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Capelin in the Estuary and Gulf of St. Lawrence (NAFO Divisions 4RST) in 2022 and 2023

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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

The 2022 and 2023 4RST Capelin fishing seasons had significant reductions in landings compared to the previous four years, with less than half of the Total Allowable Catch being landed; primarily by the Tuck seine fleet off the West coast of Newfoundland. The fishery was also delayed relative to historical patterns. Commercial biological data, including length compositions, mean lengths, relative conditions, sex ratios, and mean gonadosomatic indices, remained consistent with the last decade, showing no apparent temporal trends that could indicate fishery-induced changes or environmental shifts. Besides data from the commercial fishery, the assessment relies upon relative abundance indices derived from bottom trawl surveys in the southern and northern Gulf of St. Lawrence (sGSL and nGSL). While mature Capelin biomass estimates from these surveys had significant interannual variability and large confidence intervals, the overall trends revealed a decline in the nGSL index since 2017, contrasted by a marked increase in the sGSL index in 2023. The fishing mortality index, derived from landings relative to mature biomass was highly variable and was notably low in 2022 and 2023. Despite uncertainties in the time-series data, evidence suggests that landings are substantially lower than the consumption rates of mature Capelin by predators, indicating that fishing mortality is comparatively lower than natural mortality. The current stock status of 4RST Capelin remains uncertain due to the absence of a limit reference point, yet the variability in mature biomass and the low fishing mortality suggest that recent harvest levels are unlikely to jeopardize the stock in the near future.

1. INTRODUCTION

This research document describes 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 2022 and 2023. These results were presented for peer review at a Canadian Science Advisory Secretariat (CSAS) process for Fisheries and Oceans Canada (DFO) that took place on February 27-28, 2024 to provide advice for the 2024-2025 Capelin fishing seasons (DFO 2024). 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 took place in the winter of 2022 and provided advice for the 2022 fishing season (DFO 2022a). A science response was produced in 2023 to guide management decisions regarding the 2023 fishing season (DFO 2023a). The main conclusion of those processes was that plausible fishery exploitation rates were at least one order of magnitude smaller than natural mortality rates estimated from 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 10,225 t for the 2023 fishing season, as it was in 2022. 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). 4RST Capelin has been proposed to be included in Batch 4 of the Fish Stock Provisions, which means that Limit Reference Point (LRP) development should be completed by March 2029. To fulfil these requirements, candidate LRP and stock status indicators, such as the mature biomass and recruitment, were assessed to evaluate their reliability, plausibility, and uncertainties.

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 indicate 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). 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 behaviour, diet, colour, morphology, number of vertebrae, and other life-history traits (Templeman 1948, O'Boyle and Lett 1977, Sharp et al. 1977, Carscadden 1979, Carscadden and Misra 1979, Lambert and Bernier 1989, Dodson et al. 2007, Praebel et al. 2008, Kenchington et al. 2015).

[1] Northwest Atlantic Fisheries Organization

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. The sexes are indistinguishable until after their second winter, whereupon sexual dimorphism begins to appear. Males grow larger and reach sexual maturity at a larger size relative to females. Males also develop secondary sexual characteristics such as enlarged pectoral fins and two pairs of ridges, or spawning carina (one dorso-lateral and one at the base of the anal fins (Templeman 1948).

Capelin are a cold water species generally found at temperatures from -1 °C to 4 °C but 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). Capelin feed almost exclusively on zooplankton, the composition of which varies seasonally, spatially, and with respect to the size of the individual. Larvae (< 71 mm) mostly consume the 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 (Vesin 1981, Dalpadado and Mowbray 2013). Their diel vertical migrations coincide with those of their zooplankton prey, and most feeding occurs during daytime (Templeman 1948, Vesin 1981, 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 important prey for fishes such as Greenland Halibut (*Reinhardtius hippoglossoides*) and Atlantic Cod (*Gadus morhua*; Ouellette-Plante et al. 2020), marine mammals, and seabirds (Buren et al. 2012). 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). The relative abundance indices used in this assessment were found to be associated with several environmental and biological variables known to influence capelin survival and cohort strength (Lehoux et al. 2022). Variation in the abundance indices were associated with variation in body condition, sea surface temperatures, the timing of ice retreat in the GSL, as well as the abundance and phenology of one of the major prey items of capelin (*Calanoid* copepods). The findings of the study reinforce the hypothesis that capelin abundance is regulated by bottom-up processes in the first few years of their lives (Lewis et al. 2019).

1.3. REPRODUCTIVE CYCLE

Capelin are broadcast spawners, have determinate fecundities, and spawn only once a year. 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 °C - 12 °C (Templeman 1948, Parent and Brunel 1976, de Lafontaine et al. 1991, Davoren and Montevecchi 2006, Purchase 2018). The timing and location of those reproductive migrations are highly variable both within and among regions (Penton et al. 2012). 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 for both beach and demersal spawners. Demersal spawners have a higher proportion of semelparous individuals than beach spawners, where higher proportions of iteroparous individuals are observed (Christiansen et al. 2008).

The lengthy spawning season begins in late April–early May in the St. Lawrence estuary 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, the 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 have been 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 (vessels > 19.81 m (65 ft.)) and small (vessels < 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 are required to have their catch monitored at dockside and the return of logbooks is mandatory.

2. METHODS

2.1. COMMERCIAL FISHERY

2.1.1. Landings

Detailed commercial fisheries landing data (1985–2023) 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, landing data for the 2022 and 2023 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 2023 lack geographic coordinates. Landings by NAFO Division were deemed more appropriate for this purpose.

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 consisted of total length measurements and sex determinations for 150 randomly selected fish from a single fishing trip. From 1984 to 1987, fish were measured with a precision of 5 mm, but subsequently, a 1 mm precision was used. These data allowed for the calculation of the mean size of female and male Capelin in Divisions 4R and 4ST for the 1984–2023 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 included: 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 the 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, sex ratio and gonadosomatic index

Mean body condition of male and female Capelin was estimated by calculating the relative condition factor (*Kn*; Le Cren 1951) for each sex using the commercial biological data with the following equation:

$$\text{(eq. 1) } Kn_i = W_i / aL_i^b$$

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 the relative condition of both sexes were assessed by fitting generalized linear models (GLS) using an identity link with Kn as the response variable and year, month, and fishing gear as the independent variables coded as factors. Separate models were developed for each sex and NAFO division pair. Standardized Kn time-series were then developed from the model estimates by adjusting the month variable to June and the fishing gear to seiners.

Mean annual sex ratios were calculated for NAFO divisions 4R, 4S, and 4T using the commercial biological data. Gonadosomatic indices (GSI) were also calculated for males and females using gonad mass (GM) and somatic weight (SM) of Capelin in the commercial biological data according to the following equation :

$$\text{(eq. 2) } GSI = \frac{GM}{SM} \times 100$$

Individuals whose sex could not be identified, those weighing less than 5 g, and males with a 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 95% confidence intervals were computed for each sex.

2.3. TRAWLABLE MATURE BIOMASS

2.3.1. Trawl survey

Multi-species bottom-trawl surveys have taken place every year in the nGSL in August (1990-2023) and in the sGSL in September (1971-2023). The sGSL survey used a Western IIA trawl from 1971 to 2022 and a Northeast Fisheries Science Center Ecosystem Survey Trawl (NEST) from 2022 onward (Chadwick et al. 2007, Benoît and Yin 2023). The nGSL survey used a URI trawl from 1990 to 2005 and then a Campelen shrimp trawl from 2004 onward (Bourdages et al. 2019, Chamberland et al. 2025). Both surveys followed stratified-random design with an annual mean number of tows of 180 for the nGSL and 170 for the sGSL. The use of different gear and standard trawl duration (15 and 20 minutes) for the nGSL and the sGSL respectively, has so far precluded the development of a single standardized index for the entirety of the GSL. Data obtained from each tow in the sGSL survey included total Capelin catch (kg), length frequencies (total length, cm) and individual weights (g). Lengths were measured from the entire catch when it was small or from a random sample of up to 100 individuals when the catch was large. Length-stratified subsamples were used to obtain individual weights (1 fish per 1 cm bin). Annual proportions of Capelin per length category were then calculated and scaled to the number of Capelin caught in the tow. In the nGSL survey, total Capelin catch (kg) per tow was measured and a random sample of 30 fish were measured for total length (mm) and weight (g). Length frequencies in the nGSL survey were also scaled to the number of Capelin caught in the tow. Biological samples from the nGSL (2018-2023) and the sGSL (2020-2023) surveys were also preserved for subsequent length and maturity measurements at MLI. Maturity stages were assigned according to criteria established by Winters (1970). Capelin classified as “resting” or “maturing” were considered mature.

2.3.2. Trawl survey indices

A survey design-based and modelling approach was recently developed to estimate relative abundance indices for the nGSL and sGSL from the bottom trawl surveys described above (section 2.3.1). The indices are estimated in units of survey-specific mean number of Capelin caught per tow (MNPT, see Chamberland et al. 2022 for model details). As Capelin are associated with cold conditions and perform vertical migrations that affect their availability to the survey gear, tows made in Capelin’s preferred thermal habitat (PTH; -1 to 3.2 °C in the nGSL and 0 to 2 °C in the sGSL) and unfavourable thermal habitats (UTH) were used separately to derive the indices. The definition of PTH and UTH were based on cumulative frequencies of Capelin catch in relation to bottom temperatures recorded when the gear touched the sea floor (Chamberland et al. 2022, Figure 3). Tows retained for the derivation of the abundance indices were defined as when more than 50% of the tows sampled in a survey stratum fell within the favour PTH (Figure 3). There is clear evidence that the bottom trawl has a higher probability of capturing more Capelin in the PTH. Removing stations with low catchability results in the need to extrapolate Capelin abundance in the UTH, however, keeping them might be more appropriate if the data from these UTH strata are still informative on stock trends.Therefore, based on those conclusions, we estimated two indices of relative abundance of mature Capelin (MNPT) for each combination of survey and habitat (nGSL-PTH, nGSL-UTH, sGSL-PTH and sGSL-UTH) from 1995 to 2023. According to Chamberland et al. (2022), the number of mature Capelin in each tow has to be calculated first before using the model to estimate MNPT values. The length frequencies weighted by the catch from both surveys (Figure 4) were used to approximate the number of mature Capelin using the proportion of mature individuals for each length bin. It was not possible to estimate the abundance of mature fish before 1995 in the nGSL since no Capelin were not previously measured. The number of mature Capelin caught in each tow (N_m) was calculated with the following equation :

$$\text{(eq. 3) } N_m = \sum(\frac{N_l}{N_e} N_c P_m)$$

This was done by adding the product of the ratio of the number at length in the sample representative of the catch (N_l) on the number of Capelin in the sample (N_e), the total number of Capelin caught (N_c) and the proportion of mature Capelin for each 1 mm length bin (P_m) estimated from biological samples taken during the surveys between 2018 and 2023. Since there were no significant differences between the lengths at which 50% of Capelin were mature (males:11.9 cm; females:11.2 cm; undetermined sex: 11.3 cm; Figure 5) or among years (Figure 6), all sexes and years were pooled together to calculate P_m (Figure 7). The number of fish from each maturity stage and year of sampling are presented in Figure 8.

Tows from the survey can have different durations which may affect the total number of Capelin caught. For that reason, the number of mature Capelin in each tow were adjusted for a standard tow of 15 minutes in the nGSL and 20 minutes in the sGSL. The adjusted number of mature Capelin per tow in each survey-habitat was then used in the modelling approach of Chamberland et al. (2022) to estimate the four different MNPT values (one for each survey-habitat). The trawlable mature biomasses (B_m) in each survey-habitat were then calculated according to the equation below :

$$\text{(eq. 4) } B_m = MNPT \times TU \times W$$

where B_m is the product of the mean number of mature Capelin per tow estimated as per Chamberland et al. (2022) ($MNPT$), the number of trawlable units in each survey-habitat (TU) and the mean weight of a mature Capelin (W). The later variable was calculated by using an annual length-weight relationship to predict the weight of each mature Capelin measured and then estimating the annual mature biomass with a mean weighted by the catch of mature Capelin in each tow (Figure 9). TU was obtained by dividing the total area of the nGSL-PTH (41,076 km^2), nGSL-UTH (75,039 km^2), sGSL-PTH (51,502 km^2) and sGSL-UTH (15,704 km^2) by the area covered by a standard tow of 15 minutes in the nGSL (0.0232 km^2) and 20 minutes in the sGSL (0.027 km^2). Mature biomasses estimated in each survey-habitat were added together without any correction for catchability to obtain the trawlable mature biomass of the stock. Temporal changes in the contribution of each survey-habitat to the trawlable mature biomass of the stock was also carried out by comparing the proportion of mature biomass in a survey-habitat to the total mature biomass.

2.3.3. Scale of mature stock biomass

Scaling the mature biomass of the stock with plausible and conservative catchability coefficients (q) is required for the approximation of fishing mortality rates and for comparison with rates that are deemed sustainable for other small pelagic fish stocks. In the stock assessment of 4RST

Capelin conducted in 2021 (Chamberland et al. 2022), a *q* equal to 0.0045 and 0.00087 were applied to the sum of the nGSL and sGSL biomasses to approximate the different scales of exploitation rates (landings over biomass). Values of *q* were based on catchability information of other pelagic fish in bottom trawl surveys (Harley et al. 2001, Benoît and Swain 2008). Following the 2022 stock assessment (Boudreau et al. 2023), a conservative *q* of 0.1 for the sGSL and 0.01 for the nGSL surveys were deemed realistic for the approximation of maximal exploitation rates, following the representation of PTH compared to UTH strata in both surveys (Figure 3) and according to the information provided in O'Driscoll, Rose and Anderson (2002). These authors compared the acoustic density and trawl catchability of Capelin from a survey directed specifically at Capelin. They showed the relationship between the density of Capelin in the trawlable area compared to that in the overall water column (Figure 10). Based on their work, an average value of *q* in an area where Capelin are more likely to be caught can be assumed to range from 0.01 to 0.1. Different combination of *q* values and survey-habitat were presented and evaluated during the 2024 stock assessment. The catchability scenario selected by the regional science peer-review committee assumed that:

1. catch efficiency remained constant through the time series;
2. catches reflect roughly Capelin density in the water column;
3. catchability is lower in UTH (q = 0.01) than in PTH (q = 0.1) strata.

The mature biomass was then estimated according to these assumptions for each survey-habitat and added together for the approximation of fishing mortality at the scale of the 4RST Capelin stock.

2.4. RECRUITMENT INDEX

An age-1 recruitment index was estimated following the same steps employed for the mature biomass (see eq. 3) with the differences that the proportion of mature Capelin for each length (P_m) is in this case the proportion of age-1 for each length. The proportion of age 1 at length was estimated from age at length data obtained from samples collected during the 2017 and 2018 surveys. We assumed that the MNPT of age-1 Capelin represents a proxy of the recruitment in the previous year. The annual recruitment in number of fish (R_y) for each combination of survey-habitat was estimated with the equation below :

$$\text{(eq. 5) } R_y = MNPT_{y+1} \times TU$$

Recruitment indices in each survey-habitat were scaled with the previously mentioned scenarios (see section 2.3.3). Recruitment estimated in each survey-habitat were then added together to obtain the trawlable recruitment of the stock in number. As it was also the case for the trawlable mature biomass, the proportion of each survey-habitat on the total recruitment values were compared to verify changes in their respective contribution to recruitment.

2.5. NATURAL MORTALITY

Approximations of exploitation rates for Capelin are ideally estimated using the biomass available to the fishery. The fishery in NAFO Divs 4RST takes place between May and July and mainly targets aggregations of fish that are about to spawn. Because the mature biomass index is estimated using the bottom trawl surveys in August and September, it might differ substantially from the biomass available to the fishery due to autumn, winter, and pre-spawning natural morality (*M*). Capelin are very short-lived species that experience high and extremely variable interannual rates of natural mortality (Carscadden and Miller 1981, ICES 2023) and for whose cohort strengths and survival are regulated by bottom-up processes (Lewis et al. 2019, Lehoux et al. 2022). The natural mortality of 4RST Capelin is an important component of the stock dynamic that has not been studied much due to the combined effect of several factors that can influence it, notably the abundance and feeding efficiency of various predators (e.g. sea birds, groundfish, and marine mammals) along various environmental gradients. In the previous stock assessment, the biomass available during the spawning season was calculated by reducing the biomass from the previous year's surveys by half of a constant *M* of 0.67 (Boudreau et al. 2023), derived from a single empirical natural mortality estimation method that uses a maximum age of 7 years old (Chamberland et al. 2022). For the 2024 assessment, we presented different scenarios of potential interannual variability of *M* to project the mature biomass from the surveys to the time of the fishery:

1. "Time-varying wide" [0.3 to 2]. The annual rate of natural mortality of 2-3 years Capelin has been reported to vary largely between 0.3 and 2 for the 2J3KL (Carscadden and Miller 1981) and Barents Sea stock (ICES 2023).
2. "Time-varying narrow" [0.4 to 1.12]. The *metaM* function from the FSA package (Ogle et al. 2023) was used to estimate *M* based on a set of life history traits and environmental preferences specific to 4RST Capelin.
3. "Constant 0.85". A scenario based on the mean of the values obtained with the *metaM* function.

Following the recommendations of the peer-review committee, the first two scenarios were deemed improbable given that modulation of an appropriate time-varying natural mortality would require at least to be able to follow cohort and age structure of the population with a dedicated Capelin survey, which we lacked at the time. Therefore, the scenario that uses an annual rate of 0.85 was selected for subsequent analyses.

2.6. SCALE OF FISHING MORTALITY

The annual exploitation (E_y) and fishing mortality rate (F_y) for the 4RST Capelin stock were calculated based on scenarios of catchability (see section 2.3.3) and natural mortality (see section 2.5) previously selected with the following equations:

$$\text{(eq. 6) } E_y = \frac{L_y}{B_{y-1} - [(1 - e^{-8/12M}) \times B_{y-1}]}$$

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 the year y in the nGSL and sGSL surveys

M : the annual rate of natural mortality

The instantaneous rate of fishing mortality was calculated as

$$\text{(eq. 7) } F_y = -\ln\left(1 - E_y\right)$$

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

E_y : the exploitation rate estimated during year *y*

A constant monthly natural mortality was assumed for the biomass reduction of the 4RST Capelin in the same way as for the Barents Sea stock whose estimated biomass in autumn is projected at the time of the fishery in the following winter (ICES 2023). Since there are approximately 8 months between the surveys and the start of the fishery in the GSL, the biomass reduction resulting from *M* is equal to 8/12 of the annual rate of *M*. Projecting the mature biomass available to the fishery from the biomass in the previous fall and the natural mortality during the following winter is considered 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).

Since the variation in the stock biomass of 4RST Capelin are not likely influenced by the variation in the landings (Boudreau et al. 2023), a proper scaling of the stock biomass should result in sustainable levels of removals. Hence, the ranges and the mean values of *E* and *F* estimated with the selected scenarios of *q* and *M* were compared to those deemed sustainable for other pelagic fish stocks according to Patterson et al. (1992). The latter compiled data for 28 stocks of 11 small pelagic species and concluded that *F* lower than ½ *M* or *E* lower than 30% could allow stocks to increase in size under certain conditions.

2.7. EVALUATION OF LIMIT REFERENCE POINTS (LRP)

The limit reference point is the limit of a stock state below which serious harm is caused to the stock according to DFO's Precautionary Approach Policy (DFO 2009). Serious harm is an undesirable state that may be irreversible or only slowly reversible over the long-term. Best-practices principles described in the recent science advice on guidance for limit reference points under the fish stocks provisions are provided to give overarching guidance on recommendations for selecting, estimating and updating indicators, LRPs and stock status metrics (DFO 2023b). Those best-practices principles are as follows:

1. Indicators, LRPs and stock status metrics should be selected based on the best available information for the stock.
2. Indicators, LRPs and stock status metrics should be consistent with an objective to prevent serious harm to the stock.
3. Indicators, LRPs and stock status metrics should be feasible and reliable.
4. Indicators, LRPs and stock status metrics should take into account reliability, plausibility and uncertainty.
5. The rationale for choice of indicator, LRP or stock status metric may change over time.
6. Advice on indicators, LRPs and stock status metrics should be clearly communicated.

The guidance document proposes a set of approaches that could be used to determine LRP for data-limited to data-rich stocks (DFO 2023b). The 4RST Capelin is considered a data-limited stock because there is no analytical assessments supported by age-structured, size-structured or surplus production models. Therefore, many LRP approaches are simply not feasible for this stock. Boudreau and Duplisea (2022) identified different data-limited methods to estimate an LRP but most of them are only considered reliable as long as the stock structure responses to different level of exploitation, which is not the case for the 4RST Capelin. Hereafter, we review the common LRP approaches proposed in the DFO (2023b) guidance document that rely only on empirical data, which are accurate for data-limited stock, to identify those who are potentially feasible and reliable for 4RST Capelin.

2.7.1. Evaluation

Following DFO (2023b) guidance document, the B_{min}, $B_{MSY\text{-}High}$, $B_{MSY\text{-}Productive}$ and B_{opt} approaches applied to 4RST Capelin for determining LRPs have been evaluated with the two sets of index estimated previously based on their reliability, plausibility and uncertainties:

1. Trawlable mature biomass (section 2.3.2) and recruitment (section 2.4)
2. Scaled mature biomass (section 2.3.3) and recruitment (section 2.4)

A LRP is considered reliable when its estimation is acceptably robust to key uncertainties and assumptions in the advice framework. In that case, the robustness of the estimates is evaluated by considering the reliability, the consistency, the variance, and the bias of the data required to estimate indicators and LRP.

A plausible LRP means that the estimates should be consistent with empirical data, ecosystem and population dynamic taking into account the best available information about the stock. The evaluation of the LRP plausibility should notably consider any evidence of serious harm to the stock, life history information, and choices made for analogous stocks that proved successful. The evaluation and selection of the most plausible LRP can also be based on a weight-evidence approach.

The rational for selecting an LRP should also consider the evaluation of uncertainties associated with different approaches and their impact on the estimation of indicators and LRPs. Scientific uncertainties such as imprecision, bias or assumption in the indicators (i.e. mature biomass, recruitment, surplus production, natural mortality) and the parameters used for estimating those indicators (length-at-maturity, length-at-age 1) were listed for the different scenarios and LRP approaches for the selection of the LRP.

2.7.2. B_{min}

B_{min} refers to the lowest observed biomass from which a recovery to either average biomass levels has been observed ($B_{min\text{-}recovery}$) or to other minimum biomass estimates that produced “good” recruitment ($B_{min\text{-}good\ recruitment}$). The LRP corresponding to $B_{min\text{-}recovery}$ has been calculated as the geometric mean of the lowest biomass values from consecutive years which preceded sufficient increase of the mature biomass. $B_{min\text{-}good\ recruitment}$ can be estimated using a low percentile of low biomass values that resulted in “good” recruitment. Choosing appropriate percentiles that define these thresholds of low biomass and good recruitment is particularly subjective and can differ according to expert judgement. Hereafter, the LRP corresponding to $B_{min\text{-}good\ recruitment}$ was calculated as the geometric mean value of biomasses lower than the 25th, 30th, 35th , and 40th percentile that produced recruitment greater than the 50th, 60th , and 70th percentile.

2.7.3. $B_{40\%\ of\ MSY\text{-}proxy}$

Proxies of B_{MSY} are threshold determined on previously observed stable states (abundance, biomass or fishing mortality). These proxies can be defined as the mean or median value of abundance/biomass over a period with the highest fishing mortality still resulting in stable recruitment ($B_{MSY\text{-}High}$). Alternatively, these proxies can be estimated as the abundance/biomass over a productive period ($B_{MSY\text{-}Productive}$). For 4RST Capelin, time series of mature stock biomass at the time of the fishery, recruitment indices, and surplus production were visually analysed to determine period reflecting high values of the mature stock biomass, stable recruitment and high surplus production. The annual surplus production (SP_y) was calculated with the following equation based on the Fletcher (1978) formulation:

$$\text{(eq. 8) } SP_y = B_{y+1} - B_y + C_y$$

Where B_y and C_y are respectively the mature biomass at the time of the fishery and the total catch in year y. The LRP was estimated as 40% of the geometric mean of biomass values observed during the selected periods in accordance with DFO's Precautionary Approach Policy (DFO 2009).

2.7.4. B_{opt}

An LRP can also be defined as the stock level below which productivity is sufficiently impaired to cause serious harm (DFO 2009). In this context, the LRP should aim at maintaining the surplus production of mature biomass at a level that can potentially provide sufficient number of mature fish despite highly variable environmental conditions. One candidate LRP that could satisfy this objective is low values of mature biomass that lead to good levels of surplus production. For this approach, the LRP corresponding to B_{opt} was calculated as the geometric mean of biomass values lower than the 25th, 30th, 35th, and 40th percentile that produced surplus production greater than the 50th, 60th, and 70th percentile.

3. RESULTS AND DISCUSSION

3.1. COMMERCIAL LANDINGS

Annual commercial landings of 4RST Capelin were less than 2,000 t from 1960 to 1977, but rapidly increased to about 10,000 t in 1978 and 1979 (Figure 11, Table 2). From 1985 to 2023, 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 mainly due to unfavourable market conditions and weather. The TAC was exceeded in 1992, 1993, 2020, and 2021. Capelin have mostly been landed by the mobile gear fleet (small and large purse seiners) in NAFO Division 4R (Figure 11A), constituting an average of 65% of the annual landings for 2010–2023. In the GSL (NAFO Divisions 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 (Figure 11B). The preliminary landings for NAFO Divisions 4R, 4S and 4T were respectively 4,886 t, 117 t and 10 t for an annual total of 5,013 t in 2022 and 1,147 t, 12 t and 2 t for a total of 1,161 t in 2023. A higher proportion of the total catch was landed by the fixed gear fleet of tuck seine and trap nets (3,549 t in 2022 and 971 t in 2023) than the mobile fleet composed of large and small seiners (1,464 t in 2022 and 190 t in 2023) compared to previous years (Figure 11B).

In 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 12A, Table 3). During the 2018-2021 period, the purse and tuck seiners landed similar proportions of the TAC and landings quantities, while trap nets represented a smaller proportion of the annual catch in this Division (Figure 12B). Total landings from 4R in 2022 (4,886 t) and 2023 (1,147 t) were mainly located in unit area 4Ra (3,730 t in 2022 and 1,054 t in 2023). The tuck seiner fleet took on average 65% of the total landings in 2022 and 2023 compared to 23% for the small and large seiners, and 13% for trap nets (Table 4).

In 4ST, most of the landings since 2005 occurred in unit areas 4Sw (Quebec's Lower North Shore) and 4Tn (mouth of the Baie des Chaleurs) by purse seines and weirs (Figure 13). Landings markedly increased in 2020 and 2021 compared to previous years and totaled 2,405 and 1,921 t respectively, a level not observed since the period 2006–2011 (Figure 13A, Table 3). In 2022 and 2023, annual landings in 4ST were the lowest annual landings observed since 2017 and were located in unit areas 4Sw (117 t in 2022 and 12 t in 2023) and 4Tp (10 t in 2022 and 2 t in 2023). Landings in 2022 and 2023 were relatively evenly distributed between fishing gear (Figure 13B) including purse seine, weir along with beach, bar and pair seine.

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 14). In 4ST, the fishery usually starts earlier than in 4R and shows more interannual variation in the timing of the landings (Figure 15). The lower number of fishing trips during the fishing season in 4ST compared to 4R explained the jagged line pattern observed in the cumulative landings.

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 5. 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 6. On average, a total of 515 individual fish taken from 24 biological samples are dissected for detailed biological examination annually. In 2023, 4 samples for a total of 823 fish were measured, which corresponds to the lowest sampling effort in two decades and the second lowest values since the beginning of the series in 1984. This low sampling effort was directly related to the lowest observed landings seen since 2001.

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 16). 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 and 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 in 4R.

The time series mean (± S.D.) of total lengths for females and males caught by the 4R seiner fleet were respectively 147 ± 7 mm and 165 ± 6 mm (Figure 17). Both sexes showed similar trends over the years for which data were available (1984–2023). 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 14), and a low number of samples processed (Table 5). From 2015 to 2018, mean lengths were lower than average. These values increased to near the time series mean in 2019 and 2021 and a small decrease was observed in 2023 although only three samples were collected. 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 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 18).

3.2.2. Condition, sex ratios and GSI

The coefficients of the fitted length-weight relationship equation ($Weight = a \times Length^b$) were: $\mathrm{a} = 1.23 \times 10^{-6}$, $\mathrm{b} = 3.23$ for females and $\mathrm{a} = 1.89 \times 10^{-6}$, $\mathrm{b} = 3.25$ for males (Figure 19). Interannual variations of the standardized mean relative condition factors for males and females caught in June by seiners in 4RST were consistent but differed in scale (Figure 20). For example, relative condition in 4T was 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 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 4RS while slightly below the average in 4T. In 2022 and 2023, there was a reduction of Capelin body condition in 4S with values decreasing near the time series average and the condition index increased in 4R in 2023 after a slight decrease observed in 2022. A greater number of years with no length data is observed in 4S (Figure 20) than there are standardized condition factors for this Division (Figure 15) as beach seines, nets, traps, weirs, and other artisanal gears were excluded from the analyses of the former.

Capelin sex ratios in the commercial fishery are generally biased towards females in samples from 4R (Figure 21), which is consistent with this commercial fishery specifically targeting ripe females. Samples taken from 4ST have higher proportions of males, 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 GSI ranged between 20 and 30% (Figure 22). Male gonad mass represented, on average, less than 1.5% of total mass. No major temporal trend was apparent in either time series. Female GSI was generally close to or lower than the time series average from the mid-1980s to mid-1990s then increased and remained most of the time over the average until an important reduction was observed from 2015 to 2018. Since then, female GSI returned to values slightly lower than average from 2019 to 2021 before decreasing again in 2023. There were no temporal trends observed for male GSI as it remained fairly close to the average of the time series.

3.3. STOCK STATUS INDICATORS

3.3.1. Mature biomass

The abundance indices for each combination of survey area (sGSL and nGSL) and thermal habitat (PTH and UTH) had noticeably different trends (Figures 23 and 24). The abundance index of mature Capelin (MNPT) in the nGSL-PTH varied greatly from the beginning of the time-series (1995) to 2011. The index has remained low since, except for 2017. (Figure 23A). For the nGSL-UTH, the index remained stable at low values, with the exception of a peak period between 2010 and 2013 (Figure 23B). The abundance index of Capelin in the sGSL-PTH was below average until the peak period of 2010 to 2014 (Figure 24A). In the last decade (2015-2023), the index fluctuated around the average. For the sGSL-UTH, the index showed little variability, although higher values were observed over 2008-2015 (Figure 24B).

The trends in the nGSL and sGSL trawlable mature biomass were driven by the trends estimated in their respective PTH habitat (Figure 25). The nGSL-PTH and -UTH mature biomass trends were also very similar but to a lesser level, which is an indication that changes in Capelin abundance can also be observed in the unfavourable thermal habitat. From 1995 to 2009, most of the mature biomass was caught in the nGSL-PTH (Figure 25A), which contributed to more than half of the mature biomass for this period (Figure 26). Then, this contribution decreased to less than half for the past decade with a shift of the sGSL-PTH mature biomass contribution that increased to values mostly higher than half. The contribution of nGSL-UTH mature biomass remained fairly stable and fluctuated between a proportion of 0.25, while the sGSL-UTH stayed negligible during the whole time series. The time series of trawlable mature biomass for the 4RST stock showed significant interannual variability (Figure 27A), typical of

Capelin stocks (DFO 2022b, ICES 2023) and short-lived species with a bottom-up controlled recruitment and survival rates (Essington et al. 2015). The mature biomass of the stock was mostly lower than average in the first decade (1995-2005) and the highest values were observed from 2010 to 2013. The indice has been fluctuating around the time series average without noticeable trend since then.

3.3.2. Recruitment

Trends in the relative abundance of recruitment differed substantially between the time-series that are survey and habitat-specific (Figures 28 and 29). The index in the nGSL-PTH varied near average for the whole time series, and only displayed four significant peaks (i.e. significantly higher than normal values) in 1997, 2007, 2016 and 2022 (Figure 28A). The index in the nGSL-UTH was likewise rather trendless and showed variabilities of low magnitude since the values for the whole time series ranged between 0 and 6 mean number per tow (Figure 28B). The relative number of recruits in the sGSL-PTH remained stable at low values during the first 15 years, but has, on average, been higher since 2009 (Figure 29A). In the sGSL-UTH, no such trend was visible and the time-series was mostly characterized by one distinctive peak in 2015 (Figure 29B).

The variation in the abundance of trawlable recruits in both regions of the GSL was consistent with the trends in their respective PTH habitat index (Figure 30). There was no similarity between the PTH and UTH habitats for a given region, as the recruitment in UTH remained stable and very low. The contribution of each PTH remained variable from the beginning of the time series until 2008, where the proportion of nGSL-PTH recruitment rapidly decreased and remained at values lower than 0.3 for the last decade, except for the peak observed in 2017 (Figure 31). This coincided with the significant increase in the sGSL-PTH trawlable recruitment that remained relatively high for the last decade, making this habitat the most important contributor to the recruitment of stock over this period assuming equal catchability for all survey-habitat. The trawlable recruitment for the 4RST Capelin stock was generally lower than the time series average in the first decade and relatively higher since the mid-2000s, with three distinctive peaks observed in 2010, 2016 and 2022 (Figure 32A).

3.3.3. Scaling stock state

Comparison of the trawlable and scaled (q of 0.1 and 0.01 for the PTH and UTH, respectively) indicators showed trends that were highly correlated for both the mature biomass (Figure 27) and the recruitment (Figure 32).

3.4. NATURAL MORTALITY

The sets of life history traits and environmental preferences that were used for the estimation of M values using the *metaM* function are presented in Table 7. The M values estimated with the different methods comprised in the *metaM* function are presented in Table 8 and ranged from 0.43 to 1.12.

3.5. SCALE OF FISHING MORTALITY

Estimates of E and F calculated with the total landings and the scaled mature biomass (Table 9) were compared to thresholds of $E = 0.5$ and $F = ½$ of M identified by Patterson (1992) that are deemed sustainable for small pelagic fish stocks (Figure 33). Although 4RST Capelin landings have been variable over the time series (Figure 11), E and F have remained fairly stable, low and within levels that should not lead to stock decline. The observed harvest levels in 2022 and

2023 were also below the time series average (Table 9) corresponding to a significant decrease in landings compared to previous years.

3.6. EVALUATION OF LIMIT REFERENCE POINTS AND INDICATORS

Both the trawlable and scaled stock metrics (i.e. mature biomass and recruitment) were considered reliable because they were robust to key uncertainties (i.e. *q* and *M*) as demonstrated with similar trends observed in the ratio of the indicator over the LRP (Figures 34, 35, 36, 37 and 38). It confirms that even though assumptions about catchability and natural mortality are being made, it doesn’t impact the status of the stock in relation to the LRP. Hence, the selection of potential indicators of stock state and LRPs was based on a weight of evidence approach by evaluating the plausibility of the indicator and the LPR, along with the uncertainties of each one. All LRP values estimated are presented in Table 10.

3.6.1. $B_{min\text{-}recovery}$

The lowest values of mature biomass that led to recovery of the stock over the time-series average were observed in 2002 and 2003 for all scenarios evaluated (Figures 39 and 40). $B_{min\text{-}recovery}$ is plausible since it is related to the lowest mature biomass observed, which lead to a recovery to the average of the time series. It also indicates that even at this low level, the stock could recover over time. The uncertainties associated with this LPR are the assumption that the length-at-maturity remained constant throughout the whole time series based on the 2017-2023 biological samples from the nGSL and sGSL surveys.

3.6.2. $B_{min\text{-}good\ recruitment}$

The relationship between recruitment and the mature biomass of the 4RST Capelin was similar to that of the Barents Sea Capelin (ICES 2023) with several occurrence of high recruitment at low biomass values and a decrease in recruitment at higher biomass (Figure 41). Visual examination of this relationship showed good consistency between the trawlable and scaled indicators for the year where low values of mature biomass produced good recruitment, such as 1999, 2007, 2009, 2010, 2016, 2019 and 2020. The geometric mean values of low mature biomass corresponding to good recruitment that was estimated using the different percentiles also showed little variation (Table 11), indicating that the same years were constantly selected for the different percentiles of mature biomass and recruitment. $B_{min\text{-}good\ recruitment}$ is also considered plausible and can potentially be linked to serious harm done to the stock since it informs on minimum values of mature biomass that can produce good recruitment. This means that if the stock is under this level, the mature biomass might not have the capacity to produce amounts of recruitment that will allow the stock to sustain itself in the years that follows. The main uncertainties about this LRP are the assumption of constant length-at-maturity and constant length-at-age 1 from which the recruitment index is estimated.

3.6.3. $B_{MSY\text{-}High}$

For both the trawlable and scaled indicators, the chosen period of time where the mature biomass was considered high was 2011 to 2014 based on visual examination of temporal trends (Figures 39A and 40A). $B_{MSY\text{-}High}$ was determined to not be plausible since the ratio of mature biomass compared with LRP showed that the stock was often under the LRP even though it was able to recover (Figure 37). Therefore, $B_{SMY\text{-}High}$ was not consistent with the ecosystem and population dynamics of the 4RST Capelin and does not provide informationon the occurrence of serious harm to the stock.

3.6.4. $B_{MSY\text{-}Productive}$

The years used for estimating $B_{MSY\text{-}productive}$ were determined based on a visual examination of consecutive years of good surplus production coinciding with good recruitment (Figures 39B, 39C, 40B and 40C). For both sets of indicators, the years selected were from 2007 to 2010. $B_{MSY\text{-}Productive}$ is considered plausible as it is set in a period where the mature biomass of the stock seemed stable and the landings relatively were high, which resulted in the highest productive years of the time series. It also accounts for the good recruitment that occurred during that period. Even though the choice of what year to include in that period and the proportion of B_{MSY} (40%) is arbitrary, we can assume that this LRP is likely plausible because it is consistent with our understanding of the stock dynamic. The constant length-at-maturity and constant length-at-age 1 are the main uncertainties associated with this LRP.

3.6.5. B_{opt}

As it was previously done with $B_{min\text{-}good\ recruitment}$, visual evaluation of the relationship between surplus production and the mature biomass showed good consistency between the trawlable and scaled indicators for the years where low values of mature biomass produced good surplus production, such as 1997,1999, 2002, 2006, 2017, and 2020 (Figure 42). The geometric mean values of low mature biomass corresponding to good surplus production using different percentiles showed again small variation (Table 11), indicating consistency in the year selected. B_{opt} is also considered plausible, especially since it is directly linked to potential serious harm to the stock, as it identifies the threshold level under which the stock might not have the capacity to recover from low mature biomass values. Once again, one of the uncertainties associated with this LRP is the constant length-at-maturity along with the q and the M values used for scaling the stock, which is required when estimating surplus production estimates.

3.6.6. Selection of stock status indicators and a LRP

The choice of the indicator used to propose an LRP should be based on the evaluation of uncertainties, bias, and precautionary principles. The trawl based indicators consider only what is caught by the bottom trawl survey to estimate the MNPT index, which is scaled using the number of trawlable units in each of the survey-habitat. That way, even though the catchability of Capelin can be variable between the UTH strata, the MNPT estimated in this habitat will respond accordingly (i.e. more strata with fewer Capelin will result in a low overall MNPT for the UTH habitat). Moreover, Capelin catch using the bottom trawl has remained fairly consistent in most UTH strata, especially for the nGSL (Figure 43). We therefore considered the trawl based indicator as one good candidate for setting the LPR since it is less uncertain and more cautious by assuming a q of 1 for all sets of survey-habitat. Scaling the mature biomass with the catchability coefficient and natural mortality raises doubts about the reliability of the indicator due to their method of determination and their constancy over the whole time series. However, given that the stock status in relation to the LRP is not influenced by scaled values of q and M, it is evidence evidence that it could be used for setting the LRP of the 4RST Capelin (Figures 34, 35, 36, 37 and 38). For the choice of the LRP, $B_{min\text{-}recovery}$, $B_{min\text{-}good\ recruitment}$ and, B_{opt} would be considered the most reliable, plausible and informative regarding serious harm. The estimation of B_{opt} is considered more reliable than B_{MSY} proxies since it is not based on the arbitrary choices of a period of time that was considered productive or the fraction of B_{MSY} (40%) which has no link to the occurrence of serious harm. Moreover, $B_{min\text{-}recovery}$ and $B_{min\text{-}recruitment}$, which are often used to set LRP for other Capelin stock (ICES 2023) and small pelagic (Uriarte et al. 2023), meet the main criteria about the levels below which serious harm to the stock is observed. Following the regional peer review in February, it was agreed that these LRPs represent a good candidate. However, the adoption of one was delayed mainly due to the uncertainty (see Section 4) associated with the main stock status indicator (DFO 2024).

4. SOURCE OF UNCERTAINTY AND RESEARCH RECOMANDATIONS

The presented set of indicators are relative and have a high degree of uncertainty associated with it, as they are derived from a bottom trawl surveys, which have an unspecific and possibly varying catchability of pelagic fish. For instance, bottom trawls cover only part of the CIL, in which Capelin resides, and a change of Capelin's vertical distribution in the CIL relative to the position of the trawl will affect catchability. Changes in the characteristics of the CIL, such as a reduction in thickness or a temperature change, might impact the observed abundance. Furthermore, there is uncertainty as to whether the density of Capelin in areas where the CIL touches the bottom is similar to areas in which the CIL is far above the bottom, as these are only sampled for a very short duration by the bottom trawl. An in-depth analysis of the acoustic data collected during the bottom trawl surveys could be useful to validate various hypotheses underlying the presented index, and might lead to the development of a new abundance index. 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 potential for local depletion cannot be ruled out, as this uncertainty has not been addressed at the moment. 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.

Research recommendations that could improve the quality and confidence in the bottom-trawl indices were identified and discussed during the 2024 peer-reviewed stock assessment. The calculation of the mature biomass and recruitment indices should be reviewed to take into account diurnal catchability variability, which could reduce the variability in the annual estimates. The influence of large catches on the annual estimates should be evaluated and statistical processes, like Winsorizing, that aim at limiting the impact of aberrant data in the estimation of a value, should be used in order to reduce annual and interannual variability of the indices. Spatial patterns in survey catches should also be examined to see if there is interannual recurrence in locations of large catches, which would suggest a structure that should be taken into account in the calculation of annual estimates. On the contrary, if large catches are random in space, this suggests a pattern of variability that could justify the use of statistical processes like winsorizing. The use of an age-length key to validate the detection of cohorts in the bottom-trawl indices could also increase their level of acceptability by demonstrating that interannual variability is not only driven by observation error. Another research recommendation proposed to validate the use of the indices is to evaluate what can be learned about historical Capelin abundance through the analysis of predators' diets for which there are long time-series available.

5. CONCLUSION

The 2022–2023 4RST fishing seasons were characterized by an important reduction in the landings compared to the four previous years (2018-2021). Less than half of the TAC was landed, most landings were made off the west coast of Newfoundland-and-Labrador by the Tuck seine fleet, and the timing of the fishery occurred later than the range usually observed. The commercial biological data (length composition, mean length, relative condition, sex proportions, and mean GSI) were 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, presented in previous stock assessments (DFO 2021, 2022a) but is now supplemented with the estimation of stock status indicators such as recruitment and mature biomass with the latter being used for the approximation of the scale of fishing mortality which is more appropriate since fishing activities target individuals that are spawning or about to spawn.

The time series of mature biomass estimated from the bottom trawl surveys index showed significant interannual variability and very large confidence intervals on annual estimates. It is currently uncertain how much of the signal reflects true biological change rather than observation error. The mature biomass index of the stock was mostly lower than average in the first decade (1995 to 2005). The highest values of the index were observed from 2010 to 2013. The stock biomass has decreased and has fluctuated around the time series average since then. The mature biomass index in the northern Gulf of St. Lawrence survey has been constantly decreasing since 2017, whereas the index in the southern Gulf varied around the average of the time series, with a marked increase for 2023. The index of fishing mortality was based on the ratio of landings to the index of mature biomass, assuming a cautious survey catchability accepted in the previous assessment, and constant natural mortality between the timing of the survey and the fishery. This index was highly variable over the period 1996-2023 and was low in 2022 and 2023. Despite high variability and uncertainty in the time-series, there is evidence that landings are smaller than estimated consumption of mostly mature Capelin by a subset of predators, implying that fishing mortality is far lower than natural mortality due to predation and other causes (Savenkoff et al. 2004, Ouellette-Plante et al. 2022). Furthermore, these estimates of fishing mortality are considerably lower than a range of plausible estimates of natural mortality (Chamberland et al. 2022, Boudreau et al. 2023) and accepted sustainable fishing mortality rates for small pelagic fish (Patterson 1992).

Due to the absence of an approved Limit Reference Point, the stock status of 4RST capelin in 2022 and 2023 is uncertain. However, given that the index of mature biomass has varied without trend since the mid-2010s and the index of fishing mortality was low with respect to the biology of the species, harvest levels attained since 2015 (1,161 to 11,825 t) are unlikely to pose a risk to the stock in 2024 and 2025.

6. ACKNOWLEDGEMENTS

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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		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[3]	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**
2022[3]	4,886	117	10	**5,013**	10,225	**49**
2023[3]	1147	12	2	**1,161**	10,225	**11**

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**
2020–2023[3]	5,481	930	187	**6,598**

[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 1987. 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
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
2022	3,730	565	612	28	-	4,935	-	-	-	117	-	-	-	-	117	-	-	-	-	-	-	-	10	-	-	10
2023	1,054	-	74	-	-	1,128	-	-	-	12	-	-	-	-	12	-	-	-	-	-	-	-	2	-	-	2

*Preliminary data

Table 4: Commercial landings (t) of the GSL Capelin stock by fishing gear since 1985. Misc. = includes pair seines, stationary lift nets, pots, weirs, gillnets (set or fixed), midwater trawls (stern), shrimp trawls, bottom otter trawls (stern), beach and bar seines, unknown, hand and hand held tools, longlines, angling, and 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	362	3,210	259
2021*	3,510	2,396	560	3,342	250
2022*	1,083	395	648	2,901	33
2023*	31	159	165	806	-
Average 1985–2023	**1,982**	**2,243**	**1,134**	**1,639**	**209**

*Preliminary data

Table 5: 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	14,502
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
2022	8	9	5	1,341	1,359	788	22	3,488
2023	3	-	1	650	-	173	4	823

Table 6: 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
2022	8	5	9	245	75	119	22	439
2023	3	-	1	121	-	20	4	141

Table 7: Life history traits and environmental preferences that were used for the estimation of M values using the metaM function

Parameters	Values
Maximum age	5
Body growth coefficient for the von Bertalanffy growth function	0.5896
The asymptotic mean length (cm) from the fit of the von Bertalanffy growth function	17.6
The x-intercept from the fit of the von Bertalanffy growth function	-0.4922
The exponent from the weight-length relationship	3.25
The body length of the fish (cm)	16
The temperature experienced by the fish (C)	2
The age (time) when half the fish in the population are mature	3
The asymptotic mean weight (g) from the fit of the von Bertalanffy growth function	32.86

Table 8: Natural mortality values estimated with different methods comprised in the metaM function.

Methods	Values
PaulyL	0.43
PaulyW	0.45
ZhangMegreyP	0.49
RikhterEfanov1	0.53
HoenigOC	0.63
Charnov	0.68
Gislason	0.73
HewittHoenig	0.84
HoenigOF	0.85
ZhangMegreyD	0.85
AlversonCarney	0.86
HoenigO	0.87
JensenK1	0.88
HoenigOM	0.90
HoenigO2	0.97
HoenigO2C	0.98
HoenigO2F	0.98
HoenigO2M	0.99
K1	1
K2	1.01
tmax1	1.02
JensenK2	1.08
PaulyLNoT	1.09
HoenigLM	1.10
HoenigNLS	1.12

Table 9: Summary of values for the harvest level indicators estimated from 1996 to 2021 (mean, minimum, and maximum) and in 2022 and 2023. (CI : confidence interval)

Indicators	Mean [CI 95%]	Minimum	Maximum	2022	2023
Exploitation rate	0.094 [0.071; 0.117]	0.009	0.204	0.048	0.049
Fishing mortality	0.101 [0.075; 0.127]	0.009	0.228	0.048	0.049

Table 10: Summary of LRP values estimated with the trawlable and scaled indicators (mature biomass and recruitment).

Indicators	$B_{min\text{-}recovery}$	$B_{min\text{-}good\ recruitment}$	$B_{MSY\text{-}High}$	$B_{MSY\text{-}Productive}$	B_{opt}
Trawlable	811 t	3,237 t	9,593 t	3,113 t	2,597 t
Scaled	12,784 t	50,148 t	140,809 t	45,375 t	37,803 t

Table 11: Mature biomass mean value and 95% confidence interval (CI) estimates obtained with the percentile analyses for calculating B_{min} and B_{opt} LRPs according to percentile values of mature biomass, recruitment, and surplus production with the trawlable and scaled indicators.

Scenario	B_{min}		B_{opt}	
	Mean	**CI 95%**	**Mean**	**CI 95%**
Trawlable	3,237	[2,987; 3,487]	2,597	[2,516; 2,678]
Scaled	50,148	[49,266; 51,029]	37,803	[36,526; 39,081]

FIGURES

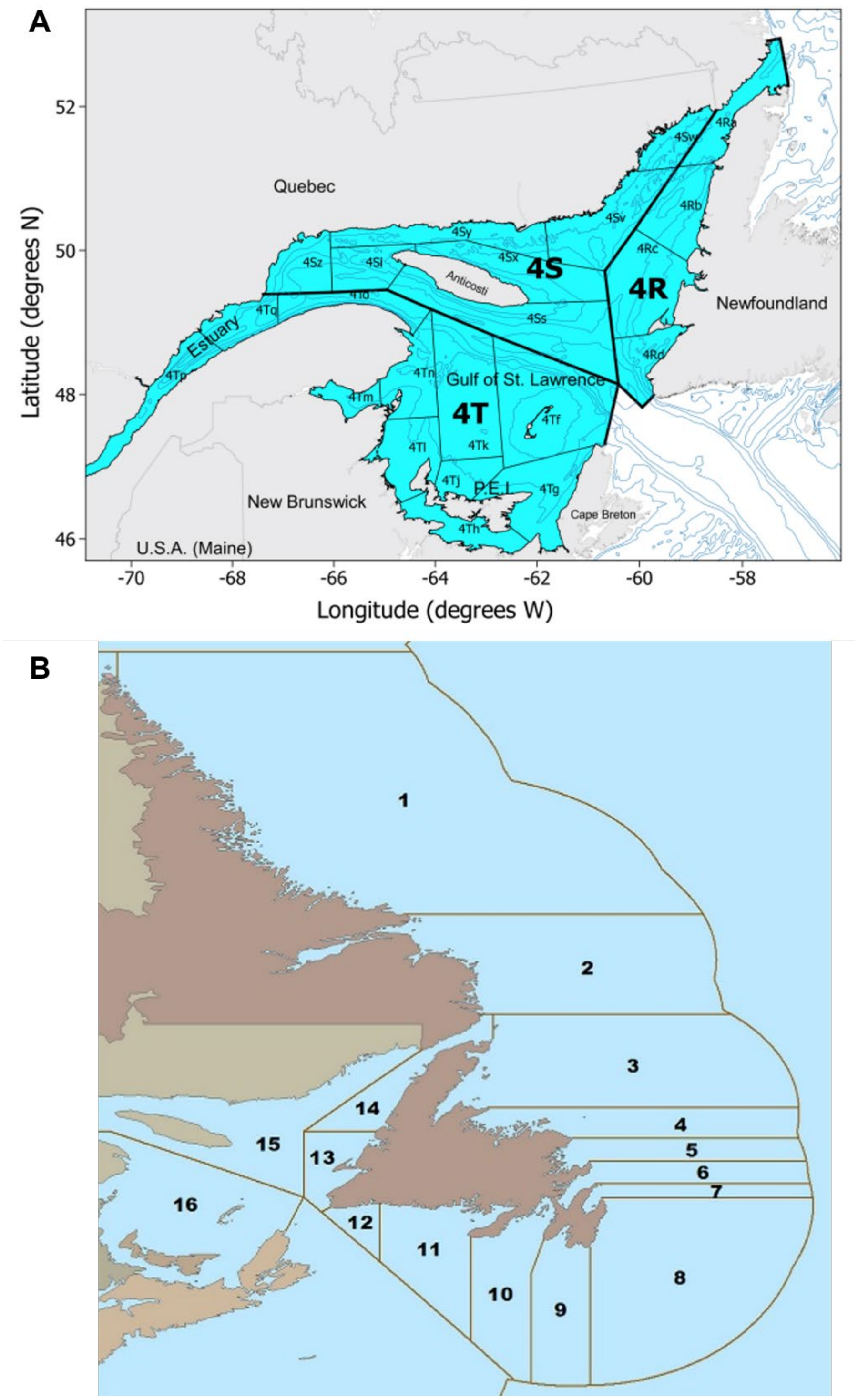

Figure 1. Maps of A) NAFO Divisions and unit areas of the Estuary and Gulf of St. Lawrence. Capelin fishing areas defined by DFO are shown in B).

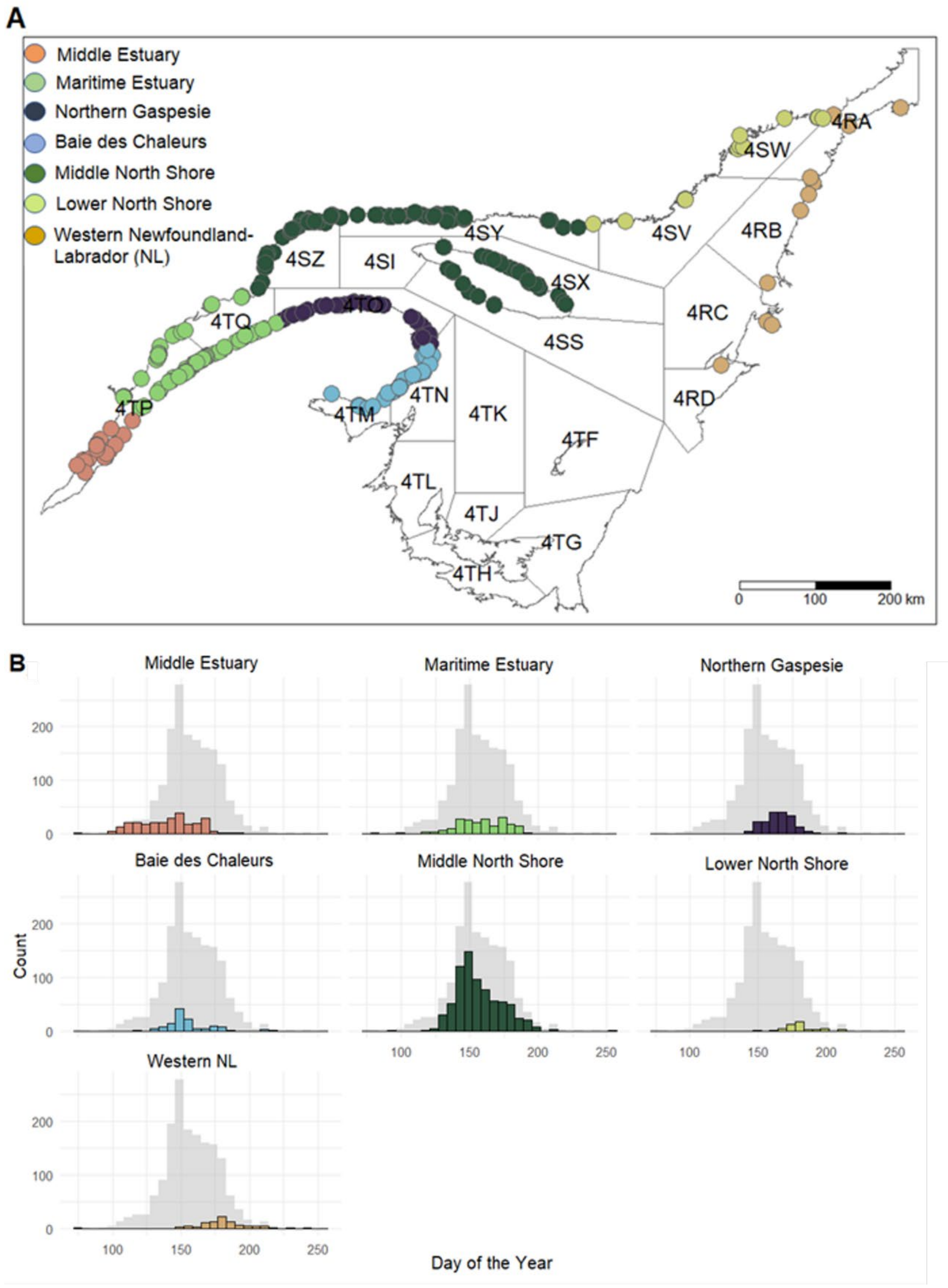

Figure 2. A) Map of Capelin Observers Network (Source: SLGO) beach spawning observations, by regions and NAFO unit areas, and B) histograms of observed spawning activity binned by week between 2006 and 2018. In the lower panel, the sum of all observations by week are presented in grey and coloured histograms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

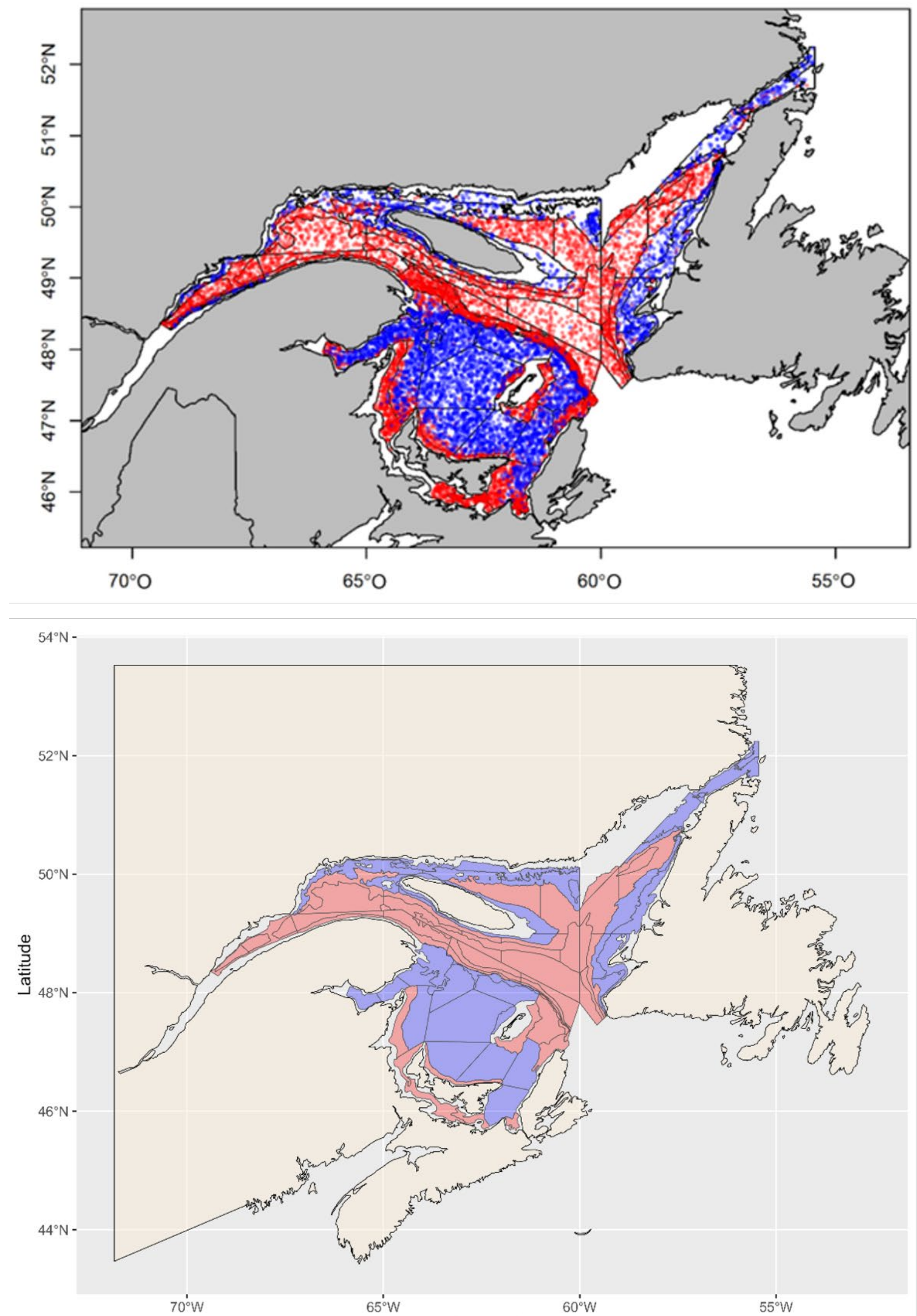

Figure 3. Map of the northern and southern Gulf of St. Lawrence bottom trawl survey tows performed inside (blue) and outside (red) Capelin preferred thermal habitat (upper panel, Source Chamberland et al. 2022). Map of the northern and southern Gulf of St. Lawrence strata identified as preferred (blue) and unfavourable (red) thermal habitat for Capelin (lower panel).

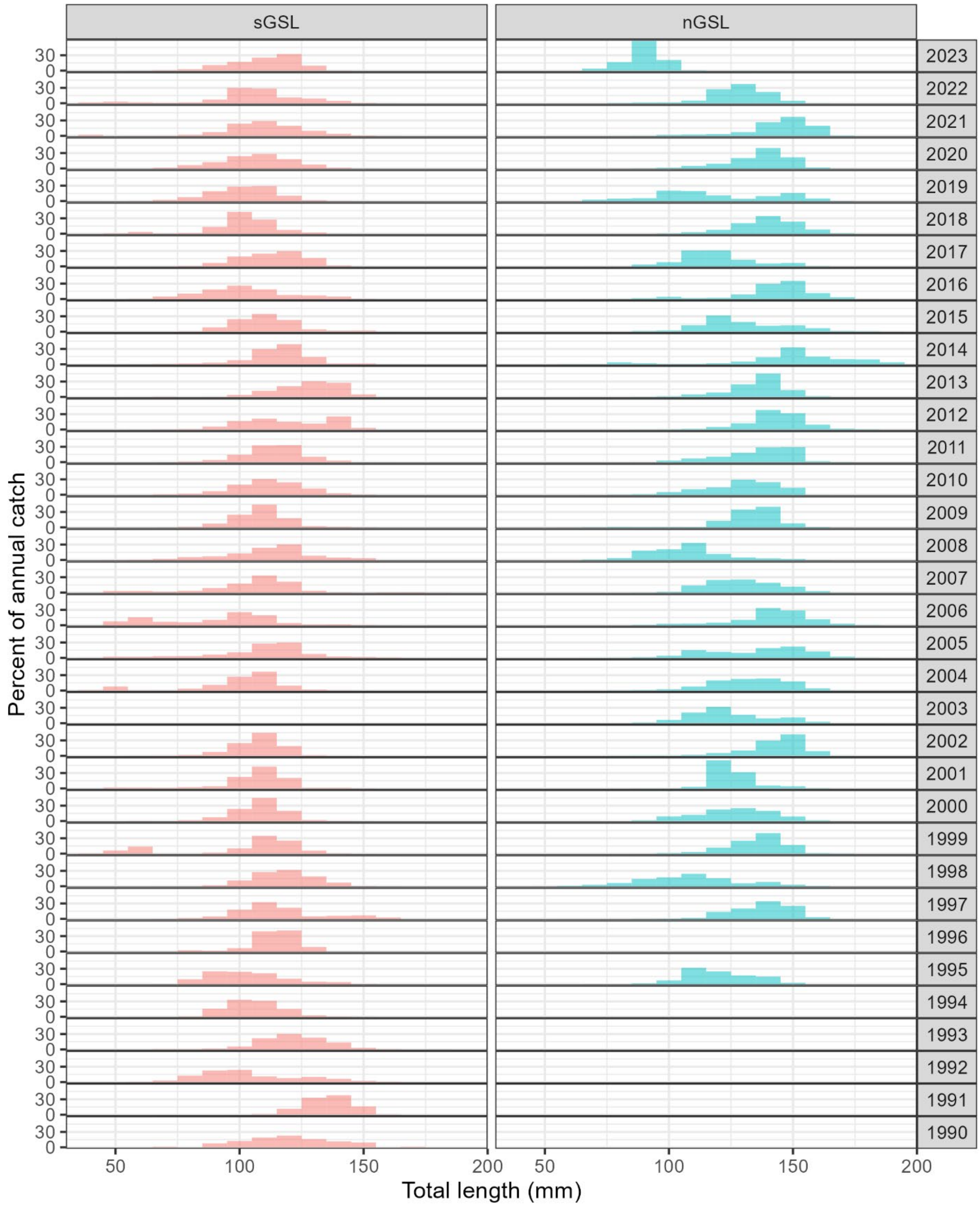

Figure 4. Comparison of annual relative length frequency distributions from the northern and southern Gulf of St. Lawrence bottom trawl surveys from 1990 to 2023. Note that length frequencies are not represented for the 1990–1994 nGSL surveys either because insufficient (n = 63 in 1990) or no length data were recorded (1991–1994).

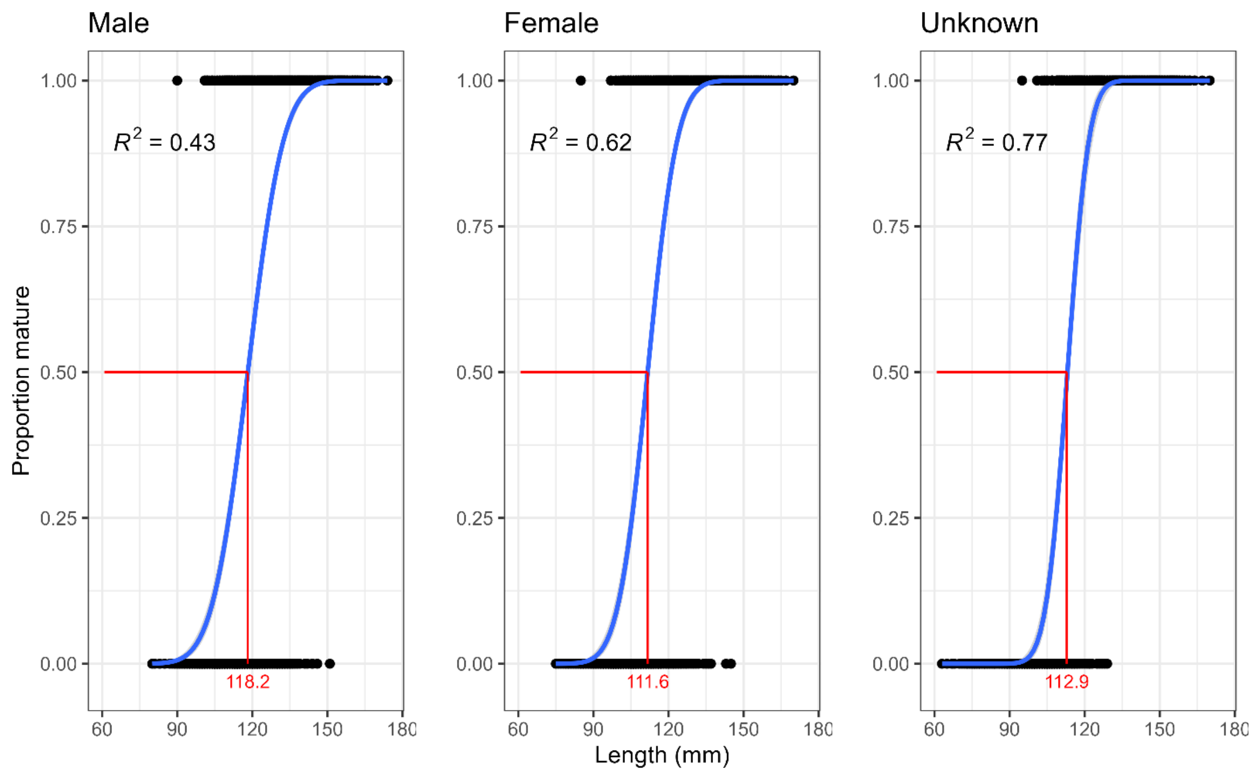

Figure 5. Capelin maturity ogives (blue lines) using data from the 2018 to 2023 bottom trawl surveys in the northern and southern Gulf of St. Lawrence. Length at 50% (red lines) maturity was estimated at 118.2 mm, 111.6 mm, and 112.9 mm for male, female, and undetermined sexes respectively.

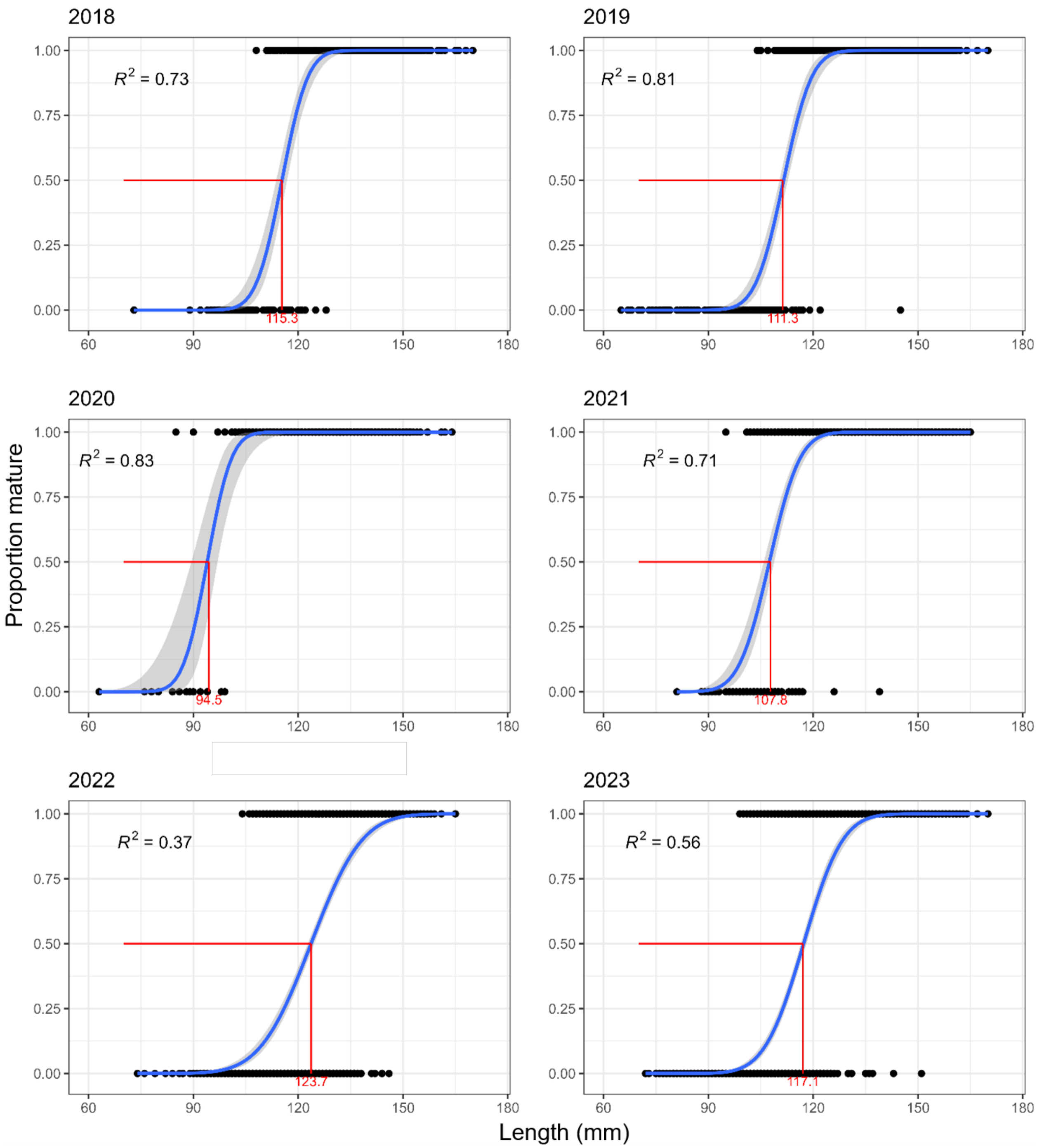

Figure 6. Global annual maturity ogives (blue lines) for capelin from the northern and southern Gulf of St. Lawrence bottom trawl surveys (2018 to 2023). Length at 50% maturity (red lines) were estimated at 115.3 mm, 111.3 mm, 94.5 mm, 107.8 mm, 123.7 mm, and 117.1 mm in 2018, 2019, 2020, 2021, 2022, and 2023 respectively.

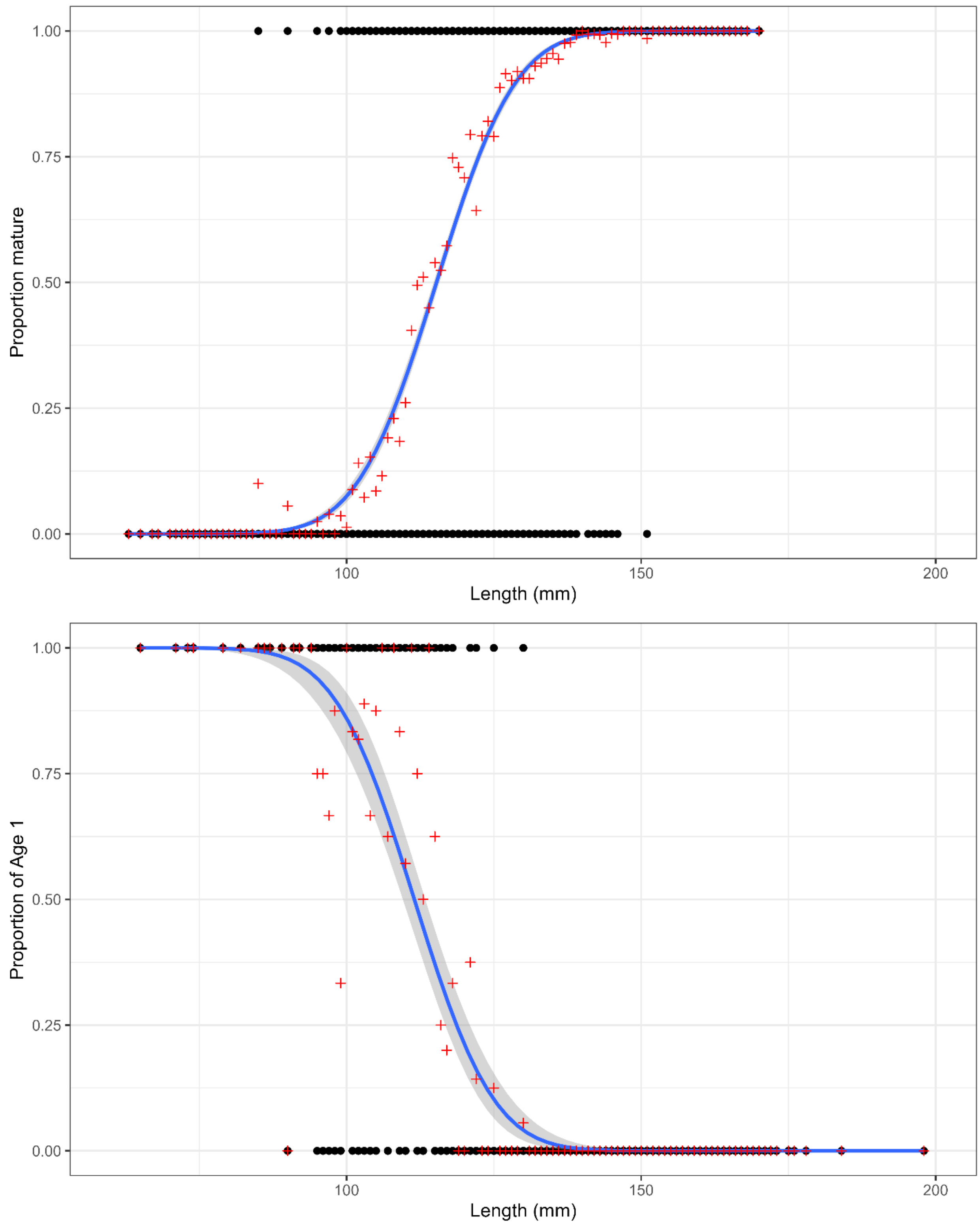

Figure 7. Estimated (blue lines) and observed (red crosses) proportions at length of mature (upper panel) and age 1 (lower panel) Capelin sampled in the northern and southern Gulf of St. Lawrence bottom trawl surveys (2018-2023).

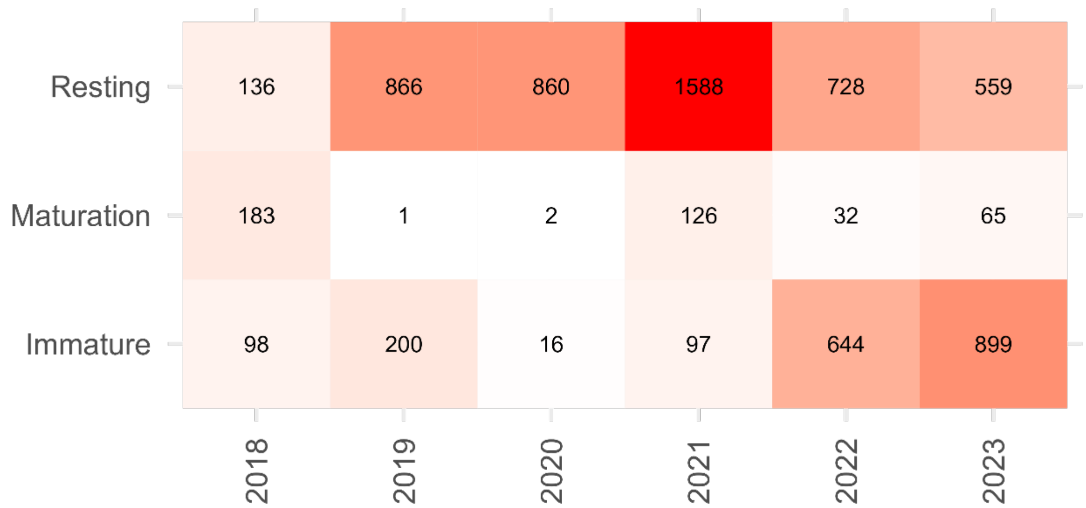

Figure 8. Number of Capelin sampled by year and maturity stage (resting, maturation, immature) from the northern and southern Gulf of St. Lawrence bottom trawl surveys (2018 to 2023).

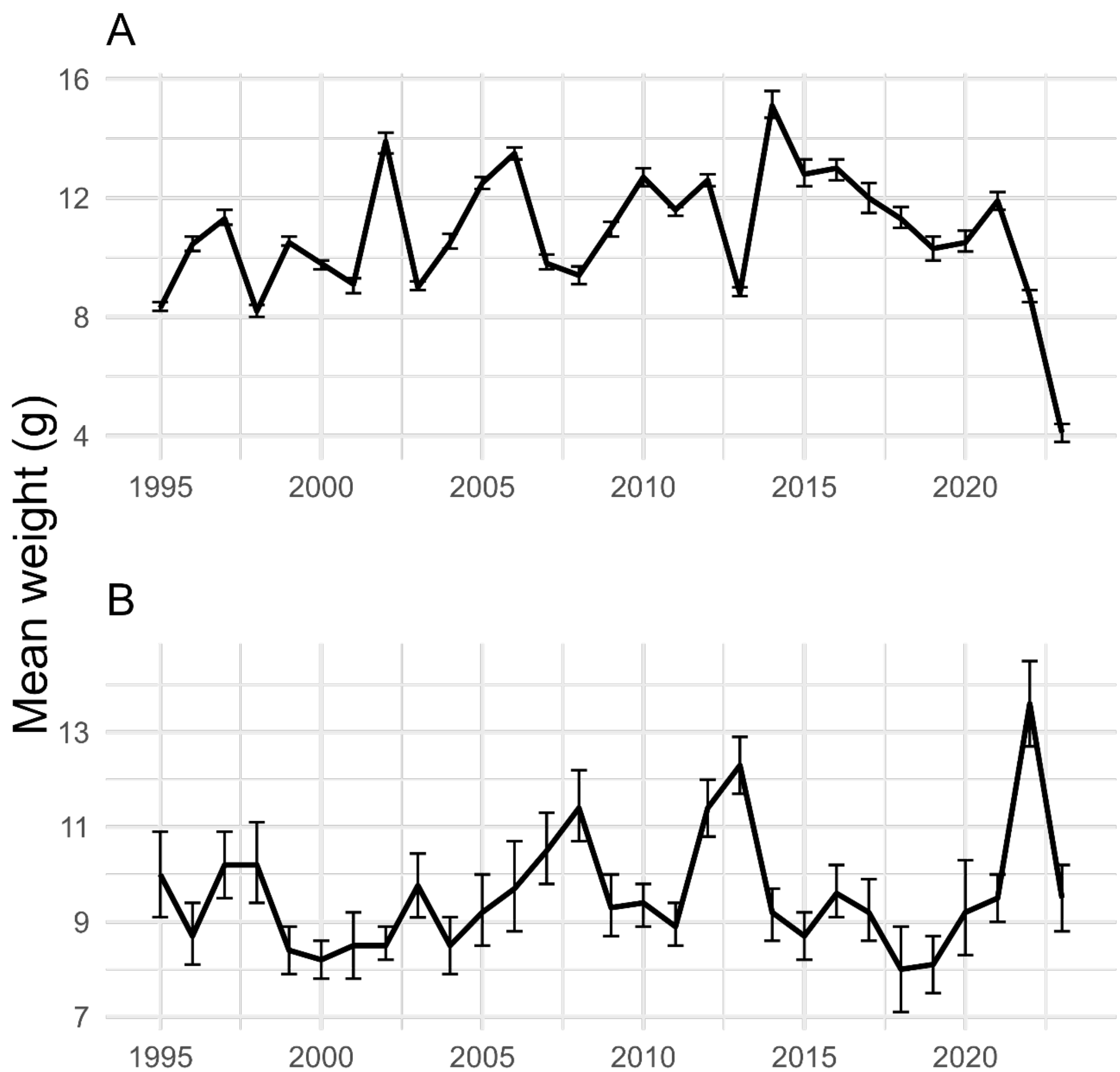

Figure 9. Mean weight (± 95% CI) of a mature Capelin predicted by an annual length-weight relationship and weighted by the catch of mature Capelin in each tow of the northern (A) and sourthern (B) Gulf of St. Lawrence surveys from 1995 to 2023.

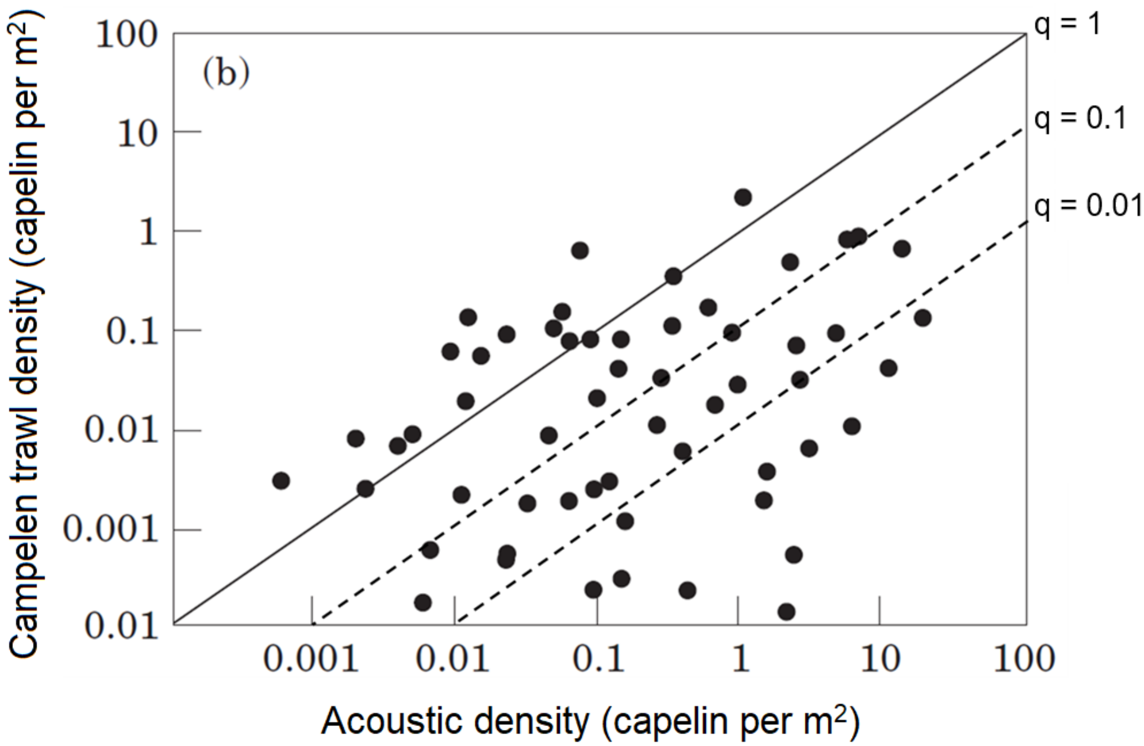

Figure 10. Capelin densities calculated form Campelen trawls compared with acoustic density in the full measured water column. Full diagonal line represent the case where trawl and acoustic estimates are equivalent (q = 1) and dashed diagonal lines represent the proportions of Capelin in the trawl compared to those measured acoustically from the water column. (modified from O'Driscoll et al. 2002).

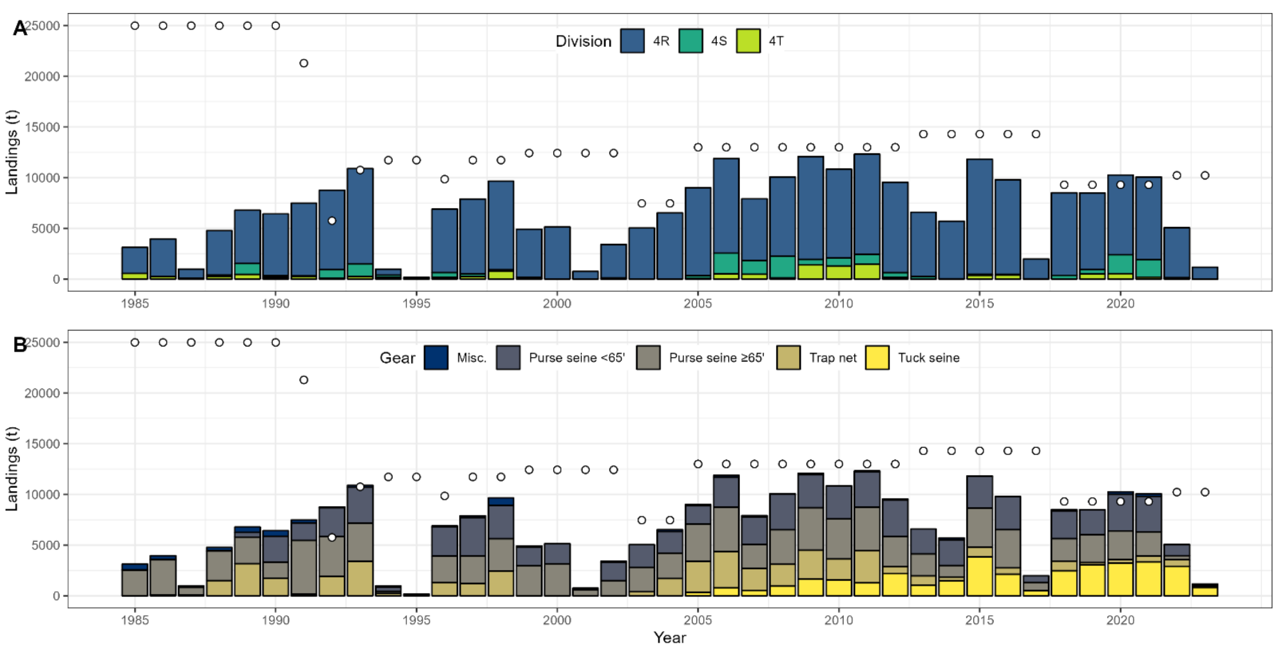

Figure 11. Capelin landings (t) by A) NAFO Division from 1960 to 2023 and B) by main fishing gears for the 1985–2023 period. The white circles represent the annual TACs. 2022 and 2023 landings are preliminary. Misc. = Miscellaneous gear types and unknown.

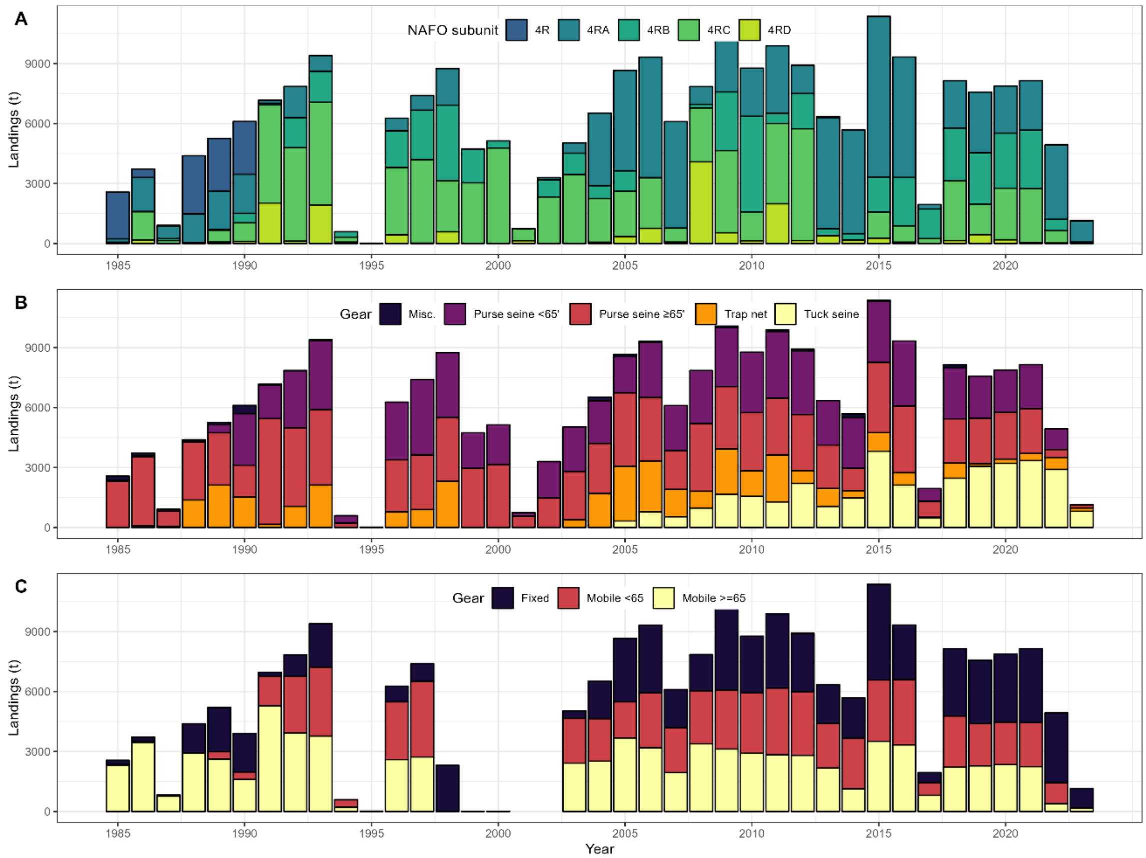

Figure 12. Annual commercial landings (t) of Capelin in NAFO Division 4R for the 1985–2023 period. A) Landings by NAFO unit area. B) Landings by major fishing gear type. C) Landings by existing allocations. Landings for 2022 and 2023 are preliminary. Misc. = Miscellaneous and unknown.

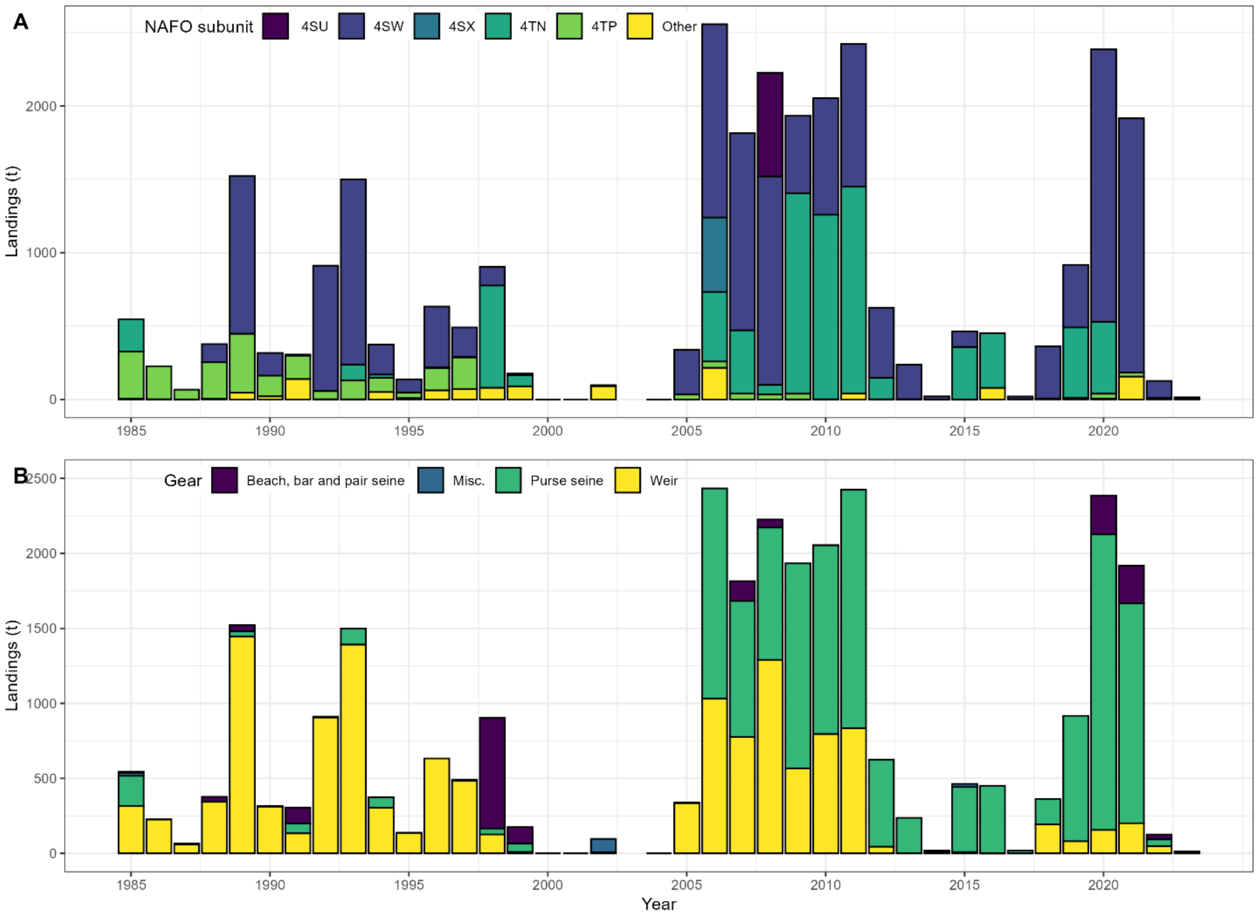

Figure 13. Annual commercial landings (t) of Capelin within NAFO Divsions 4ST for the 1985–2023 period. A) Landings by NAFO unit area. B) Landings by major fishing gear type. Landings for 2022 and 2023 are preliminary.

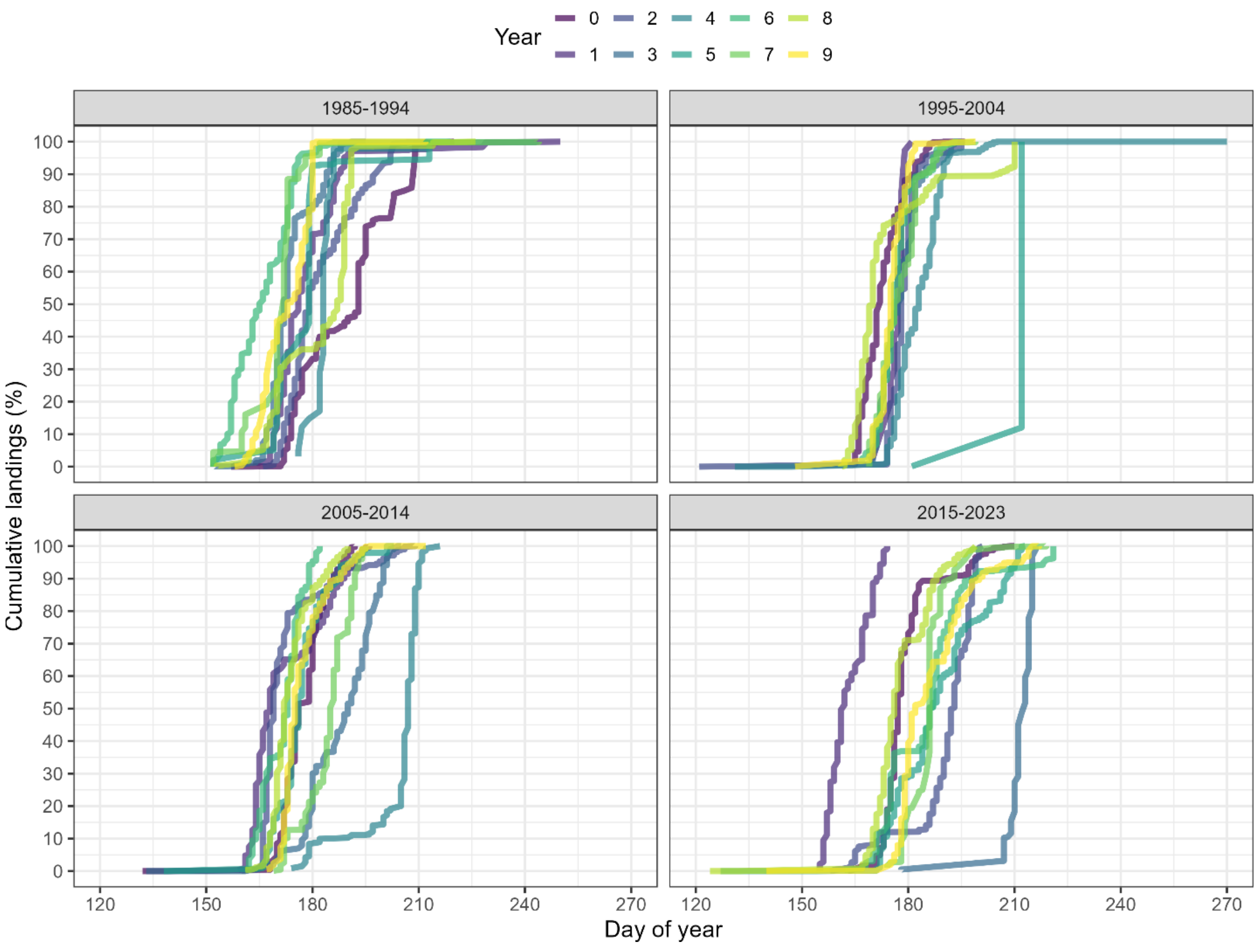

Figure 14. Cumulative distribution functions of Capelin landings (%) in relation to day of the year, for NAFO Divsion 4R. Line colours progress from violet to yellow based upon the last digit of the year (0–9).

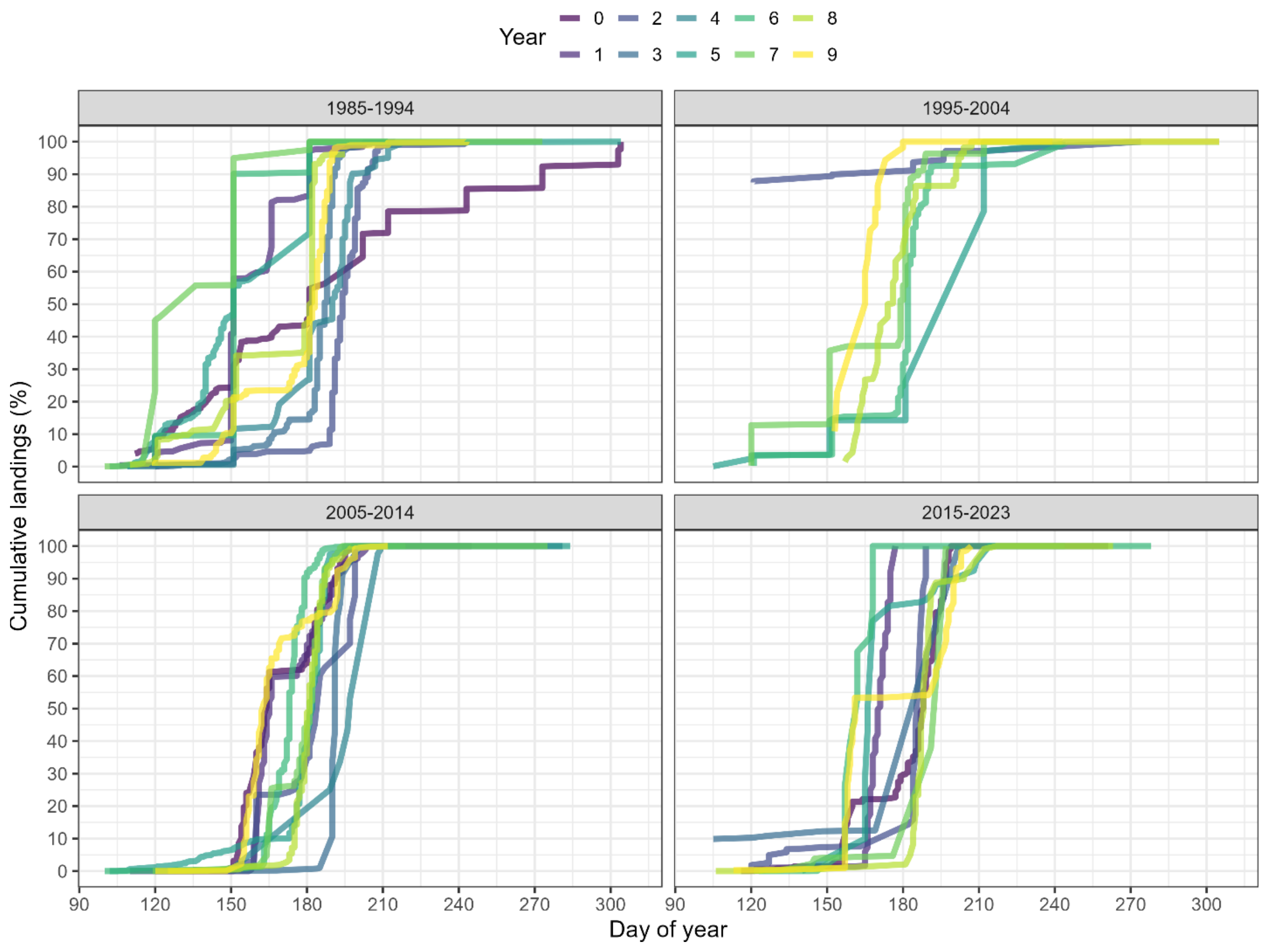

Figure 15. Cumulative distribution functions of Capelin landings (%) in relation to day of the year, for NAFO Divisions 4ST. Line colours progress from violet to yellow based upon the last digit of the year (0–9).

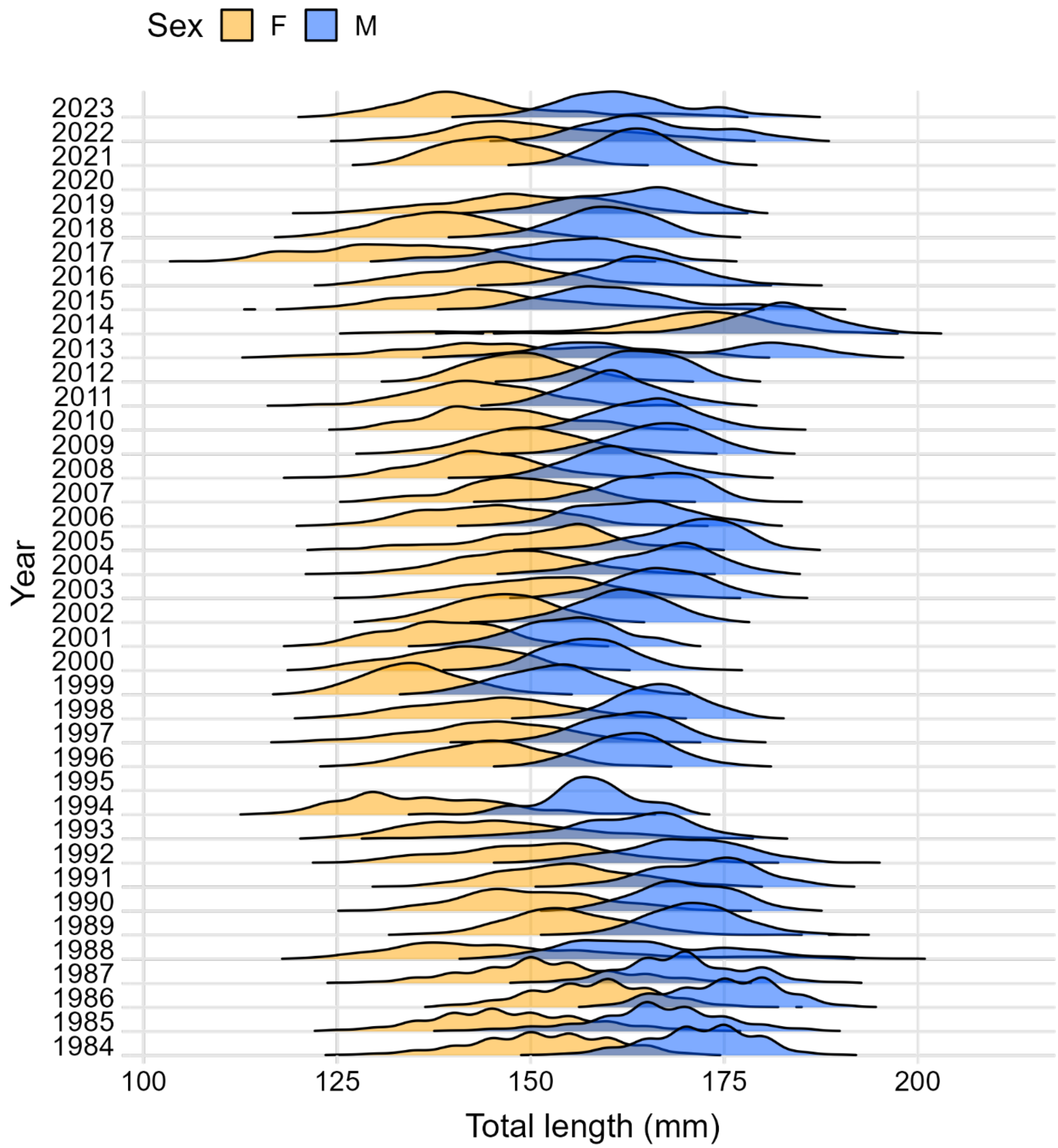

Figure 16. Annual total length (mm) compositions (kernel density estimates) of females (orange) and males (blue) sampled from purse and tuck seines in NAFO Division 4R from 1984 to 2023 by DFO's port sampling program. No samples were available in 1995 and 2020.

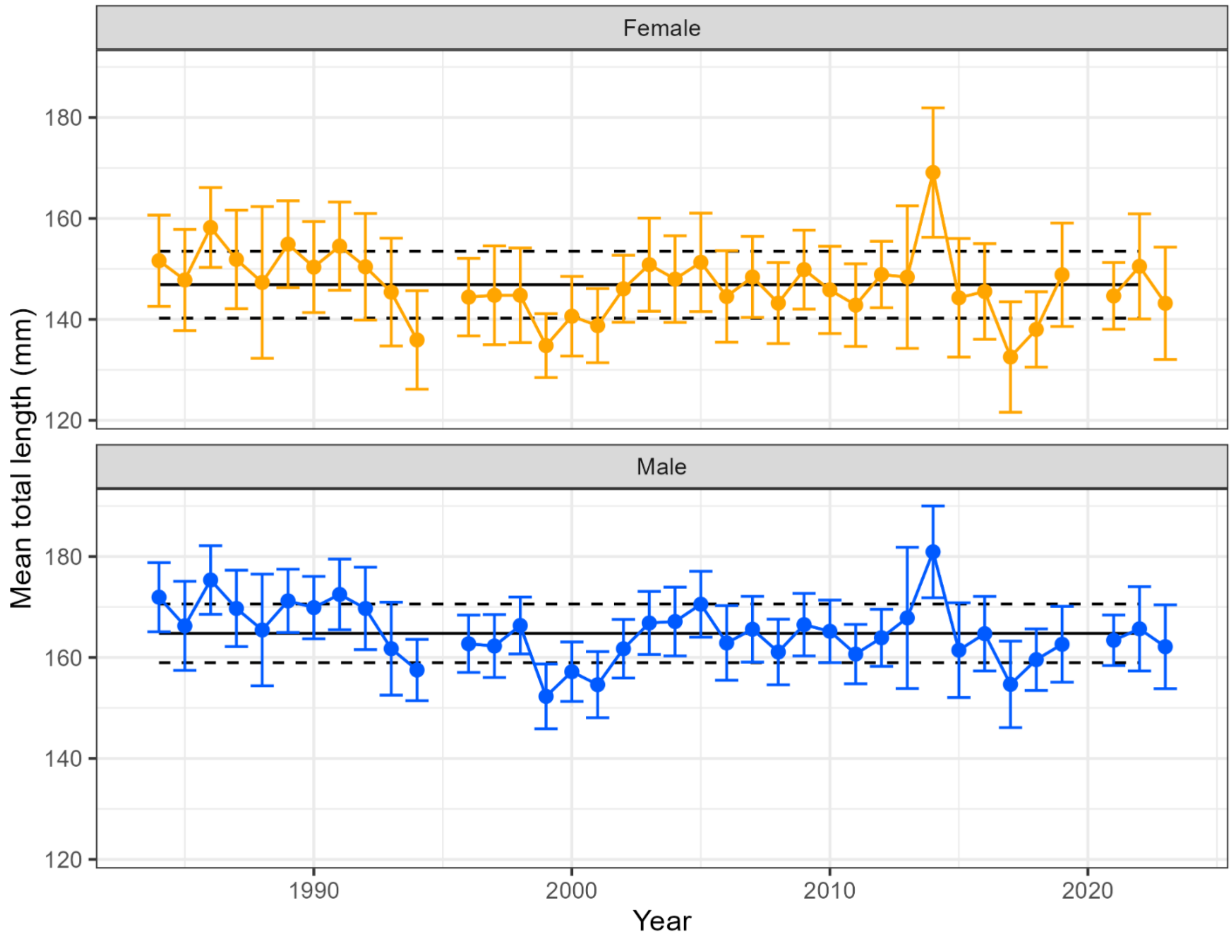

Figure 17. Annual mean total lengths (mm) of female and male Capelin sampled with purse and tuck seines in in NAFO Division 4R since 1984 by DFO's port sampling program. The horizontal lines represent the 1984–2022 mean ± 1 S.D.. Error bars represent the annual S.D.

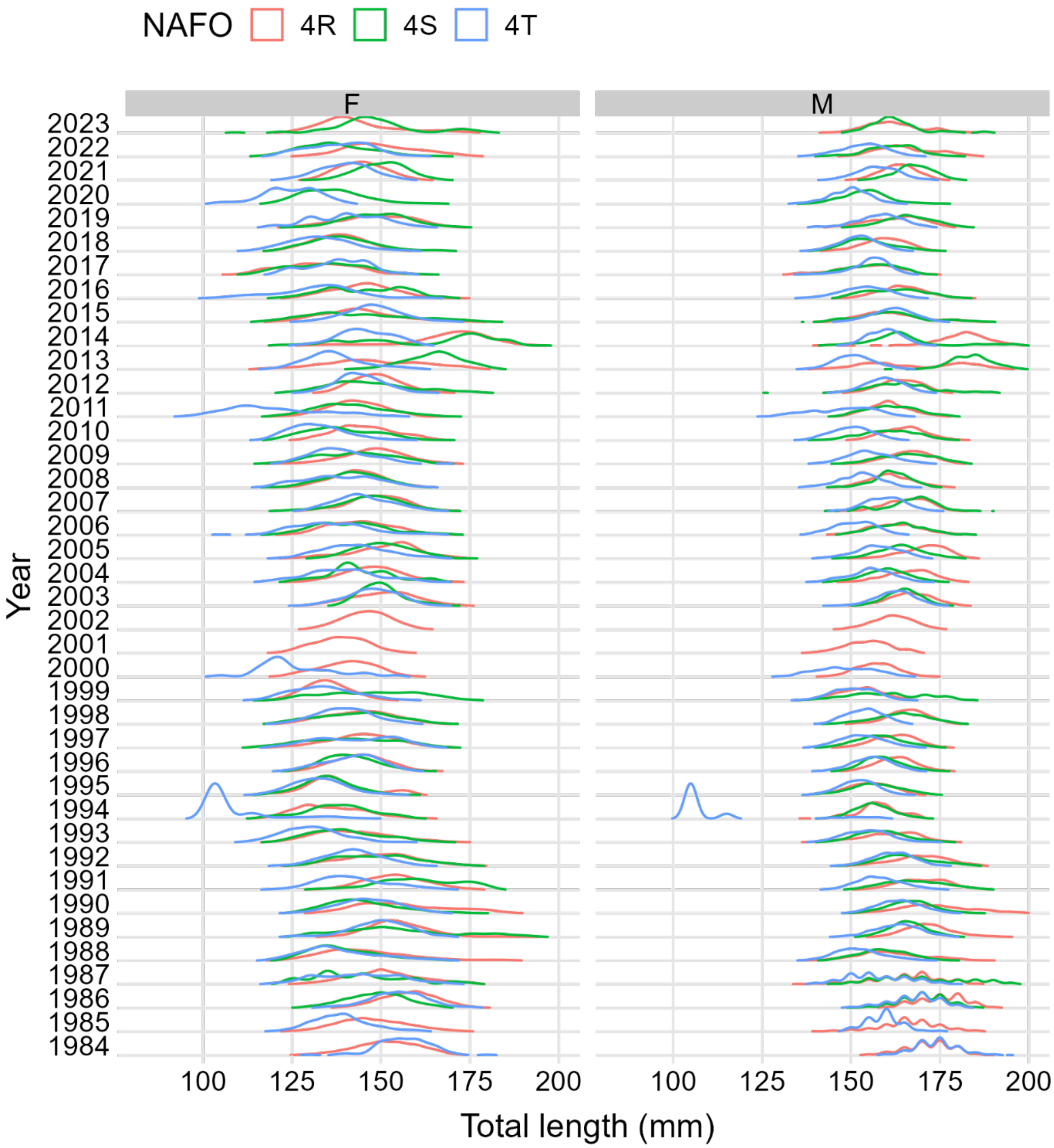

Figure 18. Length compositions (mm total length; kernel density estimates) of female (F) and male (M) Capelin caught in the NAFO Divisions 4RST from 1984 to 2023 sampled by DFO's port sampling program.

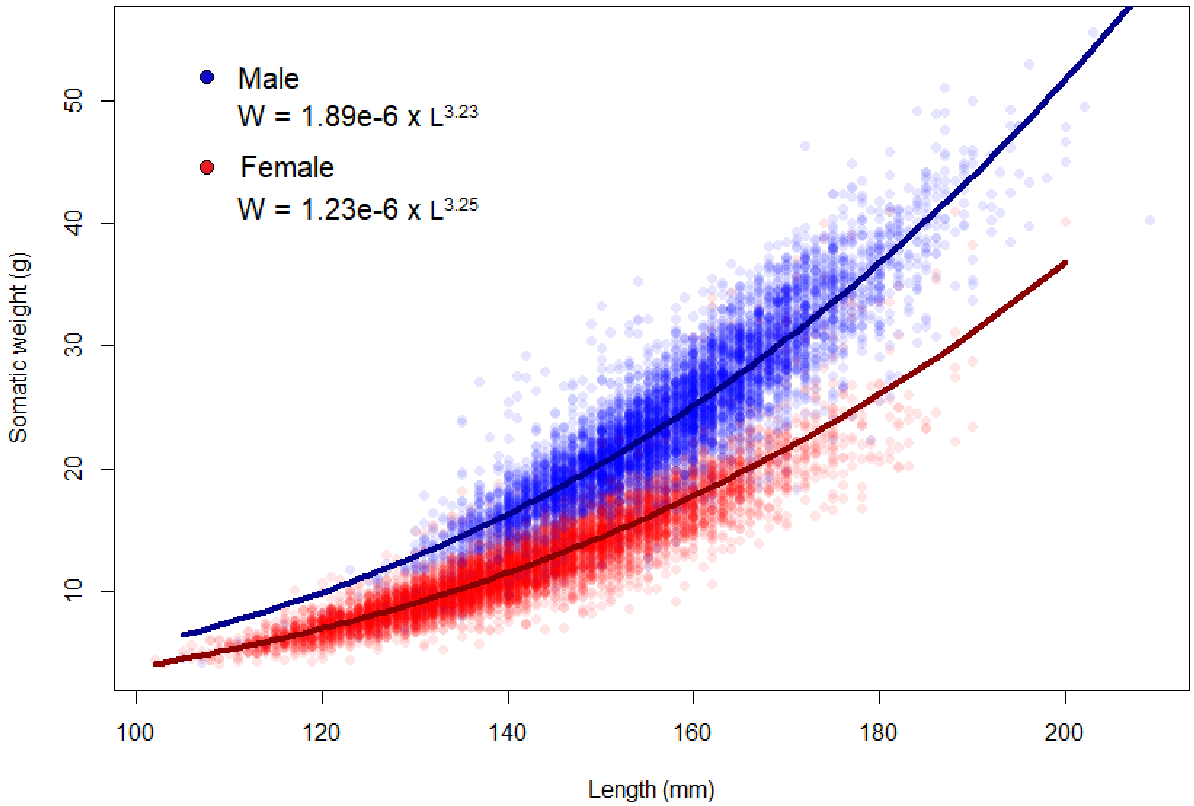

Figure 19. Length-weight relationships for Capelin caught in the commercial fisheries of NAFO Divisions 4RST from 1984 to 2023 and sampled as a part of DFO's port sampling program.

Figure 20. Standardized annual relative condition factor (Kn) of male (blue) and female (orange) Capelin from commercial samples analyzed in laboratory. Kn were standardized for the following reference levels: gear = seine (all types), month = June. Numbers of fish per sex used in the analysis are indicated on the x-axis.

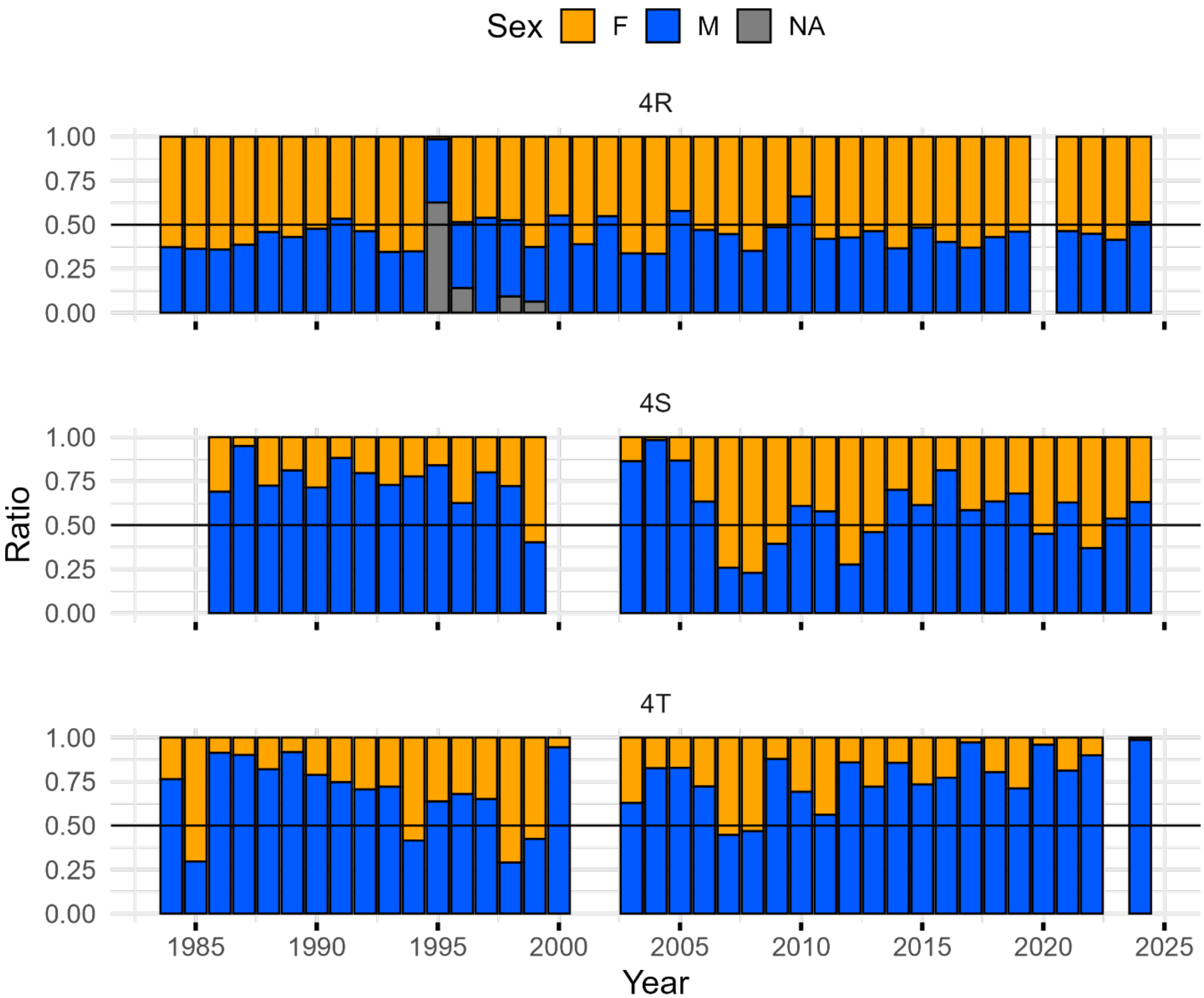

Figure 21. Annual sex proportions in Capelin commercial length frequency data from DFO's port sampling program, by NAFO Division. (NA : not available).

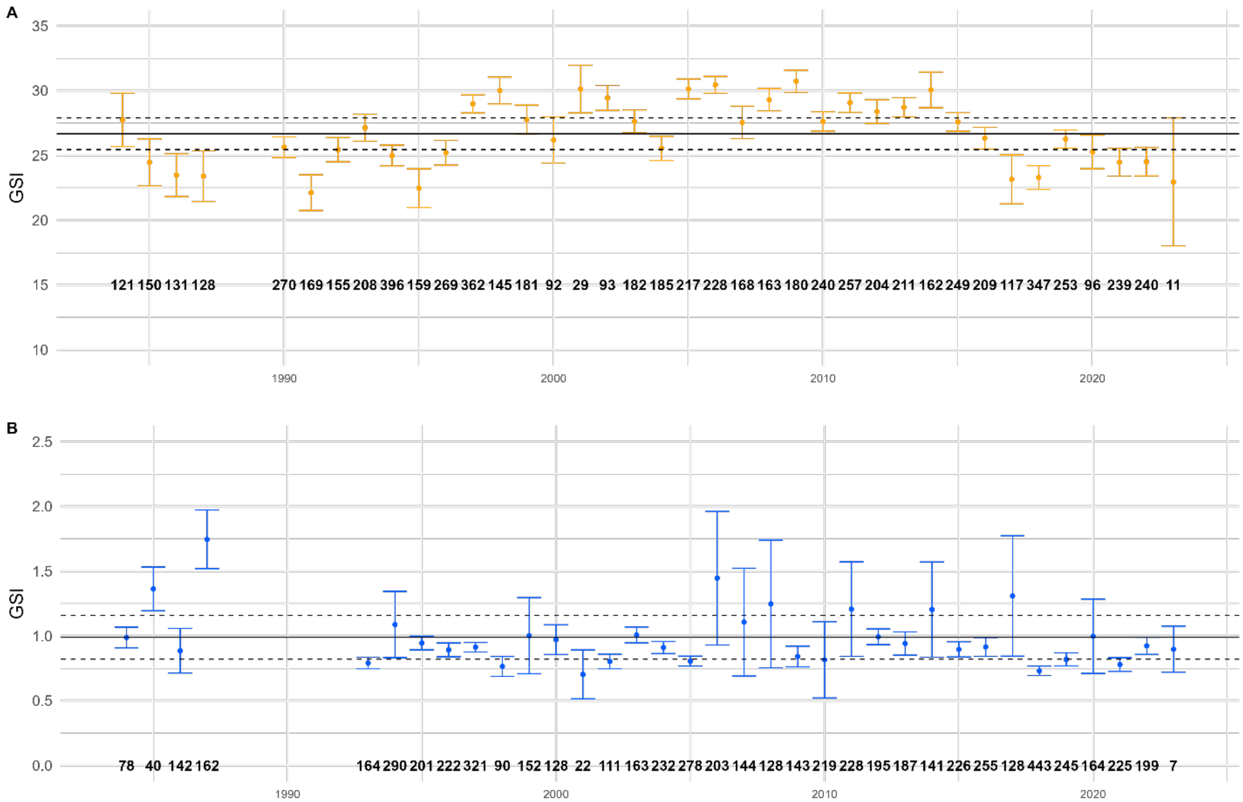

Figure 22. Estimated annual mean (Error bars represent ± 1 S.D.) gonadosomatic-Indeces (GSI) of female (A) and male (B) Capelin. Individuals whose sex could not be identified, individuals weighting < 5 g, as well as male Capelin with a GSI > 10% were excluded from the analysis. Numbers represent sample size.

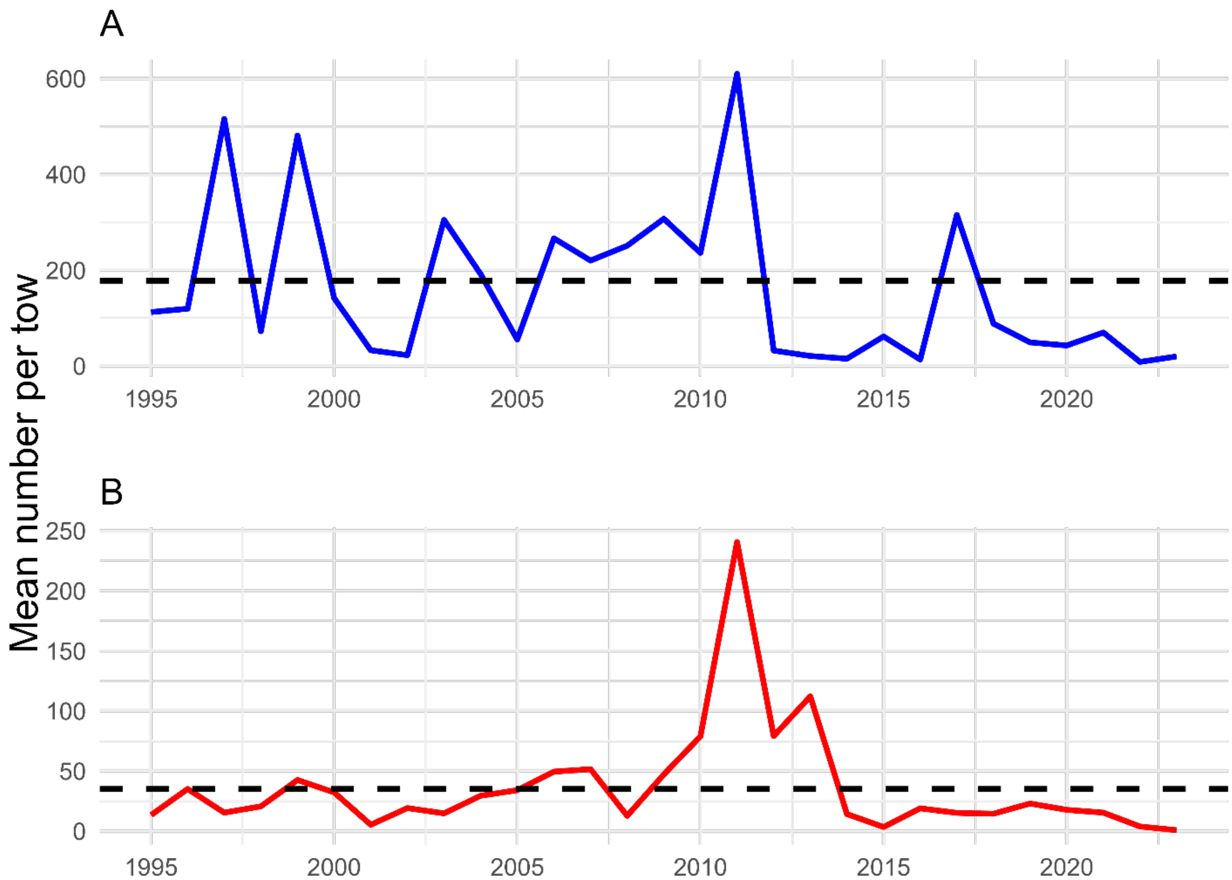

Figure 23. Mean number of Capelin per tow in the northern Gulf of St. Lawrence (A) prefered thermal habitat and (B) unfavourable thermal habitat estimated from mature fish caught in the bottom trawl survey. 95% confidence intervals are not presented for easier examination of the temporal trends. Horizontal dashed lines represent the 1995-2023 averages.

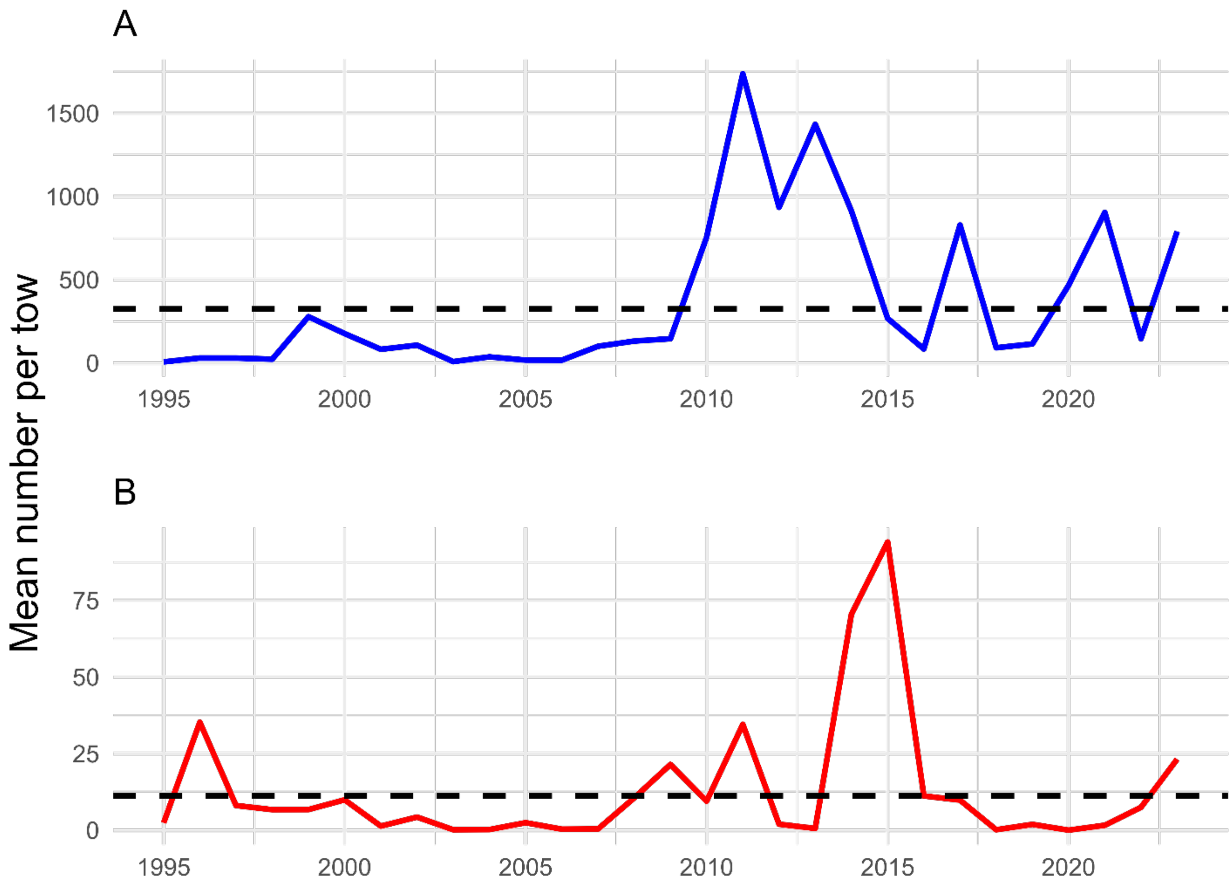

Figure 24. Mean number of Capelin per tow in the sGSL prefered thermal habitat (A) and unfavourable thermal habitat (B) estimated from mature fish caught in the bottom trawl survey. 95% confidence intervals are not presented for easier examination of the temporal trends. Horizontal dashed lines represent the 1995-2023 averages.

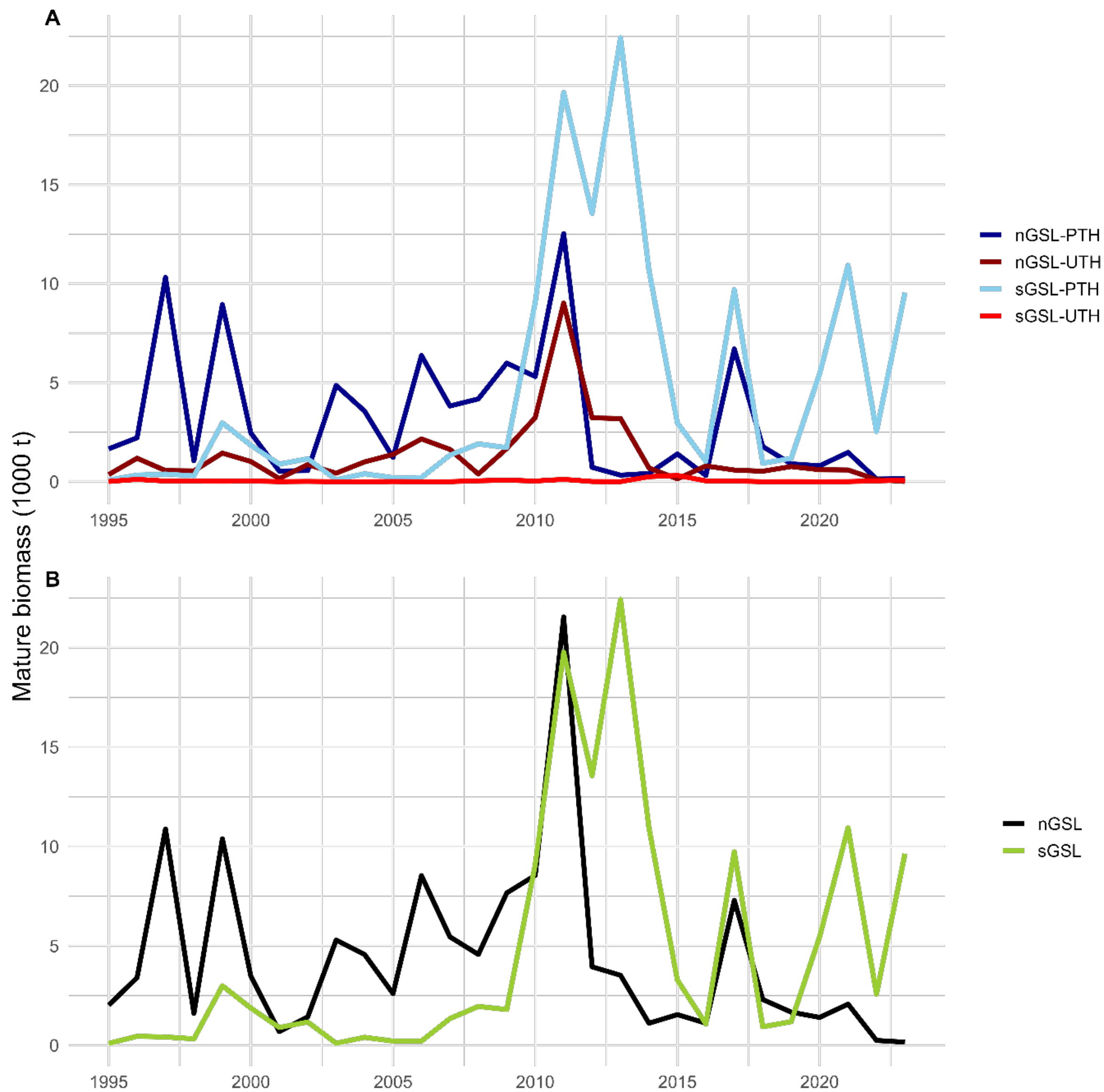

Figure 25. Mature biomass of Capelin (A) estimated in the northern (nGSL) and southern (sGSL) Gulf of St. Lawrence preferred thermal habitat (PTH) and unfavourable thermal habitat (UTH) and (B) combined for the nGSL and sGSL region. 95% confidence intervals are not presented for easier examination of the temporal trends.

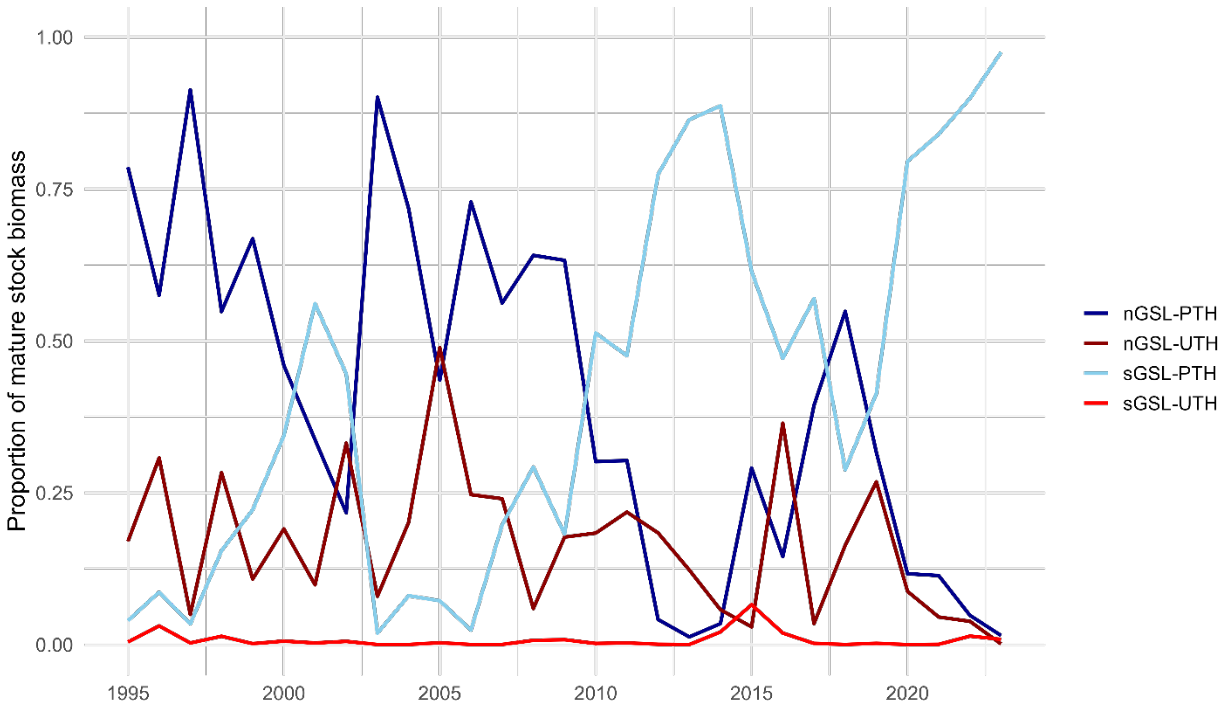

Figure 26. Proportion of the mature stock biomass represented by the northern (nGSL) and southern (sGSL) Gulf of St. Lawrence preferred thermal habitat (PTH) and unfavourable thermal habitat (UTH).

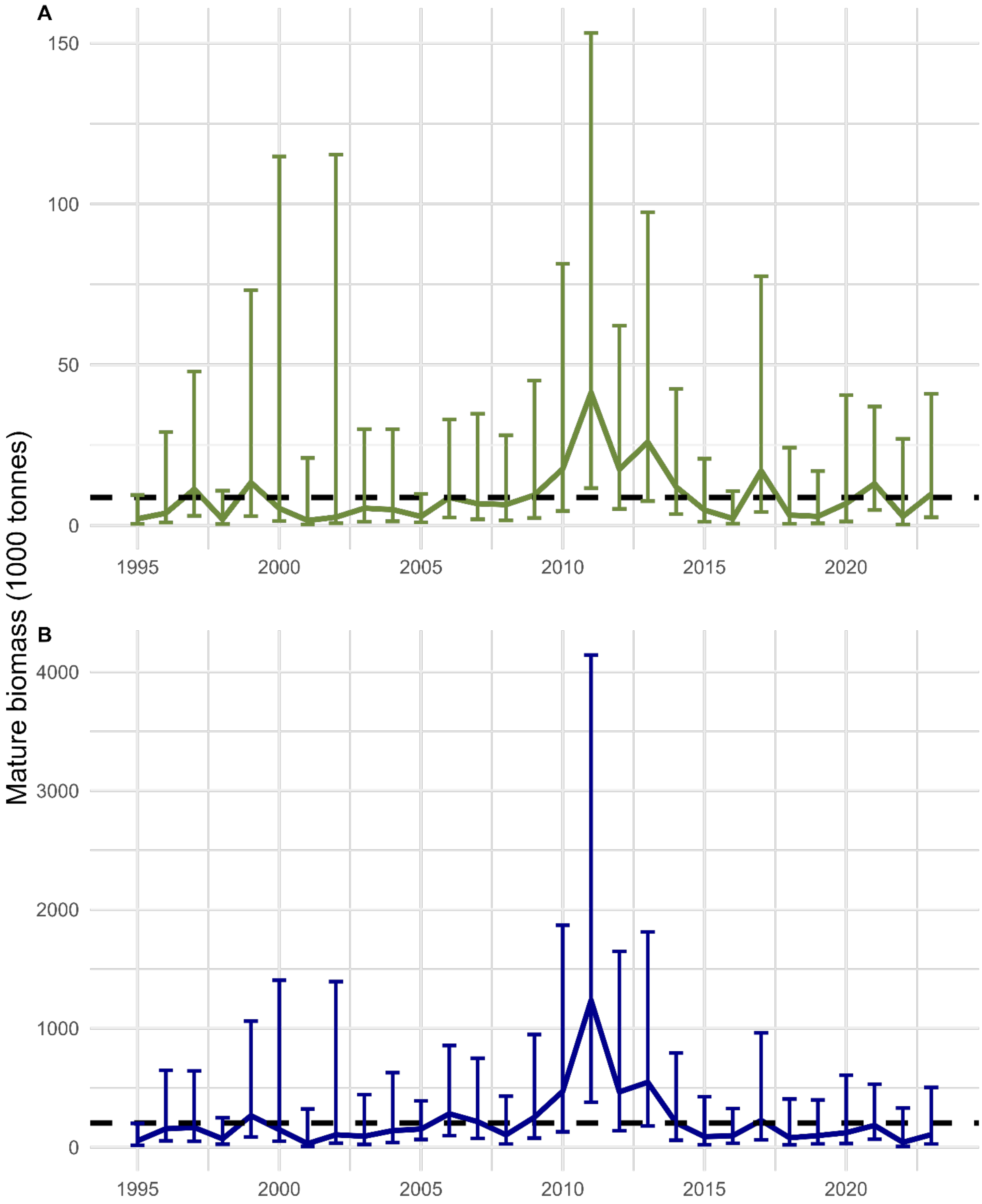

Figure 27. (A) Trawlable and (B) scaled mature stock biomass estimated with the northern and southern Gulf of St. Lawrence bottom trawl surveys combined. The verticale lines are the 95% confidence intervals and the horizontal dashed line represents the 1995-2023 average.

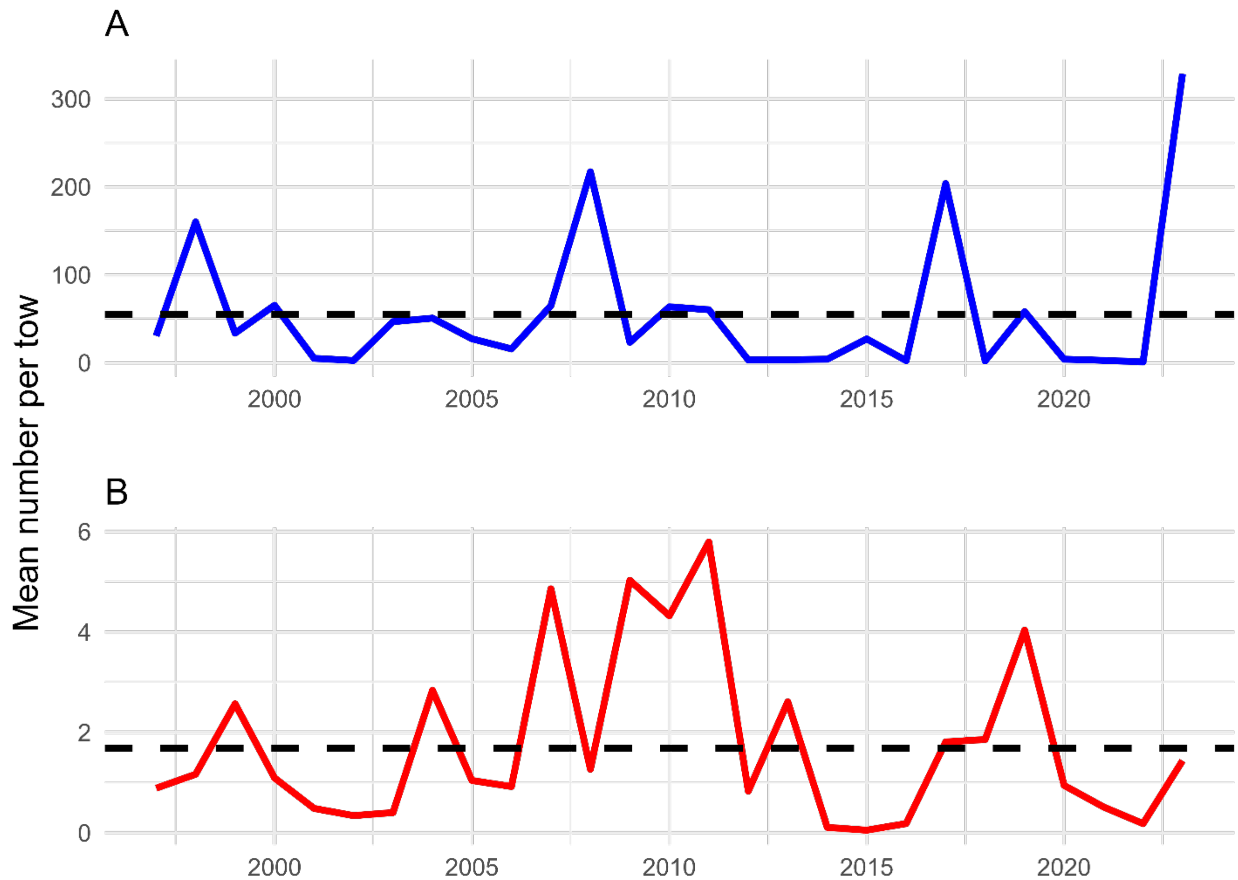

Figure 28. Mean number of Capelin per tow in the nGSL prefered thermal habitat (A) and unfavourable thermal habitat (B) estimated from age 1 fish caught in the bottom trawl survey and used as a proxy of recruitment. 95% confidence interval are not presented to allow for better examination of temporal trends. Horizontal dashed line represent the 1996-2022 average.

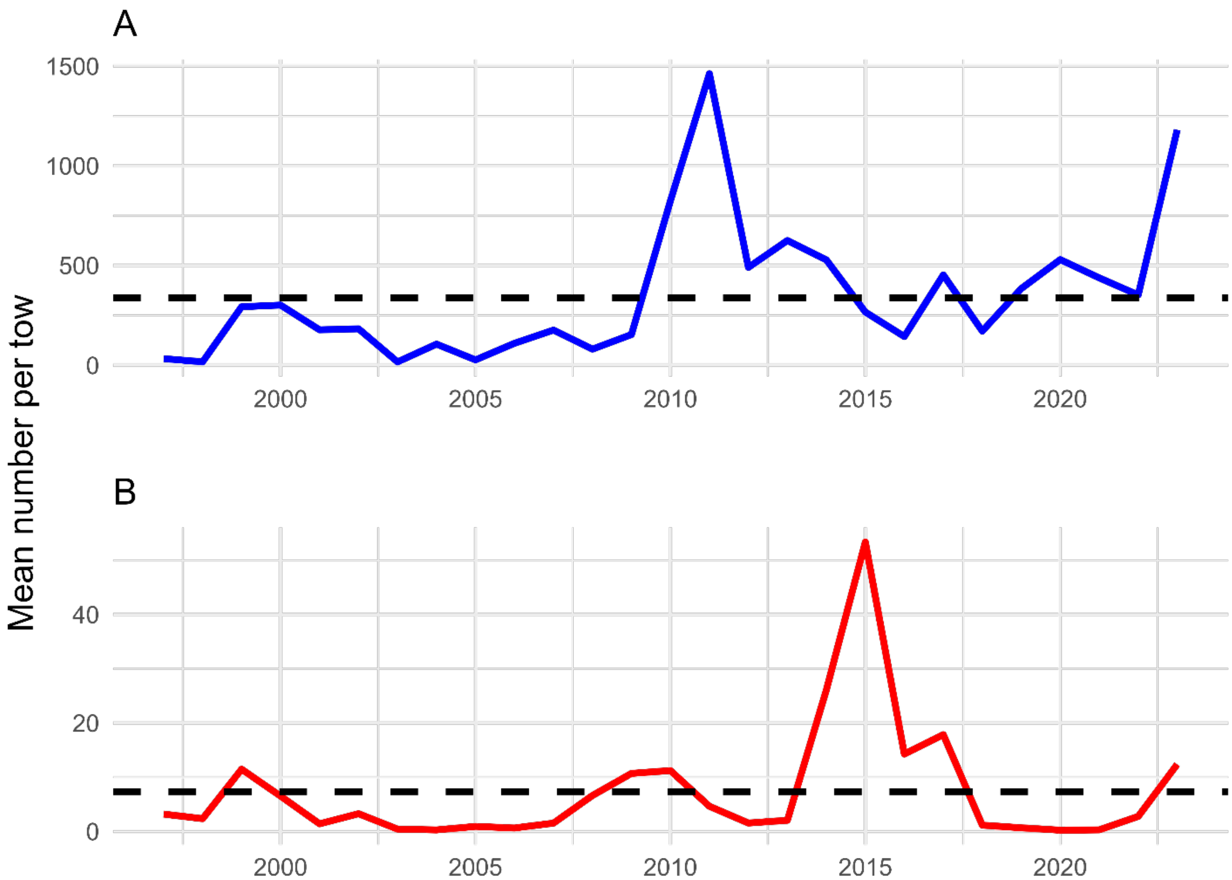

Figure 29. Mean number of Capelin per tow in the sGSL prefered thermal habitat (A) and unfavourable thermal habitat (B) estimated from age 1 fish caught in the bottom trawl survey and used as a proxy of recruitment. 95% confidence interval are not presented to allow for better examination of temporal trends. Horizontal dashed line represent the 1996-2022 average.

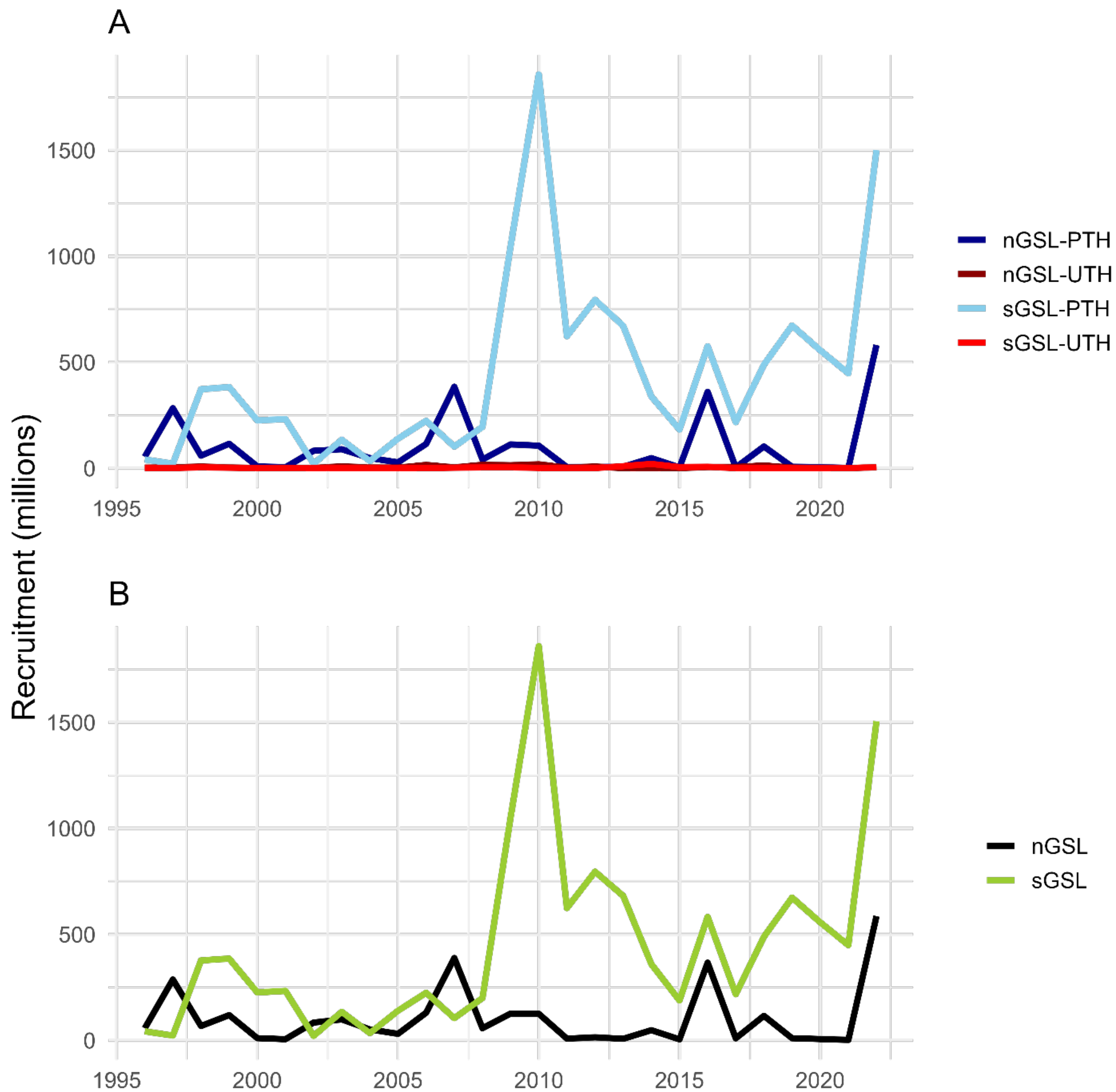

Figure 30. Recruitment index of Capelin (A) estimated in the nGSL and sGSL preferred thermal habitat (PTH) and unfavourable thermal habitat (UTH) and (B) combined for the nGSL and sGSL region. 95% confidence intervals are not presented for easier examination of the temporal trends.

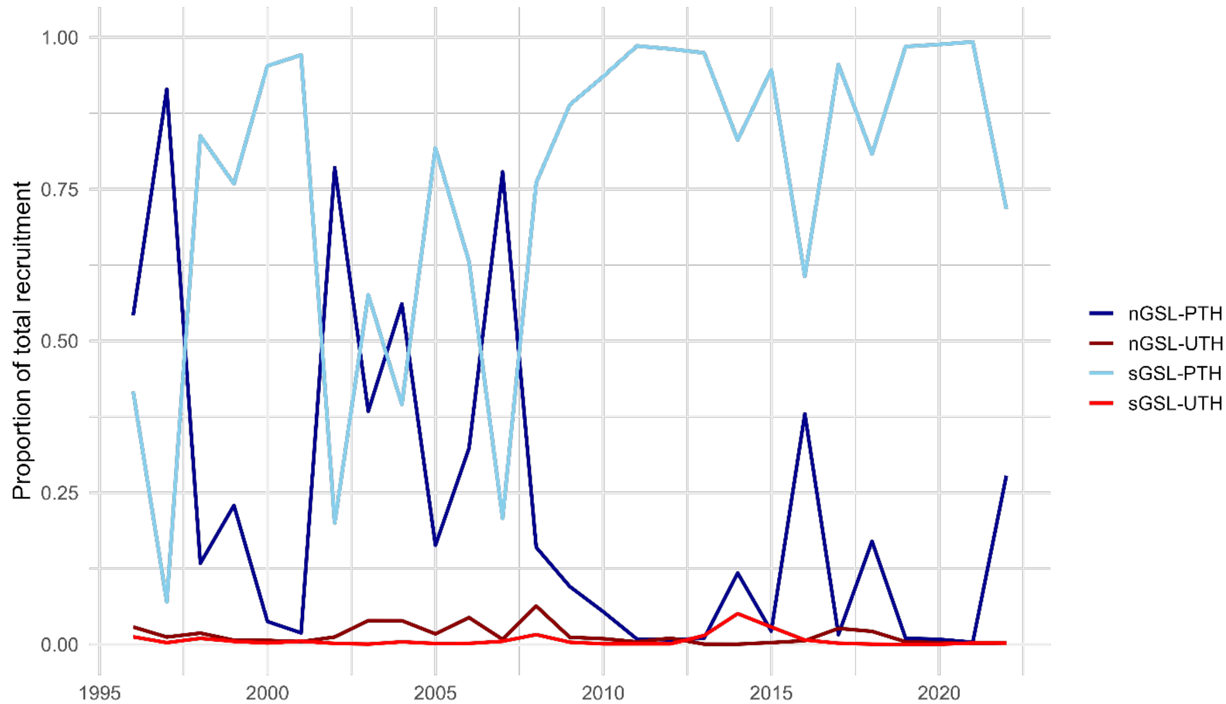

Figure 31. Proportion of recruitment index represented by the nGSL and sGSL preferred thermal habitat (PTH) and unfavourable thermal habitat (UTH).

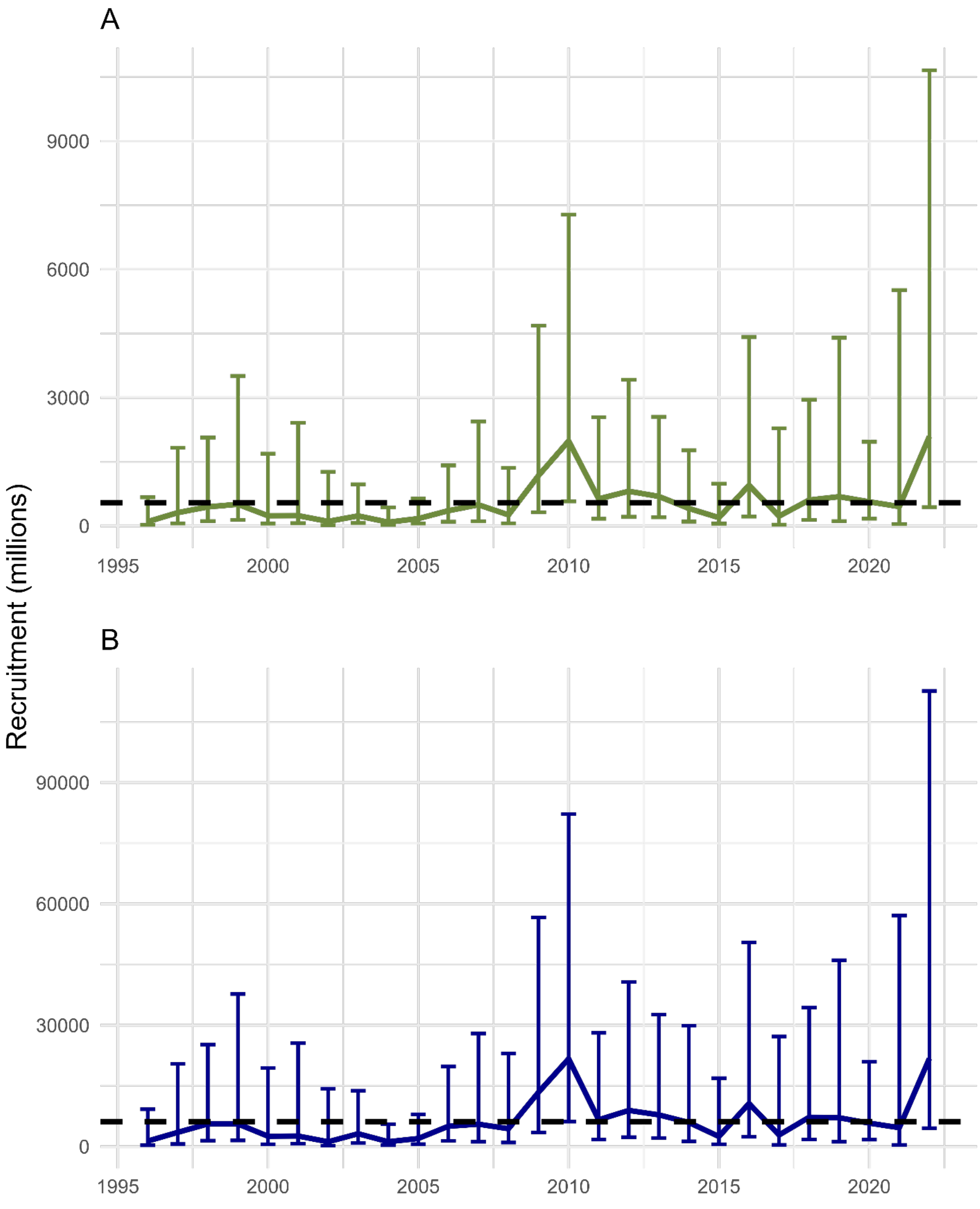

Figure 32. Trawlable (A) and scaled (B) recruitment index estimated with the nGSL and sGSL bottom trawl surveys combined. The verticale line are the 95% confidence interval and the horizontal dashed line represents the 1996-2022 average.

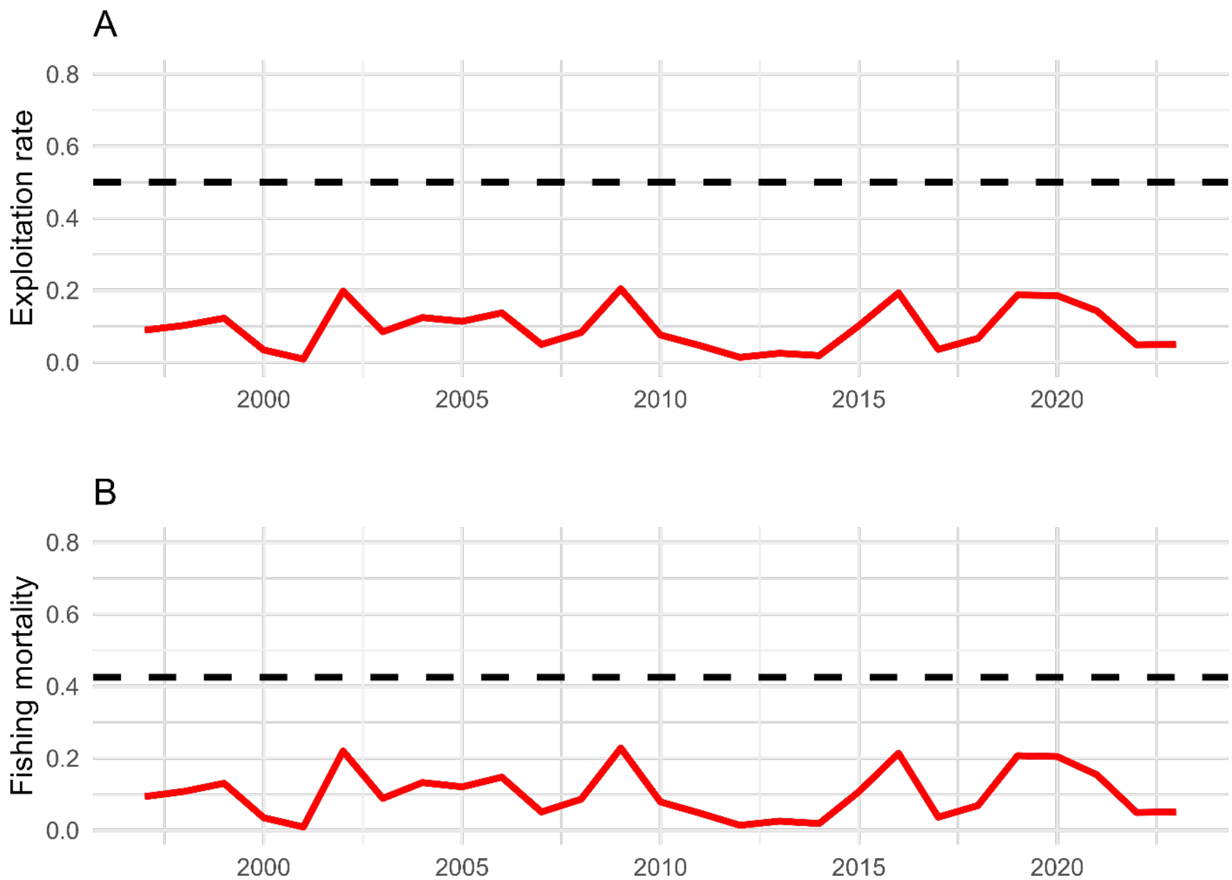

Figure 33. Time-series of (A) exploitation rate and (B) fishing mortality estimated with the ratio of total landings over the scaled mature biomass reduced by winter natural mortality. The horizontal dashed line represents levels over which harvest are causing serious harm according to Patterson 1992 (i.e. E = 0.5 and F = ½ M).

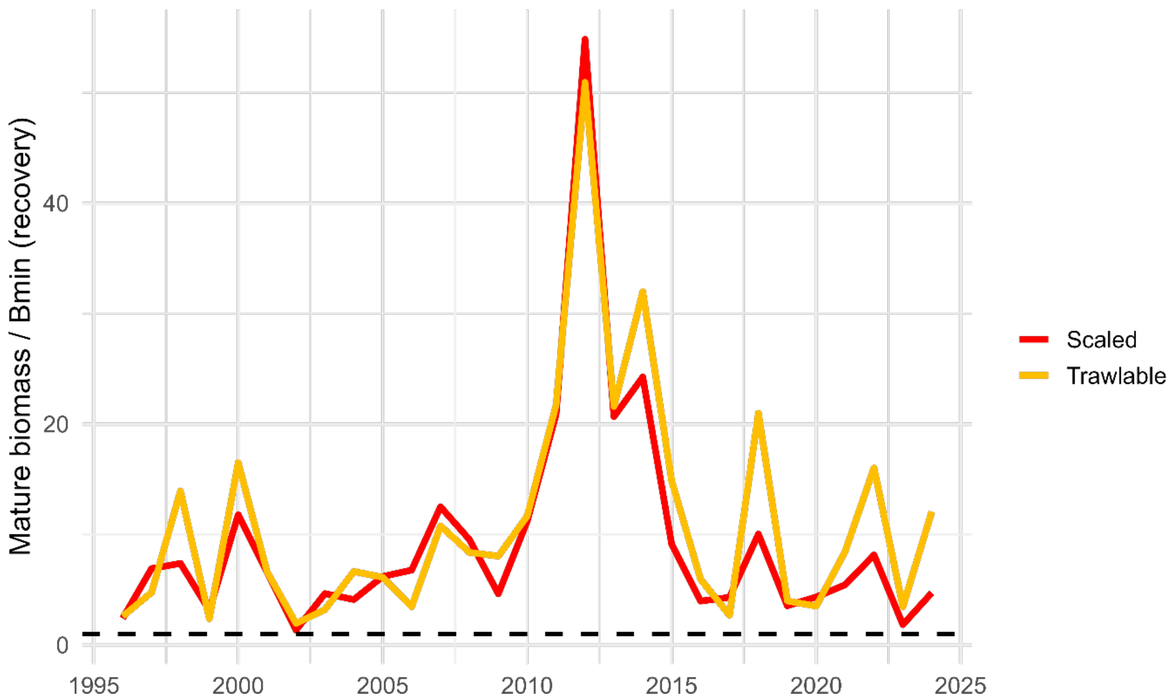

Figure 34. Ratio of mature stock biomass over the $B_{min\text{-}recovery}$ LRP. The horizontal dashed line represents a ratio of 1.

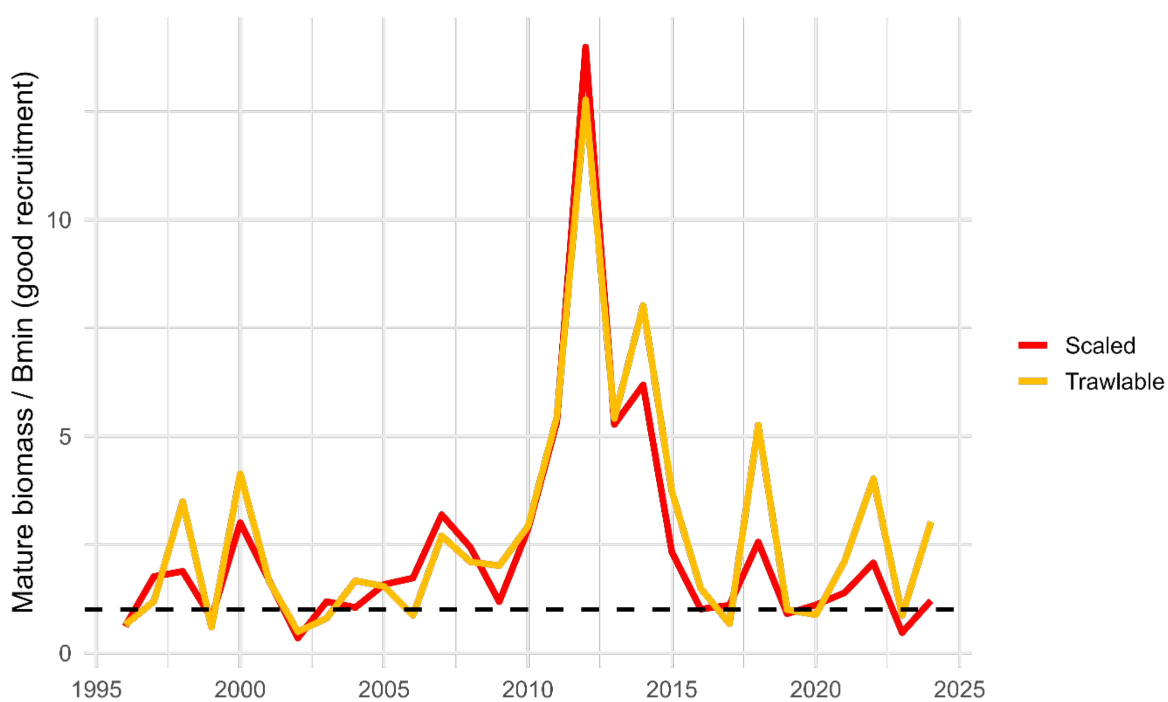

Figure 35. Ratio of mature stock biomass over the $B_{min\text{-}recovery}$ LRP. The horizontal dashed line represents a ratio of 1.

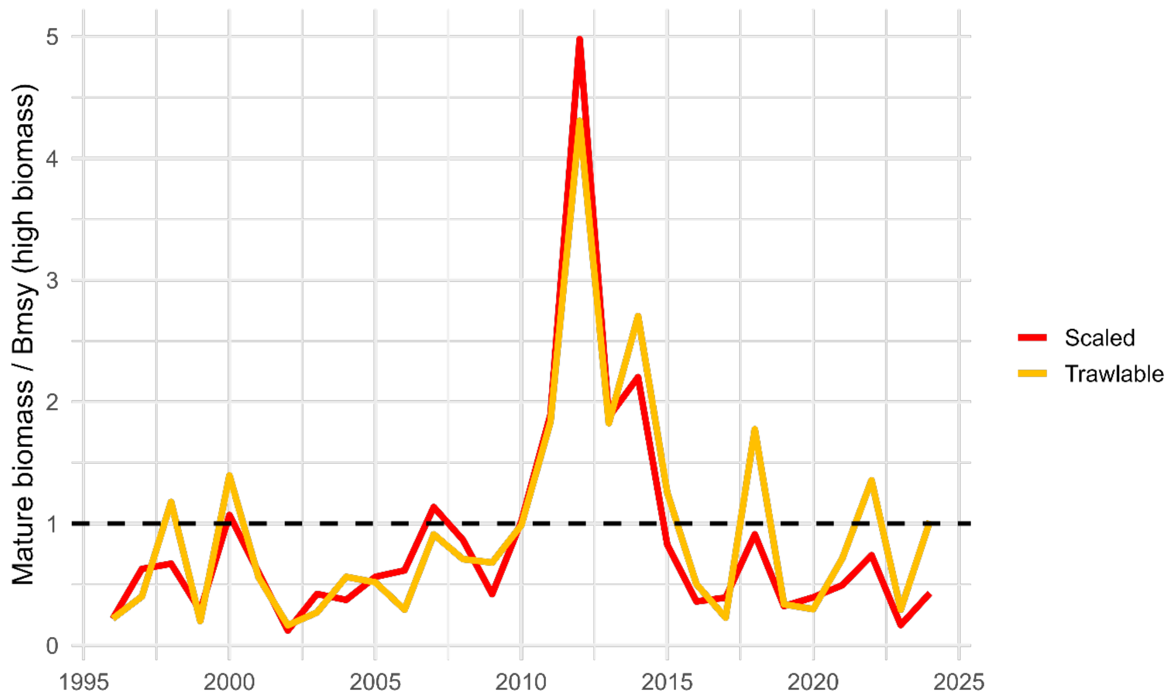

Figure 36. Ratio of mature stock biomass over the $B_{MSY\text{-}high}$ LRP. The horizontal dashed line represents a ratio of 1.

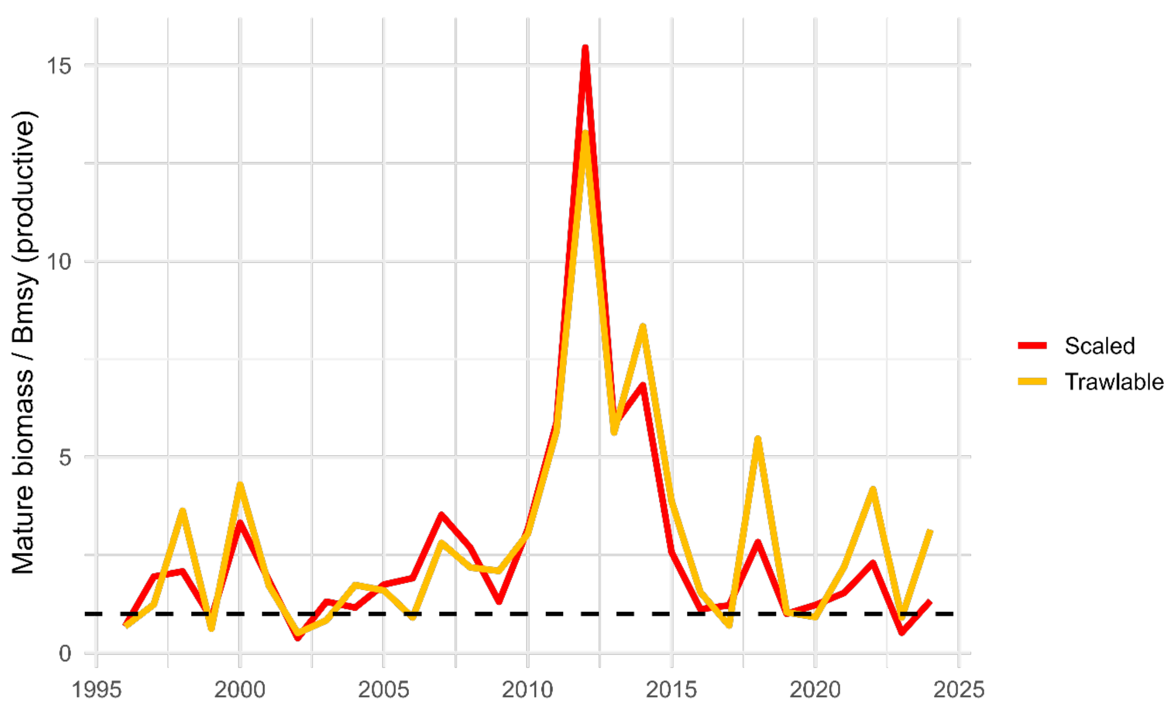

Figure 37. Ratio of mature stock biomass over the $B_{MSY\text{-}productive}$ LRP. The horizontal dashed line represents a ratio of 1.

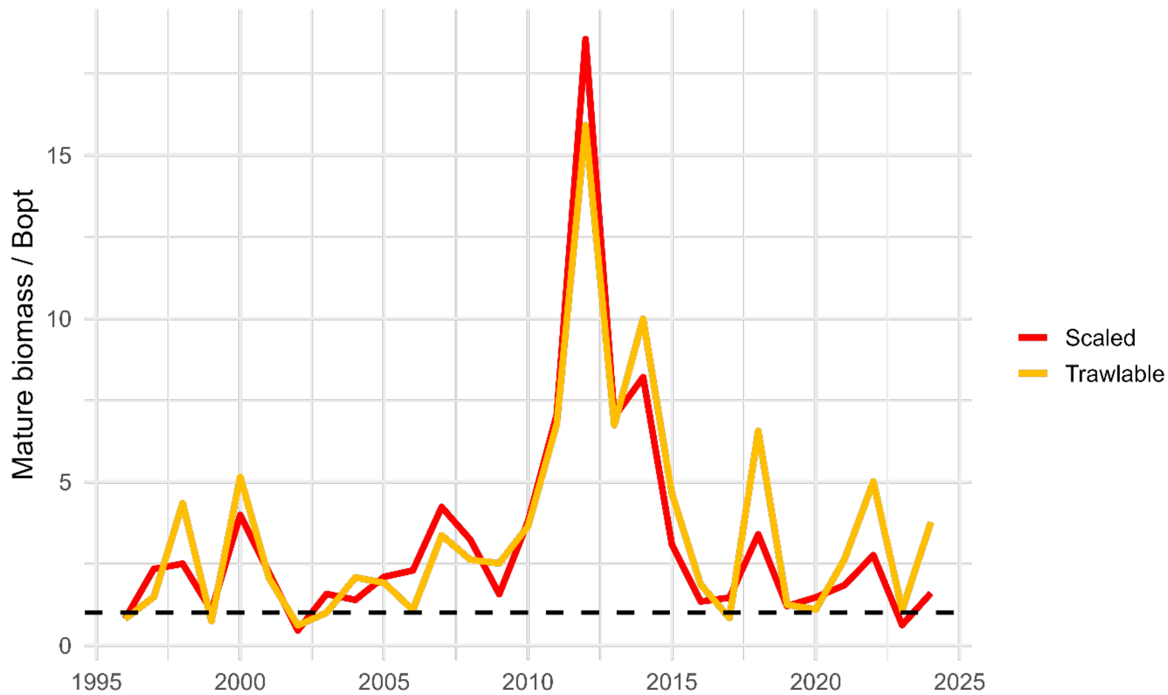

Figure 38. Ratio of mature stock biomass over the B_{opt} LRP. The horizontal dashed line represents a ratio of 1.

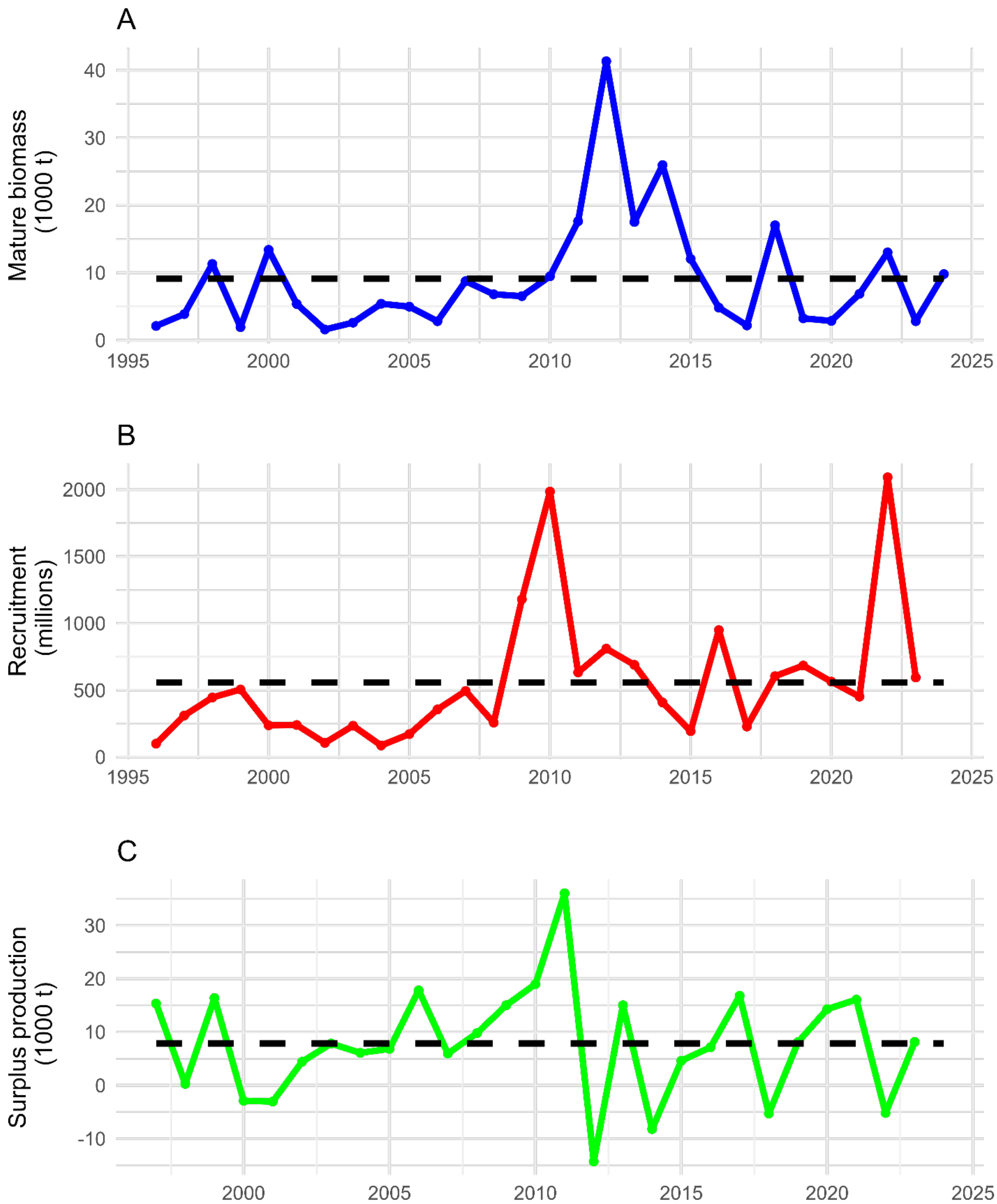

Figure 39. Time-series of mature stock biomass (A), recruitment index (B) and surplus production (C) estimated with the trawlable indicators with the nGSL and sGSL surveys combined. The horizontal dashed line represents the time-series average.

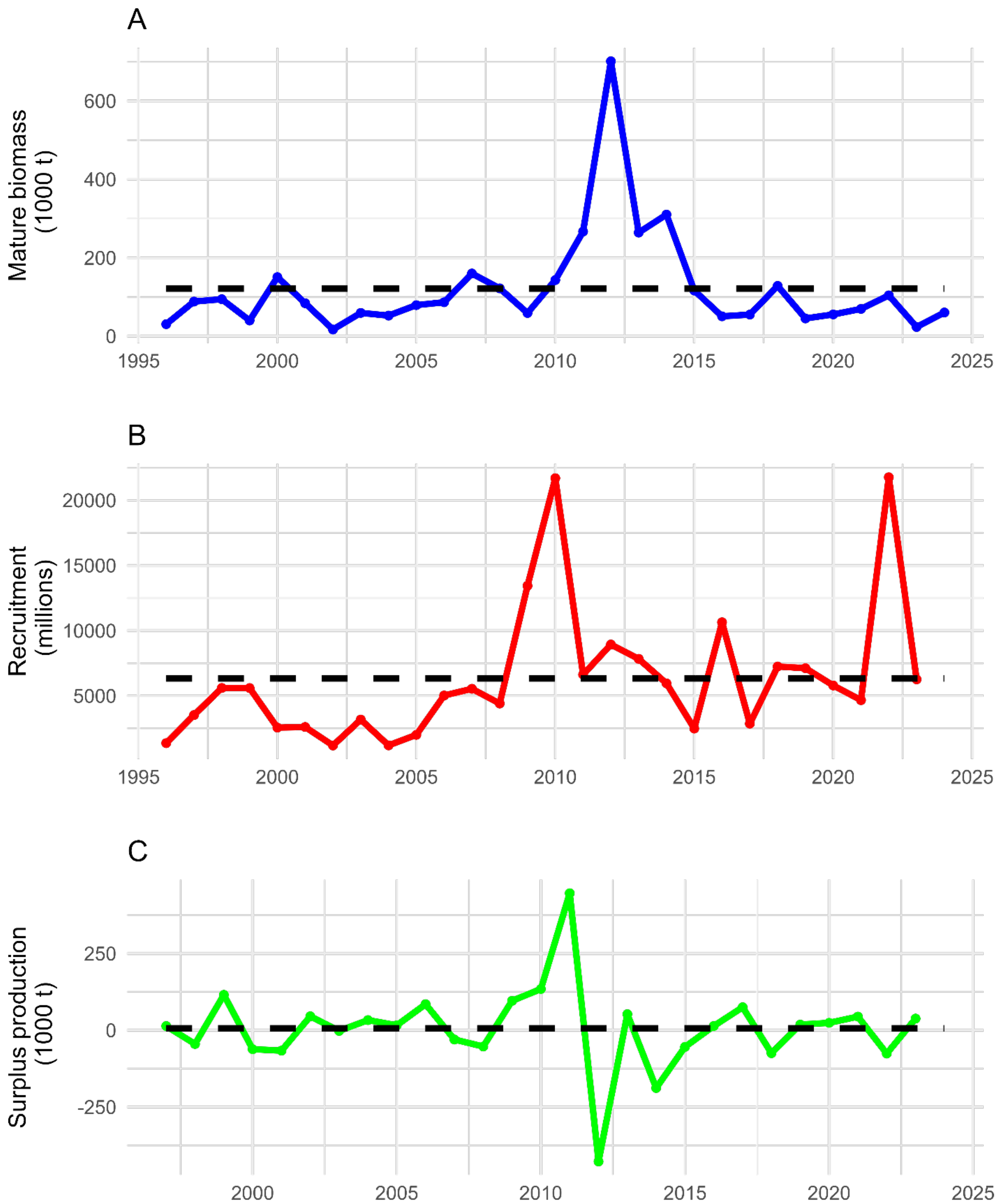

Figure 40. Time-series of (A) mature stock biomass, (B) recruitment index and (C) surplus production estimated with the scaled indicators. The horizontal dashed line represents the time-series average.

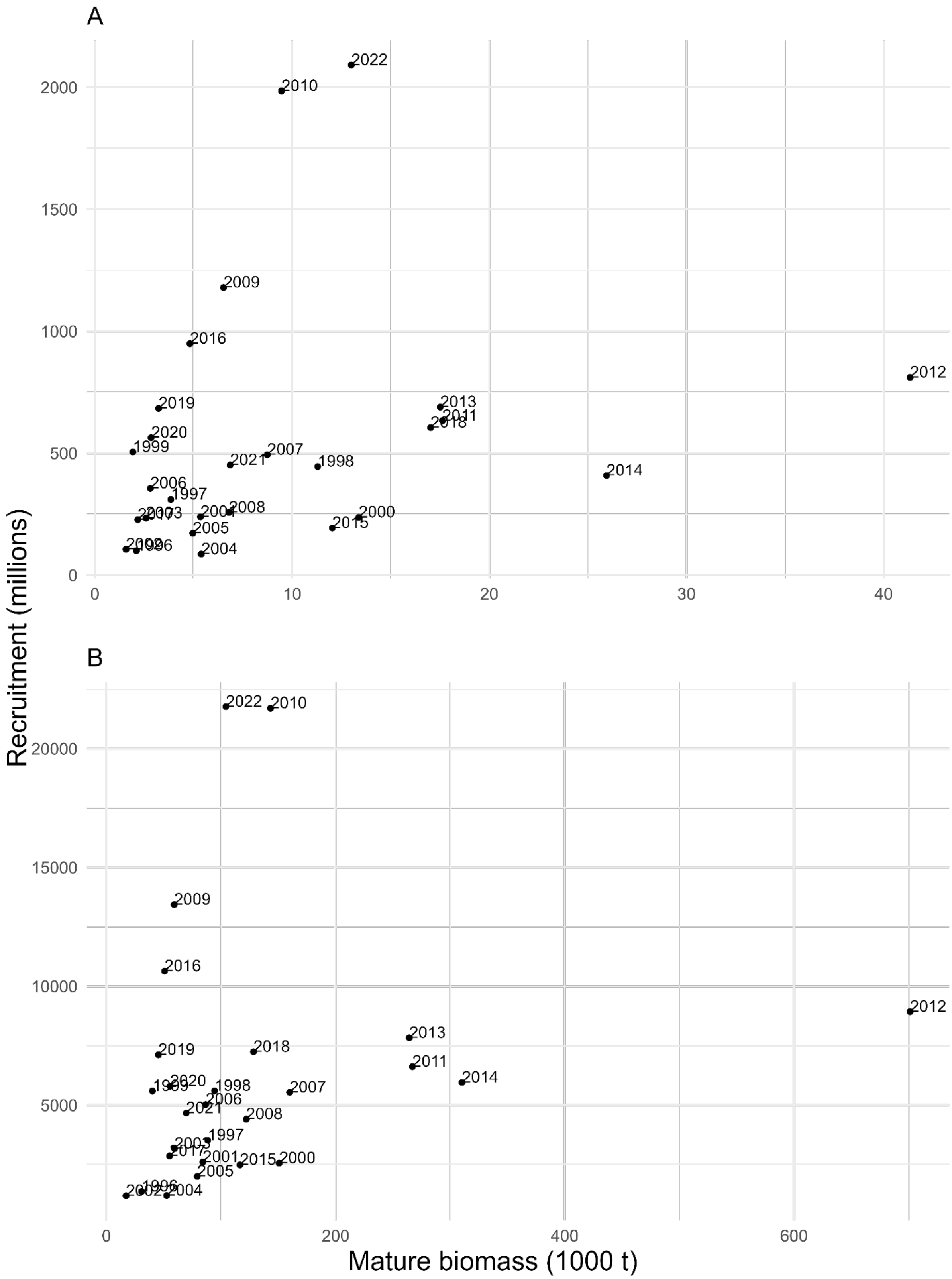

Figure 41. Recruitment index in relation to mature biomass estimated with (A) the trawlable and (B) scaled indicators.

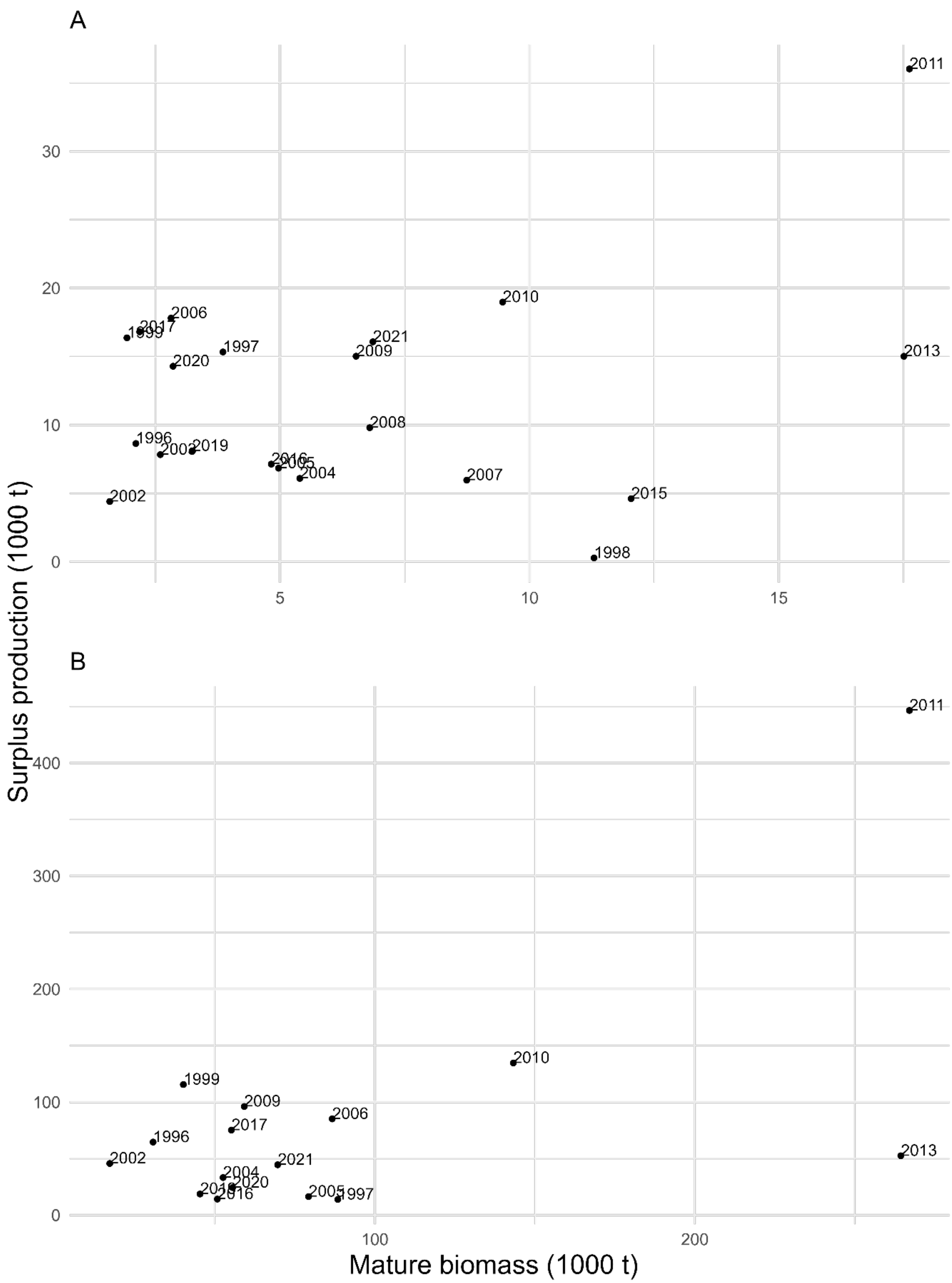

Figure 42. Surplus production in relation to mature biomass estimated with (A) the trawlable and (B) scaled indicators. Surplus production values below 0 have been removed to allow for better identification of years with low biomass and good production.

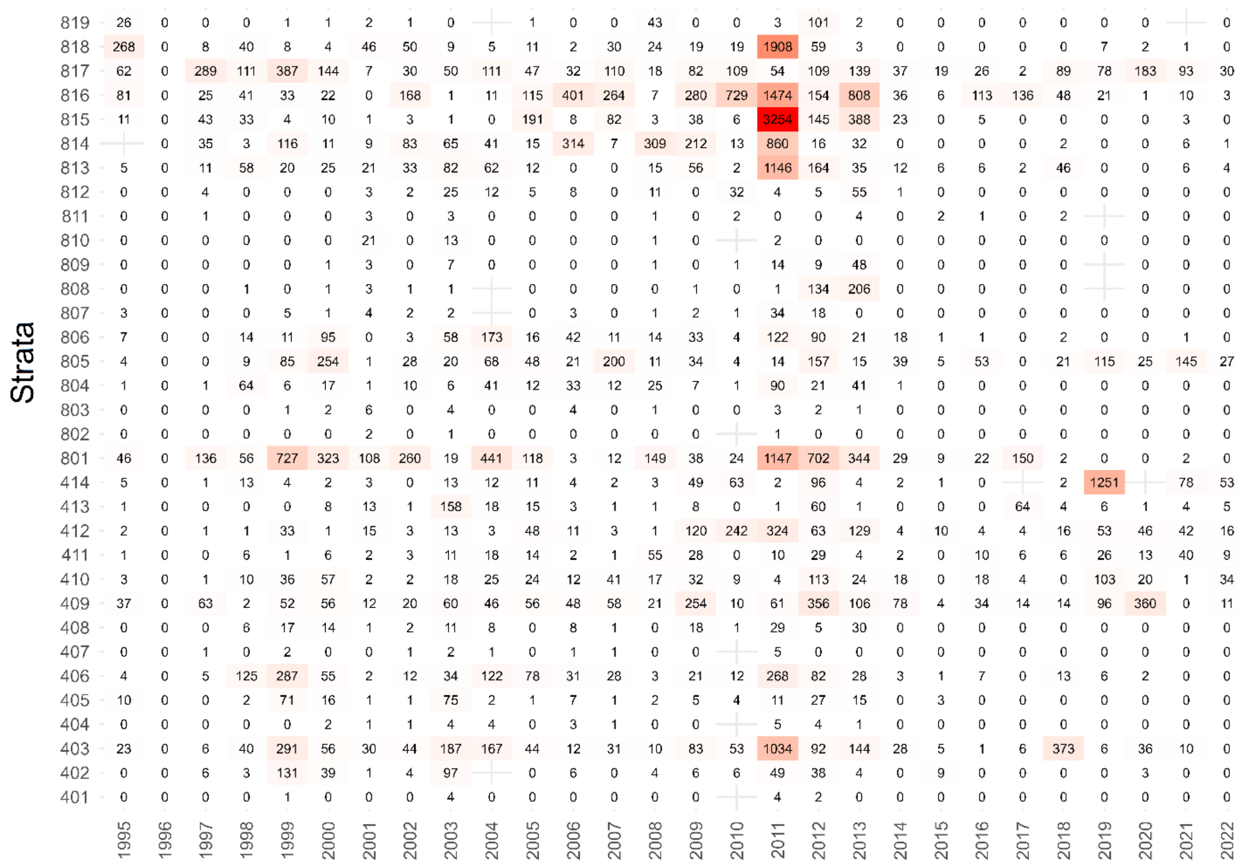

Figure 43. Time series of the mean number of Capelin caught in the northern Gulf of St. Lawrence survey for each strata (y axis) identified as Capelin unfavourable thermal habitat.

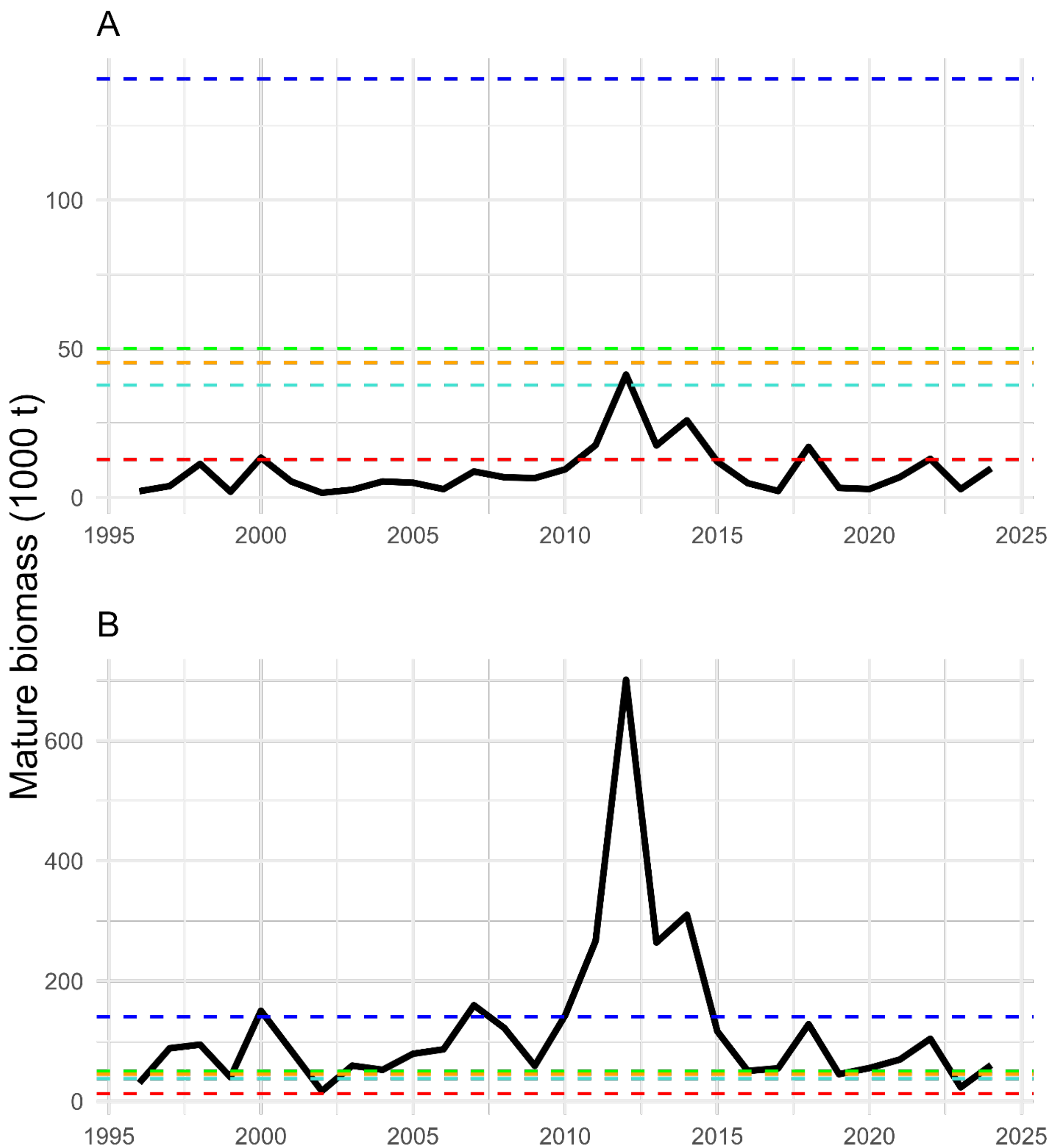

Figure 44. Time series of (A) trawlable and (B) scaled mature biomass. Coloured horizontal dashed represents $B_{min\text{-}recovery}$ (red), $B_{min\text{-}good\ recruitment}$ (green), $B_{MSY\text{-}High}$ (blue), $B_{MSY\text{-}productive}$ (orange) and B_{opt} (turquoise) LRPs estimated for each scenario.