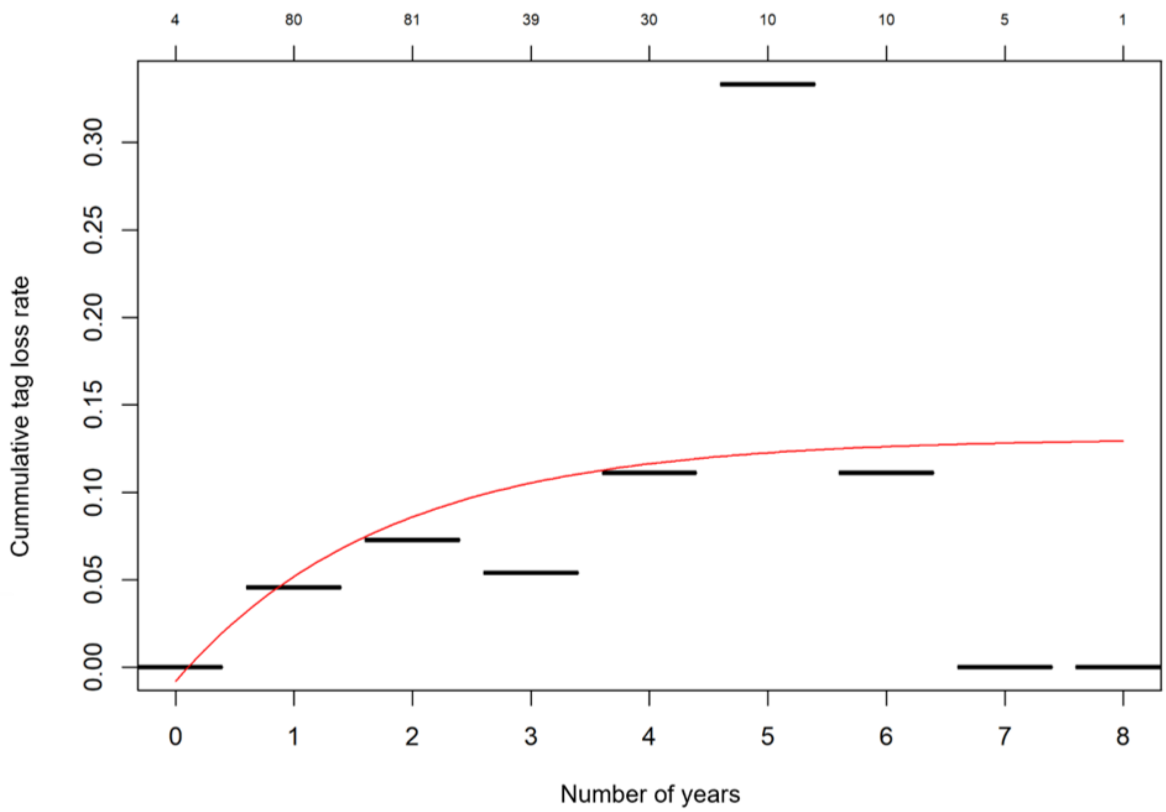

Figure 62. Estimated cumulative tag loss rates in relation to the number of years since tagging. The number of returned tags is shown at the top of the graph.