



UPDATE OF STOCK STATUS INDICATORS OF THE ESTUARY AND GULF OF ST. LAWRENCE (DIVISIONS 4RST) CAPELIN STOCK IN 2022

Context

The stock assessment of the Estuary and Gulf of St. Lawrence (EGSL) Atlantic capelin (*Mallotus villosus*) in Northwest Atlantic Fisheries Organization (NAFO) Divisions 4RST is carried out every two years and the last assessment took place in April 2022. During this assessment, the available evidence (low approximations of fishing mortality and the composite index describing the status of the stock around the long-term average) indicated that any of the harvest levels attained over the last decade were unlikely to pose a risk to the 4RST capelin stock in 2022. However, the recommendation of a total allowable catch (TAC) for the 2023 fishing season was not possible due to lack of information at the time of the assessment. The next full assessment is scheduled for winter 2024. The Fisheries and Aquaculture Management Branch has requested an update of stock indicators to determine whether any changes have occurred in the status of the resource that would require adjustments to the management plan based on the adopted conservation approach.

This Science Response Report results from the regional peer review on the update of stock status indicators for capelin in the Estuary and Gulf of St. Lawrence (NAFO 4RST) in 2022 held on April 12, 2023.

Background

Environmental drivers of capelin abundance

Atlantic capelin is a small, schooling, forage fish that plays an important role in the ecosystem of the EGSL. Environmental and biological conditions known to regulate capelin survival and cohort strength explain a large part of the variations in capelin abundance indices from the multidisciplinary groundfish and shrimp bottom trawl surveys (BTS) conducted annually by Fisheries and Oceans Canada in the EGSL (Lehoux et al. 2022). In the GSL, capelin abundance indices were mainly associated with variations in body condition in June and/or August–September, or in environmental predictors such as the timing of ice retreat, the sea surface temperature and the abundance and phenology of preys of the genus *Calanus* (Lehoux et al. 2022). This supports the conceptual hypothesis that capelin abundance is determined by bottom-up processes regulating survival during its first 2 years of life (Lewis et al. 2019; Lehoux et al. 2022). Thus, favorable environmental conditions in summer and fall of their first year of life will lead to good body condition and increased winter survival, and added to favorable conditions during spring of year 2, will increase the likelihood of producing a strong cohort.

Overview of the fishery

In the NAFO Divisions 4RST (Figure 1), most capelin catches are made on the west coast of Newfoundland by a fleet of small and large purse seiners, as well as by the fleet of tuck seiners

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and the trappers. Capelin is also caught using purse seines and traps on Quebec’s Lower North Shore and at the mouth of the Baie des Chaleurs, and using weirs in the St. Lawrence Estuary. Capelin is a regularly found in catches of shrimp trawlers and in the multidisciplinary groundfish and shrimp surveys conducted annually by Fisheries and Oceans Canada in the EGSL. The structure of capelin populations in the EGSL is not clearly defined, and capelin in Divisions 4RST are currently managed as a single stock. The 4RST capelin fishing season is generally short and corresponds to the pre-spawning period for the seine fishery and to the spawning period for the trap and weir fisheries. Capelin fishing in the EGSL is managed by a TAC. Since 1999, the TAC has been shared among the different fleets in the EGSL (Table 1).

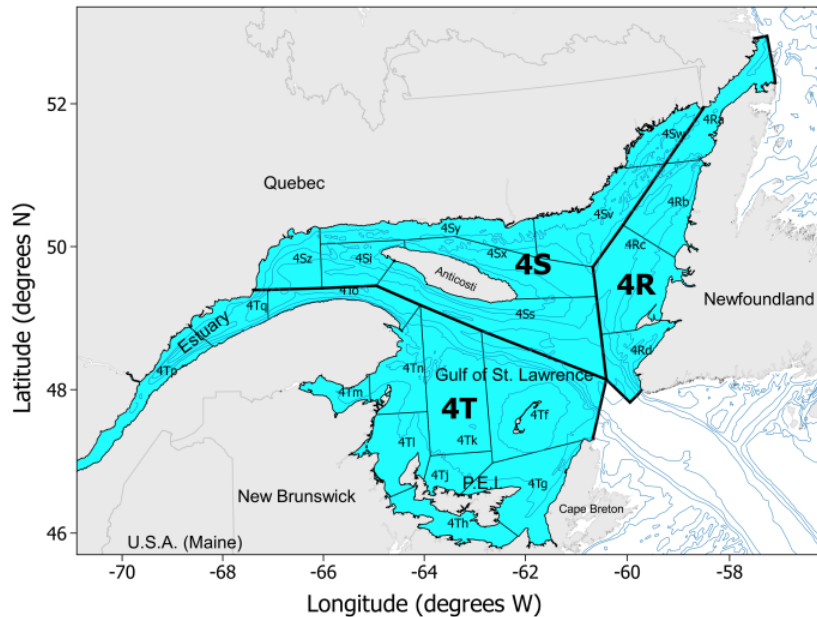


Figure 1. Map of NAFO Divisions 4RST (EGSL).

Table 1. Sharing arrangements of the 4RST capelin TAC by NAFO Division and gear type. Capelin fishing areas (CFA) are indicated in brackets.

NAFO Division (CFA)	Gear	Type of quota	Sharing arrangement (%)
4R (12*-14)	Fixed gear	Competitive	37.82
	Mobile gear < 65'	Individual	24.15
	Mobile gear ≥ 65'	Competitive	24.15
4ST (15-16)	All gear types	Competitive	13.88

Assessment of the stock

The stock assessment of the 4RST capelin is performed by evaluating the trends of different fishery dependant and independent indicators over recent years and comparing annual values to the time series average as described in Boudreau et al. (2023). The set of indicators includes: the annual total landings in NAFO Divisions 4RST, the relative condition of males and females originating from the seiner fleet and standardized for the month of June, the relative abundance indices of capelin caught by the BTS in the northern (nGSL) and southern (sGSL) Gulf of St. Lawrence, the approximations of fishing mortality rates and the composite index of the stock

status. Following the April 2022 stock assessment, a TAC of 10,225 t was adopted for the 2022 fishing season following a TAC of 9,295 t from 2018 to 2021. This TAC increase was deemed appropriate following the trends and annual values of the different indicators. The condition factor of males and females were above the 1984-2021 time series average, the approximations of the fishing mortality rates from 1997 to 2021 were likely much smaller than natural mortality rates typical of short-lived forage species and the composite index varied around the 1990-2021 long-term average since 2016 (DFO 2022a). The objective of the present science response is to update the stock status indicators of the 4RST capelin for the 2023 fishing season based on the best available data.

Analysis and Response

Description of fishing activities

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 2). From 1985 to 2022, 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 unfavorable 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 2A), constituting an average of 82% of the annual landings for 2010–2021. 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 2B). The preliminary landings in 2022 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. A higher proportion of the total catch was landed by the fixed gear fleet of tuck seine and trap nets (3,549 t) compared to the mobile fleet composed of large and small seiners (1,464 t) in 2022 compared to previous years (Figure 2B).

In NAFO Division 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 3A). 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 3B). Total landings from 4R in 2022 (4,886 t) were mainly located in unit area 4Ra (3,521 t). The tuck seiner fleet took 59% (2,901 t) of the total landings compared to 29% (1,431 t) for the small and large seiners, and 13% (646 t) for trap nets. In NAFO Divisions 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 traps (Figure 4). Landings in 4ST markedly increased in 2020 and 2021 relative to previous years and totaled 2,405 and 1,921 t respectively, a level not observed since the period 2006–2011. In 2022, annual landings in 4ST were the lowest annual landings observed since 2017 and were located in unit areas 4Sw (117 t) and 4Tp (10 t). Landings in 2022 from that Division were relatively evenly distributed between fishing gear (Figure 4B) including small purse seine (45 t), trap nets (48 t) along with beach, bar and pair seine (33 t).

**Update of stock status indicators of the
Estuary and Gulf of St. Lawrence (4RST)
capelin stock in 2022**

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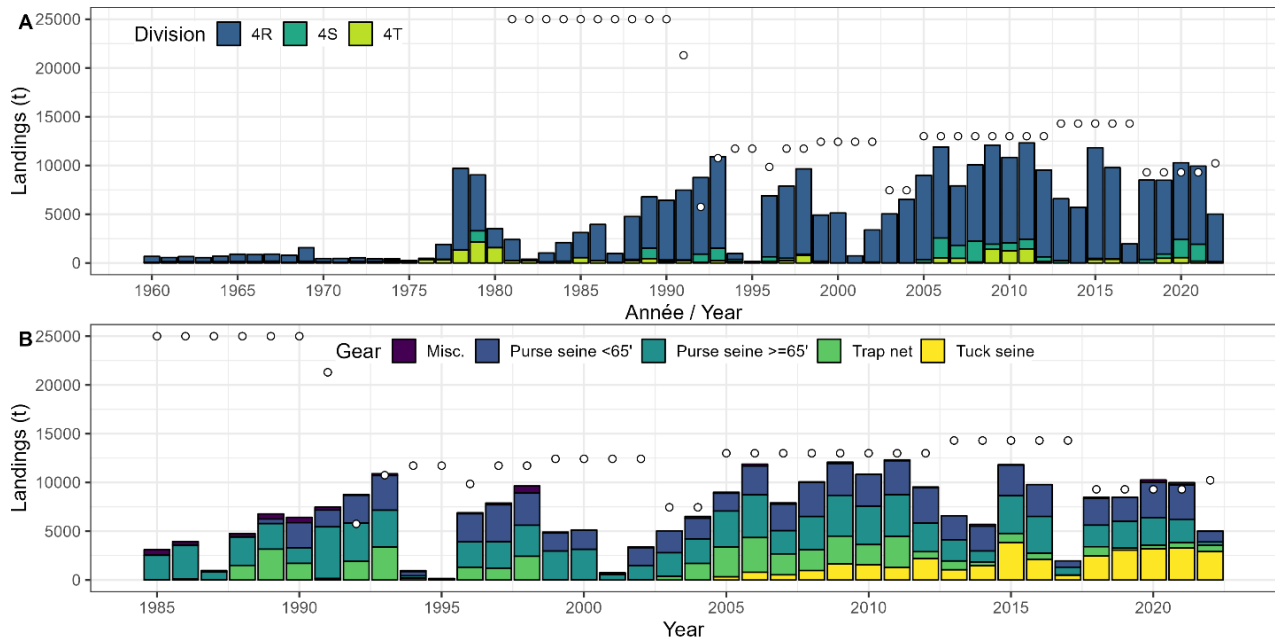


Figure 2. Capelin landings (t) by A) NAFO Division from 1960 to 2022 and B) by main fishing gear for the 1985-2022 period. The white circles represent the TAC. Landings for 2020, 2021 and 2022 are preliminary.

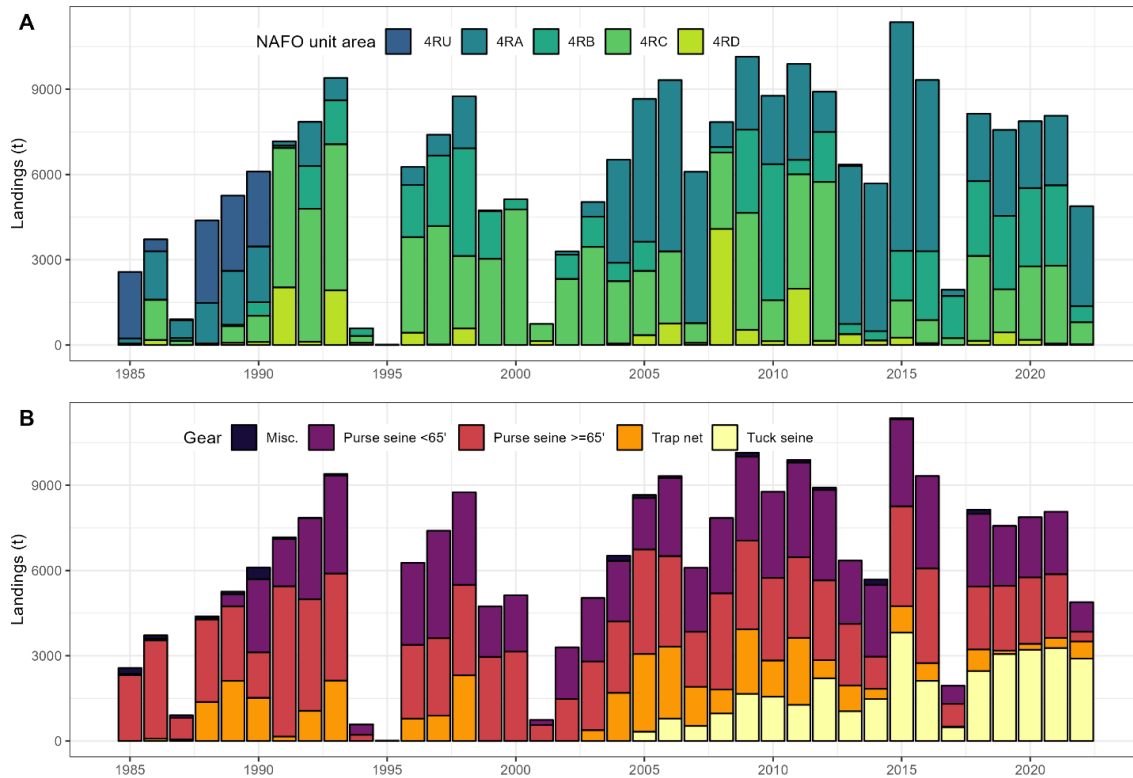


Figure 3. Annual commercial landings (t) of capelin in NAFO Div. 4R for the 1985–2022 period, by A) NAFO unit area (4RU = unknown 4R unit area) and B) main fishing gear type. Landings for 2020, 2021 and 2022 are preliminary.

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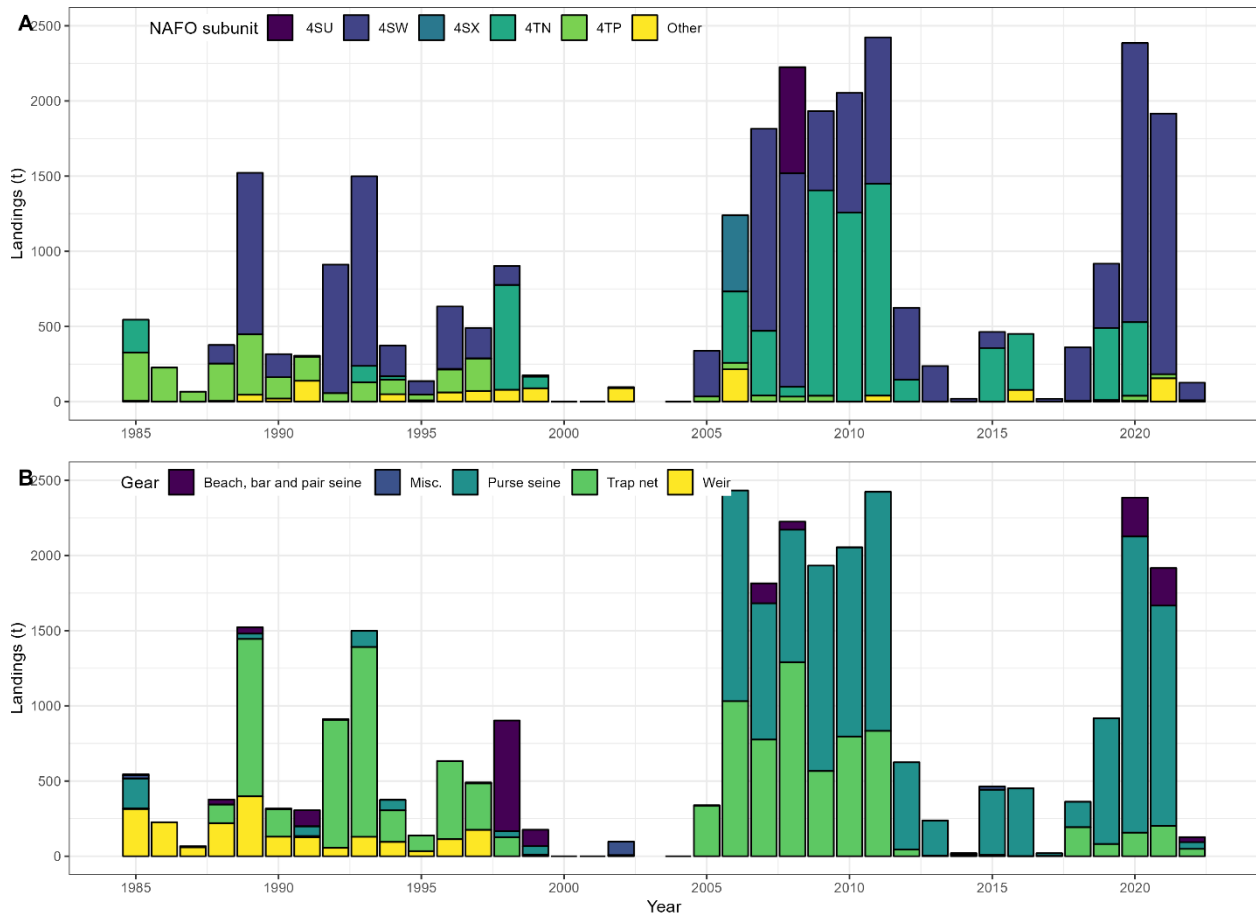


Figure 4. Annual commercial landings (t) of capelin in NAFO Divisions 4ST for the 1985–2022 period by A) NAFO unit area (4SU = unknown 4S unit area) and B) major fishing gear type. Landings for 2020, 2021 and 2022 are preliminary.

Indicators of the stock status

Relative condition factors of males and females

The relative condition factors of male and female capelin standardized for the month of June and the seiners (Chamberland et al. 2022) were generally above average in the late 1980s for all NAFO Divisions, near the time series mean from 1990 to 2000, then above average from 2000 to 2014 for NAFO Divisions 4RS (Figure 5). Since 2015, the relative condition of males and females varied near the time series average in each NAFO Divisions. Relative condition in 4T remained near the time series mean during this period. Since 2015, relative condition has been near the time series average in Divisions 4RS while slightly below the average in 4T. In 2022, there was a small reduction of capelin body condition in Divisions 4R and 4S with values decreasing near the time series average.

Relative abundance indices

A modeling approach developed by Chamberland et al. (2022) allowed for the estimation of a relative abundance indices (mean number of capelin caught per tow, MNPT) in DFO’s nGSL and sGSL BTS datasets. The MNPT calculated with the set of core strata from the nGSL and

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sGSL BTS showed that capelin abundance in the nGSL was relatively high during the 1990s, declining to low values during the first half of the 2000s, before increasing to a peak in 2011 (Figure 6). The indices subsequently declined and, with the exception of 2017, fluctuated around a relatively low level. In 2022, the MNPT in the nGSL remained under the times series average and slightly declined compared to 2021.

The MNPT from the set of core strata in the sGSL increased from the mid-1990s to a peak in 1999, before declining in the mid-2000s and increasing again to a series high in 2010–2011 (Figure 6). The indices subsequently declined, but generally remained somewhat higher than the period prior to 2010. In 2022, the estimate of relative abundance decreased compared to 2021 and was slightly below the time series average.

Length at age data collected from the commercial fishery between April and July from 1984 to 1993 (Hurtubise 1994) suggested that capelin from the sGSL BTS would be mostly 1 and 2 year old individuals, nGSL BTS would catch mostly 2 and 3 year old individuals, while the commercial fishery in the sGSL and nGSL targets individuals corresponding mostly to mature age 3+ individuals (Chamberland et al. 2022).

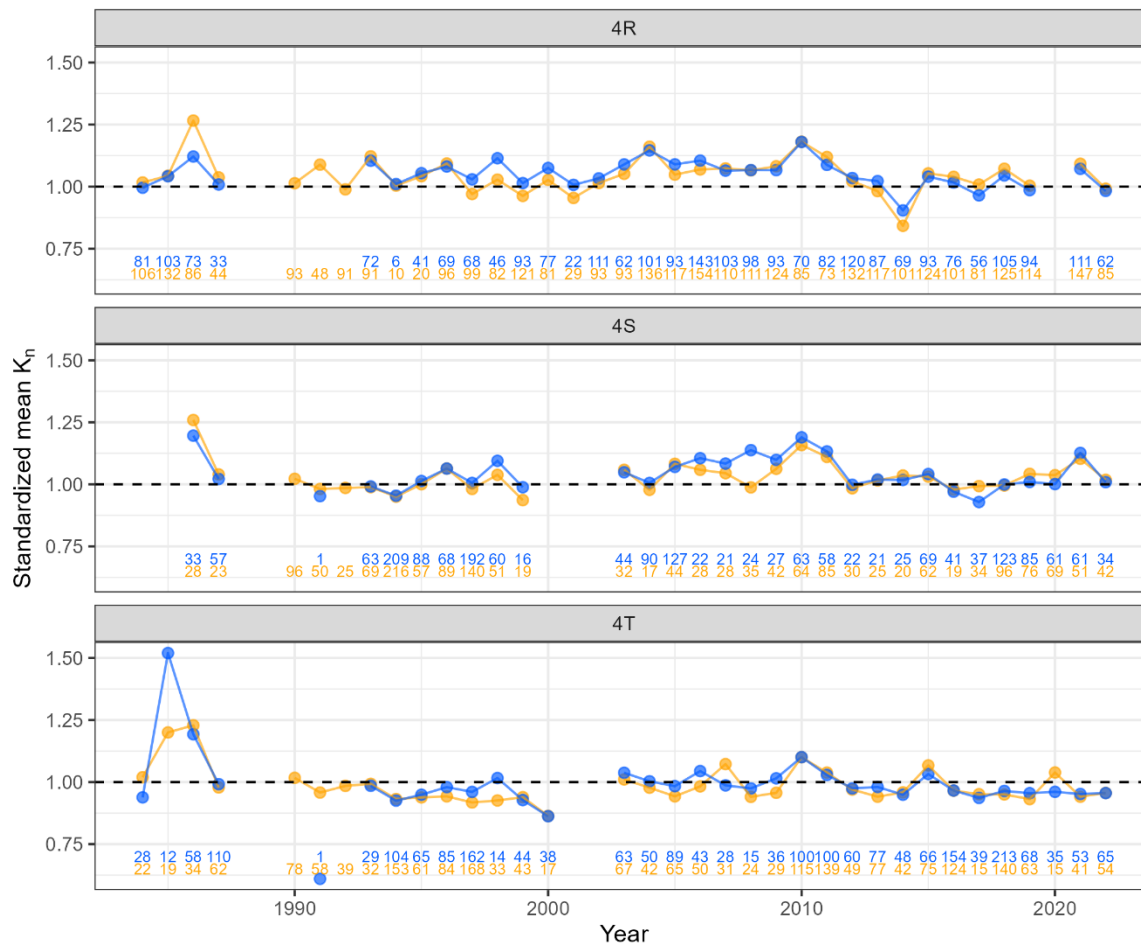


Figure 5. Standardized annual relative condition factor (K_n) of 4RST male (blue) and female (yellow) capelins from commercial samples, by NAFO Division. Numbers in each panel correspond to the number of fish used per year and sex. The horizontal dashed line represents the 1984–2022 average of the condition factor standardized for the month of June, the sex and the NAFO Division.

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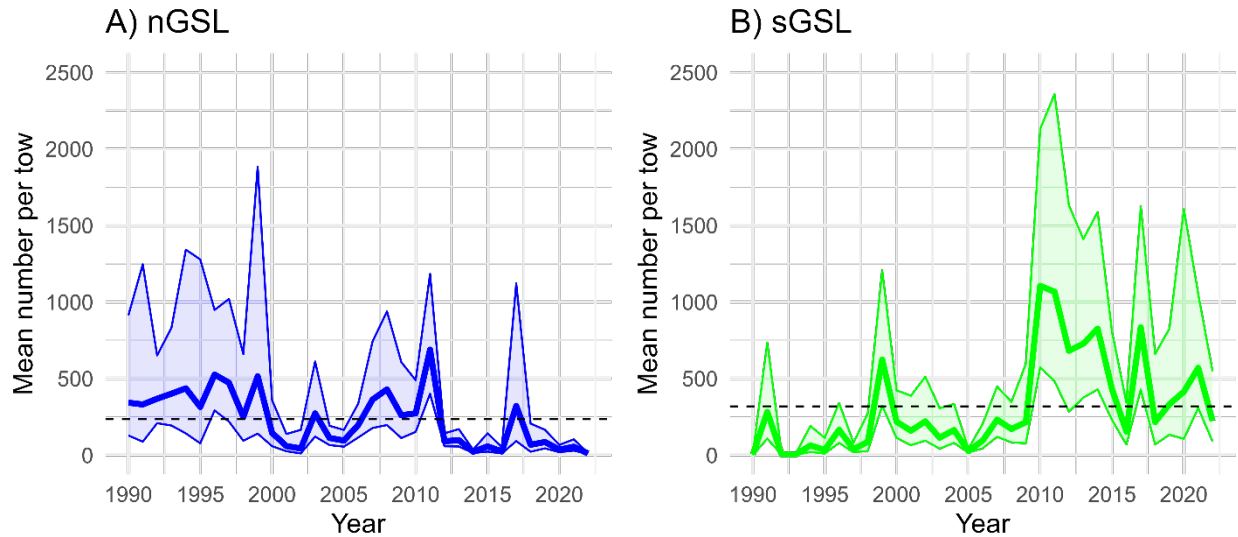


Figure 6. Capelin relative abundance indices for the nGSL (A) and sGSL (B) BTS based on core strata. Shaded area represent 95% confidence intervals. Indices for the sGSL before 1990 are not shown. Horizontal dashed line represent the 1990-2022 average.

Estimates of the magnitude of fishing mortality

Approximations of fishing mortality (F) using a cautious scenario when estimating the stock biomass since 1998 (DFO 2022a, Boudreau et al. 2023) allowed for the comparison with rates deemed sustainable for small pelagic fish. Patterson (1992) found that an $F \approx \frac{1}{2}$ of natural mortality (M) would enable stock to increase in size. When combined with a $M = 0.62$ for 4RST capelin (Chamberland et al. 2022), these findings suggest that F lower than 0.31 should allow the capelin stock to increase. Using the cautious scenario (high q , Table 2), the 1998–2022 average of F was 0.0129 with minimum and maximum values of 0.0011 and 0.0485, respectively. Maximum values observed for the time series were five times lower than the threshold ($F < \frac{1}{2} M$) that are likely to allow the stock biomass to increase. Therefore, plausible levels of the inferred fishery exploitation rate between 1998 and 2022 are considered low and sustainable when compared to those of other cautiously managed stocks of small pelagic fish like Atlantic herring (*Clupea harengus*, DFO 2022b).

Table 2. Order of magnitude of 4RST capelin stock biomass and fishing mortality rate for the 1998-2022 period. Estimations were done considering a cautious scenario with low (q nGSL = 0.0045, q sGSL = 0.01) and high (q nGSL = 0.01, q sGSL = 0.1) catchability coefficients in the surveys. Mean, min and max represent time series average, minimum and maximum values, respectively.

	Stock biomass (t)		Fishing mortality	
	low q	high q	low q	high q
Mean	2,836,139	1,146,271	0.0044	0.0129
Min	500,322	184,875	0.0004	0.0011
Max	10,999,888	4,585,037	0.0112	0.0461

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Timing of sea ice retreat

The timing of ice retreat [i.e. the last Julian day (JD) of sea ice in the nGSL] was included in the composite index of the stock status (DFO 2022a) as a proxy of capelin post-winter body condition and survival (Lewis et al. 2019; Lehoux et al. 2022). Early ice removal in the nGSL has been associated with better survival and body condition of capelin which subsequently impacts the abundance of capelin in the EGSL (Lehoux et al. 2022). A dome-shape relationship between the timing of ice retreat in a year and the relative abundance indices of capelin 2 years later indicates that ice removal between JD 100 and JD 120 are associated with higher capelin abundance. The value used for the combined index of stock status is the mean JD of the last appearance of ice matrix in the GSL (Galbraith et al. 2022), weighted by the area of the Mecatina and the northeastern GSL ecoregions (Duplisea et al. 2020, Appendix I). The timing of ice retreat showed significant interannual variations since 1993 with JD values ranging from 78 in 2010 and 164 in 2017 (Figure 7). In 2022, the timing of ice retreat was on JD 102 and earlier than the average for the 2018-2021 (JD 115). This earlier ice retreat in 2022 should lead to better post-winter survival and body condition than in recent years on average. Furthermore, the timing of ice removal during the 2020-2022 period were in the range of values that have a positive effect on the relative abundance of capelin two years later which should be favorable for the 2022-2024 period.

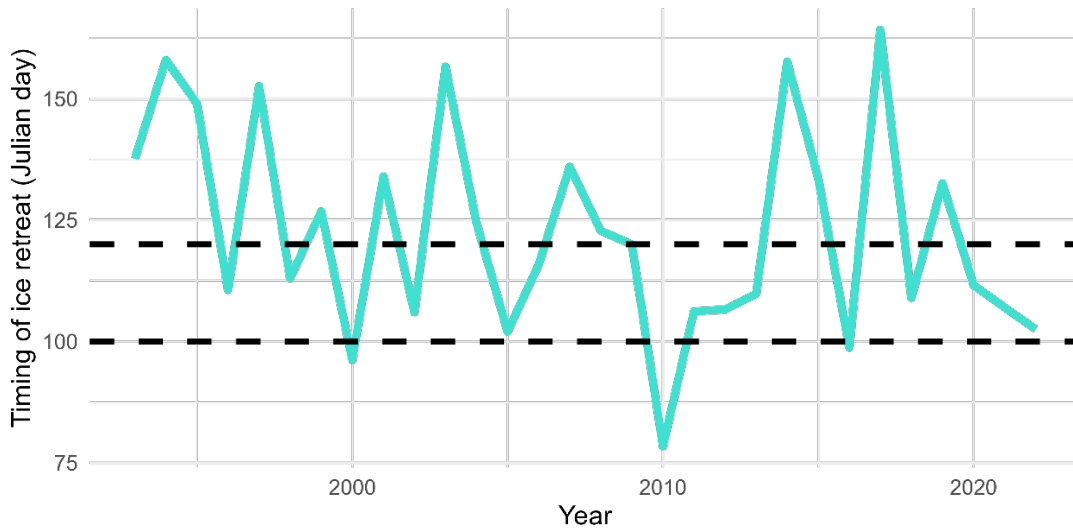


Figure 7. 1985-2022 time series of the mean Julian day of sea ice removal in the GSL. The horizontal dashed line represents the range of values for the timing of ice retreat in one year that would have positive effects on capelin relative abundance two years later.

Importance of capelin in cod and Greenland halibut diet

The stomach contents data collected during the nGSL BTS in August were recently explored by Ouellette-Plante et al. (2022) assuming that the importance of capelin in the stomach of its predators investigated might be proportional to its abundance. Atlantic cod (*Gadus morhua*) and Greenland halibut (*Reinhardtius hippoglossoides*) were chosen in part because they eat a lot of capelin, are collectively present throughout the nGSL and are known to migrate vertically in order to feed, thereby increasing the probability of observing capelin in their stomach contents. As such, interannual variation in the mean percentage of capelin in the stomach contents (by weight) of both predators estimated by Ouellette-Plante et al. (2022) for the 1993-2021 period

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were updated with the stomach of predators collected during the nGSL BTS in 2022. The percentage of capelin in their diets showed important variations over the 1993-2022 period (Figure 8). There is, however, some degree of consistency among the two predators as the percentage of capelin in their diets was generally lower in the early 2000s, followed by an increase until the interruption of the time series in 2010. Capelin also represented a high proportion of their diets in several years over the period of 2016-2021 with more interannual variations for cod and relatively consistent high values for Greenland halibut (Figure 8). In 2022, the mean percentage of capelin in the stomach contents of these two predators was the lowest estimate since 2015 for Greenland halibut and was at relatively similar levels to those observed in 2017, 2019 and 2020 for cod.

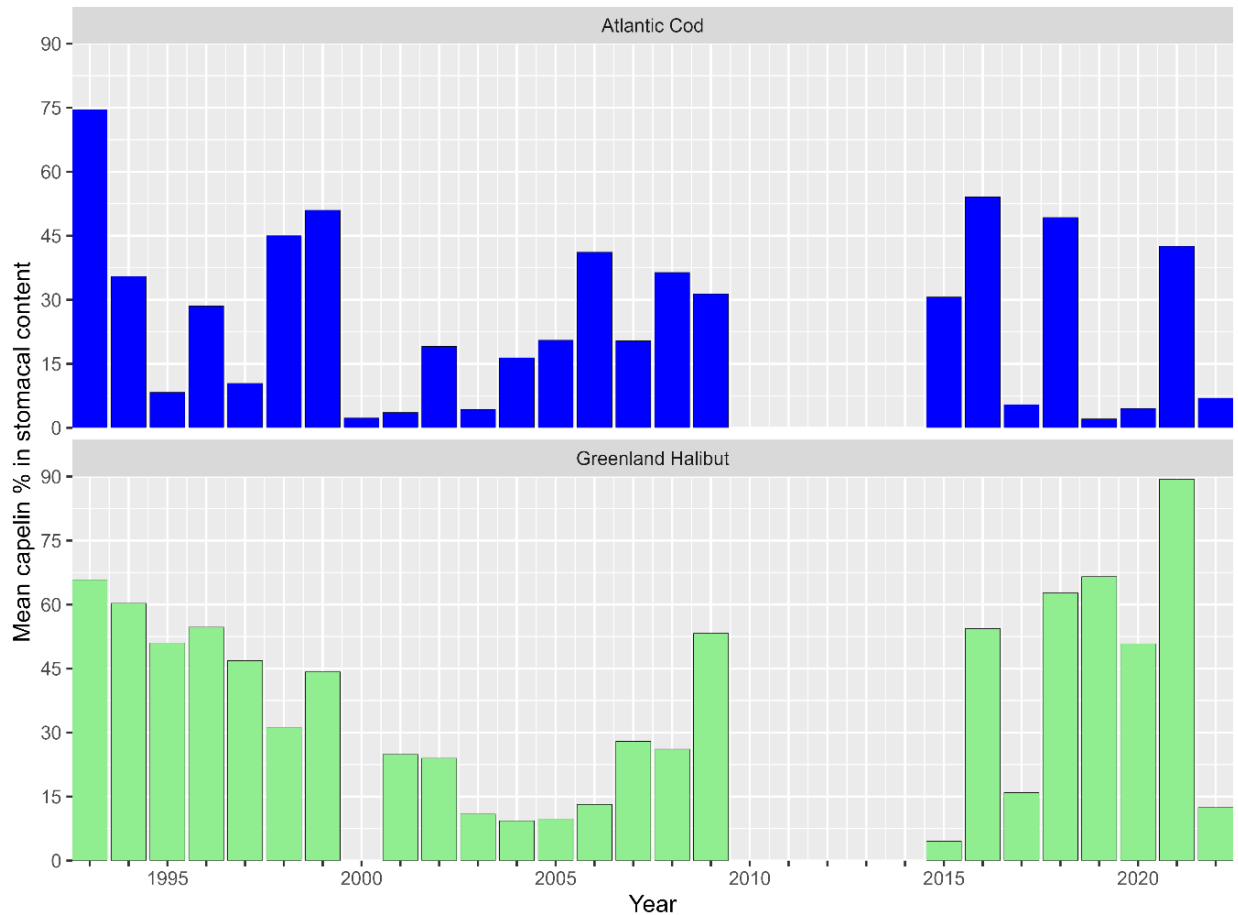


Figure 8. Percentage of average stomach contents of Atlantic cod and Greenland halibut comprising capelin (by weight), all length classes combined. No stomachs were collected during the period 2010–2014 (both predators) and in 2000 (Greenland halibut).

Composite index of stock status

The composite index used to provide a perspective on the relative stock status since 1990 (DFO 2022a, Boudreau et al. 2023) included the annual anomalies of the nGSL and sGSL relative abundance indices from the BTS, the percentage in weight of capelin in the diets of cod and Greenland halibut in the nGSL in August, and the timing of ice retreat in the nGSL. The composite index was generally near or below the long-term average during the 1990s, then

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decreased to values lower than average in the early 2000s (Figure 9). This period was followed by a sharp increase to values well above the long-term average, peaking in 2010. The composite index decreased to values below the long-term average in 2014 and 2015, then showed a general increase to values near or above the long-term average in 2020 and 2021, respectively. In 2022, the composite index decreased below the average to the lowest level observed since 2015 but remained higher than the lows observed in the 1990's and early 2000s.

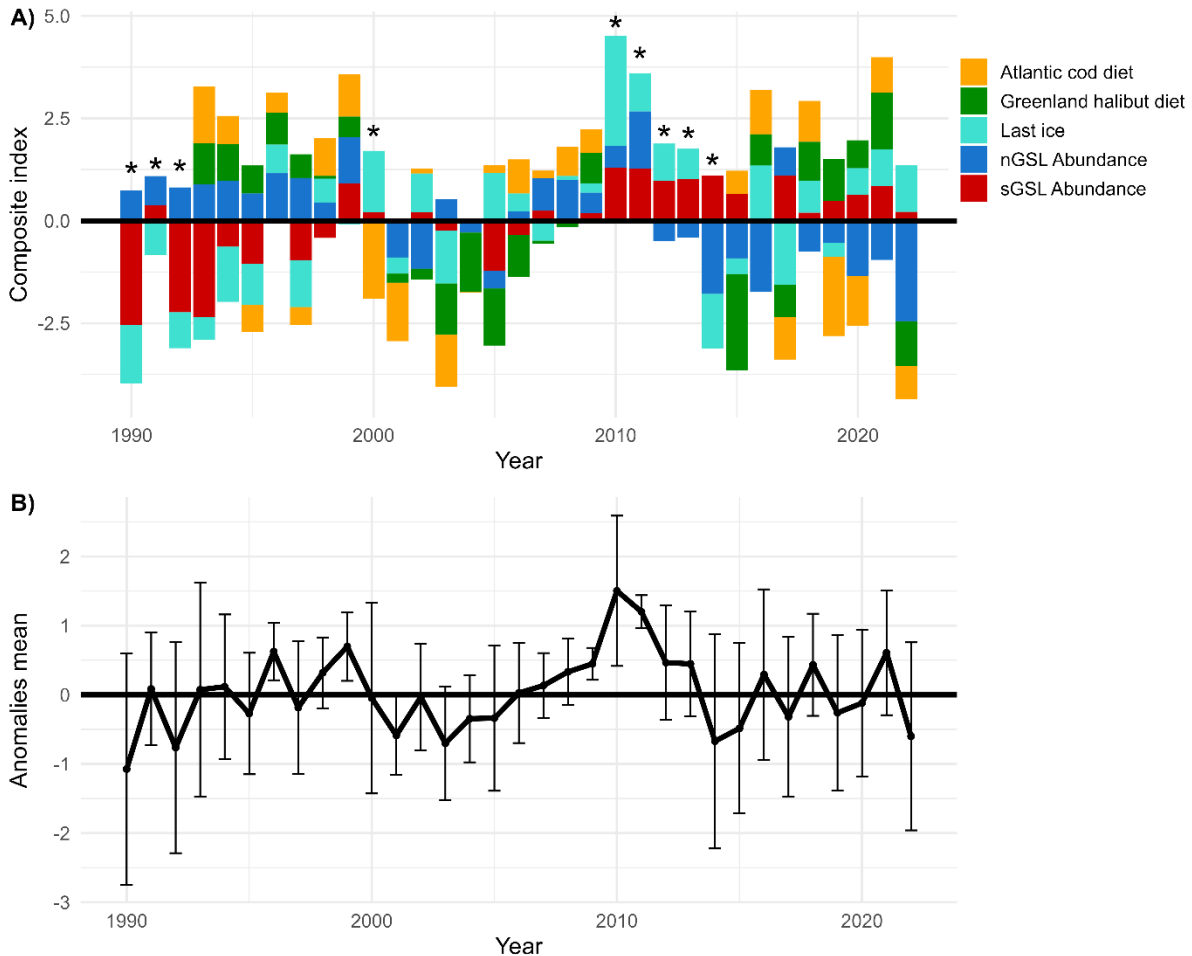


Figure 9. Composite index of stock status between 1990 and 2022 when considering the combination of A) relative abundance, capelin consumption by predators and timing of ice retreat indices anomalies. Asterisk symbols are showing years where data on predator consumption were not available. Annual estimates of the anomalies mean value with their standard deviation (vertical lines) are presented on a different scale (B).

Conclusions

The 2022 4RST fishing season was comparable to those observed in 2013 and 2014 when the amount of landings from NAFO Divisions 4ST were low and half of the 4R quota was taken. There are several factors that could explain the reduced number of landings in 2022 compared to relatively stable catch levels from 2018 to 2021 including market conditions (changes in the

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global demand and the price by capelin weight), increased cost of fishing activities (i.e. price of fuel) and the timing of the fishery in relation to fish aggregation for spawning.

Body condition of males and females in 2022 were on the long-term average in NAFO Divisions 4RS and slightly lower than the average in Division 4T. The relative abundance of capelin in the sGSL has remained generally above the time-series mean since 2010 but continues to be low in the nGSL since 2012. More investigations on changes in the bottom trawl catchability and the summer feeding habitat (i.e. at the time of the surveys) of capelin need to be carried out in order to explain those lower relative abundances in recent year. Approximations of fishing mortality during the 1998-2022 period were still considered low for a short-lived forage species such as capelin whereas the composite index of the stock status in 2022 was showing the lowest value since 2015.

Components of capelin population productivity such as body condition and survival can show significant annual variations in response to environmental factors (Lewis et al. 2019, Lehoux et al. 2022). Knowing that the estimates of the indicators used for the assessment of the 4RST stock have been fairly stable between 2018 and 2021, it would be appropriate to verify if the observations in 2022 will occur again in the next years before inferring that the stock is in poor condition. Therefore, the available evidences from the updated indicators suggest that any of the harvest levels attained over the last decade are unlikely to pose a risk to the 4RST capelin stock in 2023.

Contributors

Name	Affiliation
Belley, Rénaud	DFO, Science, Quebec region
Benoît, Hugues	DFO, Science, Quebec region
Boudreau, Mathieu (lead)	DFO, Science, Quebec region
Boudreau, Mélanie	DFO, Science, Quebec region
Cyr, Charley	DFO, Science, Quebec region
Dunne, Erin	DFO, Fisheries management, NL region
Lévesque, Laurence	DFO, Science, Quebec region
Ouellette-Plante, Jordon	DFO, Science, Quebec region
Plourde, Stéphane	DFO, Science, Quebec region

Approved by

Jean-Yves Savaria
Sciences regional directorate
Quebec region
Fisheries and Oceans Canada

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Appendix I

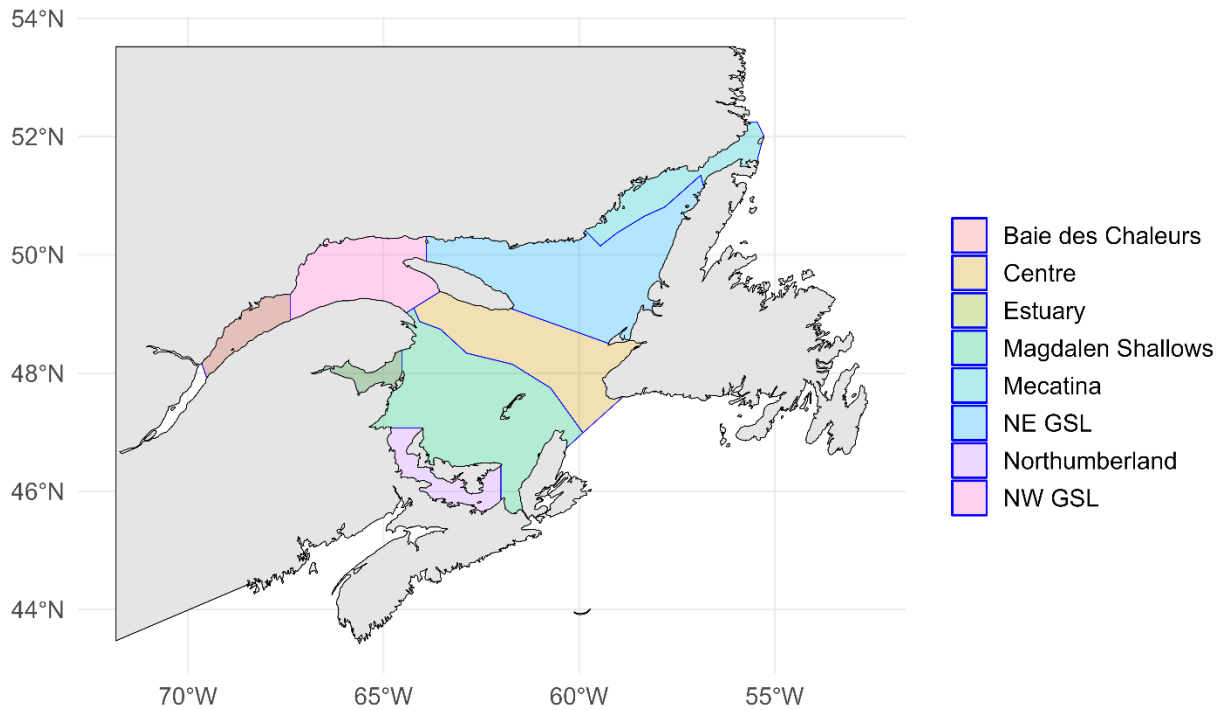


Figure A1. Ecoregions of the Gulf of St. Lawrence designated by considering different environmental variables such as depth and water temperature as described by Duplisea et al. 2020 (NE: Northeastern, NW: Northwester).

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Canada G5H 3Z4

E-Mail: dfo.csaquebec-quebeccas.mpo@dfo-mpo.gc.ca

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