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Gulf of St. Lawrence (4RST) Greenland Halibut Stock Status in 2022

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Canada

Foreword

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

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ABSTRACT

The status of the Gulf of St. Lawrence (Northwest Atlantic Fisheries Organization, NAFO, Divisions 4RST) Greenland halibut (*Reinhardtius hippoglossoides*) stock is assessed on a two-year cycle that matches the fishery management cycle for the stock. This document presents the data, analyses and indicators presented at the peer review that took place on 13 and 14 February 2023 at the Maurice-Lamontagne Institute and via the Zoom platform. The data used to assess status come from fisheries statistics, sampling of commercial catches, the at-sea observer programme and scientific surveys.

Preliminary landings and fishing effort have shown downward trends for several years and reached in the 2022-2023 fishing season the lowest values observed since the beginning of their respective series. Nonetheless, the fishing performance index was at an average level in 2022. The length composition of landings was stable from 2019 to 2022, although during this period the mean length was below the series average and the proportion of fish below the minimum legal size was above average at about 30%. Abundance and biomass indices from the three scientific surveys have been on a downward trajectory since the mid-2000s. The abundance in cohorts expected to contribute to the fishery in 2023 and 2024 ranged from low (2016) to high (2017-2018). The somatic growth rate in these cohorts appeared to be normal but their low condition in 2022 could negatively affect their growth. The exploitation rate indicator was at the lowest levels observed in 2021 and 2022. Under the precautionary approach, the stock status indicator, estimated at 33,366 t, placed the stock at the top of the cautious zone in 2022. Under the harvest control rule, all sources of removals should not exceed 2,002 t in 2023-24 and 2024-25. Current environmental conditions and climate projections suggest that the situation is likely to remain unfavourable for the stock productivity.

In this document we also present new analyses related to the spatial and environmental distribution of Greenland halibut in winter, the stock-recruitment relationship, the form of the selectivity function of the northern Gulf survey, as well as preliminary results of a project on unaccounted mortality in the directed gillnet fishery.

1. INTRODUCTION

1.1. BIOLOGY

Greenland halibut is a flatfish in the Pleuronectidae family, also known by the names black halibut and turbot. The second part of its Latin name *Reinhardtius hippoglossoides* refers to its resemblance to a horse's tongue. Like other flatfish, Greenland halibut undergoes significant physiological changes over its lifetime. At hatching, its body is bilaterally symmetrical, and it swims upright like a roundfish; shortly afterward, it turns over on its side to swim. Gradually, the eye on the lower side migrates to the upper side and its skull twists. The fact that its left eye does not migrate completely gives it extensive peripheral vision. After this metamorphosis, its diamond-shaped body becomes laterally compressed and asymmetrical. The eyed (upper) side is blackish, dark brown or gray with lighter splotches, while the blind side is usually pale grey. Principal distinguishing features include a straight lateral line and caudal fin, a large mouth and large, pointed teeth (Figure 1).

According to our current knowledge of the Gulf of St. Lawrence (GSL) stock, spawning occurs in winter (between January and March), in the deep part of the Laurentian Channel southwest of Newfoundland (Templeman 1973, Ouellet et al. 2011, Ghinter et al. 2023). In this low-fecundity species, the female lays large eggs (3.4-4.7 mm in diameter) (Kennedy et al. 2009, Dominguez-Petit et al. 2012). Greenland halibut spawns only once a year and some individuals may not reproduce every year (Kennedy et al. 2009). Histological studies (Kennedy et al. 2011, Rideout et al. 2012) identified an unusual reproduction strategy for Greenland halibut in which the simultaneous development of two cohorts of oocytes is observed. A cohort of larger oocytes develops for the upcoming spawning season and a second cohort of smaller oocytes develops for spawning in the following year. This strategy allows Greenland halibut to spawn annually in principle, although each cohort requires more than a year to complete vitellogenesis.

The eggs, owing to their specific density, are mesopelagic. During most of their development, they are found at depths of around 300 m but, in the final days before hatching, rise to shallower depths to hatch due to a substantial change in specific density (Ouellet et al. 2011). After the yolk sac is resorbed, the pelagic larvae are primarily found in the surface layer based on sampling at depths from the surface to 50 m, where larval development occurs. When development has completed, which takes up to four months, the larvae settle on the bottom to undergo metamorphosis.

The main nursery area for Greenland halibut in the Gulf of St. Lawrence (GSL) is in the lower estuary, with a secondary nursery area north of Anticosti Island (Youcef et al. 2013). One- and two-year old juveniles appear to be fairly sedentary in these two areas and are generally found at shallower depths than adults. Growth is continuous in juveniles and length increments between ages 1 and 2 are affected by temperature, dissolved oxygen levels and fish density (Youcef et al. 2015). The species is considered a strong swimmer; it makes significant daily migrations, covering more than 100 m in 15 minutes, and spends nearly 25% of its time in the water column (Albert et al. 2011).

Greenland halibut exhibit sexual size dimorphism due to slower growth upon reaching sexual maturity. Males, which reach sexual maturity at smaller sizes (36 cm) than females (45 cm), attain smaller adult sizes (Gauthier et al. 2021).

Greenland halibut has a circumpolar distribution, with the GSL representing the southern limit of its range. Blood parasite studies in the early 1990s showed that the GSL population is an isolated stock, distinct from the main population in the northwestern Atlantic, which is found east and north of the Grand Banks of Newfoundland (Arthur and Albert 1993). This study concluded that the GSL Greenland halibut stock completes its life cycle within the GSL, which is a single management area for this species (Figure 2). Recent genetic studies confirmed that GSL Greenland halibut represent a unique stock genetically distinct from Atlantic Greenland halibut east of Newfoundland (Carrier et al. 2020, Ferchaud et al. 2022). However, the low value of the differentiation factor and the identification of genetic migrants suggests that there is some gene flow between fish from the GSL and those from the Atlantic ocean.

1.2. ECOSYSTEM

The deep-water layer (>150 m) in the GSL is made up of water from the Labrador Current (cold, less salty and well oxygenated) that has mixed with water from the Gulf Stream (warm, salty and less well oxygenated). These mixed waters enter through the Laurentian Channel and flow up to the heads of the Laurentian, Anticosti, and Esquiman channels. It takes about three to four years for this bottom water to flow between the Cabot Strait and the head of the Laurentian Channel. In recent decades, Gulf Stream water has made up a greater proportion of the mix, resulting in higher temperatures and oxygen depletion in the deep waters of the GSL (Galbraith et al 2022).

In 2022, deep water temperatures continued to increase in the Gulf. New record high temperatures were observed at 150, 200, 250 and 300 m for a series which began in 1915. At 300 m, the temperature nearly reached 6.8°C, 1.5°C higher than the temperature recorded in 2009 (P. Galbraith, DFO, pers. comm., Galbraith et al. 2022). According to forecasts, temperatures in the deep waters of the GSL will continue to be high in the next few years. The cold intermediate layer (CIL) was at near normal temperatures in June 2022 and much warmer than the normal in August. These conditions may be unfavourable for Greenland halibut, which prefer waters between -0.5°C and 6°C (Scott and Scott 1988).

A laboratory study of juvenile Greenland halibut caught in the GSL found that the mortality rate increased with increasing temperature from 4.5% at 4.0 °C to 15.2% at 7.5°C. Relative growth was also lower in individuals maintained at 7.5°C (Ghinter et al. 2021).

During the progression of deep water between Cabot Strait and the head of the channels, in situ respiration and oxidation of organic matter reduce the dissolved oxygen (DO) levels. Since this water travels a greater distance to reach the head of the Laurentian Channel, the lowest levels of DO are found in the lower estuary of the St. Lawrence, where DO levels declined by 50% between 1930 and 1980 (Gilbert et al. 2005, Gilbert et al. 2007). Since 2016, saturation levels in the lower estuary have been below 18% (Blais et al. 2018).

According to research on hypoxia tolerance and the effects of low oxygen levels on the metabolic capacity of Greenland halibut, at a temperature of 5°C, juveniles have a higher critical oxygen threshold than adults (15% versus 11% saturation), indicating that they are less tolerant of hypoxia (Dupont-Prinet et al. 2013). In this study, severe hypoxia increased the duration of digestive processes in juveniles, putting them on the edge of their metabolic capacity at levels close to those currently found in the lower St. Lawrence estuary. As noted earlier, the Estuary is the main nursery area for Greenland halibut. Consequently, any worsening of hypoxic conditions could affect the growth and distribution of Greenland halibut. Another study on juvenile fish showed that the rate of growth between ages 1 and 2 varied inversely with DO levels and decreased significantly at a saturation level of less than 25% saturation (Youcef et al. 2015). However, the study also observed a greater number of juveniles in the deep waters of the Estuary, which are characterized by low oxygen levels, as well as continuous growth in juveniles throughout the year. These observations suggest that the negative effects of low DO levels are likely limited or are mostly offset by other physical or biological characteristics in the lower estuary such as food abundance. DO levels prevailing in the lower estuary during the summer 2022 were 15 % compared to 20 % in 2020 (M. Blais, DFO pers. comm.).

Species distribution models were used to predict the impact of multiple scenarios of warming and oxygen depletion in the deep waters of the GSL on the local density of northern shrimp (*Pandalus borealis*), Atlantic cod (*Gadus morua*) and Greenland halibut (Stortini et al. 2017). These models predict substantial changes within 20-40 years. Of the three species studied, Greenland halibut seems to be the one that will be most affected by these changes and is projected to lose roughly 55% of its high-density areas under the combined impacts of warming and oxygen depletion.

In the early 1990s, two of the major groundfish stocks in the ecosystem, Atlantic cod and redfish (*Sebastes* spp.), collapsed (Brassard et al. 2019, Senay et al. 2021). The resulting decline in large predators favoured an increase in forage species, including various shrimp species. Greenland halibut biomass increased concomitantly with shrimp. In recent years, a simultaneous decrease has been observed in the biomass of northern shrimp and Greenland halibut, while the biomass of redfish has increased considerably (Bourdages et al. 2022a).

The arrival of three exceptionally abundant cohorts (2011 to 2013) of redfish could result in, and/or contribute to intensified direct (for food) or indirect (for habitat) interspecific competitive interactions with Greenland halibut in the GSL ecosystem. These species feed on some of the same prey, including northern shrimp and pink glass shrimp (*Pasiphaea multidentata*). The abundance of redfish is among the highest levels observed in the GSL since longterm surveys began in 1984 (Senay et al. 2021). In 2022, the combined biomass of the two redfish species, *Sebastes mentella* and *Sebastes fasciatus*, represented 82 % of the biomass of all organisms captured during the DFO research survey, while it averaged 15% between 1995 and 2012 (Figure 3). Since these are long-lived species, redfish will share the GSL ecosystem with Greenland halibut for many years.

Overall, the ecosystem conditions observed in the GSL indicate that the structure of this ecosystem is changing, which could be favourable for some species such as redfish but unfavourable for other species such as northern shrimp and Greenland halibut.

1.3. COMMERCIAL FISHERY

1.3.1. History

Until the mid-1970s, landings of Greenland halibut in the GSL occurred mainly in the form of bycatch from trawlers in the northern shrimp- or Atlantic cod-directed fisheries (Figures 4 and 5). The directed Greenland halibut gillnet fishery began to develop in 1977 and a first peak in landings was reached in 1978, followed by a steep decline. A total allowable catch (TAC) of 7,500 t was set for the 1982 fishing season (Table 1, Figures 5 and 6). A second peak in landings was reached in 1987 and was also followed by a steep decline. From 1982 to 1992, GSL Greenland Halibut was managed as a component of the Atlantic stock. During this period, the TAC ranged from 5,000 t to 10,500 t (Figures 4, 5 and 6).

From 1988 to 1992, the status of the GSL Greenland halibut stock was not assessed, owing to the uncertainty surrounding its stock structure at the time. During these five years, the TAC remained fixed at 10,500 t, with landings ranging from 3,417 to 7,585 t.

In the early 1990s, parasite species composition studies allowed separate Greenland halibut populations to be identified and demonstrated that the GSL population was distinct (Arthur and Albert 1993). Assessments of the GSL Greenland halibut stock resumed in 1992 (Morin et al.

1992) and the TAC was decreased to 4,000 t. It was lowered further to 2,000 t in 1996 and then increased to 3,000 t and 4,000 t in 1997 and 1998.

Since 1993, recorded catches from mobile gear have been very low (less than 5% of the total catch, Table 2), due to the closure of the directed mobile gear fishery and the mandatory use of the Nordmore grate by shrimpers (1994) (Hurtubise et al. 1991, Fréchet et al. 2006). Note, however, that a variable yet relatively small amount of small turbot is annually discarded at sea by shrimp harvesters (Gauthier et al. 2021). Since 1993, the only Greenland halibut landings using mobile gear have originated from bycatch in other fisheries (directed redfish fishery and sentinel fishery surveys).

Since the closure of the mobile gear fishery, only a fraction of the TAC that used to be allocated to mobile gear has been transferred to the fixed gear fleet, and consequently a portion of the TAC is no longer fished. In this document, the term "fishing allocation" is used to indicate the sum of catch allocated to the fixed gear fleets (Tables 1 and 3, Figures 5 and 6). Currently, the Greenland halibut fishery is conducted by boats equipped with gillnets with home ports in Quebec or along the west coast of Newfoundland. The fishing allocation is divided between the two provinces, 82% for Quebec and 18% for Newfoundland.

1.3.2. Participants

In accordance with ministerial decisions in recent decades, the only fleets participating in the directed Greenland halibut commercial fishery in the GSL are fixed gear groundfish fleets from the Gaspé Peninsula and North Shore regions of Quebec and the west coast of Newfoundland.

This fishery was conducted mainly under a competitive regime prior to 1999, after which an individual transferable quota (ITQ) system was put in place (Table 1). In 2020, the majority of fishermen in Quebec were under ITQs, while all fishermen in Newfoundland were under competitive conditions.

The number of active harvesters in this fishery has been declining for several years in the GSL, from nearly 250 in 2010 to 75 in 2021[1]. The decrease is similar for the Quebec and Newfoundland fleets, where the number of harvesters respectively decreased from 135 and 99 in 2010 to 58 and 17 in 2021. This decrease could be due to the possibility of more lucrative fisheries, fuel costs and the management measures in place.

1.3.3. Management measures

Many different management and conservation measures are used to manage the fishery (Table 1). They include the closure of fishing areas, restrictions on fishing periods, restrictions on fishing gear (mesh and hook size), fleet quotas and a minimum size for the different groundfish species as part of a small fish protocol. A maximum number of gillnets are allowed and this number has varied over time and between regions (Table 1). Since the 2015-2016 fishing season, Quebec fishermen have been authorized to use 120 nets and Newfoundland fishermen 90.

The measures currently in place in the fishery include harvesters' obligation to complete a logbook (100%), to have their catches weighed at dockside (100%) and to agree to take an at-sea observer on board at the request of DFO (5% to 15% coverage, depending on the fleet). In addition, the use of the vessel monitoring system (VMS) has been mandatory for all Quebec

[1] Deschênes, M., Fisheries Management Directorate, Statistics and Licensing Division, personal communication 2023-03.

fleets since 2017. In Newfoundland, the use of the VMS is not required for all fleets. The license conditions for the Greenland halibut gillnet fishery in Quebec indicate since 2014 that the period of time between the setting in the water and the hauling of the nets (soak time) must not exceed 72 hours (3 days). In Newfoundland, the Atlantic Fishery Regulations stipulates that "No person shall leave fishing gear unattended in the water for more than 72 consecutive hours". Inclement weather or vessel breakdown are some of the factors that are taken into account in allowing a soak time greater than 72 hours.

Until 1998, a calendar-year cycle was used to manage this resource and the TAC was set for the period January 1 to December 31 of the same year. Since 2000, the management cycle has been defined as from May 15 of a given year to May 14 of the following year. In 1999, to bridge the gap between the two management cycle, the TAC was established for the period January 1, 1999 to May 14, 2000.

2. METHODS

2.1. COMMERCIAL FISHERY DATA

2.1.1. Statistics on landings and effort

Since 1996, Greenland halibut harvesters have been required to complete logbooks, including all vessels in Quebec and vessels over 35 feet in Newfoundland. Along with the estimated weight of the catch, information such as the date and fishing area, type of gear, effort (amount of gear), soak time and position are noted for each day at sea.

In Newfoundland, harvesters in the under-35-foot fleet must complete a science logbook, which is then sent to the DFO Science Sector for analysis. The level of compliance with this requirement is not very high. This fleet accounts for less than 5% of annual landings in the directed Greenland halibut gillnet fishery.

Under the Dockside Monitoring Program, all harvesters are required to have their landings weighed at dockside at designated ports. Logbook data are validated using processors' purchase slips and dockside weigh-out summaries that are entered by teams in charge of gathering fishery statistics for each DFO region. Each region then makes these data available in a ZIFF (Zonal Interchange File Format) file. The resulting files are consolidated at Maurice Lamontagne Institute and contain information on all the fleets. Since these files are not generally considered to be final until two years after the fishing activities in question, the data for the current stock assessment year are therefore considered to be preliminary.

Data on Greenland halibut landings before 1985 come from NAFO Statistical Bulletins (Bernier and Chabot 2013), while those from 1985 to 2022 were collated from ZIFF files (Tables 1, 2 and 3). The 1985-1997 data differ from those published previously in Bernier and Chabot (2013) and Morin and Bernier (2003). Landing values based on the ZIFF data are slightly higher than the previously published data. The differences between these two data sources are less than 1%, except for the years 1989, 1993 and 1997 when the difference was 2%, 6% and 7% respectively.

Maps showing the spatial distribution of fishing activities in the GSL were generated using data on locations (latitude and longitude) and fishing grids (10 minutes by 10 minutes) extracted from the ZIFF files. In the ZIFF files for the current year, which are considered to be preliminary, fishing location information is sometimes missing, which is exacerbated in the case of data from the Newfoundland Region.

Another source of data for illustrating the spatial distribution of directed Greenland halibut fishing operations in the GSL come from the VMS. The use of the VMS has been gradually implemented in Quebec since 2013 and has been mandatory on all vessels since 2017. In Newfoundland, the use of the VMS is not required for the fleet of less than 35 feet, the fleet of vessels over 35 feet used for the inshore crab fishery, and vessels which are used only in groundfish fixed gear fisheries. This system tracks vessels' locations by satellite every 30 minutes during fishing trips. The information gathered includes the Canadian Fishing Vessel Number (CFV), location (latitude and longitude), date and time, but the system does not provide information on whether the vessel is actually fishing. To exclude fishing activities not directed at Greenland halibut, we compared the logbook data (ZIFF files) with the CFV information and the dates in the VMS data. All positions that overlap within plus or minus one day when a Greenland halibut catch was recorded in the logbooks are retained. The VMS data are then selected based on the speed of the vessels determined by the distance between two positions. Positions where the vessel was traveling (speeds over 2.5 knots) or was stationary at sea or at dockside (speeds less than 0.5 knot) were eliminated from the analyses. The positions of vessels travelling at speeds between 0.5 and 2.5 knots are kept. These speeds, deemed to represent directed Greenland halibut fishing activities, were validated with harvesters. The resulting Greenland halibut fishing locations were aggregated annually in grid squares of one minute longitude by one minute latitude for mapping purposes.

2.1.2. Catch per unit effort (CPUE)

Data for calculating catch per unit effort (kg/net) were extracted from the consolidated ZIFF files. For this subset of data, only activities involving the use of gillnets as fishing gear and directed at Greenland halibut were retained. Over 98% of landings in the directed Greenland halibut fishery are obtained with gillnets. The catch and effort data were validated and fishing activities with erroneous or missing values for catch or effort were excluded from the subsequent analyses. Non-standardized CPUE corresponds to the landings divided by fishing effort (in numbers of gillnets hauls) in this subset of data. The total (nominal) effort is then estimated by dividing the total landings in directed gillnet fisheries (including those without effort) by the CPUE.

The CPUE values presented cover the years from 1999 to 2022. Data before 1996 were not included, mainly due to the change in gillnet mesh size from 140 to 152 mm (5.5 to 6 inches) in the directed Greenland halibut fishery, which make catch values in the two periods difficult to compare. In addition, the data for 1996 to 1998 were excluded because they are incomplete. Annual CPUE values are presented for the entire Gulf (4RST) and for the three fishing sectors (western Gulf, Anticosti and Esquiman).

2.1.2.1. CPUE standardization

Annual CPUE values were standardized using a multiplicative model (Gavaris 1980) to account for interannual variation in the seasonality of the fishery, location of fishing activities and fishing practices (soak time categories). General linear models between the logarithm of the CPUE values and the factors year, month, NAFO unit areas and soak time categories were used. The models account for the effects of these three factors, making CPUE values comparable across years. The analyses were carried out using the GLM procedure in SAS software (SAS 1996). Standardization was done separately for each fishing sector and for the entire Gulf (4RST). The annual standardized CPUE values correspond to a reference fishing activity carried out in July with a soak time of three days. The reference unit areas are 4Si for the entire GSL and the western Gulf sector, 4Rb for the Esquiman sector and 4Sx for the north Anticosti sector.

2.1.3. Gillnet deployment depth and soak time

The data used to calculate gillnet deployment depth and soak times were extracted from the validated data files used to calculate CPUE values. Exact depth data have been available in the ZIFF files since 2008; previously only depth classes were reported. Deployment depths were represented in box and whisker plots and immersion times in proportion of fishing activities using immersion times of 1, 2, 3 or ≥4 days.

2.1.4. Commercial catch sampling and size structure

Commercial catches are sampled in two different programs: the DFO's port sampling program and the At-Sea Observer (ASO) Program. In the first program, which was established in the early 1980s, DFO samplers are spread over the entire territory. Their work consists in, among other things, gathering data on the size and sex of fish landed, either at dockside or at the processing plant. The At-Sea Observer Program allows detailed information to be collected on fishing activities at sea, including data on the target species, bycatch and discards. Data on Greenland halibut from this program is available since 1994. The information gathered in these two programs, at dockside and at sea, enable the average fish size and sex ratio in landings to be determined annually. This information was extracted from the databases for the two programs and then validated. Samples were rejected when fish were not sexed, the proportion of females was questionable (females are larger and more numerous in gillnet hauls), the average length of males was greater than that of females, or measurements were made on only a small number of fish. When sample weights were not available or were greater than the catch weight, they were calculated using the sample length frequencies and length-weight relationships from the DFO August research survey.

The number of fish measured per sample varies greatly between the data collected by DFO samplers (a sample of 250 fish prior to 2005, and 150 since, per trip) and the observer program (150-200 fish per sample and several hauls sampled per trip). The length-frequencies of fish captured in the commercial fishery are estimated as follows. First, for each sex separately, relative length (fork length) frequency per DFO sample and per observer trip (many hauls) was calculated. Secondly, the average of the relative frequencies in the samples for the same combination of NAFO division, year and quarter was calculated. Length frequency distributions were then weighted by annual landings per NAFO division and quarter to generate an annual size structure. Average size and the proportion of females caught in the fishery were calculated from the numbers at length obtained. No observers were deployed in 2021 and 2022 on vessels from the province of Newfoundland and Labrador.

2.1.5. Bycatch in the directed Greenland halibut gillnet fishery

Data from two sources, ZIFF files and the ASO program, were combined to give an overall picture of bycatch in the Greenland halibut targeted gillnet fishery. The ZIFF files provide comprehensive information on total reported landings. The ASO program covers a certain percentage of fishing trips and therefore provides only partial information on bycatch, but is the only source of data on discards at sea, which are not recorded in the ZIFF files.

Greenland halibut harvesters are required to take an at-sea observer on board when requested by DFO. The targeted minimum coverage under the program is 5% of all directed fishing trips, although this percentage may reach 15% in some fleets directing for other species, such as the Quebec longliners' fleet. Coverage required for the Newfoundland fleet is 10%. Observers record detailed information on gillnet hauls (position, duration, catch by species or taxon and length of specimens for certain species). Data from the At-Sea Observer Program collected between 2000 and 2022 in the directed GSL Greenland halibut fishery were used to estimate bycatch. No observers were deployed in 2021 and 2022 on vessels from the province of Newfoundland and Labrador.

The methodology used to process the bycatch data from the At-Sea Observer Program is similar to that described in Savard et al. (2013). Since 2000, approximately 10,000 fishing activities have been sampled. Weighting factors (the ratio between the Greenland halibut catch by harvesters and the Greenland halibut catch in the observed activities) were calculated to scale the bycatch results obtained from the observer program database to the totality of fishing activities carried out by the Greenland halibut fleet.

2.1.6. Greenland halibut bycatch in the directed shrimp fishery

Shrimpers are also required to take an at-sea observer on board at DFO's request. The At-Sea Observer Program aims for 5% coverage of all fishing trips by shrimpers. The information collected is the same as for the Greenland halibut fishery. The data processing methodology used is described in Savard et al. (2013). Since 2000, approximately 22,000 tows have been sampled under the program. Weighting factors (Σ shrimpers effort/Σ observer effort) were calculated and used to scale the results of observer data to the total effort expended by the GSL shrimper fleet.

2.2. RESEARCH SURVEY DATA

2.2.1. Description of surveys

2.2.1.1. DFO survey in the northern Gulf of St. Lawrence

Since 1984, a research survey has been conducted annually in August in the lower estuary and northern Gulf of St. Lawrence (nGSL) to estimate the abundance of groundfish and northern shrimp (Bourdages et al. 2022a). This survey is carried out by DFO's Quebec Region and covers NAFO Divisions 4R, 4S and part of 4T (northern part of GSL) (Figures 2 et 7).

From 1984 to 1990, the survey was conducted on the *Lady Hammond* equipped with a *Western IIA* trawl with a 19 mm lining. From 1990 to 2005, the survey was conducted on board the *CCGS Alfred Needler*, equipped with a URI 81'/114' (University of Rhode Island) shrimp trawl with a 19-mm lining. From 2004 to 2022, the survey was conducted on board the *CCGS Teleost* with a *Campelen 1800* shrimp trawl and a 12.7 mm lining. Finally, in 2021 and 2022, the survey was conducted by the *CCGS John Cabot* with a slightly modified *Campelen 1800* shrimp trawl with a 12.7 mm liner. The main difference between the *Teleost* and *Cabot Campelen 1800* trawls was at the footgear level as well as a few minor differences in the trawl itself (see details in Benoît et al. 2024). The *Cabot* trawl footgear was slightly heavier than that of the *Teleost*. Comparative fishing experiments were carried out in 1990, 2004, 2005, 2021 and 2022 to evaluate differences in catchability between the two vessel-gear tandems and to establish conversion factors (Yin et Benoît 2022, Benoît et al. 2024). The results from these experiments were used to produce a standardized series by adjusting the catches of the Lady Hammond, CCGS Needler and Teleost into equivalent catches of the CCGS John Cabot.

The standard tows performed with the Campelen trawl since 2004 have a target duration of 15 minutes, starting from the time the trawl touches the sea floor as determined by the Scanmar™ hydroacoustic system. Towing speed is 3 knots. Fishing operations are conducted 24 hours a day.

A stratified random sampling plan is used for this survey. The study area is divided into 56 strata based on depth, NAFO Division and substrate type (Figure 7).

2.2.1.2. DFO survey in the southern Gulf of St. Lawrence

Every September since 1971, bottom-trawl surveys have been conducted on board a research vessel in the southern Gulf of St. Lawrence (sGSL) (NAFO Division 4T) (Figure 7). This survey has been led by DFO's Gulf Region since the mid-1980s.The primary objective of the survey is to obtain abundance indices for the diverse groundfish species in this region.

A stratified random sampling plan is used in this survey. Figure 7 shows the areas covered by the nGSL and sGSL surveys. There is some overlap between certain strata covered by the two surveys along the southern edge of the Laurentian Channel.

From 1971 to 1985, the sGSL survey was conducted on board the *E.E. Prince* using a *Yankee 36* trawl. Surveys were performed on board the *Lady Hammond* from 1985 to 1991, the *CCGS Alfred Needler* in 1992-2002 and 2004-2005, the *Wilfred Templeman* in 2003 and the *CCGS Teleost* since 2004. The fishing gear used by the *Hammond*, *Needler*, *Templeman* and *Teleost* was the *Western IIA* trawl equipped with a 19-mm mesh codend liner. In 2021 and 2022, the survey was conducted on board the *CCGS Captain Jacques Cartier* using a slightly modified version of the Northeast Fisheries Science Center Ecosystem Survey Trawl (NEST). At each change of vessel and/or type of gear, comparative fishing experiments were conducted to generate conversion factors, which have allowed a continuous and consistent time series to be maintained since 1971 (Benoît and Swain 2003a, Benoît 2006, Benoît and Yin 2023). A standard tow was carried out at a speed of 3.5 knots for a target duration of 30 minutes for the surveys using the *Yankee 36* or *Western IIA*, and 20 minutes at 3.0 knots for the tows performed with the *CCGS Captain Jacques Cartier*. The survey operated only during daylight hours from 1971-1984, and on a 24-hr schedule since. The catchability of Greenland halibut to the survey did not appear to differ between day and night, and as a result no adjustment is made for this change in protocol (Benoît and Swain 2003b).

2.2.1.3. Mobile gear sentinel surveys in the nGSL

Mobile gear surveys conducted in July in the nGSL since 1995 under the Sentinel Fishery Program (MSP) are also used to assess the status of the GSL Greenland halibut stock. The sampling plan and fishing protocol are similar to those used in the DFO's nGSL research surveys. This survey covers NAFO areas 3Pn, 4RS and a portion of 4T, but not the lower estuary (strata 411 to 414, 851, 852, 854, and 855) where a large proportion of Greenland halibut, particularly juveniles, occur in summer. Annually, nearly 300 fishing stations are apportioned between the six to nine trawlers from Newfoundland and Quebec participating in the survey. The vessels participating in the survey all use the same type of gear, a Star Balloon 300 trawl with rockhopper footgear. This trawl has 145-mm mesh and a 40-mm lining in the codend. The standard tow is carried out at a speed of 2.5 knots for a target duration of 30 minutes. The 30-minute time frame is calculated from the time the winches are stopped (after the gear is deployed) to the time they are reactivated to raise the trawl. The total Greenland halibut catch is weighed at the end of each tow and a maximum sample of 200 individuals is taken to determine certain biological characteristics, including size (fork length) and sex. A description of the mobile gear sentinel survey is available on the St Lawrence Global Observatory website.

2.2.1.4. Winter surveys

The spatial and depth distributions of Greenland halibut in winter surveys is presented in the context of a possible return of the winter redfish fishery. Such information could be useful in attempting to limit the bycatch of Greenland halibut in this fishery (Rolland et al. 2022). Data from two winter surveys are presented, from the *MV Gadus Atlantica* (1978 – 1994) and the *Mersey Venture* (2022). For each survey, the spatial distribution of Greenland halibut is presented as a map of catch rates (in numbers and weights per standard tow). The cumulative proportion of catches (by weight) of Greenland halibut, redfish (*Sebastes fasciatus* and *mentella*) and tows sampled by depth are also presented.

The random stratified bottom trawl survey conducted from 1978 to 1994 (excluding 1982) in January operated on a charter vessel, the *MV Gadus Atlantica* using an Engel 145 Otter trawl with a 160 mm liner in the trawl codend (McCallum and Walsh 1997). The study area included NAFO Divisions 4RST and unit area 3Pn. Although a stratification scheme identical to that used in the summer nGSL survey was used (Figure 7, Fréchet 1986), the spatial coverage of the survey was highly variable from year to year, particularly in 4S, and the study area was never completely covered due to ice, which prevents the estimation of a standardised abundance index (*e.g.* Rivest et al. 2021). The geographical coordinates of the stations were recorded from 1979. The mission was abandoned in 1995 mainly because nGSL cod were in 3Ps during the survey period and hence biomass estimates were considered biased (Fréchet and Schwab 1995). Another reason given was the retirement of the vessel Gadus Atlantica (Fréchet et al. 1994).

A winter survey was conducted from 10 to 26 February 2022 aboard a chartered vessel, the *Mersey Venture*, a vessel of identical length and width to the CCGS Teleost built that same year by the same shipyard (DFO 2020). The objective of this new survey, planned for three consecutive years, is to determine the current winter geographic distribution of fish species in the deep channels in the event of a re-opening of the redfish fishery. The vessel fished with a *Campelen 1800* trawl net with a 12.7 mm liner, as in the DFO nGSL survey. The study area for the 3-year survey includes depths of 150 m and more in the Laurentian Channel from the western tip of Anticosti Island to the opening of the channel Laurentian in 3Ps and 4Vn, as well as the Esquiman, Anticosti and Hermitage channels (Figure 8). The stations were determined according to an unaligned systematic sampling plan, which consists of gridifying the study area (in NAD83 Québec Lambert), placing a station on each grid node and adding 1 random x component per line and 1 random y component per column (Ripley 1981). The number of stations in the study area was determined in order to obtain an average between stations distance of 11 nautical miles, or about 1.5 hours of transit at 7.5 knots. The spSample function of the R library ‘sp ‘(Pebesma and Bivand 2005) was used for drawing station locations. The survey objective in 2022 was to fish 108 stations in the central portion of this study area (Figure 8).

2.2.2. Abundance indices

For the DFO’s nGSL survey and the MSP survey, the standard estimator for stratified random sampling is used to calculate annual indices (see Bourdages et al. 2022a for more details). A multiplicative model (Gavaris 1980) was used to correct number and weight estimates of catch rate indices for strata not sampled by a minimum of two tows in a given year. This model predicts the values for these inadequately covered strata by using the data from the current year and the previous three years. For the years in which comparative fishing experiments were conducted (1990, 2004, 2005, 2021 and 2022), the catch (in number and weight) of the comparative sets is averaged so as not to underestimate the variance (the comparative stations are not independent). Thus, the indicators presented for a given series are representative of a total standard area, the sum of the area of the sampled strata i.e. 116,115 km^2 for the nGSL survey (excluding strata 851, 852, 854 et 855 added in 2008), 111,855 km^2 for the MSP survey and 73,180 km^2 for the sGSL survey.

The annual numbers at length (number by 1 cm length bin) in the nGSL and MSP surveys was computed as followed: the number by length bin in a standard tow (y_{hij}) is first calculated, then the mean number per tow and length bin in a given stratum ($\bar{y}_{hj}$) and third the weighted mean of strata mean number per tow and length bin, where the weighting factor is the proportion of the annual study area represented by each stratum (W_h):

$$y_{hij} = x_{hij} \frac{1}{f_{hij}}$$

$$\bar{y}_{hj} = \frac{\sum_{i=1}^{n_h} y_{hij}}{n_h}$$

$$\bar{y}_j = \left(\sum_{h=1}^{H} \bar{y}_{hj} * W_h \right)$$

$$W_h = \frac{N_h}{\sum_{h=1}^{L} N_h}$$

where x_{hij} is the number of Greenland halibut in size class *j* sampled in tow *i* of stratum *h* and f_{hij} is the sampled fraction. Note that x_{hij} is expressed in *Cabot Campelen* equivalent for a standard tow of 15 minutes at 3 knots with an opening of 16.71 meters and therefore takes into account the conversion factors to ensure continuity in the time series despite the ship changes. N_h is the size of the stratum *h* size expressed in number of trawlable units and *H* is the number of strata sampled.

The last step consisted in correcting the annual numbers at length by multiplying them by the ratio of the size aggregated abundance index (C, representative of the whole study area) and the sum of uncorrected numbers at length:

$$\bar{y}_{jcorr} = \bar{y}_j * C \Big/ \sum_{j=1}^{J} \bar{y}_j$$

where *J* is Greenland halibut maximum length in the survey. We therefore assumed that, for a given year, the average annual size structure ($\bar{y}_j$) of the sampled strata was representative of that of the entire study area. The size structure by sex was calculated using the same method. Very few fish were sexed in 1984 and 1985 in the nGSL survey (less than 75). The size structure by sex was therefore calculated from 1986 onwards.

The number and weight indices for each size class ([0-20] cm,]20-30] cm]30-40] cm and > 40 cm) were obtained by converting standard tow number-at-length values to weight-at-length values using annual length-weight relationships derived from the nGSL and MSP surveys. Differences of between roughly 1% and 10% can be observed between the total biomass values obtained from catch weights and those calculated from catch numbers converted to weight using length-weight relationships, summed over all lengths and both sexes. A ratio was then applied to the weight-at-length values to convert them to the equivalent of the total biomass obtained with catch weights. The weight-at-length values obtained were then combined by size class. The annual indices were computed using the stratified random estimator after imputing values for a small number of year strata with the multiplicative model.

Size aggregated abundance and biomass indices for the sGSL survey were calculated following the methodology used in the nGSL and MSP surveys, but numbers at length were calculated by first imputing values in unsampled year strata using the multiplicative model, and then using the standard estimator for random stratified surveys.

2.2.3. Summer geographic distribution

The geographical distribution of the catch rates obtained in the DFO and MSP surveys in the GSL, presented as weight and numbers per tow, was compiled for four- or five-year periods. The interpolation of survey catch rates was performed on a grid covering the study area and using inverse distance weighting interpolation (R version 2.13.0, Rgeos library; R Development Core Team 2011). The isoline contours were then plotted for four catch rate levels approximating the 20th, 40th, 60th and 80th percentiles of the non-zero values. The geographic distribution of Greenland halibut is presented in terms of total biomass and spatial distribution maps showing numbers per tow are also provided for each of the following length classes: 0-20 cm, 20-30 cm, 30-40 cm and > 40 cm.

2.2.4. Spatial distribution indices

Three descriptors, or indices, of spatial distribution were calculated with data from the DFO nGSL survey: the design-weighted area of occupancy (DWAO), the D95 and the Gini index. The design-weighted area of occupancy (DWAO) is the area of the study zone where Greenland halibut is found (Smedbol et al. 2002). The D95 index describes geographic concentration. This descriptor corresponds to the minimum area containing 95% of Greenland halibut biomass (Swain and Sinclair 1994). The Gini index quantifies the degree of homogeneity of Greenland halibut distribution. This index is calculated using the Lorenz curve (Myers and Cadigan 1995). Values for the index range from 0 to 1, where 0 corresponds to a perfectly homogenous distribution and 1, to a very concentrated distribution.

2.2.5. Summer environmental distribution

The cumulative proportion of catches (in weight) in the nGSL survey (1984-2022) was compiled according to depth and temperature, while taking into account the random stratified survey plan (Perry and Smith 1994). This relationship was depicted graphically jointly with the cumulative proportion of the number of stations sampled in the study area. The annual cumulative proportion of catches as a function of depth, temperature and percentage of dissolved oxygen were also calculated by size classes (0-20] cm,]20-30] cm,]30-40] cm et > 40 cm), and by fishing sector. Box plots were used to represent the 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles of the annual cumulative catch distributions.

2.2.6. Demographic structure

Length frequency distributions are presented in two different forms. The first figure consists of a matrix chart where pixel color is proportional to the number of individuals caught of a given size. The second figure shows the distributions for the last two years of the series (2021 and 2022) as well as the average distribution for the reference period (1984-2022 for the nGSL survey and 1995-2022 for the MSP survey). Length frequency distribution values are expressed as the mean number of individuals per tow in one-centimeter increments.

2.2.7. Recruitment

Recruitment strength is estimated from the annual abundance of fish of size ≥ 12 and ≤ 21 cm caught in the DFO's nGSL and sGSL surveys. This size range corresponds to one-year-old Greenland halibut. For the 2014 cohort, the range of lengths corresponding to one-year-old fish was reduced to reduce overlap with the 2013 cohort, for which growth was less than expected. The recruitment strength of the 2014 cohort was estimated by the abundance of fish from ≥ 12 to ≤ 18 cm long. A recruitment index is not calculated for the MSP survey, which catches few small Greenland halibut as a result of a larger cod-end mesh size.

In previous assessments, recruitment was calculated by summing the annual length frequencies for the size ranges corresponding to individuals of 1 year. The method of estimating annual length frequencies assumes that the size structure in strata with more than 2 stations is representative of the entire study area (no imputation is made for non-sampled strata). From 1984 to 1986 and in 1989, the 4 strata of the estuary (the main nursery of the stock) were not sampled during the nGSL survey. The use of annual size frequencies to estimate recruitment would underestimate recruitment in these years. Recruitment was therefore calculated by imputing values in these missing years strata. Specifically, the number of one-year fish (≥12 and ≤ 21 cm or ≥12 and ≤18 cm in 2015) was calculated for each station and then the multiplicative model was used to impute values in the missing strata-years. The standard estimator for the sampling design was then used to calculate the annual recruitment index.

2.2.8. Stock – recruitment relationship

The relationship between spawning stock biomass and recruitment (hereafter referred to as the stock-recruitment relationship) was investigated to better understand population demography and productivity using the nGSL survey data.

The ideal spawning stock indicator is the number of eggs (Hilborn and Walters 1992). Although there is a relationship between size and fecundity for the GSL Greenland halibut stock (Bowering 1980), sex of fish was determined in the nGSL starting in 1986, and maturity starting in 1995, preventing the use of an estimated egg number or biomass of mature females as an indicator of spawning stock. Spawning stock biomass was therefore defined as fish biomass over 40 cm and recruitment as in the previous section. The recruitment vector was lagged by 1 year to match the biomass that produced it.

Four models of the relationship between stock (S) and recruitment (R) were fitted to the data: the density independent model $E[R|S] = aS$, the Beverton-Holt (1957) $E[R|S] = \frac{aS}{1+bS}$ and the Ricker (1954) $E[R|S] = aSe^{-a\frac{S}{R_p e}}$, where *a*, *b* and R_p are estimated parameters. A null model comprising the intercept only was also adjusted to compare with the previous models and validate that a stock-recruitment relationship exists. All models were fitted assuming a multiplicative error term by applying the natural logarithm on both sides of the equations. The nls function of the 'stats' library of the R (R Core Team 2021) package was used to fit the models. The models were compared using the Akaike Information Criteria (AIC) and the residuals (on the log scale) were plotted as a function of years.

2.2.9. Condition

The Fulton condition index for Greenland halibut (K= weight [g]/length^3 [cm]), determined using data from the DFO's nGSL survey (1989 to 2022), is used as an indicator of the condition of Greenland halibut in August. It is calculated based on the total weight of the fish. Using somatic weight (the fish's total weight, minus gonad weight and stomach content weight) to calculate this index is generally preferable in order to eliminate the variability that can be caused by feeding intensity and/or different degrees of gonad maturation in fish (Dutil et al. 1995). However, since somatic weight was not available in this study, total weight was deemed adequate for determining this index, given that the index was calculated in the same period every year (August), outside of the spawning period.

An analysis of covariance (ANCOVA) was used to compare values for this index from year to year. Using ANCOVA allows the linear effects of fish length on the condition index to be removed and the year effect to be assessed. The condition index is estimated by size intervals: 10-20 cm, 20-30 cm, 30-40 cm and over 40 cm. The model predicts a condition index for each year for length values of 15, 25, 35 and 45 cm. These annual predictions are then compared with each other. Abnormally high K values were obtained for several lengths in 1987, 1988 and 1989. The indices are therefore presented from 1990 onwards.

2.2.10. Size at sexual maturity

Information has been collected in the DFO's nGSL survey every year since 1996 to determine size at sexual maturity in Greenland halibut. The stage of sexual maturity is determined by the visual inspection of the gonads using morphological criteria in individuals over 22 cm long, in up to 100 fish per tow. The size at which 50% of fish are mature (L_{50}) is determined separately by year for males and females. A glm for each year and sex using a Bernouilli distribution and a logit link function was used to estimate the L_{50} , which, in such a model, corresponds to the absolute value of the ratio of the intercept to the slope.

2.2.11. Selectivity of the nGSL survey

2.2.11.1. Context

The shape of the Greenland halibut (GH) selectivity function for the nGSL bottom trawl survey is uncertain for large individuals. A logistic or sigmoid selectivity implies that large individuals are fully selected by the survey while a dome shape selectivity implies that large individuals can avoid the trawl, as has been observed in bottom trawl surveys elsewhere (Albert et al. 2003), or that the survey does not adequately cover areas where the largest individuals are found. In the context of modeling the population dynamics of this stock, these 2 possible selectivity functions lead to contrasting interpretation of the nGSL survey length frequency distributions (LFD). In the former case the survey would be interpreted as providing reliable relative estimates of number at length for large individuals present in the population. In the GSL bottom trawl surveys (nGSL, sGSL and mobile sentinel), cohorts appear to recruit to these sizes regularly but do not result in sustained increases in the abundance of large fish, suggesting that these individuals may be subject to high total mortality (or emigration, which is unlikely). In the latter case, the few large individuals observed in the surveys would be interpreted to reflect the decreasing selectivity (individuals are present, but unlikely to be sampled). Thus the two selectivity scenarios lead to important differences in the interpretation of the productivity of the stock and likely the demographic factors affecting productivity.

Contrary to survey trawls, longlines are generally optimized to attract and catch large individuals (Løkkeborg and Bjordal 1992, Clark and Kaimmer 2006). The comparison of nGSL LFD with length data collected with a typical logistic or sigmoid selective gear such as longline (LL, Cox et al. 2016) could inform on the shape of selectivity function of the bottom trawl survey. Data from the gillnet fishery was not considered because of the typical dome shape selectivity of this gear (Hamley 1975, Kurkilahti et al. 2002).

In this context, LFD from the nGSL bottom trawl survey were compared to the LFDs observed in the Atlantic halibut longline (LL) survey as well as with At Sea Observer (ASO) data from LL fisheries to inform on the shape of the nGSL survey selectivity function. Biological data from the *Gadus* winter survey (1978 – 1994) was also investigated to see if evidence exists that bottom trawl selectivity varies with regards to season or sampling location.

2.2.11.2. Methods

2.2.11.2.1. Comparison of GH LFD from bottom trawl and longline samples

In the 4RST Atlantic halibut longline survey, GH length measurements were collected from 2019 to 2021. Unfortunately, few individuals were measured in these three years and this dataset was abandoned for the rest of the analyses.

ASO program has operated on the longline (LL) fishery in the GSL since 1999. The protocol requires to collect two biological samples per day of the target species and one every two days for the two main bycatch species. One sample corresponds to 175 randomly selected individuals. Catch and length frequency data for GH were extracted for longline catches from fishing activities targeting the following species: Atlantic halibut, GH[2] and Atlantic cod. This corresponds to a total of 324 catch observations from 1999 to 2021 where GH were measured. For each year and target species, LFD were computed as mean number per haul and 1 cm length bin, for all years and annually. Mapping of hauls with GH LF data was performed by year blocks to assess potential sampling differences between ASO and the nGSL survey. Number of hauls with GH LF data were also tabulated by year and month and plotted against depth to qualitatively evaluate the assumption that the 2 data sources sampled the same population.

The nGSL survey data were spatially subset to select data from strata for which there where GH LF data in the ASO dataset. This was done in order to coarsely control for possible spatial and depth differences in length structure. Some differences in sampled depth by the 2 data sources remained after this operation. Therefore, the nGSL survey data were used to evaluate if GH length is related to depth by regressing mean GH length by set against depth, with correlated random intercept and slope within year. Catch biomass was used as weighting factor.

Mean number per tow were computed by 1 cm length bins (see section Demographic structure) from the subset nGSL survey database. Before comparison, all LFDs were transformed into proportions by dividing by yearly totals.

Comparison of the annual LL ASO (O_{yl}) and nGSL LFD (S_{yl}) were done by plotting the datasets and by computing the ratio of LFD (R_{yl}) for year y and length class l:

$$R_{yl} = O_{yl}/(O_{yl} + S_{yl})$$

2.2.11.2.2. Comparison of GH LFD from bottom trawl and winter surveys

A random stratified bottom trawl survey was undertaked in January from 1978 to 1994 with a chartered vessel, the *NM Gadus Atlantica*. The vessel fished with an Engel Trawl (GOV) so that selectivity at length is not directly comparable with the Campelen converted August nGSL survey. The presence of large GH (for instance > 80 cm) in the winter survey could however indicate that these individuals are present in the population and are not available and/or selected by the summer nGSL survey. This hypothesis was qualitatively evaluated by computing raw proportion at length on an annual basis and for the entire *Gadus Atlantica* data series and was compared to the mean of the annual proportion at length in the August nGSL survey.

2.3. UNACCOUNTED MORTALITY IN THE GH GILLNET FISHERY

2.3.1. Context

The commercial fishery for Greenland halibut in the Gulf of St. Lawrence uses gillnets almost exclusively. A large proportion of fishing trips have employed prolonged soak times, exceeding the regulated 72 hours maximum soak time. Excessive soak times have previously been associated with degradation of the catch to the point at which some may fall out of the nets or be depredated before the nets are retrieved (e.g., Ward et al. 2004). This drop-out loss constitutes a source of unaccounted fishing mortality (Uhlmann and Broadhust 2015), which is

[2] LL fishery targeting Greenland halibut was authorized for a few years in the 2000s (Trottier, S., DFO Fisheries Management, pers. comm.).

known to increase with soak time (Patterson et al. 2017). There is some anecdotal evidence that some harvesters in the fishery may deliberately employ long soak times as a form of self-baiting gillnetting, with the aim of increasing catch rates. The magnitude of unaccounted fishing mortality due to drop-out in the GSL GH fishery is unknown.

Exploitation rates on the stock have been low since at least the early 2000s, yet adult abundance has declined considerably since the late 2000s despite reasonable levels of recruitment in most years. Change in the stock's habitat characterized by progressive warming and deoxygenation have been hypothesized as a potential cause (DFO 2021a; Duplisea et al. 2021); however, unaccounted fishing mortality constitutes an alternative or complementary hypothesis. Establishing the magnitude of unaccounted mortality caused by drop-out is key to understanding how fishing affects the stock and for establishing reliable approaches for the sustainable management of the stock during a time of environmental change. Furthermore, understanding how soak time affects the magnitude and condition ('freshness') of the catch could help improve the profitability of the fishery, in addition to its sustainability.

In this context, analyses were performed to understand the relationship between soak time and i) landed biomass (ZIFF and ASO data), ii) discard amounts and fish condition ('freshness') in data collected by the ASO Program, and iii) fish decomposition in experiments undertaken in 2022 to characterize the processes determining fish condition.

2.3.2. Methods

2.3.2.1. Gillnet commercial landings - soak time relationships.

The relationship between landed biomass and soak time was investigated in order to understand how the performance of the fishery is related to soak time. Factors expected to affect GH gillnet catches include the number of gillnets, the soak time, and the biomass or number of fish available, which is expected to vary in space and time (seasonally and interannually). These different effects will be accounted for in the following analyses.

Analyses of catch biomass as a function of soak time were performed on two independent datasets: the ZIFF database previously used for calculating commercial CPUE (hereafter the catch and effort dataset (see section Catch per unit effort (CPUE)), as well as the ASO database. Both datasets were subset to only keep fishing activities for which the target species was GH and fishing gear was gillnet. The catch and effort dataset consisted in 38,647 observations spanning the 1999-2021 period, with most observations occurring in NAFO subunits 4Rb, 4Si, 4Sx, 4To, 4Tp and 4Tq (Table 21). The ASO database consisted in 10,064 observations spanning the same time period, with most observations coming from the same areas, except that NAFO subunits 4Tp was slightly underrepresented compared to the ZIFF dataset (Table 22).

Data exploration was performed by plotting cumulative proportion of fishing activities as a function of soak time (hour) for the whole GSL and by fishing area (western Gulf, Esquiman and North Anticosti, Figure 9). Separate analyses were undertaken for soak times categorized into 6 and 12 hours categories. The number of observations (fishing activities) was tabulated by soak time category for the whole GSL and by fishing area, as well as the number of unique year-month-NAFO subunits. These subunits were used to account for expected spatio-temporal differences in fish density, and were also used in subsequent modelling.

Four groups of models relating landed (retained) catch as a function of covariates were fitted to the ZIFF data: for the whole GSL (global analysis) and by fishing area. Only the whole GSL model was fitted to the ASO data. We employed models assuming a Tweedie (TW) distributed error and a log-linear mean that is a function of a soak time category, random intercepts defined by the combination of NAFO subunit and year (ASO data) or NAFO subunit, year and month (ZIFF data), as well as an offset accounting for number of gillnets (on the log scale). However, the number of gillnets was not available in the ASO data at the time these analyses were performed. Specifically the model was defined as follows:

$$Y_{i,s,t} \sim TW(\mu_{s,t}, \varphi, \rho)$$

$$E[Y_{i,s,t}] = \mu_{s,t} = \exp(\lambda_c + \delta_{s,t} + \text{offset})$$

$$Var[Y_{i,s,t}] = \varphi(\mu_{s,t})^{\rho}$$

$$\delta_{s,t} \sim N(0, \sigma^2)$$

where

- $Y_{i,s,t}$ is the GH landed biomass from unique trip i, NAFO subunit s and year-month (ZIFF) or year (ASO) t,
- $\mu_{s,t}$ is the mean landed biomass in s and t,
- φ is the dispersion parameter of the Tweedie distribution (Dunn and Smyth 2005),
- ρ is the power parameter, restricted to the interval 1< ρ <2 (Dunn and Smyth 2005),
- λ_c is a fixed effect for soak time categories, and
- $\delta_{s,t}$ is the normally distributed random intercept with mean 0 and variance σ^2, for each NAFO subunit s and year-month t.

The Tweedie distribution was chosen because it has been shown to fit well to CPUE data (Candy 2004, Shono 2008) and it produced more adequate residuals compared to Gamma and lognormal models (analyses not shown). Models were fitted using the glmmTMB function from the homonymous R package (Brooks et al. 2017). Model validation was performed by inspecting scaled (quantile) residuals with DHARMa diagnostic tools (Hartig 2022): quantile-quantile plot, Kolmogorov-Smirnov, dispersion and outlier tests as well as residuals against predicted values. Random effects were simulated from their estimated distribution for computation of the quantile residuals. The assumption about the distribution of the random intercepts was validated using quantile-quantile plots from the car library (Fox and Weisberg 2019). The Akaike (AIC) and Bayesian (BIC) information criteria were used to compare the models with the same response variable but with different soak time categories (6 and 12 hours) used as predictors.

2.3.2.2. ASO discard and condition data

ASO coverage of the GH gillnet fishery is briefly described in section Bycatch in the directed Greenland halibut gillnet fishery. We used data from this program covering the 1999-2021 period for GH catch in NAFO 4RST when GH was the target species and gillnets were employed. For each fishing activity (haul of a series of nets), information recorded included fishing effort (number of nets and soak time), biomass kept and biomass discarded. High proportions (> 0.75) of discards were noted for some hauls. The proportion of total catch discarded was therefore related to the retained Greenland halibut biomass and a cubic smoothing function was applied to visualize the trend. Biological information (fork length and sex for individuals > 22 cm) of 2 samples (175 randomly selected fish) was collected each day. Additionally, since 2021, the condition ("freshness") of 25 sequential individuals chosen at a random point during retrieval of the gillnets was assessed. Condition was defined as live/viable (L), fresh dead (F, hard to the touch, no signs of life) or dead decomposing (D, soft, flaccid and in advanced stages, may break apart or already be partially lost). The condition data collected in 2022 was not available at the time of production of this document and the 2021 sample size was deemed too small to be presented in this document.

2.3.2.3. 2022 soak time and decomposition experiments

Soak time and decomposition experiments were carried out simultaneously in 2022 to (1) identify and quantify factors that contribute to drop-out mortality in the GH gillnet fishery, (2) estimate the magnitude of the drop-out mortality as well as (3) estimate and describe how catch quantity and condition vary with soak time, to demonstrate how the efficiency and profitability of the catch could be maintained or improved if the fishery used shorter immersion times. Experiments performed in 2022 were preliminary, with the aim of adjusting the protocol if necessary for more extensive sampling in 2023.

The soak time experiment consisted in a series of gillnets fished jointly at a particular site, each net employing a different soak time pattern, specifically hauled and re-set after 24, 48, 72 hours and hauled after 96 and 120 hours. The experiment was designed to provide the data necessary to characterize the time-course of catches and of catch condition (freshness). Assuming no drop-out mortality in short soaks, drop-out losses in the other treatments can be inferred. Replication across different times and areas will allow for evaluation of the factors that affect catch, catch condition and drop-out amounts over time. The experiment was replicated twice in 2022, which was deemed to be too small a sample to detail the methods and results.

During the soak time experiment, a decomposition experiment was performed by soaking a small number of live or freshly dead GH for different periods of time to independently characterize the time-course of degradation. Specifically, four live or fresh GH were randomly placed on each gillnet series and their condition was assessed after 24, 48 and 72 hours. Prior to soaking, fish were measured, identified with a tag and their condition was assessed. Half of the fish were tied to the lead line (bottom) and half were tied to the float (top) line. Probability of being decomposed after n days was calculated using a binomial glm with a logit link for each line.

2.4. RELATIVE EXPLOITATION RATE

A relative indicator of the annual (January 1st – December 31st) exploitation rate was obtained by dividing the total weight of the commercial catch in the directed Greenland halibut gillnet fishery by the biomass of fish > 40 cm estimated with data from the DFO research survey in the nGSL or by main fishing area. The biomass was expressed in Teleost equivalents and the conversion factors used are those of Bourdages et al. 2007. This method does not allow an absolute exploitation rate to be estimated, nor for it to be related to target exploitation rates. However, it does enable tracking of changes over time.

3. RESULTS AND DISCUSSION

3.1. COMMERCIAL FISHERY

3.1.1. Landings

The TAC remained fixed at 4,500 t for the 2004-2005 to 2017-2018 fishing seasons, with a fixed gear fishing allocation of 3,751 t (Tables 1 and 2, Figures 5 and 6). This fishing allocation was completely fished until the 2011-2012 season. The greatest gap between the fishing allocation and landings was observed during the 2017-2018 season, with landings totalling 1,767 t, which is much lower than the average of 3,678 t recorded in the previous ten years.

The update of stock status indicators for GSL Greenland halibut in the fall of 2017 concluded that the trigger point for a complete stock assessment in an interim year had been crossed (DFO 2018a). Based on the conclusions drawn in the peer review (DFO 2018b), the decision was made to reduce the TAC by 25% to 3,375 t for the 2018-2019 fishing season, with a fishing allocation of 2,813 t.

The TAC was further reduced to 2,250 t for the 2020-2021 fishing season with a fishing allocation of 1,875 t. In 2020, landings totaled 1,330 t or 71% of the fishing allocation and represent the lowest landings since the 2001-2002 season. (Tables 1 and 3, Figure 4). The fixed gear fleets of Quebec and Newfoundland landed respectively 66% and 96% of their allocation, for the 2020-2021 season. These landings data are preliminary, but should not increase significantly with the continued fishing in Quebec next spring.

In 2021 and 2022, landings in the GSL totalled 1195.3 and 929.8 t respectively, according to the Canadian Atlantic Quota Report (CAQR, page accessed 2023-01-23), which is lower than the quantities landed in 2019 and 2020 and is among the lowest values observed since 1970 (Figure 4). Since the 2010-11 fishing season, more than 98% of landings have been made by the gillnet fishery targeting this species and the 2021-23 and 2022-23 fishing seasons are no exception (Table 2, Figure 4). For these fishing seasons respectively, 71% and 46% of the fixed gear allocation was caught (Table 1, Figure 5).

Fishing is carried out in the three NAFO Divisions of the GSL : 4R, 4S and 4T. The proportion of annual landings from each Division has varied over time. The fishing effort has shifted from 4S to 4T in the past two years. In 2021, 11% of Greenland halibut landings were registered in 4R, 45% in 4S and 44% in 4T, while in 2022 these percentages were 13, 18 and 69 respectively (Table 3, Figure 6).

For more than 10 years, over 98% of landings have been from the gillnet fishery and almost all landings of Greenland halibut have been associated with directed fishing for this species (Table 2, Figure 4).

Across the Gulf, the directed gillnet fishery for Greenland halibut occurs from April to November (Table 4). The highest proportion of landings is generally recorded in June and July, these two months accounting for almost 60% of annual catches. The years 2021 and 2022 were fairly typical in terms of the seasonality of fishing at the NAFO 4RST level (Table 4, Figure 10).

3.1.2. Depth of deployment of gillnets

The directed Greenland halibut directed fishery is concentrated in 3 main sectors: the western Gulf, north Anticosti and Esquiman sectors, which correspond to the species' concentration areas (Figure 9).Some of the indicators used to assess the state of the population are presented for the entire Gulf (4RST) as well as for each of these three sectors in order to determine the presence of spatial variability that can be attributed to differing inter-region environmental dynamics or fishing practices.

In the directed Greenland halibut gillnet fishery, the median depth at which gillnets were deployed during the period 2010-2022 was nearly 296 m for the entire Gulf (4RST), 298 m in the western Gulf, 265 m in north Anticosti and 302 m in Esquiman (Figure 11A). The difference in the depth of deployment of the gear between the western Gulf, Esquiman and North Anticosti reflects the bathymetry specific to each of these sectors.

For the 2020-2021 season, fishing for Greenland halibut has been prohibited in water depth less than 229 m (125 fathoms) in Division 4S for all fixed gear fleets less than 19.81 m from the Quebec region due to the high number of cod bycatch. This new temporary closure is clearly visible when the depth data of fishing activities are represented according to the NAFO Division (Figure 11B). A ban on fishing in waters less than 229 m has also been in place in Division 4R since 2001, and it was increased to 256 m in 2014. Figure 11B also shows that fishing activities were carried out at greater depth than average in 4T in 2019, 2020, 2021 and 2022.

3.1.3. Soak time in the directed gillnet fishery

Figure 12A shows the annual proportion of gillnet fishing activities by soak time categories of 1, 2, 3, or 4 or more (4+) days of soak time. The 4+ category involves four to eight days of soak time. The proportion of activities in the 4+ category (which exceeds the three days of soak time allowed under the licence conditions) ranged from 13% to 32% during the 1999-2022 period with an average of 22%. In 2021, the proportion of fishing activities that exceed 72 hours was 17%. The highest proportion of fishing activity exceeding 72 hours occurs in the Esquiman sector. Because data on fishing effort were not available for this sector in 2022, the GSL-wide proportion of fishing activities exceeding 72 hour soak is likely underestimated for 2022.

When the soak times are analyzed by fishing sector, the western Gulf and North Anticosti sectors show on average nearly 20% of activities that have soak times exceeding 72 hours and this percentage increases to almost 40% in the Esquiman sector (Figure 12B). Prolonged soak times could reduce the quality of the fish landed and increase unaccounted fishing mortality due to the loss of degraded fish when hauling gillnets.

3.1.4. Location of directed Greenland halibut gillnet fishing

Directed Greenland halibut gillnet fishing is carried out in three sectors (Figure 10). The western Gulf and Esquiman sectors were fished annually while the north Anticosti sector is fished sporadically (Figures 13, 14). In years when the north Anticosti sector was not fished, the fishing effort shifted to the western Gulf. Between 1999 and 2021, an average of 67%, 24% and 7% of the fishing effort was deployed in the western Gulf, Esquiman and north Anticosti sectors respectively. The proportion of the fishing effort deployed in Esquiman represented 20% in 2020 and 17% in 2021. Proportions of fishing effort by sector are not presented for 2022 as no effort data were available from Newfoundland fleets.

3.1.5. Fishing effort, catch, and catch per unit of effort

For the GSL as a whole (4RST), the annual estimated fishing effort showed a decreasing trend since the mid 2000s. From 2015 to 2019, estimated fishing effort was fairly stable and below the series average, with nearly 130,000 nets deployed annually. This number dropped from 2019 to 2021 and reached 74,202 in 2021, the lowest observed value (Table 5, Figure 15). The 2022 fishing effort estimate was lower than in 2021, but this estimate assumes that the non-standardized CPUE in western GSL and north Anticosti are representative of those in Esquiman in 2022. This estimate could be biased given that non-standardized CPUE differs by sector (Figure 15) and that no effort data were available in 2022 for the Esquiman sector.

In the western Gulf, the situation is similar to that of the entire Gulf with some of the lowest fishing effort and landings of the series in 2022. Catch per unit of effort is however increasing since 2018.

The north Anticosti sector is frequented sporadically by Greenland halibut fishermen (Figure 14). This sector experienced an increase in effort and significant landings from 2006 to 2010, and a high and sustained effort and landings between 2009 and 2013 (Figure 15). Landings and effort subsequently declined and this area was abandoned from 2015 to 2017. Fishing activities resumed from 2018 to 2020, but landings and effort decreased in 2021 and 2022.

Landings in the Esquiman sector fell sharply between the peaks in 2011–2012 and 2017, despite the sustained level of effort. Landings and fishing effort decreased from 2019 to 2021. CPUEs showed a substantial and continuous decline from 2011 to 2017; they then increased and remained stable from 2018 to 2021, but are below the series average since 2013 (Figure 15).

3.1.6. Fishery performance index

The standardised CPUE for the commercial fishery, or commercial catch rate, is used as an index of fishery performance rather than an index of abundance of exploitable stock. Trends for the standardized and non-standardized CPUE series are similar (Table 6, Figures 15 and 16).

The trajectory of the indices is similar for the entire Gulf and for the western Gulf sector. These indices showed a decrease of more than 50% between 2015 and 2018 and fell below the series average in 2017. In 2021 and 2022, the index increased to reach the average of the series (Figure 16).

In the north Anticosti and Esquiman sectors, the fishing performance indices have decreased by more than 75% between 2012 and 2017 and are below the average of their series since 2013. Between 2021 and 2022, the index is stable and below the average in north Anticosti. The index seemed to decrease in 2021 in Esquiman (Figure 16).

3.1.7. Composition of catches

The average length of Greenland halibut caught in the commercial fishery increased from 44 cm to 47.6 cm between 1995 and 1996, owing to the increase in the minimum mesh size from 140 mm (5.5 inches) to 152 mm (6.0 inches) (Table 7, Figures 17 and 18). An experimental fishery using 140 mm mesh contributed to the reduction in average size recorded in 2002 (Morin and Bernier 2003).

These annual variations in average commercial size can be explained in part by the strength of the cohorts recruited to the fishery : a strong cohort entering the fishery will reduce the average size of the fish caught. The average sizes decreased between 1997 and 2002 (48 cm to 45 cm) and then increased steadily to reach 49 cm in 2012, the highest value in the series (Figure 17). This increase is due to the growth of the strong cohorts of 1997 and 1999, which made up a large part of the catches between 2003 and 2006, as well as by the growth of the large cohorts of 2001 and 2002, which began to be recruited to the fishery around 2006 and were still present in catches in 2010 (estimated length at more than 50 cm) (Figure 17). The average size fluctuated between 2012 and 2016 and reached the second highest value in the series. Subsequently, the average size decreased markedly from 2018 to 2019 when it was 45.3 cm, more than 1.5 cm lower than the average for the 1996-2019 series. The average size remained stable from 2019 to 2022.

The analysis of data by division indicated that the mean length of the Greenland halibut caught in Division 4R was greater than that of the individuals caught in 4S and 4T from 2003 to 2015 (Table 7, Figure 17). From 2016 to 2019, the average size of the fish caught in Division 4R was comparable to that in 4S. The fish caught in 4T are the smallest on average. This difference can be explained by the fact that the main Greenland halibut nursery area is located in the lower estuary of the St. Lawrence, which is in Division 4T.

The average length of the females caught is greater than that of males (Table 7, Figure 17). Annual fluctuations in the average sizes of males and females are generally in phase. The size of Greenland halibut caught in gillnets with the regulated 152-mm mesh (1996 onward) ranges from 37 cm to 61 cm for females and from 37 cm to 53 cm for males (Figure 17). In 2019, the average sizes of male and female fish decreased and stayed below the average until 2022 at values among the lowest since 1996. From 2019 to 2022, the average length of males stood at 41 cm, which is 3 cm less than the series average and below the minimum legal size of 44 cm while the average length of females, 46 cm, was nearly 2 cm less than the series average. The decrease in average fish size has a significant impact on the number of fish landed for a given landing by weight. Between 2016 and 2022, annual landings in tonnes decreased by 72%

whereas the number of fish landed decreased by 58%. This difference is also linked to the important drop in mean body condition in 2022 (see Section Condition index).

During the 1996-2020 period, 18% of fish caught in the Greenland halibut directed gillnet fishery were less than 44 cm long on average, compared with 31% and 32% in 2021 and 2022 respectively (Figures 18 and 19). These are the largest proportions fish under the legal size observed since 2002. The minimum legal size is 44 cm in the existing conservation measures.

Sexual dimorphism in Greenland halibut explains the large proportion of females in catches and the difference observed in the maximum sizes of the two sexes. The mesh size used in the fishery targets sexually mature individuals so that the fish can reproduce before being caught and thus contribute to recruitment to the population. The proportion of females in commercial catches has been higher on average since the increase in mesh size in 1996 (Table 8, Figure 20). Before 1996, the average proportion of females was 60%; it rose to 81% during the 1996–2020 period. In 2021 and 2022, females made up respectively 76 and 88% of catches.

3.1.8. Bycatch in the directed Greenland halibut gillnet fishery

Although the commercial fishery endeavors to maximize the target species catch, bycatch of non-targeted marine species is common. Bycatch in the directed Greenland halibut gillnet fishery was estimated for the 2000-2022 period using data from the At-Sea Observer Program, which has yearly variation in realized coverage (Table 9). Bycatch in this fishery averages 457 t annually (Figure 21). Nearly one third of bycatch is landed, with the remainder being discarded at sea. Bycatch represents 19% of Greenland halibut landed weight on average (Table 10, Figure 22). The most common bycatch species are, in order of importance, American plaice (*Hippoglossoides platessoides*), redfish, snow crab (*Chionoecetes opilio*), thorny skate (*Amblyraja radiata),* Atlantic halibut, northern stone crab (*Lithodes maja*), witch flounder (*Glyptocephalus cynoglossus*) and various other species of skates (Table 11 and Figure 23). In terms of biomass, Atlantic halibut is the most important bycatch in the entire series, but a decrease in estimates for this species has been noted since 2016 (Figure 23). The occurrence of redfish in the bycatch, which were above the average between 2017 and 2020, were below average in 2021 and 2022. Discards at sea include species that can be released by the harvesters such as black dogfish (*Centroscyllium fabricii*), Lumpfish (*Cyclopterus lumpus*), Atlantic hagfish (*Myxine glutinosa*) and Atlantic wolffish (*Anarhichas lupus*); mandatory release species such as Atlantic halibut under 85 cm, snow crab and skates; and taxa of no current commercial value such as starfish, skate eggs and polychaetes. The 2021 and 2022 estimates assume that the activities observed in 4S and 4T are representative of those in 4R since no observers were deployed in this region for those years.

3.1.9. Greenland halibut bycatch in the directed shrimp fishery

The shrimp fishery uses small-meshed trawls that catch and retain many species of fish and marine invertebrates. Although large fish can escape from trawls due to the mandatory use of separator grates installed inside the trawl, shrimpers' catches still contain a certain number of small specimens. Greenland halibut bycatch in the shrimp fishery from 2000 to 2020 was examined using the at-sea observer database (Table 12). Data from 2000 to 2017 are also published in Bourdages et al. (2022b).

The spatial distribution of Greenland halibut bycatch in the directed shrimp fishery obtained from at-sea observer data is shown for the 2000-2021 period (Figure 24). The average catch (kg/tow) in all tows within a 5-minute square is shown for the 2000-2021 period and on an annual basis for 2020 and 2021. Greenland halibut were present on average in 91% of sampled activities.

Greenland halibut bycatch generally accounts for less than 3 kg per tow and mainly consists of 1-year-old juveniles, and to a lesser extent, 2-year-old juveniles (Figure 25). Between 2000 and 2021, the estimated average annual Greenland halibut bycatch in the directed shrimp fishery in the Estuary and Gulf was 95.7 t (Figure 26). In 2020 and 2021, the estimated bycatch was 78 t and 58 t respectively, which represents approximately 0.23% and 0.48% of the biomass of Greenland halibut less than 31 cm estimated in the DFO's nGSL survey (Table 12 and Figure 27).

Greenland halibut is caught in fisheries directing for other groundfish, but these should be landed and therefore occur in the catch records.

3.2. RESEARCH SURVEYS

3.2.1. Summer spatial distribution

The spatial distribution of the GSL Greenland halibut population is fairly well represented by the study area of the DFO nGSL survey which takes place in August. At that time of year, the largest halibut concentrations are found in the St. Lawrence lower estuary, in the Sept-Îles Basin, the Laurentian Channel south of Anticosti Island, and at the heads of Anticosti and Esquiman channels. Figure 28 shows the spatial distribution of the species by 5- or 6-year blocks until 2019 and by 3 year blocks for the most recent period. An increase in the spatial distribution of high catch rates is observed from the 1990-1994 to the 2005-2009 period, followed by a decrease during the 2015-2019 period and a stabilization thereafter. The distribution of Greenland halibut catch rates obtained in the mobile gear sentinel program (MSP) survey in July shows a similar pattern, although this survey does not cover the lower estuary (Figure 29).

Greenland halibut in the 0-20 cm length class (i.e., ≤1 year) are found mainly in the Lower Estuary, the Sept-Îles Basin and north of Anticosti Island (Figure 30). Studies have shown that the Estuary is the main nursery area for GSL Greenland halibut, with a secondary nursery located north of Anticosti Island (Ouellet et al. 2011, Youcef et al. 2013). Maps show the distribution of Greenland halibut by size classes (0-20, 20-30, 30-40 and > 40 cm) based on data from DFO's nGSL surveys and the mobile gear sentinel survey (Figures 30 to 37).

The spatial distribution of catch rates for Greenland halibut (number per tow) obtained in DFO's sGSL survey is presented in 9 to 13 year blocks between 1971 and 2019 and for 2020-2022 (Figure 38). In the area covered by this survey in the 1970s, Greenland halibut was only found off the tip of Gaspé Peninsula, along with a few individuals caught in Chaleur Bay. In the 1980s, the species' abundance increased, although its spatial distribution remained similar to that in the 1970s. Then, in the 1990s and 2000s, as the abundance of Greenland halibut continued to increase, it expanded its range along the south side of Laurentian Channel and in the Cape Breton Trough. This expansion continued during the years between 2010 and 2019 with the observation of a new concentration of Greenland halibut in Shediac Valley. Its spatial distribution in 2021 and 2022 was similar to that in 2010-2019.

The historical perspective provided by the sGSL survey suggests that Greenland halibut abundance in the GSL was low in the 13 years (i.e. from 1971 to 1983) before the nGSL summer survey began.

Spatial distribution indices calculated from the DFO nGSL survey data indicate that Greenland halibut occurs in over 85,000 km^2 of the northern Gulf of St. Lawrence, with 95% of its biomass concentrated in less than 50,000 km^2. Since the mid-2000s, the area of occupancy (DWAO) remained stable, but the minimum area occupied by 95% (D95) of the stock biomass decreased. At the same time, the Gini index of aggregation has increased, indicating a concentration of the Greenland halibut population within its range (Figure 39).

3.2.2. Summer environmental distribution

In the August nGSL survey, Greenland halibut is found mainly in channels at depths ranging from 200 m to 400 m, with over 80% of the biomass occurring at depths between 226 m and 379 m, at bottom temperatures ranging from 4.5°C to 6.1°C (Table 13, Figure 40). This pattern based on all years of the nGSL survey could have been influenced by the extension of the range of GH during periods of high abundance to sub-optimal habitats but, as shown in Figure 41, the limited inter-annual variation in its depth distribution suggests that this is not the case. This would be due to low GH catch rates in sub-optimal habitats compared to preferred habitats (Figures 28 to 38).

The annual distribution of Greenland halibut biomass by size classes ([0-20] cm, [20-30] cm, [30-40] cm and > 40 cm) with regards to depth, water temperature and oxygen saturation is shown in Figure 41. Biomass distribution by size class in relation to depth is generally similar from year to year and shows no temporal trend. On average, individuals in the ([0-20] cm size class were found at shallower depths (268 m) than large individuals (nearly 300 m) (Figure 41A). This was not the case for the distribution of biomass relative to water temperature and the dissolved oxygen (DO) saturation level (Figure 41BC). Since 2010, all size classes of Greenland halibut have been found in increasingly warm waters. Since at least 2016, these fish have been found in waters with progressively lower dissolved oxygen levels.

Between 2010 and 2020, the median temperature of the waters where fish longer than 40 cm are found increased from 5.1°C to 6.3°C (Figure 42). This increase is most pronounced in the Esquiman sector, where the median water temperature increased from 4.9°C to 6.8°C. For the same size class, the DO saturation level decreased from 32.5 to 21% over a period of six years. The largest decrease occurred in the western Gulf, which had a median DO saturation level of 20.1% in 2022.

When these analyses are limited to the Lower Estuary, the water temperature in locations where Greenland halibut biomass was found increased from 4.9°C to 6.4°C during the last decade while the DO level decreased from 21.8 to 15.0% in the same period (Figure 43). This means that 50% of Greenland halibut biomass in the estuary is exposed to oxygen concentrations of 15% or less during the summer. The addition of coastal strata in 2008 does not change this picture since very little biomass is found in these coastal areas, but confirms that Greenland halibut depth use in the summer has not changed in response to changes in its environment.

As a result, the habitat used by Greenland halibut of all sizes continued to warm and deplete in oxygen in 2021 and 2022, while its depth distribution did not change in response to these changes.

3.2.3. Spatial and environmental distribution in the winter surveys

As mentioned in section 2.2.1.4, the spatial and depth distributions of Greenland halibut in winter surveys is presented in the context of a possible return of the winter redfish fishery, which could be useful in attempting to limit the bycatch of Greenland halibut in this fishery.

In both survey series (*Gadus Atlantica*, 1978 – 1994, and *Mersey Venture*, 2022), the highest catch rates of Greenland halibut were observed in the Laurentian Channel from southern Anticosti to the Cabot Strait. Some aggregations of Greenland halibut of lesser importance were also observed in some years at the head of the Esquiman Channel in the *Gadus* survey (Figures 44 et 45).

Surveys on the *Gadus* and the *Mersey Venture* sampled similar depths, although the depths covered by the *Mersey Venture* were slightly deeper (Figure 46). In both surveys, Greenland halibut were found deeper than the redfish. For Greenland halibut, more than 75% of the biomass was between 400 and 500 m in winter (Table 14, Figure 46) while in summer 75% of the biomass was between 250 and 330 m deep (Table 13). In comparison, 67% of the redfish biomass was at depths less than 400 m in the *Gadus* survey and 49.7% in the *Mersey Venture* survey. These proportions increased to 75% at a depth of approximately 430 m (Table 13, Figure 46). The apparent difference in the distribution of redfish biomass as a function of depth in the *Gadus* and *Mersey Venture* series could be explained by a different species composition for these two periods. Acadian redfish (*S. fasciatus*) generally occupies depths less than Atlantic redfish (*S. Mentella*) and made up a greater proportion of the biomass in the 1980s than recently (Senay et al. 2021).

The present analyses showed the importance of deep channels (greater than 400 m in depth) in the winter for Greenland halibut.

3.2.4. Recruitment and demographic structure

Recruitment has varied greatly from year to year, and since the late 1990s, strong and weak cohorts have alternated (Figure 47). Recruitment indices estimated from DFO’s nGSL and sGSL surveys generally show a good correlation (Figure 47B). Analyses have shown that GSL Greenland halibut showed a density dependent range expansion in the northern portion of the sGSL as abundance increased, and contracted when abundance decreased (Yin and Benoît 2022). This phenomenon is also observed at the recruitment level (Figure 47B inset). According to information provided by the sGSL survey, recruitment was not strong in the area covered by the survey between 1971 and 1996. Both surveys identify the 1997, 1999, 2001, 2004, and 2010 cohorts as substantial. The abundance of the 2013 and 2017 cohorts was above average according to the nGSL survey, but lower according to the sGSL survey. The 2018 cohort is the most recent high abundance cohort in the two surveys and recruitment has been low in the last 3 years.

The length frequency distributions for Greenland halibut observed in the nGSL, sGSL and mobile gear sentinel surveys are shown in Figure 48. The three surveys show a similar overall pattern, but due to the selectivity of the different trawls used and the different areas sampled, smaller Greenland halibut are better represented in the nGSL survey and larger individuals comprise a greater proportion of the catch in the sGSL and mobile gear sentinel surveys. The nGSL survey also has greater mean catch rates than the mobile sentinel survey. The nGSL survey uses a trawl with a smaller mesh size, allowing for more effective sampling of small, one-year-old individuals (modal size ~ 16 cm). In addition, unlike the other two surveys, this survey covers the Estuary, which is the species’ main nursery area. The mobile gear sentinel survey allows a higher proportion of large individuals to be sampled.

The three surveys accurately depict the arrival of two extraordinarily strong cohorts in the history of this stock: the 1997cohort (modal size ~ 16 cm at age 1 in 1998) and the 1999 cohort (modal size ~ 16 cm at age 1 in 2000). These cohorts were responsible for the substantial increase in the stock’s abundance in the 2000s, and the arrival of the strong cohorts of 2001, 2002, 2004 and 2007 supported a major fishery. Significant numbers of individuals larger than 40 cm were also noted from 2003 to 2008, but their abundance declined from 2009 to 2013 and they have been rare since 2015 (Figure 48).

According to its normal growth curve in the GSL, Greenland halibut generally recruit to the fishery at an average age of 6 years for females and 7 years for males. The strong 2010 cohort had a modal size of 16 cm in 2011, 27 cm in 2012, 35 cm in 2013, and between 40 and 44 cm in 2014. This cohort seems to have had a more rapid growth rate than the 1997 and 1999 cohorts. It may have begun recruiting to the fishery in 2014, which would explain the decreasing size of Greenland halibut in the commercial catch (Figure 17). The cohort still stood out at more than 44 cm in 2015. The entry of this cohort into the fishery in 2014 increased catch rates (Figures 15 and 16).

The situation of the abundant 2013 cohort is particular. The size frequency distributions show a very high abundance in 2014, with the cohort reaching a modal size of 16 cm, and a high abundance in 2015, but with a modal size of 20 cm compared to the expected size of close to 27 cm. This represents a reduction in the rate of growth of about 45% between ages 1 and 2, compared to the average growth rate for this stock. The slowing of growth observed for this cohort has delayed its recruitment to the fishery. Since the reading of otoliths cannot currently be used for age determination in this stock, it is difficult to track cohorts effectively after age 2.

The abundance of the 2018 cohort at ages 1 and 2 is among the highest in the series and the growth rate is normal (Figures 47 and 48). These fish could begin to recruit to the fishery around 2024.

Figure 49 provides a perspective on the size structure in 2021 and 2022 relative to the historical average. The highest abundances are in the size class 30-40 cm and the abundances of the 1-year and 2-year-old fish (~ 16 cm and 27 cm) are below average.

The representation of size structure by sex facilitates cohort tracking over time as male and female growth differs in Greenland halibut (Bowering 1983, Figure 49). The asymptotic size (parameter L_∞ of the Von Bertalanffy growth model) seems to be around 45 and 40 cm for female and male respectively, which is in sharp contrast to the NAFO 2 and 3KLMNO population, where males and females L_∞ were 109 and 90 cm respectively (Dwyer et al. 2016).

3.2.5. Stock – recruitment relationship

The relationship between the indicator of spawning stock biomass and recruitment is characterized by low recruitment in the late 1980s and early 1990s when the stock was at its lowest levels and by recruitment that tends to increase proportionally with stock biomass (Figure 51). Variability also tends to increase with the stock status indicator, justifying the choice of a multiplicative error term.

The fit of the density-independent, Berverton-Holt and Ricker models were similar, as evidenced by differences in AIC below 2 (Table 15). On the other hand, the intercept only model was clearly less supported by the data than these, which supports the existence of a relationship between the reproductive biomass and the number of recruits This means that the conservation of a large spawning biomass will tend to produce more recruitment and thus maintain the stock at high levels. The relatively low biomass from 2019 to 2021 produced low levels of recruitment, as expected by the various relationships illustrated (Figure 51). However, similar biomasses produced strong recruitment in 2017 and 2018.

Residuals as a function of year did not have a specific pattern and had positive and negative values over the past decade (Figure 52). Warming has been observed since 2010 in Greenland halibut habitat (Figure 42). The absence of residual patterns over time indicates that the stock-recruitment relationship is not influenced by environmental changes such as these at the moment.

3.2.6. Biomass and abundance indices

Abundance (mean number per tow) and biomass (mean weight per tow) indices based on the data from the sGSL, nGSL and, MSP surveys are presented in Tables 16 and 17, as well as in Figure 53.

The sGSL survey encompasses a longer time period (1971-2022) than the nGSL (1984-2022) and MSP (1995-2022) surveys, but covers a limited portion of the overall Greenland halibut range in the GSL (Figures 28 and 38). From a historical viewpoint, the sGSL survey indicates that Greenland halibut abundance and biomass were low from 1971 to 1997 in the portion of the GSL sampled (Figure 53). In 1998, the abundance index suddenly jumped from 2.6 to 13 fish per tow whereas biomass increased more gradually. From 1998 to 2010, abundance and biomass indices fluctuated, although values were still high relative to survey averages. The trend in biomass and abundance indices was downward from 2011 to 2022, except for 2020 where an increase in indices is observed and was is likely caused by the recruitment of small individuals from the 2018 cohort. Abundance and biomass indices were at low levels and below average in 2021 and 2022.

Of the two surveys carried out in the nGSL, the DFO survey covers the largest area of Greenland halibut habitat (Figures 28 and 29). The area sampled in the MSP survey is included in that of the DFO survey, except that it does not cover the lower estuary. Similar trends were found in the abundance and biomass indices from 1995 to 2008 in these two surveys: a substantial rising trend until 2004 followed by a stable trend until 2008 (Figure 53). Subsequently, while the abundance index from the DFO nGSL survey showed some stability, the biomass index as well as the abundance and biomass indices from the MSP survey showed a continuing downward trend until 2018 or 2019. During the period 2006-2019, the nGSL survey biomass index decreased by 56%. The abundance and biomass indices from the nGSL and PSM surveys increased slightly from 2019 to 2021. In 2022, the nGSL mean number per tow was below average and at the series average in weight per tow, while the MSP indices were lower but close to average.

When the abundance index (mean number per tow) obtained from the nGSL survey is broken down by size classes (0–20, 20–30, 30–40 and > 40 cm), it can be seen that the 0–20 cm size class (1-year-old individuals) was abundant in 2019 and the 20–30 cm size class (2-year-old individuals) was abundant in 2020 (Table 18, Figure 54). The nGSL survey shows a close correlation between the abundance of a given cohort at age 1 and at age 2 the following year (Figure 49). The abundance of 30-40 cm fish was above average in 2021 and 2022. Fish over 40 cm abundance, which was declining from 2014 to 2017, remained stable between 2017 and 2020, increased in 2021 and remained at average levels in 2022 (Figure 54).

Abundance indices derived from MSP survey data indicated that, with the exception of 30-40 cm fish, the other size classes were below the series average in 2022 (Table 19, Figures 49 et 54).

Based on the typical growth estimates for individuals in this stock, fish in the 2012, 2013 and 2014 abundant cohorts would normally have reached a modal size of approximately 49, 47 and 44 cm respectively by 2020. An increase in fish abundance > 40 cm was expected in 2022, but did not materialize (Figures 49 et 54). These abundant cohorts of juveniles likely led to an increase in the number and biomass of individuals > 40 cm in 2021 (Figure 50).

3.2.7. Comparison of sGSL, nGSL and MSP survey indices

Normalized biomass (divided by the mean) indices for fish > 40 cm derived from DFO's sGSL and nGSL surveys and the mobile gear sentinel survey show similar trends for the 1995 to 2022 period which is common to the three surveys (Figure 55). A large increase occurred in the early

2000s and then stabilized at peak biomass levels for this stock. This was followed by a downward trend, with decreases of 84%, 68% and 79% being observed between 2008 and 2019 in the sGSL, nGSL and mobile gear sentinel surveys, respectively. A less pronounced decrease in the indices was seen from 2018 to 2019, followed by a slight increase in 2020 in all three surveys. The sGSL survey showed that in the 15 years before the nGSL survey (from 1971 to 1983), the biomass of Greenland halibut > 40 cm was low in this ecosystem.

3.2.8. Condition index

The Fulton condition index for Greenland halibut, which was determined using data from the DFO nGSL survey, was estimated for four length classes: 15 cm (~1 year old); 25 cm (~2 years old); 35 cm (3-5 years old) and 45 cm (> 5 years old) (Figure 56). The condition of 1-year-old fish fluctuated from 1990 to 2020, often inversely related to the abundance of the different cohorts. In strong cohorts, the condition of fish was likely to be below average. The abundant 1999 and 2010 cohorts, 1-year-old (15 cm) respectively in 2000 and 2011, had a Fulton condition index lower than the series average. Recently, there were three consecutive years, 2012 to 2014, during which the abundance of cohorts ranged from medium to high, which also had Fulton condition indices below the series average at 15 cm (2013–2015). These low values were maintained as the fish in these different cohorts grew (25 cm, 35 cm and 45 cm series in 2015–2017).

In 2022, the estimated condition indices for each size of Greenland halibut decreased sharply and were well below average. These low value could be explained by the low stomach fullness indices for turbot harvested on the 2022 nGSL survey (Figure A1, Laurie Isabel, DFO, pers. comm.), which are likely caused by the low abundance of capelin and biomass of northern shrimp in 2022, two of the main prey items of Greenland halibut (Ouellette-Plante et al. 2020). Indeed, the abundance and biomass indices for capelin and northern shrimp estimated in the nGSL survey in 2022 were at the lowest values in their respective series (Figure A2 and Bourdages et al. 2023).

3.2.9. Length at 50% maturity (L_{50})

The size at which 50% of Greenland halibut are sexually mature (L_{50}) decreased sharply in males between 1997 and 2001, and in females between 1998 and 2004. It remained fairly stable at close to average values from 2004 to 2014. Subsequently, the L_{50} decreased, reaching the lowest values in the series in 2019 for both sexes, before trending upward for males and increasing suddenly for females to reach average levels in 2022 (Figure 57). The rapid decline in L50 in 2019 may be related to the arrival of individuals from the 2013 cohort in the mature population as the L_{50} of females (37 cm) and males (29 cm) were in the size ranges for this cohort in 2019 (Figure 50). This decrease in L_{50} could also be explained by density-dependent phenomena, with the 2013 cohort preceded and succeeded by abundant cohorts, and sharing resources with the large redfish cohorts (Gauthier et al. 2021).

3.2.10. Selectivity of the nGSL survey

3.2.10.1. Comparison of GH LFD from bottom trawl and longline samples

Less than 100 GH were measured annually in the 4RST Atlantic halibut LL survey, leading to very noisy patterns in annual LFD (Figure 58) and suggesting this dataset currently contains insufficient information to support analyses on selectivity.

ASO LL hauls where GH LFD were recorded in the GSL occurred between May and August (87% of hauls), with the majority of hauls from July and August (Table 20). Overall, hauls with GH LFD recorded occur in all the nGSL survey area, but the highest concentrations are around

Anticosti Island and in the north-western GSL. There is high variability in spatial distribution of sampled hauls from year to year (Figure 59). There is also yearly variation in the depth of haul from which GH were measured, but approximately 75% of the data were recorded at depths from 200 to 300 m (Figure 60). By comparison, GH preferred depth range in the nGSL survey is from 261 to 339 m (25 and 75 percentile of the cumulative frequency, Table 13). This difference is however reduced by the spatial subset performed on nGSL survey data to match LL ASO data since the 25 and 75 percentile of the cumulative frequency distribution of total catch were respectively 230 and 273 m after the spatial subset was performed (Figure 60). Mean GH length in the nGSL survey tend to increase slightly with depth, going from 29.2 cm at 200 m to 30.8 cm at 250 m (Figure 61). This suggests depth differences between LL ASO and the subset nGSL survey data have a negligible effect on length structure, if GH depth utilisation in August is representative of other months when ASO data were collected (Table 20).

In the ASO LL dataset, there were few trips where target species was GH (Figure 62). These data were nonetheless kept in further analyses because they were validated (LL permits have been issued for GH in the past). When pooling LL ASO data for all years, LFD peaked at around 45 cm and started to decrease at 50 cm for all 3 target species (Figure 63). The lefthand side of the GH LFD in the Atlantic halibut fishery notably differs from the 2 other LFD in Figure 63, which is not surprising given hook opening is optimized for Atlantic halibut of legal size (> 85 cm, Desgagnés 2016). The righthand side of LFD is however identical for the 3 target species and large (> 65 cm) individuals are nearly absent (Figure 63), which is a first evidence that the absence of large fish in the nGSL survey reflects availability and is not a result of selectivity. ASO LL LFD by year are more variable than nGSL survey data (Figure 64), probably because fewer fish were sampled by the former and because there is more variability in various other factors like location and date.

Catch ratios generally stabilized for lengths greater than 60 cm (Figure 65). This means either the LL and survey trawl selectivity are constant for these length classes, or that they co-vary in the same direction. It is not possible to distinguish between these 2 possibilities with the present data. However, it is unlikely that selectivity in both gear would decline at the same rate even if the nGSL selectivity function was dome shaped. Additionally, the shape of the catch proportions in Figure 65 is exactly as expected if survey trawl and LL selectivity were both sigmoid (Huse et al. 1999, Figure 67). In their simulation, Huse et al. (1999) supposed trawl and LL sampled the same population and had a normal selectivity with mean of respectively 50 and 60 cm, or a sigmoidal selectivity with L_{50} of respectively 42 or 50 cm. Moreover, the great consistency of the pattern in catch ratios between years supports the fact that what is observed is not an artifact.

The catch ratios tended to stabilize close to 1 (Figures 65) because the nGSL survey LFDs have more length classes than observer data. When computing annual length frequency proportions and catch ratios excluding length classes < 45 cm, the catch ratios seemed to stabilize at around 0.75 (Figure 66), meaning ASO LL observe greater proportions of large fish than the subset survey data. This result is not surprising since LL are optimized to select larger fish.

In the previous analyses, we supposed that LL selectivity at length was sigmoid, but some authors found evidence for a dome shape selectivity in LL fishery for GH. However, in the cases surveyed, the decreasing part of the curve was at sizes that are rare or absent in the GSL. For instance, Woll et al. (1998) performed a GH LL selectivity experiment at depths ranging from 750 to 1080 m using 12 and 14 mm hooks. The LL selectivity started to decrease at 83 cm or more, depending on hook size and fitted model, while only 3 of the 255 000 measured GH during the nGSL survey (1990-2021) had a length > 80 cm. For comparison, Atlantic halibut longline fishery in the GSL uses 15.4 mm hooks. Clark and Kaimmer (2006) estimated Pacific halibut LL selectivity from many tag and release experiments and found evidence for a decreasing selectivity starting at 110 cm to 150 cm depending on the areas. An additional evidence that large GH are rare or absent in the GSL is that surveys in other areas using the same trawl as the nGSL survey (Campelen 1800 from 2004-2021) regularly observe fish of length > 80 cm. For instance, GH of these length classes were caught every year in the Spanish Spring Survey in NAFO 3NO from 1997-2010 (Gonzáles-Troncoso et al. 2011), while female length at fifty percent maturity (L_{50}) is consistently greater than 70 cm in the Canadian NAFO divisions 2J3K fall surveys, indicating female of length > 70 cm are frequent (Healey et al. 2010).

Comparing LFD collected with different gear relies on the assumption that they sample the same part of the population (same length structure). This assumption seems supported in the present case because potential differences in length structure caused by sampling differences in space and depth were controlled for and mean GH length covariation with depth was unimportant at depths considered.

3.2.10.2. Comparison of GH LFD from bottom trawl and winter surveys

The spatial coverage of the *Gadus Atlantica* winter survey varied from year to year depending on the ice conditions, but tows were regularly performed in the Laurentian channel in the Cabot strait area as well as in NAFO 3Pn (Figure 44). The unweighted 1978 – 1994 length frequency distribution increased sharply from 30 to 40 cm, reached a maximum at around 40 – 45 cm and than decreased rapidly (Figure 68), similar to what was observed in the LL ASO data (Figure 63). Compared to the nGSL survey LFD, the individuals measured in the winter survey are bigger, probably because the survey area covered the spawning grounds located Laurentian channel in the Cabot straight area and southwest of Newfoundland (Templeman 1973, Ouellet et al. 2011). There is however no evidence from the winter survey that large individuals could be present in the population and unavailable to and/or unselected by the nGSL survey since very few large individuals were present (Figure 69). Indeed, only 8 out of 11 398 measured fish in the winter survey were greater than 80 cm. In comparison, GH of length > 80 cm were observed annually in the Spanish Spring Survey in NAFO 3NO (1997-2010, González-Troncoso et al. 2011) and female length at maturity computed from the fall 1978 – 2009 2J3K DFO bottom trawl survey was about 80 cm for the 1965 to 1979 cohorts (Healey et al. 2010).

3.2.10.3. Conclusion

The analyses presented above analyses suggest that the nGSL survey selectivity is sigmoid. They support the idea that the low abundance of large GH in the nGSL survey does reflect a low relative abundance and not avoidance, and indicate a fairly high total mortality rate for indivuals of length > 40 cm.

3.3. UNACCOUNTED MORTALITY IN THE GILLNET FISHERY

3.3.1. Gillnet commercial landing - soak time relationships

The proportion of fishing activities with a soak time greater than 72 hours was 25% for the whole GSL, 22% in the western GSL, 24% in north Anticosti and 41% in Esquiman (Figure 70). The number of observations by soak time category in the ZIFF and ASO database was higher for time categories representing discrete number of days, and tended to increase from 0 to 72 hours and decrease afterwards (Figures 71 and 72). The same pattern was also observed in the western GSL and Esquiman fishing areas, but the number of fishing activities per soak time category tended to decrease starting at 24 hours in the Anticosti area (Figure 73). In this fishing area, more than 80% of biomass is landed in Gaspésie. This opposite pattern is likely caused by harvester from the Gaspésie region hauling their nets more frequently to maximize their return on this long distance fishing trip. The number of observations per soak time category in the ZIFF database was always greater than 70 for categories in the 0 – 120 hours range and generally greater than 30 for categories associated with longer soak times (Figure 71). When disaggregating the ZIFF data by region, number of observations per soak time category followed similar patterns and the use of 12-hours soak time categories (instead of 6-hours) ensured more data points were available for model fitting (Figure 73). The number of observations per soak time category in the ASO database was always greater than 28 for categories in the 0 – 120 hours range and generally greater than 15 for categories associated with longer soak times (Figure 72).

The global models fitted to the ZIFF and ASO data and with 6-hours soak time categories had a lower AIC than the 12 hours soak time category model, but the opposite was observed when looking at BIC (Table 23). For both of these models, diagnostics were judged acceptable since DHARMa residuals were almost uniformly distributed, dispersion was within the range of simulated values, outliers were present but not in great abundance and random intercepts were normally distributed (Figure A3 to Figure A6). Consequently, predictions were presented for both models. Models fitted to ZIFF and ASO data both showed a decrease of mean biomass landed per 90 gillnets from 6 to 18 hours, an intriguing result. The “v” shape in the biomass – soak time relationship is likely not caused by the incorrect presence of zero values in the effort data because the minimal soak time in the 0-6 and 0-12 hour soak time categories was 6 hours. Moreover, the similarity in the independent analyses of the ZIFF and ASO data reinforces the idea that this result is not fortuitous. Investigation of the time and location of the 6 hours hauls and a deeper understanding of the catch decomposition process could provide explanation for this consistent pattern. A linear increase of mean biomass was present from 18 to 72-78 hours followed by a stabilization of the biomass landed for greater soak time categories according to the ZIFF data analysis (Figure 74). According to the ASO data, mean landings seemed to increase from 18 to 60 hours, stabilize from 60 to 108 hours and were variable for longer soak times (Figure 75).

Diagnostics were similar for fishing area specific models fitted to the ZIFF data, except that residual distribution departed somewhat from the uniform distribution for the north Anticosti model (Figure A7 to Figure A9), which indicates a slight model mispecification. Further inspection of the scaled quantile residuals showed signs of heteroscedasticity with regards to soak time categories. Results were still presented because the Tweedie distribution improved model fit for this region compared to Gamma and lognormal models (results not shown) and GLMM are remarkably robust to violation of distributional assumptions (Schielzeth et al. 2020). Care should however be taken when interpreting predicted values.

Both in north Anticosti and wGSL fishing areas, mean landings per 90 gillnets increased from approximately 1000 kg after 12-24 hours to reach an asymptote at 72-84 hours (Figure 76). The increase in landings was however more important in north Anticosti, an area sporadically visited by harvesters. There was greater uncertainty around Esquiman model coefficients for the 0 – 84 hours soak time categories compared to the other 2 regions, but that was not the case for soak times greater than 84 hours where uncertainty was higher in North Anticosti. Random effect variance was also greater for the model in the Esquiman area compared to the other two regions (Table 23, Figure 76). In all 3 regions, an asymptote in mean landed biomass seemed to be reached at soak times of around 72 hours.

3.3.2. Discard proportions in ASO data

In the ASO data for the turbot gillnet fishery, the proportion of total catch discarded tended to increase with the soak time (Figure 77). This pattern was similar for the whole dataset (4RST) and for the western GSL and north of Anticosti fishing areas. The Esquiman fishing area stood out from the others with smaller discard proportions for the shorter immersion periods (1-4 days) and a barely noticeable upward trend. After 5 days of immersion, the proportions discarded were similar to those in other fishing areas. Although the median discard proportions were not high, large proportions were discarded for some trips (Figure 77). These large proportions can be explained by looking at the relationship between discarded proportions and GH total catch. Discarded proportions show a strong downward trend for GH catches from 0 to 200 kg, and a gradual decline for GH catches from 200 to 1,500 kg (Figure 78). Eight of the 10 hauls with more than 75% of GH catch discard had a catch of less than 5 kg, the other 2 had larger GH catches (820 and 403 kg).

These discard “losses” could be considered in the assessment by applying a relationship with soak time. These losses are not the same as drop-out losses, which are not carried on board and therefore not accounted for in the presence of an ASO.

3.3.3. 2022 decomposition experiments

The rate of fish decomposition was surprisingly high for fish attached to the lead line. There were 20 of 22 and 8 of 9 decomposed GH after respectively 24 and 48 hours on the lead line, while 7 of 25 and 7 of 11 GH were decomposed after respectively 24 and 48 hours on the floating line (Table 24). Amphipods were observed in and on decomposed GH (Figure 79) and could explain the difference in the observed decomposed proportions for fish tied to the lead compared to the floating line. The binomial probabilities of being decomposed after 24 hours were 0.819 and 0.187 for fish tied on the lead and floating line respectively. If we suppose that that the average rate of decomposition for fish meshed in the net is intermediate to the values for the lead and float line, then about 50% of the fish would be decomposed 24 hours after dying in the nets. This proportion would be a bit more than 80% after 48 hours. This indicates that the magnitude of unaccounted fishing mortality in the GH gillnet fishery could be important, but replication of the experiments will be essential to produce whole fishery estimates. Additional sampling and analysis are required to estimate the rate at which captured fish die while in the net. Once estimates of capture rate, mortality rate following capture and decomposition rate following death are derived, it will be possible to estimate drop-out losses.

The rapid decomposition rates observed in the experiment could explain the “V” shape of the relationship between landings and soak time observed in both ZIFF and ASO data. Indeed, the accumulation of catches in nets during the first 24 hours may be slower than decomposition rate. After 24 hours of immersion, the nets would reach a certain degree of self-baiting and the accumulation of catches would be more important than decomposition. This suggests that the use of short immersion times (less than 24 hours) could limit drop-out losses.

3.3.4. Conclusion

Analyses of ZIFF and ASO data have shown that landed quantities tend to peak at immersion times of about 72 hours. This means that catches per unit effort (biomass/gear/hour) decrease after 72 hours. The proportion of discarded Greenland halibut catches tended to increase with immersion time based on ASO data. The decomposition rates estimated in summer 2022 were high and could explain the initial decrease followed by the increase in landings as a function of soak time during the first 48 hours. Continued immersion and decomposition experiments in 2023, as well as the collection of decomposition data by ASO, will be useful in estimating unaccounted mortality in the directed gillnet fishery for Greenland halibut.

In conclusion, we encourage the practice of short soak times in this fishery and believe that this practice will be beneficial from the point of view of both harvesters and conservation.

3.4. EXPLOITATION RATES AND PRECAUTIONARY APPROACH

3.4.1. Relative exploitation rates

Annual relative exploitation rates were calculated for the entire Gulf (4RST) and by fishing sector. The nGSL survey strata used to determine biomass by fishing sector are shown in Figure 80. These exploitation rates are calculated on the basis of landed quantities and do not take into account unaccounted fishing mortality.

In 2021 and 2022, the exploitation rate for the Gulf as a whole (4RST) were 3.35 and 3.10%, which below the 6.5% average for the 1996–2020 series (Table 25, Figure 81). The average exploitation rate was 4.8% for the 2001–2008 period, a period during which the stock increased and remained abundant. The 2009–2017 period, for which the exploitation rate was near the average, corresponds to a period with a fairly steady decrease in the biomass of fish > 40 cm (Figure 81). This could indicate that exploitation rates have been too high during those years.

In the western Gulf, the exploitation rate indicator increased between 2012 and 2017. Following a decrease in landings and a stable or increasing biomass level, the exploitation rate for this sector decreased in 2021 and 2022 to be well below the series average. For the north Anticosti and Esquiman areas, exploitation rates were increasing to some of the highest levels in the series in 2020 and subsequently decreased in 2021 and 2022. For the Esquiman area, fish biomass > 40 cm estimated from the nGSL survey show a downward trend since 2011 and reached its lowest value of the series in 2020 and its highest exploitation rate. Biomasses estimated in this sector in 2021 and 2022 were among the 3 lowest values in the series, but low landings for these years resulted in low exploitation rates.

3.4.2. Precautionary Approach

The use of the precautionary approach (PA) in fisheries management aims to prevent serious harm to fish stocks or their ecosystems, and involves being cautious when scientific knowledge is uncertain and not using the absence of adequate scientific information as a reason to postpone or fail to take action. This approach is widely accepted nationally and internationally as an essential part of sustainable fisheries management.

A first PA has been completed for the GSL Greenland halibut stock in 2022 (DFO 2022a). It is based on empirical reference points and harvest control rule.

The selected stock status indicator is the biomass of fish > 40 cm estimated from the nGSL survey. This survey covers almost the entire range of the stock and this indicator represents a relative approximation of the spawning stock biomass since the catchability of Greenland halibut in this survey is not known (DFO 2018b). The stock status indicator is expressed in Teleost equivalents and the conversion factors between *Needler* and *Teleost* used are those of Bourdages et al. (2007).

The selected LRP (limit reference point) was defined as the geometric mean of the indicator for the 1990–1994 period, which corresponds to the period when the population was at its lowest level and from which a recovery of the stock was observed in the survey series. The LRP was estimated at 10,000 t (Figure 82A). The upper stock reference point (USR) is based on distinct periods of stock productivity, i.e. the 1996–2002 period of average productivity and the 2004–2012 period of high productivity (Figure 82A). In this proposal, a proxy of the biomass at maximum sustainable yield (B_{msy}) is the mean of the biomasses of the two periods, i.e. 47,170 t. The USR corresponds to 80% of this B_{msy}, i.e. 37,740 t. The B_{msy} is considered the target reference point (TRP) in this approach. This choice of this USR was made to account to some extent for ecosystem changes in the GSL and decreased stock productivity (DFO 2022a).

The Harvest Control Rule (HCR) was developed in accordance with the PA principles using the stock biomass indicator and reference exploitation rates (DFO 2009). The HCR is a “status-based” rule, where projected exploitation rates and corresponding removals are a function of stock status (Kronlund et al. 2014). The maximum reference exploitation rate was defined as the arithmetic mean of the average exploitation rates for the 1996-2002 (excluding 1998) and 2004-2012 periods, which were used to define the TRP and USR, and corresponds to 6.51%.

According to the HCR, the exploitation rate when any stock status ≥ TRP is 6.51%, while the exploitation rate in the middle of the cautious zone, which is the average of the LRP and USR, was set at 5.31%, which is the average exploitation rate for a period of growth from 2002 to 2006 (DFO 2022a). The exploitation rates at the TRP and in the middle of the cautious zone are then converted into removals (kg) and a straight line is drawn to connect these values and join the LRP. The removals on the line are then converted into exploitation rates. This results in a curvilinear decrease in exploitation rates in the cautious zone as the stock status indicator approaches the LRP (Figure 82B). The exploitation rate for the LRP is 1.94%. The HCR does not project removals beyond a biomass of 76,805 t (5,000 t / 6.51%) as the stock has never been able to sustain annual landings of more than 5,000 t in the past (Gauthier et al. 2021).

The stock status index was on a downward trend with a decline of over 60% between 2008 and 2017, going from the healthy zone to the cautious zone. The indicator was stable in the middle of the cautious zone from 2017 to 2020. It increased to 35,859 t in 2021, just below the USR and was still in the Cautious Zone in 2022, at 33,366 t (Figure 82A). According to the HCR, the annual projected removals should be a maximum of 2,002 t for the 2023-2024 and 2024-2025 management years (Figure 82B).

According to the PA for this stock (DFO 2022a), the decision regarding the TAC will be applied for 2 years. During interim years, an update of the stock status indicator will be produced. In the event of exceptional circumstances during an interim year, such as a variation of more than 30% in the biomass indicator, the projected removals from the HCR will be recalculated.

4. CONCLUSION

In 2021 to 2022, commercial fishing performance indices were increasing in the western GSL, stable in north Anticosti and decreasing in Esquiman. The index for the GSL as a whole was at the average level in 2022, while noting that overall effort has decreased considerably since 2013.

Cohorts (2016, 2017 and 2018) expected to recruit and contribute to the fishery in 2023 and 2024 range from low (2016) to high (2017-2018) abundance. Somatic growth in the abundant 2018 cohort appears normal. Individuals from this cohort are expected to start recruiting to the fishery in 2024, but their low condition in 2022 could hinder their growth. The low recruitment from 2020 to 2022 will have a negative impact on the biomass available for fishing in subsequent years. However, this low recruitment came from years with low levels of spawning biomass. Spawning biomass rebuilt in 2021 and 2022, which could lead to improved recruitment.

Landings in the commercial fishery continued to decline in 2021 and 2022, reaching the lowest levels since the 1980s. The biomass of individuals > 40 cm increased in 2021 compared to 2020 and remained stable in 2022. This resulted in a significant decrease in the exploitation rate indicator in 2021 and 2022, which represent the lowest values observed since 1996.

In 2022, the stock status index was estimated at 33,135 t, slightly below the upper stock reference point. The stock is therefore at the top of the cautious zone. Under the harvest control rule, all sources of removals should not exceed 2,002 t in the 2023-2024 and 2024-2025 management years. The outlook for the Greenland halibut stock in the GSL is uncertain given ecosystem changes likely to be unfavourable for this species and declining condition indices in 2022.

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7. TABLES

Table 1. History of the main management measures put in place for the directed Greenland halibut fishery. F-ALL: Fishing Allocation; Comp: Competitive Regime; ITQ: Individual Transferable Quota; Bo : Boat

Management year	TAC (t)	F-ALL	Landing (t)	Fishing Regime	Mesh size (inch)	Number of net	Minimum size[4] (cm)
1980	-	-	7,006	*Freeze on the issuance of groundfish licenses*			
1981	-	-	3,176	-	-	-	-
1982	7,500	-	2,269	*Establishment of a management plan*			
1983	5,000	-	1,105	-	-	-	-
1984	5,000	-	2,126	-	-	-	-
1985	5,000	-	2,369	-	-	-	-
1986	5,000	-	6,595	-	-	-	-
1987	8,900	-	11,080	*Problem of high bycatch by mobile gear > 65 feet*			
1988	10,500	-	7,569	-	-	-	-
1989	10,500	-	5,136	-	-	-	-
1990	10,500	-	2,445	-	-	-	-
1991	10,500	-	2,293	-	-	-	-
1992	10,500	-	3,419	Comp.	5.5	>120	-
1993	4,000	-	2,602	Comp.	5.5	>120	-
	Recognition than GSL Greenland halibut is distinct from the Atlantic one. *Stop of mobile gear directed fishery.* *Progressive use of Nordmore grid by shrimpers to reduce bycatch of Greenland halibut > 30cm*						
1994	4,000	-	3,620	Comp.	5.5	120 (Bo < 45 ft.) 160 (Bo > 45 ft.)	-
1995	4,000 (-,900[1])	-	2,426	Comp.	70% 5.5 30% 5.7	120	-
1996	2,000	-	1,962	Comp.	30% 5.7 70% 6.0	80 = QC 120 = NL	42
1997	3,000	-	2,633	Comp.	6.0	80 = QC 120 = NL	44
1998	4,000	-	3,945	Comp.	6.0	80 = QC 120 = NL	44
1999-2000	4,500	-	3,674	QC = ITQ + Comp. NL = Comp.	6.0	80 = QC 120 = NL	44
2000-2001	4,500	-	2,078	Idem	6.0	80/100 = QC [3] 120 = NL	44
2001-2002[9]	4,500	-	1,288	Idem	6.0	120	44
2002-2003	3,500	-	1,752	Idem	QC[2] = 5.5 et 6.0 NL : 6.0	120	44
2003-2004	3,500	2,917	3,573	Idem	QC[2] = 5.5 et 6.0 NL : 6.0	120	44
2004-2005	4,500	3,751	3,952	Idem	6.0	120	44
2005-2006	4,500	3,751	4,048	Idem	6.0	120	44
2006-2007	4,500	3,751	3,868	Idem	6.0	120	44
2007-2008	4,500	3,751	3,921	Idem	6.0	120	44
2008-2009	4,500	3,751	3,770	ITQ + Comp. = QC	6.0	120	44

Management year	TAC (t)	F-ALL	Landing (t)	Fishing Regime	Mesh size (inch)	Number of net	Minimum size[4] (cm)
				Comp. = NL			
2009-2010	4,500	3,751	4,268	Idem	6.0	120	44
2010-2011[5]	4,500	3,751	3,972	Idem	6.0	120	44
2011-2012	4,500	3,751	3,872	Idem	6.0	QC = 120 NL = 90	44
2012-2013	4,500	3,751	3,481	Idem	6.0	QC = 120 NL = Option A- 80 and 3 fishing days, or Option B- 35 and 5 fishing days	44
2013-2014	4,500	3,751	2,774	Idem	6.0	QC = 120 NL = Option A- 80 and 3 fishing days, or Option B- 35 and 5 fishing days	44
2014-2015[10]	4,500	3,751	3,179	Idem	6.0	QC = 120 NL = 80	44
2015-2016	4,500	3,751	3,410	Idem	6.0	QC = 120 NL = 90	44
2016-2017	4,500	3,751	3,300	Idem	6.0	QC = 120 NL = 90	44
2017-2018	4,500	3751	1,765	Idem	6.0	QC = 120 NL = 90	44
2018-2019	3,375	2,813	1,604	Idem	6.0	QC = 120 NL = 90	44
2019-2020	3,375	2,813	1,896	Idem	6.0	QC = 120 NL = 90	44
2020-2021 [11]	2,250	1,875	1,330	Idem	6.0	QC = 120 NL = 90	44
2021-2022[8]	2,025	1,688	1,195	Idem	6.0	QC = 120 NL = 90	44
2022-2023[8]	2,400	2,000	930	Idem	6.0	QC = 120 NL = 90	44

[1] TAC reduction to protect juvenile fish.
[2] QC experimental fishery (4T4 et 4T3a): fishery with 5,5 inches mesh size gillnet allowed to catch 30% du IQ of traditional fishers. The other fishers used 6 inches.
[3] The maximum number of nets was increased from 80 to 100 from July 17, 2000 to May 14, 2001 for QC fishers.
[4] Minimum size of small fish protocol.
[5] Establishment of quota reconciliation.
[6] Mandatory use of Vessel Monitoring System (VMS) for some QC fleet.
[7] Mandatory use of VMS for all QC fleet.
[8] Landing data are preliminary.
[9] Ban on fishing in depth less than 125 fathoms in Division 4R from 2001 to 2013.
[10] Ban on fishing in depth less than 140 fathoms in Division 4R since 2014. For the Quebec Region, the maximum 72-hour time between launching and hauling of the nets is added to the licence conditions starting in May 2014
[11] Ban on fishing in depth less than 125 fathoms in Division 4S, measure implemented in 2020.

Table 2. Landings (t) of Greenland halibut by fishing gear and management year. Data source 1977-1983: Morin and Bernier 2003 ; 1984-2022 ZIFF updated on 2023-01-12.

Management year	Gillnet	Longline	Bottom trawl	Seine	Shrimp trawl	Other	Total
1977	1,329	3	1,626	0	993	10	3,961
1978	3,450	0	1,577	0	1,210	10	6,247
1979	3,373	1,901	2,888	0	609	20	8,791
1980	5,239	39	1,042	0	686	0	7,006
1981	2,464	7	409	0	286	10	3,176
1982	1,771	3	165	0	330	0	2,269
1983	469	94	231	0	311	0	1,105
1984	1,026	36	582	0	457	25	2,126
1985	1,451	61	97	1	650	108	2,369
1986	4,941	122	231	1	1,299	0	6,595
1987	8,350	147	1,199	4	1,376	4	11,080
1988	5,793	52	694	19	1,010	1	7,569
1989	4,193	22	404	0	517	0	5,136
1990	1,937	39	178	0	290	0	2,445
1991	1,372	74	141	4	700	2	2,293
1992	2,401	112	156	16	733	0	3,419
1993	2,334	59	62	8	127	12	2,602
1994	3,436	86	18	5	10	66	3,620
1995	2,330	17	10	14	1	54	2,426
1996	1,811	34	93	23	1	0	1,962
1997	2,456	57	89	30	1	0	2,633
1998	3,765	34	117	27	1	0	3,945
1999-2000	3,384	28	188	71	2	1	3,674
2000-2001	1,875	78	99	26	1	0	2,078
2001-2002	1,156	66	39	24	2	0	1,288
2002-2003	1,568	87	54	34	1	8	1,752
2003-2004	3,413	49	66	43	2	0	3,573
2004-2005	3,801	48	40	61	1	0	3,952
2005-2006	3,837	39	49	122	0	0	4,048
2006-2007	3,722	47	48	49	2	0	3,868
2007-2008	3,743	47	15	111	2	4	3,921
2008-2009	3,627	47	28	55	2	12	3,770
2009-2010	4,159	28	52	14	1	15	4,268
2010-2011	3,904	20	18	11	1	18	3,972
2011-2012	3,791	20	27	16	1	18	3,872
2012-2013	3,417	15	19	16	1	13	3,481
2013-2014	2,722	5	11	14	1	21	2,774
2014-2015	3,139	6	3	10	1	20	3,179
2015-2016	3,363	5	7	15	1	19	3,410
2016-2017	3,277	3	8	11	1	0	3,311
2017-2018	1,744	7	1	14	1	8	1,773
2018-2019	1,575	6	3	12	1	2	1,598
2019-2020	1,873	7	2	7	1	9	1,890
2020-2021	1,443	9	0	3	1	40	1,456
2021-2022*	1187	7	1	2	2	0	1,198
2022-2023*	930	5	0	0	1	0	937

*Preliminary data

Table 3. Landings (t) by NAFO Divisions and Total Allowable Catch (TAC) of Greenland halibut by management year. Fishing allocation (F-ALL) is shown from 2003 onwards. Data source 1977-1983: Morin and Bernier 2003 ; 1984-2022 ZIFF updated on 2023-01-12.

Management year	NAFO Division				Total	TAC	F-ALL
	4R	4S	4T	n. d.**			
1970	381	496	255	-	1,132	-	-
1971	300	450	204	-	954	-	-
1972	199	379	105	-	683	-	-
1973	216	431	116	-	763	-	-
1974	167	752	92	-	1,011	-	-
1975	195	1,102	247	-	1,544	-	-
1976	517	1,367	135	-	2,019	-	-
1977	1,108	2,298	555	-	3,961	-	-
1978	1,344	3,549	1,354	-	6,247	-	-
1979	2,920	1,889	3,982	-	8,791	-	-
1980	1,631	2,063	3,312	-	7,006	-	-
1981	533	803	1,840	-	3,176	-	-
1982	158	548	1,563	-	2,269	7,500	-
1983	205	444	456	-	1,105	5,000	-
1984	200	571	1,355	-	2,126	5,000	-
1985	213	863	1,292	-	2,369	5,000	-
1986	148	2,161	4,286	-	6,595	5,000	-
1987	229	4,395	6,456	-	11,080	8,900	-
1988	366	2,366	4,838	-	7,569	10,500	-
1989	389	1,872	2,875	-	5,136	10,500	-
1990	304	828	1,313	-	2,445	10,500	-
1991	627	877	789	-	2,293	10,500	-
1992	751	856	1,811	-	3,419	10,500	-
1993	398	709	1,495	-	2,602	4,000	-
1994	507	795	2,318	-	3,620	4,000	-
1995	320	425	1,681	-	2,426	4,000	-
1996	359	532	1,071	-	1,962	2,000	-
1997	549	439	1,645	-	2,633	3,000	-
1998	690	879	2,376	-	3,945	4,000	-
1999-2000	553	837	2,283	-	3,674	4,500	-
2000-2001	513	483	1,082	-	2,078	4,500	-
2001-2002	408	233	647	-	1,288	4,500	-
2002-2003	567	298	888	-	1,752	3,500	-
2003-2004	1,062	807	1,704	-	3,573	3,500	2,917
2004-2005	1,035	1,097	1,820	-	3,952	4,500	3,751
2005-2006	1,192	1,201	1,656	-	4,048	4,500	3,751
2006-2007	1,032	1,696	1,140	-	3,868	4,500	3,751
2007-2008	944	2,107	866	3	3,921	4,500	3,751
2008-2009	739	1,746	1,272	12	3,770	4,500	3,751
2009-2010	1,320	1,890	1,044	15	4,268	4,500	3,751
2010-2011	1,193	1,920	841	18	3,972	4,500	3,751
2011-2012	1,636	1,822	397	17	3,872	4,500	3,751
2012-2013	1,457	1,334	676	13	3,481	4,500	3,751
2013-2014	793	1,387	573	21	2,774	4,500	3,751
2014-2015	488	1,396	1,275	20	3,179	4,500	3,751
2015-2016	477	1,726	1,187	19	3,410	4,500	3,751
2016-2017	519	1,453	1,328	11	3,311	4,500	3,751
2017-2018	210	823	732	8	1,773	4,500	3,751
2018-2019	549	574	475	10	1,608	3,375	2,813
2019-2020	537	460	893	-	1,890	3,375	2,813
2020-2021	310	434	711	-	1,456	2,250	1,875
2021-2022*	130	543	526	-	1,198	2,025	1,688
2022-2023*	126	165	647	-	937	2,400	2,000

*Preliminary data, **n. d. not determined

Table 4. Monthly gillnet catch (t) for the entire Gulf (4RST), by sector and calendar year. Data source: ZIFF, 2023-01-12

4RST

Year	J	F	M	A	M	J	J	A	S	O	N	D
1985	0	0	0	30	221	249	188	323	252	178	8	0
1986	-	-	-	149	766	770	792	612	1193	641	18	0
1987	-	-	-	487	1,088	1,484	1,879	2,343	1,034	33	1	0
1988	-	-	5	307	668	1,064	1,588	1,105	707	340	9	0
1989	-	-	4	183	809	1,127	1,079	603	247	106	34	1
1990	-	-	2	69	413	456	392	270	163	148	21	2
1991	-	-	-	47	190	382	285	233	167	61	8	0
1992	-	-	-	98	417	595	609	377	229	72	5	-
1993	-	-	-	35	184	521	583	550	295	128	38	-
1994	-	-	-	42	540	714	719	657	276	-	-	-
1995	-	-	-	-	665	826	794	46	-	-	1	-
1996	-	-	-	-	117	995	588	89	11	10	-	-
1997	-	-	-	-	822	1,374	252	2	3	3	-	-
1998	-	-	-	-	25	273	2,323	465	596	82	2	-
1999	-	-	-	-	10	1,222	828	566	448	155	25	1
2000	-	-	-	33	249	452	664	441	114	15	5	-
2001	-	-	-	8	41	185	581	264	57	25	14	-
2002	-	-	-	7	22	254	501	420	155	69	21	-
2003	-	-	1	43	369	1,030	1,245	521	193	54	5	-
2004	-	-	-	57	694	1,155	966	648	210	45	0	-
2005	-	-	-	43	743	1,514	757	534	199	80	1	-
2006	-	-	-	43	396	1,387	863	645	207	31	1	-
2007	-	-	-	118	726	1,538	697	545	95	43	0	-
2008	-	-	-	87	615	1,208	893	480	184	49	2	-
2009	-	-	-	130	661	2,032	934	317	145	25	-	-
2010	-	-	-	131	561	2,066	671	392	111	38	0	-
2011	-	-	-	55	618	1,589	970	269	109	40	0	-
2012	-	-	-	95	719	1,165	955	376	179	15	0	-
2013	-	-	-	71	319	595	767	386	185	147	4	-
2014	-	-	-	109	799	1,080	637	521	247	60	-	-
2015	-	-	-	23	726	1,238	769	386	211	72	-	-
2016	-	-	-	45	436	1,274	782	430	207	69	40	3
2017	-	-	-	35	280	559	399	282	110	44	10	-
2018	-	-	-	56	85	293	501	377	138	84	38	-
2019	-	-	-	48	120	432	549	434	182	82	0	-
2020	-	-	-	71	157	370	400	183	142	126	1	-
2021*	-	-	-	48	244	376	261	137	84	51	-	-
2022*	-	-	-	42	147	242	277	173	112	41	0	-

Western Gulf

Year	J	F	M	A	M	J	J	A	S	O	N	D
1999	-	-	-	-	2	1,049	671	378	316	116	24	1
2000	-	-	-	32	236	294	377	307	98	11	5	-
2001	-	-	-	8	41	119	382	148	22	5	0	-
2002	-	-	-	2	13	53	181	341	140	46	18	-
2003	-	-	-	43	359	542	608	362	193	54	5	-
2004	-	-	-	57	256	603	708	648	209	44	0	-
2005	-	-	-	43	307	652	752	530	197	80	1	-
2006	-	-	-	40	61	570	721	598	203	31	1	-
2007	-	-	-	118	632	573	586	493	94	42		-
2008	-	-	-	87	562	537	618	374	164	26	2	-
2009	-	-	-	130	601	578	500	308	141	24	-	-
2010	-	-	-	131	435	697	357	253	48	5	-	-
2011	-	-	-	55	433	306	230	138	87	40	-	-
2012	-	-	-	79	435	329	269	96	40	14	-	-
2013	-	-	-	61	260	191	263	203	112	54	-	-
2014	-	-	-	107	794	654	522	478	239	58	-	-
2015	-	-	-	23	726	1,018	633	311	169	57	-	-
2016	-	-	-	45	432	1,063	651	341	162	29	-	-
2017	-	-	-	35	280	486	372	239	71	16	1	-
2018	-	-	-	56	85	76	179	219	112	63	19	-
2019	-	-	-	48	118	160	367	287	142	58	0	-
2020	-	-	-	69	153	181	258	84	81	80	-	-
2021*	-	-	-	48	238	287	180	97	65	50	-	-
2022*	-	-	-	42	147	200	187	131	92	41	0	-

North Anticosti

Year	J	F	M	A	M	J	J	A	S	O	N	D
1999	-	-	-	-	-	2	8	39	53	11	-	-
2000	-	-	-	1	1	2	41	27	1	-	-	-
2001	-	-	-		0	0	13	25	7	-	-	-
2002	-	-	-	5	1	-	5	70	9	-	-	-
2003	-	-	-	-	3	5	46	13	-	-	-	-
2004	-	-	-	-	-	9	5	-	-	-	-	-
2005	-	-	-	-	6	-	0	1	-	-	-	-
2006	-	-	-	3	-	114	93	45	4	-	-	-
2007	-	-	-	-	8	-	74	51	-	-	-	-
2008	-	-	-	-	-	25	46	89	2	-	-	-
2009	-	-	-	-	3	115	403	5	-	-	-	-
2010	-	-	-	-	1	243	212	126	60	31	-	-
2011	-	-	-	-	20	184	165	87	19	-	-	-
2012	-	-	-	-	12	108	235	92	51	-	-	-
2013	-	-	-	-	23	34	241	119	18	-	-	-
2014	-	-	-	3	1	46	35	21	-	-	-	-
2015	-	-	-	-	-	-	0	-	-	-	-	-
2016	-	-	-	-	-	2	1	3	-	-	-	-
2017	-	-	-	-	1	4	1	-	-	-	-	-
2018	-	-	-	-	-	35	106	55	15	-	-	-
2019	-	-	-	-	2	10	45	49	22	-	-	-
2020	-	-	-	2	-	23	64	46	54	43	1	2
2021*	-	-	-	-	2	38	40	16	4	-	-	-
2022*	-	-	-	-	-	24	23	-	0	-	-	-

Esquiman

Year	J	F	M	A	M	J	J	A	S	O	N	D
1999	-	-	-	-	7	172	146	148	78	28	1	-
2000	-	-	-	-	11	156	244	106	15	4	0	-
2001	-	-	-	-	-	65	183	89	28	19	14	-
2002	-	-	-	-	8	201	311	9	7	23	4	-
2003	-	-	1	-	7	483	590	146	-	-	-	-
2004	-	-	-	-	437	541	253	0	1	1	-	-
2005	-	-	-	-	429	861	3	2	1	1	-	-
2006	-	-	-	-	331	703	48	1	0	0	0	-
2007	-	-	-	-	86	966	37	0	1	1	0	-
2008	-	-	-	-	52	645	227	15	18	23	-	-
2009	-	-	-	-	57	1,338	30	3	4	1	-	-
2010	-	-	-	-	125	1,123	100	6	3	2	0	-
2011	-	-	-	-	164	1,096	572	43	3	-	0	-
2012	-	-	-	16	271	728	449	188	88	1	0	-
2013	-	-	-	10	36	369	262	63	55	93	4	-
2014	-	-	-	-	4	380	78	22	9	2	-	-
2015	-	-	-	-	-	220	136	75	42	15	-	-
2016	-	-	-	-	3	208	131	86	45	40	40	3
2017	-	-	-	-	-	68	26	43	36	28	9	-
2018	-	-	-	-	-	183	215	102	11	21	19	-
2019	-	-	-	-	-	262	136	98	18	23	-	-
2020	-	-	-	-	4	166	78	53	7	2	-	-
2021*	-	-	-	-	-	51	39	25	14	1	-	-
2022*	-	-	-	-	-	18	46	42	19	0	-	-

*Preliminary data

Table 5. Number of observations (N obs), catch (t), effort (number of gillnets), catch per unit effort (CPUE, kg/net) and its standard error (SE), percentage (%) of landings corresponding to observations, landings (t) and nominal effort for gillnets by fishing sector and calendar year. Data source: ZIFF, 2023-01-12

4RST

Year	N obs	Catch	Effort	CPUE	SE	%	Tot. lan. (t)	Tot. effort
1999	1,332	1,198	79,096	15,2	0.3	37	3,254	214,935
2000	1,221	918	83,688	11,0	0.2	47	1,973	179,974
2001	405	249	23,182	10,8	0.4	21	1,175	109,349
2002	658	434	29,200	14,9	0.5	30	1,450	97,659
2003	1,161	1,407	63,856	22,0	0.5	41	3,462	156,894
2004	2,586	2,811	152,127	18,5	0.3	75	3,775	204,197
2005	2,664	2,834	163,802	17,3	0.3	73	3,871	223,773
2006	2,291	2,986	148,991	20,0	0.3	84	3,573	178,219
2007	1,898	3,199	121,159	26,4	0.4	85	3,762	142,540
2008	1,986	3,091	131,091	23,6	0.3	88	3,518	149,137
2009	2,027	3,481	130,865	26,6	0.4	82	4,244	159,591
2010	2,002	3,552	143,085	24,8	0.4	90	3,970	159,872
2011	1,851	3,222	132,475	24,3	0.5	88	3,650	150,028
2012	1,777	3,001	121,075	24,8	0.5	86	3,504	141,443
2013	2,192	2,235	159,792	14,0	0.2	90	2,474	176,957
2014	2,002	3,141	148,411	21,2	0.3	91	3,454	163,268
2015	1,759	3,130	118,439	26,4	0.4	91	3,425	129,583
2016	1,814	2,980	121,245	24,6	0.4	91	3,286	133,677
2017	1,513	1,564	111,986	14,0	0.2	91	1,720	123,197
2018	1,569	1,452	112,797	12,9	0.2	92	1,572	122,075
2019	1785	1,697	122,302	13.9	0.2	92	1,847	133,082
2020	1389	1,355	94,608	14.3	0.3	93	1,450	101,293
2021*	898	1,065	65,748	16.2	0.3	89	1,202	74,208
2022*	667	833	46,409	18.0	0.4	81	1,034	57,579

Western Gulf

Year	N obs	Catch	Effort	CPUE	SE	%	Tot. lan. (t)	Tot. effort
1999	836	731	39,775	18.4	0.4	29	2,555	139,073
2000	825	531	49,497	10.7	0.3	39	1,360	126,915
2001	362	218	21,007	10.4	0.4	30	727	70,023
2002	614	358	26,636	13.4	0.4	45	793	59,060
2003	1,003	1,010	51,384	19.7	0.4	47	2,167	110,266
2004	2,386	2,277	136,695	16.7	0.2	90	2,526	151,547
2005	2,532	2,451	155,761	15.7	0.2	96	2,562	162,760
2006	1,912	2,100	118,994	17.7	0.3	94	2,225	126,053
2007	1,516	2,371	92,910	25.5	0.4	93	2,538	99,475
2008	1,547	2,240	98,796	22.7	0.3	95	2,371	104,546
2009	1,546	2,047	99,791	20.5	0.3	90	2,282	111,250
2010	1,349	1,836	94,447	19.4	0.3	95	1,927	99,105
2011	1,097	1,265	79,591	15.9	0.3	98	1,290	81,133
2012	954	1,145	67,249	17.0	0.4	91	1,262	74,144
2013	1,208	1,090	95,171	11.5	0.2	95	1,144	99,865
2014	1,484	2,679	117,635	22.8	0.3	94	2,851	125,144
2015	1,282	2,790	92,716	30.1	0.4	95	2,937	97,596
2016	1,255	2,560	86,004	29.8	0.4	94	2,723	91,494
2017	1,240	1,408	92,332	15.3	0.2	94	1,500	98,330
2018	967	777	69,288	11.2	0.2	96	809	72,175

Year	N obs	Catch	Effort	CPUE	SE	%	Tot. lan. (t)	Tot. effort
2019	1,108	1,118	79,063	14.1	0.3	94.7	1,181	83,488
2020	918	871	66,647	13.1	0.3	96.1	907	69,352
2021*	712	895	53,254	16.8	0.4	92.8	965	57,386
2022*	626	787	43,169	18.2	0.5	93.7	839	46,072

North Anticosti

Year	N obs	Catch	Effort	CPUE	SE	%	Tot. lan. (t)	Tot. effort
1999	136	103	8,027	12.8	0.6	92	113	8,773
2000	73	72	4,446	16.2	1.0	98	74	4,551
2001	40	29	1,927	15.1	1.4	65	45	2,988
2002	31	70	1,985	35.2	4.2	78	90	2,551
2003	33	66	2,329	28.2	2.6	97	67	2,394
2004	7	13	532	-	-	95	13	562
2005	3	6	150	-	-	89	6	169
2006	111	243	9,702	25.0	1.1	94	259	10,365
2007	65	129	5,506	23.4	1.5	97	133	5,676
2008	89	162	5,968	27.2	1.9	100	162	5,968
2009	172	499	15,748	31.7	1.1	95	527	16,629
2010	299	667	25,831	25.8	1.0	99	672	26,013
2011	279	458	22,764	20.1	0.8	96	475	23,614
2012	201	442	16,002	27.6	1.1	89	499	18,061
2013	359	424	31,367	13.5	0.4	97	436	32,237
2014	113	104	8,921	11.7	0.7	98	106	9,066
2015	-	-	-	-	-	-	0	-
2016	8	5	357	13.2	1.8	89	5	403
2017	7	5	541	8.6	1.7	95	5	569
2018	184	209	15,921	13.2	0.6	100	210	15,969
2019	143	126	10,127	12.5	0.6	98.6	128	10,271
2020	135	220	10,475	21.0	1.1	94.9	232	11,038
2021*	79	99	5,897	16.8	1.1	98.9	100	5,963
2022*	39	45	3,173	14.2	1.2	96.3	47	3,295

Esquiman

Year	N obs	Catch	Effort	CPUE	SE	%	Tot. lan. (t)	Tot. effort
1999	358	361	31,101	11.6	0.4	62	581	50,082
2000	322	314	29,672	10.6	0.4	59	537	50,635
2001	1	2	102	-	-	0	397	25,500
2002	13	6	579	11.1	1.9	1	562	52,636
2003	125	331	10,143	32.7	1.5	27	1,226	37,567
2004	192	520	14,820	35.1	1.5	42	1,234	35,202
2005	125	373	7,652	48.7	2.5	29	1,297	26,569
2006	268	643	20,295	31.7	1.2	59	1,083	34,167
2007	317	699	22,743	30.7	1.2	64	1,091	35,536
2008	349	688	26,293	26.2	0.7	70	980	37,454
2009	309	935	15,326	61.0	1.7	65	1,435	23,506
2010	347	1,037	22,167	46.8	1.4	76	1,360	29,052
2011	473	1,497	29,957	50.0	1.3	80	1,879	37,587
2012	620	1,413	37,740	37.4	1.0	81	1,741	46,535
2013	622	720	32,984	21.8	0.5	81	893	40,872
2014	403	355	21,685	16.4	0.6	72	495	30,202
2015	477	341	25,723	13.2	0.4	70	488	36,852

Year	N obs	Catch	Effort	CPUE	SE	%	Tot. lan. (t)	Tot. effort
2016	550	414	34,817	11.9	0.3	74	557	46,797
2017	266	151	19,113	7.9	0.3	72	211	26,657
2018	418	466	27,588	16.9	0.5	85	551	32,610
2019	534	452	33,112	13.7	0.3	84.2	537	39,325
2020	334	262	17,396	15.1	0.6	84.5	310	20,587
2021*	103	67	6355	10.6	0.5	51.8	129	12,268
2022*	-	-	-	-	-	-	125	-

*Preliminary data

Table 6. Standardized annual catch per unit effort (CPUE) and its standard error (SE) for the gillnet fishery for the whole Gulf (4RST) and by fishing sector. Data source: ZIFF, 2023-01-12

Year	4RST		Western Gulf		North Anticosti		Esquiman	
	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE
1999	21.49	0.48	28.53	0.72	16.56	0.95	11.19	0.38
2000	14.06	0.31	14.45	0.35	21.78	1.50	11.22	0.38
2001	14.27	0.50	13.67	0.47	18.74	1.72	12.91	1.98
2002	19.05	0.56	18.05	0.51	39.81	3.92	33.07	1.69
2003	30.10	0.68	29.11	0.66	33.17	3.03	31.71	1.38
2004	25.11	0.44	23.97	0.41	-	-	48.34	2.81
2005	23.01	0.40	21.63	0.36	-	-	33.51	1.35
2006	25.50	0.45	23.19	0.41	46.12	2.59	30.31	1.10
2007	34.67	0.65	34.01	0.65	44.77	3.11	26.39	0.89
2008	32.84	0.61	32.98	0.63	41.87	2.58	66.32	2.44
2009	35.67	0.66	29.26	0.56	56.36	2.56	52.84	1.87
2010	32.75	0.62	27.57	0.56	41.82	1.67	66.36	2.03
2011	29.15	0.56	20.18	0.44	33.70	1.37	48.68	1.39
2012	32.26	0.64	23.22	0.54	43.53	1.89	23.25	0.61
2013	18.53	0.34	15.33	0.32	21.07	0.75	15.67	0.50
2014	29.22	0.54	34.29	0.67	17.16	0.94	13.45	0.39
2015	34.73	0.67	46.66	0.95	-	-	11.16	0.33
2016	31.15	0.60	44.22	0.90	13.48	2.54	7.54	0.29
2017	18.87	0.38	21.72	0.44	10.15	1.99	17.04	0.51
2018	16.77	0.34	15.09	0.34	18.72	0.84	14.64	0.41
2019	18.32	0.35	19.03	0.41	16.34	0.82	14.59	0.48
2020	18.88	0.40	18.77	0.44	23.71	1.25	10.16	0.56
2021*	20.71	0.51	22.28	0.57	22.84	1.40	11.19	0.38
2022*	25.16	0.71	25.30	0.69	19.86	1.68	11.22	0.38

*Preliminary data

Table 7. Average length (cm) of fish caught in the commercial gillnet fishery by sex (Male, Female and Total) and NAFO Division.

Year	4RST			4R			4S			4T		
	M	F	T	M	F	T	M	F	T	M	F	T
1987	42.2	44.5	43.5	43.0	45.3	44.2	43.0	45.3	44.2	41.5	44.1	43.1
1988	42.5	45.1	44.0	43.3	45.5	44.6	43.2	45.6	44.6	42.2	44.8	43.7
1989	44.0	47.8	46.4	43.2	46.4	44.5	43.3	46.1	44.7	45.9	48.8	48.2
1990	44.6	48.5	46.2	44.9	49.7	46.9	44.5	48.9	46.3	44.6	47.9	46.0
1991	43.9	47.0	45.3	43.5	45.8	44.5	43.5	45.8	44.4	45.2	48.9	47.4
1992	43.4	44.8	44.3	48.2	49.2	48.7	41.2	44.3	43.1	42.2	44.2	43.5
1993	42.2	44.0	43.3	46.1	48.0	47.0	42.4	44.6	43.9	41.0	43.1	42.4
1994	39.2	42.8	42.0	36.6	38.0	37.6	40.8	44.0	43.4	40.0	43.8	43.0
1995	41.8	44.9	44.0	41.9	43.1	42.6	42.1	44.8	43.9	41.7	45.2	44.3
1996	45.1	48.2	47.6	45.0	47.6	46.6	45.6	48.5	48.0	44.7	48.3	47.9
1997	44.5	48.9	48.1	44.5	48.4	47.5	44.7	48.7	47.8	44.5	49.1	48.4
1998	44.5	49.0	47.3	44.4	49.2	47.9	44.6	48.3	46.7	44.5	49.1	47.4
1999	44.7	47.4	46.8	43.7	46.1	45.5	44.6	48.0	47.4	44.9	47.6	46.9
2000	43.7	47.1	46.4	43.0	46.4	45.7	44.3	48.3	47.3	43.7	47.1	46.4
2001	43.6	46.9	46.2	44.6	46.4	46.0	43.5	49.2	48.5	42.8	46.4	45.6
2002	42.6	45.2	44.8	43.2	46.0	45.6	41.5	47.2	46.4	42.5	44.2	43.9
2003	43.9	46.1	45.7	46.4	48.0	47.5	41.3	46.1	45.5	41.2	45.4	44.9
2004	42.6	46.6	46.1	45.4	48.4	47.9	41.9	46.5	45.9	41.2	45.8	45.3
2005	43.6	46.7	46.1	46.0	48.1	47.5	42.7	47.2	46.5	40.8	45.7	45.1
2006	44.3	47.5	46.9	45.9	48.9	48.1	44.0	47.7	47.2	42.6	45.9	45.4
2007	43.6	47.8	47.0	45.9	50.0	48.6	42.0	47.7	46.6	43.1	46.8	46.4
2008	44.1	47.4	46.8	45.9	48.9	48.0	44.0	47.5	46.8	42.4	46.8	46.1
2009	44.4	47.7	47.2	46.8	49.7	49.0	43.0	47.4	46.8	42.9	46.5	46.0
2010	45.6	48.8	48.2	47.1	50.0	49.2	45.0	48.9	48.1	43.0	47.5	46.9
2011	46.3	49.1	48.4	47.4	50.8	49.6	45.1	48.5	47.9	44.3	46.8	46.3
2012	46.6	49.6	48.8	47.9	51.7	50.3	45.8	49.4	48.7	42.7	47.3	46.7
2013	45.6	48.4	47.8	47.4	50.3	49.4	44.4	48.0	47.4	44.4	47.0	46.5
2014	44.4	47.3	46.7	46.2	48.6	47.9	43.8	47.1	46.4	44.4	47.2	46.7
2015	45.1	48.8	48.3	47.1	50.6	50.1	45.1	48.9	48.3	43.9	48.2	47.8
2016	45.0	49.6	48.7	45.1	49.8	48.9	45.5	50.2	49.0	44.2	49.0	48.3
2017	44.1	48.4	47.4	43.8	47.0	46.2	44.4	48.7	47.7	43.7	48.4	47.6
2018	44.4	48.4	47.8	44.9	48.3	47.5	43.9	48.6	48.1	43.6	48.4	47.9
2019	41.2	46.0	45.3	42.6	46.2	45.3	42.7	47.2	46.8	39.1	45.3	44.5
2020	41.2	46.0	45.6	42.5	47.6	47.2	43.1	47.5	47.1	40.1	44.9	44.4
2021*	41.8	46.3	45.2	44.0	47.8	47.0	43.5	47.3	46.7	40.9	44.8	43.5
2022*	41.1	45.7	45.1	43.6	47.0	46.1	43.4	47.4	47.0	39.7	45.2	44.6

*Preliminary data

Table 8. Estimated number (thousand) of males (M) and females (F) Greenland halibut caught and proportion (Prop) of females in the gillnet fishery by NAFO Division.

Year	4RST			4R			4S			4T		
	M	F	Prop.	M	F	Prop.	M	F	Prop.	M	F	Prop.
1987	6252	8130	0.57	144	141	0.49	2777	2718	0.49	3331	5270	0.61
1988	4024	5475	0.58	181	259	0.59	1151	1682	0.59	2692	3534	0.57
1989	1993	3318	0.62	277	195	0.41	1144	1104	0.49	572	2019	0.78
1990	1550	1065	0.41	183	123	0.40	527	347	0.40	840	595	0.41
1991	1405	1224	0.47	446	324	0.42	639	443	0.41	321	457	0.59
1992	1632	2719	0.62	396	328	0.45	456	715	0.61	780	1675	0.68
1993	1216	2241	0.65	206	201	0.49	301	613	0.67	709	1426	0.67
1994	1263	4185	0.77	367	727	0.66	222	873	0.80	673	2585	0.79
1995	848	2156	0.72	189	246	0.57	175	360	0.67	484	1549	0.76
1996	350	1532	0.81	149	223	0.60	87	413	0.83	115	896	0.89
1997	439	1951	0.82	117	402	0.77	95	313	0.77	227	1236	0.84
1998	1376	2384	0.63	181	450	0.71	378	495	0.57	817	1439	0.64
1999	879	2816	0.76	144	493	0.77	160	652	0.80	575	1672	0.74
2000	504	1864	0.79	120	473	0.80	117	385	0.77	267	1007	0.79
2001	297	1117	0.79	110	350	0.76	30	189	0.86	158	578	0.79
2002	301	1661	0.85	95	549	0.85	39	269	0.87	167	843	0.83
2003	692	3287	0.83	347	698	0.67	120	790	0.87	225	1799	0.89
2004	560	3699	0.87	165	835	0.83	166	1028	0.86	229	1836	0.89
2005	799	3570	0.82	366	810	0.69	194	1054	0.84	239	1706	0.88
2006	681	3122	0.82	253	723	0.74	238	1412	0.86	190	987	0.84
2007	779	3236	0.81	285	590	0.67	379	1743	0.82	114	903	0.89
2008	740	3070	0.81	203	509	0.72	351	1414	0.80	187	1147	0.86
2009	756	3657	0.83	283	919	0.76	304	1700	0.85	170	1038	0.86
2010	756	3029	0.80	296	767	0.72	351	1492	0.81	109	771	0.88
2011	845	2585	0.75	490	920	0.65	289	1355	0.82	66	309	0.82
2012	786	2456	0.76	443	759	0.63	252	1039	0.80	91	659	0.88
2013	533	1893	0.78	212	494	0.70	220	974	0.82	102	425	0.81
2014	766	2770	0.78	121	330	0.73	371	1344	0.78	274	1096	0.80
2015	431	2785	0.87	55	333	0.86	276	1394	0.83	100	1058	0.91
2016	588	2407	0.80	88	369	0.81	322	977	0.75	177	1061	0.86
2017	382	1364	0.78	59	172	0.74	191	620	0.76	132	573	0.81
2018	238	1284	0.84	125	420	0.77	60	471	0.89	54	394	0.88
2019	328	1816	0.85	152	479	0.76	47	450	0.91	130	887	0.87
2020	137	1487	0.92	20	288	0.93	36	371	0.91	81	828	0.91
2021*	328	1046	0.76	26	104	0.80	89	499	0.85	213	442	0.67
2022*	150	1101	0.88	37	105	0.74	18	165	0.90	96	831	0.90

*Preliminary data

Table 9. Percentage of Greenland halibut catches covered by at-sea observers in the directed Greenland halibut gillnet fishery by combinations of NAFO unit areas.

Sector	Western Gulf				North Anticosti	Esquiman
	4Tp 4Tq	4Sz	4Si 4Ss 4Sy	4Tk 4Tn 4To	4Ss 4Sv 4Sx 4Sy	4R 4Rb 4Rc 4Sv
2000	18	9	3	12	-	3
2001	14	4	1	6	2	1
2002	18	5	3	15	-	2
2003	17	15	10	11	-	3
2004	3	7	5	6	-	0
2005	3	6	4	4	-	3
2006	5	5	3	4	5	4
2007	6	3	5	7	-	3
2008	5	1	5	7	25	6
2009	3	7	5	4	3	1
2010	4	4	6	5	5	5
2011	2	4	3	6	6	6
2012	3	4	4	7	14	11
2013	6	5	7	5	11	3
2014	6	13	8	6	14	0
2015	5	12	10	4	-	0
2016	6	8	9	4	-	1
2017	5	9	7	5	-	2
2018	7	9	4	6	11	4
2019	3	4	2	5	8	2
2020	2	7	1	4	8	1
2021*	5	2	4	3	-	-
2022*	3	-	-	0	4	-

*Preliminary data

Table 10. Bycatch (t) and ratio (%) of bycatch to total catch of Greenland halibut by year and area for all species combined.

Sector	Bycatch (t)				Ratio (%)			
	West Gulf	North Anticosti	Esquiman	4RST	West Gulf	North Anticosti	Esquiman	4RST
2000	210	0	71	281	37.22	-	13.1	25.4
2001	176	19	37	232	63.82	44.2	8.7	31.1
2002	143	0	18	161	29.76	-	3.1	15.1
2003	176	0	65	241	13.46	-	5.2	9.5
2004	487	0	107	594	18.92	-	8.4	15.4
2005	423	0	20	442	15.47	-	1.5	11.0
2006	317	29	67	414	13.74	11.1	6.2	11.3
2007	310	0	191	500	11.73	-	17.4	13.4
2008	252	62	322	637	10.16	37.7	29.2	17.0
2009	280	46	21	346	11.52	8.6	1.5	7.9
2010	275	113	84	472	13.61	16.7	6.2	11.7
2011	247	86	74	408	17.60	17.9	3.7	10.5
2012	234	101	274	609	17.35	19.4	15.0	16.5
2013	329	155	231	716	25.57	32.4	25.4	26.7
2014	325	23	550	897	10.80	21.0	111.1	24.8
2015	239	0	103	343	7.48	-	20.9	9.3
2016	258	0	242	500	8.55	-	30.8	13.1
2017	605	0	234	839	35.28	-	85.8	42.2
2018	349	73	104	525	38.38	32.5	16.6	29.9
2019	388	63	41	492	29.37	43.9	7.0	23.9
2020	347	37	152	536	35.61	15.4	30.4	31.3
2021*	193	0	**	193	19.27	-	**	19.3
2022*	109	14	**	123	13.69	28.2	**	14.5
Mean 2000-2022	290	36	131	457	21.7	25.3	21.3	18.7

*Preliminary data

**No observer data

Table 11. Average occurrence (%) and bycatch (kg) of other species in the directed gillnet Greenland halibut fishery for the period 2000 to 2020 and for the years 2021 and 2022.

	Occurrence (%)			Catch (kg)		
Taxon	2000-2020	2021	2022	2000-2020	2021	2022
Greenland halibut	99.7	99.4	100.0	2942114	1001711	846581
American plaice	77.3	96.1	100.0	47002	49193	25467
Redfishes	61.7	81.9	55.8	29113	13059	1374
Snow crab	56.1	18.7	9.3	61021	3570	771
Thorny skate	52.2	84.5	46.5	61939	31685	14706
Atlantic halibut	48.4	42.6	27.9	102953	30698	10503
Norway king crab	47.3	19.4	0.0	22553	2635	0
Witch flounder	41.8	63.9	100.0	10540	5591	16630
Skates	39.8	29.0	60.5	43204	11835	13241
Anthozoan	26.8	17.4	46.5	6168	1773	3954
White hake	21.4	64.5	86.0	9316	16676	21637
Monkfish	20.2	36.8	30.2	7383	7750	9197
Atlantic cod	19.0	6.5	0.0	17087	2713	0
Smooth skate	14.9	2.6	2.3	8238	124	34
Black dogfish	12.9	20.6	11.6	26133	4112	402
Sea stars	8.8	7.1	37.2	1168	369	519
Scyphozoans	8.2	8.4	55.8	1433	514	1965
Atlantic hagfish	7.8	3.2	18.6	726	197	644
Sea pen	7.0	18.7	37.2	704	1025	536
Silver hake	5.4	0.0	7.0	696	0	443
Spiny dogfish	5.4	0.6	0.0	4397	119	0
Skate eggs	3.8	0.0	18.6	287	0	268
Sea star	3.0	4.5	0.0	341	199	0
Wrymouth	2.0	1.3	0.0	525	50	0
Sculpins	1.8	1.3	0.0	385	50	0
Whelks	1.8	0.0	0.0	139	0	0
Winter flounder	1.7	0.0	0.0	571	0	0
Atlantic herring	1.7	0.0	0.0	643	0	0
Sponges	1.6	3.2	18.6	136	103	268
Longfin hake	1.3	0.0	0.0	582	0	0
American lobster	1.1	7.1	0.0	154	306	0
Sea raven	0.9	0.6	2.3	181	46	34
Righteye flounders	0.9	0.0	0.0	527	0	0
Brittle stars	0.8	4.5	2.3	64	145	34
Sharks	0.7	0.0	0.0	7776	0	0
Grenadiers	0.6	0.6	4.7	151	25	67
Northern shrimp	0.6	1.3	0.0	122	6000	0
Lumpfish	0.6	0.0	0.0	44	0	0
Eelpouts	0.5	0.0	0.0	83	0	0

Taxon	Occurrence (%)			Catch (kg)		
	2000-2020	2021	2022	2000-2020	2021	2022
Toad crabs	0.5	1.9	0.0	90	75	0
Yellowtail flounder	0.4	0.0	0.0	171	0	0
Sea peach	0.4	0.0	0.0	66	0	0
Pollock	0.4	0.0	0.0	97	0	0
Crabs	0.4	9.7	0.0	60	2240	0
Finfishes (ns)	0.3	0.0	0.0	288	0	0
Marlin-spike	0.3	0.6	0.0	30	25	0
Haddock	0.3	0.0	0.0	75	0	0
Atlantic mackerel	0.3	0.0	0.0	37	0	0
Squids	0.3	0.0	0.0	19	0	0
Sea cucumbers	0.2	0.0	0.0	25	0	0
Comb jellies	0.2	0.0	0.0	8	0	0
Mud star	0.2	0.0	0.0	18	0	0
Atlantic wolffish	0.2	0.0	0.0	117	0	0
Porbeagle	0.2	0.0	0.0	2015	0	0
Eels	0.2	0.0	0.0	53	0	0
Spotted wolffish	0.2	0.0	0.0	59	0	0
Sea spiders	0.2	0.0	0.0	17	0	0
Harbour porpoise	0.2	0.0	0.0	873	0	0
Sea urchins	0.2	0.0	2.3	11	0	34
Gannet	0.1	0.0	0.0	117	0	0
Purple sunstar	0.1	0.0	0.0	49	0	0
Greenland cod	0.1	0.0	0.0	31	0	0
Blue mussel	0.1	0.0	0.0	5	0	0
Basket stars	0.1	0.0	0.0	14	0	0
Arctic cod	0.1	0.0	0.0	20	0	0
Shads	0.1	0.0	0.0	17	0	0
Blue shark	0.1	0.0	0.0	730	0	0
Waved whelk eggs	0.1	0.0	4.7	6	0	67
Alewife	0.1	0.0	0.0	10	0	0
Decapods	0.1	0.0	0.0	7	0	0
North atlantic octopus	0.1	0.0	0.0	6	0	0
Sea potato	0.1	0.0	0.0	15	0	0
Capelin	0.1	0.0	0.0	5	0	0
Incirrata octopuses	0.1	0.0	0.0	3	0	0
Harp seal	0.0	0.0	0.0	287	0	0
Polychaetes	0.0	0.0	0.0	3	0	0
Common sunstar	0.0	1.3	0.0	4	75	0
Fourbeard rockling	0.0	0.0	0.0	3	0	0
Greenland shark	0.0	0.0	0.0	1081	0	0
Basking shark	0.0	0.0	0.0	1475	0	0

	Occurrence (%)			Catch (kg)		
Taxon	2000-2020	2021	2022	2000-2020	2021	2022
Dogfishes	0.0	0.0	0.0	12	0	0
Molluscs	0.0	0.0	0.0	3	0	0
Gull, *larus sp.*	0.0	0.0	0.0	2	0	0
Seals	0.0	0.0	0.0	210	0	0
Barnacles	0.0	0.0	0.0	2	0	0
Striped bass	0.0	0.0	0.0	27	0	0
Northern pipefish	0.0	0.0	0.0	13	0	0
Atlantic argentine	0.0	0.0	0.0	2	0	0
Blood star	0.0	0.0	0.0	1	0	0
Fulmar, northern noddy	0.0	0.0	0.0	1	0	0
Dolphin	0.0	0.0	0.0	77	0	0
Blue whiting	0.0	0.0	0.0	3	0	0
Shrimp	0.0	0.0	0.0	2	0	0
Gull, herring	0.0	0.0	0.0	1	0	0
Kittiwake, black-legged	0.0	0.0	0.0	1	0	0
Alcids	0.0	0.0	0.0	13	0	0
Atlantic salmon	0.0	0.0	0.0	1	0	0
Blueback herring	0.0	0.0	0.0	2	0	0
Atlantic sturgeon	0.0	0.0	0.0	23	0	0
Longfin snailfish	0.0	0.0	0.0	2	0	0
Crustaceans	0.0	0.0	0.0	1	0	0
Isopods	0.0	0.0	0.0	0	0	0
Balanidae	0.0	0.0	0.0	1	0	0
Northern wolffish	0.0	0.0	0.0	7	0	0
Atl. white sided dolphin	0.0	0.0	0.0	56	0	0
Windowpane	0.0	0.0	0.0	1	0	0
Whales	0.0	0.0	0.0	64	0	0
Northern moonsnail	0.0	0.0	0.0	0	0	0
Mussels	0.0	0.0	0.0	1	0	0
Stimpson's surf clam	0.0	0.0	0.0	0	0	0
Heart urchin	0.0	0.0	0.0	1	0	0
American shad	0.0	0.0	2.3	1	0	25
Pandalids	0.0	0.0	0.0	0	0	0

Table 12. Estimated Greenland halibut bycatch in number and weight by shrimpers in the GSL, abundance and biomass of Greenland halibut less than 31 cm estimated in the DFO nGSL survey and ratio (Ratio %) of bycatch to survey estimate.

Year	Number (x1000)		Weight (t)		Ratio (%)	
	Bycatch	Survey	Bycatch	Survey	N	Weight
2000	2,281	422,177	123	42,439	0.54	0.29
2001	831	267,550	87	31,954	0.31	0.27
2002	1,577	203,433	104	19,048	0.78	0.55
2003	1,099	457,484	92	55,438	0.24	0.17
2004	642	152,257	62	21,968	0.42	0.28
2005	1,241	211,082	41	13,699	0.59	0.30
2006	1,135	271,862	83	35,617	0.42	0.23
2007	1,275	210,047	83	19,560	0.61	0.42
2008	2,130	270,492	122	25,755	0.79	0.47
2009	834	187,252	66	20,672	0.45	0.32
2010	841	163,592	72	20,005	0.51	0.36
2011	2,323	300,873	84	20,365	0.77	0.41
2012	508	266,470	51	34,176	0.19	0.15
2013	2,750	199,356	95	12,317	1.37	0.77
2014	3,812	415,041	117	28,787	0.92	0.41
2015	2,552	461,880	132	39,432	0.56	0.34
2016	2,339	237,130	133	30,755	1.01	0.43
2017	1,403	160,799	109	22,336	0.87	0.49
2018	2,147	197,051	76	13,750	1.09	0.55
2019*	6,723	287,457	212	17,980	2.34	1.18
2020**	1,372	274,432	73	34,210	0.5	0.21

*****Data from the at-sea observer program are preliminary
**No data for the Estuary.

Table 13. Cumulative distribution of Greenland halibut catches (percentile) from the nGSL survey by depth and temperature.

Percentile	Depth (m)	Temperature (°C)
5	202	4.0
10	226	4.5
25	261	5.1
50	304	5.4
75	339	5.7
90	379	6.1
95	408	6.4

Table 14. Cumulative proportion of catches (by weight) of Greenland Halibut (GH) by depth in DFO nGSL Winter Surveys. p: percentile

Vessel	Year	Species	p5	p25	p50	p75	p95
Gadus Atlantica	1978	GH	270	353	466	493	515
Gadus Atlantica	1979	GH	265	431	464	494	507
Gadus Atlantica	1980	GH	275	348	444	484	488
Gadus Atlantica	1981	GH	286	329	430	457	481
Gadus Atlantica	1983	GH	232	328	420	495	514
Gadus Atlantica	1984	GH	258	340	443	462	494
Gadus Atlantica	1985	GH	253	372	458	496	511
Gadus Atlantica	1986	GH	271	415	430	475	509
Gadus Atlantica	1987	GH	293	381	410	454	484
Gadus Atlantica	1988	GH	250	360	430	469	495
Gadus Atlantica	1989	GH	269	417	435	469	502
Gadus Atlantica	1990	GH	350	444	462	497	512
Gadus Atlantica	1991	GH	294	425	457	473	507
Gadus Atlantica	1992	GH	320	448	481	506	522
Gadus Atlantica	1993	GH	271	396	440	467	501
Gadus Atlantica	1994	GH	307	429	453	467	504
Gadus Atlantica	1978 - 1994	GH	271	407	449	494	519
Mersey Venture	2022	GH	356	422	468	485	501
Gadus Atlantica	1978 - 1994	Redfish	209	290	349	430	473
Mersey Venture	2022	Redfish	290	353	408	436	485

Table 15. Comparison of the 4 fitted stock-recruitment models.

Model	Degrees of freedom	AIC	ΔAIC
Intercept	2	130.6	6.3
Density independant	2	124.2	0.0
Beverton-Holt	3	125.5	1.3
Ricker	3	125.4	1.1

Table 16a. Mean number and mean weight per 15-minute tow observed in the DFO nGSL survey for Greenland halibut and the 95% confidence interval (C.I.), in Cabot equivalent.

Year	Number/tow		Weight (kg)/tow	
	Mean	C.I. 95%	Mean	C.I. 95%
1984	44.6	(7.3 - 81.9)	11.2	(3.2 - 19.1)
1985	33.1	(23.8 - 42.3)	11.8	(8.6 - 15.1)
1986	36.9	(24.3 - 49.5)	19.5	(14 - 25)
1987	21.5	(17.1 - 25.9)	9.3	(7.3 - 11.3)
1988	15.1	(12 - 18.1)	7.4	(5.8 - 9)
1989	16	(10.3 - 21.6)	4.8	(3.6 - 6.1)
1990	29.5	(23 - 35.9)	4.7	(4 - 5.5)
1991	42.3	(34.9 - 49.8)	8.2	(6.6 - 9.9)
1992	40.4	(33.1 - 47.7)	8.6	(7 - 10.2)
1993	13.3	(9.3 - 17.3)	4.3	(3.3 - 5.4)
1994	23.1	(17.6 - 28.5)	7.9	(6.1 - 9.7)
1995	20.9	(16.6 - 25.1)	9.3	(7.3 - 11.3)
1996	35.9	(27.1 - 44.7)	11.8	(7.5 - 16)
1997	43.2	(31.9 - 54.5)	12.7	(11 - 14.5)
1998	73.5	(60.1 - 86.8)	12.5	(10.8 - 14.1)
1999	76.1	(67.5 - 84.7)	18.5	(16.6 - 20.4)
2000	156.0	(135.1 - 176.9)	32.9	(27.9 - 38)
2001	126.5	(99.8 - 153.1)	29.9	(23.8 - 36.1)
2002	87.4	(75.1 - 99.6)	23.6	(19.8 - 27.5)
2003	181.6	(152.7 - 210.4)	54.4	(46 - 62.8)
2004	75.3	(61.2 - 89.4)	30.6	(24.2 - 37)
2005	97.0	(84.5 - 109.5)	30.5	(27.1 - 33.9)
2006	92.3	(78.3 - 106.3)	31.6	(27.8 - 35.3)
2007	95.3	(79.8 - 110.8)	32.8	(26.7 - 38.9)
2008	101.0	(86.8 - 115.2)	31.0	(25.3 - 36.6)
2009	67.1	(54.7 - 79.5)	21.2	(17.9 - 24.4)
2010	72.6	(61 - 84.1)	26.6	(22.5 - 30.7)
2011	97.0	(81.6 - 112.5)	25.3	(22.1 - 28.5)
2012	88.9	(73.8 - 104)	25.1	(22.1 - 28.1)
2013	73.7	(62.6 - 84.8)	19.9	(16.1 - 23.7)
2014	109.3	(93.2 - 125.4)	24.1	(20 - 28.2)
2015	119.8	(93.4 - 146.2)	24.5	(21.2 - 27.7)
2016	77.0	(61.6 - 92.5)	23.0	(18.4 - 27.5)
2017	59.1	(46.9 - 71.2)	17.0	(14.3 - 19.7)
2018	61.9	(45.3 - 78.5)	14.9	(12.6 - 17.2)
2019	77.5	(63.8 - 91.2)	14.1	(12.1 - 16.1)
2020	84.0	(68.1 - 99.9)	20.3	(16.6 - 24)
2021	59.0	(51.3 - 66.7)	23.3	(20.2 - 26.4)
2022	44.6	(36.4 - 52.8)	18.1	(14.8 - 21.4)

Table 16b. Mean number and mean weight per 20-minute tow (in Jacques Cartier – NEST equivalent) observed in the DFO sGSL survey for Greenland halibut and the 95% confidence interval.

Year	Number/tow		Weight (kg)/tow	
	Mean	C.I. 95%	Mean	C.I. 95%
1971	0.0	(0.00 - 0.15)	0.1	(0.07 - 0.22)
1972	0.0	(0.00 - 0.08)	0.0	(0.03 - 0.1)
1973	0.1	(0.00 - 0.17)	0.1	(0.08 - 0.32)
1974	0.4	(0.22 - 0.52)	0.0	(0.01 - 0.04)
1975	0.3	(0.04 - 0.54)	0.1	(0.02 - 0.27)
1976	0.4	(0.1 - 0.68)	0.2	(0.05 - 0.4)
1977	0.3	(0.14 - 0.41)	0.4	(0.17 - 0.6)
1978	0.2	(0 - 0.47)	0.5	(0.04 - 0.95)
1979	0.1	(0.06 - 0.21)	0.2	(0.09 - 0.34)
1980	0.1	(0.02 - 0.14)	0.1	(0.04 - 0.26)
1981	0.0	(0.00 - 0.04)	0.0	(0.04 - 0.13)
1982	0.3	(0.03 - 0.53)	0.2	(0.06 - 0.39)
1983	0.9	(0.01 - 1.77)	0.2	(0.03 - 0.34)
1984	0.3	(0.08 - 0.56)	0.1	(0.05 - 0.21)
1985	1.1	(0.44 - 1.7)	0.6	(0.27 - 0.84)
1986	1.3	(0.57 - 2.02)	1.1	(0.54 - 1.62)
1987	1.0	(0.45 - 1.52)	0.8	(0.37 - 1.19)
1988	0.4	(0.27 - 0.52)	0.4	(0.32 - 0.52)
1989	0.2	(0 - 0.46)	0.1	(0.05 - 0.21)
1990	1.0	(0.4 - 1.55)	0.4	(0.18 - 0.67)
1991	1.2	(0.3 - 2.04)	0.3	(0.06 - 0.62)
1992	1.5	(0.76 - 2.29)	0.6	(0.41 - 0.85)
1993	1.9	(0.73 - 3)	0.9	(0.37 - 1.44)
1994	1.8	(0.98 - 2.65)	0.7	(0.31 - 1.08)
1995	1.7	(0.35 - 3.06)	1.0	(0.41 - 1.65)
1996	2.2	(0.96 - 3.39)	1.0	(0.44 - 1.65)
1997	1.8	(1.11 - 2.47)	1.2	(0.71 - 1.67)
1998	13.9	(9.9 - 17.98)	2.6	(1.72 - 3.57)
1999	8.9	(4.85 - 12.97)	2.2	(1.3 - 3.19)
2000	15.7	(9.69 - 21.72)	4.6	(3.06 - 6.12)
2001	12.9	(5.59 - 20.26)	4.4	(1.99 - 6.79)
2002	13.2	(6.25 - 20.08)	3.7	(1.67 - 5.7)
2003	12.2	(6.8 - 17.65)	6.3	(2.33 - 10.27)
2004	6.4	(3.74 - 8.99)	3.6	(2.14 - 5.05)
2005	15.0	(8.93 - 21.11)	6.8	(3.3 - 10.39)
2006	9.0	(6.15 - 11.81)	3.6	(2.22 - 4.96)
2007	12.4	(7.84 - 16.97)	5.5	(2.6 - 8.34)
2008	15.3	(9.3 - 21.39)	5.9	(3.47 - 8.37)
2009	8.1	(4.4 - 11.71)	2.8	(1.42 - 4.24)
2010	10.2	(6.79 - 13.69)	4.4	(2.73 - 6.11)
2011	13.9	(8.23 - 19.48)	5.5	(2.53 - 8.4)
2012	7.6	(4.54 - 10.65)	3.0	(1.38 - 4.55)
2013	9.0	(5.93 - 12.13)	2.7	(1.26 - 4.15)
2014	5.4	(3.02 - 7.84)	1.9	(0.62 - 3.16)
2015	6.5	(3.96 - 9.08)	2.3	(1.2 - 3.35)
2016	6.5	(3.83 - 9.12)	2.0	(1.23 - 2.8)
2017	6.1	(3.75 - 8.54)	2.1	(1.32 - 2.94)
2018	4.4	(2.2 - 6.54)	1.2	(0.66 - 1.75)
2019	5.3	(3.69 - 6.88)	1.0	(0.44 - 1.62)
2020	8.8	(2.33 - 15.33)	2.0	(0.91 - 3.02)
2021	3.5	(1.73 - 5.27)	1.1	(0.71 - 1.53)
2022	1.4	(0.9 - 1.94)	0.5	(0.23 - 0.7)

Table 17. Mean number and mean weight per 30-minute tow observed in the mobile sentinel survey for Greenland halibut and the 95% confidence interval.

Year	Number/tow		Weigth/tow	
	Mean	C.I. 95%	Mean	C.I. 95%
1995	4.2	(3 - 5.3)	2.3	(1.7 - 2.9)
1996	7.3	(5.4 - 9.1)	4.8	(3.5 - 6.1)
1997	7.9	(6.5 - 9.3)	4.6	(3.8 - 5.4)
1998	10.7	(8.8 - 12.5)	6.2	(5.1 - 7.2)
1999	17.3	(14.2 - 20.4)	7.2	(6 - 8.4)
2000	22.9	(13.9 - 32)	7.3	(3.3 - 11.3)
2001	16.2	(12.5 - 19.8)	6.3	(5.1 - 7.5)
2002	12	(8.3 - 15.8)	6	(4.2 - 7.7)
2003	17.2	(14.8 - 19.6)	8	(6.9 - 9.1)
2004	16.8	(14.4 - 19.3)	9.3	(7.8 - 10.7)
2005	23.5	(16.6 - 30.3)	13.2	(9.7 - 16.7)
2006	21.6	(18.2 - 25)	11.4	(9.9 - 12.8)
2007	24.2	(20 - 28.4)	13.5	(11.1 - 15.9)
2008	23.3	(19.4 - 27.1)	12.1	(10.6 - 13.5)
2009	12.4	(10.5 - 14.2)	7.3	(6.3 - 8.3)
2010	15.4	(13.4 - 17.4)	9.1	(8 - 10.3)
2011	8.7	(6.8 - 10.5)	5.4	(4.3 - 6.5)
2012	9.5	(7.6 - 11.3)	5.3	(4.4 - 6.3)
2013	7.6	(5.9 - 9.3)	4.2	(3.2 - 5.2)
2014	13.3	(10.8 - 15.9)	8.6	(7.2 - 10)
2015	10	(8.2 - 11.7)	5.3	(4.5 - 6.1)
2016	6.2	(4.3 - 8)	4	(3.2 - 4.8)
2017	7.6	(5.8 - 9.3)	3.6	(2.9 - 4.3)
2018	4.8	(3.7 - 5.9)	2.8	(2.2 - 3.4)
2019	6.2	(4.8 - 7.7)	2.7	(2 - 3.5)
2020	10.1	(8 - 12.2)	4.3	(3.2 - 5.4)
2021	9.7	(7.5 - 12)	4.9	(3.8 - 6)
2022	8.6	(6.5 - 10.8)	5.1	(4 - 6.3)

Table 18. Mean number per 15-minute tow (in Cabot equivalent) observed in the DFO nGSL survey for different size categories of Greenland halibut.

Year	Number/tow			
	0 – 20 cm	20 – 30 cm	30 - 40 cm	> 40 cm
1984	3.47	32.43	7.11	2.12
1985	3.59	7.53	15.45	4.35
1986	1.34	5.31	14.41	10.90
1987	0.62	2.40	6.84	6.26
1988	0.73	0.93	3.09	6.86
1989	4.15	1.13	2.07	3.41
1990	13.64	4.44	2.08	1.97
1991	8.68	18.47	5.35	2.94
1992	7.18	10.99	14.85	2.01
1993	0.52	4.86	6.07	1.87
1994	4.00	2.85	11.06	3.58
1995	3.80	4.11	5.64	7.26
1996	16.56	4.40	6.33	8.55
1997	11.02	16.81	7.14	8.14
1998	52.14	5.31	10.25	5.76
1999	9.03	48.20	10.18	9.13
2000	58.57	27.24	61.24	9.10
2001	19.53	39.27	56.73	9.22
2002	29.90	13.96	35.09	8.39
2003	38.50	59.36	59.58	24.15
2004	5.56	20.14	33.86	15.84
2005	37.18	8.62	31.91	18.70
2006	12.81	38.96	21.74	18.83
2007	21.40	17.39	37.63	18.87
2008	26.58	25.41	31.12	17.89
2009	11.28	24.10	20.43	11.28
2010	9.29	19.05	30.04	14.17
2011	41.70	16.18	25.43	13.73
2012	3.87	46.33	23.04	15.64
2013	32.38	5.07	26.31	9.95
2014	53.63	28.58	11.12	15.95
2015	32.17	56.57	19.03	12.01
2016	5.98	37.10	24.06	9.88
2017	6.82	21.03	24.98	5.91
2018	27.07	9.74	18.73	6.30
2019	41.23	16.36	14.93	5.30
2020	9.09	43.42	24.43	5.68
2021	1.35	10.19	38.43	9.09
2022	3.78	3.43	27.90	9.11

Table 19. Mean number per 30-minute tow observed during the mobile sentinel survey for different size classes of Greenland halibut.

Year	Number/tow			
	0 – 20 cm	20 – 30 cm	30 – 40 cm	> 40 cm
1995	0.38	1.04	0.99	1.74
1996	0.75	0.93	2.09	3.47
1997	0.03	2.66	1.44	3.75
1998	1.46	0.90	4.16	4.11
1999	0.64	7.71	3.61	5.32
2000	4.67	4.87	10.03	3.38
2001	1.11	4.84	7.61	2.51
2002	1.02	2.14	5.66	3.23
2003	0.24	4.64	6.88	5.42
2004	0.37	2.50	8.35	5.65
2005	2.18	1.82	11.62	7.73
2006	1.07	7.24	4.95	8.30
2007	0.60	2.81	11.98	8.80
2008	1.89	4.19	8.69	8.49
2009	0.45	2.27	4.43	5.19
2010	0.25	2.29	6.86	5.95
2011	0.66	1.03	3.25	3.73
2012	0.03	2.19	3.59	3.64
2013	1.14	0.55	3.12	2.82
2014	0.99	2.79	2.93	6.64
2015	0.73	3.25	2.09	3.90
2016	0.07	1.42	2.23	2.45
2017	0.38	2.04	3.16	1.97
2018	0.24	0.60	2.44	1.51
2019	0.84	1.49	2.23	1.69
2020	0.57	3.25	3.97	2.19
2021	0.00	0.86	5.99	2.90
2022	0.00	0.29	5.17	3.15

Table 20. Number of hauls with GH length frequency data collected by at-sea observers in the longline fisheries by month and year.

Year	Month						
	4	5	6	7	8	9	10
1999	0	2	0	2	0	0	0
2000	0	1	0	0	0	0	0
2001	0	1	0	0	0	0	0
2003	0	0	4	20	11	0	0
2004	0	0	3	6	12	0	0
2005	0	19	0	4	0	0	0
2006	0	6	0	1	1	1	0
2007	0	0	16	0	0	0	0
2008	0	5	6	26	9	5	0
2009	0	4	0	3	14	8	0
2010	0	4	0	2	0	0	0
2011	4	4	0	13	8	0	0
2012	2	1	0	6	1	1	2
2013	0	0	2	6	2	1	0
2014	0	2	0	0	1	6	0
2015	0	0	5	3	0	0	0
2016	0	1	0	10	2	0	1
2017	0	0	1	3	1	0	0
2018	0	2	0	5	8	3	0
2019	0	1	0	3	3	3	2
2020	0	0	0	1	3	2	0
2021	0	0	0	2	0	0	0

Table 21. Number of observations by year and NAFO subunit in the validated ZIFF used in the landing - soak-time analysis.

year	4ra	4rb	4rc	4rd	4si	4ss	4sv	4sw	4sx	4sy	4sz	4tf	4th	4tk	4tl	4tm	4tn	4to	4tp	4tq
1999	22	256	39	0	143	27	38	6	82	71	443	0	0	0	0	0	2	142	14	47
2000	0	273	12	0	191	37	63	0	15	49	160	0	0	2	0	0	37	153	93	136
2001	0	0	0	0	97	7	4	0	8	29	51	0	0	4	1	0	4	86	27	87
2002	0	3	1	0	9	15	9	0	17	18	87	0	0	0	0	0	6	153	29	311
2003	0	60	14	0	118	28	51	0	26	8	199	0	0	7	0	0	15	303	126	206
2004	0	111	14	0	261	13	68	1	3	2	373	0	0	6	0	0	56	702	405	571
2005	0	61	15	0	331	24	51	0	1	0	436	0	1	41	0	1	103	813	400	386
2006	0	215	4	0	463	2	58	1	101	2	342	0	0	20	0	0	85	587	135	276
2007	3	219	16	0	374	97	82	1	61	1	393	0	0	25	0	0	26	417	30	153
2008	4	187	30	0	347	82	134	2	66	21	302	0	0	43	0	0	80	480	86	122
2009	1	230	34	0	322	84	50	0	155	11	250	0	0	42	0	0	26	537	49	236
2010	0	277	8	3	290	95	103	0	252	6	247	0	0	25	1	0	33	477	40	145
2011	2	326	68	0	317	82	86	0	260	10	272	0	0	30	0	0	18	287	35	58
2012	4	413	91	0	180	14	124	0	164	25	208	0	0	76	0	0	26	378	45	27
2013	7	535	10	0	280	81	99	1	318	11	263	2	0	95	0	0	54	314	71	51
2014	14	378	2	0	302	35	15	0	103	4	415	0	0	49	0	1	54	410	46	173
2015	1	465	1	0	306	16	10	0	0	0	439	0	0	12	0	0	34	286	69	120
2016	2	479	43	0	317	56	31	0	0	3	298	0	0	2	0	0	3	314	112	154
2017	1	226	27	0	381	30	14	0	2	3	243	0	0	1	0	0	20	348	66	151
2018	1	414	0	0	251	26	2	1	171	13	127	0	0	44	0	0	27	354	29	109
2019	3	526	4	0	224	33	5	0	134	5	152	0	0	4	0	0	4	237	299	155
2020	0	332	2	0	68	18	1	0	133	1	129	0	0	3	0	0	5	229	251	214
2021	0	3	0	0	164	64	0	0	77	6	107	0	0	1	0	0	1	96	97	155

Table 22. Number of observations by year and NAFO subunit in the at-sea observer GH gillnet database.

year	4ra	4rb	4rc	4si	4ss	4sv	4sx	4sy	4sz	4tk	4tn	4to	4tp	4tq
1999	0	17	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	42	5	50	9	0	0	0	48	0	2	169	53	127
2001	0	13	0	8	6	0	2	2	6	0	0	48	11	106
2002	0	15	0	9	0	0	0	0	22	0	0	141	49	240
2003	0	29	0	99	0	0	0	17	84	0	2	241	47	141
2004	0	9	0	92	1	0	0	0	120	2	17	182	49	130
2005	0	44	0	51	0	0	0	0	95	5	2	155	37	99
2006	0	52	2	65	0	0	34	10	73	4	3	112	22	88
2007	0	39	5	78	42	1	0	4	60	2	5	110	0	48
2008	2	67	5	83	21	17	32	48	22	4	0	123	23	24
2009	0	12	0	100	3	0	37	0	63	0	0	123	7	40
2010	0	48	10	105	14	39	72	42	45	0	0	104	2	38
2011	0	33	1	54	22	60	87	7	46	0	0	86	1	10
2012	0	129	118	43	0	90	126	26	34	56	0	66	5	6
2013	0	58	5	117	28	74	184	6	77	27	0	59	0	31
2014	0	4	0	181	0	0	78	0	229	26	27	128	22	66
2015	0	3	0	165	10	0	0	0	223	0	0	68	6	35
2016	0	26	0	129	11	0	0	0	118	0	0	57	10	59
2017	0	24	10	143	22	2	0	0	130	0	0	92	3	58
2018	0	48	1	23	0	3	88	16	40	5	11	69	4	42
2019	0	26	0	22	2	0	31	6	40	0	0	47	58	23
2020	0	2	0	11	0	0	59	0	21	0	0	39	20	34
2021	0	0	0	46	15	0	0	1	6	0	0	8	7	69

Table 23. Comparison of the Tweedie random intercepts regression models. The dispersion and power parameters of the Tweedie distribution are respectively φ and ρ, σ^2 is the random intercept variance.

Dataset	Fishing area	Fixed effect soak time categories	n obs.	n levels of random effects	df	AIC	BIC	φ	ρ	σ^2
ZIFF	4RST	6 hours	39193	1381	37	600917	601234	1.59	1.73	0.28
ZIFF	4RST	12 hours	39193	1381	20	600956	601127	1.58	1.73	0.28
ZIFF	wGSL	12 hours	28654	993	20	-	-	2.62	1.66	0.22
ZIFF	N Anti	12 hours	3585	225	20	-	-	0.95	1.80	0.36
ZIFF	Esquiman	12 hours	6964	168	20	-	-	0.24	2.00	0.52
ASO	4RST	6 hours	10064	204	37	129042	129309	1.53	1.72	0.32
ASO	4RST	12 hours	-	-	20	129086	129230	1.52	1.72	0.32

Table 24. Number of fresh and decomposed fish and binomial probability of being decomposed (ProbD) by soak time and gillnet line from the 2022 decomposition experiments.

Experience	Line	1 day			2 days		
		Fresh	Decomposed	ProbD	Fresh	Decomposed	ProbD
1	Bottom	0	6	0.819	0	2	0.998
2	Bottom	2	14		1	6	
1	Top	1	5	0.187	0	5	0.628
2	Top	17	2		6	2	
Mean				0.503			0.813

Table 25. Annual landing and biomass of Greenland halibut > 40 cm (in Teleost equivalent) and relative exploitation rate for the Gulf (4RST), by fishing sector.

4RST

Year	Landing (t)	Biomass (t)	Exploitation rate (%)
1996	1,811	34,994	5.18
1997	2,456	34,239	7.17
1998	3,765	23,462	16.05
1999	3,254	33,852	9.61
2000	1,973	33,869	5.83
2001	1,175	28,804	4.08
2002	1,450	30,522	4.75
2003	3,462	87,143	3.97
2004	3,775	65,736	5.74
2005	3,871	71,870	5.39
2006	3,573	76,437	4.67
2007	3,762	74,926	5.02
2008	3,518	68,668	5.12
2009	4,244	46,960	9.04
2010	3,970	58,836	6.75
2011	3,650	55,939	6.53
2012	3,504	56,109	6.24
2013	2,474	39,192	6.31
2014	3,454	66,308	5.21
2015	3,425	54,935	6.23
2016	3,286	45,559	7.21
2017	1,720	25,445	6.76
2018	1,572	27,509	5.71
2019	1,847	22,143	8.34
2020	1,450	24,515	5.92
2021*	1,202	35,859	3.35
2022*	1,034	33,366	3.10

Western Gulf

Year	Landing (t)	Biomass (t)	Exploitation rate (%)
1996	1,488	23,651	6.29
1997	1,905	22,448	8.49
1998	2,893	14,845	19.49
1999	2,555	19,467	13.13
2000	1,360	20,788	6.54
2001	727	14,724	4.94
2002	793	18,031	4.40
2003	2,167	49,939	4.34

Year	Landing (t)	Biomass (t)	Exploitation rate (%)
2004	2,526	35,177	7.18
2005	2,562	38,380	6.67
2006	2,225	38,231	5.82
2007	2,538	35,592	7.13
2008	2,371	39,057	6.07
2009	2,282	21,909	10.42
2010	1,927	27,214	7.08
2011	1,290	22,430	5.75
2012	1,262	30,014	4.20
2013	1,144	18,065	6.33
2014	2,851	44,458	6.41
2015	2,937	39,159	7.50
2016	2,723	29,233	9.32
2017	1,500	14,542	10.31
2018	809	15,978	5.06
2019	1,181	14,187	8.32
2020	907	16,033	5.66
2021*	965	25,150	3.84
2022*	839	23,018	3.64

North Anticosti

Year	Landing (t)	Biomass (t)	Exploitation rate (%)
1997	2	3,073	0.07
1998	52	1,482	3.48
1999	113	3,031	3.71
2000	74	2,941	2.51
2001	45	619	7.26
2002	90	4,186	2.14
2003	67	3,359	2.01
2004	13	3,329	0.40
2005	6	6,636	0.09
2006	259	9,553	2.71
2007	133	7,188	1.85
2008	162	4,658	3.48
2009	527	5,203	10.13
2010	672	10,650	6.31
2011	475	7,765	6.12
2012	499	7,155	6.97
2013	436	7,117	6.12
2014	106	4,427	2.39
2015	0	3,982	0.00
2016	5	2,721	0.20
2017	5	3,744	0.13
2018	210	3,673	5.71
2019	128	1,607	7.98
2020	232	2,391	9.70
2021*	100	2,494	4.03
2022*	47	3,432	1.37

Esquiman

Year	Landing (t)	Biomass (t)	Exploitation rate (%)
1996	315	2,835	11.11

Year	Landing (t)	Biomass (t)	Exploitation rate (%)
1997	546	2,847	19.18
1998	746	2,313	32.24
1999	581	4,554	12.75
2000	537	2,622	20.47
2001	397	5,598	7.10
2002	562	2,508	22.42
2003	1,226	13,101	9.36
2004	1,234	11,279	10.94
2005	1,297	16,023	8.09
2006	1,083	15,898	6.81
2007	1,091	13,022	8.38
2008	980	9,964	9.84
2009	1,435	11,246	12.76
2010	1,360	11,914	11.41
2011	1,879	16,823	11.17
2012	1,741	10,243	17.00
2013	893	4,158	21.47
2014	495	6,546	7.56
2015	488	4,338	11.25
2016	557	2,598	21.42
2017	211	2,213	9.52
2018	551	3,274	16.83
2019	537	2,054	26.14
2020	310	560	55.41
2021*	129	1,716	7.54
2022*	125	1,595	7.86

*Landings data are preliminary

8. FIGURES

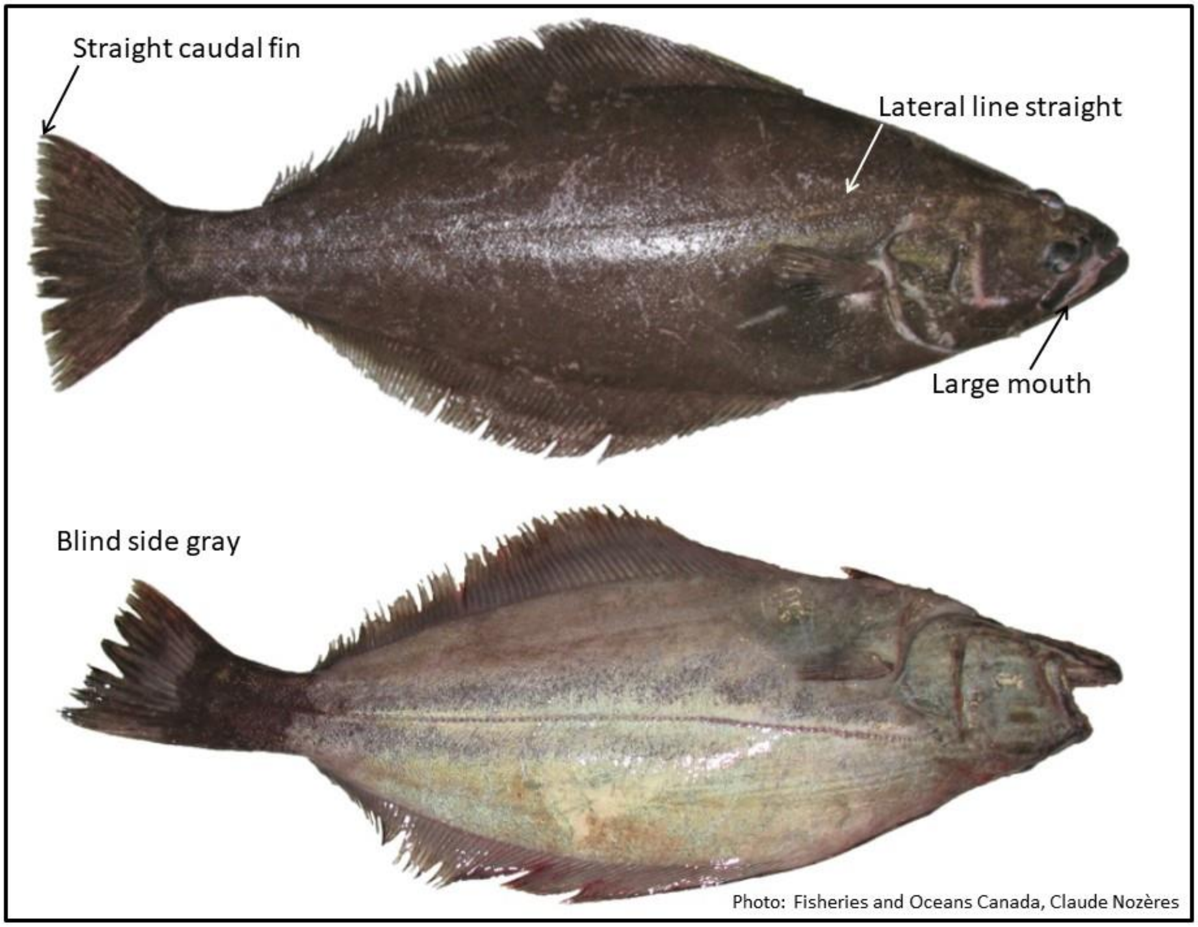

Figure 1. Greenland halibut morphology.

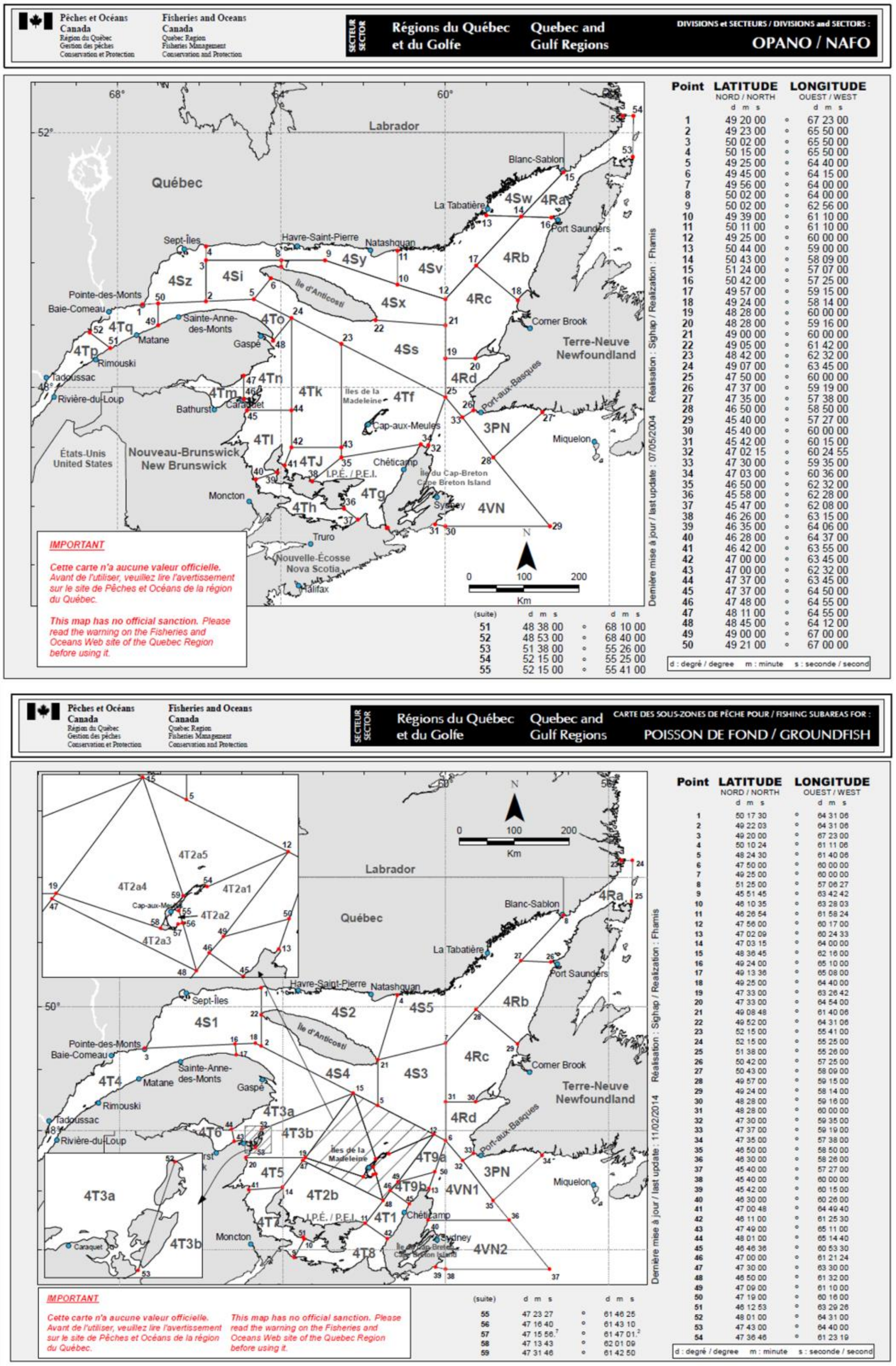

Figure 2. Unit Areas in the Gulf of St. Lawrence (top map). Map of Gulf of St. Lawrence Groundfish Sub-Areas (bottom map).

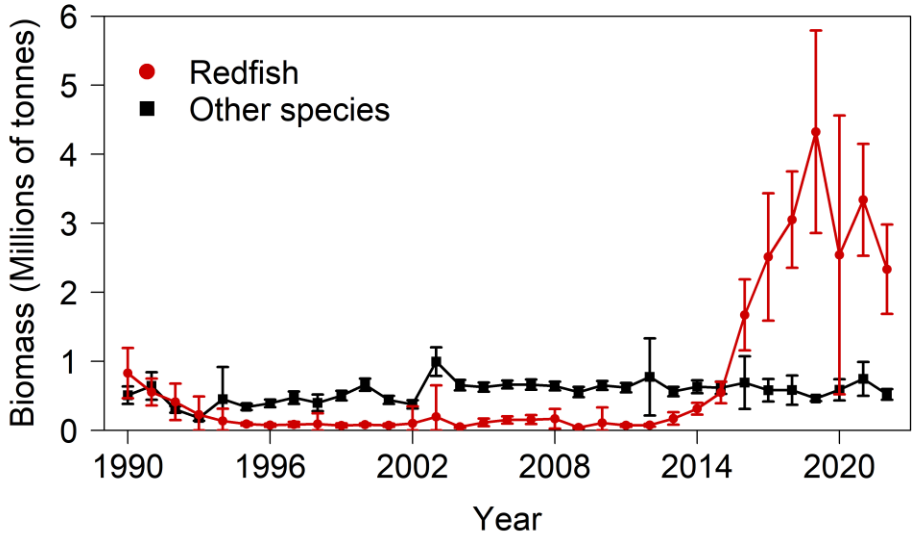

Figure 3. Biomass indices (million tonnes) estimated for the two redfish species combined and for all other species caught during the DFO survey in the nGSL.

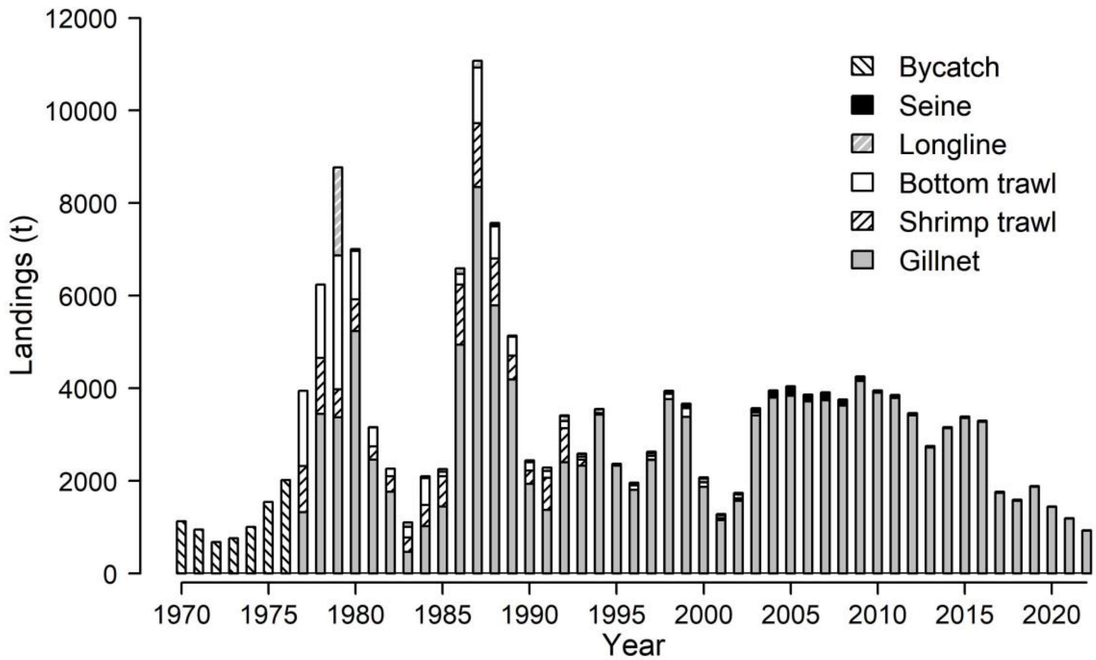

Figure 4. Greenland halibut landings (t) as bycatch, and by gear as a function of management year.

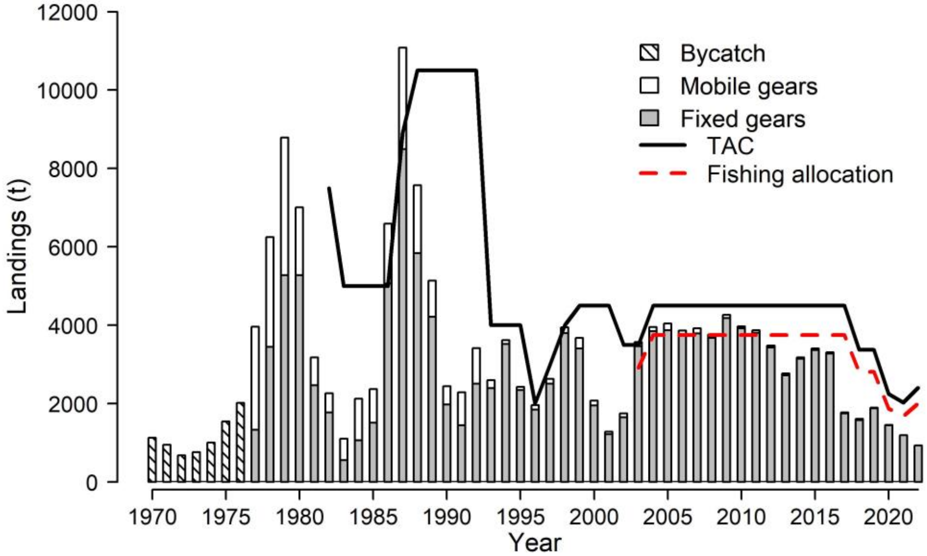

Figure 5. Greenland halibut landings (t) for fixed and mobile gears by management year. Total Allowable Catch (TAC) and Fishing allocation are indicated.

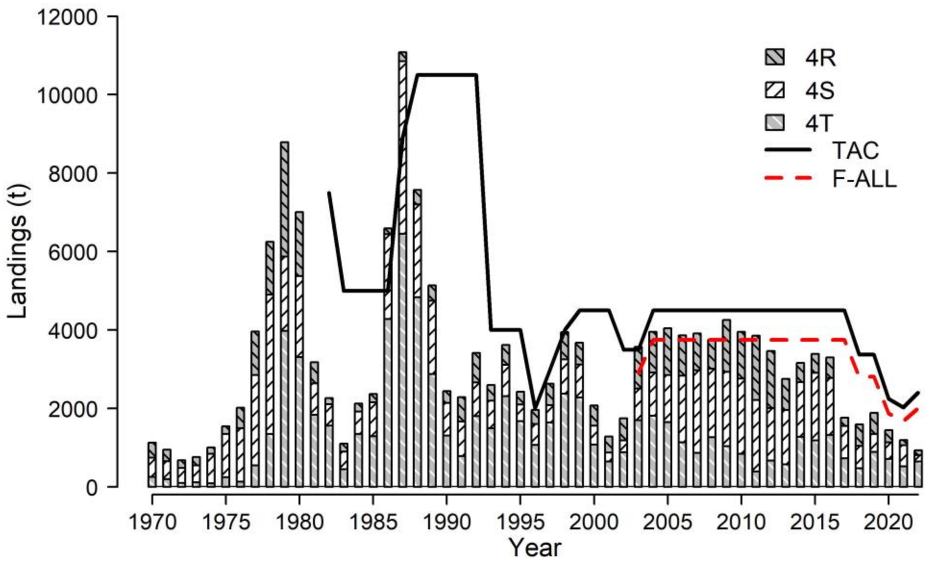

Figure 6. Greenland halibut landings (t) by NAFO Divisions and management year. Total Allowable Catch (TAC) and Fishery Allocation (F-ALL) are indicated.

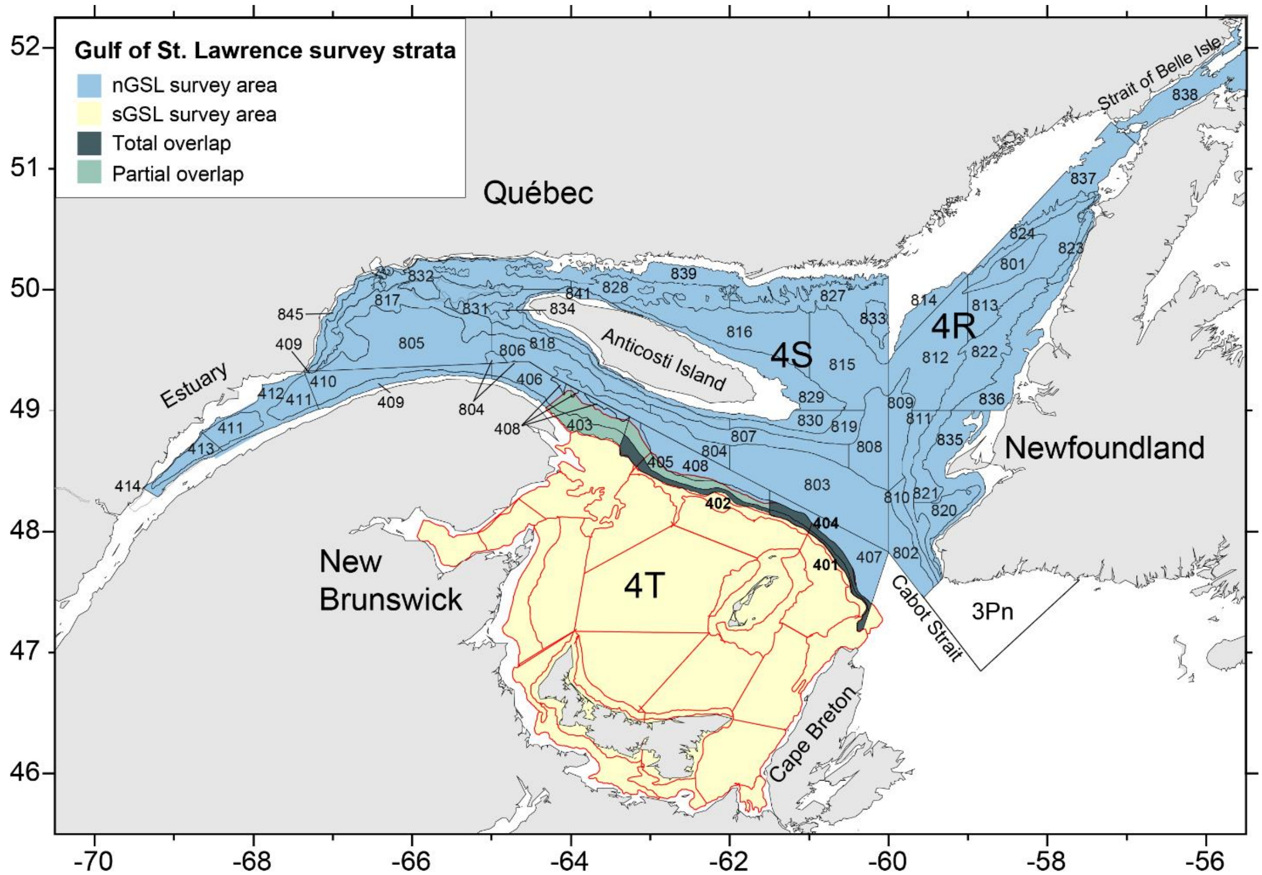

Figure 7. Map illustrating the stratification scheme of the multi species research survey in the Lower Estuary and northern Gulf of St. Lawrence (nGSL) (blue) and the southern Gulf of St. Lawrence survey (sGSL) (yellow. 4T). The areas of partial (light green) and total (dark green) overlap at the boundary between these two surveys are also identified.

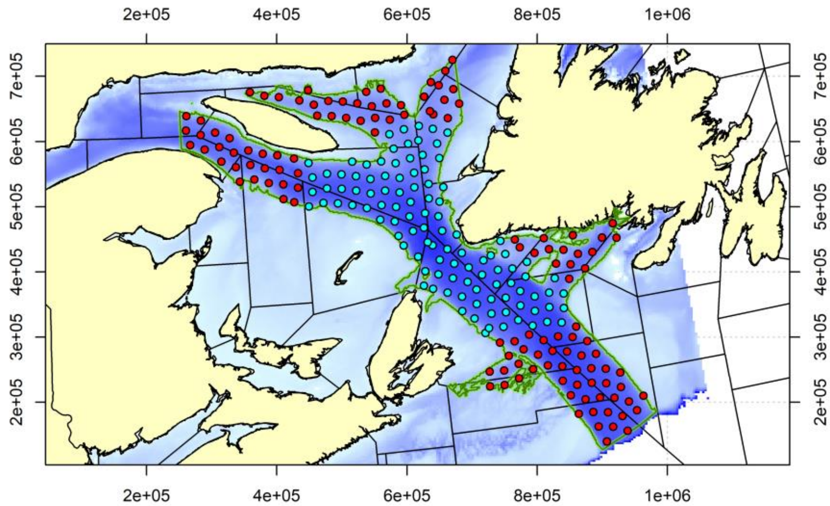

Figure 8. Survey plan for the winter survey on the Mersey Venture. Green contour : 150 m isobath (study area), red dots : survey location planned for 2023 and 2024, blue dots: survey locations planned in 2022. Coordinates in x and y are in meters (NAD83 Québec Lambert).

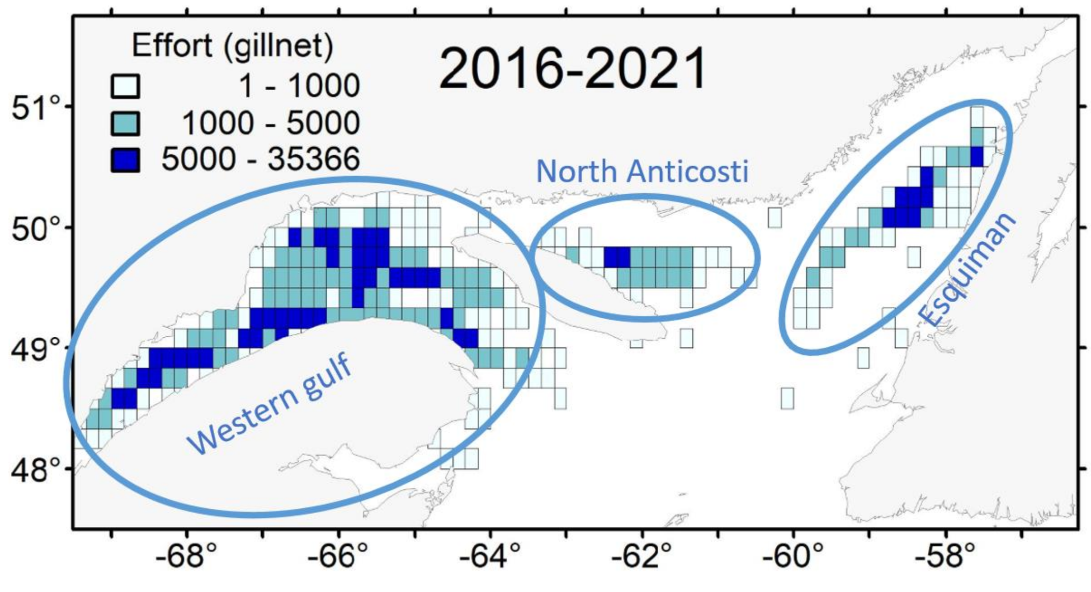

Figure 9. Fishing effort deployed in total number of nets per fishing statistical square from 2016 to 2021. Fishing effort concentrations define three sectors: Western Gulf, north Anticosti and, Esquiman.

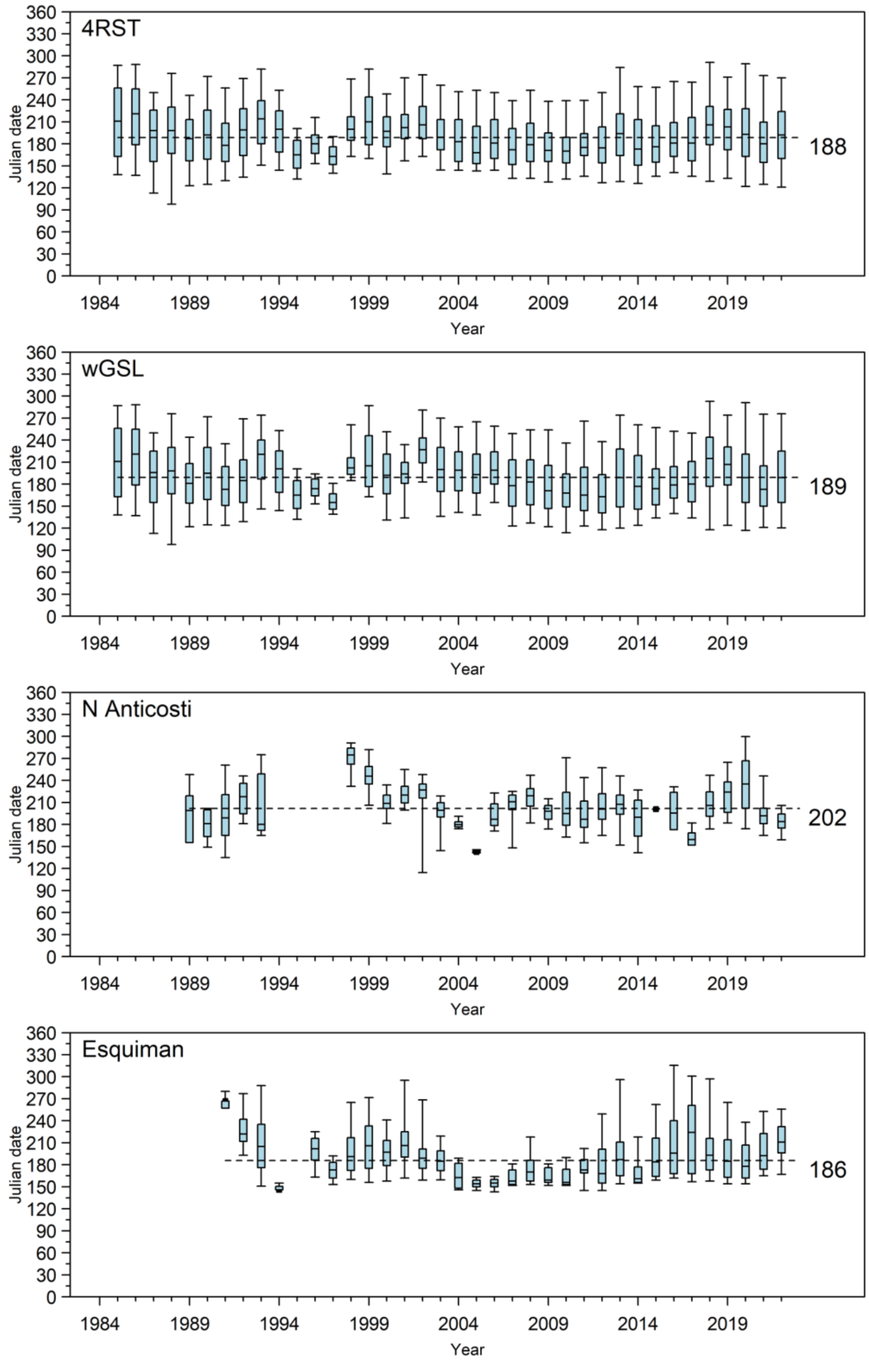

Figure 10. Annual distribution of Greenland halibut landings as a function of julian day for the GSL (4RST) and by fishing sector. Box and whiskers plot: the line inside the box represents the median (50% of landings). the box extends from percentiles 25 to 75 and the whiskers extend from percentiles 5 to 95. The horizontal dotted line on each graph shows the average of the series. The day 135 corresponds to May 15, which is the start date of the management year.

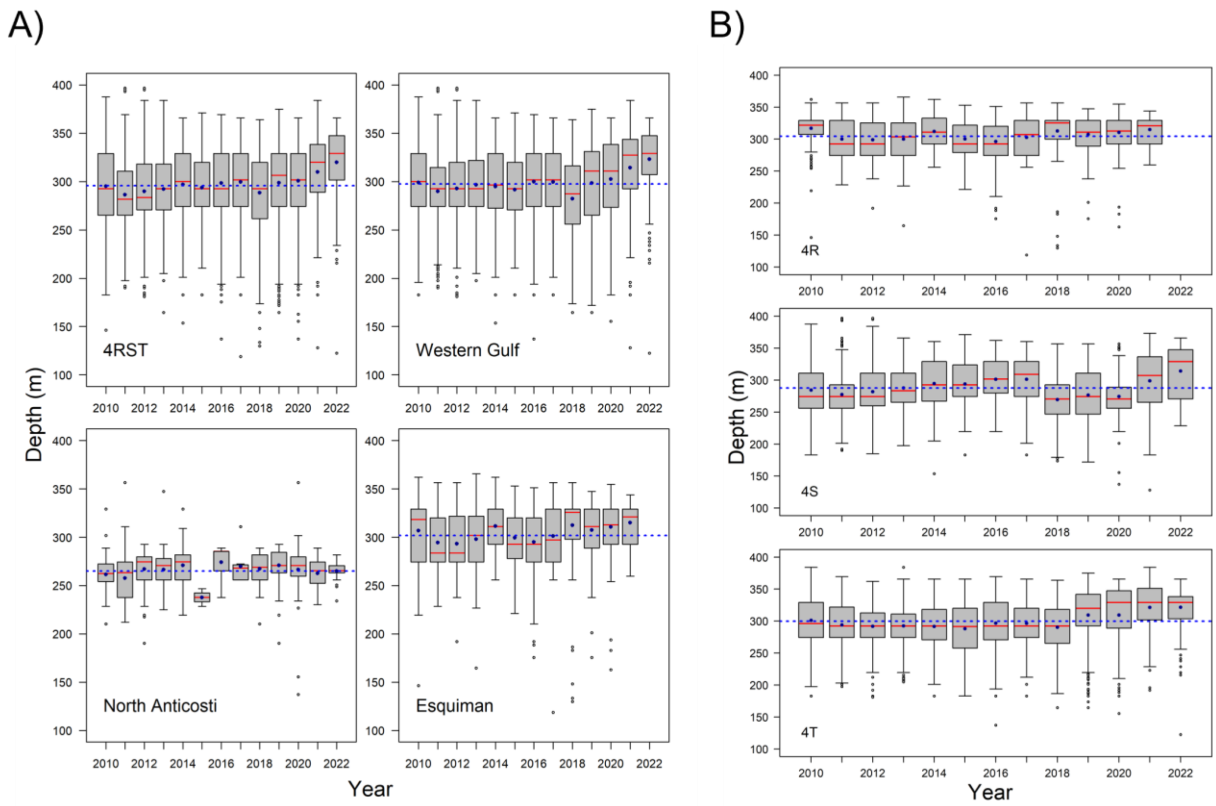

Figure 11. Annual deployment depth of directed Greenland halibut gillnet fishery in A) the Gulf (4RST) and by fishing sector B) by NAFO Division. Box and whiskers plot; box extends from percentile 25 to 75, line in the box represents the median, full circle represents the mean, whiskers extend from percentile 5 to 95 and open circles represent extreme values. Horizontal lines are average of each series. No depth data from the Esquiman sector in 2022.

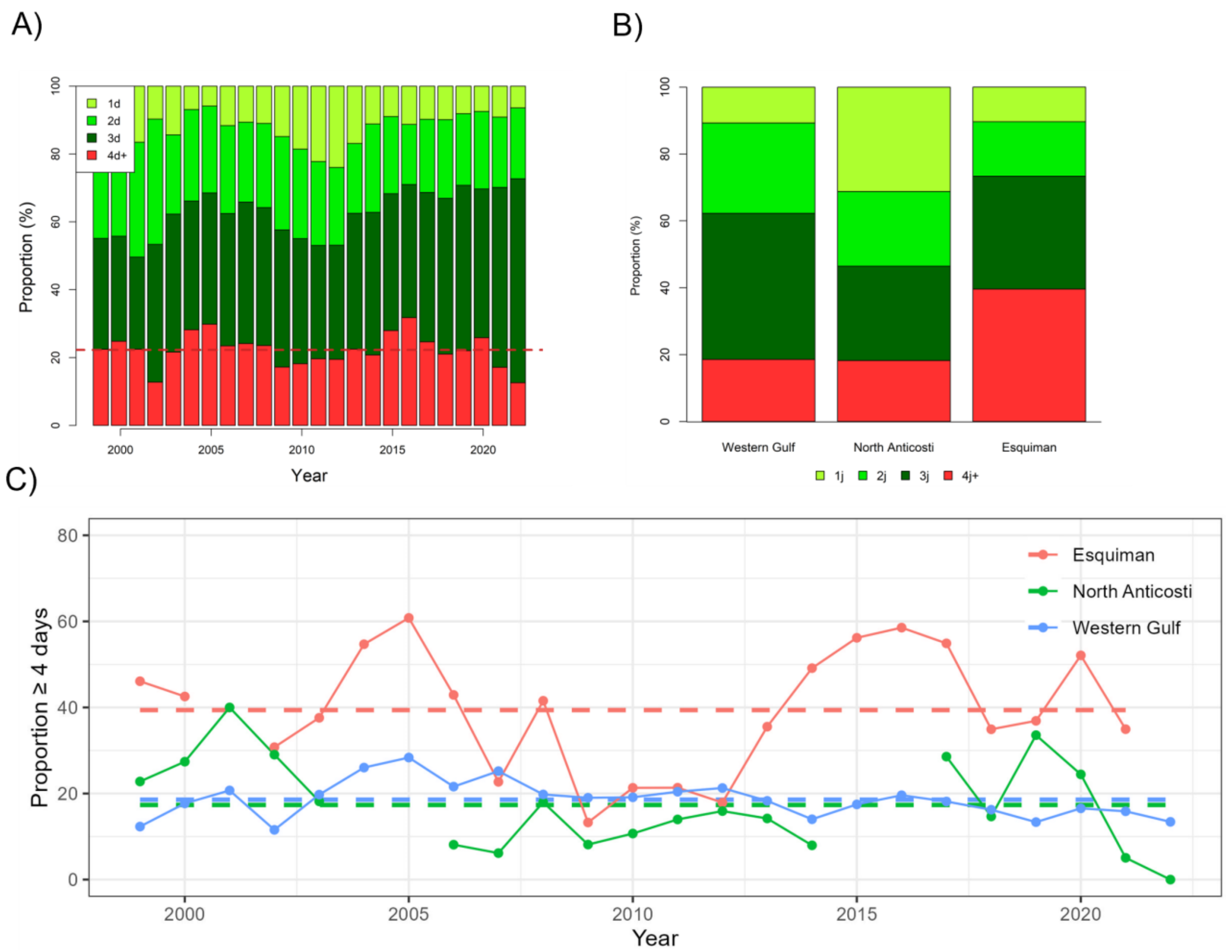

Figure 12. A) Annual proportion (%) of fishing activities by soak time categories (1 to 4 days and over) in the gillnet directed commercial Greenland halibut fishery from 1999 to 2022. The horizontal line represents the average (22%) for immersion of 4 days and over. B) Average proportion (1999-2022) of fishing activities exceeding soak times of 4 days by fishing sector. C) Proportion of fishing activities employing soak times of 4 days and over. No effort data were available for the Esquiman sector in 2022.

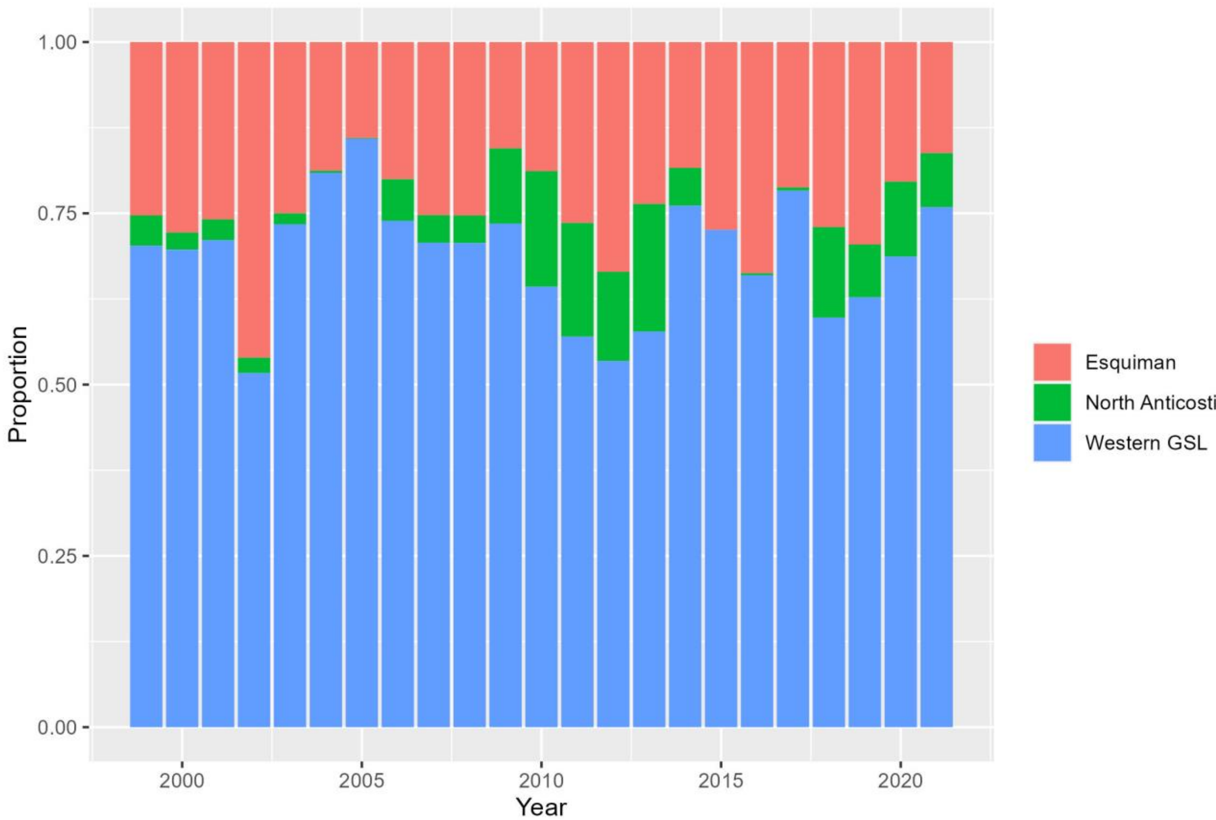

Figure 13. Proportion of fishing effort deployed by fishing sector in the directed Greenland halibut gillnet fishery from 1999 to 2021. No effort data were available for the Esquiman sector in 2022.

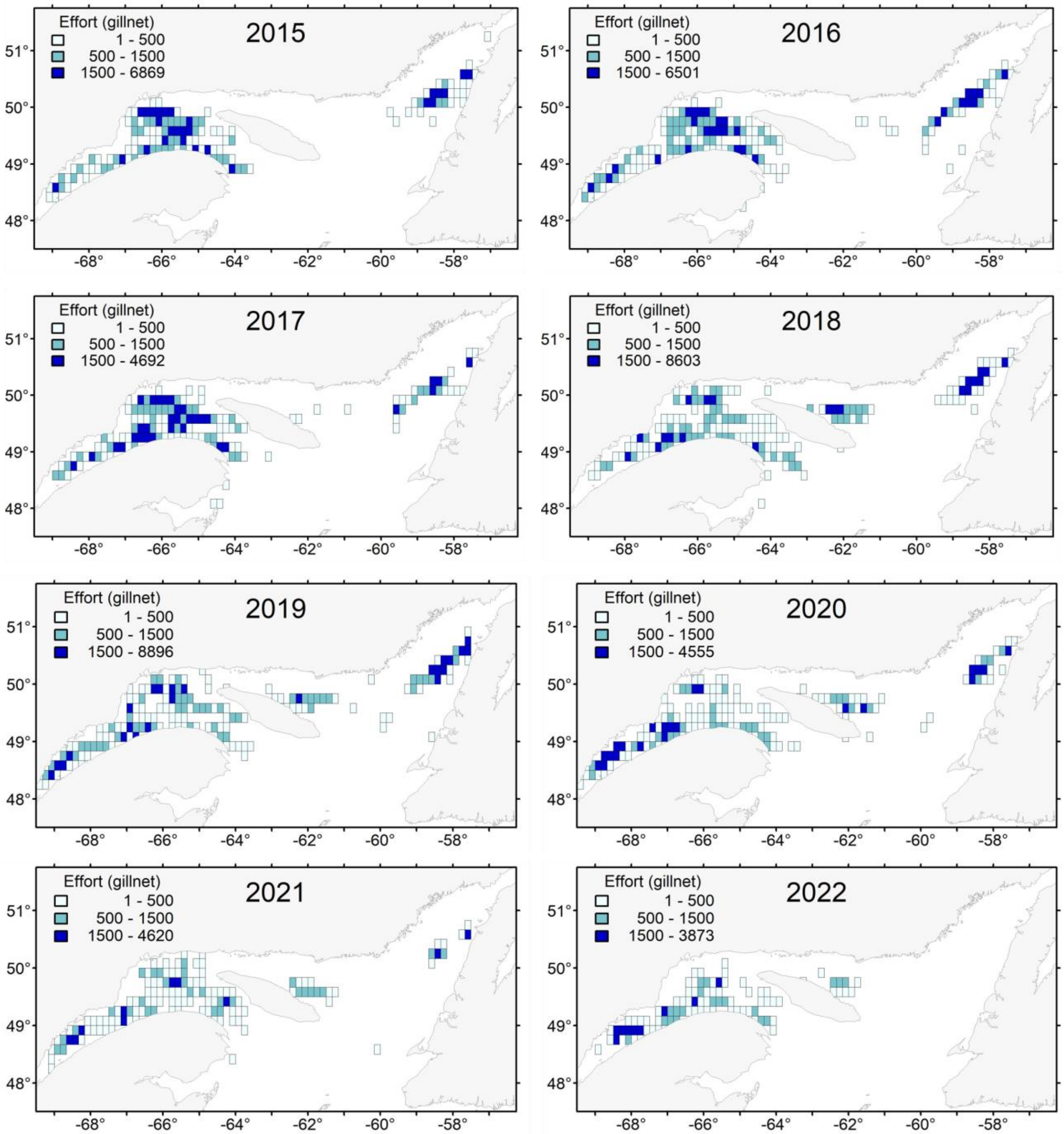

Figure 14a. Annual fishing effort (number of gillnets) by statistical square. 2015 to 2022. The information is from ZIFF files and the 2021 and 2022 data are preliminary. From 2015 to 2022, fishing effort data are available for more than 98% of landings in the western Gulf and north Anticosti sector. For the Esquiman sector, data are available for nearly 77% of landings from 2015 to 2021 and no effort and position data were available for the Esquiman sector in 2022.

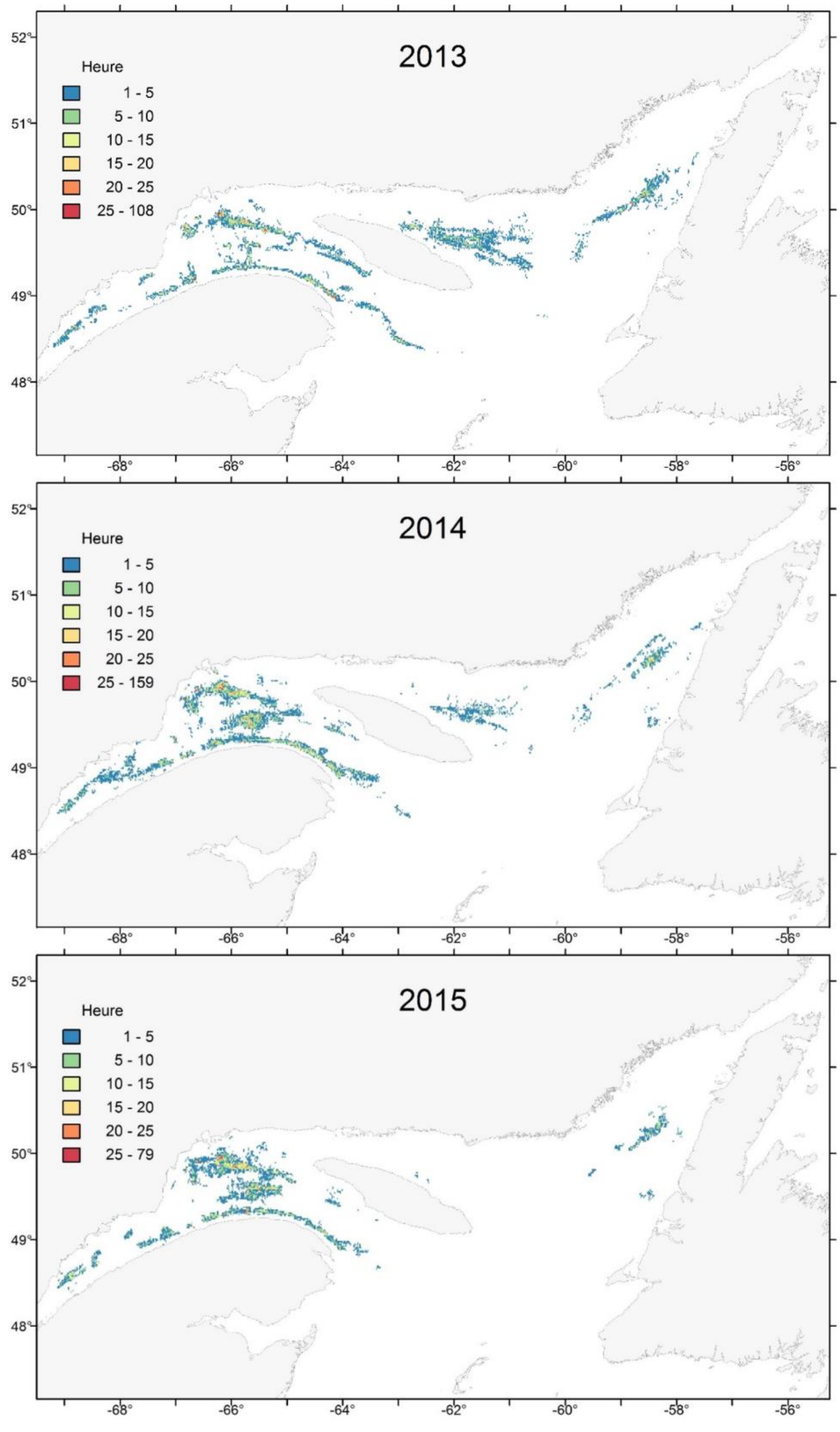

Figure 14b. Distribution of directed fishing effort for Greenland halibut in the Gulf of St. Lawrence from 2013 to 2022 according to Vessel Monitoring System (VMS) data, number of hours per 1 minute square. Since 2017, data has been available for nearly 100% of the activities of the Quebec fleets. The proportion is less than 50% for the Newfoundland and Labrador fleets that fish in easter GSL.

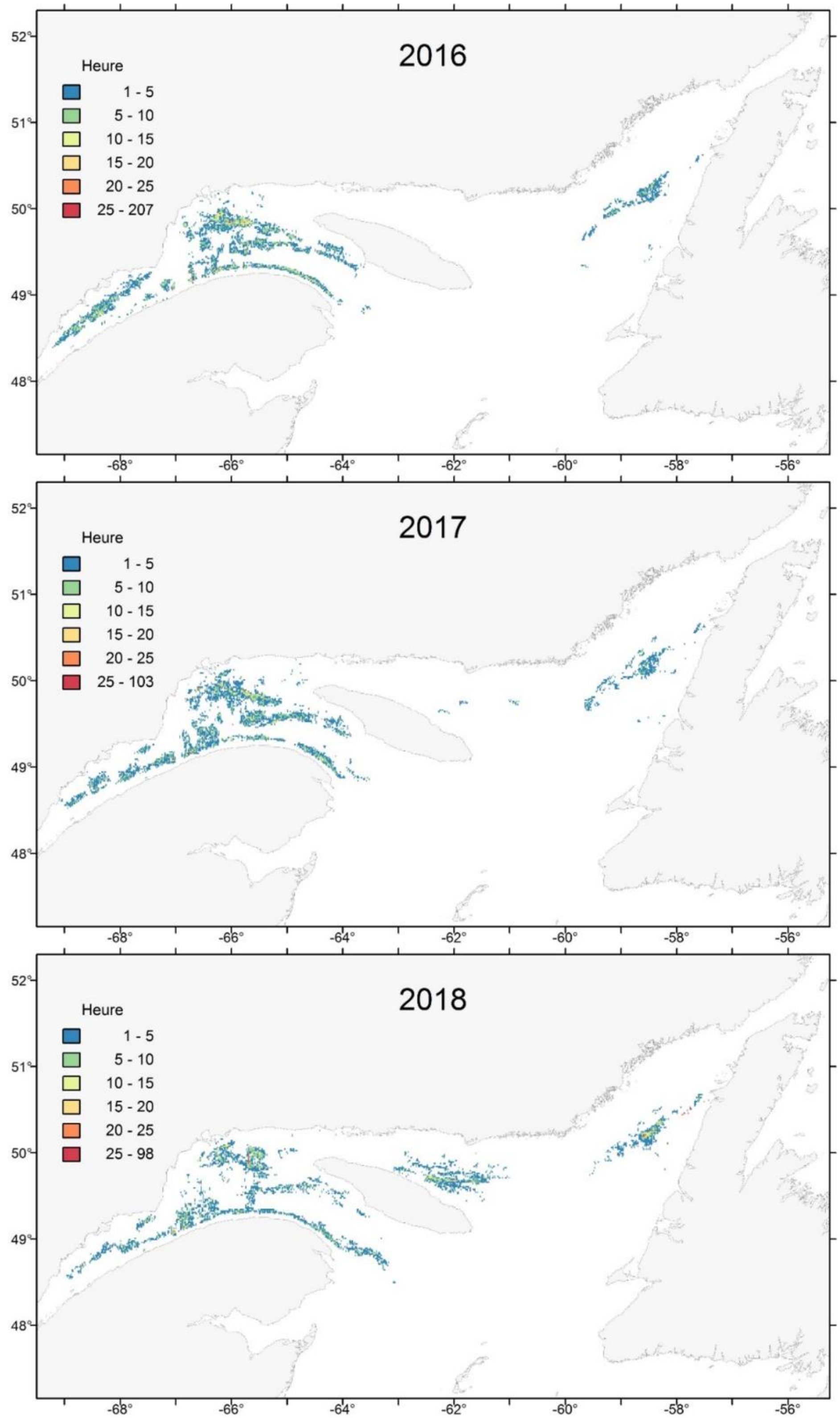

Figure 14b. (Continued).

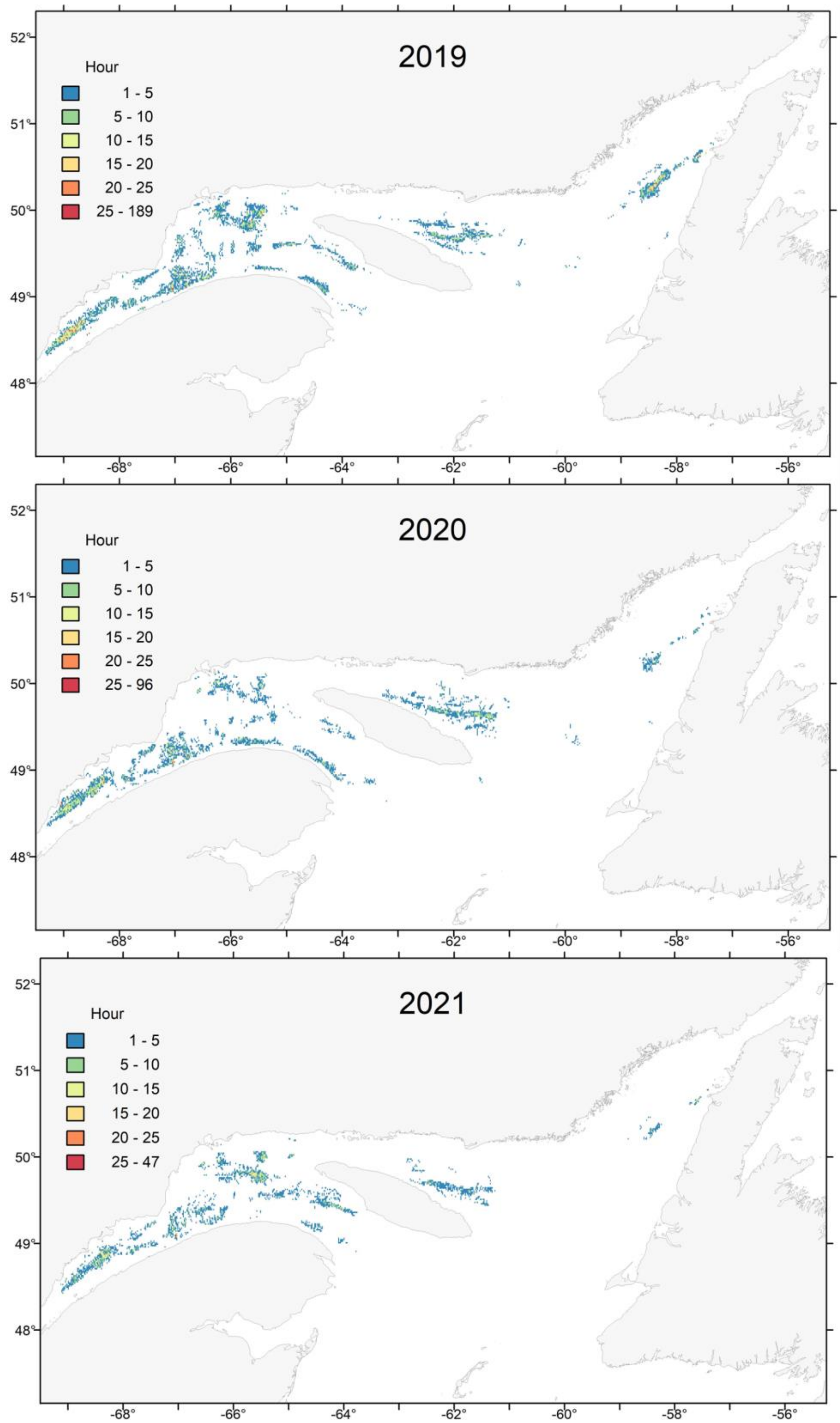

Figure 14b. (Continued).

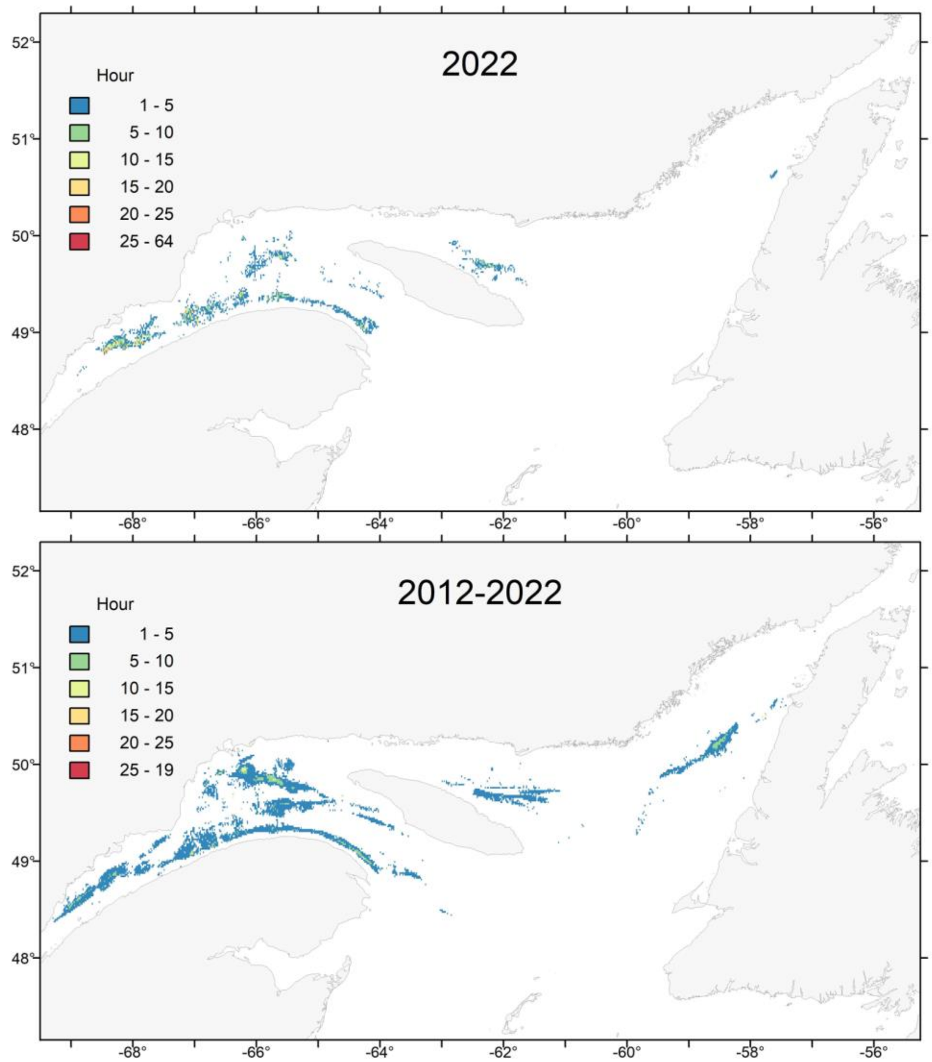

Figure 14b. (Continued).

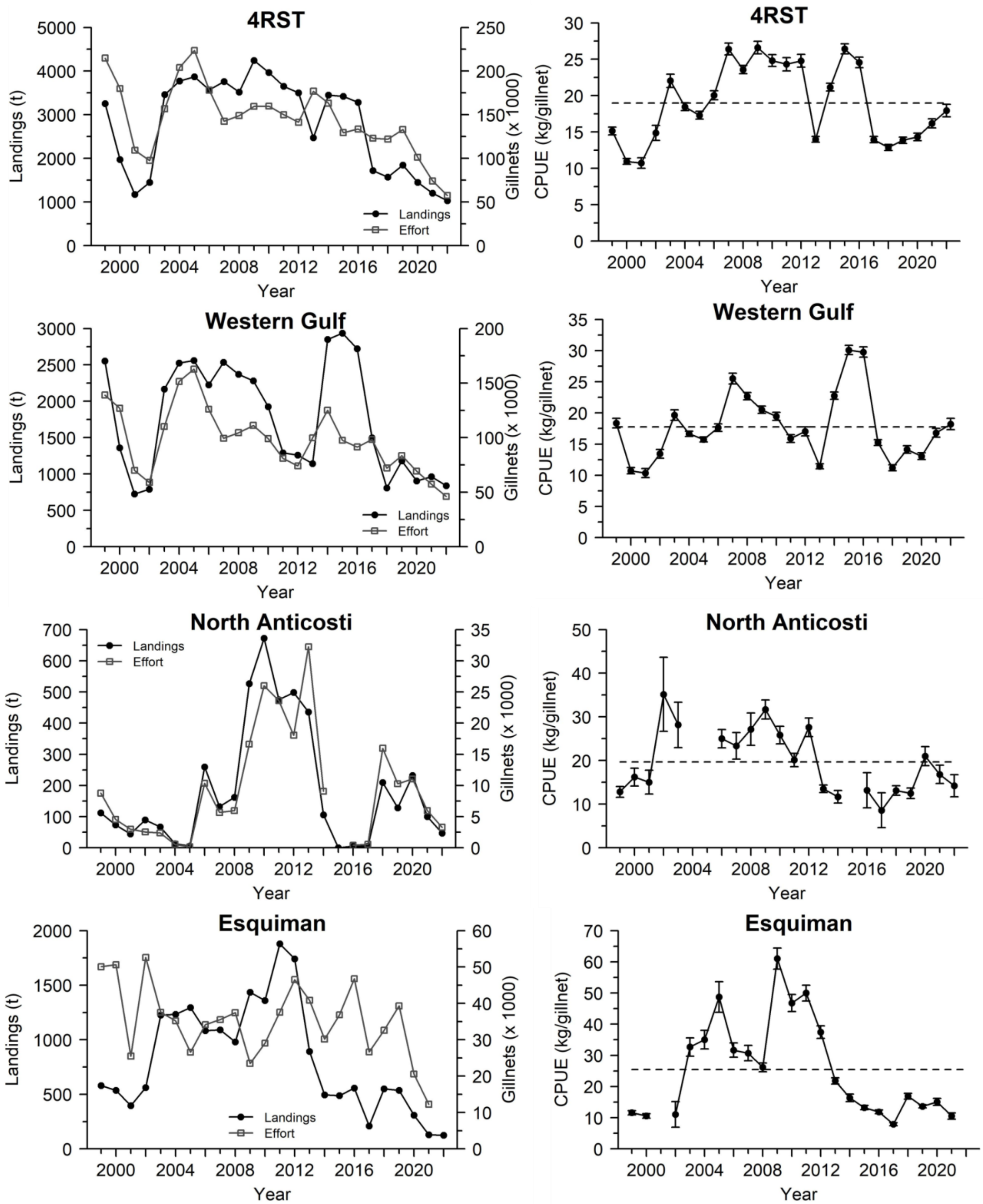

Figure 15. Landing, nominal effort and catch per unit effort (CPUE) ± 95% confidence interval, by year and fishing sector. No effort data were available for the Esquiman sector in 2022.

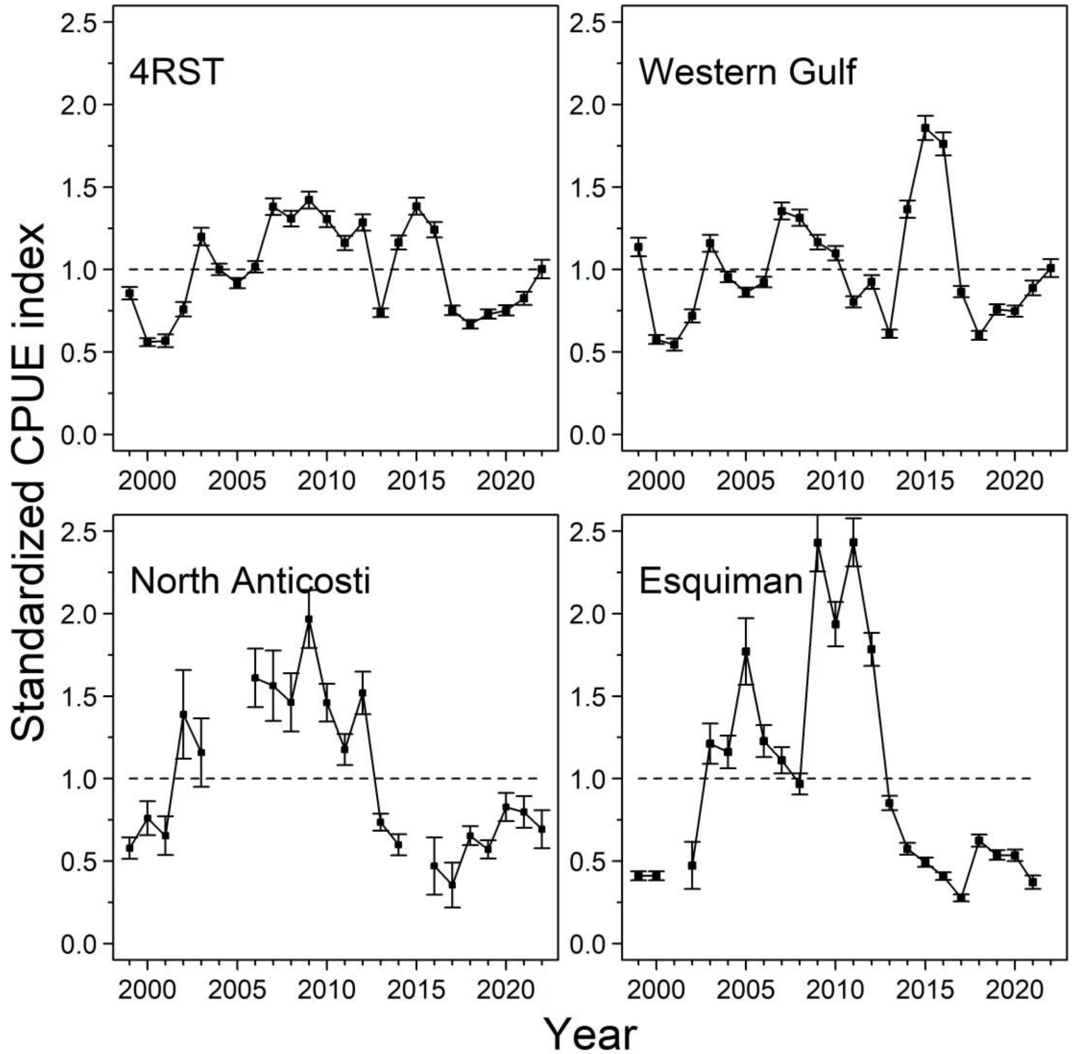

Figure 16. Annual fishing performance index (standardized CPUE) ± 95% confidence interval for the Gulf as a whole (4RST) and by fishing sector. No effort data were available for the Esquiman sector in 2022.

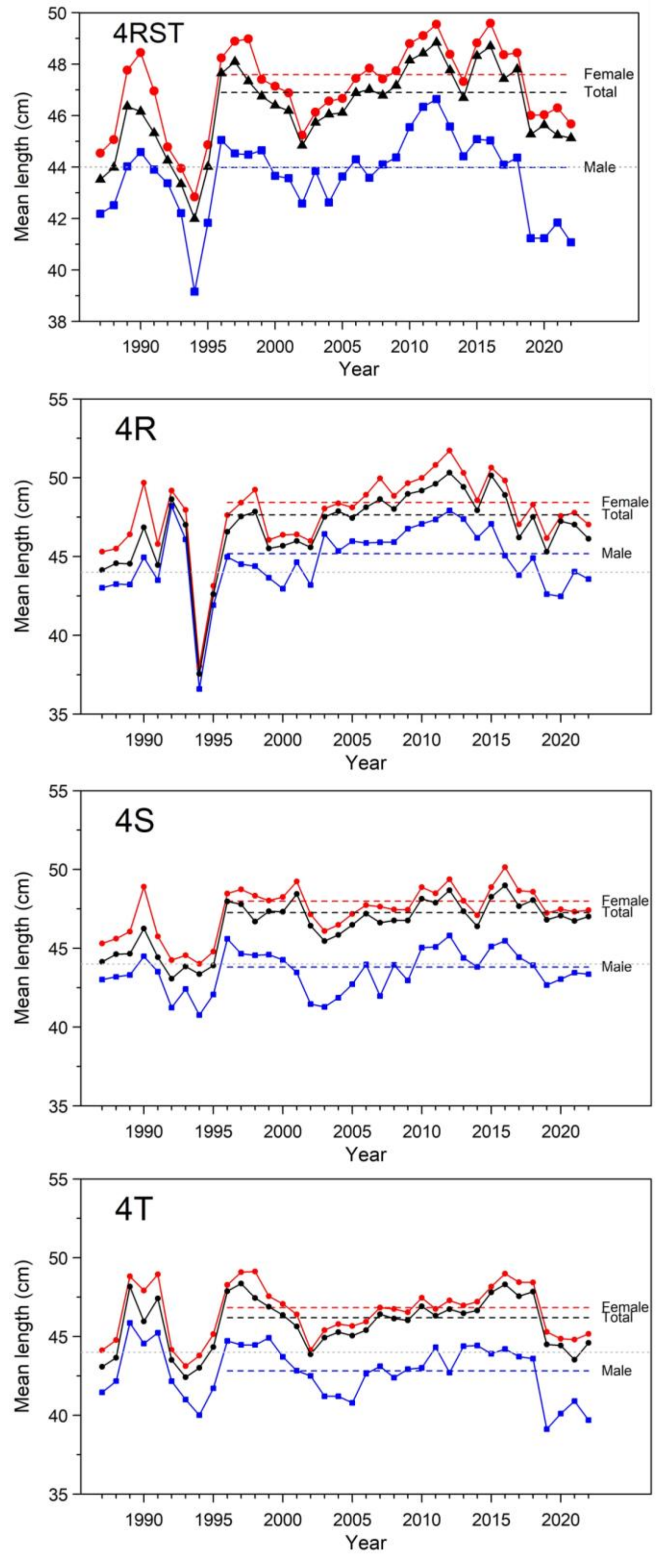

Figure 17. Average annual length of Greenland halibut caught in the commercial gillnet fishery by sex and NAFO Division from 1987 to 2022. The dotted lines represent the average for each series since the change in mesh size in 1996.

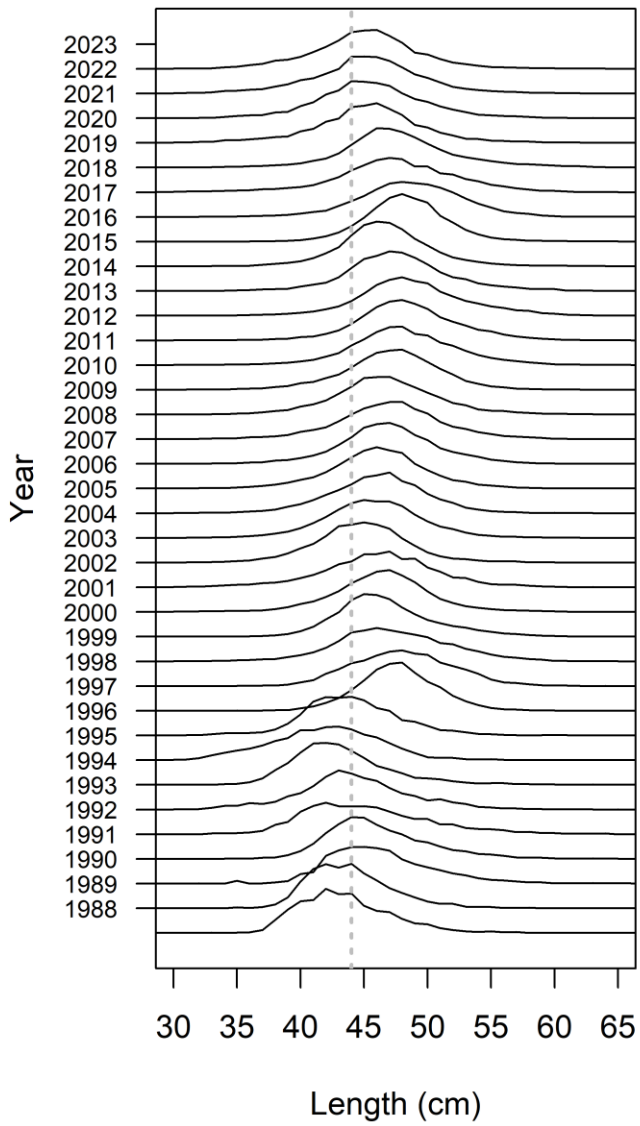

Figure 18. Catch at length of Greenland halibut caught in the commercial fishery from 1987 to 2022. In 1996, the mesh size increased from 127 à 152 mm. The vertical line intersects the graph at 44 cm which is the minimum size of the small fish protocol.

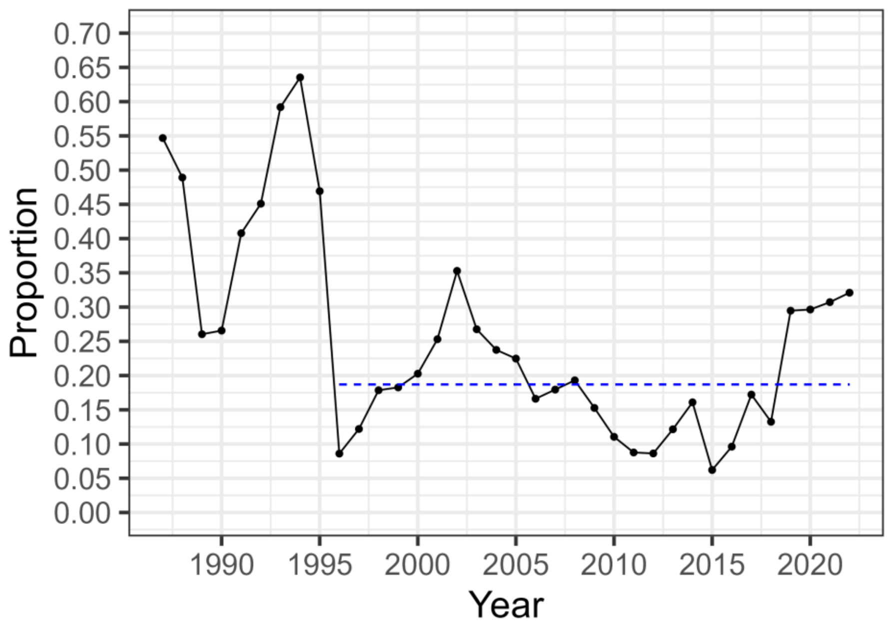

Figure 19. Annual proportion of Greenland halibut less than the minimal size of 44 cm in the commercial catch. The dotted line represents the average 1996-2022. i.e. after the change in gillnet mesh size.

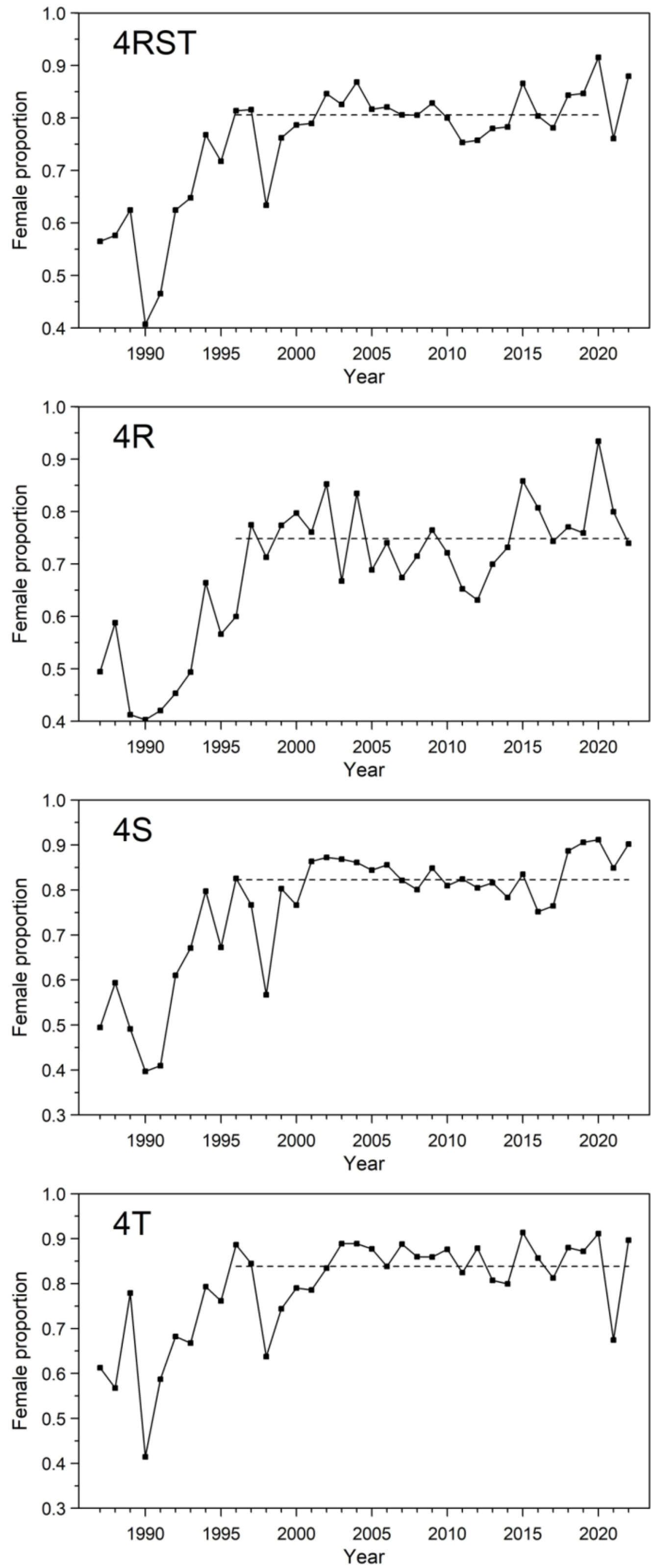

Figure 20. Proportion of females in gillnet catches by NAFO Division. The dotted line represents the average starting in 1996, the year of the change in mesh size from 127 to 152 mm.

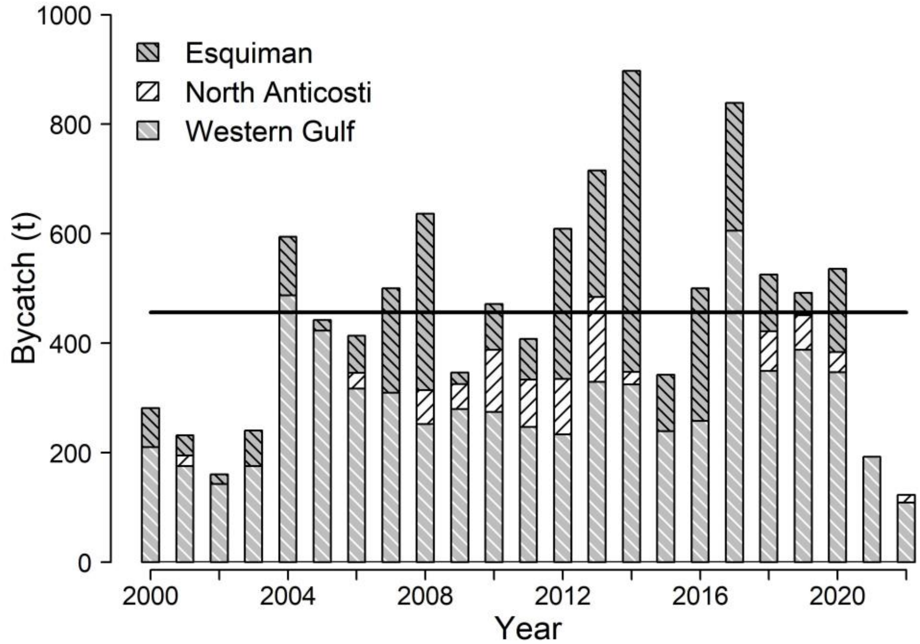

Figure 21. Total bycatch (t) of all species in the directed Greenland halibut gillnet fishery by year and fishing area estimated with data from the at-sea observer program. Solid line indicates the average for the years 2000-2022. Data for 2022 are preliminary and no observers were deployed in 2021 and 2022 on vessels from the province of Newfoundland and Labrador.

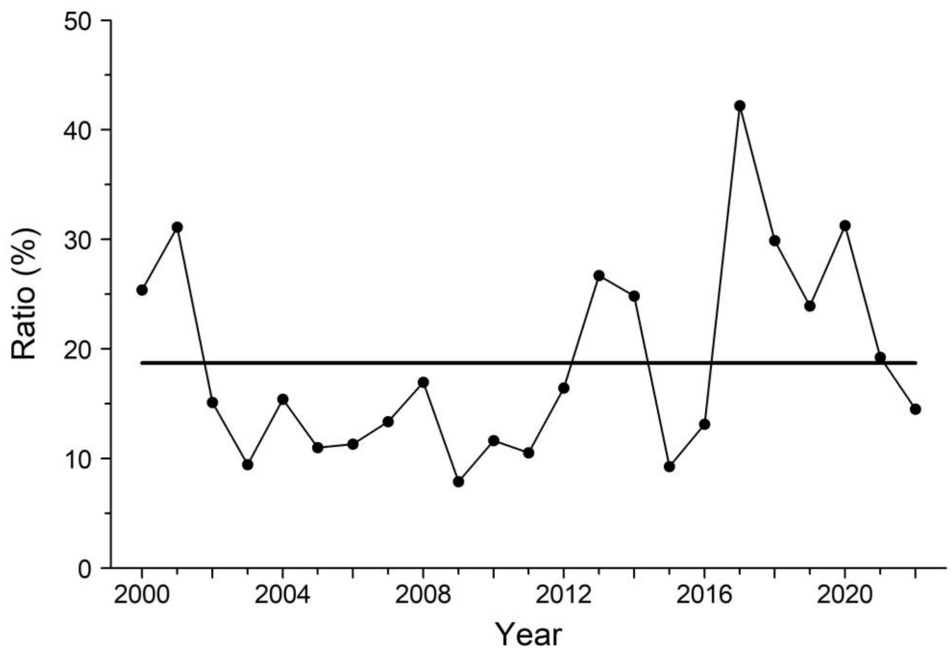

Figure 22. Ratio (%) of bycatch for all species combined to total Greenland halibut catch. Solid line indicates the average for the years 2000-2022. Data for 2022 are preliminary and no observers were deployed in 2021 and 2022 on vessels from the province of Newfoundland and Labrador.

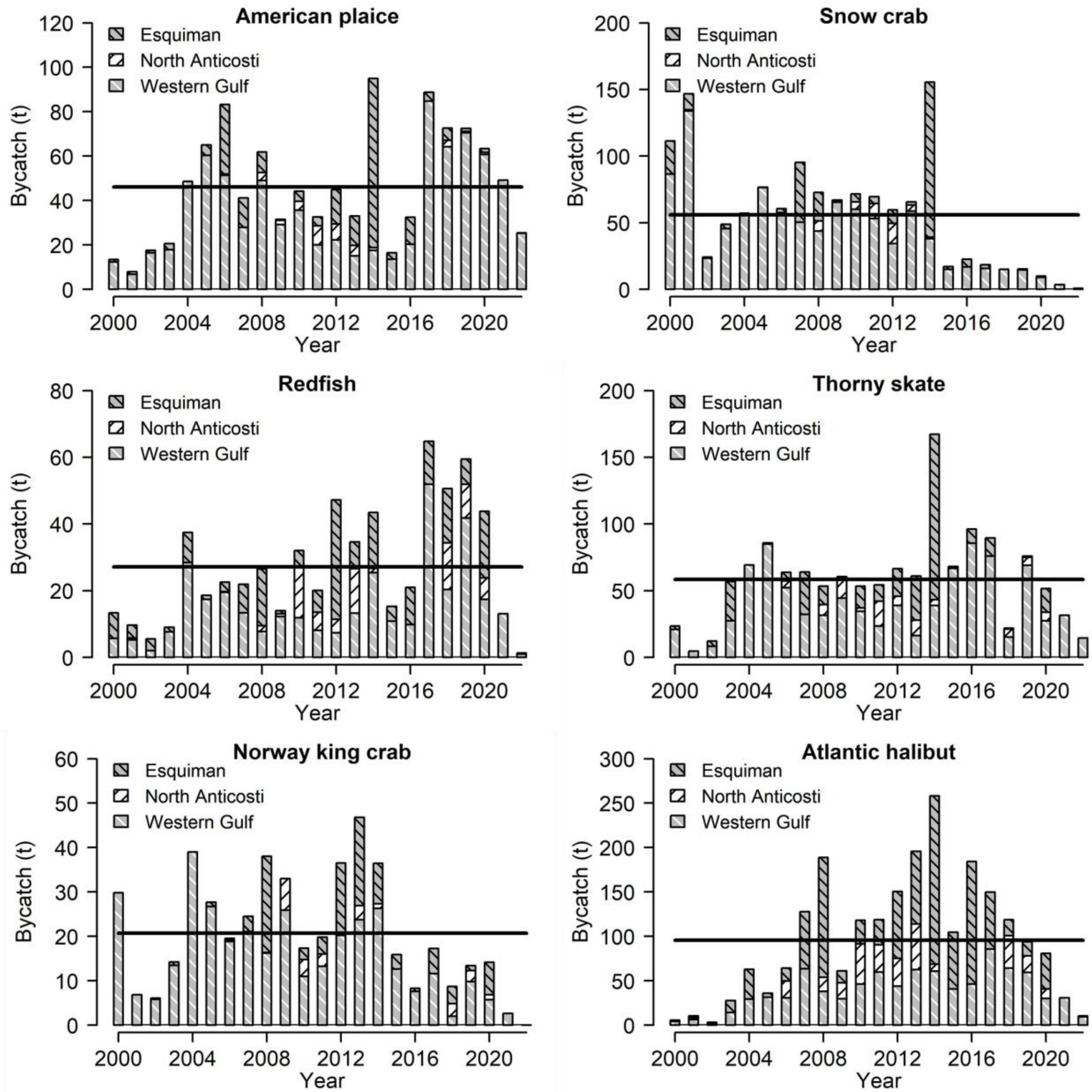

Figure 23. Annual bycatch in the directed Greenland halibut gillnet fishery, estimated for six species per fishing sector based on data from the at-sea observer program. The solid line indicates the average for the years 2000-2022. Data for 2022 are preliminary and no observers were deployed in 2021 and 2022 on vessels from the province of Newfoundland and Labrador.

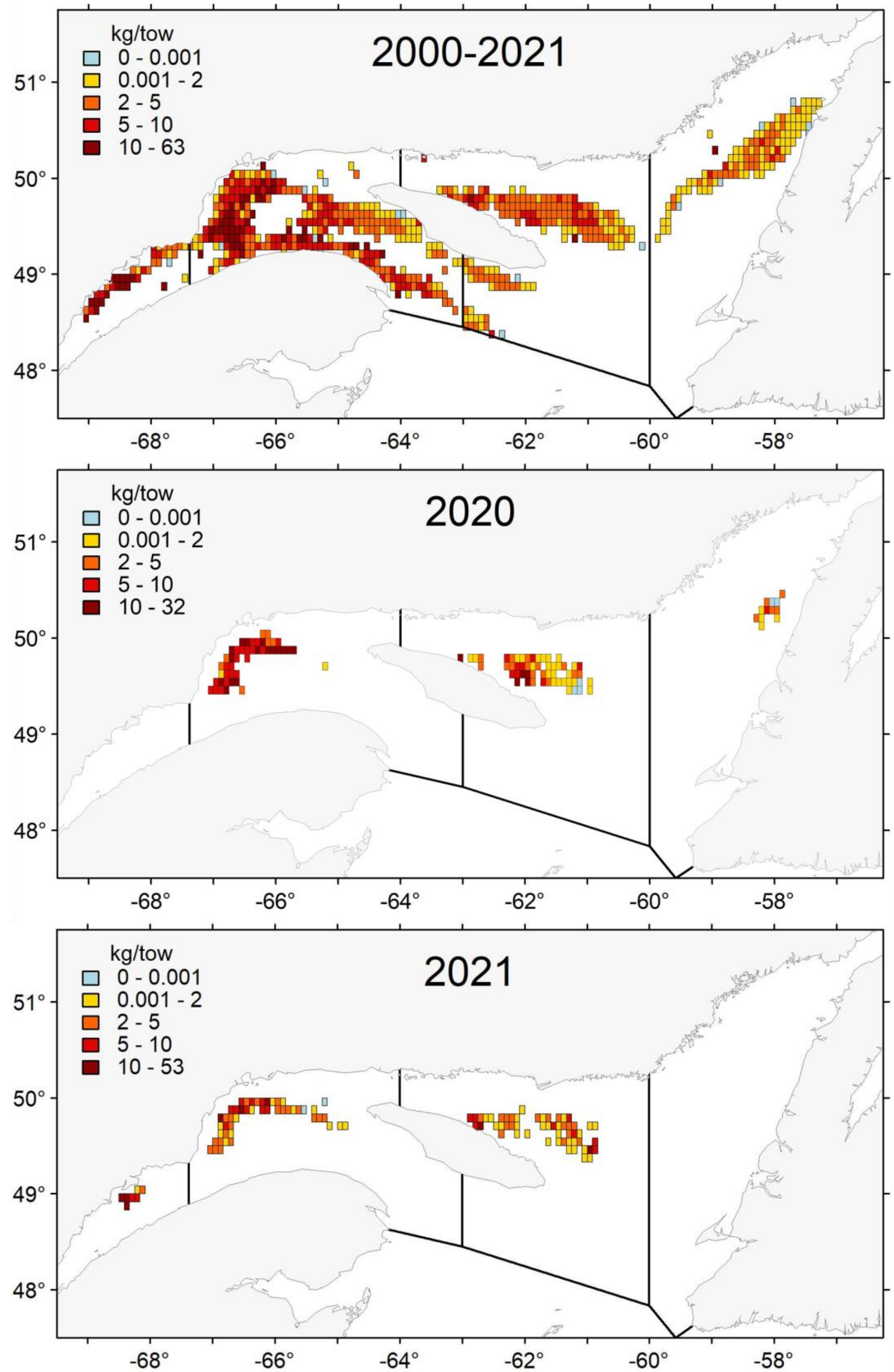

Figure 24. Spatial distribution of Greenland halibut bycatch averaged per 5-minute square in directed shrimp fisheries in the presence of an at-sea observer. Average for 2000-2021 and data for 2020 and 2021.

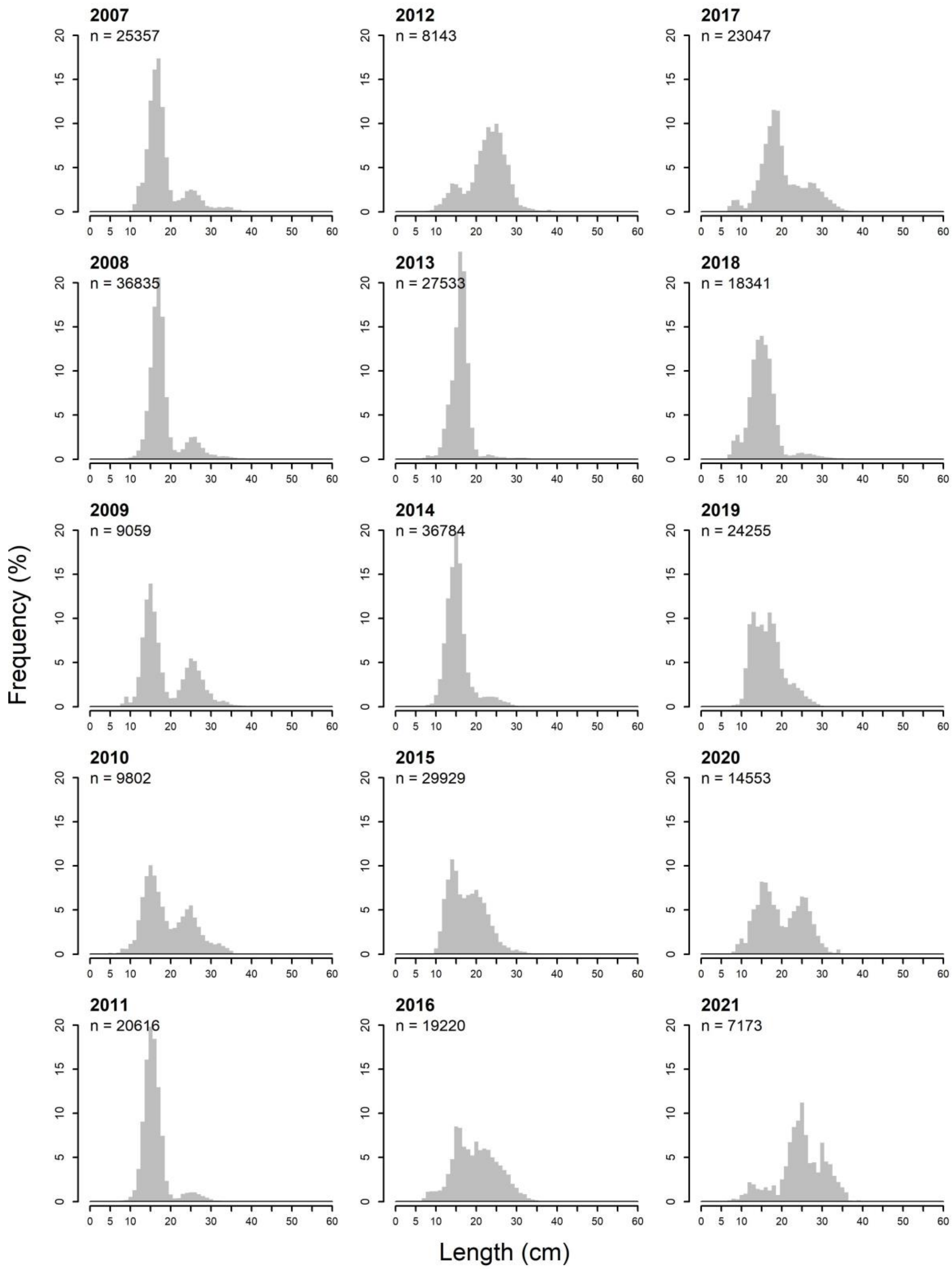

Figure 25. Length frequency distribution of Greenland halibut sampled by at-sea observers from 2007 to 2021 in the directed shrimp fishery. The number (n) of specimens measured is indicated.

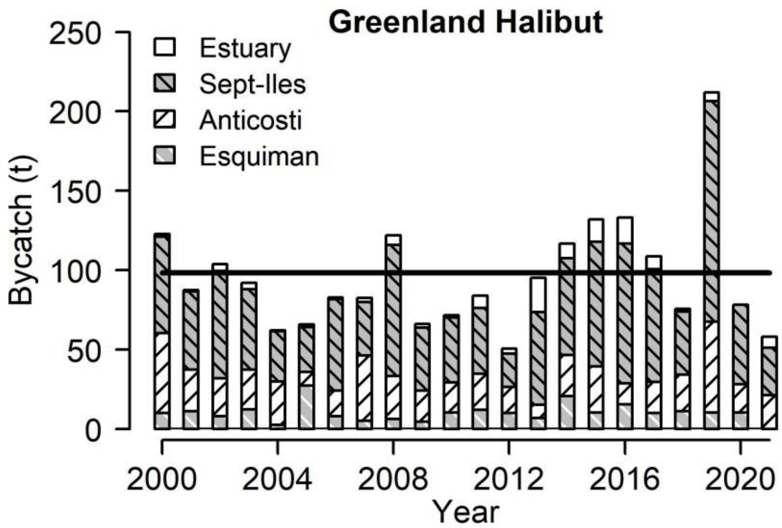

Figure 26. Bycatch of Greenland halibut in the directed shrimp fishery, estimated annually by at-sea observers according to shrimp fishing areas. The solid line indicates the average for the years 2000-2021. No data were available for the Estuary in 2020 and Esquiman in 2021.

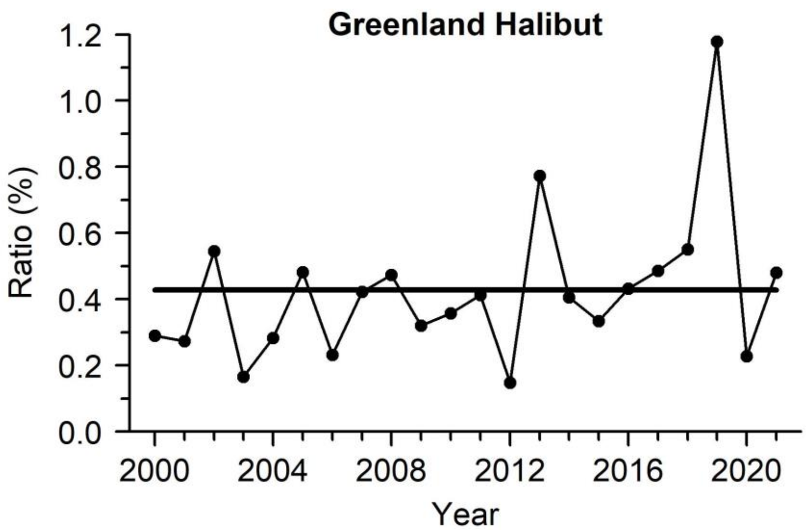

Figure 27. Ratio (%) of Greenland halibut bycatch bycatch in the shrimp fishery to estimated Greenland halibut biomass estimated using the Northern Gulf of St. Lawrence Groundfish Survey data. Solid line indicates the average for the years 2000-2021. No data were available for the Estuary in 2020 and Esquiman 2021.

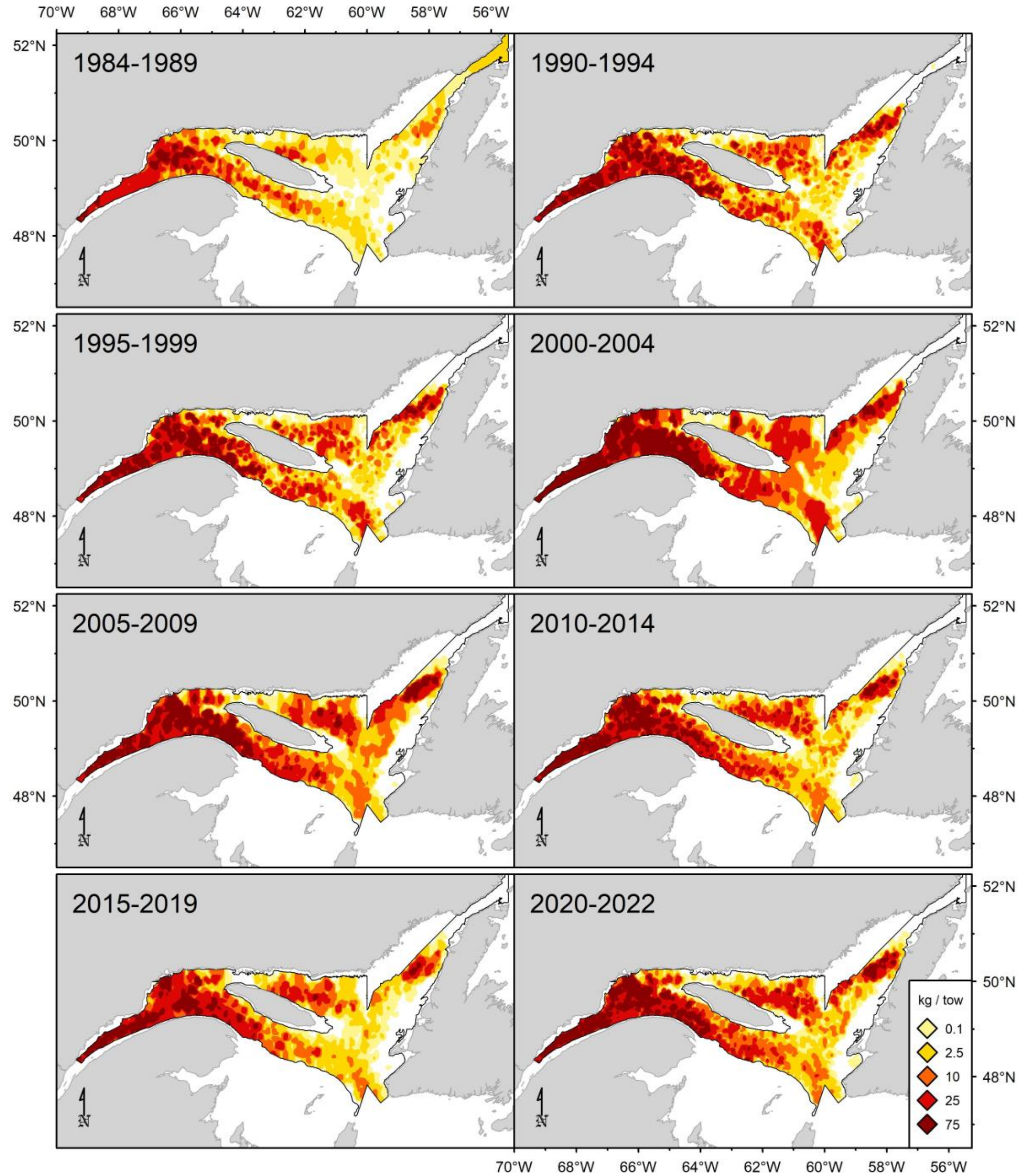

Figure 28. Spatial distribution of catch rates (kg / 15-minute tow) of Greenland halibut during the DFO nGSL survey over five or six year periods.

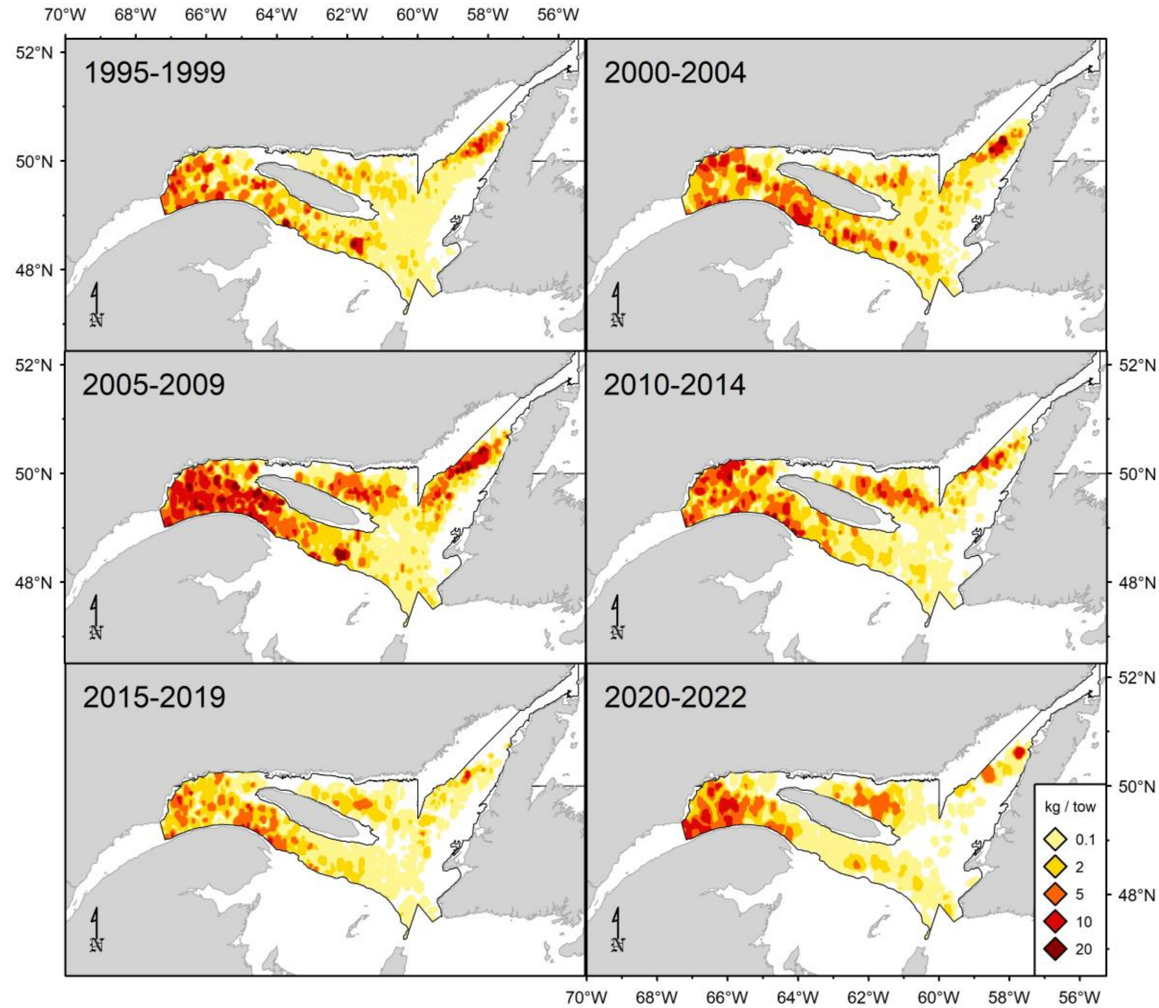

Figure 29. Spatial distribution of catch rates (kg / 30-minute tow) of Greenland halibut in the mobile sentinel survey over five year periods.

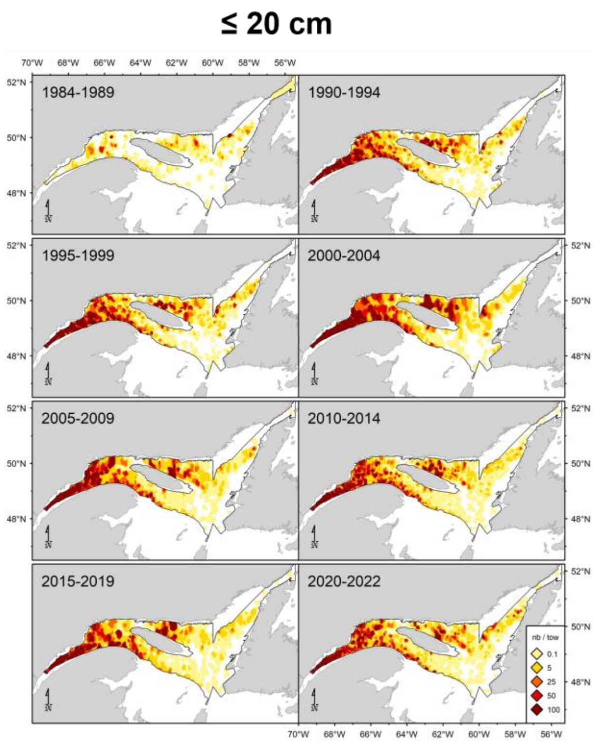

Figure 30. Spatial distribution of catch rates (number / 15 minute tow) of Greenland halibut ≤ 20 cm in the DFO nGSL survey over five or six year periods.

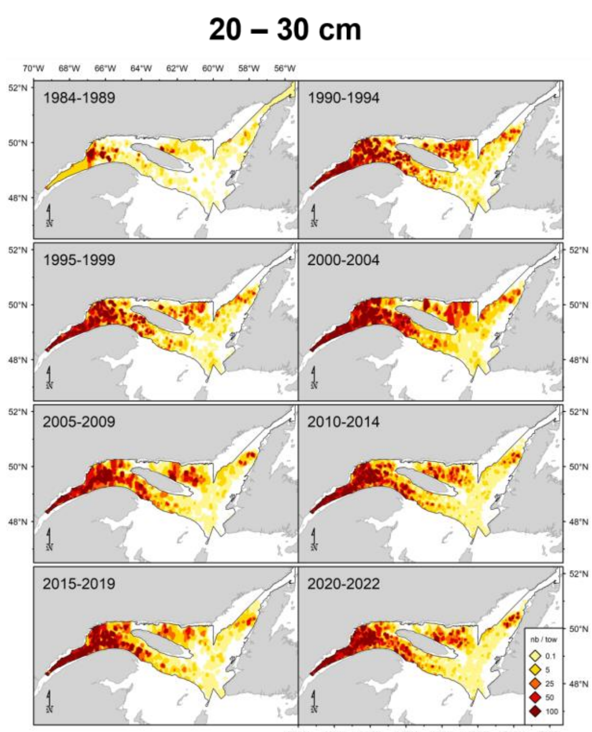

Figure 31. Spatial distribution of catch rates (number / 15 minute tow) of 20 to 30 cm Greenland halibut in the DFO nGSL survey five or six year periods.

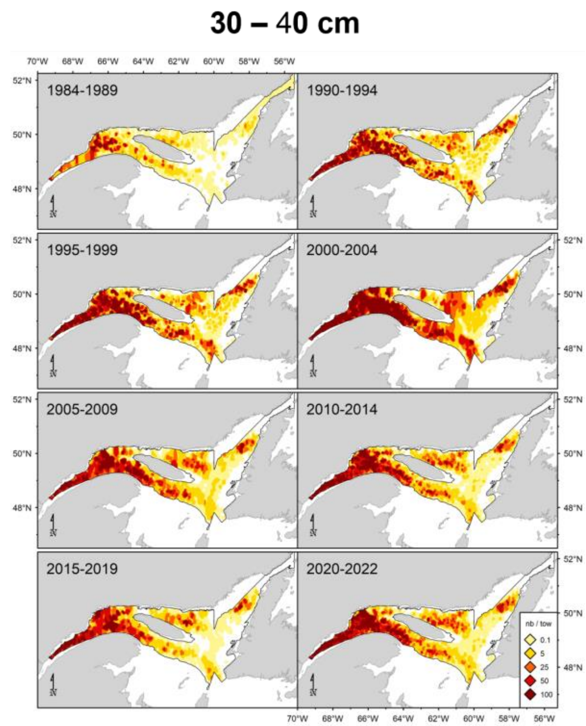

Figure 32. Spatial distribution of catch rates (number / 15 minute tow) of 30 to 40 cm Greenland halibut in the DFO nGSL survey over five or six year periods.

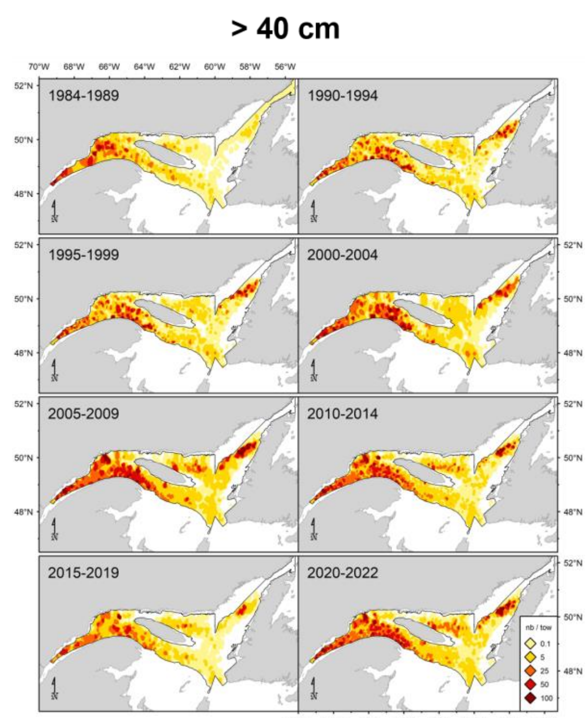

Figure 33. Spatial distribution of catch rates (number / 15 minute tow) of Greenland halibut greater than 40 cm the DFO nGSL survey over five or six year periods.

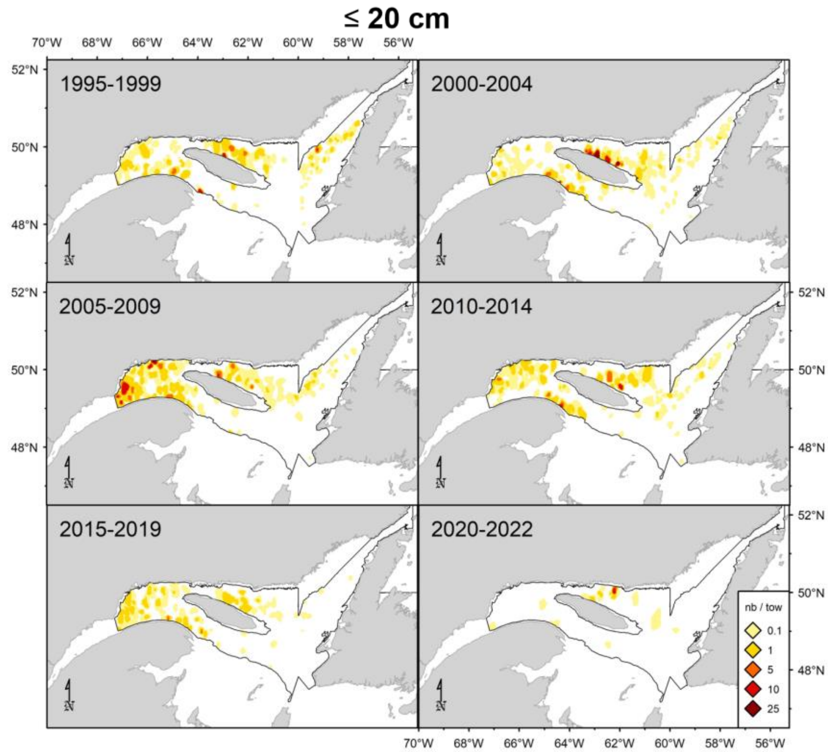

Figure 34. Spatial distribution of catch rates (number / 30-minute tow) of Greenland halibut less than 20 cm in July mobile sentinel survey over five year periods.

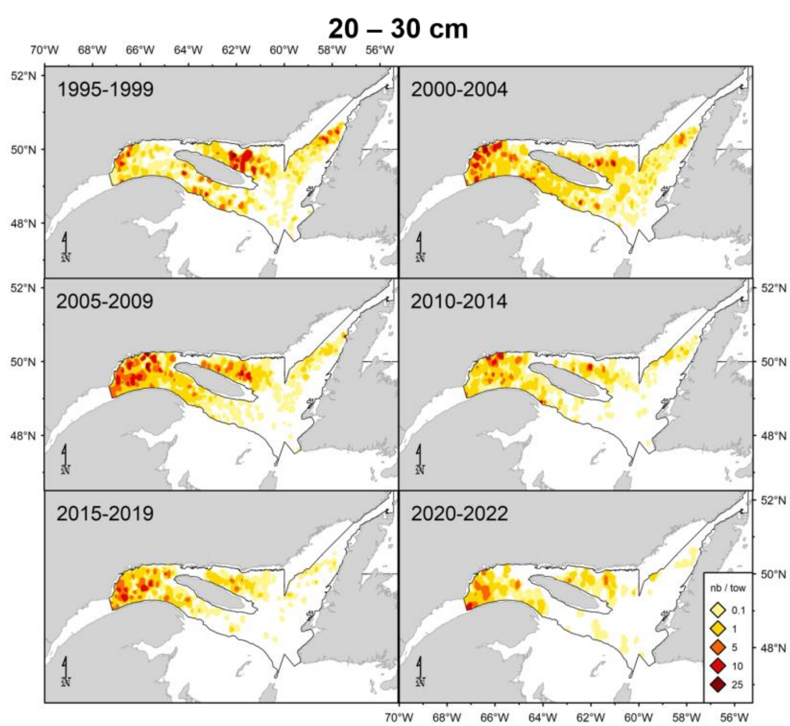

Figure 35. Spatial distribution of catch rates (number / 30 minute tow) of Greenland halibut 20 to 30 cm in July mobile sentinel survey over five year periods.

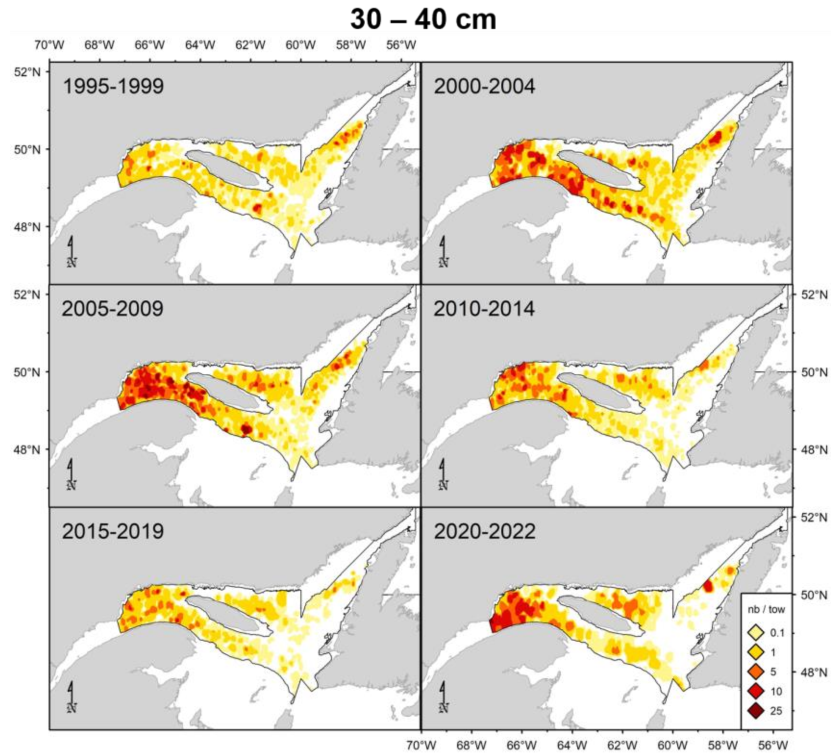

Figure 36. Spatial distribution of catch rates (number / 30 minute tow) of Greenland halibut 30 to 40 cm in July mobile sentinel survey over five year periods.

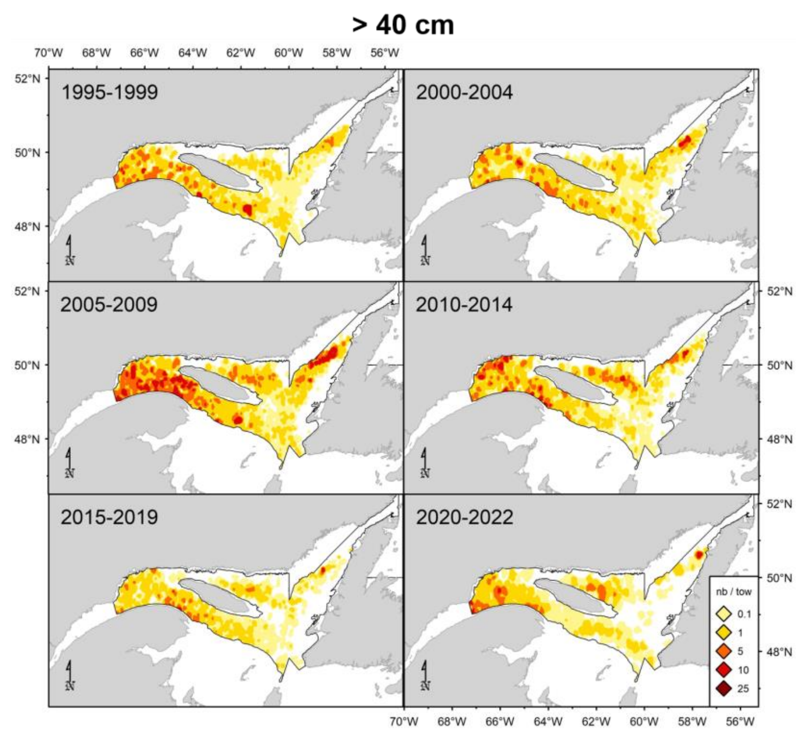

Figure 37. Spatial distribution of catch rates (number / 30-minute tow) of Greenland halibut greater than 40 cm in July mobile sentinel survey over five year periods.

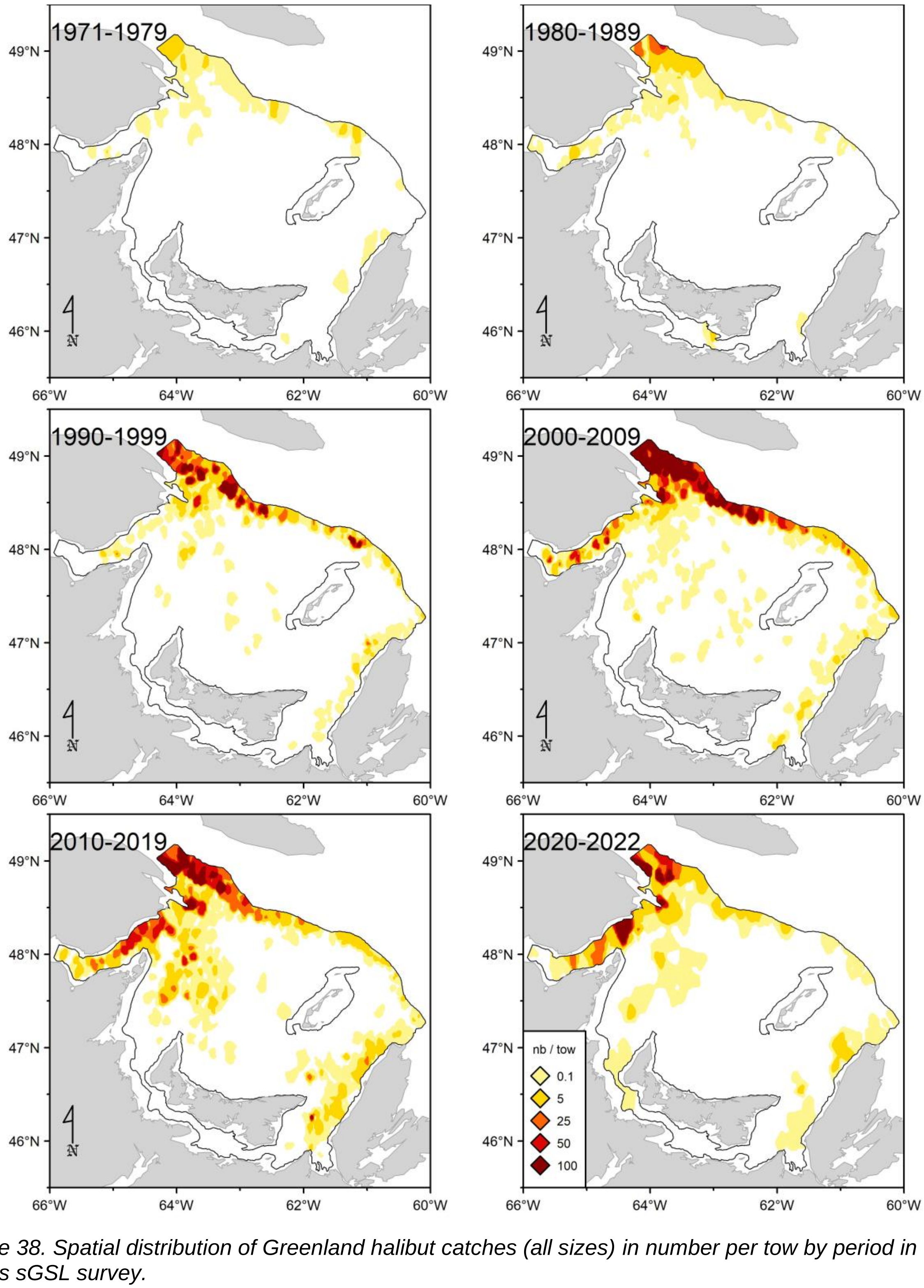

Figure 38. Spatial distribution of Greenland halibut catches (all sizes) in number per tow by period in DFO's sGSL survey.

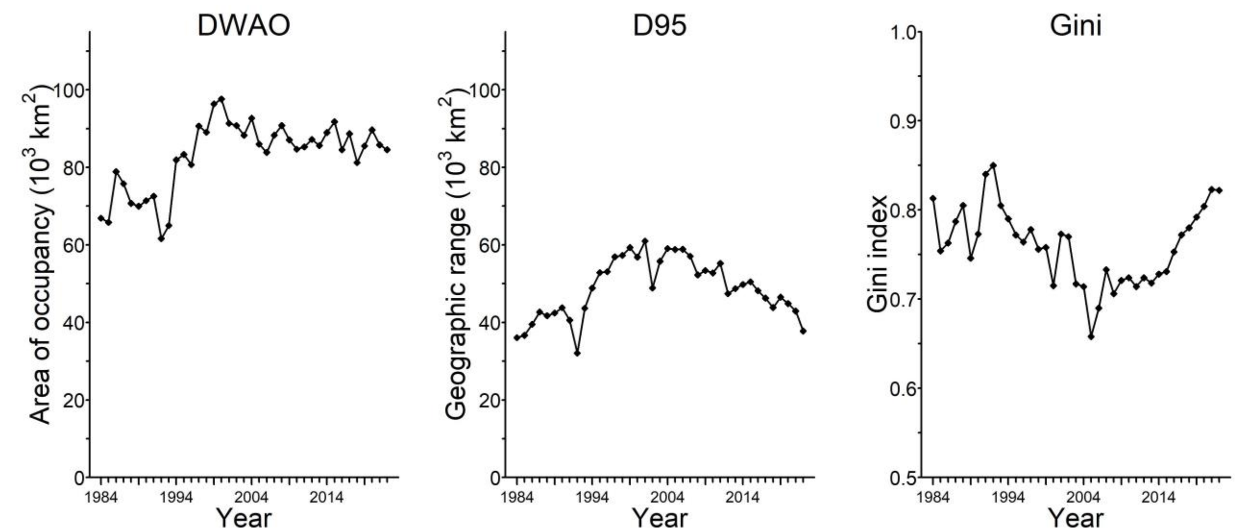

Figure 39. Spatial distribution indices: DWAO, weighted area of occupancy. D95, minimum area where 95% of the biomass is concentrated, and Gini index. The total DFO nGSL surveyed area is 116,115 km^2.

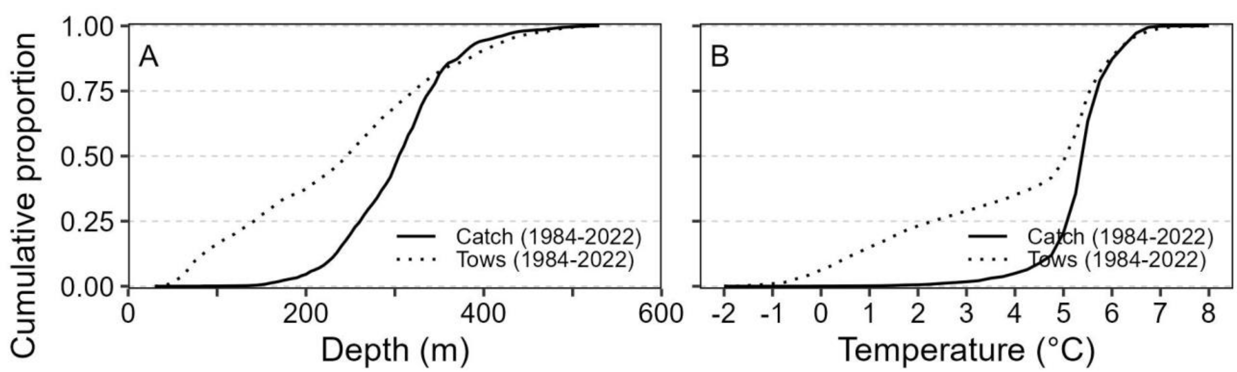

Figure 40. Cumulative proportion of Greenland halibut catches (weight per tow) and number of stations sampled as a function of depth (left graph) and bottom temperature (right graph) in the DFO nGSL survey from 1990 to 2022.

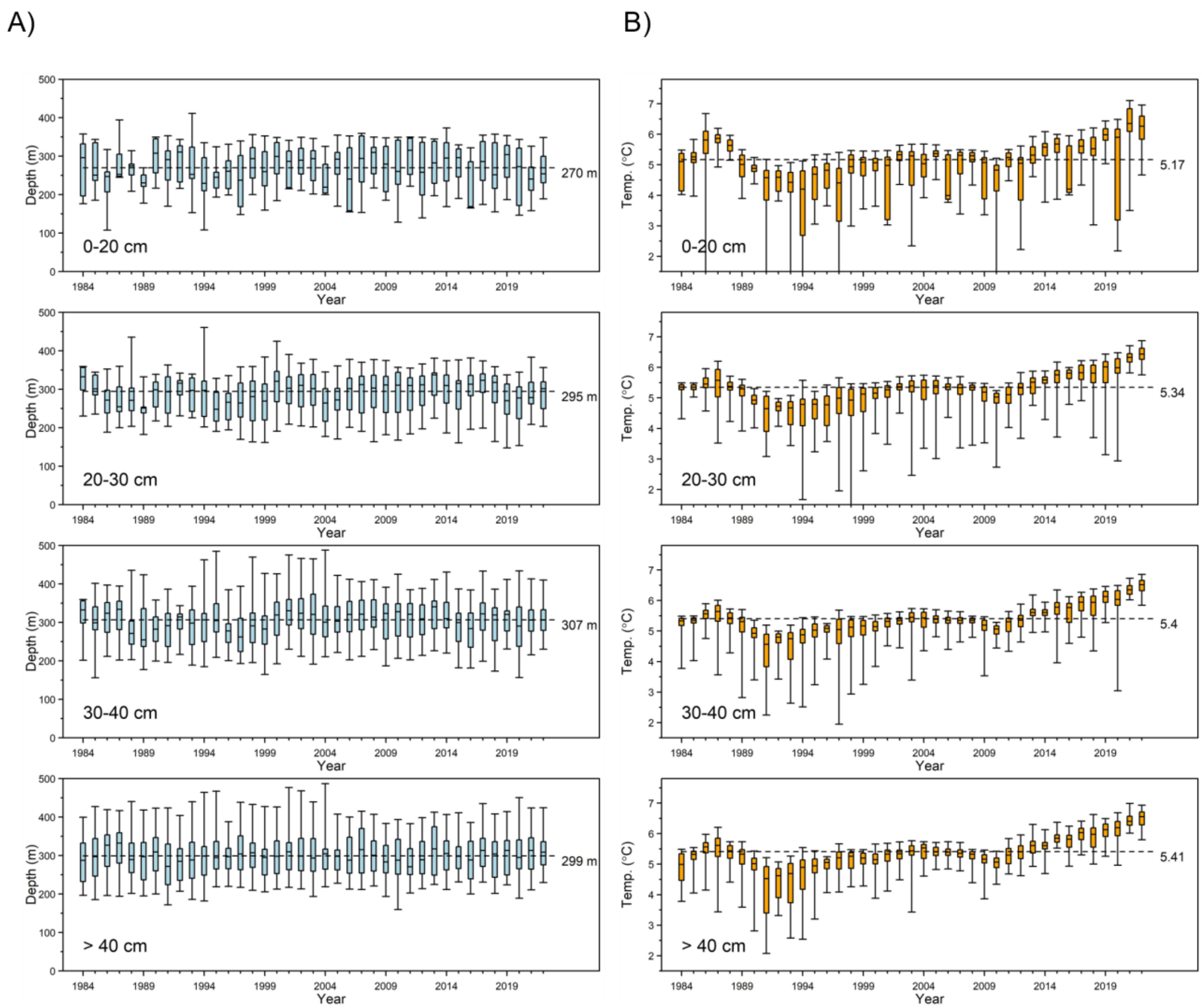

Figure 41. Distribution of Greenland halibut biomass as a function of A) depth B) temperature and C) oxygen saturation level for different size categories observed in the DFO nGSL survey. Box and whiskers plot: the line inside the box represents the median. the box extends from percentiles 25 to 75 and the whiskers (vertical lines on either side of the box) extend from percentiles 5 to 95. The horizontal dotted line on each graph shows the average of the series.

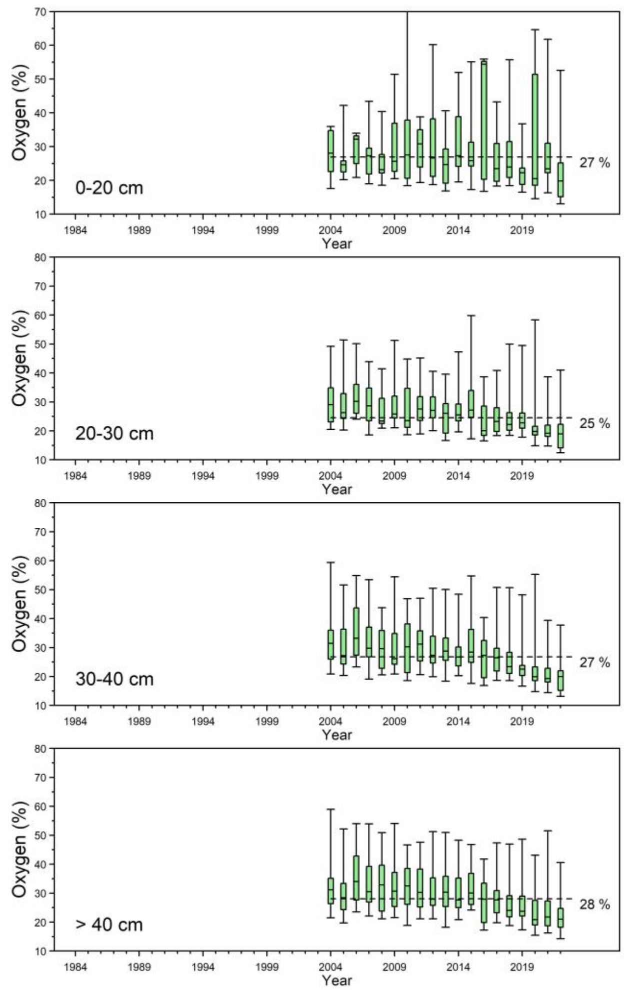

Figure 41C.

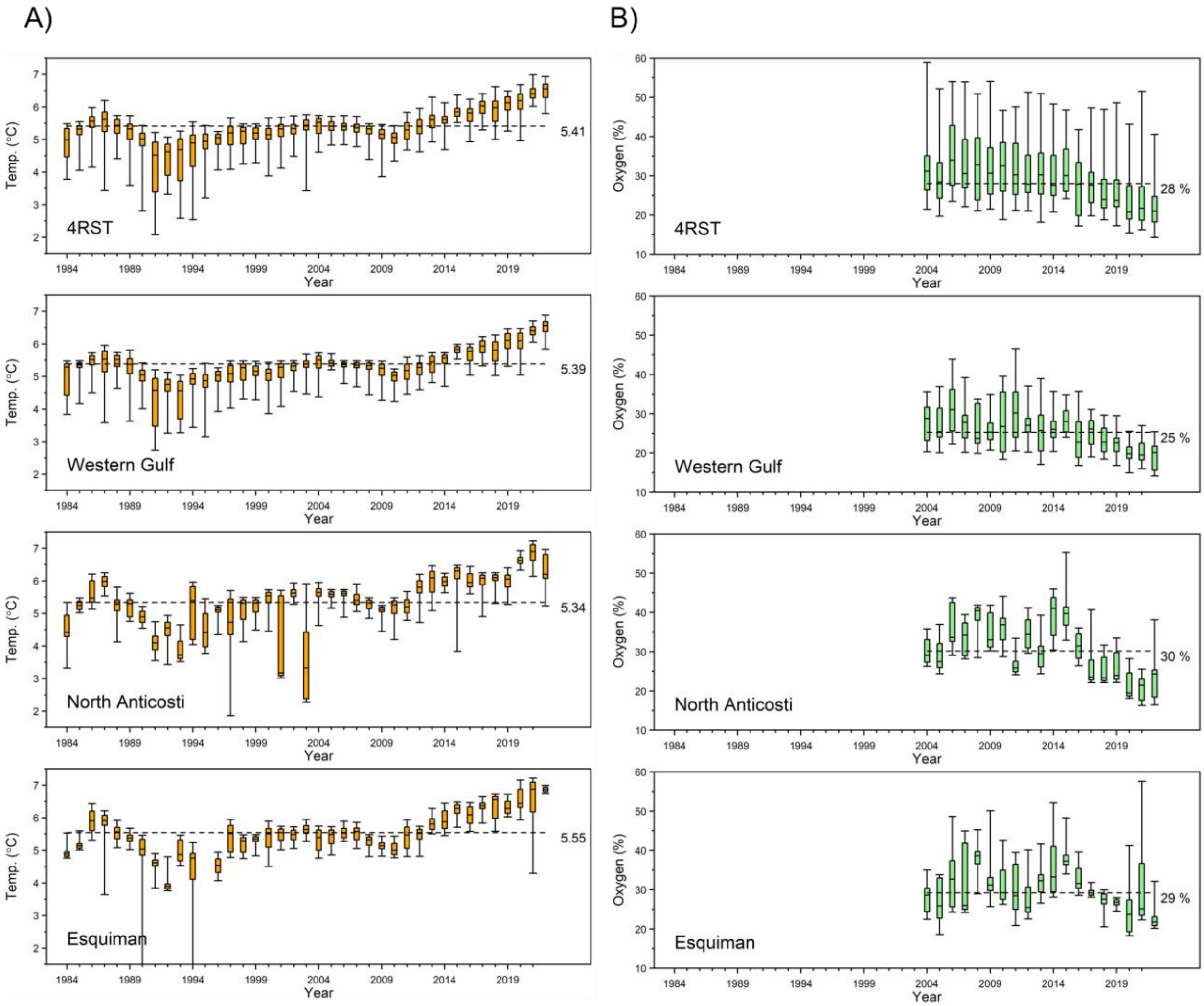

Figure 42. Distribution of Greenland halibut biomass as a function of A) bottom temperature, B) oxygen saturation level by fishing sector for fish larger than 40 cm observed in the DFO nGSL survey. Box and whiskers plot: the line inside the box represents the median, the box extends from percentiles 25 to 75 and the whiskers (vertical lines on either side of the box) extend from percentiles 5 to 95. The horizontal dotted line on each graph shows the average of the series.

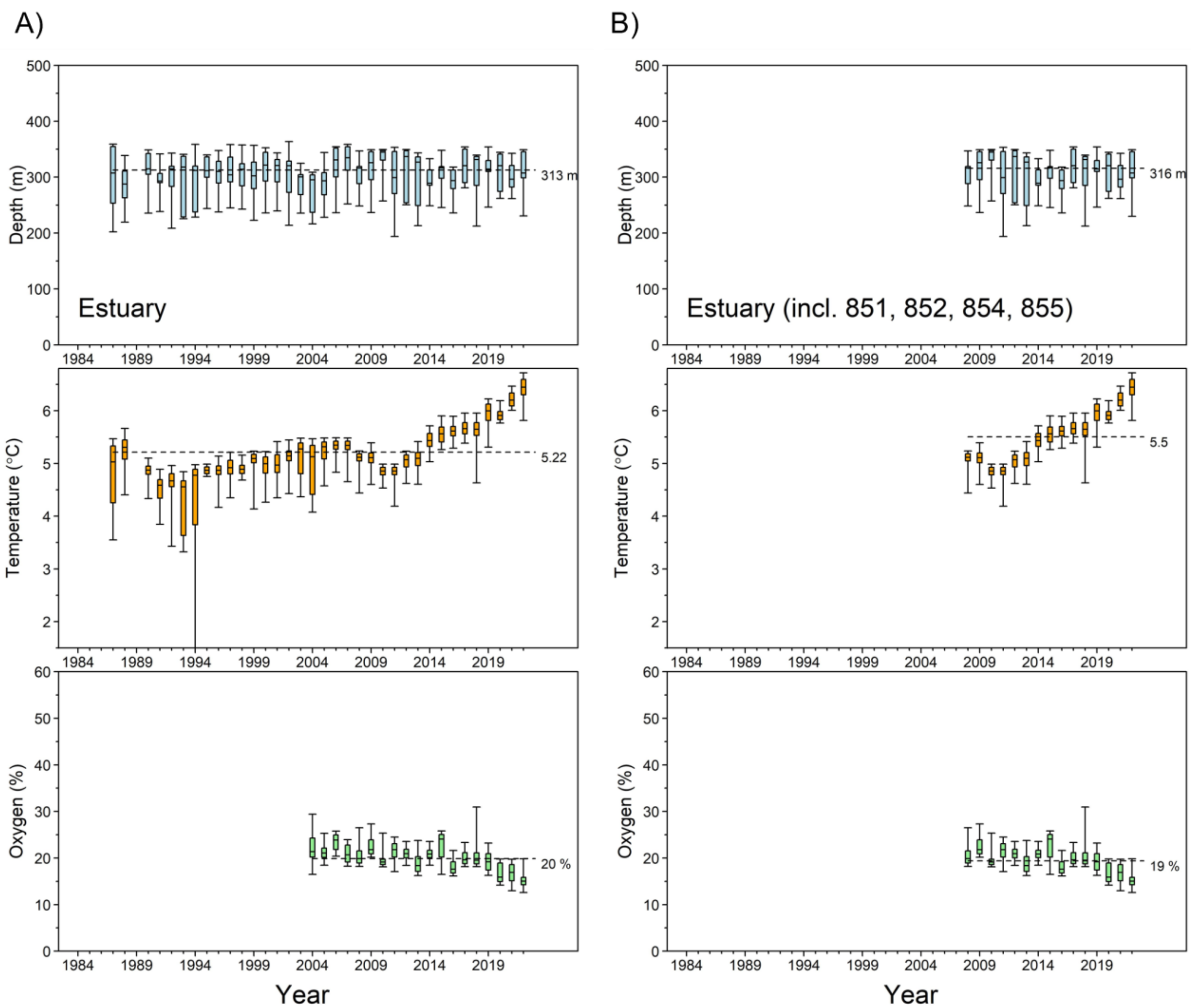

Figure 43. Greenland halibut biomass distributions in the Lower Estuary as a function of depth, bottom temperature and oxygen saturation level based on DFO nGSL survey data in A) the estuary (strata 411 to 414) and B) the estuary including the strata added in 2008 (851, 852, 854, 855). Boxplot graphical representation: the line inside the box represents the median, the box extends from the 25th to 75th percentiles, and the whiskers (vertical lines on either side of the box) extend from the percentiles 5 to 95. The dashed horizontal line on each of the graphs represents the series mean.

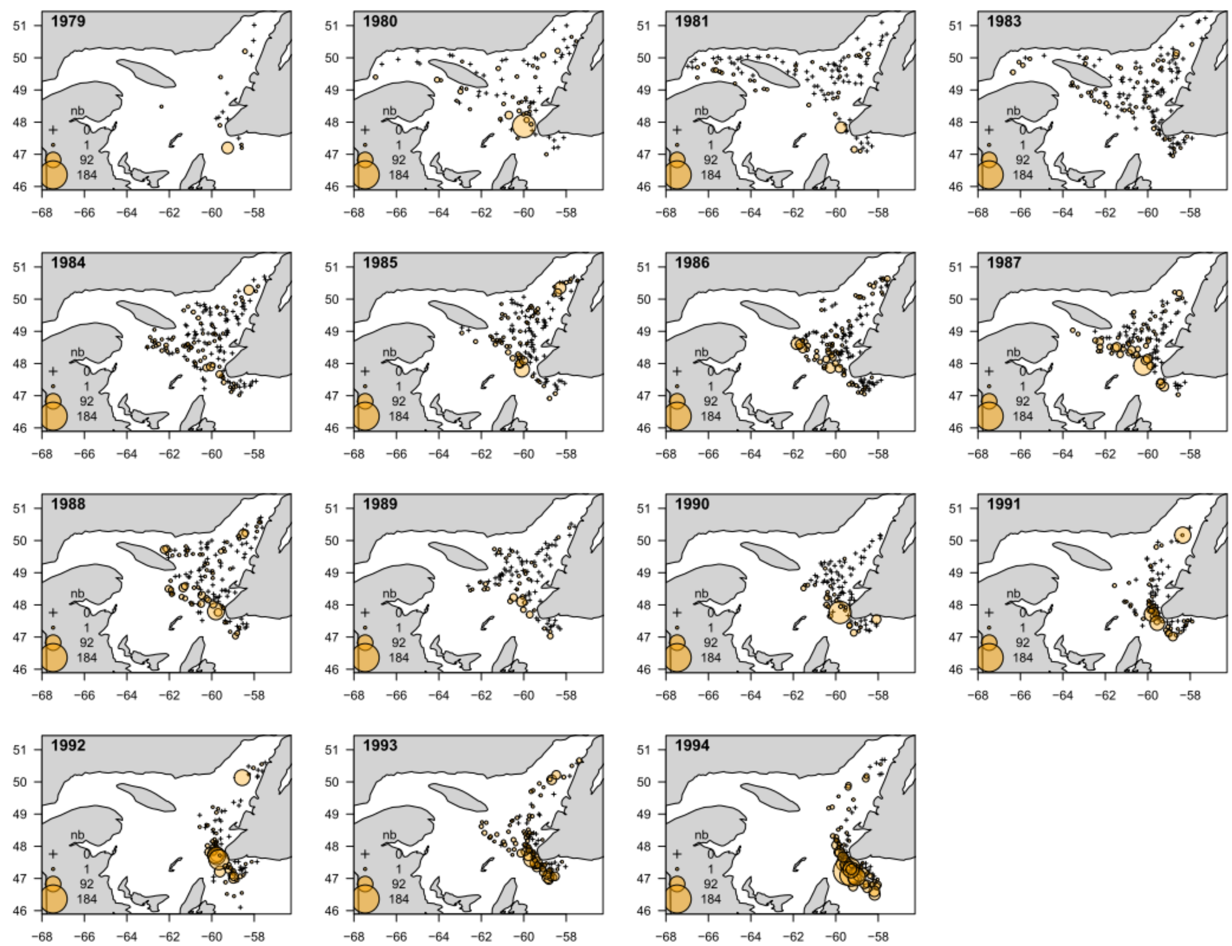

Figure 44. Annual Greenland halibut catch rates (number / 1.75 nm standard tow) in the 1978 – 1994 Gadus Atlantica winter survey.

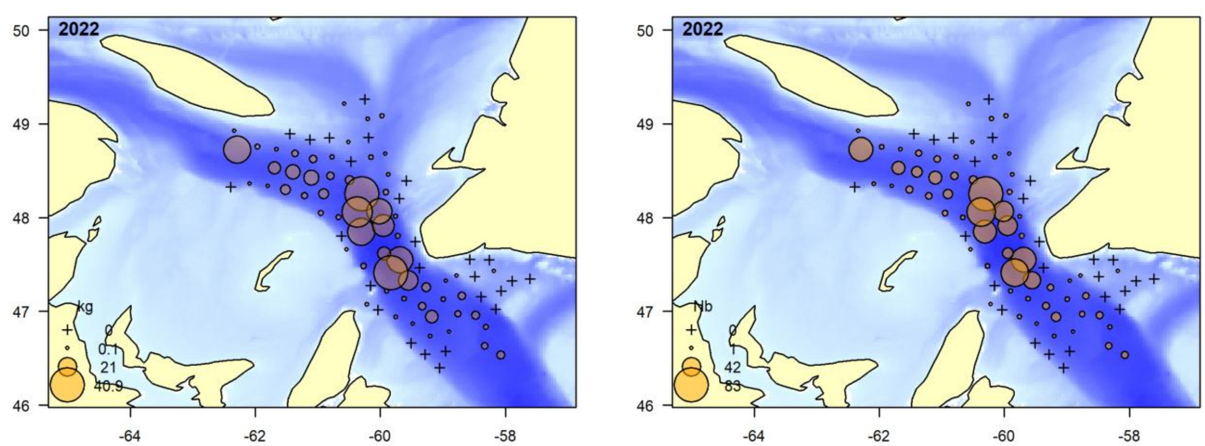

Figure 45. Distribution of GH catch rates (kg and number / 0.75 nm standard tow) in the 2022 winter survey.

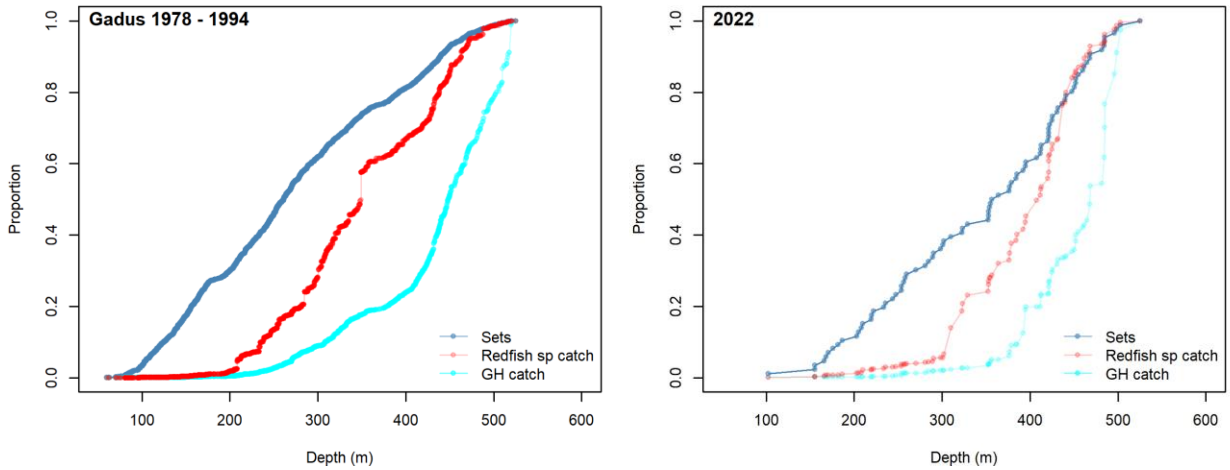

Figure 46. Cumulative proportion of catch (by weight) of Greenland halibut (light blue) and redfish (S. Mentella and Fasciatus) in winter surveys performed by the Gadus Atlantica (left) and Mersey Venture (right), and cumulative proportion of stations sampled (dark blue) as a function of depth.

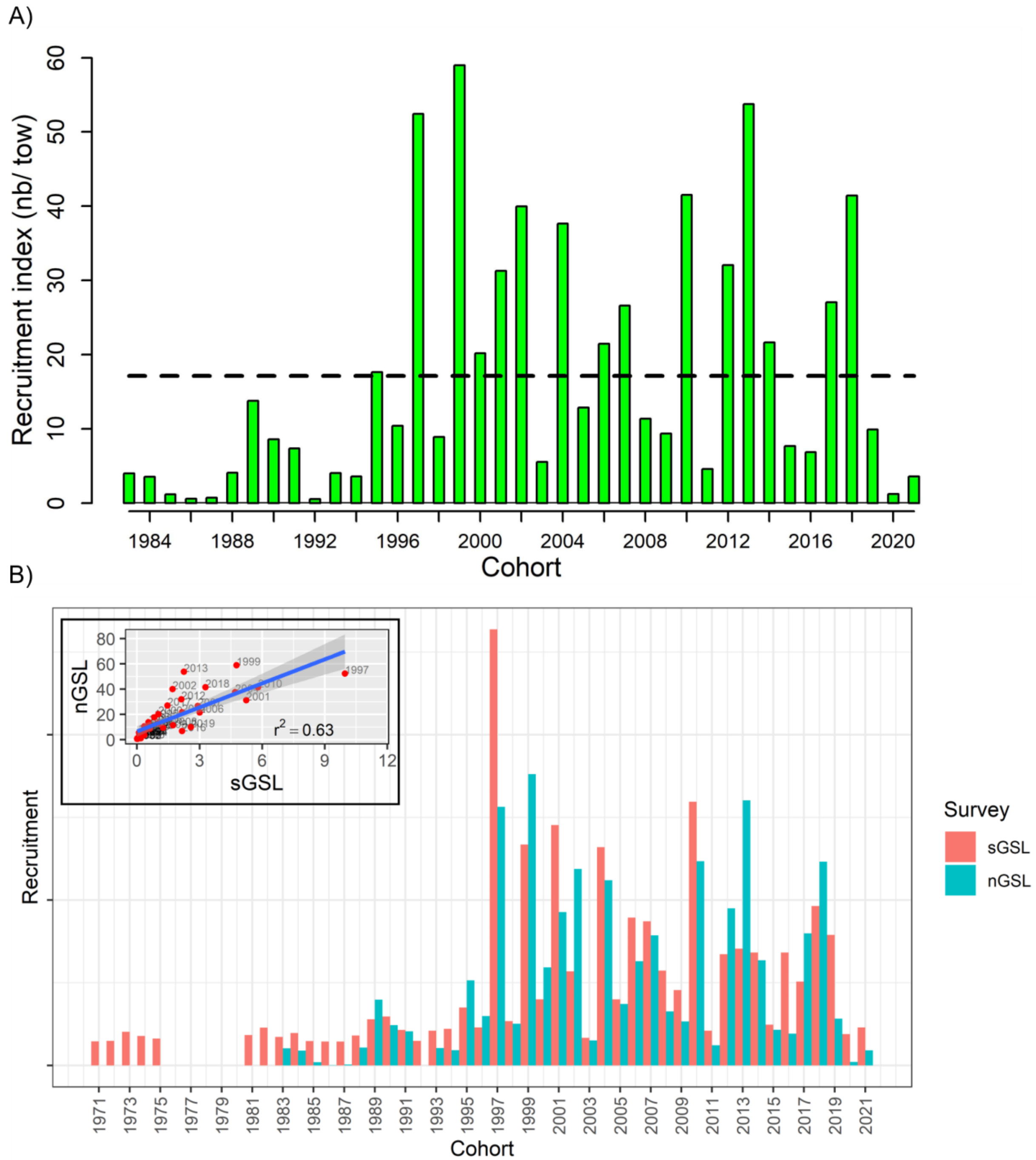

Figure 47. Recruitment indices for Greenland halibut estimated by the annual abundance of 12-21 cm (age 1) fish on the DFO A) nGSL survey. B) Comparison of recruitment indices for Greenland halibut from the DFO nGSL and sGSL surveys. The box shows the relationship between the annual cohort abundance estimated by each survey.

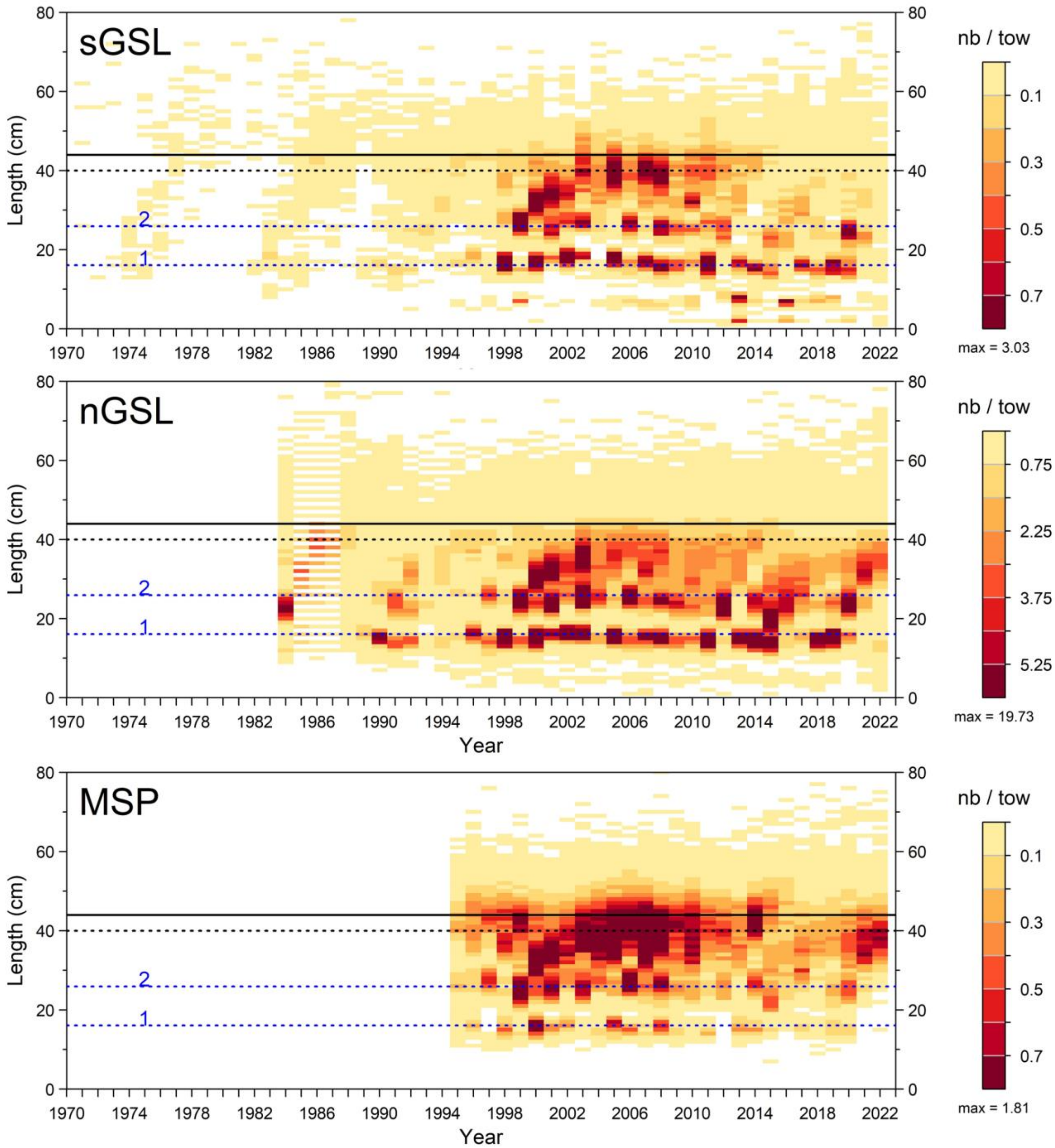

Figure 48. Length frequency distributions observed during DFO sGSL (1971-2022), and nGSL (1984-2022) surveys and MSP (1995-2022) survey. The blue dotted lines indicate the average lengths expected for 1- and 2-year-old fish. Black dotted lines at 40 cm indicate the limit for biomass indices for fish over 40 cm. Black solid lines at 44 cm indicate the minimum size of the small fish protocol.

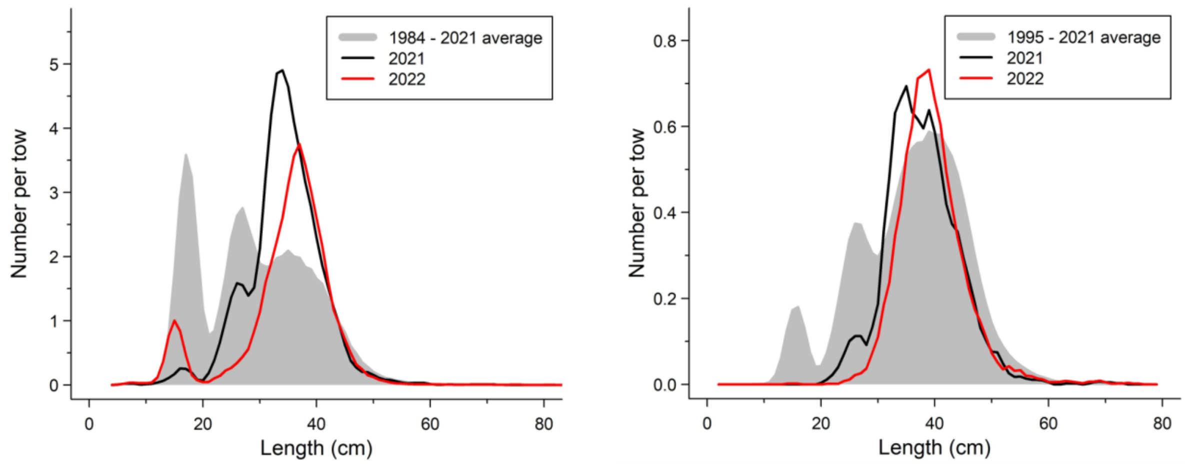

Figure 49. Length frequency distributions (mean number per tow) observed in the DFO nGSL (left) and mobile sentinel (right) surveys for Greenland halibut.

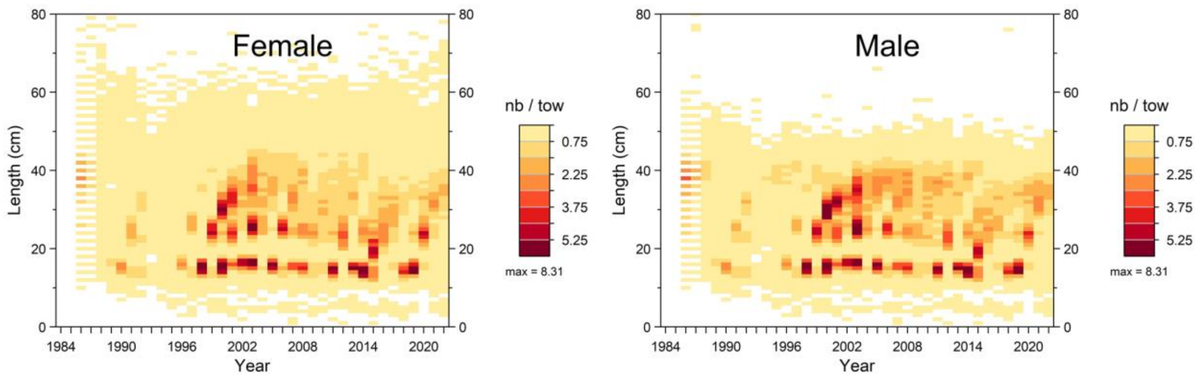

Figure 50. Length frequency distribution by sex and year in the nGSL survey (1986-2022).

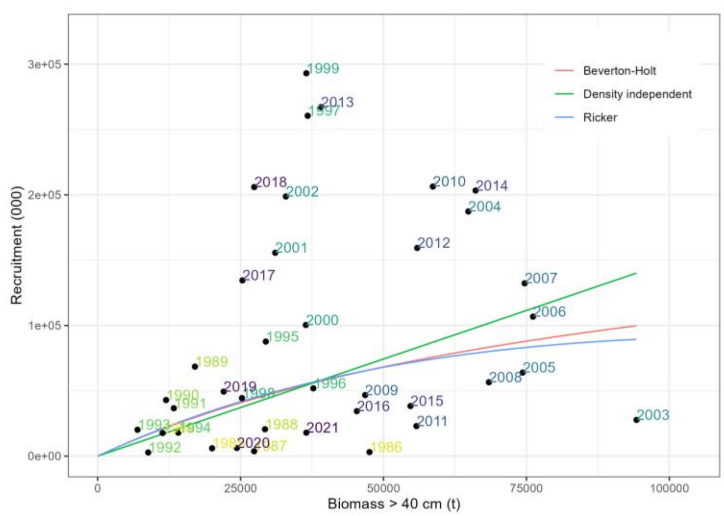

Figure 51. Relationship between biomass of Greenland halibut greater than 40 cm and recruitment (number of 1 year old individuals) estimated in the nGSL survey. The predictions of the density independent, Beverton-Holt and Ricker models are presented as lines.

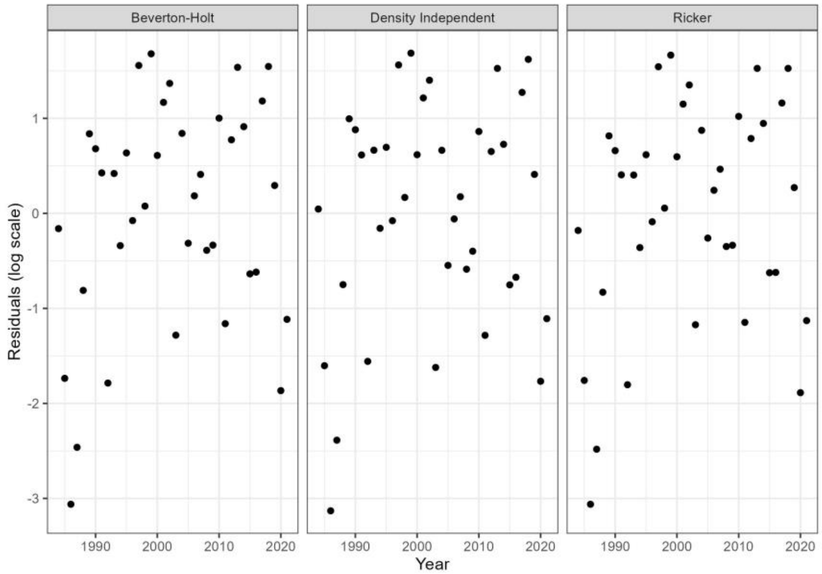

Figure 52. Residuals of the stock-recruitment relationships (log scale) as a function of year.

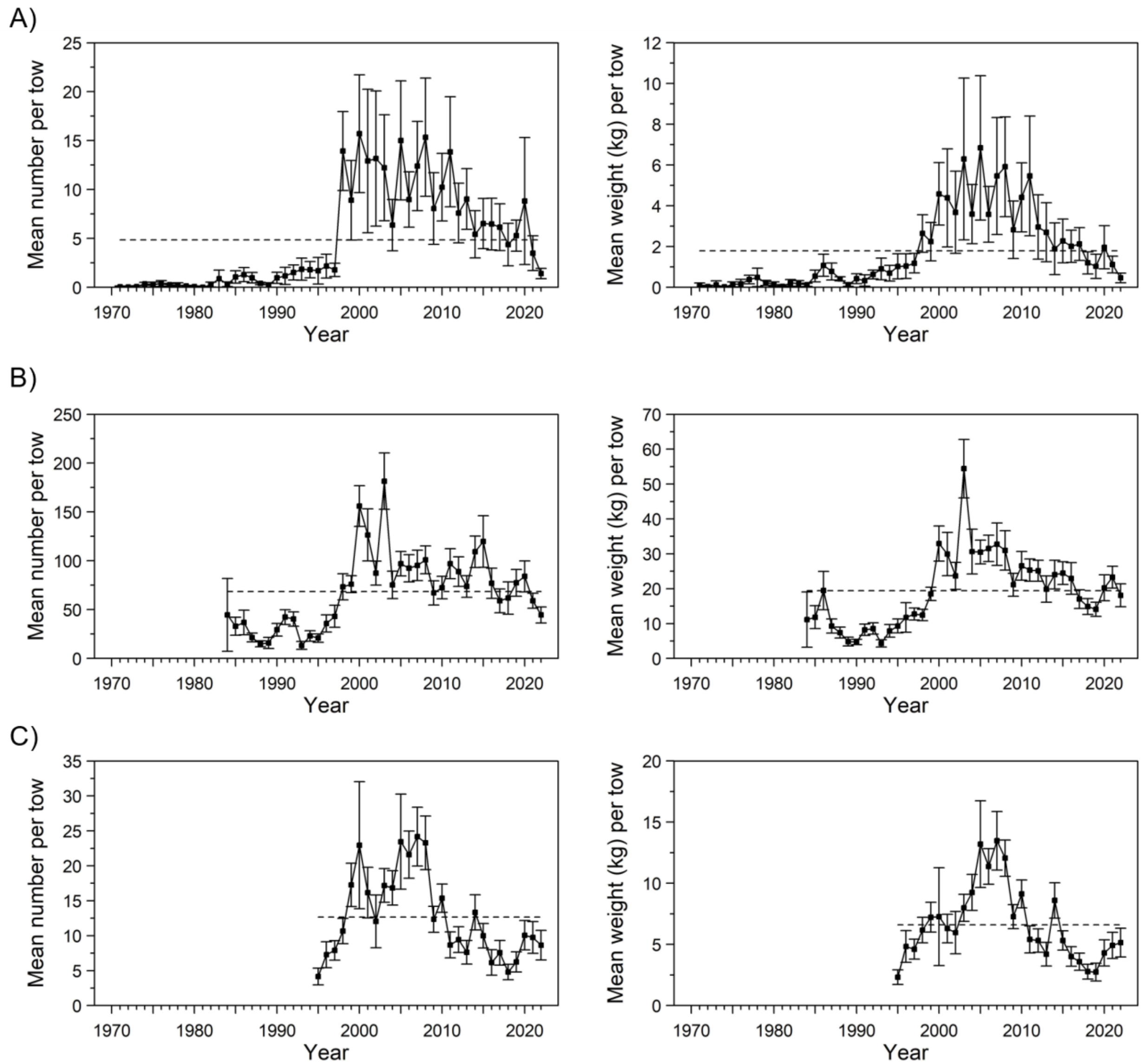

Figure 53. Mean number and weight per tow for Greenland halibut observed in A) the sGSL (1971-2022), B) the nGSL (1984-2022) and, C) the mobile sentinel (1995-2022) surveys. Error bars indicate the 95% confidence interval. Horizontal lines indicate average for each series.

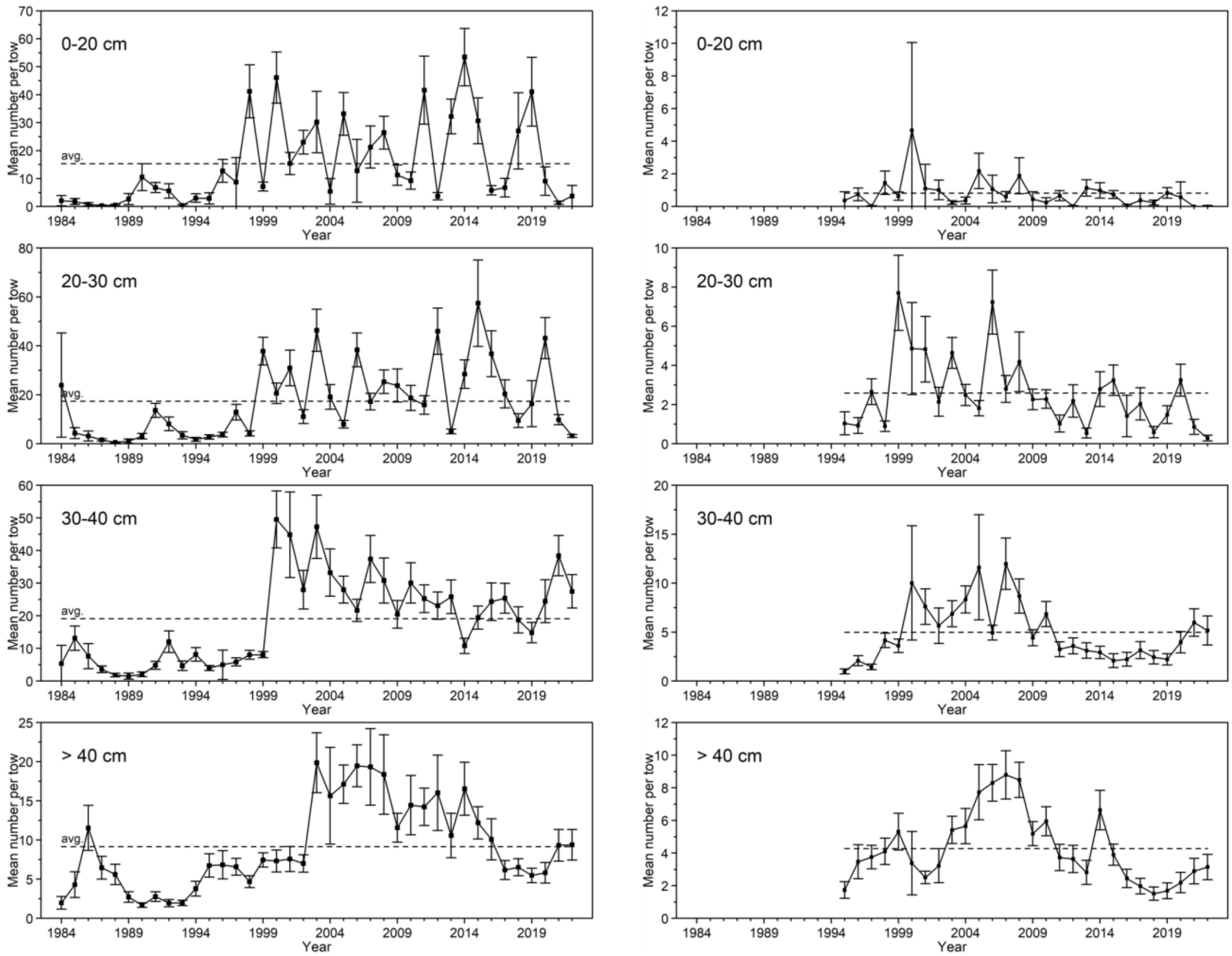

Figure 54. Greenland halibut abundance indices (mean number per tow) for different size categories observed in the nGSL (left) and mobile sentinel (right) surveys.

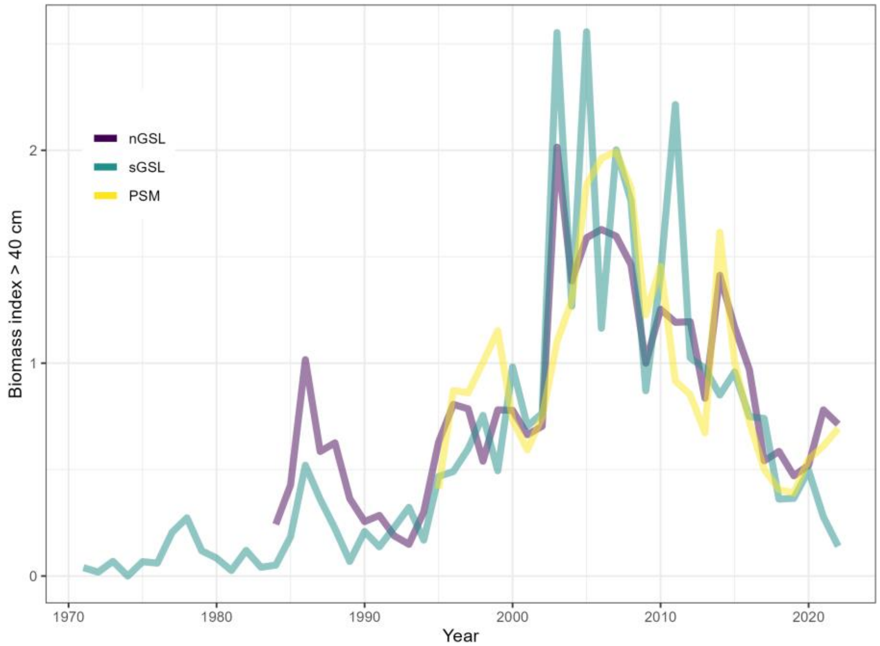

Figure 55. Normalized biomass (divided by the mean) indices for Greenland halibut > 40 cm calculated from DFO sGSL, nGSL surveys and MSP surveys.

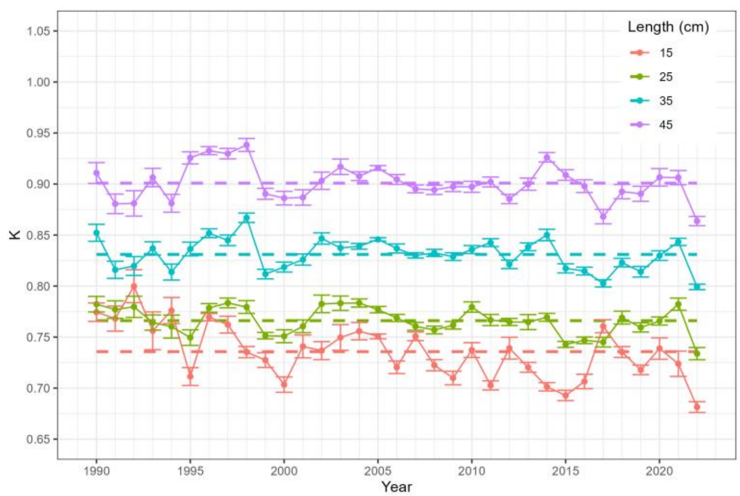

Figure 56. Annual Fulton condition index for 15, 25, 35 and, 45 cm Greenland halibut measured during the DFO nGSL survey. Dotted lines represent time series averages.

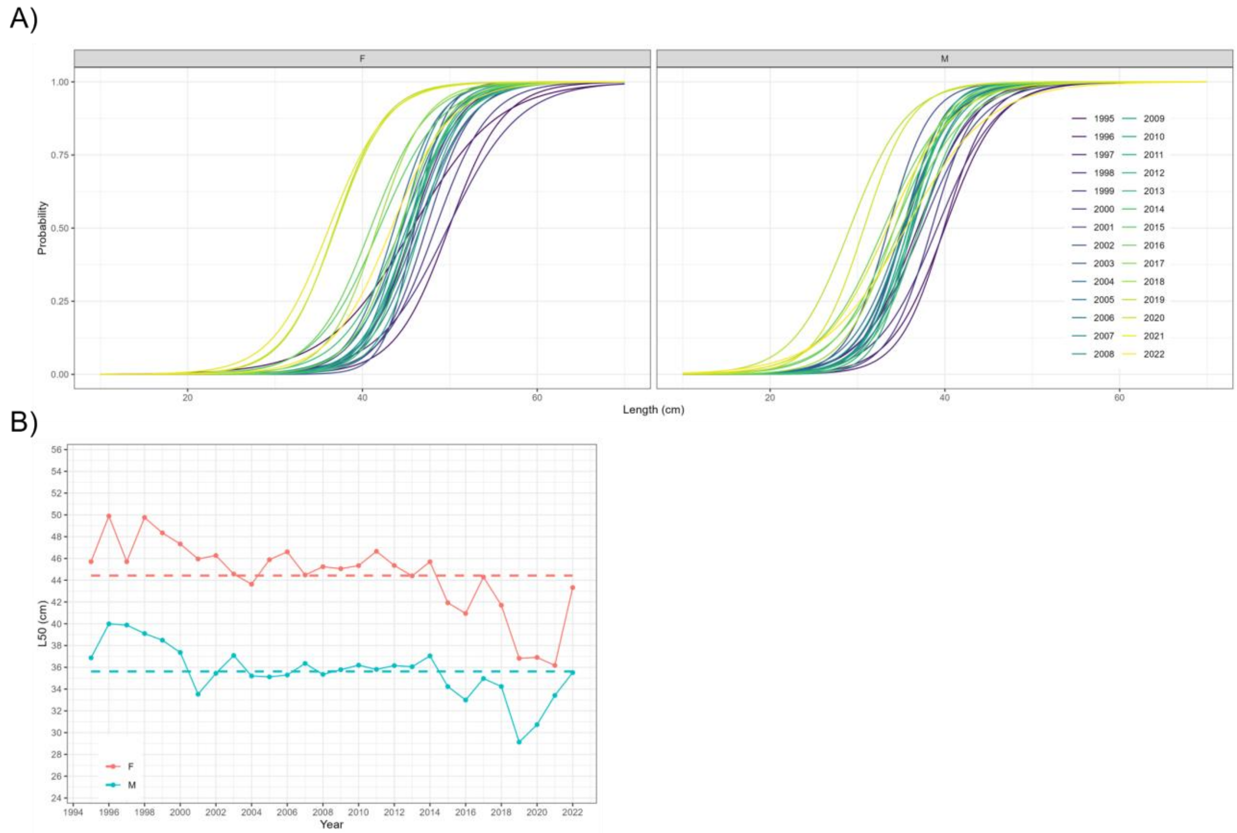

Figure 57. (A) Maturity ogives based on visual determination of the gonad state for male and female Greenland halibut and (B) length at which 50% of male (blue) and female (red) fish are sexually mature (L_{50}). These values are based on data collected during the DFO nGSL survey.

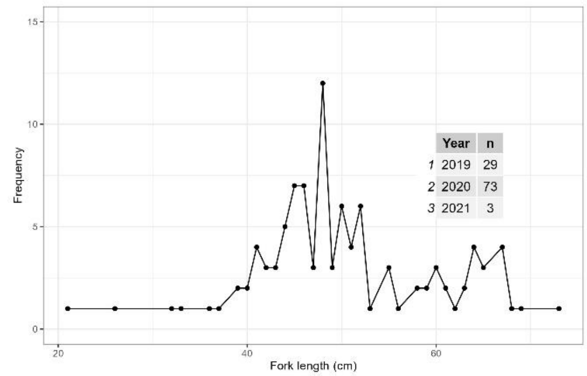

Figure 58. Greenland halibut length frequency distribution from the Atlantic halibut longline survey (2019 to 2021) and number of Greenland halibut measured by year.

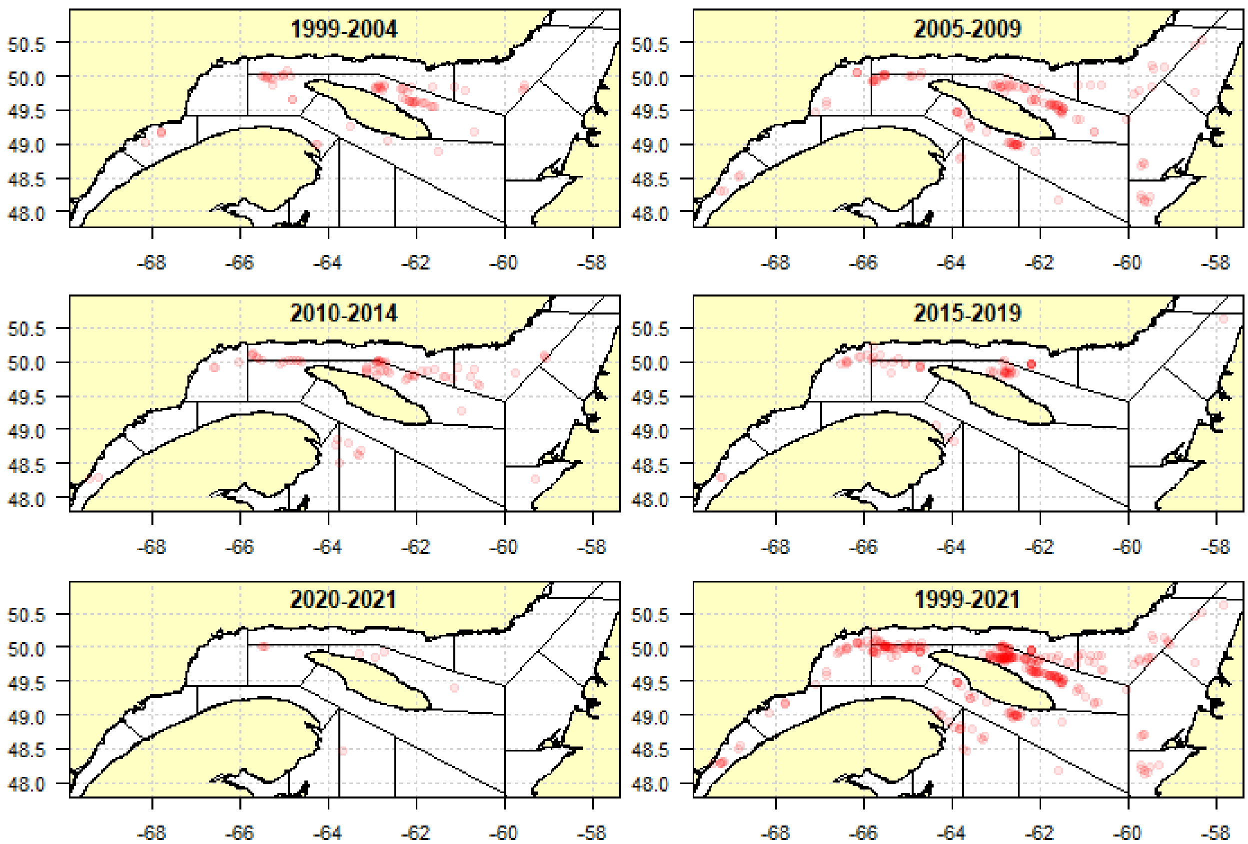

Figure 59. Spatial distribution by year blocks of longline hauls where Greenland halibut length were measured by at-sea observers in longline fisheries. White polygons represent NAFO subunits.

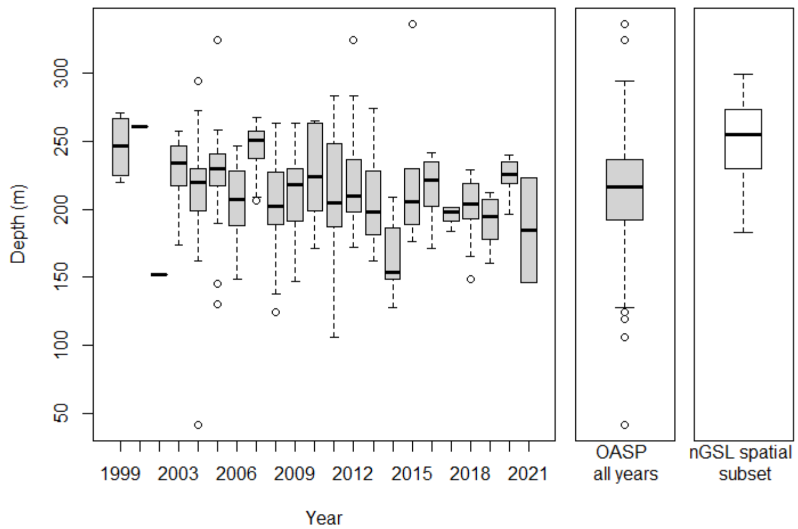

Figure 60. Box and whisker plots of longline at-sea observers haul depths where Greenland halibut length frequency distribution were recorded, by year and for all years, compared with nGSL observations which were spatially subset to match at-sea observer data.

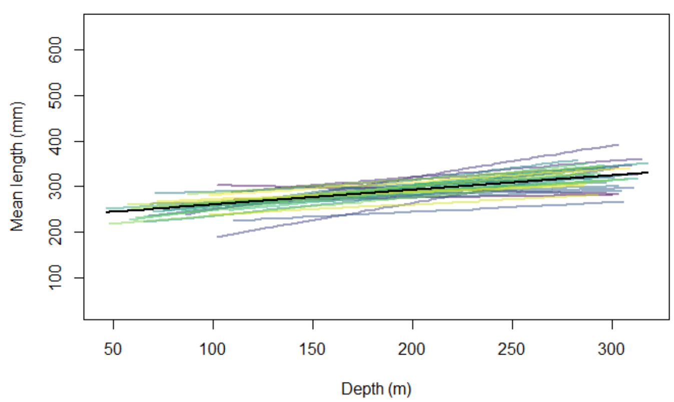

Figure 61. Mean predicted length in the nGSL survey (spatial subset) as a function of depth by year. Colored lines represent year specific predicted values while the black line represents the population level predictions.

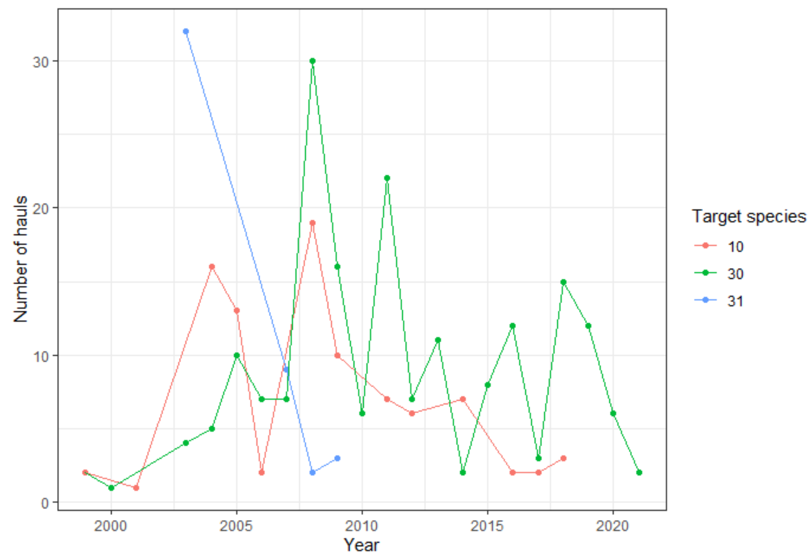

Figure 62. Number of hauls with Greenland halibut measured per year by the at-sea observers in the 4RST longline fisheries targeting cod (10), Atlantic halibut (30) and Greenland halibut (31).

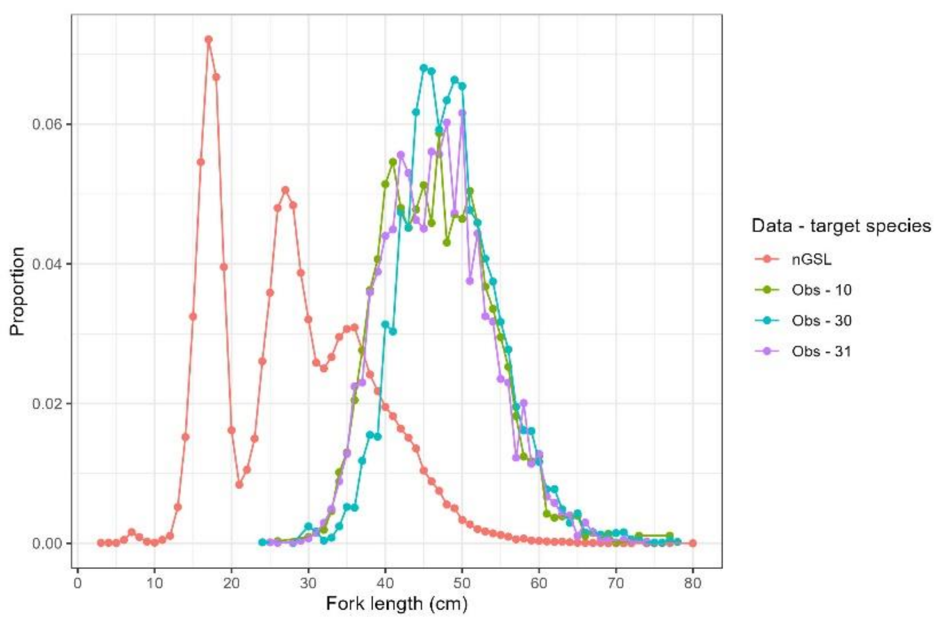

Figure 63. Greenland halibut relative length frequency distributions (proportions at length) from the nGSL bottom trawl survey, as well as from at-sea observer data in longline fisheries targeting Atlantic cod (10), Atlantic (30) and Greenland halibut (31).

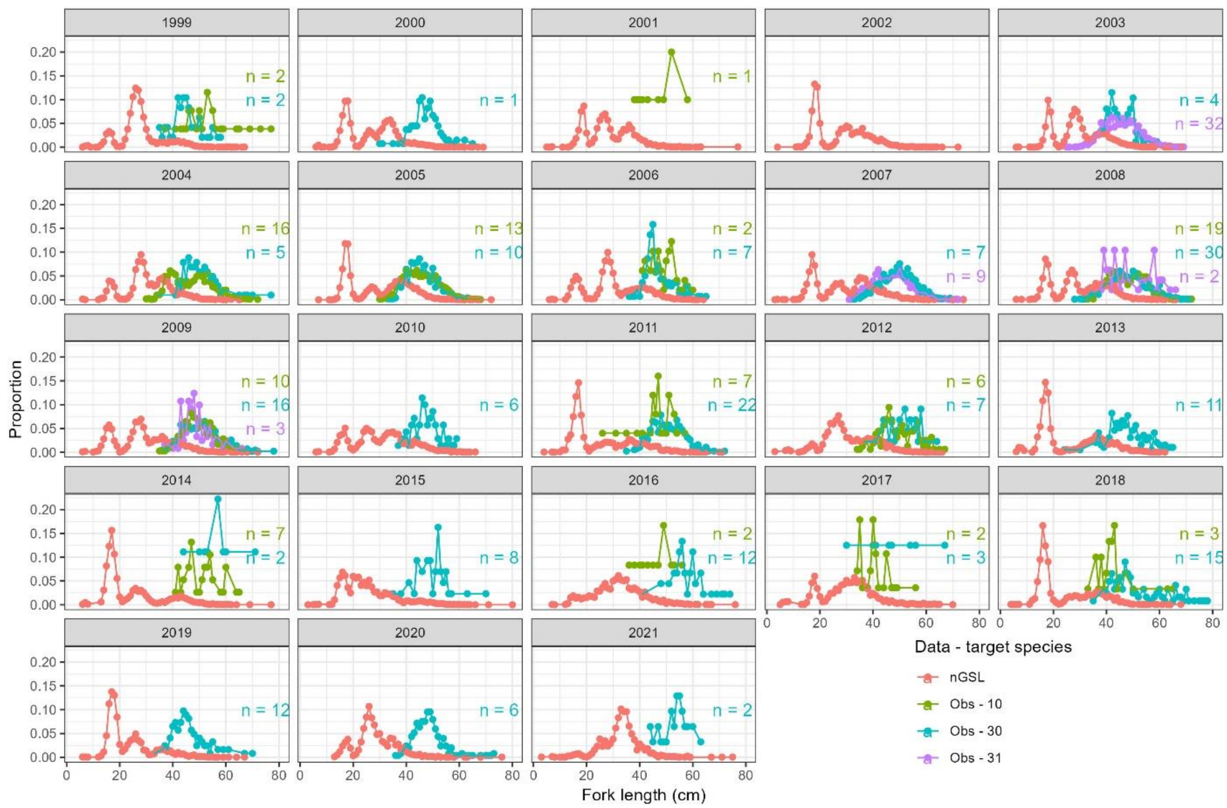

Figure 64. Greenland halibut length frequency per set/haul in the nGSL survey and at-sea observer data for longline fisheries targeting Atlantic cod (10), Atlantic (30) and Greenland halibut (31). Number of longline hauls for which Greenland halibut length data was recorded is indicated on the right side of each panel.

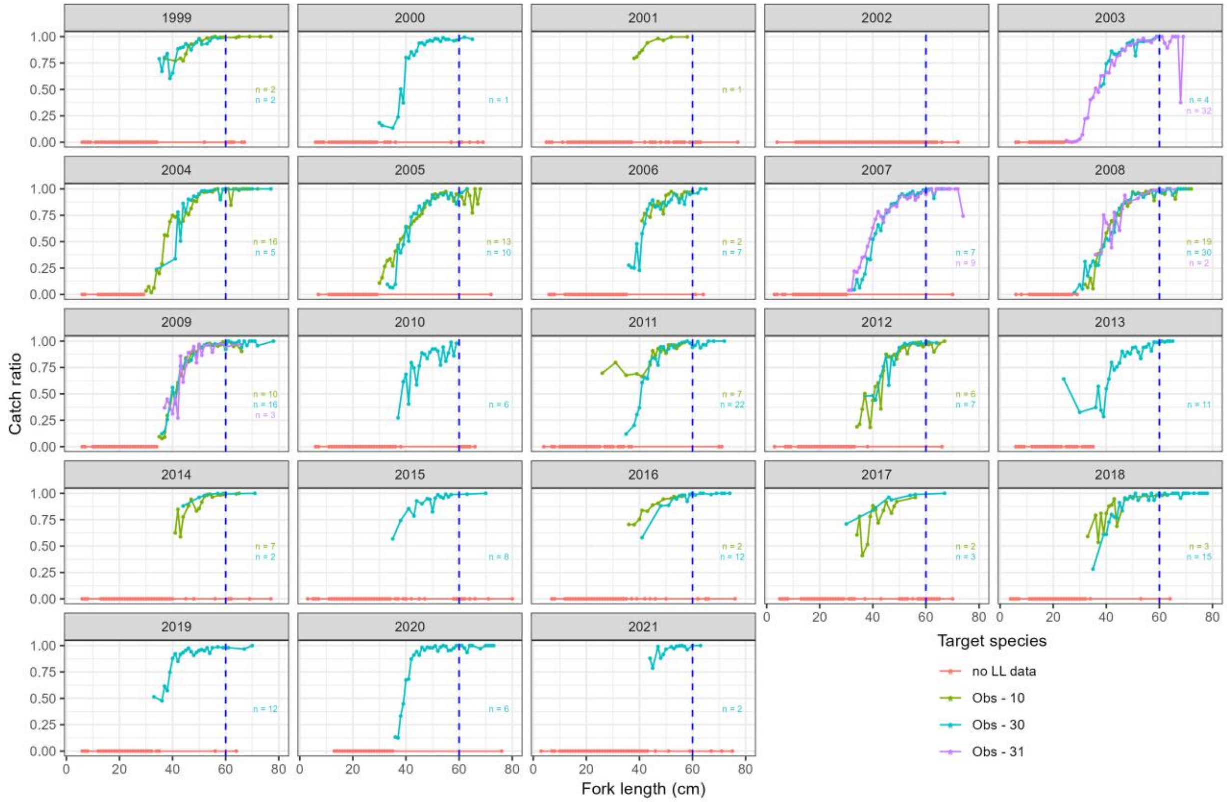

Figure 65. Catch at length ratios between longline at-sea observer data and nGSL bottom trawl survey. The ratios are calculated for each length bin as (mean longline catch proportion)/(trawl catch prop + longline catch prop). The blue vertical dashed line represents the length at which longline length frequency distribution start to decrease. The red dots represent length classes for which no at-sea observer longline length frequency data were available, leading to a ratio of 0.

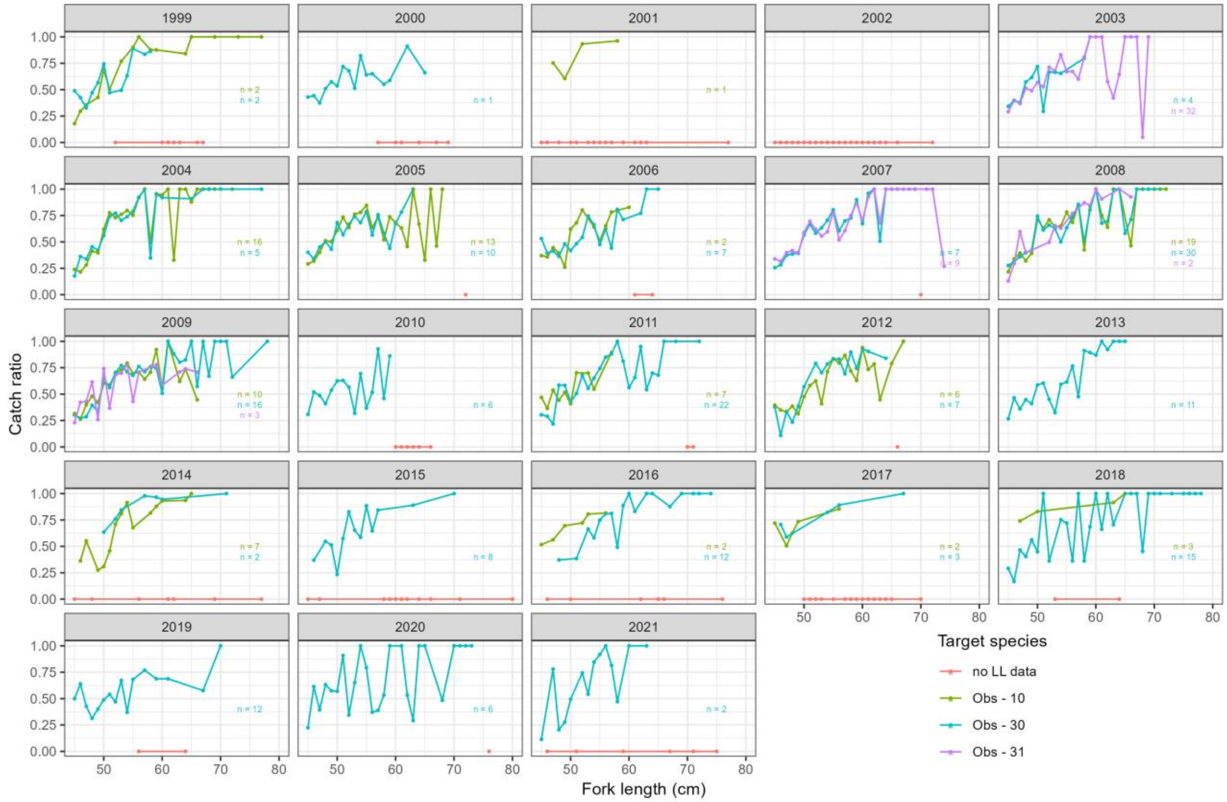

Figure 66. Catch ratios between longline at-sea observer data and nGSL bottom trawl survey excluding fish of length < 45 cm. The proportions are calculated for each length bin as (longline catch proportion)/(trawl catch prop + longline catch prop). The red dots represent length classes for which no at-sea observer longline length frequency data was available, leading to a ratio of 0.

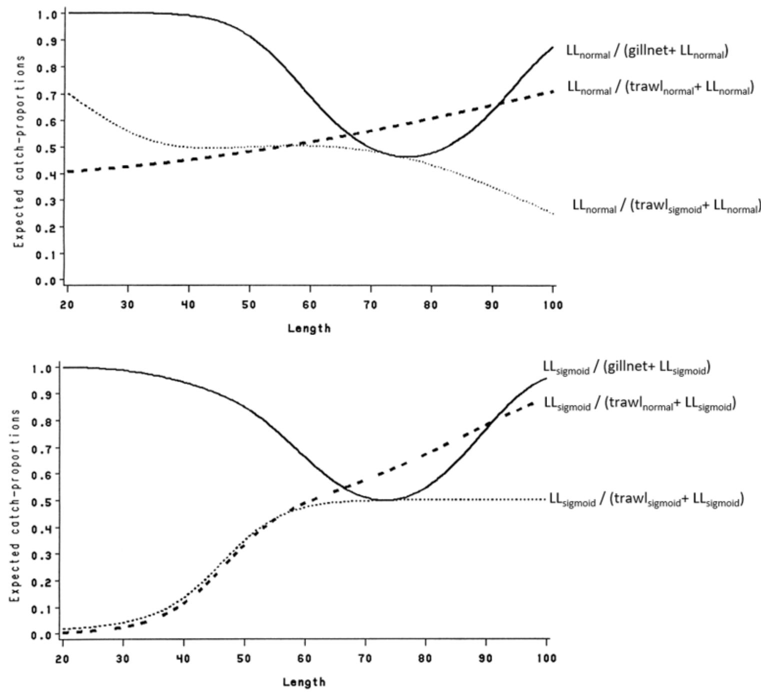

Figure 67 Theoretical catch ratios when longline selectivity is assumed to be normally distributed (top panel) or sigmoid (bottom panel). Modified from Huse et al. (1999).

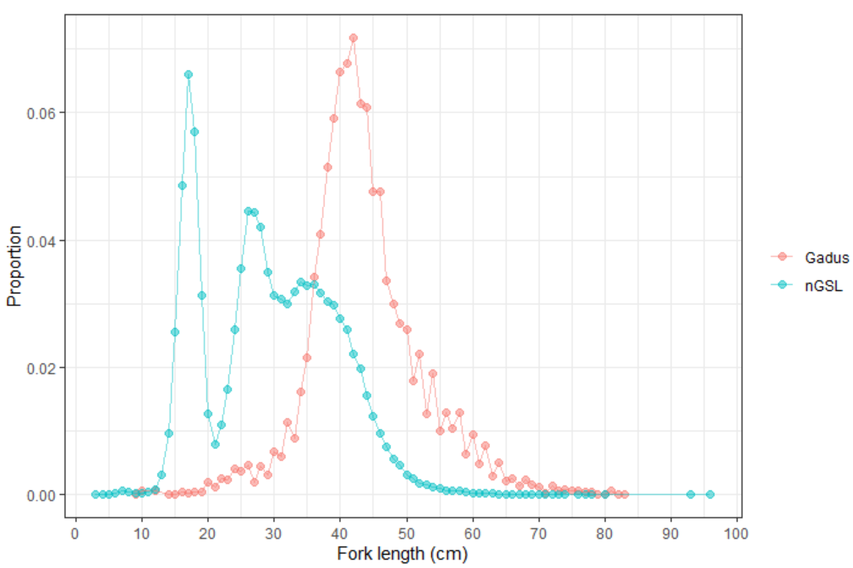

Figure 68. Greenland halibut proportion at length in the Gadus Atlantica (1978 – 1994) and nGSL (1990 – 2021) surveys.

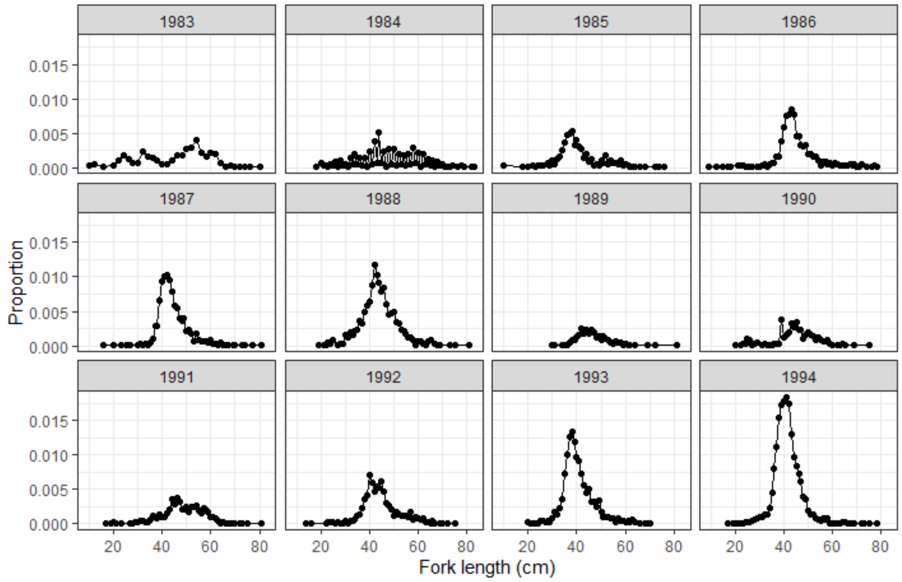

Figure 69. Annual proportion at length of Greenland halibut in the Gadus Atlantica winter bottom trawl survey.

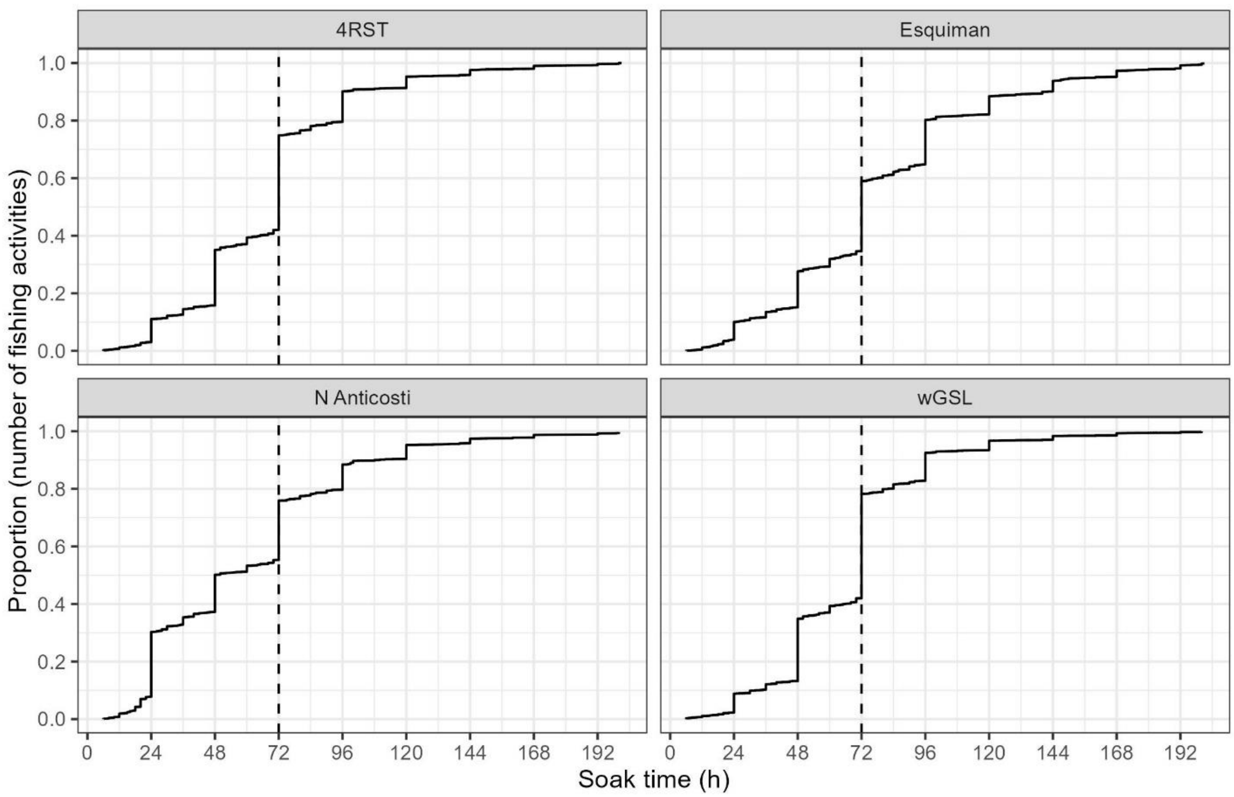

Figure 70. Cumulative proportion of fishing activities as a function of soak time and fishing area.

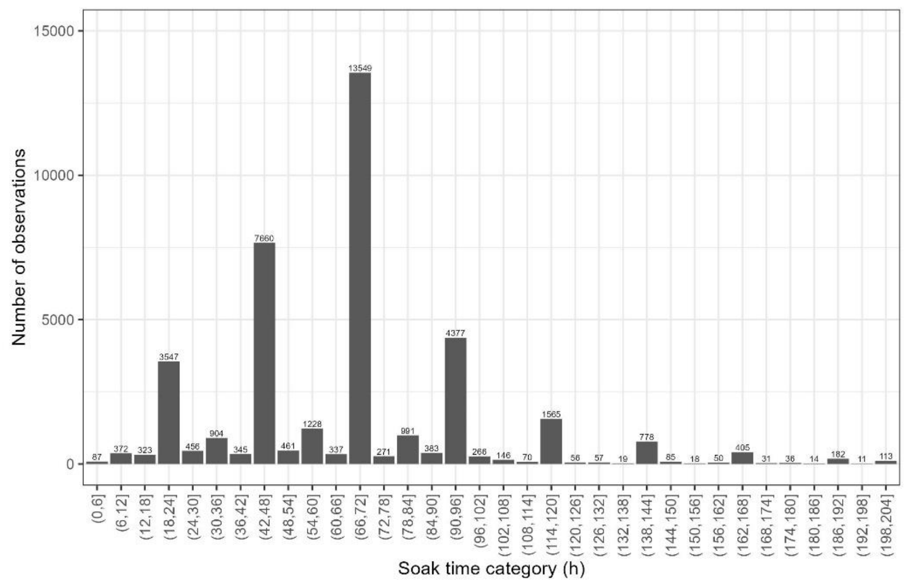

Figure 71. Number of observations per 6 hours soak time category in the 4RST Greenland halibut gillnet ZIFF data. Number of observation is indicated above each bar.

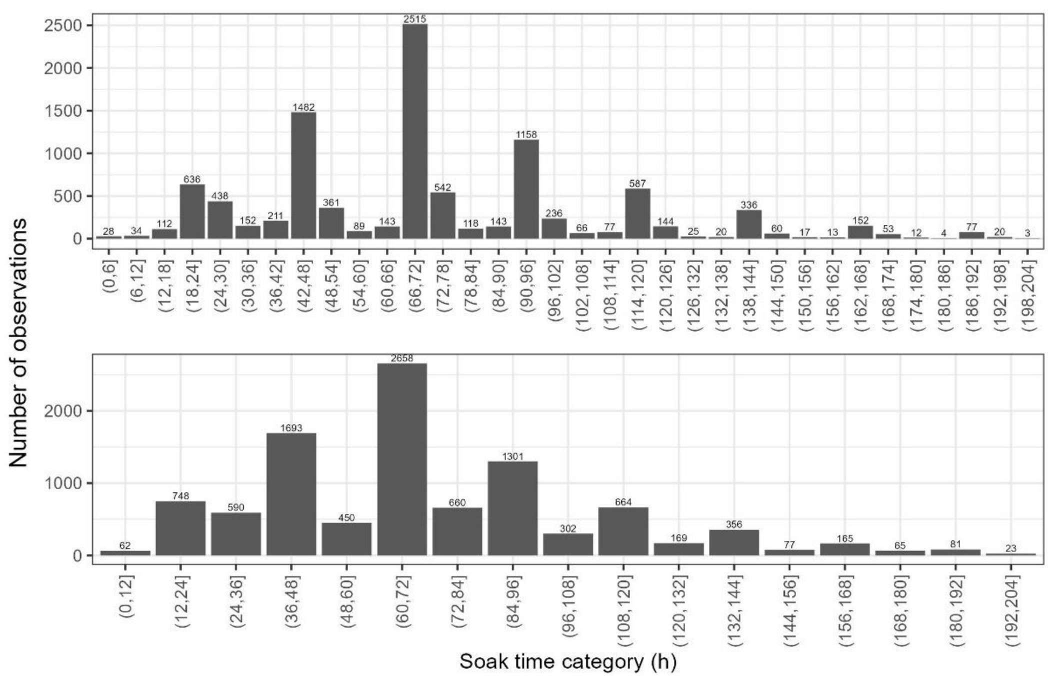

Figure 72. Number of observations per 6 (top) and 12 (bottom) hours soak time category in the 4RST directed Greenland halibut gillnet at-sea observer data. Number of observation is indicated above each bar.

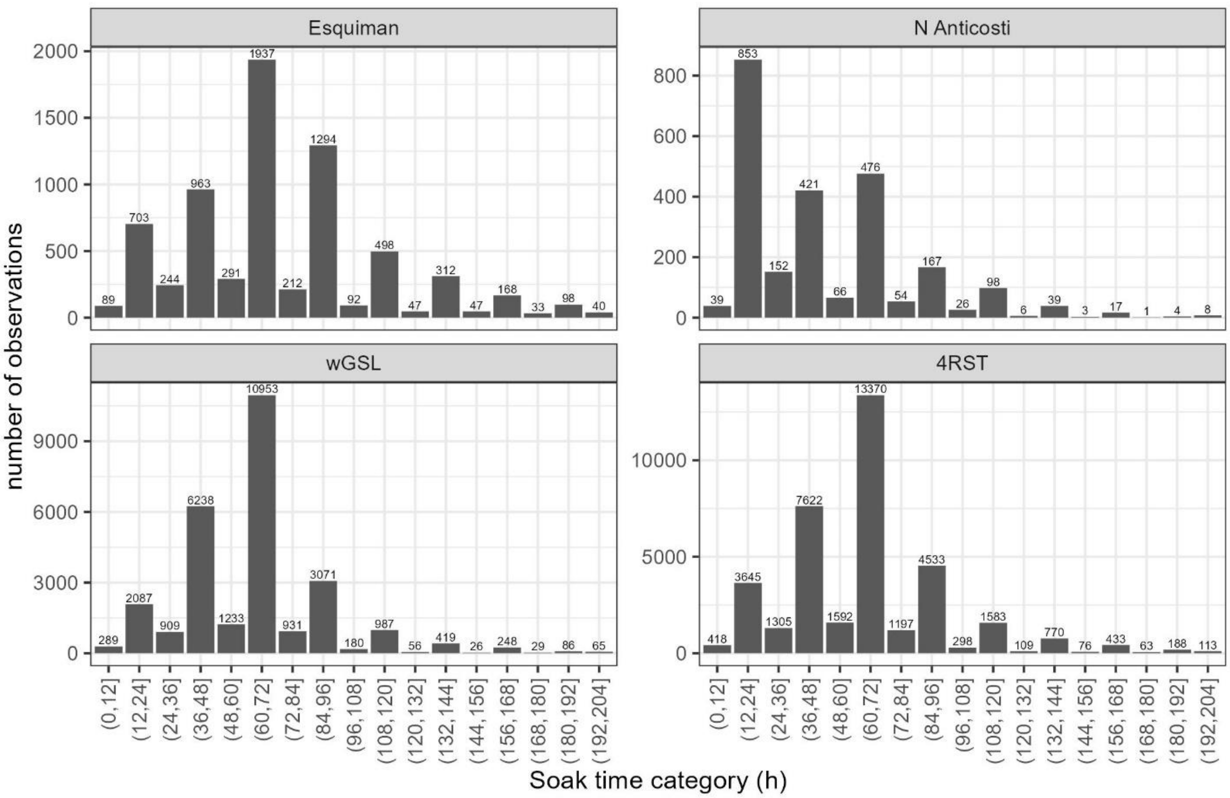

Figure 73. Number of observations per 12 hours soak time category by fishing area in the 4RST directed Greenland halibut gillnet fishery (ZIFF data). Number of observations is indicated above each bar.

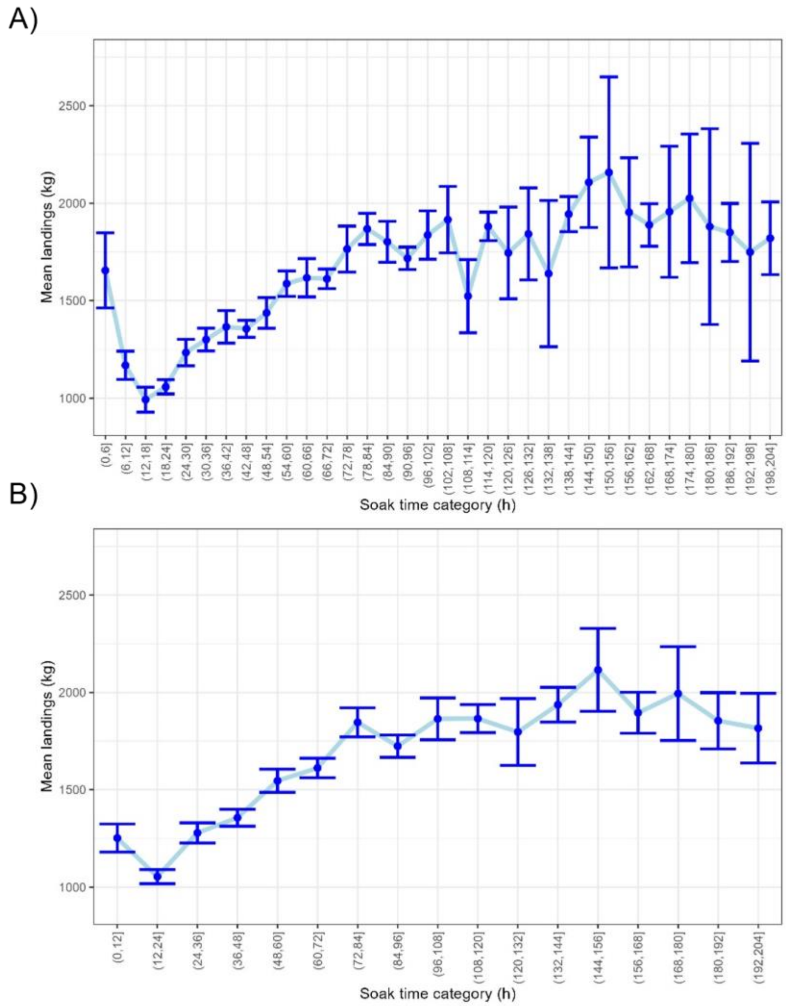

Figure 74. Predicted mean landings as a function of (A) 6 or (B) 12 hours soak time categories from the all zones Tweedie models fitted to the ZIFF data. Predictions are for 90 gillnets. Error bars represent approximate 95% confidence intervals.

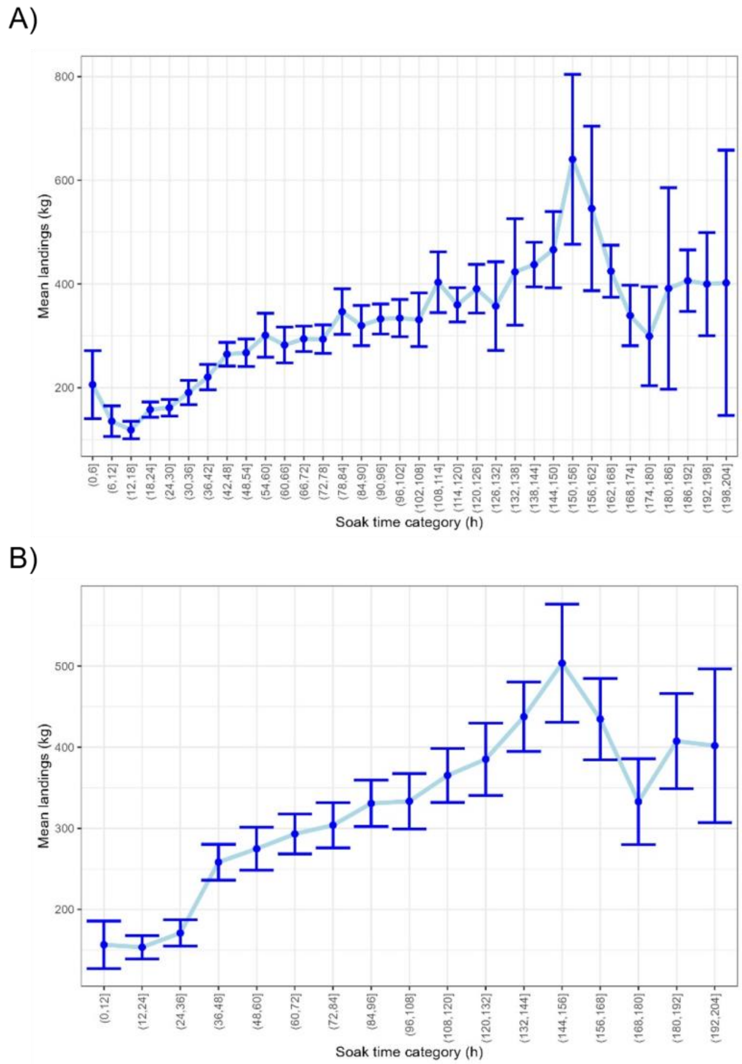

Figure 75. Predicted mean landings as a function of (A) 6 or (B) 12 hours soak time categories from the Tweedie models fitted to the at-sea observer data. Predictions are for 90 gillnets. Error bars represent approximate 95% confidence intervals.

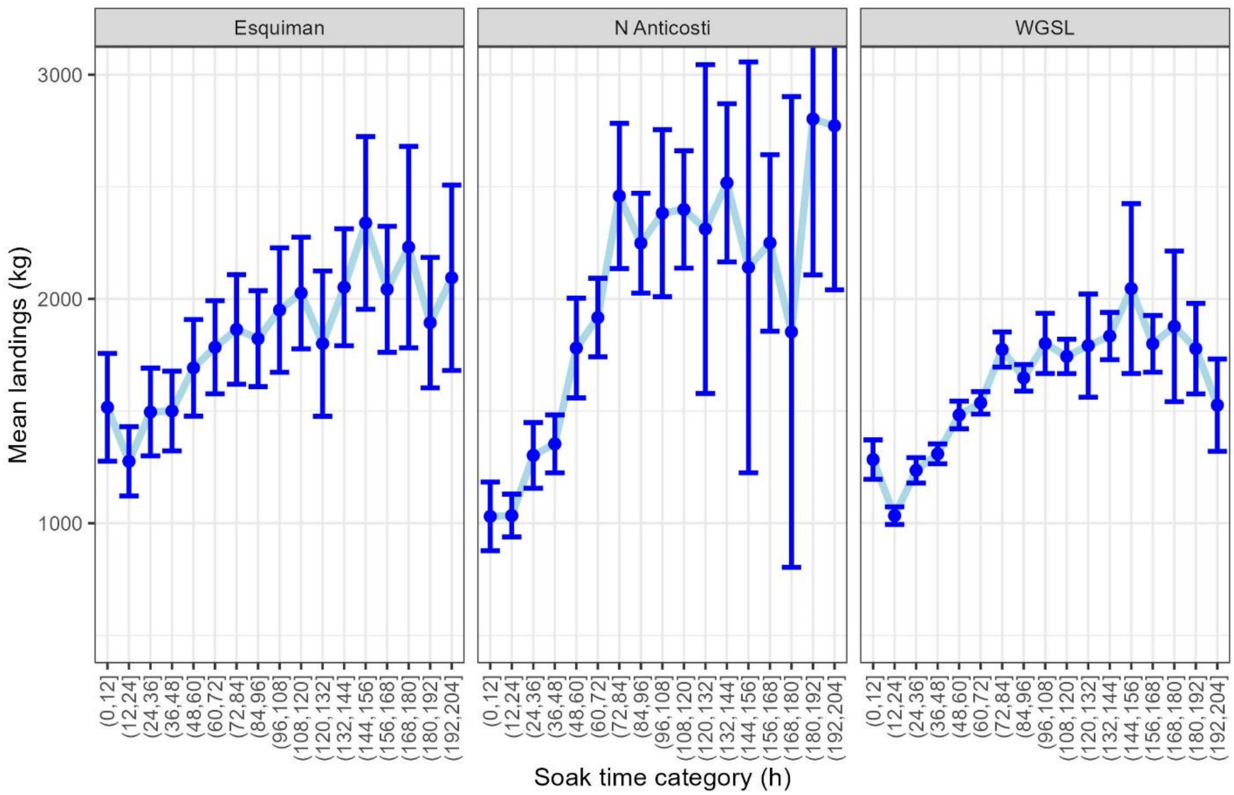

Figure 76. Predicted mean landings as a function of 12 hours soak time categories from the Esquiman, north Anticosti and western GSL Tweedie models fitted to the ZIFF data. Predictions are for 90 gillnets. Error bars represent approximate 95% confidence intervals.

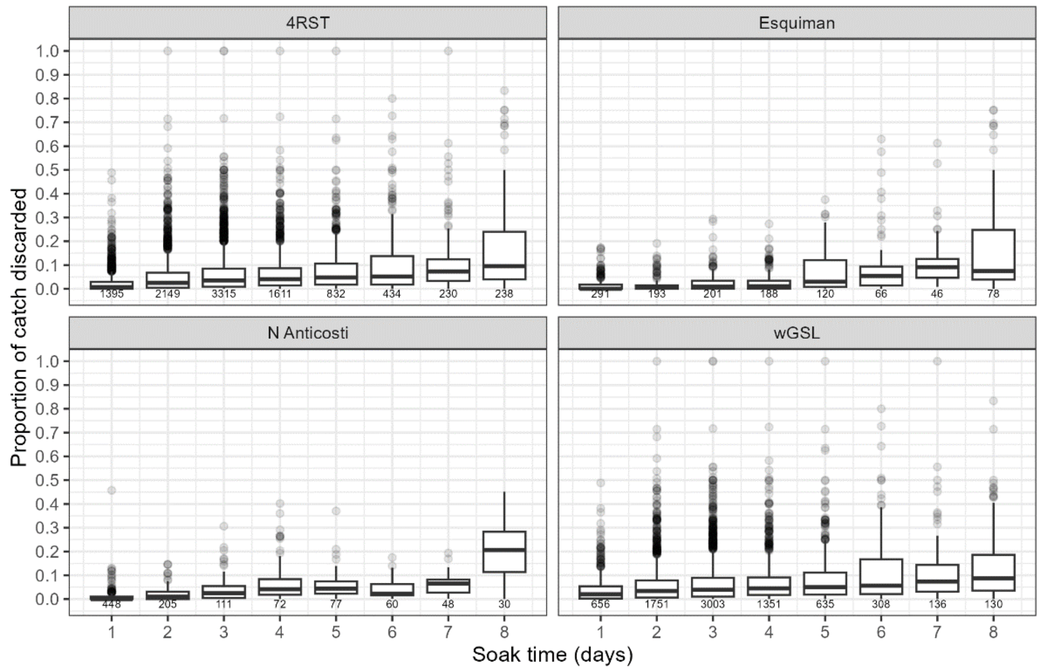

Figure 77. Boxplots of the proportion of Greenland halibut catch discarded as a function of soak time (times rounded to integer days) and fishing area in the at-sea observer database for NAFO 4RST when GH is the target species. Based on comments in the records, discards constitute Greenland halibut unfit for human consumption. Note that category 1 is for ≤1 day and 8 is for ≥8 days. Number of observations is indicated below each boxplot.

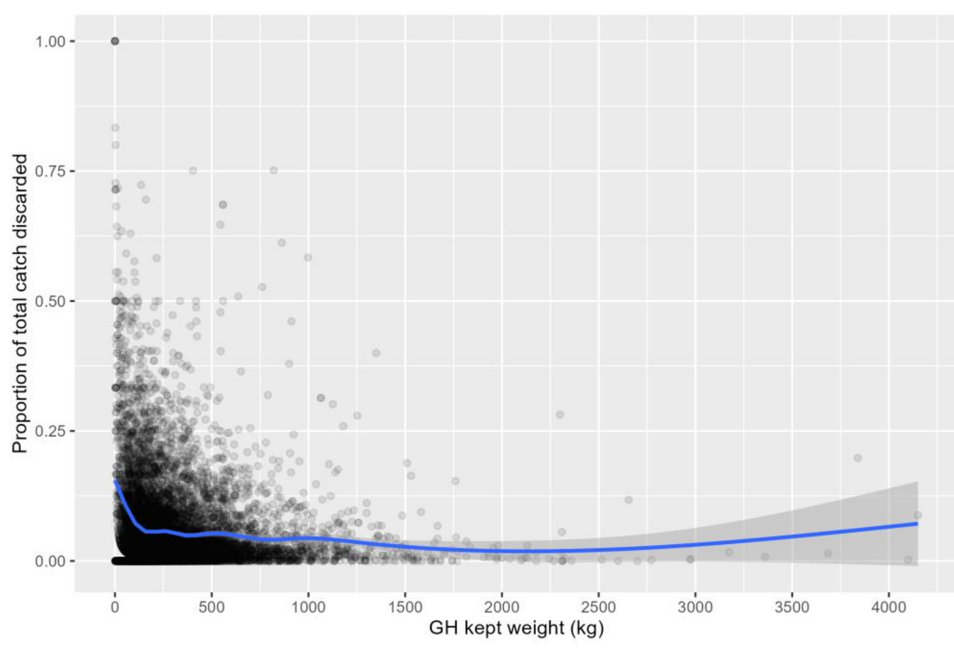

Figure 78. Proportion of GH catch discarded as a function Greenland halibut kept catch biomass in the gillnet Greenland halibut directed fishery. Data source: at-sea observer program.

Figure 79. Photo of Greenland halibut soaked for 24 hours. The fish at the bottom was considered dead fresh even though it would not be consumable, while the other 3 were considered decomposed.

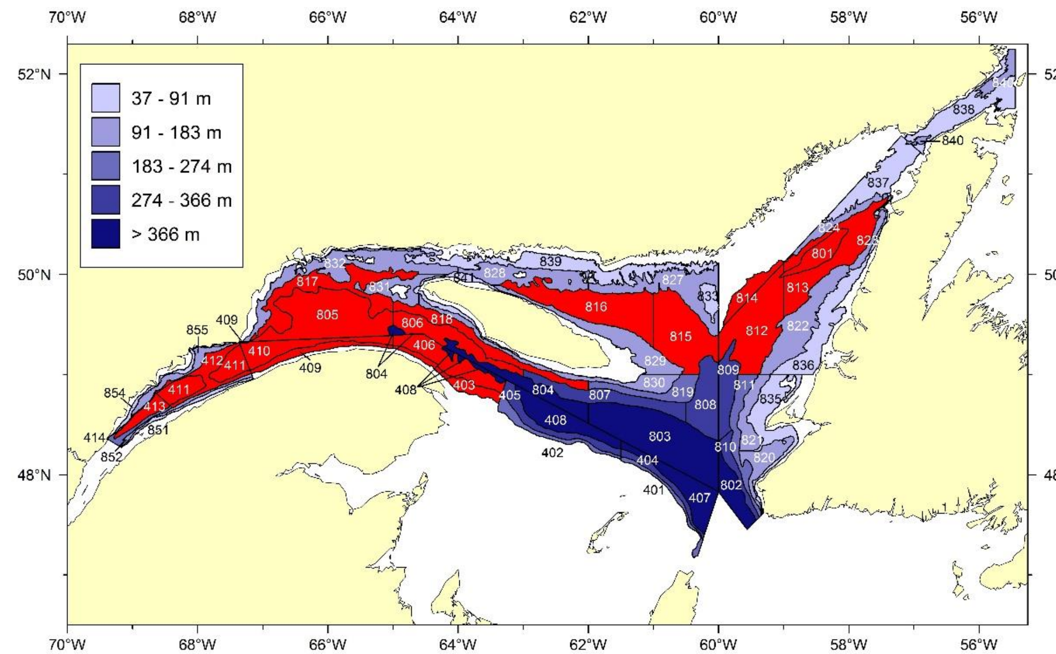

Figure 80. Identification of nGSL DFO survey strata corresponding to the commercial fishing sectors (Western Gulf (403, 406, 409, 410, 411, 412, 413, 805, 806, 817, 818), north Anticosti (815, 816) and, Esquiman (801, 812, 813, 814)).

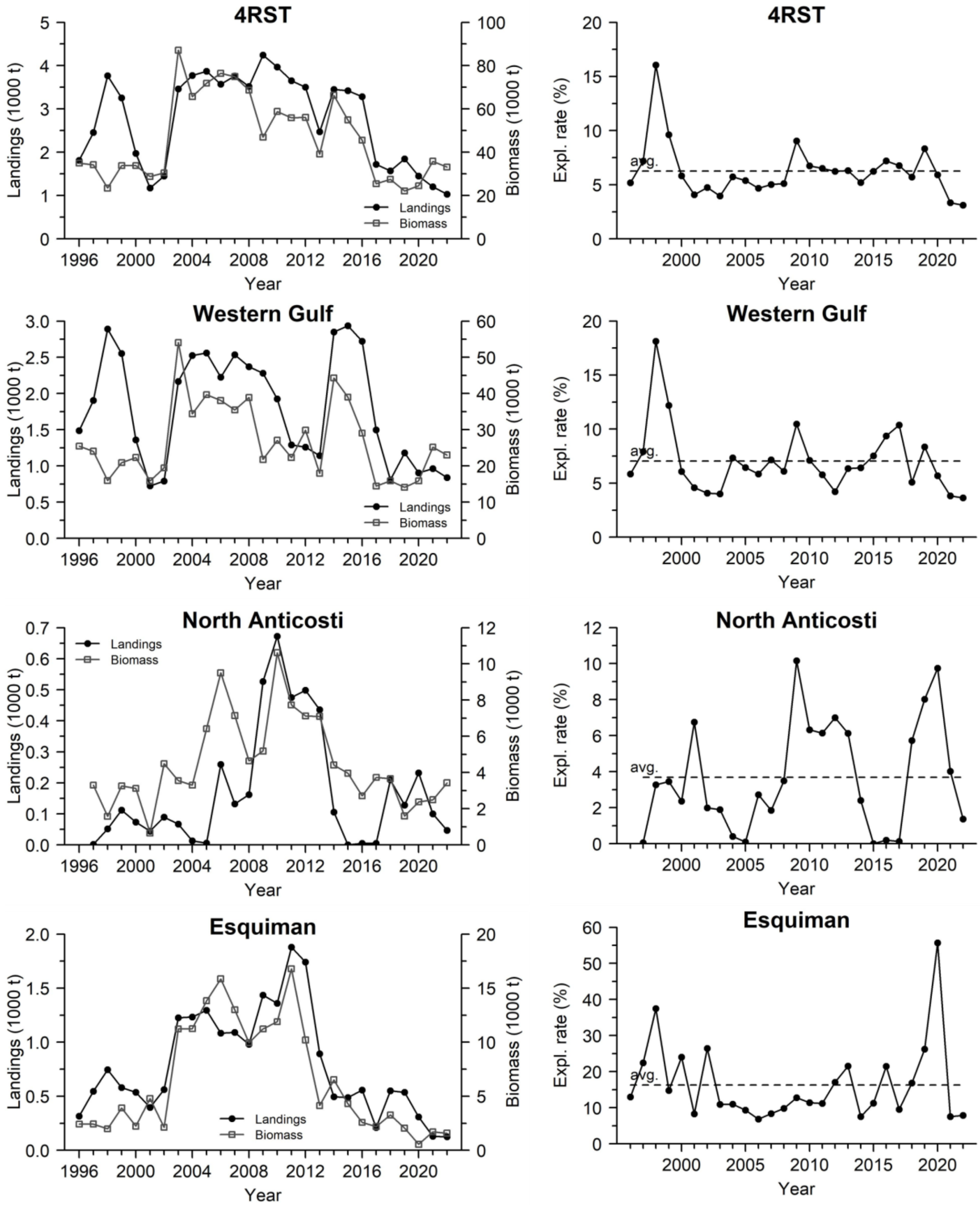

Figure 81. Annual landings and biomass of Greenland halibut > 40 cm (Teleost equivalent) and relative exploitation rate (Expl. Rate (%)) for the entire Gulf (4RST) and by fishing sector.

A)

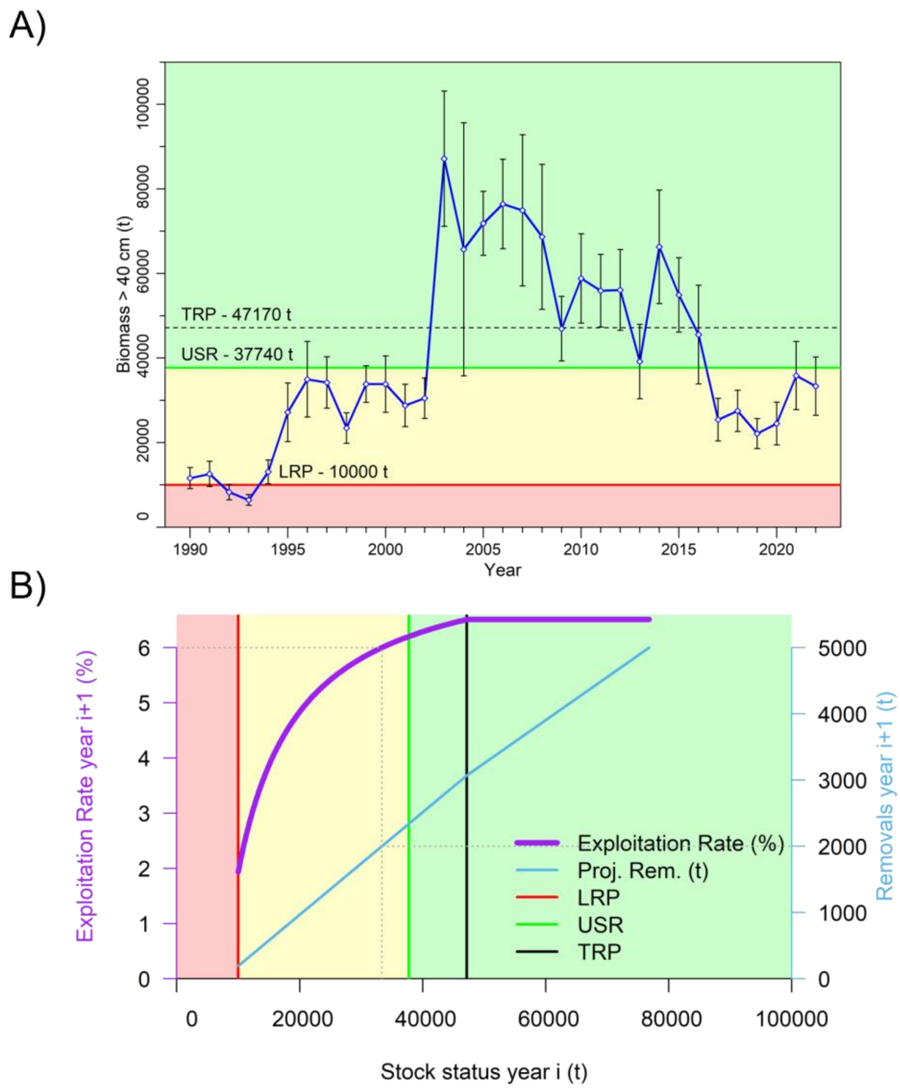

Figure 82. A) Greenland halibut biomass index > 40 cm estimated from nGSL survey. The red horizontal line identifies the limit reference point (LRP) that delineates the critical (red) and cautious (yellow) zones. The horizontal green line is the upper stock reference point (USR) that delineates the cautious and healthy (green) zones. The black line indicates the target reference point (TRP). Error bars indicate the 95% confidence interval. B) Harvest control rule in terms of projected exploitation rate (purple) and removals (blue). The grey dotted lines indicate the projected removal and exploitation rates for the next seasons.

9. ANNEXES

9.1. GREENLAND HALIBUT FULLNESS INDICES AND PREY ABUNDANCE INDEX

This section presents the Greenland halibut stomachs fullness index (Figure A1, Laurie Isabelle, DFO, pers. comm.) and the capelin abundance index calculated from the nGSL survey data (Figure A2). The latter was calculated using the order 1 autoregressive negative binomial model described in Chamberland et al. (2022) and used in recent capelin stock assessments (DFO 2021b and DFO 2022b). However, the 2022 index is preliminary as it was only calculated from NGGC Teleost data, without including NGGC John Cabot data.

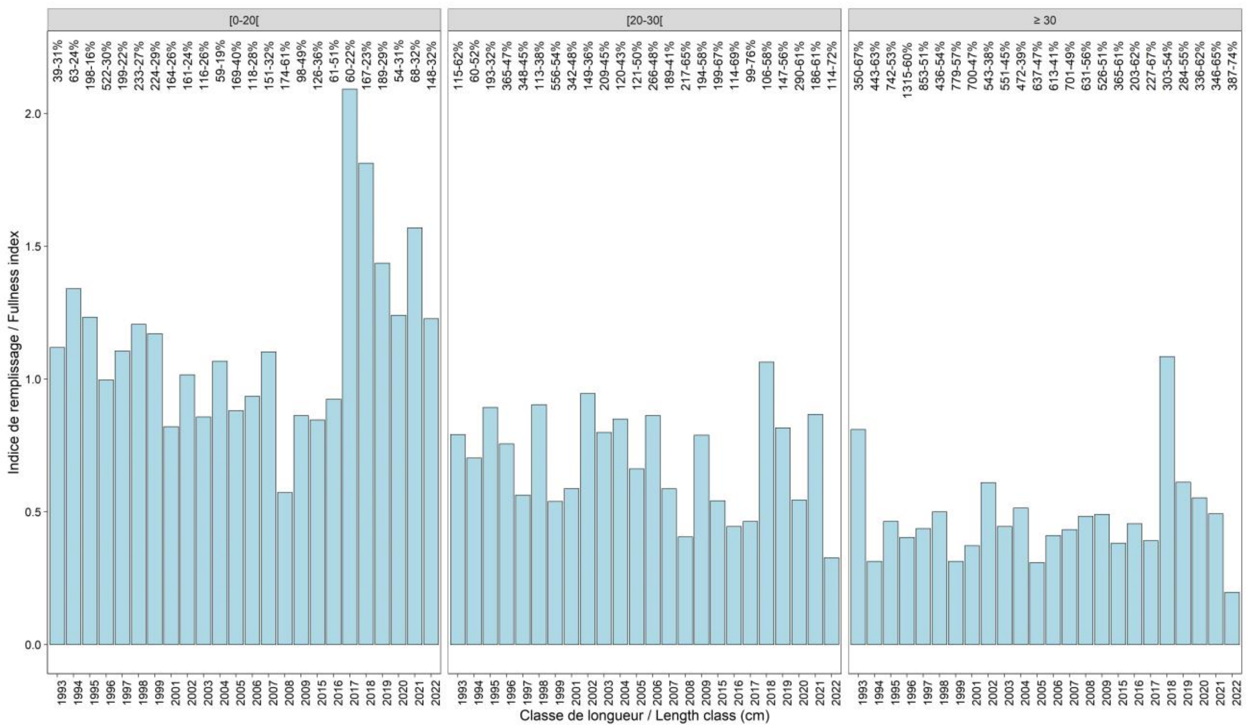

Figure A1. Greenland halibut stomach fullness indices by year and size classes. No stomach were available for the 2010-2014 period. Values at the top of each panel are the sample size and the percent of empty stomach.

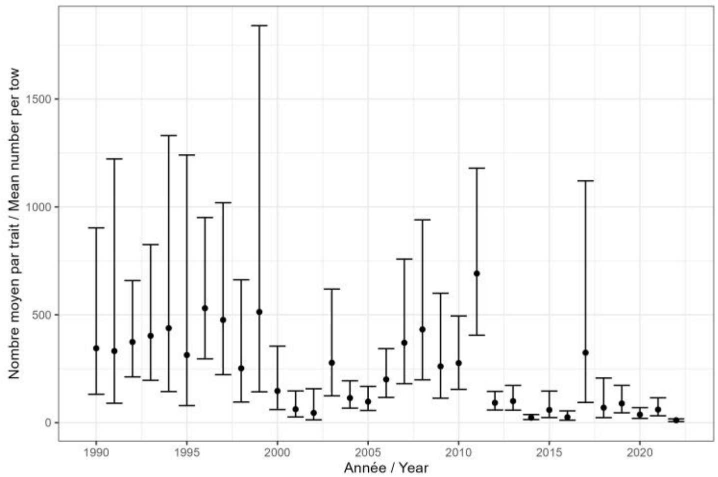

Figure A2. Capelin index of abundance estimated from the northern Gulf of St. Lawrence survey, based on all strata that had been part of the sampling design since 1990. The 2022 index is preliminary as it was calculated using only CCGV Teleost data (without CCGV John Cabot data).

9.2. MODEL DIAGNOSTICS

This section presents the diagnostics of the GLMM models used to relate landing and soak time in section Gillnet commercial landing - soak time relationships.

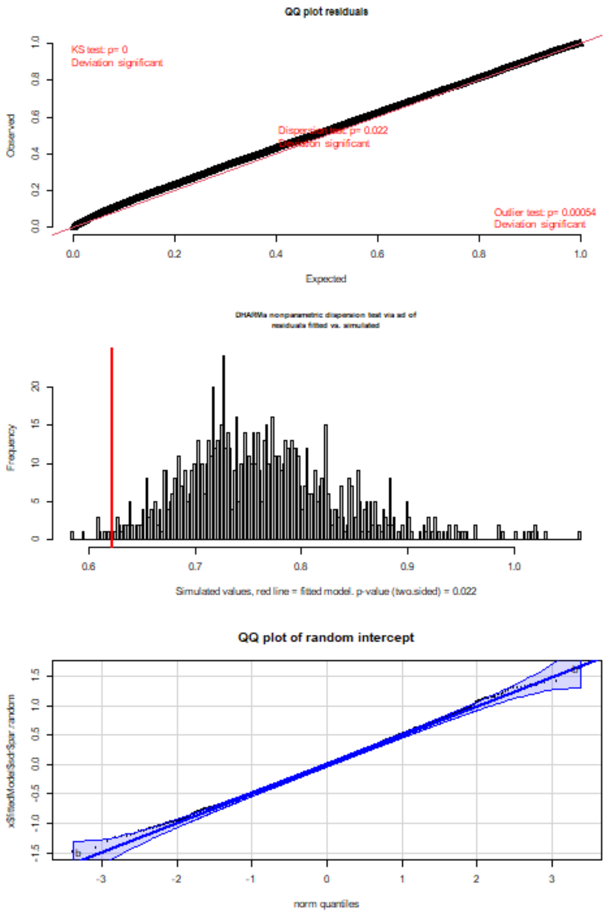

Figure A3. DHARMa diagnostics of the Tweedie global model (4RST, 6 hours soak time categories) fitted to the ZIFF data (top and middle row panels) and quantile-quantile plot of the random intercept distribution (bottom row).

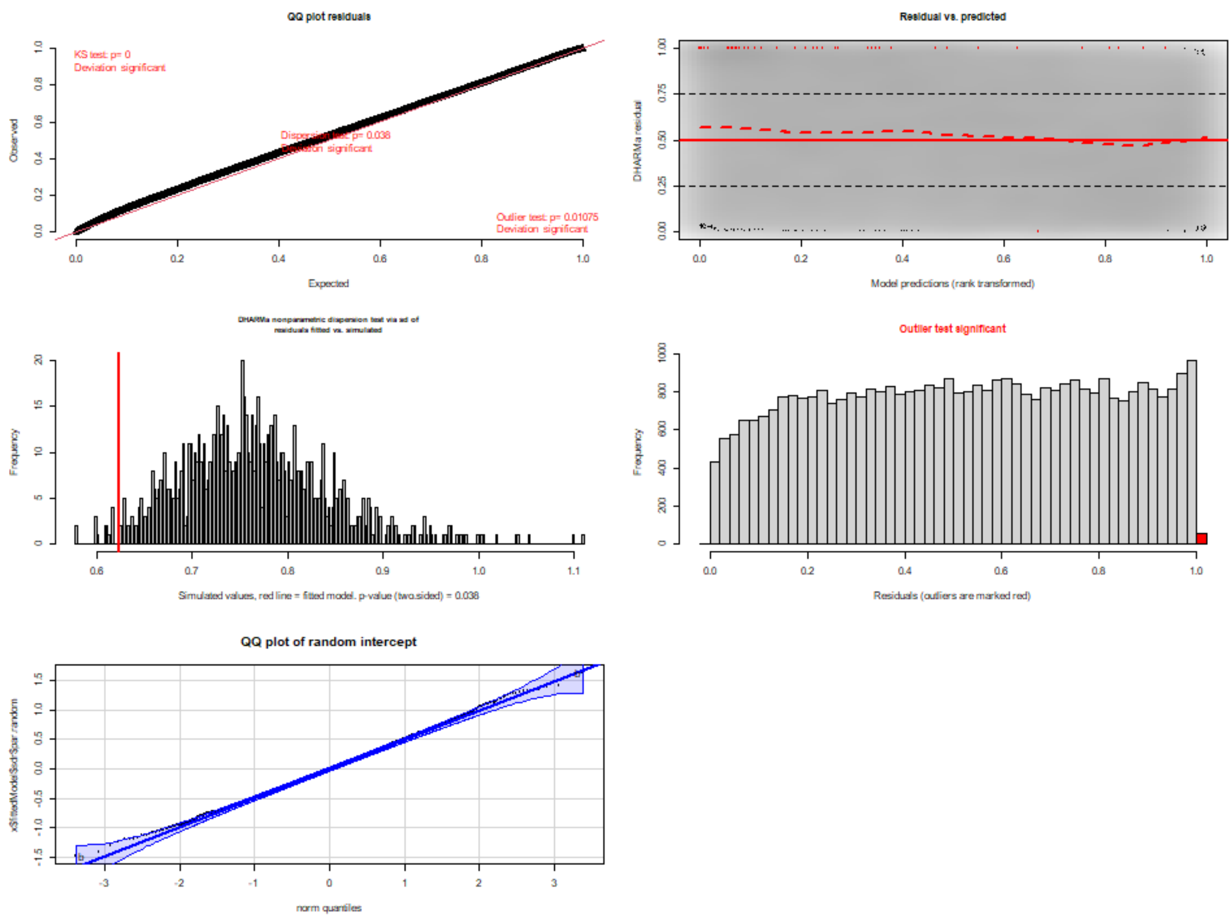

Figure A4. DHARMa diagnostics of the Tweedie global model (4RST, 12 hours soak time categories) fitted to the ZIFF data (top and middle row panels) and quantile-quantile plot of the random intercept distribution (bottom row).

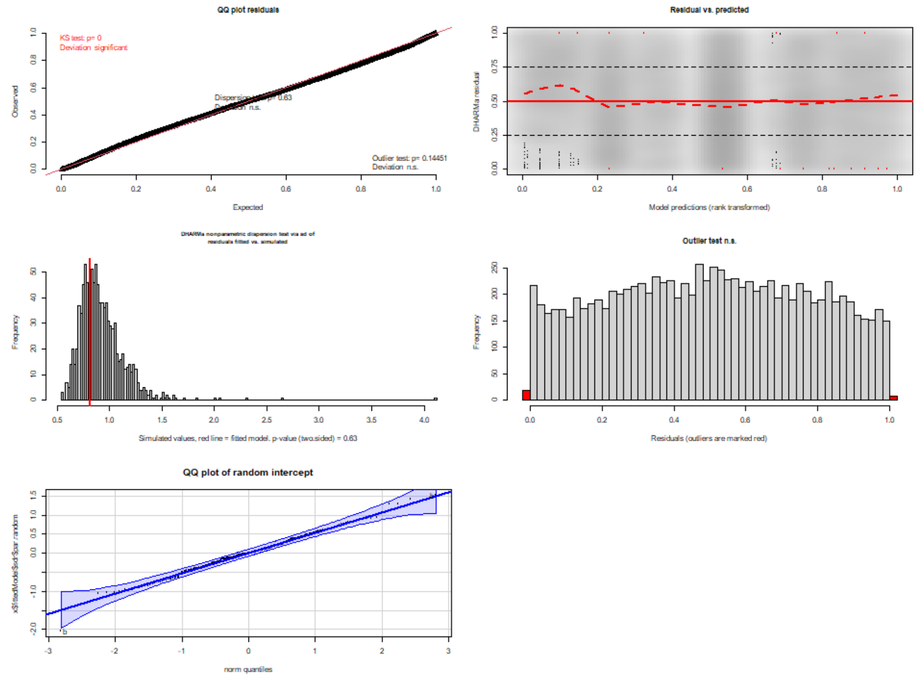

Figure A5. DHARMa diagnostics of the Tweedie global model (4RST, 6 hours soak time categories) fitted to the ASO data (top and middle row panels) and quantile-quantile plot of the random intercept distribution (bottom row).

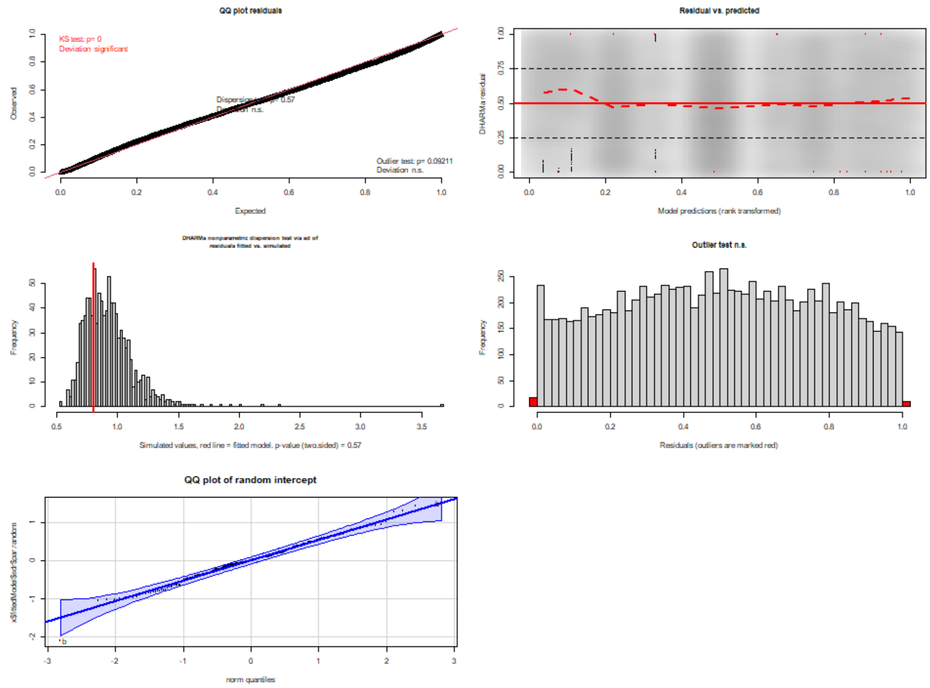

Figure A6. DHARMa diagnostics of the Tweedie global model (4RST, 12 hours soak time categories) fitted to the ASO data (top and middle row panels) and quantile-quantile plot of the random intercept distribution (bottom row).

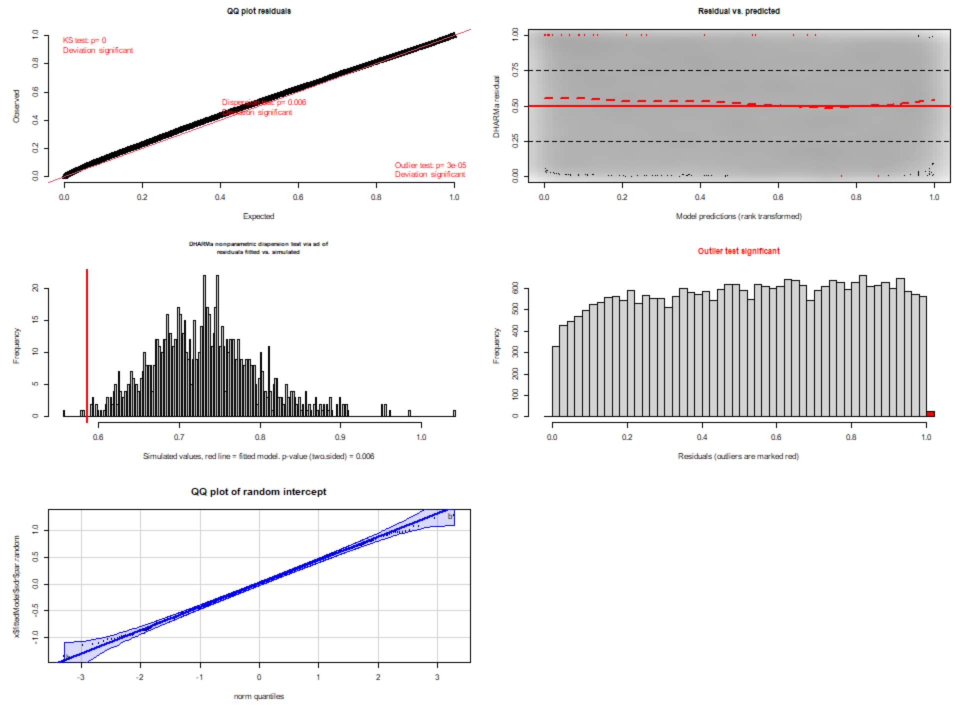

Figure A7. DHARMa diagnostics of the wGSL Tweedie model (top and middle row panels) fitted to the ZIFF data and quantile-quantile plot of the random intercept distribution (bottom row).

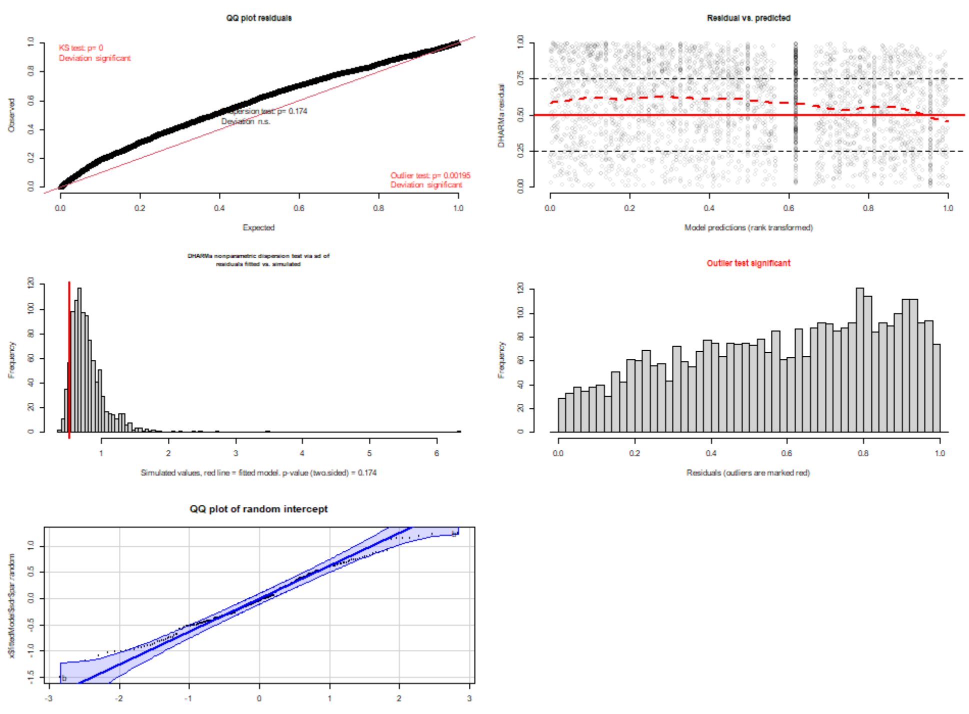

Figure A8. DHARMa diagnostics of the north Anticosti Tweedie model (top and middle row panels) fitted to the ZIFF data and quantile-quantile plot of the random intercept distribution (bottom row).

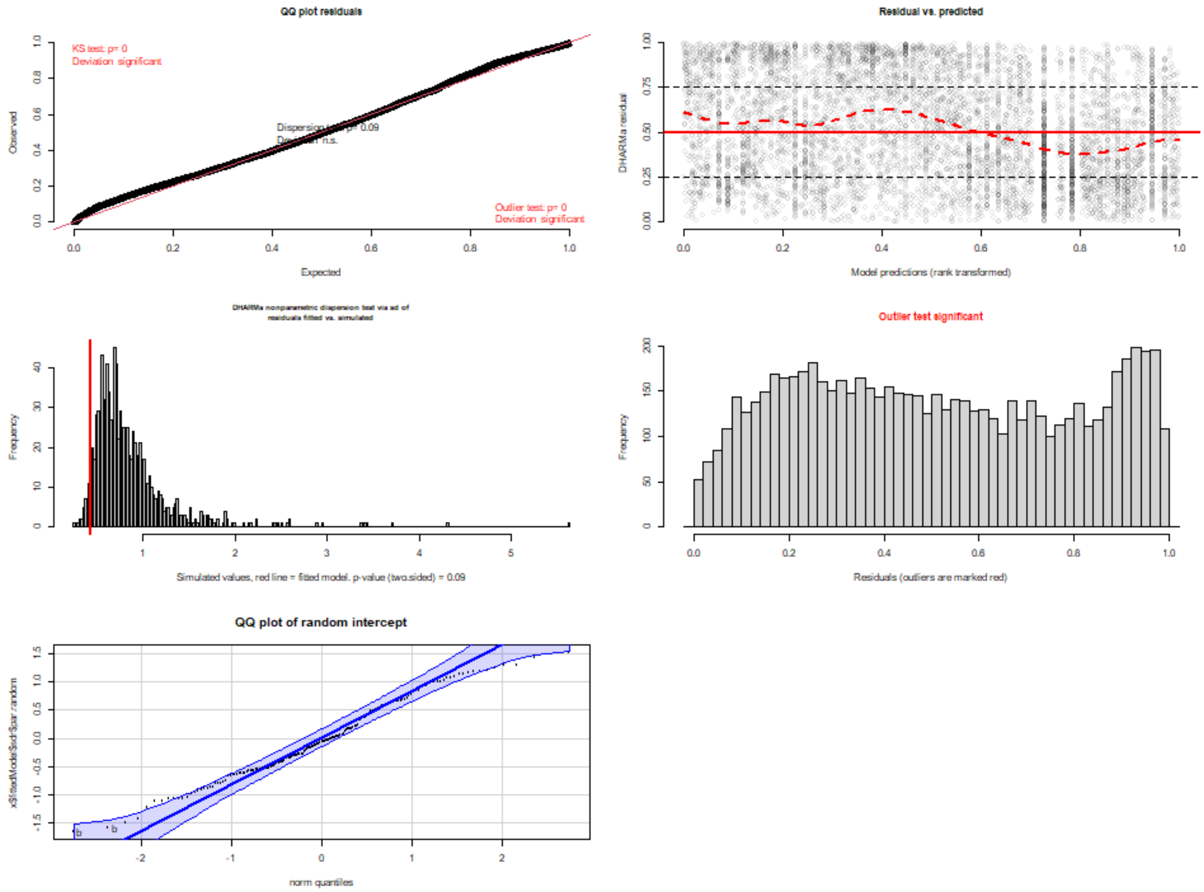

Figure A9. DHARMa diagnostics of the Esquiman Tweedie model (top and middle row panels) fitted to the ZIFF data and quantile-quantile plot of the random intercept distribution (bottom row).