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Capelin in the Estuary and Gulf of St. Lawrence (NAFO Divs. 4RST) in 2021

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Foreword

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

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ABSTRACT

Since 2000, an annual average of 8,068 t of capelin were landed in the Estuary and Gulf of St. Lawrence (GSL), which encompasses divisions 4RST of the Northwest Atlantic Fisheries Organization (NAFO). In 2020 and 2021, the annual total allowable catch was 9,295 t and preliminary landings were 10,281 and 9,934 t respectively, principally from the NAFO div. 4R seine fishery. The performance index for that fishery increased from 2004 to 2010, and subsequently varied above the 1986–2021 time series average. The condition factor of males and females fished in NAFO divisions 4RS in 2021 was above the 1984–2021 time series average. The relative abundance index from the northern GSL bottom-trawl survey has generally been below the long-term average (1990–2021) since 2012. In contrast, the relative abundance index in the southern GSL bottom-trawl survey has been above the long-term average since 2010. Approximations of the fishing mortality rates from 1997 to 2021 were much smaller than natural mortality rates typical of short-lived forage species such as Capelin. A new composite index of 4RST capelin stock status, comprising 5 independent indices (northern GSL and southern GSL relative abundance indices, percentage in weight of Capelin in diets of two key predators, and timing of last ice) has varied around the long-term (1990–2021) average since 2016. The inferred low fishing mortality and the status inferred from the composite index indicate that harvest levels in 2022 that are comparable to those attained over the last decade are unlikely to pose a risk to the 4RST capelin stock in 2022.

1. INTRODUCTION

This research document provides a description of the capelin (*Mallotus spp.*) fishery in the Estuary and Gulf of St. Lawrence (GSL; NAFO[1] Divisions 4RST; Figure 1), as well as a description of fishery dependent and independent biological data and information used to assess 4RST capelin stock status in 2021 (Chamberland et al. 2022; Lehoux et al. 2022; Ouellette-Plante et al. 2022). These results were presented at a DFO Canadian Science Advisory process that took place on April 20-21, 2022 and which sought to provide advice for the 2022 capelin fishing season (DFO 2022). Stock assessments for capelin in the GSL are normally undertaken every two years by DFO at the Maurice Lamontagne Institute (MLI) in Mont-Joli, Quebec. The last stock assessment for capelin in the GSL took place in the winter of 2021 and provided advice for the 2021 fishing seasons (DFO 2021). The main conclusion of that assessment was that plausible fishery exploitation rate levels were at least one order of magnitude smaller than natural mortality calculated based on capelin life history traits. Therefore, it was assumed that the current fishing mortality for 4RST capelin was unlikely to be deleteriously affecting the population. The Total Allowable Catch (TAC) remained at 9,295 t for the 2021 fishing season like it was in 2018, 2019 and 2020. There is currently no stock assessment model used to assess capelin nor are there established reference points with respect to DFO's Precautionary Approach Policy (DFO 2009) or the recently amended Fisheries Act (Bill C-68).

1.1. STOCK STRUCTURE

Capelin have a circumpolar distribution and are mostly found in coastal and continental shelf waters with major populations occurring in the Northwest Atlantic Ocean, the northern Pacific Ocean, the waters around Iceland and in the Barents Sea. While Capelin were previously considered a single species (i.e., *Mallotus villosus*), morphological, genetic, and genomic evidence indicates that there are multiple parapatric species of Capelin (Dodson et al. 2007; Kenchington et al. 2015; Mecklenburg and Steinke 2015; Mecklenburg et al. 2018; Cayuela et al. 2020). The Atlantic Capelin found in the Arctic and Atlantic Oceans are divided into three distinct clades including the Northeast/Central Atlantic clade, the Arctic clade and the Northwest Atlantic clade. Within the Northwest Atlantic clade, three distinct haplotypes have been identified but all are found across the Newfoundland and Labrador Shelf, the Gulf of St. Lawrence, and into the upper St. Lawrence Estuary (Cayuela et al. 2020). Previous attempts to examine the stock structure of Capelin in the Northwest Atlantic including the GSL have highlighted multiple instances of phenotypic variation between spawning sites for traits such as spawning behavior, diet, colour, morphology, number of vertebrae and other life-history traits (Templeman 1948; O'Boyle and Lett 1977; Sharp et al. 1978; Carscadden 1979; Carscadden and Misra 1979; Lambert and Bernier 1989; Dodson et al. 2007; Praebel et al. 2008; Kenchington et al. 2015).

1.2. ECOLOGY

Capelin are a small schooling pelagic forage fish in the Osmeridae family (smelts). They can live up to 6 years and reach sexual maturity after 2–3 years. Due to absence of sex-specific differences in morphology, the sexes are indistinguishable until after their second winter, whereupon sexual dimorphism begins to show. Males grow larger and reach sexual maturity at a larger size relative to females. They also develop secondary sexual characteristics such as

[1] Northwest Atlantic Fisheries Organization

enlarged pectoral fins and two pairs of ridges, or spawning carina (one dorso-lateral and one at the base of anal fins (Templeman 1948).

Capelin are a cold water species generally found at temperatures from -1°C to 4°C and can also be observed over a wider range of temperatures (-2°C–14°C, Carcadden 1979; Mowbray 2002; Simard et al. 2002; Rose 2005; Ingvaldsen and Gjøsæter 2013). In the GSL, Capelin feed almost exclusively on zooplankton, the composition of which varies seasonally, spatially and with respect to the size of the individual. Larval capelin (< 71 mm) mostly consume early stages of small calanoid copepods (90–130 µm) while juveniles and adults (> 75 mm) consume larger prey generally dominated by late stages of *Calanus* species and euphausiids (Dalpadado and Mowbray 2013). Their diel vertical migrations coincide with those of their zooplankton prey, and most feeding occurs during daytime (Templeman 1948; Vesin 1979; Courtois and Dodson 1986; Dalpadado and Mowbray 2013; Aarflot et al. 2020). However, these patterns can differ according to season and may be disrupted by changes in the physical environment or the presence of predators (Bailey et al. 1977; Rose 1988; Mowbray 2002).

Capelin are widely distributed throughout the GSL (Carscadden 1979; McQuinn et al. 2012) and can be an important prey for marine fishes such as Greenland Halibut (*Reinhardtius hippoglossoides*), Atlantic Cod (*Gadus morhua*; Ouellette-Plante et al. 2020), marine mammals and seabirds. Predation was estimated to be the main source of Capelin mortality in the GSL during the mid-1980s and the mid-1990s with variations in overall mortality being associated with the abundance of predators (Savenkoff et al. 2004).

1.3. REPRODUCTIVE CYCLE

During the spring and summer, sexually segregated schools of mature capelin migrate inshore to spawn on beaches or at demersal sites with suitable substrates (sand and fine gravel) and water temperatures of 2–12°C (Templeman 1948; Parent and Brunel 1976; de Lafontaine et al. 1991; Davoren and Montevecchi 2006; Purchase 2018). Mature female Capelin migrate to appropriate spawning sites where they lay eggs that adhere to sediments where they are fertilized by males. The timing and location of those migrations are highly variable both within and among regions (Penton et al. 2012). Capelin are broadcast spawners, have determinate fecundities and spawn only once a year. Mature female ovaries contain an average of 41,767 eggs (Grégoire et al. 2004). Similar to beach spawners, demersal spawners tend to spawn on sites composed of sandy or fine gravel substrate but are exposed to generally lower, more constant temperatures and higher salinities than on beaches. Post-spawning mortality is significant and seems to be higher for males than females, and also for demersal spawners (higher proportion of semelparous individuals) than on beaches where higher proportions of iteroparous individuals are observed (Christiansen et al. 2008). Upon hatching, larvae develop in the upper layers of the water column. Most of the growth occurs within the first two years of life. Capelin reach sexual maturity around 2–3 years of age.

The lengthy spawning season begins in late April–early May and progresses eastwards and northwards, reaching the Strait of Belle Isle in July and August as temperatures increase throughout the GSL (Figure 2). Capelin have been observed spawning along Quebec's North shore, the Saguenay Fjord, the Gaspé Peninsula, the Baie des Chaleurs, the northern and southern shores of Anticosti Island, St. George's Bay, Nova Scotia, and off the west coast of Newfoundland (Templeman 1948; Parent and Brunel 1976; Carscadden 1979; Courtois et al. 1982; Nakashima et al. 1982; Ouellet 1987; Lambert and Bernier 1989; Sirois et al. 2009).

1.3.1. Larval Emergence, Distribution and Abundance

Egg incubation time varies according to temperature and salinity, but typically takes 15–20 days at 10°C (Frank and Leggett 1981; Penton et al. 2012). Upon emerging from beaches or the ocean bottom, capelin larvae are approximately 3–5 mm long. In the northwestern GSL, Capelin larvae can grow to 43–56 mm by their first winter. Larvae will metamorphose after their first winter at lengths of approximately 66–71 mm and will grow to approximately 80–110 mm by their second winter (Bailey et al. 1977; Jacquaz et al. 1977).

Capelin larvae are distributed broadly throughout the GSL (de Lafontaine et al. 1991). Upon rising to surface waters (0–20 m) following their emergence, larvae are quickly dispersed by the prevailing water currents, tides, and winds (Jacquaz et al. 1977; Bailey et al. 1977; Fortier and Leggett 1983, 1985; Ouellet et al. 2013). Areas of high larval density include the Saguenay Fjord (Sirois et al. 2009), the Estuary and northwestern GSL (Jacquaz et al. 1977; Ouellet et al. 2013), the mouth of the Baie des Chaleurs and the Shediac Valley (O'Boyle and Lett 1977; Grégoire and Girard 2014), all along Quebec's North Shore, St. George's Bay Nova Scotia (Carscadden 1979; Lambert and Bernier 1989), and in the large bays along the west coast of Newfoundland (Carscadden 1979; Grégoire et al. 2013).

1.4. COMMERCIAL FISHERY

The commercial fishery for Capelin in the GSL is co-managed by DFO's Newfoundland and Labrador, Gulf, and Quebec regions under an evergreen Integrated Fishery Management Plan (IFMP) that was approved in 2017 and updated in 2021. The majority of the commercial fleet is based on the west coast of Newfoundland (NAFO Division 4R). Fishing seasons are generally short and coincide with the inshore Capelin spring spawning migration.

The opening date for the commercial fishery is chosen based on the availability of capelin to fishing gear, weather and recommendations from the industry (the latter being motivated to maximize the number of larger roe-bearing females in their catch for export to foreign markets). While females and their roe are largely sold for human consumption, males have traditionally been released, discarded, or used as fertilizer. In recent years both male and female Capelin are sold as animal feed for zoos and marine parks, both domestically and abroad.

The TAC for Capelin in the GSL has rarely been limiting and landings have historically been market-driven (Grégoire et al. 2013). The TAC is currently split by fleet and NAFO Division (Table 1). The 4R fixed gear fleet, which includes tuck seiners, has an allocation of 37.82% of the total TAC under a fully competitive quota. The 4R mobile gear fleet, includes large (vessel > 19.81 m (65 ft.)) and small (vessel < 19.81 m) purse seiners, each with an allocation of 24.15% of the total TAC. Small seiners are managed through individual quotas while larger seiners are managed as a competitive fishery. The allocation for 4ST is 13.88% of the total TAC and is managed as a competitive fishery across all gear types. All licence holders in 4R are required to have their catch monitored at dockside and the return of logbooks is mandatory.

1.5. RELATIVE ABUNDANCE IN THE GSL

Recent work by Chamberland et al. (2022) has shown that DFO bottom trawl surveys in the northern GSL (nGSL, August 1990–2021) and southern GSL (sGSL; September 1970–2021) can be used to generate an index of relative Capelin abundance. Using a conceptual model that predicts summer foraging habitat use, Chamberland et al. (2022) show that Capelin caught in these surveys were associated with cold conditions typical for Capelin (≤ 3°C in the nGSL and ≤ 2°C in the sGSL). The conceptual model also showed that more Capelin were caught in the bottom trawl during the day than at night, which is consistent with the vertical feeding migrations of Capelin. This research indicates that Capelin abundance indices derived from DFO bottom trawl surveys can inform on interannual variation in relative Capelin abundance in the GSL.

1.6. ENVIRONMENTAL DRIVERS OF CAPELIN ABUNDANCE

Environmental and biological conditions known to regulate Capelin survival and cohort strength explain a large part of the variations in Capelin abundance indices from the bottom trawl surveys (Lehoux et al. 2022). In the GSL, Capelin abundance indices were mainly associated with variations in body condition in June and/or August–September, or in environmental predictors such as the timing of ice retreat, the sea surface temperature and the abundance and phenology of preys of the genus *Calanus* (Lehoux et al. 2022). This supports the conceptual hypothesis that Capelin abundance is determined by bottom-up processes regulating survival during its first 2 years of life (Lewis et al. 2019; Lehoux et al. 2022). Thus, favorable environmental conditions in summer and fall in the first year of life and subsequently the following spring at age 2, each leading to good body condition and winter survival, increase the chances of producing a strong cohort.

2. METHODS

The data available for this assessment include reported commercial landings (1960–2021), a fishery performance index derived from commercial landings of the 4R seiner fleet (1986–2021), Capelin bycatch data from the shrimp trawler fleet in the GSL (2000–2021), biological samples from commercial catches (1984–2020), Capelin catch density and biological samples from DFO's summer multispecies bottom-trawl surveys covering the sGSL and the nGSL. The treatment of each data source is described below.

2.1. COMMERCIAL FISHERY

2.1.1. Landings

Detailed commercial fisheries landing data (1985–2021) were extracted from the most recent Zonal Interchange File Format database (ZIFF) compiled by MLI's data management section and DFO's regional statistics bureaus. Landings prior to 1985 were extracted from the Northwest Atlantic Fisheries Organisation landings database. At the time of this assessment, landings data for the 2020 and 2021 fishing seasons were still preliminary.

Landings data were summarized by year, NAFO Division and gear type. The seasonality of the Capelin fishery was summarized yearly by calculating the cumulative daily percentage of the annual total landings. The spatial distribution of landed catches was not mapped because the majority of Capelin ZIFF data between 1985 and 2021 lack geographic coordinates. Landings by NAFO Division were deemed more appropriate for this purpose.

2.1.2. Seiner Performance Index

Most Capelin landings on the West coast of Newfoundland (NAFO 4R) are caught by purse seine and tuck seine. This fishery takes place near the coast and fishing vessels generally make one trip per day. A standardized index was developed by Chamberland et al. (2019) to measure the performance of this fishery using a multiplicative model (Gavaris 1980) applied to the log catches-per-unit-effort (CPUE). The model was updated with the 2020 and 2021 data.

The following equation was fitted with all explanatory variables coded as factors:

$$ln(y_i) = b_0 + b_1x_{i1} + b_2x_{i2} + b_3x_{i3} + b_4x_{i4} + b_5x_{i5} + \varepsilon_i$$

Where y_i: CPUE (ton/day/boat) for each assumed fishing trip (*i*) from the database

x_{i1}: year, from 1986 to 2021

x_{i2}: month of the year, where June = 6, July = 7 and August = 8

x_{i3}: length class of vessels where 1 ≤ 35', 2 = [35–45'[, 3 = [45–65'[, 4 = [65–100'[, 5 = [100–125'[, and 6 ≥ 125'

x_{i4}: NAFO unit areas of Division 4R: 4Ra, 4Rb, 4Rc and 4Rd

x_{i5}: Fishing gear: tuck seine and purse seine

ε_i: Error distributed normally

This model considered each entry in the database as one fishing day per boat. Only landings caught by purse and tuck seiners from June to August between 1986 to 2021 in 4R areas were included. Entries with missing or unknown vessel length classes were removed if this information could not be found elsewhere in the database using the unique vessel identification number. Entries where the NAFO unit area information indicated simply the NAFO Division (i.e., 4R) were also omitted.

The work from Chamberland et al. (2019) demonstrated that the catch rate increase as the season progresses (month effect) and are greater for large vessel length classes (length class 4, 5 and 6), for NAFO unit areas further south (4Rc and 4Rd) and for purse seiners compared to tuck seiners. The standardized annual CPUEs were produced using the values predicted by the model for June, length class 2, unit area 4Rc and purse seines. Predicted values were back-transformed to the original scale using the Delta method (Cox 2005). Residuals and Cook's distances were examined to verify whether the model assumptions were met.

2.1.3. Bycatch in the Shrimp Fishery

Bycatch of Capelin by the commercial shrimp fishery in the GSL has been estimated with catch and effort data acquired by the At-Sea-Observer-Program (ASO) since 2000. Annual coverage is approximately 5% of total fishing for this fleet. Results of the at-sea observer sampling are scaled to the total fishing effort of the entire shrimp fleet by using weighting factor (∑ shrimper effort / ∑ observer effort) which allow for the estimation of bycatch for the entire fleet (Savard et al. 2013; Bourdages et al. 2020b). Estimated annual bycatch (t) of Capelin was broken down by shrimp fishing areas (SFA; Estuary, Sept-Îles, Anticosti, and Esquiman, see Appendix 1 for their location). Geographic distribution of the estimated bycatch was presented as the mean kg/tow in 5 × 5 minute cells. In 2020, no tows were sampled by ASO in the Estuary despite landings being recorded in this SFA. Also, ASO data were not available for the Newfoundland fleet at the time of the assessment. Therefore, current estimates in Esquiman SFA were derived using only available data from the Quebec, New-Brunswick and Nova Scotia fleets. Consequently, 2021 estimates of Capelin by-catch in the shrimp fishery are preliminary.

2.2. COMMERCIAL SAMPLING

2.2.1. Size Distribution

DFO's port sampling program provides data on the length and sex composition of commercial landings (hereafter commercial length frequency data) for key Capelin fishing activities in the GSL (Lambert and Ménager 1998, Daigle et Benoît 2007). Samples consist of measurement and sex determination for 150 randomly selected fish from individual chosen fishing trips. From 1984 to 1987, fish were measured with a precision of 5 mm, but subsequently a 1 mm precision has been used. These data allowed for the calculation of the mean size of female and male Capelin in Divisions 4R and 4ST for the 1984–2021 period.

A sub-sample of one Capelin per sex per 5 mm bin from each port sample was analyzed in the laboratory at MLI (hereafter, commercial biological data). Measurements taken at MLI include: total length (nearest mm), mass (nearest 0.1 g), sex, gonad mass (nearest 0.1 g), maturity stage (immature, maturing, pre-spawning, spawning or recovering), and age via the extraction and examination of otolith structure. The latter measure was carried out in the past (1976–1993) and a renewed age reading program is being developed.

2.2.2. Relative Condition Factor

Mean body condition of male and female Capelin was estimated by calculating the relative condition factor (*Kn*; Le Cren 1951) based on the biological samples from the fishery using the following equation for each sex :

$$Kn_i = W_i / aL_i^b$$

where *a* and *b* are the coefficients of the length-weight relationship, L_i is the length in millimetres and W is the observed somatic mass in grams for the *i*th fish. The effects of different factors on relative condition of both sex were assessed by fitting a Gaussian general linear model (glm) and an identity link using *Kn* as the response variable and year, month and fishing gear as factors. *Kn* was then standardized by predicting the annual mean for each sex and NAFO divisions by fixing factors month (June) and fishing gear (seiners) to the bulk of samples.

2.2.3. Sex Ratio and Gonadosomatic Index

Mean annual sex ratios were calculated for NAFO divisions 4R, 4S, and 4T using commercial length frequency data (arithmetic mean).

A gonadosomatic index (*GSI* = (*gonad mass / somatic weight*) × *100*) was calculated for male and female Capelin caught in the commercial fishery in 4RST. Individuals whose sex could not be identified, those weighing less than 5 g and male with GSI greater than 10% were considered outliers in the data and were excluded from the analysis. Data were pooled across fishing gears because GSI did not differ significantly between them. Annual means and standard deviations (SD) were computed for each sex.

2.3. RELATIVE ABUNDANCE INDEX

A modeling approach developed by Chamberland et al. (2022) allowed for the estimation of a relative abundance index (mean number of Capelin caught per tow, MNPT) in DFO's nGSL and sGSL bottom trawl surveys datasets. Two series of annual MNPT were estimated for each survey since 1970 for the sGSL and since 1990 for the nGSL. The first one (core strata) calculates annual MNPT with all strata that were consistently part of the sampling design over the years, while the second one (cold intermediate strata, or CIL) uses the average density of Capelin found only in strata occurring in their preferred habitat. Those time series were updated to include the data collected in 2021.

2.4. SCALE OF FISHING MORTALITY

Capelin is a small pelagic species subjected to a high natural mortality (*M*) with rates expected to vary between 0.62 and 0.82 (Chamberland et al. 2022). Patterson (1992) compiled data for 28 stocks of 11 small pelagic species and concluded that a fishing mortality (*F*) lower than ½ *M* or a relative exploitation rate (*E*) lower than 30% would allow stocks to increase in size. The order of magnitude of *E* and *F* for the 4RST Capelin stock was estimated using data from nGSL and sGSL bottom trawl surveys, catchability coefficients (q) from the literature for Capelin (O'Driscoll et al. 2002) and small pelagics (Benoît and Swain 2008) in this type of survey and commercial landings. A first scenario (Scenario 1) estimated annual values of *E* and *F* based on the total landings in NAFO 4RST and the combined stock biomass approximated in the nGSL and the sGSL. The stock biomass was calculated using the following equation :

$$B_y = \frac{MW_y \times MNPT_y \times TU}{q}$$

where B_y : the stock biomass estimated during the year *y*

MW_y : the mean weight (g) of individuals in the survey during the year *y*

$MNPT_y$: the mean number of Capelin per tow in the survey during the year y

TU : the number of trawlable unit in the survey

q : assumed catchability coefficient of the survey

Individual weights of Capelin in the surveys since 1997 were used in the calculation of the exploitation rates. Capelin mean weight in nGSL and sGSL bottom trawl surveys were calculated using survey mean length and survey-specific annual length-weight relationships. It was not possible to compute length-weight relationships for nGSL surveys in 1997. Therefore, the overall (1990–2009, Bourdages and Ouellet 2011) length-weight relationship was used. Capelin length and weight in the surveys were not available or were poorly sampled prior to 1997. The number of trawlable units were 7,933,617 and 1,806,408 for the nGSL and the sGSL surveys, respectively. As a precaution, the relative abundance indices based on the core strata were used since estimates in the CIL strata were higher for most of the time series in both surveys. Low (*q* nGSL = 0.0045, *q* sGSL = 0.01) and high (*q* nGSL = 0.01, *q* sGSL = 0.1) catchability coefficients were used to approximate stock biomass and to compare the different order of magnitude estimated. Higher catchability coefficients were applied for the sGSL surveys because of the greater proportion of bottom trawl survey tows performed inside Capelin preferred thermal habitat (Chamberland et al. 2022). Exploitation rates were calculated using the following equations :

$$E_y = \frac{L_y}{B_y}$$

where E_y : the exploitation rate estimated during year *y*

L_y : the annual total landings in NAFO 4RST during year *y*

B_y : the stock biomass estimated during year *y*

The instantaneous rate of fishing mortality was calculated as

$$F_y = -\ln\left(1 - E_y\right)$$

where F_y : the fishing mortality rate estimated during year *y*

E_y : the exploitation rate estimated during year *y*

A cautious scenario for estimating the stock biomass (Scenario 2) was also evaluated and is described by the following equations :

$$B_{y-1} = \frac{MW_{y-1} \times MNPT_{y-1} \times TU}{q}$$

$$B_y = B_{y-1} - \left[(1 - e^{-0.5M}) \times B_{y-1}\right]$$

This scenario considered a lag of one year in the relative abundance indices when estimating the stock biomass (B_{y-1}). The lag of one year was applied to account for the timing of the bottom trawl surveys (August to September) and the fishing activities (May to July of the following year). It also considered an annual reduction of the stock biomass to account for the natural mortality during the winter season. Capelin are subject to high *M*, with annual rates that can vary between 0.62 and 0.82 based on life history (Chamberland et al. 2022). The *M* value of 0.62 was chosen for further analysis to be consistent with the value selected for the fishing mortality threshold, i.e., the value representing the lowest fishing mortality that could possibly impact the increase of the Capelin stock. Hereafter, a biomass reduction equal to 0.31 (half of *M* = 0.62) was also applied in the cautious scenario. This scenario was expanded to include an approximation of the stock biomass that can be available to the fishery and is the result of the abundance of Capelin in the previous year and the natural mortality during the following winter. This approach is cautious because it does not account for the annual increase in stock biomass resulting from individual growth, which would have resulted in lower values of *E* and *F*. Furthermore, mortality associated with the winter season is probably lower than what is assumed given that a significant portion of the natural mortality occurs during the spawning season (after the fishery and before the surveys).

2.5. IMPORTANCE OF CAPELIN IN COD AND GREENLAND HALIBUT DIET

Ouellette-Plante et al. (2022) recently explored the stomach contents data collected during the nGSL multispecies survey, assuming that the importance of Capelin in the stomach contents of its predators investigated might be proportional to its abundance. As such, interannual variation in the proportion of capelin in the diets of Atlantic Cod and Greenland Halibut might reflect interannual variation in Capelin abundance. Those two species were chosen in part because they are known to eat a lot of Capelin (Bowering and Lilly 1992; Savenkoff et al. 2004; Ouellette-Plante et al. 2020), are collectively present throughout the nGSL (Bourdages et al. 2020a) and are known to migrate vertically in order to feed (Le Bris et al. 2013; Boje et al. 2014), thereby increasing the probability of observing Capelin in their stomach contents. Following Ouellette-Plante et al. (2022), the annual mean percentage of Capelin in the stomach contents (by weight) of Cod and Greenland Halibut was estimated for 1993-2020.

2.6. COMPOSITE INDEX OF STOCK STATE

A new composite index summarizing specific indices was developed to provide a perspective on the relative stock state between 1990–2021. The indices considered were the nGSL and sGSL relative abundance indices from the bottom trawl surveys, the percentage of Capelin in the diets of Atlantic Cod and Greenland Halibut in the nGSL in August, and the timing of ice retreat in 4S and 4R. The relative abundance and diet indices were used as indicators of Capelin abundance in late summer and early fall (Chamberland et al. 2022; Ouellette-Plante et al. 2022). The timing of ice retreat (the last day of ice in the nGSL) was included as an indicator of Capelin post-winter body condition and survival (Lewis et al. 2019; Lehoux et al. 2022). Each index used in the composite index was standardized to a mean of zero and unit variance (annual anomaly, unitless). Since data on the percentage of Capelin in predator diets were not available for some years (1990-1993, 2000, 2010-2015, 2021), the average of the time series was assumed for missing years.

3. RESULTS AND DISCUSSION

3.1. COMMERCIAL FISHERY

3.1.1. Landings

Annual commercial landings of Capelin in the GSL were less than 2,000 t from 1960 to 1977 but rapidly increased to about 10,000 t in 1978 and 1979 (Table 2, Figure 3). From 1985 to 2021, annual landings varied substantially from a minimum of 152 t in 1995 to a maximum of 12,313 t in 2011 and were characterized by a number of years where few to no landings occurred (e.g. 1982, 1987, 1994, 1995, 2001 and 2017). The preliminary landings for 2021 were 9,934 t (Table 2, Figure 3). The TAC was exceeded in 1992, 1993 and in the last two years (Table 2, Figure 3).

Capelin have continued to be mostly landed by the mobile gear fleet (small and large purse-seiners) in NAFO Div. 4R, constituting an average of 82% of the annual landings for 2010–2021 (Table 3, Figure 3A). In the GSL (NAFO Divs. 4RST), the seiner fleet landed most of the TAC, although there was an increase in landings by fixed gear types since the mid-2000s largely attributable to the arrival of the tuck seine (Table 4, Figure 3B).

In NAFO Div. 4R, landings typically occurred in unit areas 4Rabc and were more evenly distributed within these units during the 2018–2021 period than in previous years (Figure 4A). Since 2012, the large and small purse seiners landed similar proportions of the TAC and landings, while trap nets represented a smaller proportion of the annual catch in this Division (Figure 4).

In NAFO Divisions 4ST, most of the landings since 2005 occurred in unit areas 4Sw (Québec's Lower North Shore) and 4Tn (mouth of the Baie des Chaleurs) by purse seines and traps (Figure 5). In 2020 and 2021, landings in 4ST markedly increased relative to previous years and totaled 2,405 and 1,921 t respectively, a level not observed since the period 2006–2011 (Figure 5).

The Capelin fishery in 4R generally occurs in June and July and the timing of the landings has varied little since detailed records have existed (Figure 6). In Divs. 4ST, the fishery usually starts earlier than in 4R and shows more interannual variation in the timing of the landings (Figure 7). The lower number of landings during the fishing season in 4ST compared to 4R explained the jagged line pattern observed in the cumulative landings.

3.1.2. Seiner Performance Index

The model used to standardize purse seiner CPUE in NAFO Div. 4R explained 38.3% of the total variance ($p < 0.001$) and model factors were statistically significant ($p < 0.01$) (Table 5, see also Grégoire and Bruneau 2012). Residuals (Figure 8A) and standardized residuals (Figure 8B) indicate a violation of variance homogeneity with a clear propensity for negative residuals. However, this was not considered problematic since the objective was to estimate standardized CPUE and not to evaluate the influence of the different factors on the commercial CPUE (Zuur et al. 2010). The residuals followed a distribution that deviated from normal (Figure 8C) but did not show extreme values that could influence the model (all Cook's distances < 0.5, Figure 8D).

The effects (Figure 9) of each independent variable indicated that CPUEs were similar among months, but were more variable as the season progressed. Larger vessels had greater CPUEs than smaller ones and vessels fishing in the NAFO unit areas 4Rcd had greater CPUEs than those fishing in 4Rab. Purse seiners outperformed tuck seiners. These differences were accounted for in the standardized index, which depicted the annual mean CPUE realised by a purse seiner of length class 35–45' fishing in NAFO Divs. 4Rc in June.

The performance index increased rapidly from 2004 to reach the time series maximum in 2013 at 57.0 t day^{-1} (Figure 10). The performance index subsequently remained above the long–term average (31.2 t day^{-1}), varying between 54.3 t day^{-1} (2014) and 37.0 t day^{-1} (2017). The performance index was 44.9 t day^{-1} in 2020 and 54.2 t day^{-1} in 2021 (Figure 10).

3.1.3. Bycatch in the Shrimp Fishery

Estimated annual bycatch of Capelin by shrimp trawlers in the GSL for 2020 and 2021 was below the time series (2000–2020) mean of 144 t (Table 6, Figure 11). Decreases in Capelin bycatch by this fleet are likely related to decreases in shrimp TAC throughout the GSL and efforts by the industry to avoid capturing Capelin. Capelin are mainly caught in the lower Estuary, the Northwest GSL, the Laurentian channel south of Anticosti Island, the Anticosti Channel, and the Esquiman Channel (Figure 11). In recent years, there were fewer instances of reported bycatch in the Esquiman Channel.

3.2. COMMERCIAL SAMPLING

The number of commercial length frequency samples and the number of specimens obtained by the DFO port-sampling program are presented in Table 7. On average, 24 samples are measured annually and are generally spread evenly among NAFO Divisions (7–8 samples per Division annually). This corresponds to an average of 5,493 individual fish measured annually and an average of about 1,200–2,000 fish per NAFO Division depending on the year.

The number of biological samples (a subset of the above as well as some opportunistic samples) analyzed are shown in Table 8. On average, a total of 515 individual fish taken from 24 biological samples are dissected for detailed biological examination annually.

3.2.1. Length Distribution

Length distributions and the size differences between males and females caught by the 4R seiner fleet were relatively similar from one year to another (Figure 12). Differences from one year to another may be due to differences in sampling effort, the dominance of particular cohorts in the fishery, or environmental conditions. The length frequencies for male et female in 2013 and 2014, which deviate from the ranges of values observed in other years, are the result of a small number of commercial samples collected.

The time series mean (± SD) of total lengths for females and males caught by the 4R seiner fleet were respectively 147 ± 7 mm and 165 ± 6 mm (Figure 13). Both sexes showed similar trends over the years for which data were available (1984–2021). From the mid-1980s to the early 1990s, lengths of both male and female Capelin were above average. This was followed by a decline in annual mean length that persisted until 2003, when these values increased to near the time series means. The particularly large mean length observed for both sexes in 2014 occurred during a year with a later than normal timing of the fishery (Figure 6), and a low number of samples processed (Table 7). From 2015 to 2018, mean lengths were lower than average. These values increased to near the time series mean in 2019 and 2021. No samples were collected by port samplers in 4R in 2020.

As the commercial fishery for Capelin using various type of seines has only occurred periodically in NAFO Divs. 4S and 4T, it is difficult to observe trends in length frequencies over time. The size distributions of 4S show more similarity with those of 4R than with those of 4T, which show more small specimens at least since 2006 (Figure 14).

3.2.2. Relative Condition Factor

The coefficients of the fitted length-weight relationship equation ($Weight = a \times Length^b$) were: $\mathrm{a} = 1.14 \times 10^{-6}$, $\mathrm{b} = 3.27$ for females and $\mathrm{a} = 2.18 \times 10^{-6}$, $\mathrm{b} = 3.24$ for males (Figure 15). Interannual variations of the standardized mean relative condition factors for males and females caught in June by seiners in NAFO Divs. 4RST were consistent but differed in scale (Figure 16). For example, relative conditions in 4T were consistently lower than the other two divisions for most of the time series. Relative conditions were generally above average in the late 1980s for all NAFO Divisions, near the time series mean from 1990 to 2000, then above average from 2000 to 2014 for NAFO Divs. 4RS. Relative condition in 4T stayed near the time series mean during this period. Since 2015, relative condition has been near the time series mean in Divs. 4RS while slightly below the average in 4T. A greater number of years with no length data is observed in 4S (Figure 14) than there are standardized condition factors for this Division (Figure 16) as beach seines, nets, traps, weirs and other artisanal gears were excluded from the analyses of the former.

3.2.3. Sex Ratio and Gonadosomatic Index

Capelin sex ratios in the commercial fishery are generally biased towards females in samples from NAFO Divs. 4R (Figure 17), which is consistent with this commercial fishery specifically targeting ripe females. Samples taken from NAFO Divs. 4ST have higher proportions of males (Figure 17), which could be explained by a higher proportion of opportunistic (dip net) and fixed gear samples in these areas and males being more vulnerable to these gear types as they tend to stay in aggregations in coastal waters longer than females (Templeman 1948; Friis-Rodel and Kanneworff 2002; Maxner et al. 2016).

Female annual mean gonado-somatic indices ranged between 20 and 30% (Figure 18). Male gonad mass represented on average less than 1.5% of total mass. No major temporal trend was apparent in either time series.

3.3. RELATIVE ABUNDANCE INDEX

The core strata abundance index in the nGSL was relatively high during the 1990s, declining to low values during the first half of the 2000s, before increasing to a peak in 2011 (Figure 19). The core strata index subsequently declined and, with the exception of 2017, fluctuated around a relatively low level. The CIL strata abundance index followed a similar trend to those described for core strata index. The core strata abundance index in the sGSL increased from the mid-1990s to a peak in 1999, before declining in the mid-2000s and increasing again to a series high in 2010–2011 (Figure 19). The core strata index subsequently declined, but generally remained somewhat higher than the period prior to 2010. The CIL strata abundance index followed similar trends, although the peak around 2010 was more pronounced, while the subsequent period was more variable and suggested a less pronounced decline.

There was an opposite trend in long-term variations in Capelin relative abundance indices in the nGSL and sGSL. The 1990–1998 period which correspond to the end of a cold period in the GSL (Galbraith et al. 2021) is associated with high relative abundance in the nGSL and low relative abundance in the sGSL. A period of low abundance in both regions of the GSL was observed from the late 1990s to the mid-2000s. From the early 2010s to 2021, the index was low in the nGSL and high in the sGSL. The variations observed in the nGSL and the sGSL and particularly the inverse signal in the last decade could be related to a change in the distribution and migration patterns of Capelin. A change in Capelin's catchability associated to a change in vertical distribution particularly in the nGSL could also be another explanatory factor.

3.4. ESTIMATES OF THE MAGNITUDE OF FISHING MORTALITY

The annual values of the MNPT, individual mean length from the research bottom trawl survey, *a* and *b* coefficient of the length-weight relationship and individual mean weight used in the estimation of the stock biomass are presented in Tables 9 and 10 for the nGSL and the sGSL, respectively.

Patterson (1992) found that for pelagic fish stocks included in his model, when $F \approx ½ M$, stocks were able to increase in size. If these findings can be extended to Capelin, which were not included in Patterson's model, given $M = 0.62$, this would suggest that F lower than 0.31 should allow Capelin stocks to increase. Scenario 1 produced approximations of the stock biomass during the 1997–2021 time series that varied between 655,237 and 14,824,278 t using low q, and ranged from 255,117 to 6,248,675 t using high q (Table 11). Mean values of E for both q were lower than 2% ($F < 0.0202$) and maximum values of E for low and high q were respectively 1.5% ($F = 0.0150$) and 3.83% ($F = 0.0391$). Average stock biomass of 771,210 (high q) and 2,020,818 t (low q) were estimated under the cautious scenario (Scenario 2) for the 1998–2021 time series (Table 11). Using conservative values of the stock biomass (high q), the 1998–2021 average of E was 1.85% ($F = 0.0188$) with minimum and maximum values of 0.16% ($F = 0.0016$) and 5.70% ($F = 0.0587$), respectively.

Maximum values of E and F during the time series resulted from a combination of relatively low stock biomass and high landings. Maximum values obtained with the cautious scenario and the conservative estimates of the stock biomass were five times lower than the threshold ($E < 30\%$ and $F < ½ M$) that are likely to allow the stock biomass to increase (Patterson 1992). Therefore, plausible levels of the inferred fishery exploitation rate between 1998 and 2021 are considered low and sustainable when compared to those of other cautiously managed stocks of small pelagic fish like Atlantic Herring.

3.5. IMPORTANCE OF CAPELIN IN COD AND GREENLAND HALIBUT DIET

The percentage of Capelin in the diet of Atlantic Cod and Greenland Halibut showed important variations over the 1993–2020 period (Figure 20). There is, however, some degree of consistency among the two predators. The percentage of Capelin in the diet of both predators was generally lower in the early 2000s, followed by an increase until the interruption of the time series in 2010 (Figure 20). Capelin represented a high proportion of Atlantic Cod and Greenland Halibut diet in several years over the period of 2015–2020.

3.6. COMPOSITE INDEX OF STOCK STATE

The composite index was generally near or below the long-term average during the 1990s, then decreased to values lower than average in the early 2000s (Figure 21). This period was followed by a sharp increase to values well above the long-term average, peaking in 2010. The composite index decreased to values below the long-term average in 2014 and 2015, then showed a general increase to values near or above the long-term average in 2020 and 2021, respectively. The composite index of the Estuary and GSL Capelin stock (4RST) follows a trend that differs from the interannual variation observed in the biomass index of the East coast of Newfoundland-Labrador Capelin stock (2J3KL, Bourne et al. 2021).

4. SOURCE OF UNCERTAINTY

Relative abundance indices need to be interpreted cautiously because the confidence intervals are relatively large and their sources of uncertainty will need to be addressed in the future. In particular, there is uncertainty as to whether the density of Capelin is horizontally homogenous in the cold intermediate layer (CIL) across the GSL, or if the densities in this habitat are lower when the CIL is located far above the bottom, such as when passing over deep channels, compared to habitats where the CIL is in contact with the bottom. Resolving this question would inform assumptions made when devising an abundance index. The in-depth analysis of the acoustic data collected during the bottom trawl surveys could be useful to validate the hypothesis of homogenous horizontal density in the CIL, and possibly lead to the development of an acoustic abundance index. The catchability of Capelin did not appear to be greatly affected by predation indices or habitat characteristics sampled in the sGSL, but the analyzes did not allow this effect to be quantified for the nGSL survey (violation of model assumptions, Chamberland et al. 2022). Also, changes in the characteristics of the CIL, like reduction in thickness or increase of the mean temperature, have not been linked to the catchability of Capelin in the surveys and could potentially affect the abundance indices.

The composite index was developed to provide a perception of the relative stock status by combining multiple indices. Although this approach uses indices considered to be proxies of stock status, it cannot provide biologically-based reference points. There is higher uncertainty for the years where data on the percentage of Capelin in predator diets were missing and mean values were imputed. A more appropriate approach to assign those missing values will be explored at the next stock assessment. The composite index could also be refined to include other proxies of the stock state, like body condition, to improve our understanding of the interannual variation on the state of the stock in the GSL ecosystem.

Relative exploitation and fishing mortality rates were computed based on estimates of the order of magnitude of Capelin abundance at the GSL scale, while the fishery is concentrated on the west coast of Newfoundland. The stock biomass estimates do not consider the portion of the stock vulnerable to the fishery since it is mainly targeting mature individuals. The potential for local depletion cannot be ruled out as this uncertainty has not been addressed at the moment. Estimates of the magnitude of stock biomass, relative exploitation and fishing mortality rates were provided to put the composite index describing the relative stock status in the global biological perspective corresponding to life history and productivity characteristics of forage fish species. These estimates should be used as a general indication of the magnitude of the interannual variations in stock size and the scale of the exploitation rate. They should not be used to describe the stock status for specific years since annual values of absolute stock biomass or spawning stock biomass are not available.

5. CONCLUSION

The 2020–2021 4RST fishing seasons were similar to those of the last decade. The TAC was reached or slightly exceeded, most landings were made off the west coast of NL by the purse seine fleet, the timing of the fishery was within the range usually observed, seiner performance indices were above the long term average, and estimated Capelin bycatch in the shrimp fishery was close to the 2014–2021 average. The commercial biological data were also representative of the last decade and no temporal trends were apparent, which may have indicated fishery induced phenotypic changes and/or directional environmental changes.

The present assessment describes the 4RST Capelin fishery data, fishery dependent biological data and abundance indices from sGSL and nGSL bottom trawl surveys. This information was, for the most part, previously presented in the last stock assessment in 2021 but is now supplemented with an approximation of the scale of fishing mortality and a new composite index of stock status that can help better understand the annual effect of different factors on the abundance of capelin in the ecosystem.

The abundance indices in the sGSL were near or above the average since 2010, while the nGSL abundance indices were generally below the average since 2012. Because Capelin have a short lifespan and populations consist of only a few age groups, their abundance is subject to large fluctuations. As these variations are largely regulated by environmental factors, it is currently difficult to accurately estimate the impact of fishing on GSL Capelin. However, plausible levels of the inferred exploitation rate from the fishery were at least 5 times lower than threshold of exploitation that has allowed small pelagic stocks to increase in size. The low approximations of exploitation rate since 1997 and the composite index near the long-term average since 2016 indicate that any of the harvest levels attained over the last decade are unlikely to pose a risk to the 4RST Capelin stock in 2022.

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TABLES

Table 1: Summary of the Estuary and Gulf of Saint Lawrence Capelin fishery quota split by NAFO Division and gear type. Capelin Fishing Areas (CFA) indicated in parentheses

NAFO division	Gear type	Type of Quota	Allocation (%)
4R (12*–14)	Fixed	Competitive	37.82
	Mobile < 65’	Individual	24.15
	Mobile ≥ 65’	Competitive	24.15
4ST (15–16)	All	Competitive	13.88

*CFA 12 includes NAFO 3Pn and portions of 3Ps

Table 2: Commercial landings[1,2](t) by NAFO Division, total landings since 1960, annual TAC (t) and percent (%) of annual TAC caught since 1981 of Capelin in NAFO Divisions 4RST. Decadal averages of commercial landings also shown.

Year	DIVISION			Total	TAC	%
	4R	4S	4T			
1960	600	46	32	**678**	-	-
1961	424	50	90	**564**	-	-
1962	514	4	143	**661**	-	-
1963	444	13	94	**551**	-	-
1964	563	33	101	**697**	-	-
1965	755	50	100	**905**	-	-
1966	735	88	43	**866**	-	-
1967	724	39	150	**913**	-	-
1968	734	30	32	**796**	-	-
1969	1,394	92	82	**1,568**	-	-
1970	339	75	42	**456**	-	-
1971	403	15	46	**464**	-	-
1972	370	41	126	**537**	-	-
1973	270	84	75	**429**	-	-
1974	180	113	128	**421**	-	-
1975	68	94	105	**267**	-	-
1976	92	48	336	**476**	-	-
1977	1,514	69	318	**1,901**	-	-
1978	8,341	37	1,323	**9,701**	-	-
1979	5,737	1,132	2,163	**9,032**	-	-
1980	1,939	15	1,566	**3,520**	-	-
1981	2,164	1	237	**2,402**	25,000	**10**
1982	156	2	235	**393**	25,000	**2**
1983	920	-	104	**1,024**	25,000	**4**
1984	1,907	-	180	**2,087**	25,000	**8**
1985	2,573	-	545	**3,118**	25,000	**12**
1986	3,721	-	226	**3,948**	25,000	**16**
1987	906	-	67	**973**	25,000	**4**
1988	4,386	129	248	**4,763**	25,000	**19**
1989	5,257	1,078	444	**6,779**	25,000	**27**
1990	6,105	164	153	**6,422**	25,000	**26**
1991	7,166	59	247	**7,472**	21,300	**35**
1992	7,851	856	56	**8,763**	5,750	**152**
1993	9,398	1,262	237	**10,897**	10,750	**101**
1994	592	208	165	**966**	11,725	**8**
1995	15	90	47	**152**	11,725	**1**
1996	6,265	461	172	**6,898**	9,850	**70**
1997	7,399	252	238	**7,889**	11,725	**67**
1998	8,749	126	776	**9,652**	11,725	**82**
1999	4,735	10	166	**4,911**	12,425	**40**

Year	DIVISION			Total	TAC	%
	4R	4S	4T			
2000	5,129	-	-	**5,129**	12,425	**41**
2001	741	-	-	**741**	12,425	**6**
2002	3,295	77	20	**3,392**	12,425	**27**
2003	5,032	-	-	**5,032**	7,455	**68**
2004	6,521	-	-	**6,521**	7,455	**87**
2005	8,659	305	34	**8,998**	13,000	**69**
2006	9,322	2,039	518	**11,880**	13,000	**91**
2007	6,097	1,344	471	**7,911**	13,000	**61**
2008	7,846	2,126	99	**10,071**	13,000	**77**
2009	10,147	527	1,405	**12,080**	13,000	**93**
2010	8,769	795	1,258	**10,822**	13,000	**83**
2011	9,890	974	1,449	**12,314**	13,000	**95**
2012	8,914	478	147	**9,539**	13,000	**73**
2013	6,350	236	-	**6,587**	14,300	**46**
2014	5,683	20	-	**5,703**	14,300	**40**
2015	11,361	107	357	**11,825**	14,300	**83**
2016	9,326	78	373	**9,777**	14,300	**68**
2017	1,945	19	1	**1,965**	14,300	**14**
2018	8,141	356	6	**8,503**	9,295	**91**
2019	7,569	427	490	**8,487**	9,295	**91**
2020[3]	7,876	1,858	547	**10,281**	9,295	**111**
2021[3]	8,013	1,733	188	**9,934**	9,295	**107**

Decadal averages

Period	DIVISION			Total
	4R	4S	4T	
1960–1969	689	45	87	**820**
1970–1979	1,731	171	466	**2,368**
1980–1989	2,393	122	385	**2,901**
1990–1999	5,828	349	226	**6,402**
2000–2009	6,279	642	255	**7,176**
2010–2019	7,795	349	408	**8,552**
2020–2021[3]	7,944	1,795	367	**10,107**

[1]From 1960 to 1978: ICNAF Statistical Bulletins Vol. 10 to 28; from 1979 to 1984: NAFO Statistical Bulletins Vol. 29 to 34

[2]ZIFF file since 1985

[3]Preliminary data

Table 3: Commercial landings (t) of Capelin by unit area of NAFO Divisions 4R, 4S and 4T since 1985. NK = not known.

Year	4RA	4RB	4RC	4RD	NK	TOTAL 4R	4SI	4SS	4SV	4SW	4SX	4SY	4SZ	NK	TOTAL 4S	4TF	4TG	4TJ	4TK	4TM	4TN	4TO	4TP	4TQ	NK	TOTAL 4S
1985	169	29	32	-	2,343	2,573	-	-	-	-	-	-	-	-	-	-	-	-	-	3	219	-	321	-	2	545
1986	1,696	17	1,410	174	424	3,721	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	226	-	-	226
1987	624	96	146	1	40	906	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67	-	-	67
1988	1,429	18	20	12	2,907	4,386	-	-	-	124	-	5	-	-	129	-	-	-	-	-	-	-	248	-	-	248
1989	1,897	47	585	76	2,652	5,257	-	-	2	1,075	-	1	-	-	1,078	-	-	-	-	-	-	-	402	7	35	444
1990	1,959	479	925	104	2,639	6,105	-	-	9	155	-	-	-	-	164	-	-	-	-	-	-	-	141	11	-	153
1991	154	82	4,907	2,023	-	7,166	-	-	-	7	-	-	51	-	59	-	-	-	-	65	-	-	160	23	-	247
1992	1,554	1,506	4,675	117	-	7,851	-	-	-	855	-	-	1	-	856	-	-	-	-	-	-	-	56	-	-	56
1993	791	1,543	5,142	1,922	-	9,398	-	-	-	1,262	-	-	-	-	1,262	-	-	-	-	-	108	-	129	-	-	237
1994	10	265	245	72	-	592	-	-	2	205	-	-	-	-	208	-	-	-	-	47	22	-	96	-	-	165
1995	15	-	-	-	-	15	-	-	-	90	-	-	-	-	90	-	-	-	-	-	-	3	39	5	-	47
1996	630	1,841	3,364	430	-	6,265	-	-	-	415	-	-	46	-	461	-	-	-	-	-	5	5	152	10	-	172
1997	734	2,480	4,171	14	-	7,399	4	-	-	202	-	30	16	-	252	2	5	-	-	7	2	2	214	5	-	238
1998	1,827	3,791	2,550	581	-	8,749	-	-	-	126	-	-	-	-	126	-	-	-	-	-	697	-	-	-	79	776
1999	29	1,675	3,031	-	-	4,735	-	-	-	10	-	-	-	-	10	-	-	-	-	70	77	-	-	-	19	166
2000	-	356	4,773	-	-	5,129	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2001	-	-	605	136	-	741	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2002	115	856	2,323	-	-	3,295	-	-	-	7	-	-	-	-	7	-	-	-	-	-	-	-	-	2	-	2
2003	513	1,070	3,450	-	-	5,032	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	3,630	645	2,185	61	-	6,521	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	5,025	1,028	2,260	346	-	8,659	-	-	-	305	-	-	-	-	305	-	-	-	-	-	-	-	34	-	-	34
2006	6,027	9	2,530	756	-	9,322	66	149	-	1,317	507	-	-	-	2,039	-	-	-	-	-	474	-	43	-	-	518
2007	5,326	6	691	73	-	6,097	-	-	-	1,344	-	-	-	-	1,344	-	-	-	-	-	430	-	41	-	-	471
2008	883	188	2,692	4,083	-	7,846	-	-	-	1,420	-	-	-	706	2,126	-	-	-	-	-	66	-	33	-	-	99
2009	2,570	2,929	4,116	531	-	10,147	-	-	-	527	-	-	-	-	527	-	-	-	-	-	1,367	-	39	-	-	1,405
2010	2,409	4,785	1,442	133	-	8,769	-	-	-	795	-	-	-	-	795	-	-	-	-	-	1,258	-	-	-	-	1,258
2011	3,378	507	4,021	1,985	-	9,890	-	-	-	974	-	-	-	-	974	24	-	-	16	-	1,409	-	-	-	-	1,449
2012	1,418	1,759	5,590	147	-	8,914	-	-	-	478	-	-	-	-	478	-	-	-	-	-	147	-	-	-	-	147
2013	5,557	344	16	378	54	6,350	-	-	-	236	-	-	-	-	236	-	-	-	-	-	-	-	-	-	-	-
2014	5,197	322	10	154	-	5,683	-	-	-	20	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-
2015	8,048	1,746	1,309	258	-	11,361	-	-	-	107	-	-	-	-	107	-	-	-	-	-	357	-	-	-	-	357
2016	6,026	2,425	811	65	-	9,326	-	78	-	-	-	-	-	-	78	-	-	-	-	-	373	-	-	-	-	373
2017	223	1,481	240	0	-	1,945	-	-	-	19	-	-	-	-	19	-	-	-	-	-	-	-	1	-	-	1
2018	2,375	2,633	2,988	145	-	8,141	-	-	-	356	-	-	-	-	356	-	-	-	-	-	-	-	3	-	2	6
2019	3,029	2,500	1,598	442	-	7,569	-	-	-	427	-	-	-	-	427	-	-	-	-	-	480	-	10	-	-	490
2020*	2,358	2,751	2,588	179	-	7,876	-	-	-	1,856	-	1	-	-	1,858	-	-	-	-	-	490	-	53	-	4	547
2021*	2,101	2,443	3,112	357	-	8,013	-	-	-	1,688	45	-	-	-	1,733	155	-	-	-	-	-	-	33	-	-	188

*Preliminary data

Table 4: Commercial landings (t) of the GSL Capelin stock by fishing gear since 1985. Misc. = includes pair seine, stationary lift nets, pot, weir, gillnet (set or fixed), midwater trawl (stern), shrimp trawl, bottom otter trawl (stern), beach and bar seine, unknown, hand and hand held tools, longline, angling, miscellaneous.

Year	Mobile gear		Fixed gear		Misc.
	Purse seine < 65	Purse seine ≥ 65	Trap net	Tuck seine	
1985	36	2,519	3	-	560
1986	61	3,455	82	-	349
1987	80	761	57	-	75
1988	33	2,907	1,494	-	329
1989	464	2,615	3,166	-	535
1990	2,576	1,598	1,700	-	548
1991	1,729	5,288	161	-	294
1992	2,848	3,925	1,911	-	80
1993	3,559	3,767	3,387	-	184
1994	432	217	210	-	107
1995	-	-	103	-	49
1996	2,883	2,596	1,306	-	113
1997	3,787	2,724	1,204	-	175
1998	3,295	3,186	2,435	-	736
1999	1,834	2,957	11	-	110
2000	1,985	3,143	1	-	-
2001	176	565	-	-	-
2002	1,814	1,481	7	-	90
2003	2,234	2,419	379	-	-
2004	2,128	2,511	1,694	-	188
2005	1,812	3,673	3,073	324	116
2006	2,955	4,380	3,562	788	193
2007	2,727	2,370	2,151	530	133
2008	3,506	3,410	2,135	967	54
2009	3,259	4,186	2,837	1,657	141
2010	3,251	3,946	2,067	1,558	-
2011	3,475	4,285	3,189	1,271	93
2012	3,617	2,951	684	2,204	82
2013	2,461	2,173	906	1,047	-
2014	2,537	1,129	370	1,477	190
2015	3,142	3,867	940	3,834	41
2016	3,257	3,780	623	2,116	-
2017	654	802	25	483	-
2018	2,729	2,213	951	2,462	148
2019	2,466	2,759	204	3,058	-
2020*	3,600	2,830	382	3,210	259
2021*	3,510	2,236	563	3,375	250
Average 1985–2019	**2,171**	**2,781**	**1,265**	**1,585**	**168**

*Preliminary data

Table 5: Results of the multiplicative model used to standardize the CPUE (performance index) of Capelin in the purse and tuck seine commercial fisheries of NAFO Division 4R. df = degree of freedom, SS = sum of squares, Pr = probability, Std. Err. = standard error.

ANOVA table

	df	SS	F	Pr(> F)	
YEAR	34.0	732.7	31.5	< 2e-16	***
MONTH	2.0	19.2	14.0	8.2e-7	***
LENGTH_CL	5.0	1323.6	387.5	< 2e-16	***
UNIT_AREA	3.0	82.0	39.9	< 2e-16	***
FISH_GEAR	1.0	138.3	202.4	< 2e-16	***
Residuals	5281.0	3607.4	-	-	

Model: lpue ~ YEAR + MONTH + UNIT_AREA + LENGHT_CL
Residuals: Min, 1Q, Median, 3Q, Max.

Coefficients	Estimate	Std. Err.	Value t	Pr(> |t|)	
intercept	1.01408	0.117	8.606	< 2e-16	***
YEAR1987	-0.02983	0.187	-0.163	0.870	
YEAR1988	0.45863	0.592	0.772	0.440	
YEAR1989	1.07794	0.264	4.044	0.000	***
YEAR1990	0.38529	0.246	1.479	0.139	
YEAR1991	0.87209	0.119	7.198	0.000	***
YEAR1992	0.49982	0.108	4.463	0.000	***
YEAR1993	0.32478	0.106	2.929	0.003	**
YEAR1994	0.12211	0.185	0.519	0.604	
YEAR1996	-0.04288	0.103	-0.554	0.580	
YEAR1997	0.10171	0.105	0.792	0.428	
YEAR1998	0.54799	0.109	4.956	0.000	***
YEAR1999	0.45719	0.114	3.886	0.000	***
YEAR2000	0.46916	0.114	3.956	0.000	***
YEAR2001	0.55636	0.211	2.549	0.011	*
YEAR2002	0.56343	0.120	4.553	0.000	***
YEAR2003	0.53718	0.115	4.522	0.000	***
YEAR2004	0.40130	0.111	3.517	0.000	***
YEAR2005	0.52952	0.108	4.908	0.000	***
YEAR2006	0.83790	0.107	7.823	0.000	***
YEAR2007	0.76151	0.116	6.538	0.000	***
YEAR2008	0.98987	0.114	8.545	< 2e-16	***
YEAR2009	0.96275	0.110	8.647	< 2e-16	***
YEAR2010	1.26077	0.114	10.971	< 2e-16	***
YEAR2011	1.32027	0.117	11.232	< 2e-16	***
YEAR2012	1.10944	0.111	9.851	< 2e-16	***
YEAR2013	1.47823	0.124	11.913	< 2e-16	***
YEAR2014	1.42968	0.124	11.446	< 2e-16	***
YEAR2015	1.35390	0.109	12.315	< 2e-16	***
YEAR2016	1.25965	0.113	11.089	< 2e-16	***
YEAR2017	1.05174	0.157	6.567	0.000	***
YEAR2018	1.36133	0.116	11.648	< 2e-16	***
YEAR2019	1.28014	0.112	11.281	< 2e-16	***
YEAR2020	1.23919	0.110	11.087	< 2e-16	***
MONTH7	1.42668	0.041	3.279	0.001	**
MONTH8	0.11790	0.189	1.102	0.270	
LENGTH_CL2	0.19024	0.071	5.464	0.000	***
LENGTH_CL3	0.38738	0.074	9.518	< 2e-16	***
LENGTH_CL4	0.70421	0.078	19.027	< 2e-16	***
LENGTH_CL5	1.48464	0.080	19.986	< 2e-16	***
LENGTH_CL6	1.59537	0.095	15.790	< 2e-16	***
UNIT_AREA4Rb	1.50088	0.045	2.793	0.005	**
UNIT_AREA4Rc	0.10029	0.044	8.093	0.000	***
UNIT_AREA4Rd	0.32205	0.060	4.855	0.000	***
FISH_GEAR31	0.28076	0.036	13.592	< 2e-16	***

Signif : 0 *** 0.001 ** 0.01 * 0.05
Std. Err. Residuals: 0.8265 on 5281 df
R2 multiple: 0.3889, R2 adjusted: 0.3837
R2 multiple: 0.3889, R2 adjusted: 0.3837

Table 6: Capelin by-catch in the shrimp fishery (in kg) in the GSL during the period 2000–2021. (See Appendix 1 for a description of the shrimp fishing areas in the GSL). NA = not available.

Year	Total by shrimp fishing area				Total
	12	10	9	8	
2000	4.723	72.067	24.174	25.574	126.538
2001	2.023	27.158	8.025	39.999	77.205
2002	0.678	77.133	30.359	200.824	308.994
2003	1.866	96.393	7.848	31.734	137.841
2004	0.440	154.605	12.490	144.647	312.182
2005	2.972	76.873	12.212	125.892	217.949
2006	0.393	48.813	32.288	14.113	95.607
2007	1.967	48.359	38.851	4.380	93.557
2008	0.720	32.811	30.877	29.581	93.988
2009	3.724	61.623	17.555	241.633	324.534
2010	5.307	57.172	63.780	29.176	155.436
2011	1.210	173.148	27.213	12.077	213.648
2012	0.531	98.680	26.988	23.344	149.542
2013	7.342	69.111	20.320	14.662	111.436
2014	3.155	17.814	4.464	11.879	37.312
2015	NA	11.815	71.426	0.728	83.969
2016	3.777	23.703	24.711	33.011	85.201
2017	17.910	10.419	20.075	30.943	79.347
2018	39.343	80.858	4.184	7.463	131.848
2019	33.708	22.276	30.568	6.346	92.898
2020	NA	85.244	0.846	1.089	87.179
2021	12.043	32.212	2.045	NA	46.300

Table 7: Number (#) of samples collected and individual Capelin measured by port samplers in NAFO Divisions 4RST since 1984.

Year	# Samples			# Fish			Total # Samples	Total # Fish
	4R	4T	4S	4R	4T	4S	4RST	4RST
1984	6	-	1	1,193	-	351	7	1,544
1985	7	-	1	1,954	-	375	8	2,329
1986	12	5	9	3,072	1,163	2,077	26	6,312
1987	3	3	7	826	740	1,766	13	3,332
1988	17	9	17	4,484	2,078	4,405	43	10,967
1989	10	5	6	2,470	1,331	1,506	21	5,307
1990	10	17	28	2,585	4,469	7,448	55	1,4502
1991	8	14	11	2,036	3,517	2,826	33	8,379
1992	9	12	10	2,302	3,130	2,555	31	7,987
1993	12	10	5	3,141	2,626	1,247	27	7,014
1994	1	10	7	256	2,616	1,657	18	4,529
1995	6	15	11	1,606	4,333	2,986	32	8,925
1996	13	15	15	3,479	6,200	3,811	43	13,490
1997	10	29	25	2,575	7,322	6,433	64	16,330
1998	9	8	5	2,245	2,080	1,359	22	5,684
1999	9	2	8	2,448	515	2,212	19	5,175
2000	6	-	3	1,553	-	553	9	2,106
2001	2	-	-	478	-	-	2	478
2002	7	-	-	1,974	-	-	7	1,974
2003	9	5	12	2,367	1,177	3,270	26	6,814
2004	8	6	4	2,070	1,524	1,015	18	4,609
2005	7	10	9	1,053	1,523	1,702	26	4,278
2006	10	3	4	1,980	542	1,019	17	3,541
2007	7	3	4	1,959	570	981	14	3,510
2008	7	4	2	1,360	770	517	13	2,647
2009	15	4	5	2,640	733	819	24	4,192
2010	6	8	17	1,032	1,317	3,261	31	5,610
2011	4	7	7	722	1,189	1,277	18	3,188
2012	10	3	9	1,941	486	1,507	22	3,934
2013	7	3	13	1,333	504	2,137	23	3,974
2014	4	4	8	783	717	1,240	16	2,740
2015	7	9	11	1,752	1,512	1,810	27	5,074
2016	6	4	19	1,047	627	3,433	29	5,107
2017	4	5	5	723	871	923	14	2,517
2018	9	19	19	1,620	3,144	3,403	47	8,167
2019	7	12	11	1,189	1,895	1,744	30	4,828
2020	-	8	5	-	1,355	780	13	2,135
2021	11	10	8	1,991	1,597	1,221	29	4,809

Table 8: Number (#) of Capelin collected by port samplers and analysed in the laboratory since 1984.

Year	# Samples			# Fish			Total # Samples	Total # Fish
	4R	4T	4S	4R	4T	4S	4RST	4RST
1984	6	-	1	191	-	50	7	241
1985	7	-	1	235	-	31	8	266
1986	12	5	9	164	62	98	26	324
1987	3	3	7	114	80	172	13	366
1988	17	9	17	513	188	376	43	1077
1989	10	5	6	208	401	204	21	813
1990	10	17	27	177	222	207	54	606
1991	8	14	11	129	173	157	33	459
1992	9	12	10	169	85	113	31	367
1993	12	10	5	202	157	67	27	426
1994	1	10	8	17	509	306	19	832
1995	6	15	11	202	148	127	32	477
1996	13	15	15	169	162	170	43	501
1997	10	29	25	169	339	343	64	851
1998	9	8	5	139	120	52	22	311
1999	9	2	8	241	36	100	19	377
2000	8	-	3	661	-	58	11	719
2001	2	-	-	54	-	-	2	54
2002	7	-	-	204	-	-	7	204
2003	9	5	12	159	77	135	26	371
2004	8	6	4	238	107	95	18	440
2005	7	10	9	211	176	226	26	613
2006	10	3	4	302	50	94	17	446
2007	7	3	4	218	49	72	14	339
2008	7	4	2	211	60	40	13	311
2009	15	4	5	237	70	66	24	373
2010	6	8	17	157	128	243	31	528
2011	4	7	7	158	148	258	18	564
2012	10	3	9	252	52	109	22	413
2013	7	5	13	204	77	166	25	447
2014	4	6	8	170	61	90	18	321
2015	7	9	11	217	132	141	27	490
2016	6	4	20	177	60	280	30	517
2017	4	5	5	144	71	55	14	270
2018	9	19	19	238	220	365	47	823
2019	7	12	11	209	162	131	30	502
2020	-	8	5	-	134	51	13	185
2021	11	10	8	258	113	97	29	468

Table 9: Annual values of the mean number of Capelin per tow (MNPT), the individual mean length (L, cm) and predicted mean weight (W, g) of Capelin in the nGSL summer bottom trawl survey between 1990 and 2021. a and b are the length-weight relationship coefficients estimated from the Capelin that are both weighted and measured for length (aW^b).

Year	MNPT	L	a	b	W
1990	344.8	11.7	-	-	-
1991	332.1	-	-	-	-
1992	374.0	-	-	-	-
1993	402.6	-	-	-	-
1994	438.2	-	-	-	-
1995	313.6	12.0	-	-	-
1996	530.5	-	-	-	-
1997	476.2	13.8	0.0017	3.342	11.3
1998	251.9	10.6	0.0017	3.342	4.7
1999	513.2	13.3	0.0009	3.568	9.7
2000	146.9	12.4	0.0018	3.326	8.0
2001	62.6	12.7	0.0014	3.453	9.1
2002	45.4	14.4	0.0036	3.089	13.6
2003	277.6	13.3	0.0015	3.370	9.4
2004	114.5	12.8	0.0016	3.377	9.1
2005	97.6	13.2	0.0027	3.185	9.9
2006	200.5	14.1	0.0024	3.231	12.6
2007	370.2	13.3	0.0016	3.370	9.8
2008	432.2	11.1	0.0028	3.151	5.6
2009	261.1	13.4	0.0026	3.176	10.1
2010	276.3	13.1	0.0019	3.317	9.8
2011	691.2	13.9	0.0021	3.265	11.2
2012	92.3	14.3	0.0005	3.787	11.9
2013	100.1	13.7	0.0023	3.225	10.6
2014	23.4	14.7	0.0015	3.396	13.5
2015	59.1	12.9	0.0005	3.769	8.3
2016	25.3	14.3	0.0020	3.272	12.2
2017	324.4	11.9	0.0010	3.561	6.6
2018	69.6	14.2	0.0004	3.899	12.3
2019	89.0	11.8	0.0012	3.461	6.3
2020	37.5	13.6	0.0011	3.520	10.9
2021	60.9	14.7	0.0012	3.440	13.0

Table 10: Annual values of the mean number of Capelin per tow (MNPT), the individual mean length (L, cm) and predicted mean weight (W, g) of Capelin in the sGSL summer bottom trawl survey between 1990 and 2021. a and b are the length-weight relationship coefficients estimated from the Capelin that are both weighted and measured for length (aWb).

Year	MNPT	L	a	b	W
1990	2.9	12.0	0.0057	3.018	10.4
1991	176.2	13.6	0.0048	3.067	14.3
1992	4.2	10.7	0.0063	2.934	6.7
1993	4.0	12.4	0.0139	2.607	9.9
1994	53.4	10.9	0.0100	2.751	7.1
1995	28.4	10.5	0.0040	3.102	5.8
1996	118.8	11.5	0.0058	2.951	7.7
1997	29.6	11.5	0.0034	3.154	7.5
1998	54.4	11.9	0.0038	3.111	8.2
1999	436.6	10.5	0.0035	3.141	5.8
2000	184.0	10.9	0.0051	3.007	6.6
2001	129.0	10.8	0.0025	3.310	6.4
2002	189.3	10.6	0.0070	2.902	6.5
2003	95.3	11.7	0.0035	3.154	8.1
2004	124.5	10.2	0.0037	3.139	5.4
2005	19.5	11.0	0.0011	3.606	6.2
2006	58.4	9.3	0.0022	3.319	3.6
2007	164.3	10.8	0.0060	2.934	6.5
2008	132.5	11.8	0.0032	3.188	8.2
2009	174.3	11.0	0.0036	3.158	7.0
2010	898.9	11.3	0.0038	3.095	6.9
2011	905.8	11.4	0.0046	3.030	7.4
2012	533.3	11.7	0.0034	3.174	8.3
2013	577.6	12.8	0.0050	3.017	10.7
2014	646.9	11.7	0.0036	3.128	7.8
2015	360.4	11.2	0.0028	3.215	6.6
2016	112.2	10.5	0.0037	3.124	5.6
2017	668.4	11.3	0.0028	3.230	7.0
2018	176.1	10.4	0.0037	3.132	5.6
2019	254.5	10.2	0.0033	3.175	5.3
2020	329.7	11.1	0.0018	3.426	6.8
2021	479.8	11.2	0.0027	3.254	7.1

Table 11: Order of magnitude of 4RST Capelin stock biomass, relative exploitation rate (%) and fishing mortality rate for the 1998–2021 period. Estimations were done considering a cautious scenario with low (q nGSL = 0.0045, q sGSL = 0.01) and high (q nGSL = 0.01, q sGSL = 0.1) catchability coefficients in the surveys. Mean, min and max represent time series average, minimum and maximum values, respectively.

-		**Stock biomass (t)**		**Exploitation rate (%)**		**Fishing mortality**	
		low *q*	high *q*	low *q*	high *q*	low *q*	high *q*
Scenario 1	**Mean**	3,802,646	1,569,981	0.37	1.00	0.0037	0.0100
	Min	655,237	255,117	0.04	0.11	0.0004	0.0011
	Max	14,824,278	6,248,675	1.5	3.83	0.0150	0.0391
Scenario 2	**Mean**	2,020,818	771,210	0.60	1.85	0.0060	0.0188
	Min	366,456	125,166	0.06	0.16	0.0006	0.0016
	Max	7,564,520	2,981,784	1.46	5.70	0.0147	0.0587

FIGURES

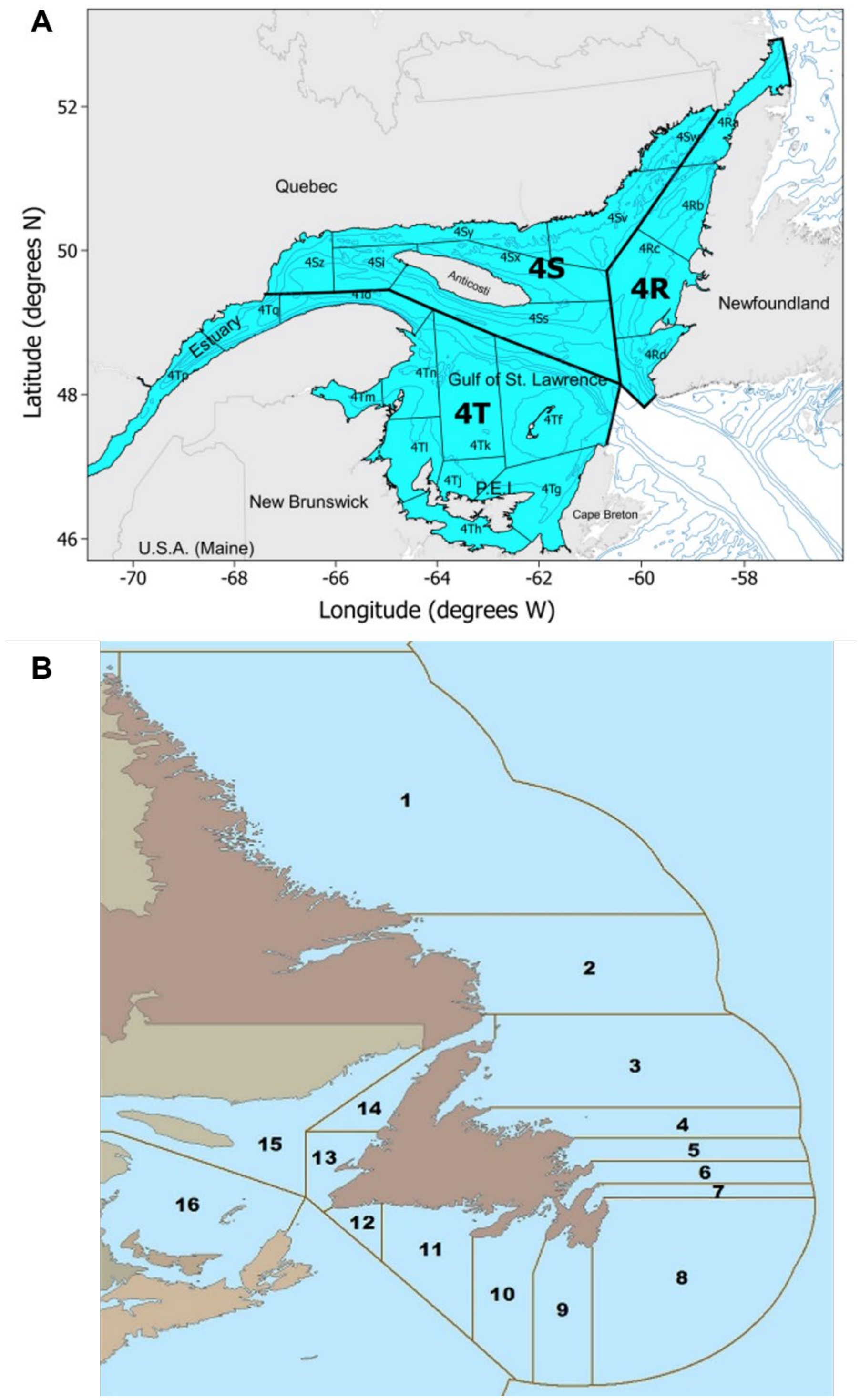


Figure 1: Maps of A) NAFO Divisions and unit areas of the Estuary and Gulf of St. Lawrence. Capelin fishing areas defined by DFO are shown in B).

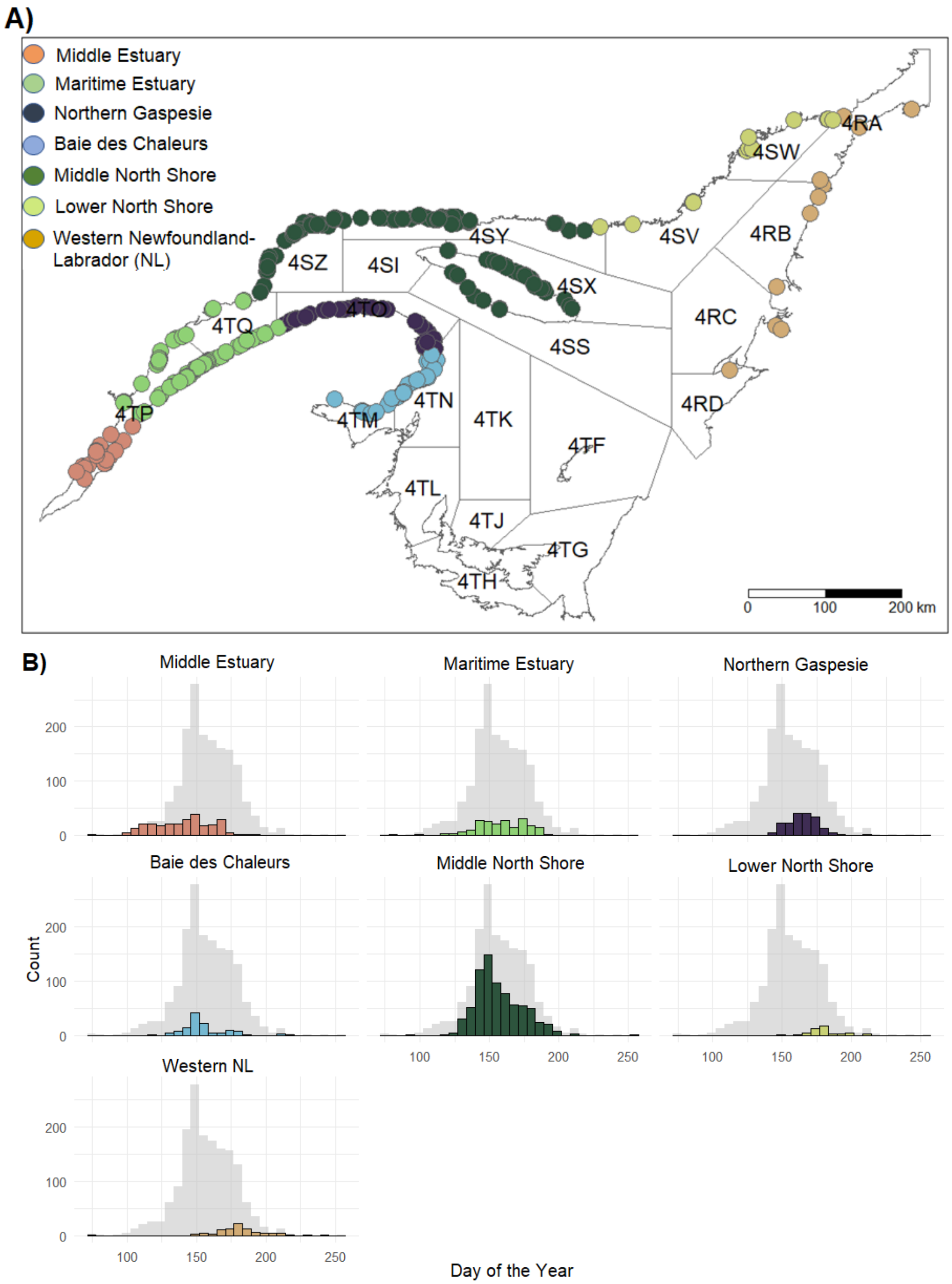


Figure 2: A) Map of Capelin Observers Network (Source: [SLGO](#)) beach spawning observations, by regions and NAFO unit areas, and B) histograms of observed spawning activity binned by week between 2006 and 2018. In the lower panel, the sum of all observations by week are presented in grey and colored histograms represent observations disaggregated by region.

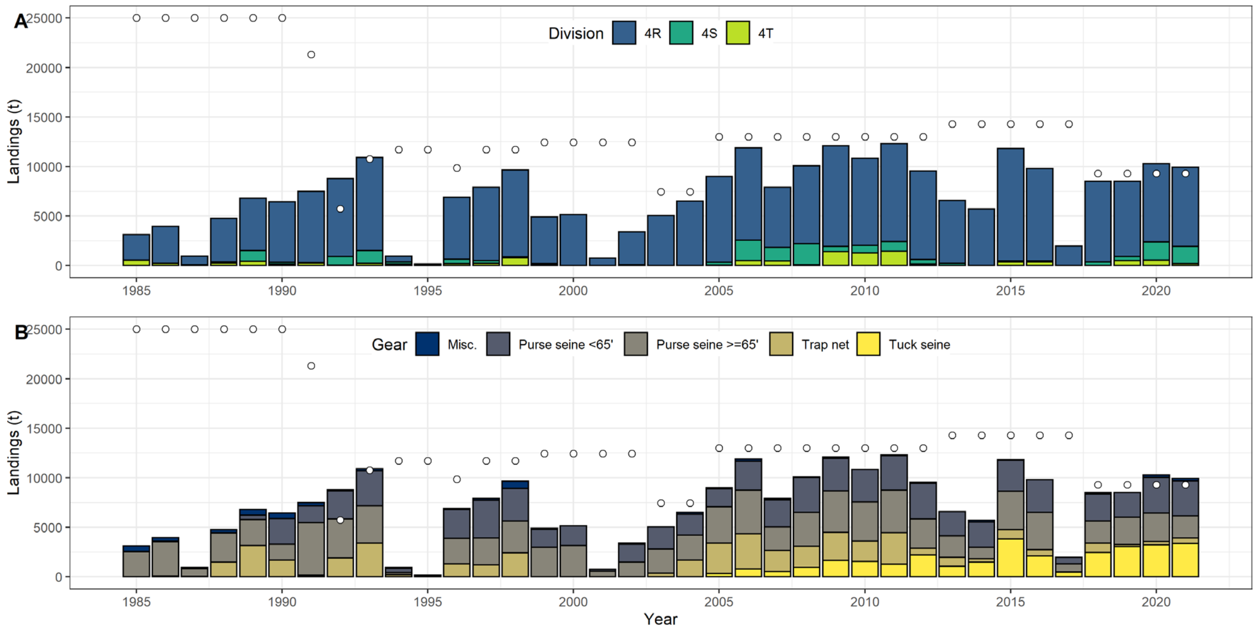


Figure 3: Capelin landings (t) by A) NAFO Division from 1960 to 2021 and B) by main fishing gear for the 1985–2021 period. The white circles represent the annual TACs. 2020 and 2021 landings are preliminary. Misc. = Miscellaneous and unknown.

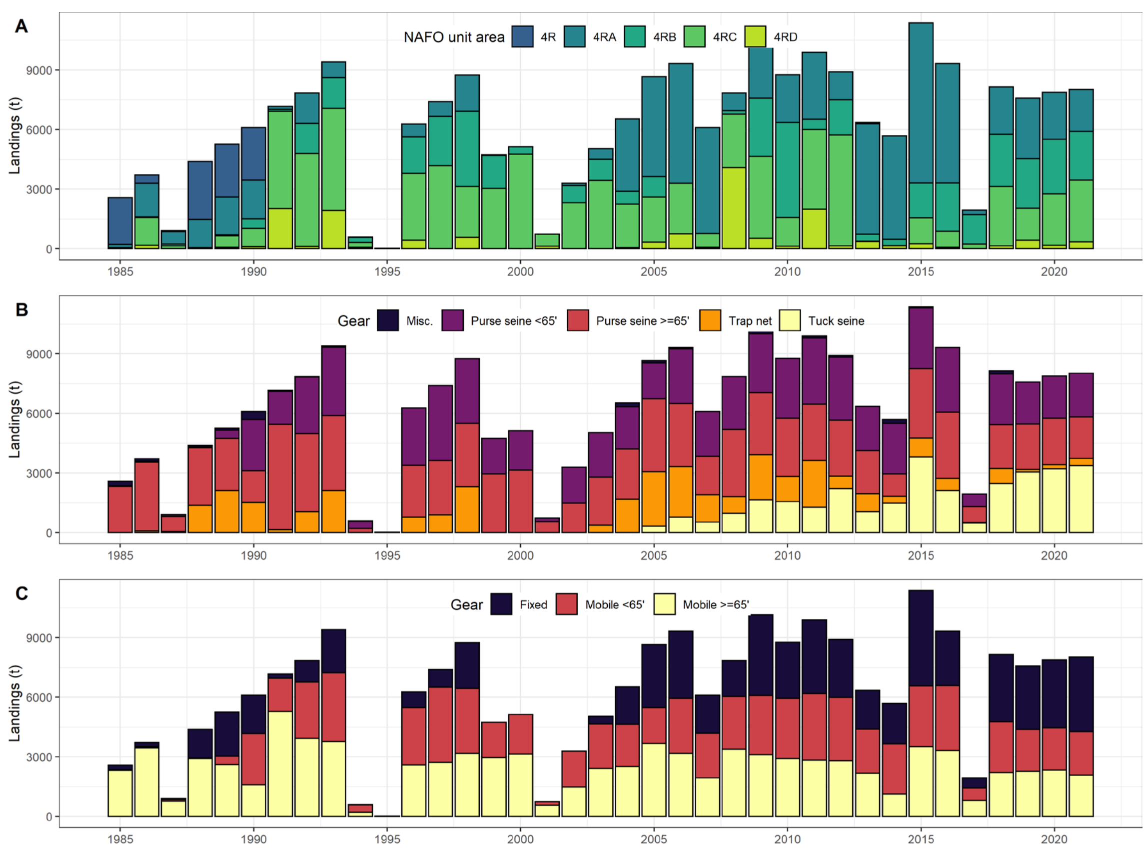


Figure 4: Annual commercial landings (t) of Capelin in NAFO Divs. 4R for the 1985–2021 period. A) Landings by NAFO unit area. B) Landings by major fishing gear type. C) Landings divided according to existing allocation. Landings for 2019 and 2020 are preliminary. Misc. = Miscellaneous and unknown.

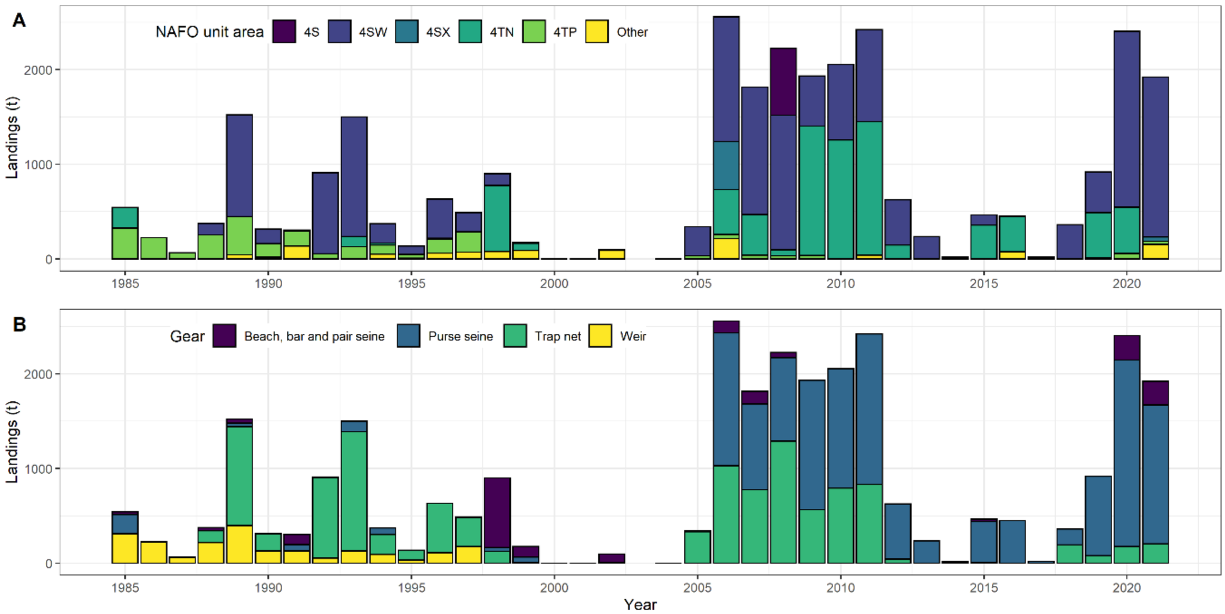


Figure 5: Annual commercial landings (t) of Capelin within NAFO Divs. 4ST for the 1985–2021 period. A) Landings by NAFO unit area. B) Landings by major fishing gear type. Landings for 2010 and 2021 are preliminary.

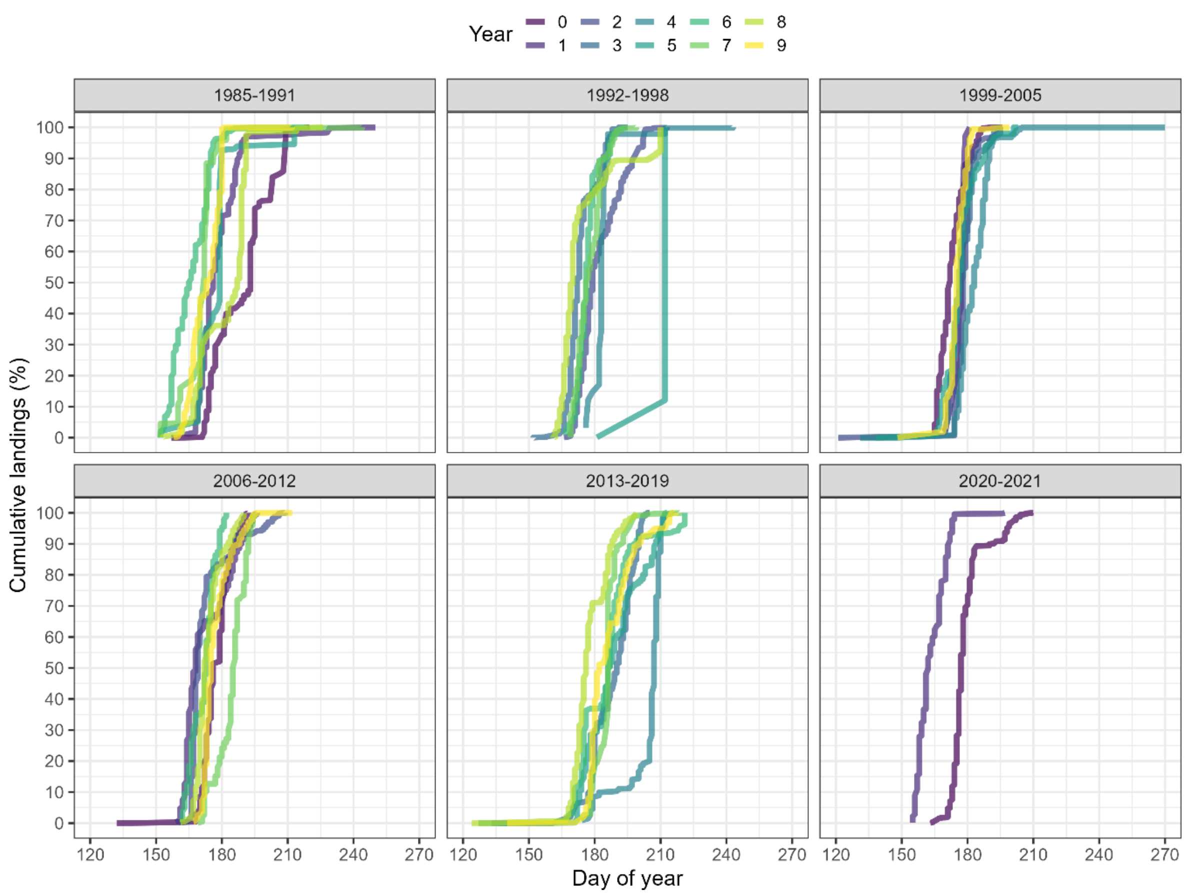


Figure 6: Cumulative directed fishery landings and bycatch (%) in relation to day of year, for NAFO Divs. 4R. Line colours progress from violet to yellow based upon the last digit of the year (0–9).

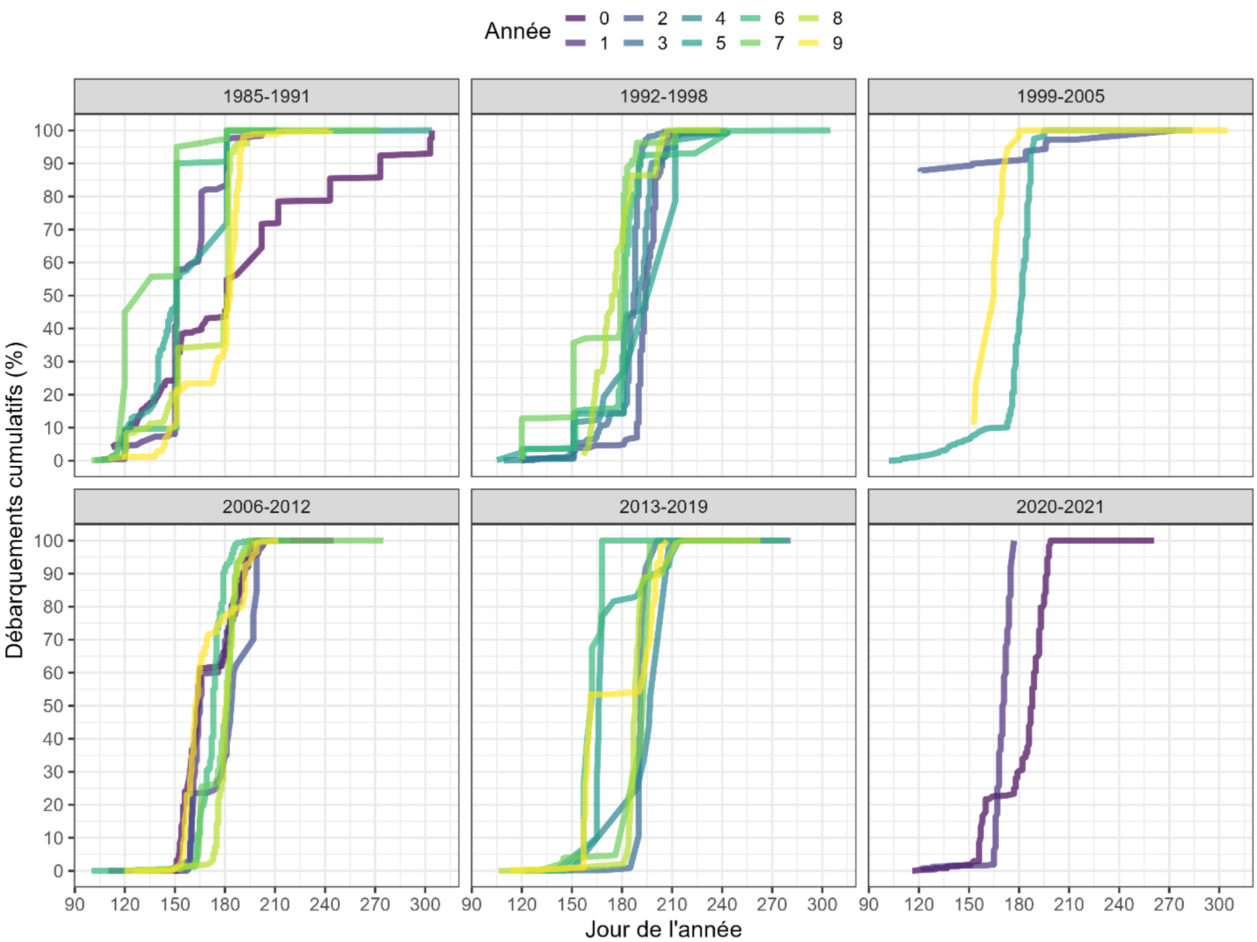


Figure 7: Cumulative commercial landings (%) in relation to day of the year, for NAFO Divs. 4ST. Line colours progress from violet to yellow based upon the last digit of the year (0–9).

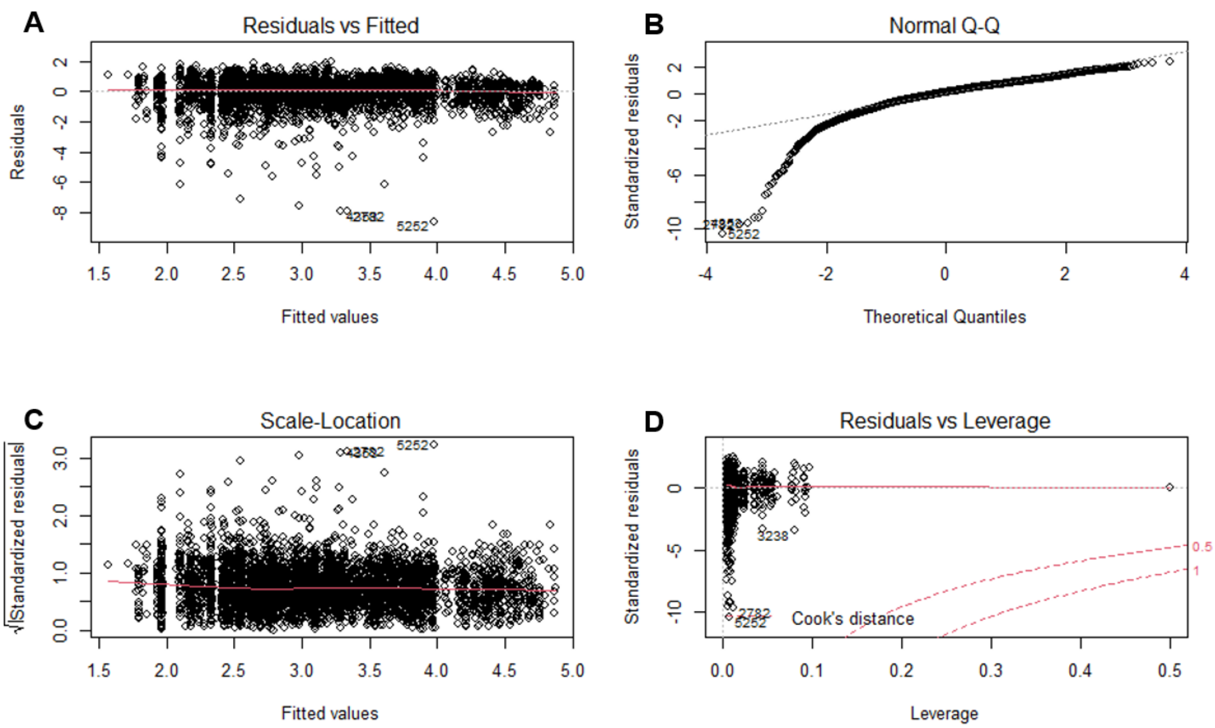


Figure 8: Diagnostics of the multiplicative model used to standardize the Capelin CPUE (performance index) in purse and tuck seine fishery in NAFO Division 4R. A) residuals vs fitted values of the model, B) quantile-quantile graph of the standardized residuals, C) square root of the absolute values of the standardized residuals vs fitted values of the model and D) standardized residuals vs. leverage graph and Cook's distances of 0.5 and 1.

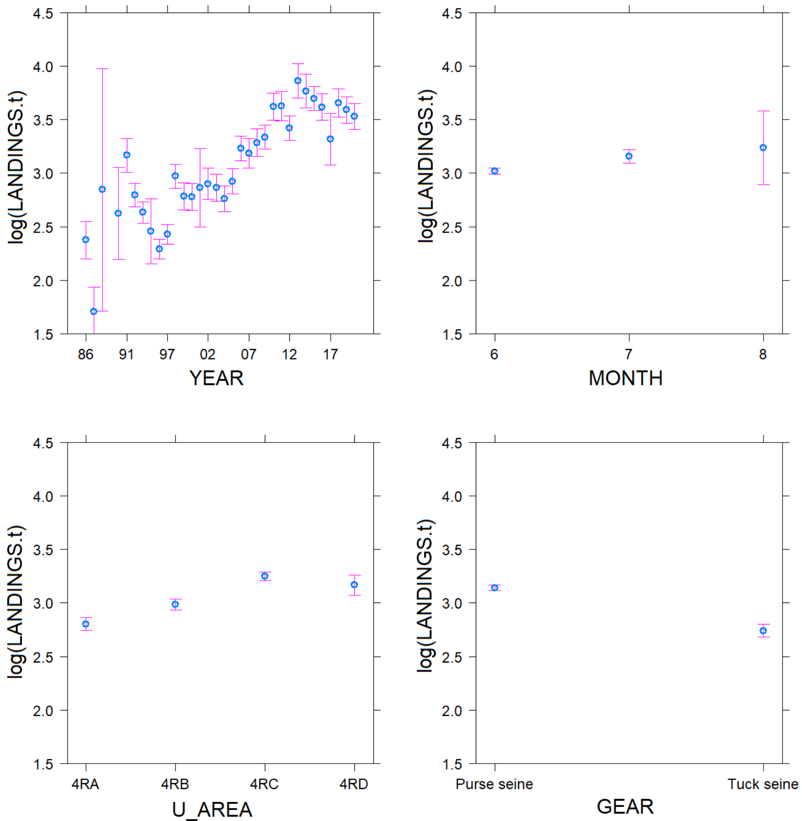


Figure 9: Effects and standard errors of the different levels of standardization factors on the performance index for the NAFO Division 4R commercial Capelin fishery. The y-axes are expressed on the linear predictor scale. LENG_CL = Vessel length class, U_AREA = NAFO subdivision, Gear 25 = Tuck seine, Gear 31 = Purse seine.

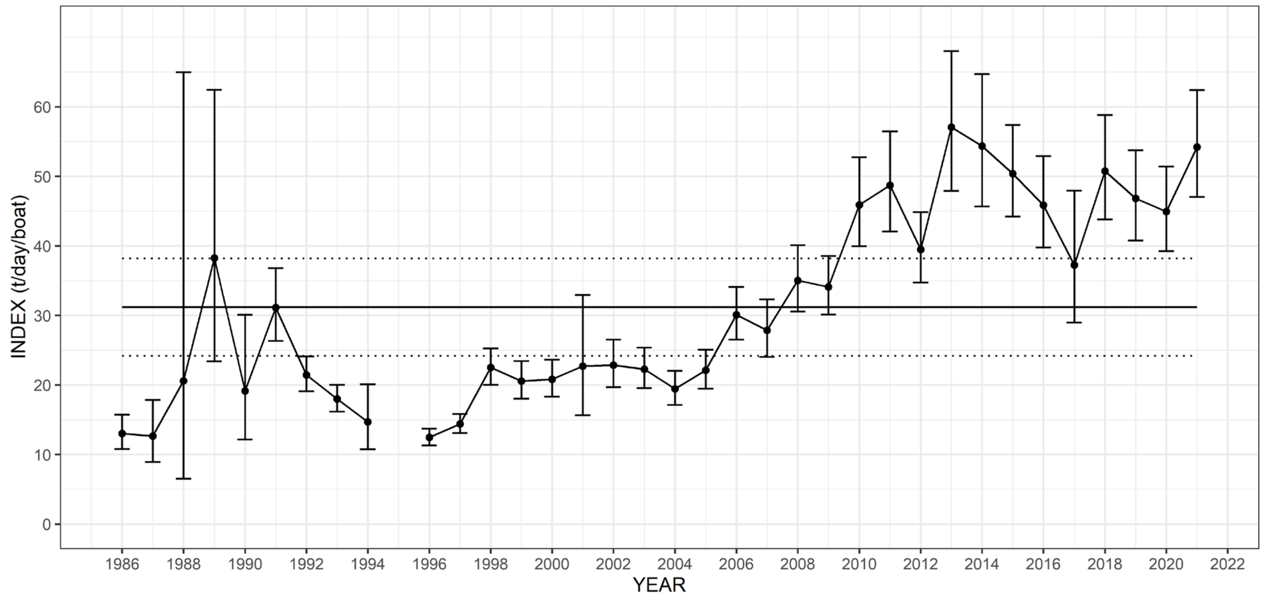


Figure 10: Performance (t/day/boat) of the purse and tuck seine fishery on the west coast of Newfoundland (NAFO Division 4R) as measured by a standardized catch-per-unit-effort index. The reference levels used in standardization are: MONTH = 6, LENG_CL = 2, U_AREA = 4Rc and GEAR = 31. The solid horizontal line represents the mean of the series (1986–2021) and the dotted lines the mean ± 0.5 SD. Error bars on the point estimates are the 95% confidence intervals. Total landings in 1995 were too low (152 t) to be considered in the analysis.

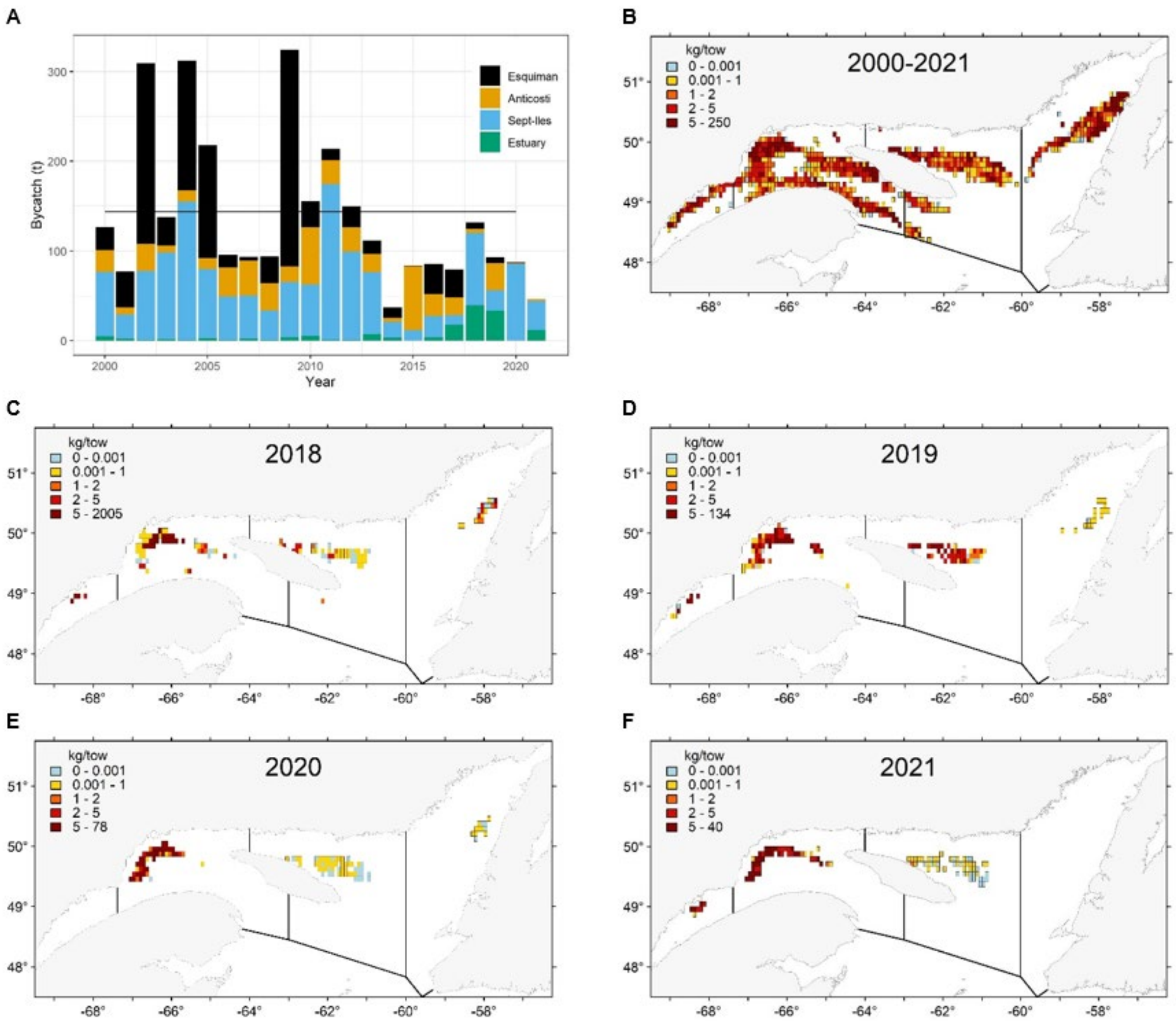


Figure 11: A) Annual estimates of Capelin caught as bycatch (t) in the Gulf of St. Lawrence shrimp fishery, by shrimp fishing area. B) Geographic distribution of the Capelin bycatch represented by estimated kg/tow in 5 by 5 minute cells for the years 2000-2021, C) 2018, D) 2019, E) 2020, and F) 2021. Capelin bycatch in the 2021 shrimp fishery was incomplete at the time of the assessment and are presented but not included in the time series average. Source: H. Bourdages, DFO personal communication.

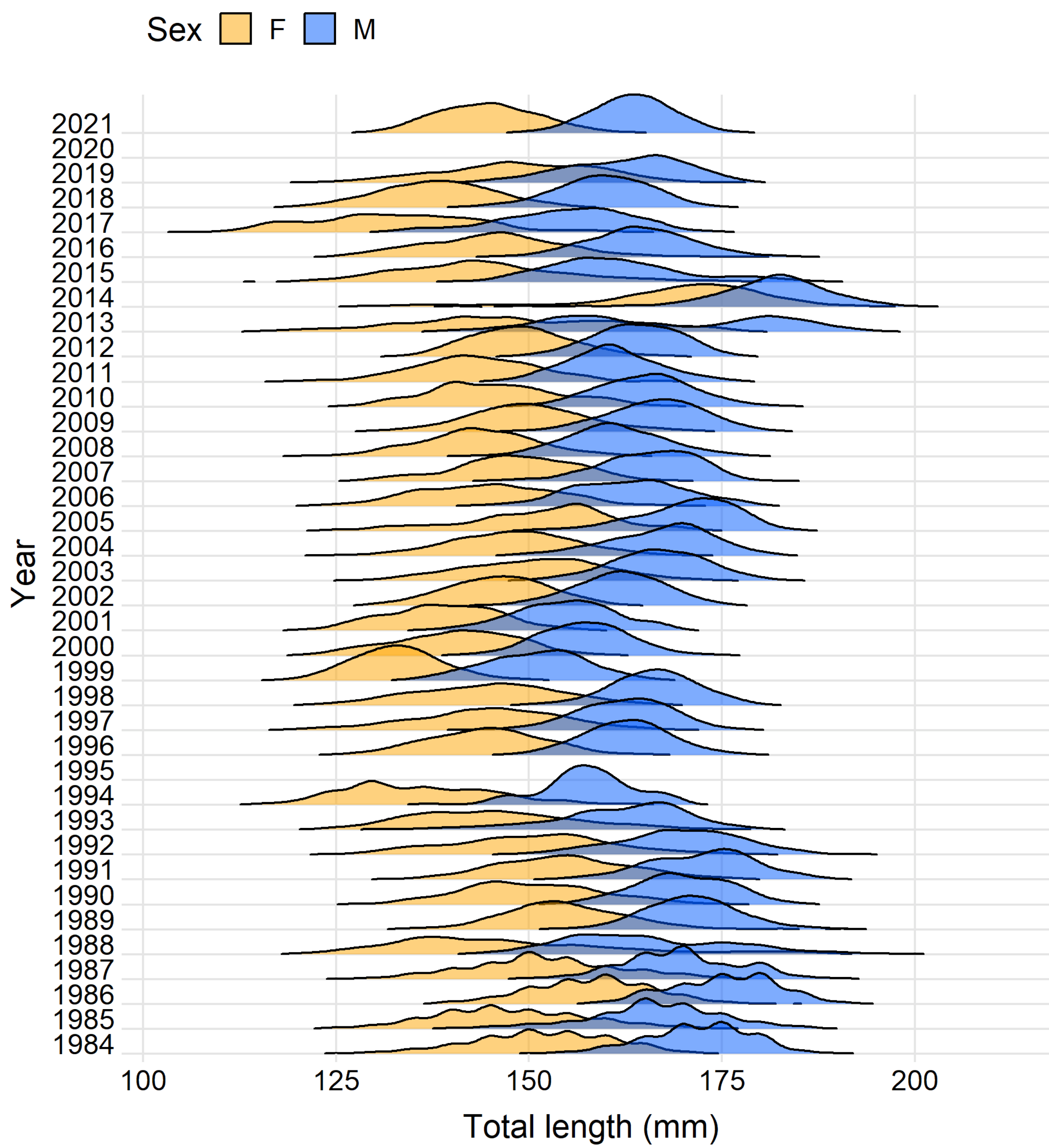


Figure 12: Total length (mm) composition (kernel density estimates) female and male Capelin caught with seines (purse and tuck) in NAFO Division 4R from 1984 to 2021 as of the DFO's port sampling program. No samples were available in 1995 and 2020.

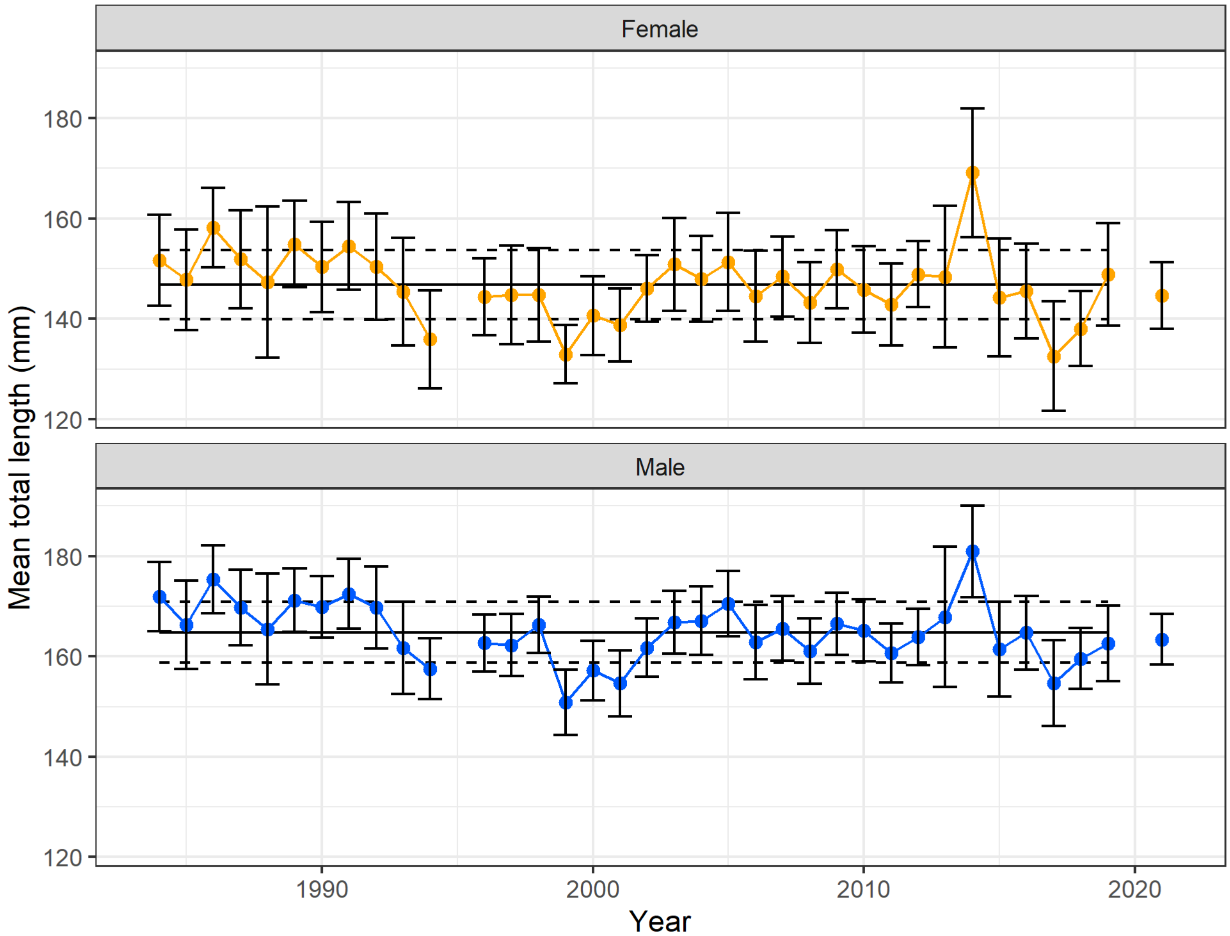


Figure 13: Mean total length (mm) of female and male Capelin caught with seines (purse and tuck) in NAFO Division 4R since 1984 from DFO's port sampling program. The horizontal lines represent the 1984–2019 mean ± 1 SD. Error bars represent the annual SD.

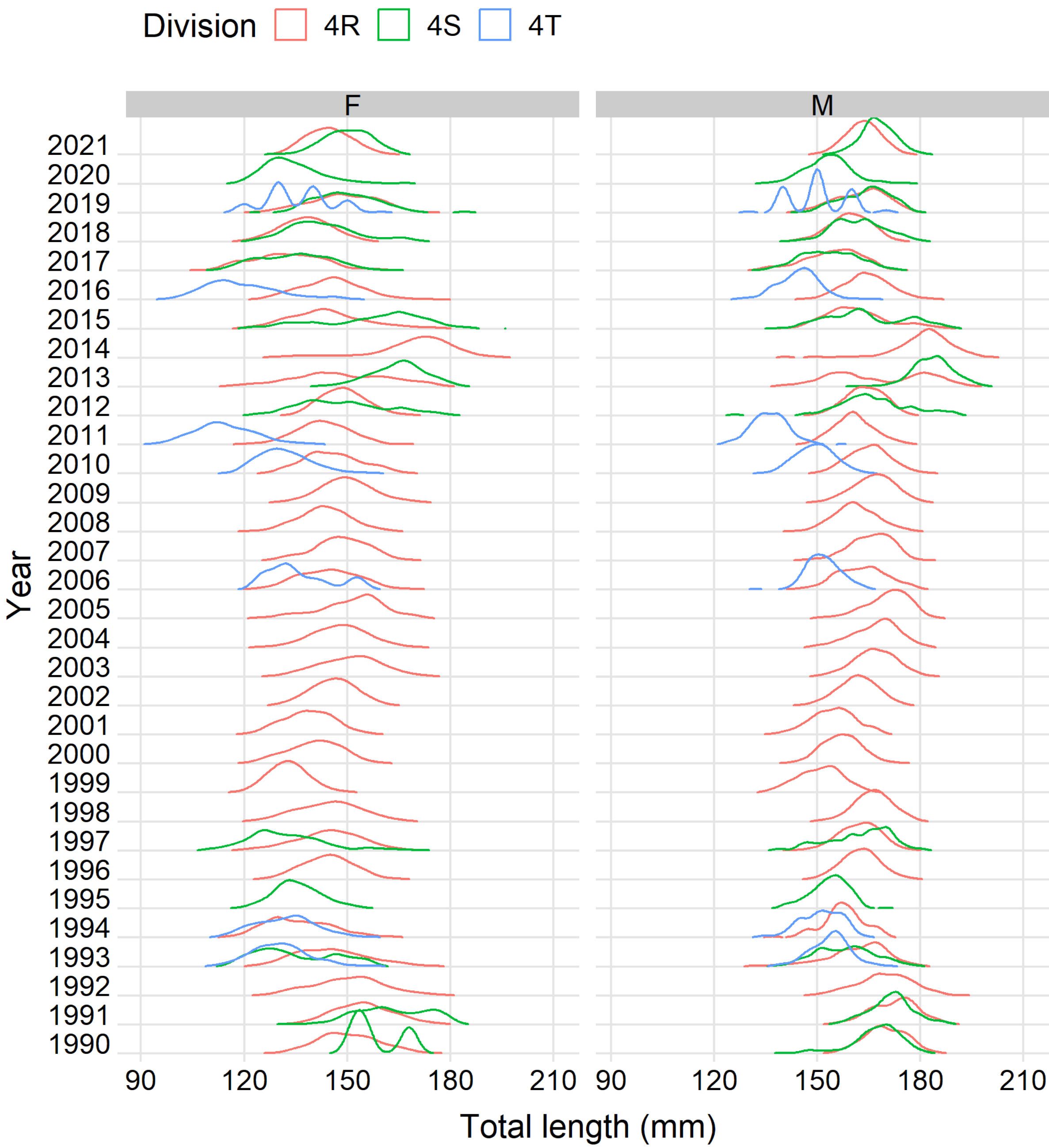


Figure 14: Length composition (mm total length; kernel density estimates) of female (F) and male (M) Capelin caught in the NAFO Divs. 4RST seine fisheries (purse and tuck) from 1990 to 2021 based samples from DFO's port sampling program.

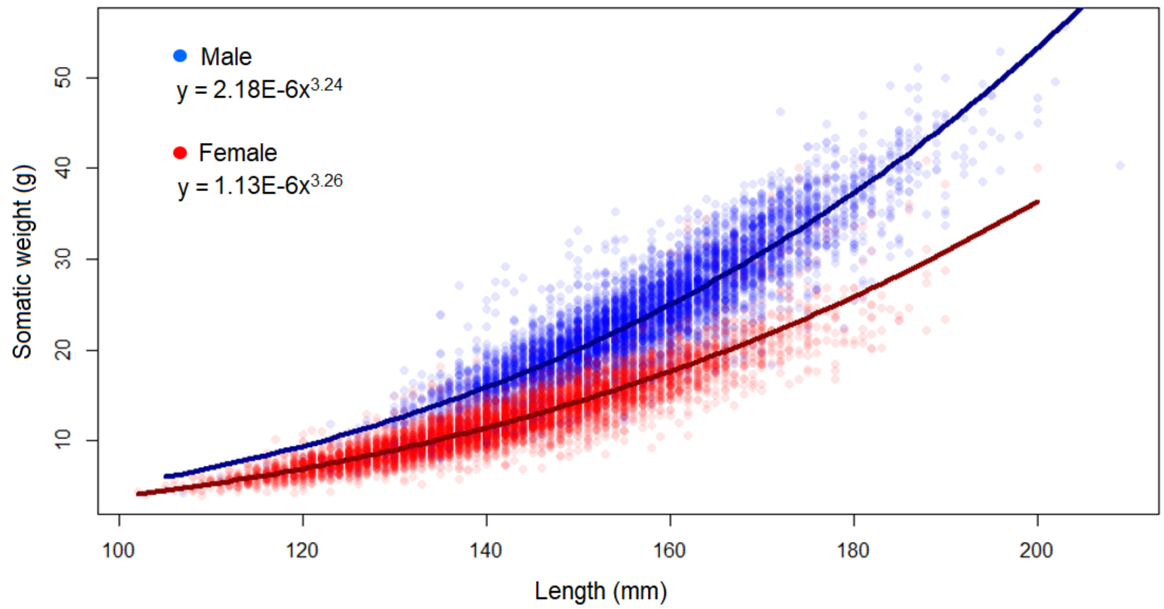


Figure 15: Length-weight relationships for Capelin caught in NAFO Divs 4RST commercial fisheries from 1984 to 2021 and sampled as a part of DFO's port sampling program.

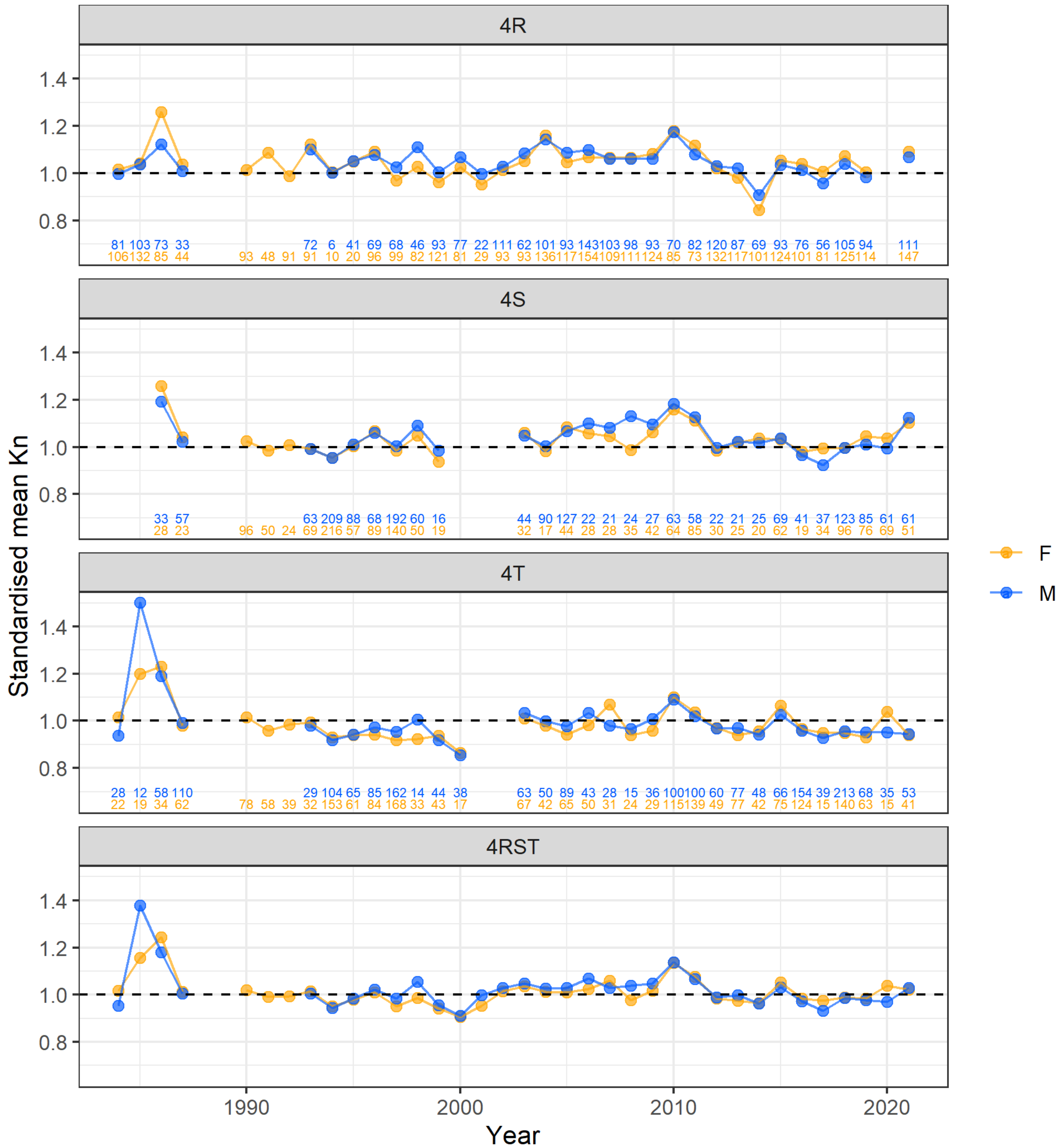


Figure 16: Standardized annual relative condition factor (Kn) of male (blue) and female (yellow) Capelin from commercial samples analyzed in laboratory. Kn were standardized for the following reference levels: gear = seine (all types), month = June. Number of fish per sex is indicated on the absciss.

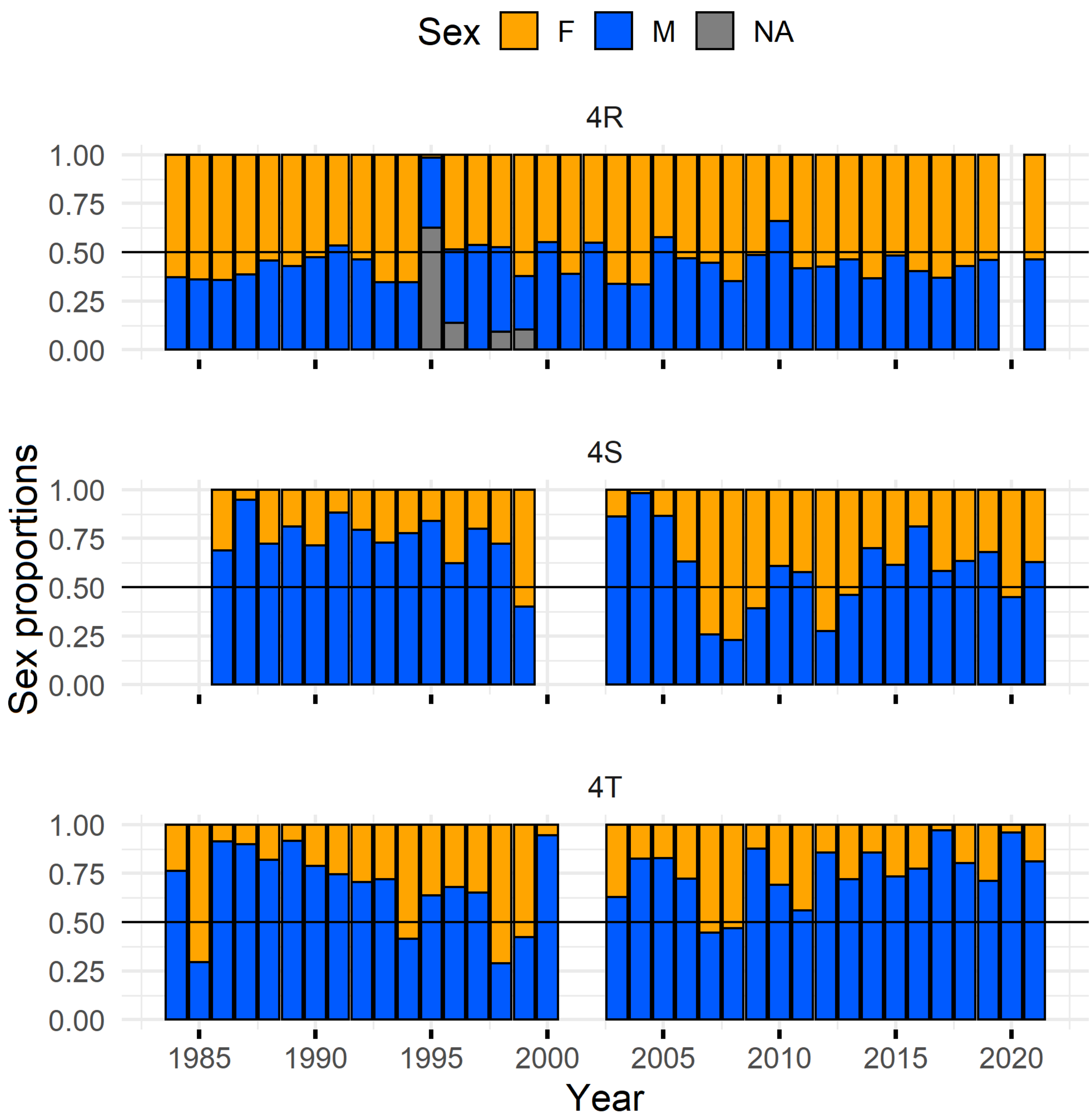


Figure 17: Annual sex proportions in Capelin commercial length frequency data from DFO's port sampling program, by NAFO Division. NA = not available)

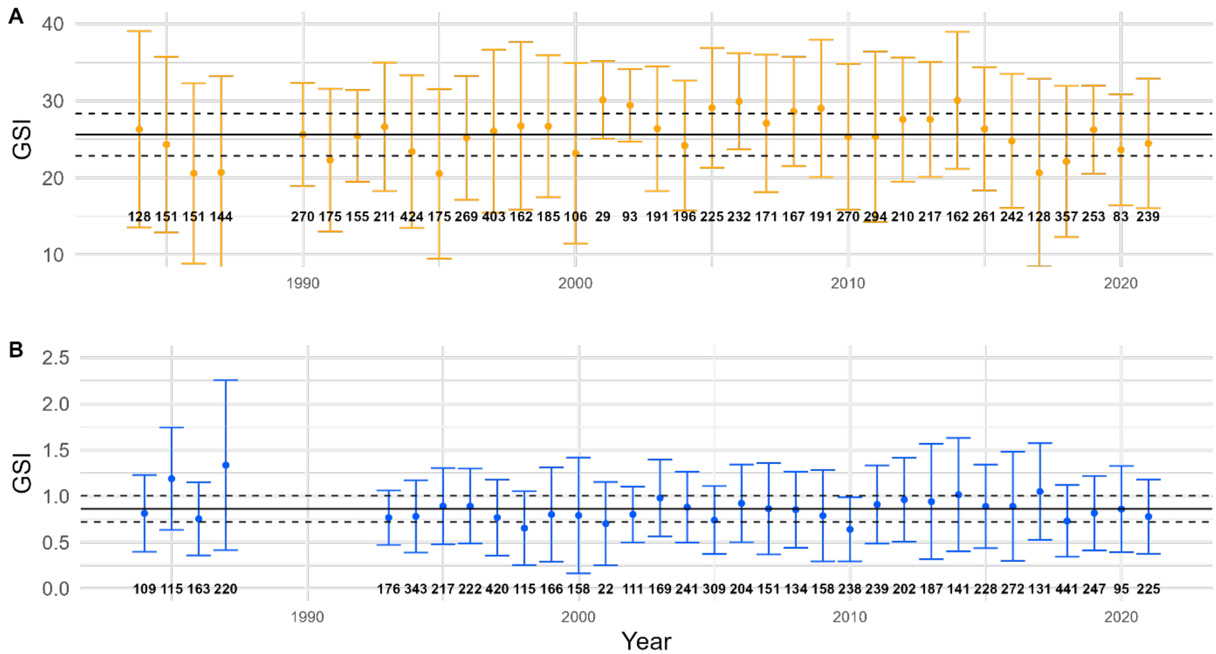


Figure 18: Estimated annual mean (± SD) Gonadosomatic-Index (GSI) of female (A) and male (B) Capelin. Individuals whose sex could not be identified, individuals weighting < 5 g, as well as male Capelin with a GSI > 10% were excluded from the analysis. Numbers represent sample size.

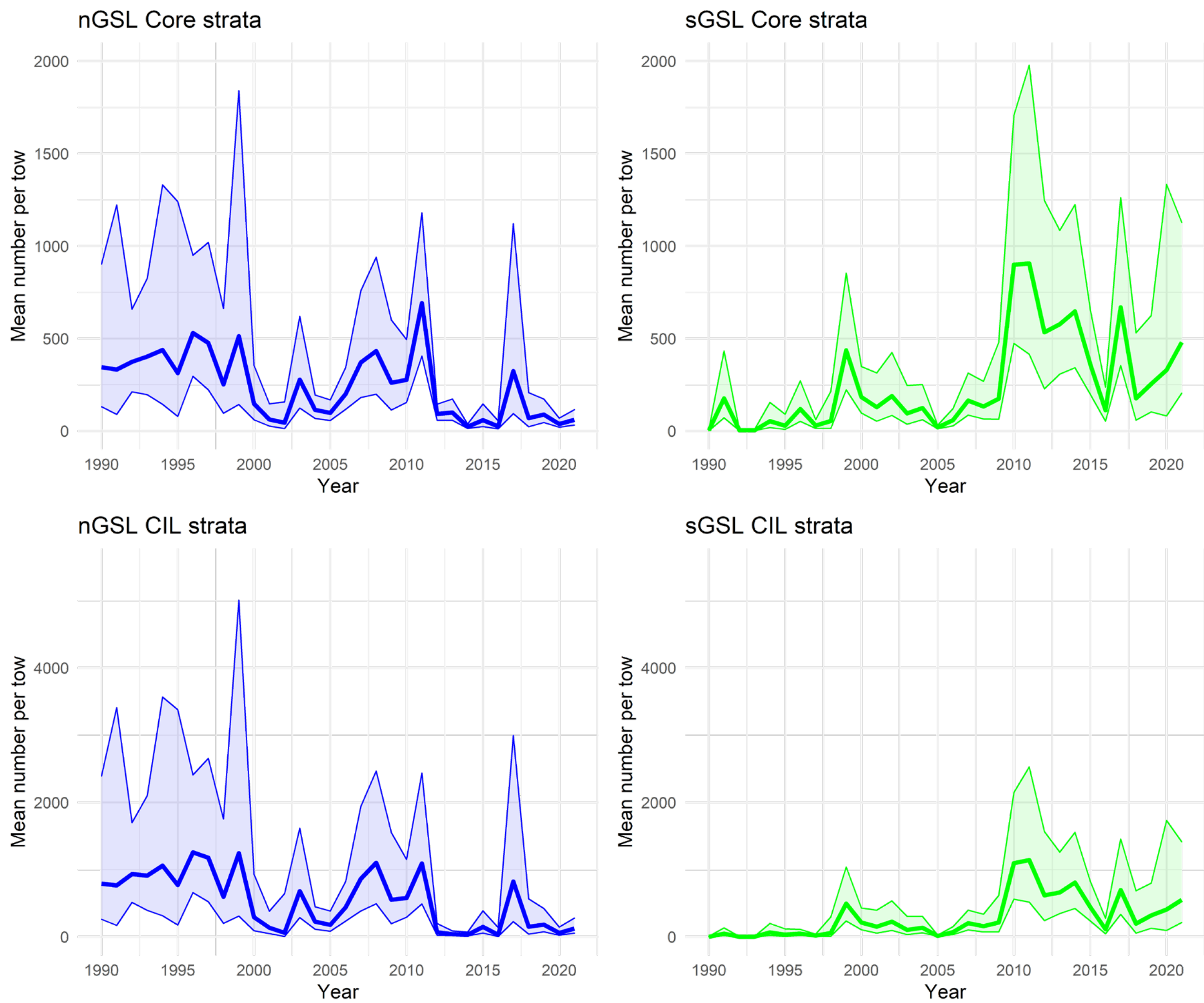


Figure 19: Estimated Capelin relative abundance indices for the northern (left panels) and southern (right panels) GSL bottom trawl surveys based on core strata (upper panels) and assuming that mean densities in strata covering favored habitat (CIL strata, bottom panels) estimate mean densities in strata occurring below this habitat. Shaded areas for each series represent 95% confidence intervals. Indices for the southern GSL before 1990 are not shown.

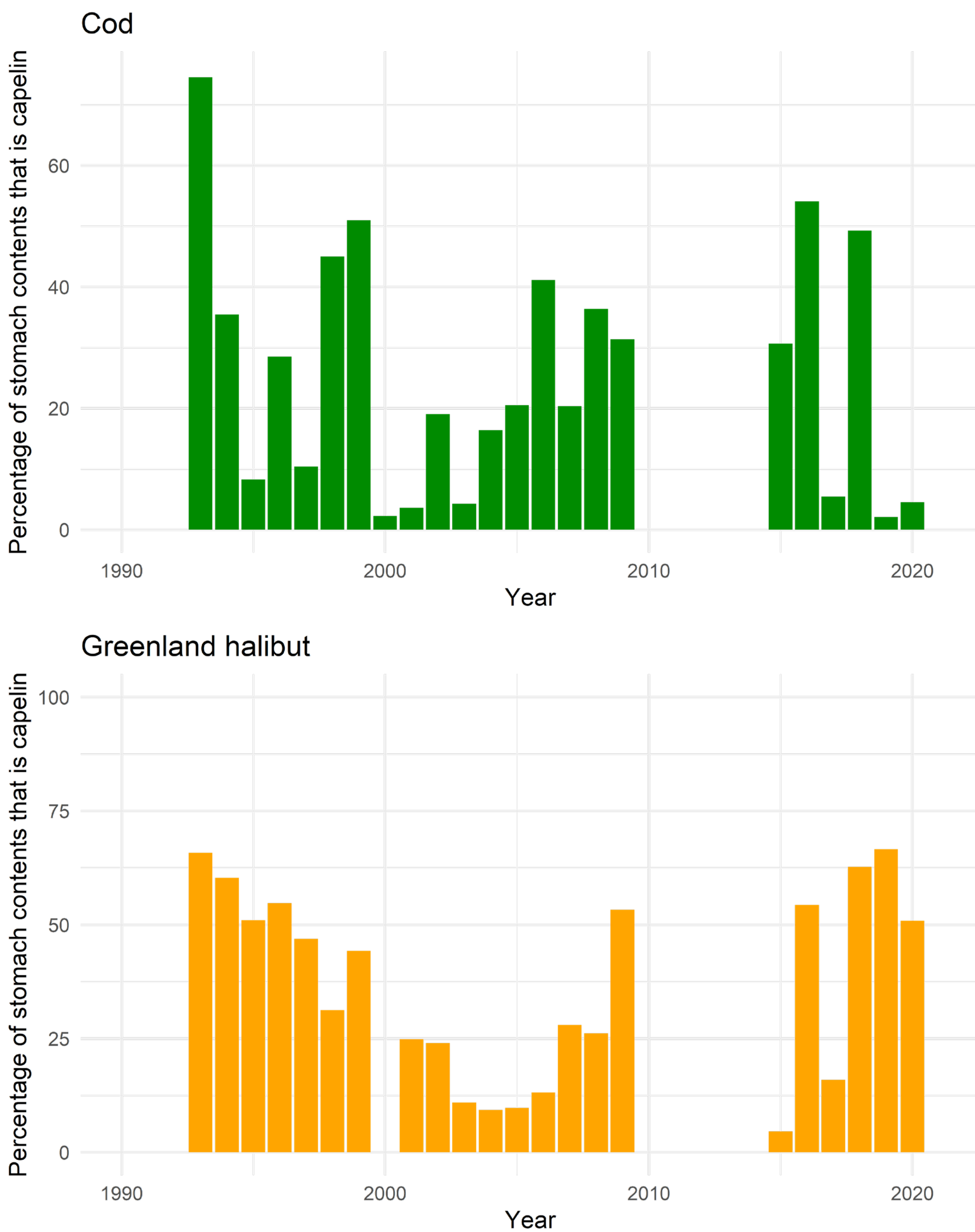


Figure 20: Percentage of average stomach contents of Atlantic cod and Greenland halibut comprising Capelin (by weight), all length classes combined. No stomachs were collected during the period 2010–2014 (both predators) and in 2000 (Greenland halibut).

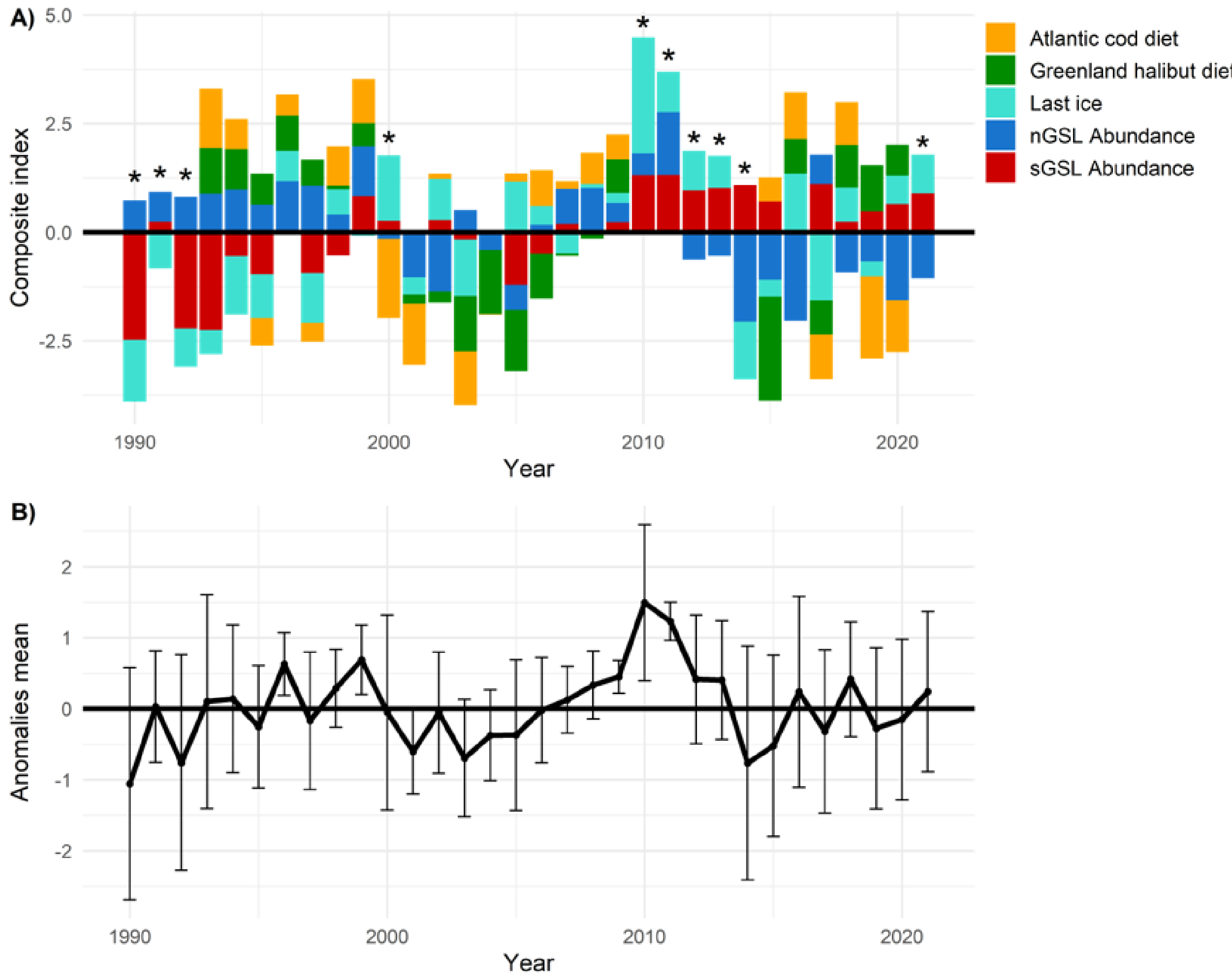
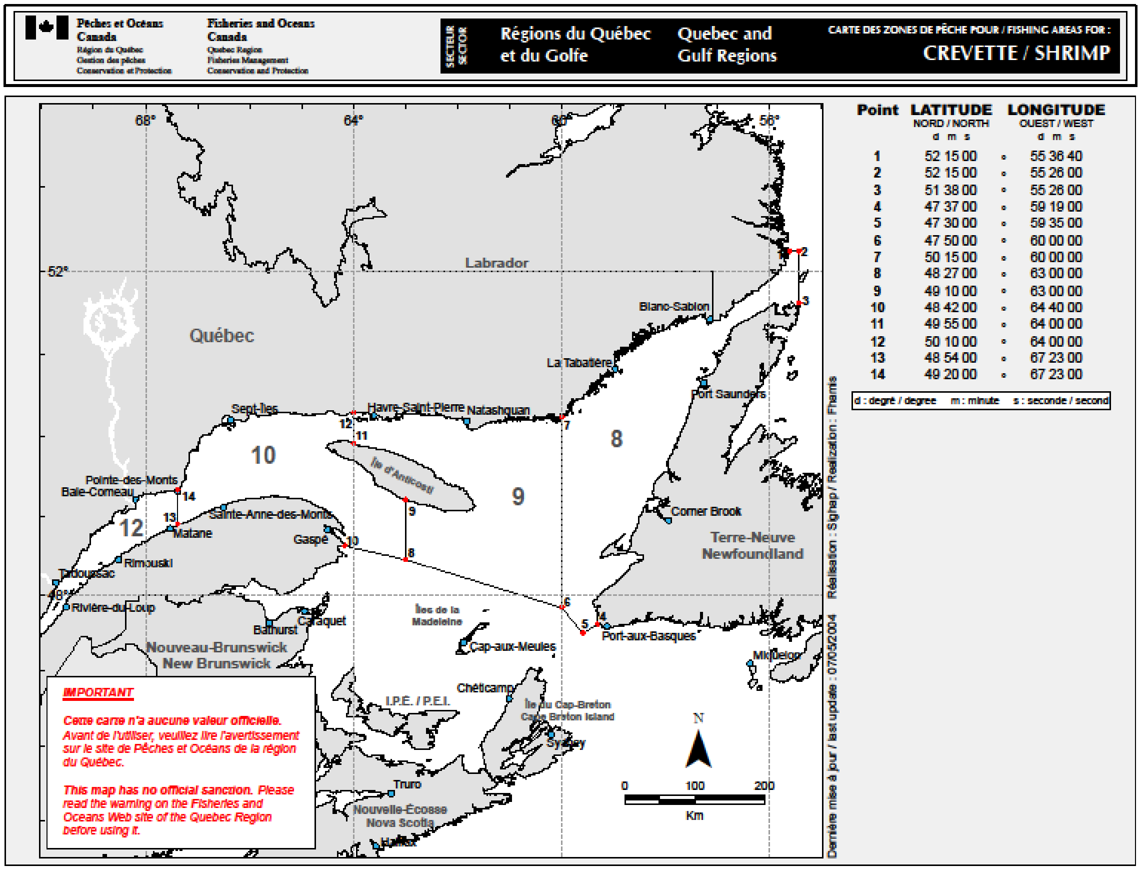


Figure 21: Composite index of 4RST Capelin stock state between 1990 and 2021 when considering the combination of A) relative abundances, Capelin consumption by predators and timing of ice retreat (last ice) indices anomalies. Asterisk symbols indicate years for which data on predator consumption were not available. B) Average estimates of the annual anomaly values with their SD (error bars) are presented on a different scale.

APPENDIX



Appendix 1: Shrimp fishery areas in the Estuary and Gulf of St. Lawrence. 8 = Esquiman; 9 = Anticosti; 10 = Sept-Îles;12 = Estuary).