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Quebec Region

Canadian Science Advisory Secretariat
Science Advisory Report 2022/023

ASSESSMENT OF THE ESTUARY AND GULF OF ST. LAWRENCE (DIVISIONS 4RST) CAPELIN STOCK IN 2021

Adult male and female capelin (Source : Claude Nozères – DFO).

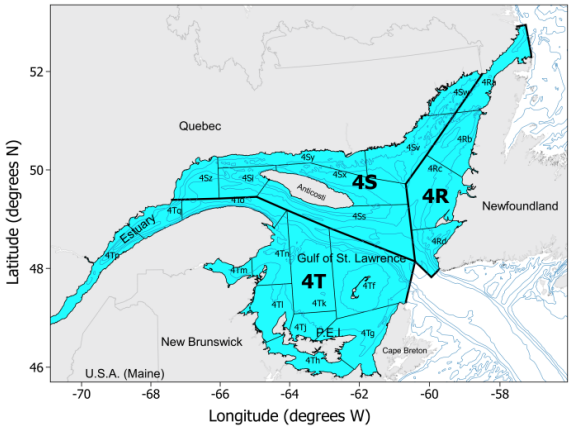

Figure 1. Map of NAFO Divisions 4RST (Estuary and the Gulf of St. Lawrence).

Context:

*Atlantic capelin (*Mallotus villosus*) is a small, schooling, forage fish that plays an important role in the ecosystems of the Estuary and the northern Gulf of St. Lawrence (GSL). Traditionally, in eastern Canada, capelin have been fished recreationally on beaches during the spawning season for consumption, for use as fertilizer and bait, and for their oil. Towards the end of the 1970s, the emergence of an Asian market for roe-bearing females resulted in rapid growth of the fishery, with average landings increasing from around 662 t to nearly 10,000 t per year. In the Northwest Atlantic Fisheries Organization (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 tuck seiners and traps. Capelin are also caught using purse seines and traps on Quebec's Lower North Shore and mouth of Chaleur Bay, and using weirs in the St. Lawrence Estuary. Capelin are a regular bycatch of shrimp trawlers and in multidisciplinary groundfish and shrimp surveys conducted annually by Fisheries and Oceans Canada in the Estuary and GSL. The structure of capelin populations in the Estuary and GSL is not clearly defined, and capelin in Divisions 4RST are currently managed as a single stock.*

A total allowable catch (TAC) of 9,295 t was applied to the entire stock for the 2018-2021 seasons. This TAC was divided as follows: 8,005 t for Division 4R and 1,290 t for all of 4ST.

The previous capelin stock assessment in Divisions 4RST was carried out in 2021. The purpose of this document is to provide recommendations on the status of capelin in Divisions 4RST based on the best available data.

SUMMARY

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

INTRODUCTION

Species Biology

Capelin are part of the *Osmeridae* family. Formerly viewed as a single circumpolar species, Atlantic (*Mallotus villosus*) and Pacific (*M. catervarius*) capelin are now considered distinct species with complex population structures (Mecklenburg et al. 2018, Mecklenburg and Steinke 2015). In the Northwest Atlantic Fisheries Organization Divisions (NAFO) 4RST (Figure 1), which cover the Estuary and GSL, Atlantic capelin (hereafter capelin) is currently considered as a single stock.

During the spawning season, there is a clear sexual dimorphism where males have larger fins and are typically larger than females. Capelin have two modes of spawning, beach and demersal, the location of both modes being dependent on the presence of appropriate substrate. In the former case, capelin are said to "roll" onto sandy or fine gravel beaches where the males and females deposit their milt and eggs that then adhere to the substrate. In the GSL, the spawning period on beaches generally begins in late April or May in the west of the Estuary and then progresses eastwards throughout the GSL to end in July or August along the Lower North Shore of Quebec and the West coast of Newfoundland. The specific location and timing of spawning are variable but could depend on water temperature. Egg and larval development and mortality are temperature dependent. Similar to beach spawners, demersal spawners tend to spawn on sites composed of sandy or fine gravel substrate but are exposed to generally lower

and more constant temperatures and higher salinities than on beaches. Post-spawning mortality is significant and seems to be higher for demersal spawners (higher proportion of semelparous individuals) than on beaches where higher proportions of iteroparous individuals are observed (Christiansen et al. 2008). Upon hatching, larvae develop in the upper layers of the water column. Most growth in capelin occurs in their two year of life and they reach sexual maturity around 2-3 years of age.

Predictions from a conceptual model of capelin summer foraging habitat use were supported by analysis performed on 2 independent bottom trawl surveys datasets (Chamberland et al. 2022). Capelin caught in these surveys were associated with cold conditions typical for capelin (= or < 3°C in northern GSL and = or < 2°C in southern GSL) and the daily pattern of catch variation was consistent with the vertical feeding migrations of capelin. Environmental and biological conditions known to regulate capelin survival and cohort strength explain a large part of the variations in capelin abundance indices from the bottom trawl surveys (Lehoux et al. 2022), which supports the conceptual hypothesis that capelin abundance is determine by bottom-up processes regulating survival during its first 2 years of life (Lewis et al. 2019; Lehoux et al. 2022). These results indicate that capelin abundance indices derived from DFO bottom trawl surveys can inform on interannual variation in relative capelin abundance in the GSL.

Overview of the Fishery

In the Estuary and GSL (NAFO Divisions 4RST, Figure 1), the capelin fishing season is generally short and corresponds with the pre-spawning period for the seine fishery and with the spawning period for the trap and weir fisheries. Seiner and trap fisheries target mature females destined for export to Asian markets. The emergence of these markets is the cause of the marked increase in landings observed at the end of the 1970s (Grégoire et al. 2013). Whereas males were once released or used as fishmeal or fertilizer, they are now also marketed as a food fishery or sold to zoos and marine parks in the United States and China.

Capelin fishing in the Estuary and GSL is managed by a total allowable catch (TAC). Since 1999, the TAC has been shared among the different fleets in the GSL (Table 1). The main fishing gears used are the purse seine, the tuck seine, and the trap. NAFO Division 3Pn is included in the Integrated Fisheries Management Plan (IFMP) for Divisions 4RST, but has never been included in the stock assessment.

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

NAFO Division	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

*CFA 12 includes NAFO Division 3Pn.

ANALYSIS

Commercial Fishery

Description of fishing activities

From 1985 to 2021, annual landings varied considerably (mean 7,056 t, standard deviation (sd) ± 3,476 t) and were characterized by a number of years in which no or very few landings were reported (*e.g.*, 1982, 1987, 1994, 1995, 2001, and 2017). Data from 2017 to 2021 indicate that landings increased from 2017 (1,965 t) to 2018 (8,503 t) and were stable for the past 4 years (mean 9,301 t, sd ± 942 t) (Figure 2). During the assessment of capelin 4RST in 2018, the low landings in 2017 were attributed to a later sea ice retreat in some areas and to poor weather conditions, limiting harvesting opportunities (DFO 2018). The TAC for this fishery was exceeded in 1992, 1993, 2020, and 2021 (Figure 2).

Capelin landings are dominated by the seine fleet (small and large purse seiners) in NAFO 4R taking 82% of the total landings during the 2010-2021 time series (Figure 2). An increase in fixed gear landings has been observed since the mid-2000s. This increase is largely attributable to the arrival of the tuck seine in the fleet, which is considered a fixed gear despite its mobility (Figure 2).

Within NAFO Division 4R, landings were generally from unit areas 4Rabc and were more evenly distributed from 2018 to 2021 than in previous years. Since 2012, large and small purse seiners have landed similar proportions of the TAC and landings with traps represented a lower proportion of the total catches (Figure 2).

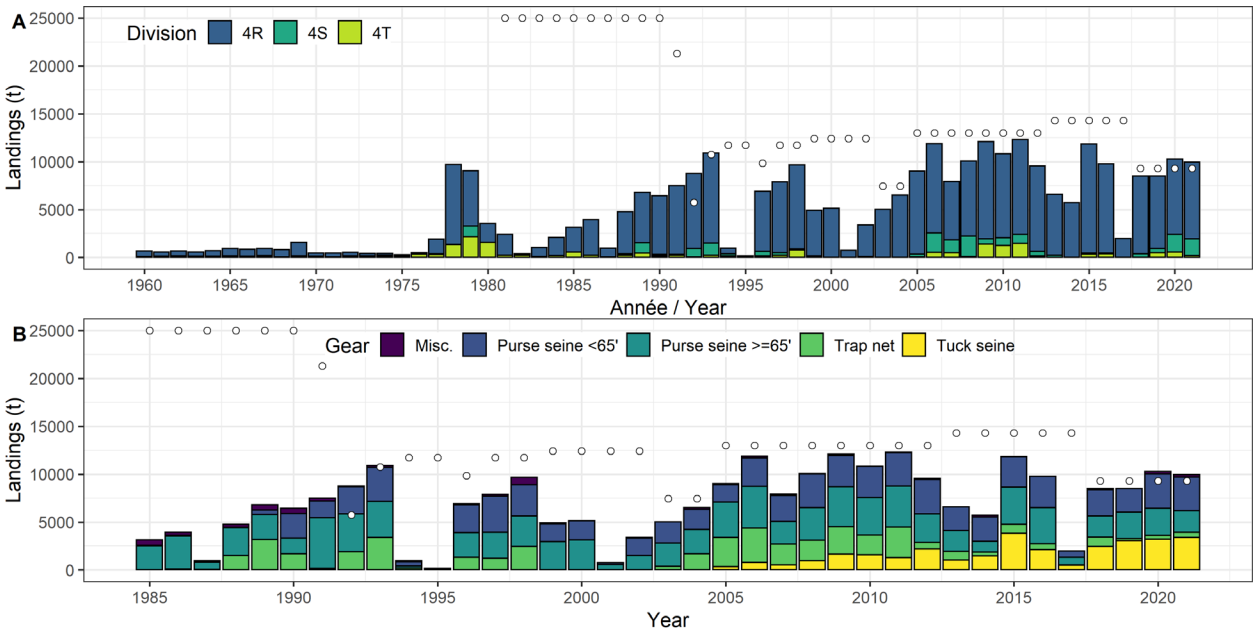

Figure 2. Capelin landings (t) by (A) NAFO Division from 1960 to 2021 and (B) by main fishing gear for the 1985-2021 period. The white circles represent the TAC. 2020 and 2021 landings are preliminary.

Purse and tuck seine fishery performance in Division 4R

A fishery performance index, expressed in tonnes per boat per day, is estimated through a standardization of catch rates for the purse and tuck seine fisheries in Division 4R. The performance index increased rapidly from 2004 to reach the time series maximum in 2013 at

57.0 t day^{-1} following a 12-year period during which it was below the long-term average (31.2 t day^{-1}) (Figure 3). The performance index subsequently remained above the long-term average varying between 54.3 t day^{-1} (2014) and 37.0 t day^{-1} (2017). The performance index was 44.9 t day^{-1} in 2020 and 54.2 t day^{-1} in 2021 (Figure 3).

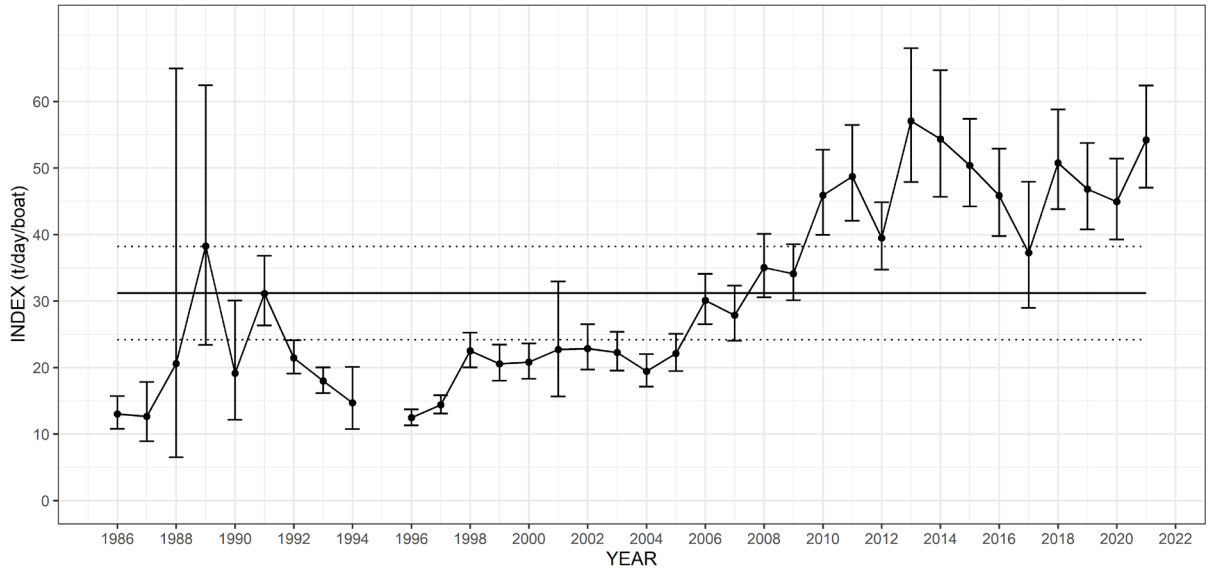

Figure 3. NAFO Division 4R purse and tuck seine performance index, 1986 to 2021.

Relative condition factor of males and females

The annual condition of male and female capelin was estimated by calculating the relative condition factor (K_n = W/W'; Le Cren 1951), where W is the observed somatic mass, and W' is the estimated mean mass given an individuals length. Interannual variations of the standardized relative condition factors for males and females caught by seiners in NAFO divisions 4R, 4S, and 4T in June were comparable (Figure 4) but differed in scale. Relative conditions in 4T were consistently lower than in the other two divisions for most of the time series. Relative condition was generally above the time series average in the late 1980s for all NAFO Divisions, near the average from 1990 to 2000 and above average from 2000 to 2014 and in 2021 for NAFO Divisions 4R and 4S. Relative condition in 4T stayed near the average since 2003.

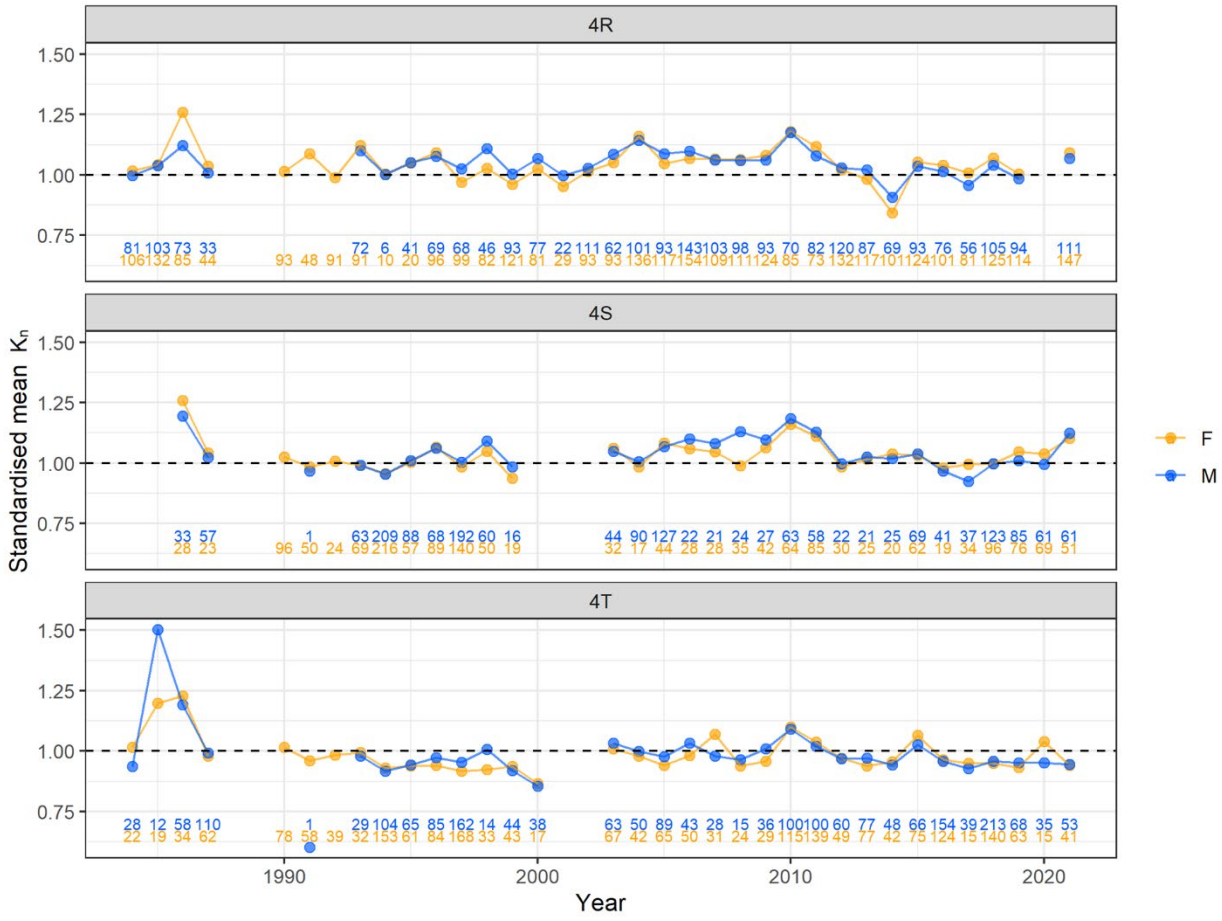

Figure 4. Standardized annual relative condition factor (K_n) of male (blue) and female (yellow) capelin from commercial samples in NAFO divisions 4R, 4S and 4T. Number of fish per sex is indicated over the abscissa. Horizontal dashed line represent the 1984-2021 average.

Fishery Independent Data

Capelin in the southern and northern gulf bottom trawl surveys

Two capelin relative abundance indices were calculated for each of the southern GSL (sGSL) and northern GSL (nGSL) bottom trawl surveys. The first index was based on all tows performed in the core survey strata (strata that were consistently part of the survey over the survey series, 1971-2021 for the sGSL, and 1990-2021 for the nGSL). The second index only considered tows performed in the preferred habitat of capelin, mainly the cold intermediate layer (CIL), and assumed that capelin density in this habitat (50 to 120 m for the sGSL survey and 50 to 175 m for the nGSL survey) was more or less homogeneous. The indices based on the assumption of homogenous density in the CIL followed a similar trend and were consistently higher than those computed with the core strata. The sGSL relative abundance index for the core strata was stable at low levels in the 1990s, peaked in 1999, then declined until the mid-2000s, and increased again to reach maximum values of the time series in 2010 and 2011 (Figure 5). The relative abundance index subsequently declined to remain generally above the long-term average until 2020. The relative abundance index based on core strata in the nGSL was relatively high over the 1990s, declining to low values during the first half of the 2000s,

before increasing gradually to a peak in 2011 (Figure 5). The index subsequently declined and, with the exception of 2017, fluctuated around a relatively low level.

The variations observed in the nGSL and the sGSL indices and particularly the inverse signal in the last decade could indicate a change in the distribution and migration patterns of capelin in response to changes in environmental conditions. A change in capelin's catchability associated to a change in vertical distribution particularly in the nGSL could also be another factor contributing to the inverse pattern observed in the nGSL and sGSL over the last decade.

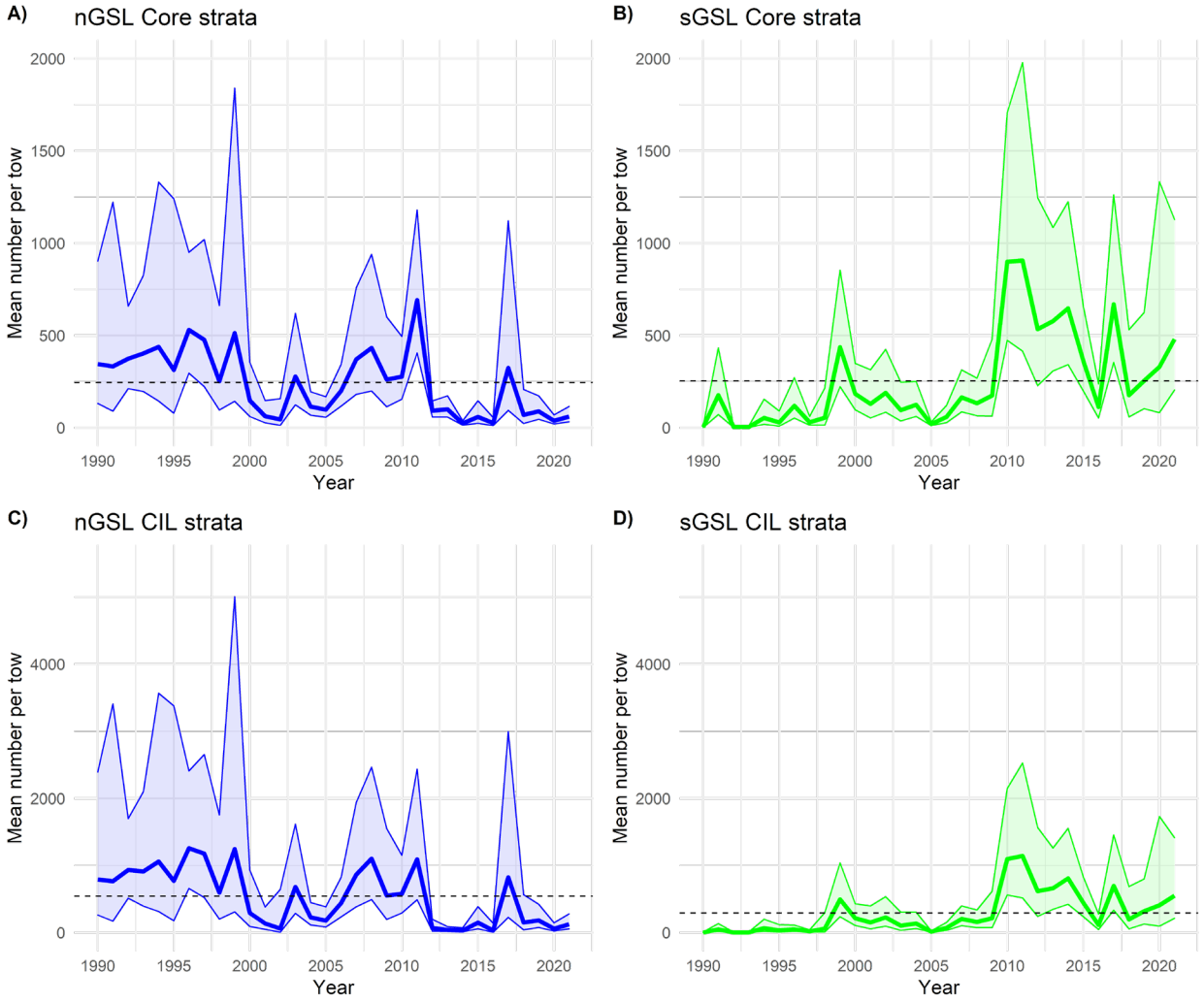

Figure 5. Capelin relative abundance indices for the northern (blue; A,C) and southern (green; B, D) Gulf of St. Lawrence survey based on core strata (A, B) and assuming that mean densities in strata covering favoured habitat (C, D) estimate mean densities in strata occurring below this habitat. Blue and green shaded area represent 95% confidence intervals. Indices for the southern GSL before 1990 are not shown. Horizontal dashed line represent the 1990-2021 average.

Estimates of the magnitude of fishing mortality

The order of magnitude of exploitation rate (E) and fishing mortality (F) for the 4RST capelin stock was estimated using data from nGSL and sGSL bottom trawl surveys, catchability coefficients (q) from the literature for small pelagic in this type of survey (O'Driscoll et al. 2002, Benoît and Swain 2008) and commercial landings between 1998 and 2021. Individual weights

of capelin in the surveys since 1998 were used in the calculation of the exploitation rates. To be cautious, the relative abundance indices based on the core strata were used since estimates in the CIL strata were higher for most of the time series in both surveys. Low (q nGSL = 0.0045, q sGSL = 0.01) and high (q nGSL = 0.01, q sGSL = 0.1) catchability coefficients were used to approximate stock biomass and to compare the different order of magnitude estimated. Higher catchability coefficients were applied for the sGSL surveys because of the greater proportion of bottom trawl survey tows performed inside capelin preferred thermal habitat (Chamberland et al. 2022).

A cautious scenario to estimate the stock biomass was evaluated and considered a lag of one year for the relative abundance indices. The lag of one year was applied to account for the timing of the bottom trawl surveys (August to September) and the fishing activities (May to July of the following year). This cautious scenario also considered an annual reduction of the stock biomass to account for the natural mortality (M) during the winter season. Because capelin are subject to a high M with rates that can vary between 0.62 and 0.82 based on life history (Chamberland et al. 2022), a biomass reduction equal to 0.31 (M = 0.62) was applied. This scenario was expanded to include an approximation of the stock biomass that can be available to the fishery and is the result of the abundance of capelin in the previous year and the natural mortality during the following winter. This scenario is cautious because it does not account for the annual increase of the stock biomass resulting from individual growth which would have resulted in lower values of E and F. The scenario is also cautious because 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.

Patterson (1992) compiled data for 28 stocks of 11 small pelagic species and concluded that a F lower than 1/2 M or a relative E lower than 30% would allow stocks to increase in size. Based on those results, F that are lower than 0.31 (M = 0.62) should at least prevent a decline of the 4RST capelin stock biomass. Average stock biomass of 771,210 t (high q) and 2,020,818 t (low q) were approximated under the cautious scenario for the 1998-2021 time series (Table 2). Using conservative values of the stock biomass (high q), the 1998-2021 average of E was 1.85% (F = 0.0188) with minimum and maximum values of 0.16% (F = 0.0016) and 5.70% (F = 0.0587), respectively.

Maximum values of E and F during the 1998-2021 time series resulted from a combination of low stock biomass and high landings. Those maximum values obtained with the cautious scenario and the conservative estimates of the stock biomass were five times lower than the threshold (E < 30% and F < 1/2 M) that would allow the stock biomass to increase (Patterson 1992). Therefore, plausible levels of the inferred fishery exploitation rate between 1998 and 2021 are considered low and sustainable when compared to those of other cautiously managed stocks of small pelagic fish.

Table 2. Order of magnitude of 4RST capelin stock biomass, relative exploitation rate (%) and fishing mortality rate for the 1998-2021 period. Estimations were done considering a cautious scenario with low (q nGSL = 0.0045, q sGSL = 0.01) and high (q nGSL = 0.01, q sGSL = 0.1) catchability coefficients in the surveys. Mean, min and max represent time series average, minimum and maximum values, respectively.

	Stock biomass (t)		Exploitation rate (%)		Fishing mortality	
	low *q*	high *q*	low *q*	high *q*	low *q*	high *q*
Mean	2,020,818	771,210	0.60	1.85	0.0060	0.0188
Min	366,456	125,166	0.06	0.16	0.0006	0.0016
Max	7,564,520	2,981,784	1.46	5.70	0.0147	0.0587

Composite index of stock state

A new composite index synthetizing specific indices was developed to provide a perspective on the relative stock state between 1990-2021. The approach also aimed at buffering the uncertainty associated with potentially strong and unexplained annual effects in some specific indices. The indices considered were the nGSL and sGSL relative abundance indices from the bottom trawl surveys, the percentage in weight of capelin in the diets of cod (*Gadus morhua*) and Greenland halibut (*Reinhardtius hippoglossoides*) in the nGSL in August, and the timing of ice retreat in 4S and 4R (Figure 1). The relative abundance indices and percentage of capelin in predator diets were used as indicators of capelin abundance in late summer and early fall (Chamberland et al. 2022, Ouellette-Plante et al. 2022). The timing of ice retreat was included as an indicator of capelin post-winter body condition and survival (Lewis et al. 2019, Lehoux et al. 2022). Each index used in the composite index was standardized to a mean of zero and unit variance (annual anomaly, unitless). Since data on the percentage of capelin in predator diets were not available for some years, the average of the time series was assumed for those missing years.

The composite index was generally near or below the long-term average during the 1990s, then decreased to values lower than average in the early 2000s (Figure 6). This period was followed by a sharp increase to values well above the long-term average peaking in 2010. The composite index decreased to values below the long-term average in 2014 and 2015, then showed a general increase to values near or above the long-term average in 2020 and 2021, respectively. The composite index of the Estuary and GSL capelin stock (4RST) follows a trend that differs from the interannual variation observed in the biomass index of the East coast of Newfoundland-Labrador capelin stock (2J3KL, Bourne et al. 2021).

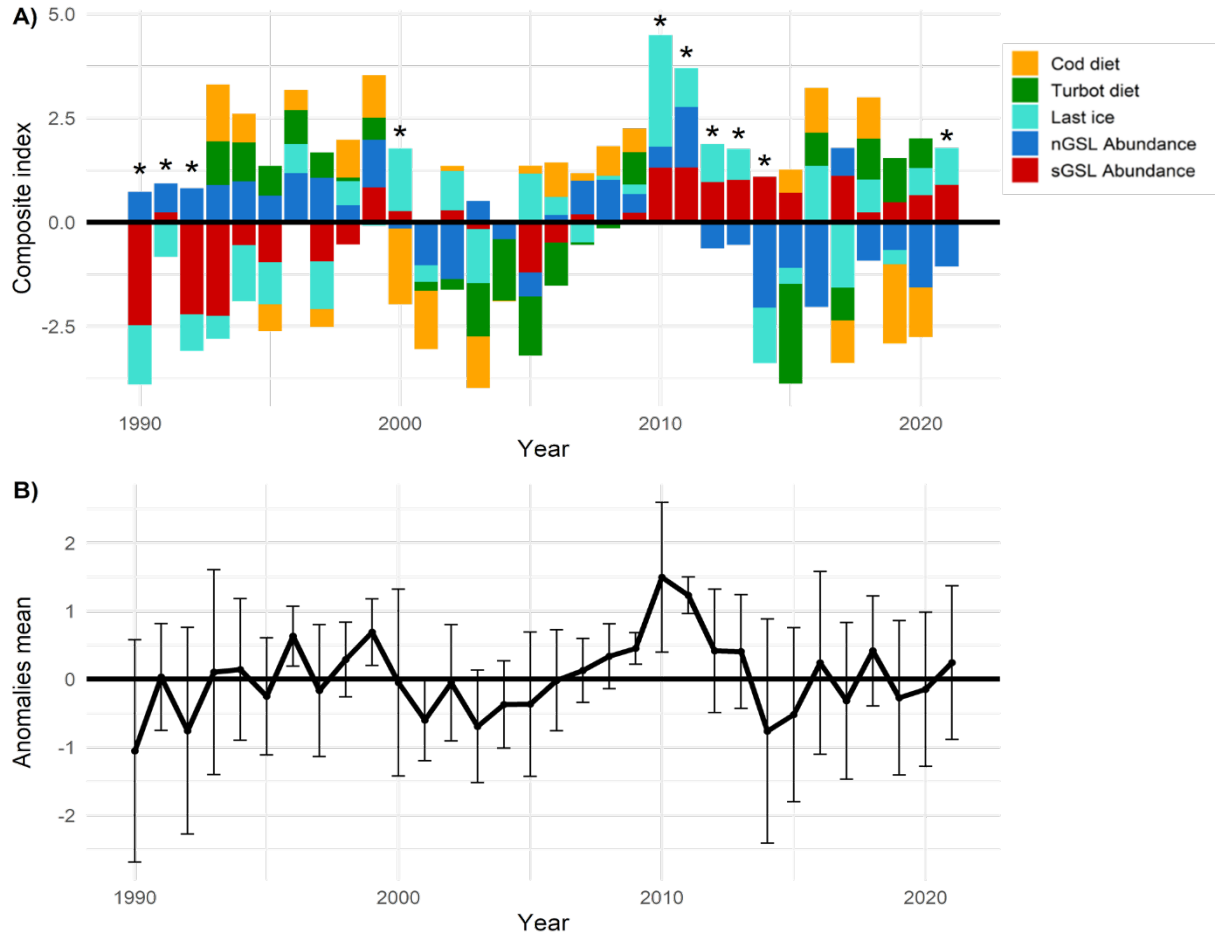

Figure 6. Composite index of stock state between 1990 and 2021 when considering the combination of A) relative abundance, capelin consumption by predators and timing of ice retreat indices anomalies. Asterisk symbols are showing years where data on predator consumption were not available. Annual estimates of the anomalies mean value with their standard deviation (vertical lines) are presented on a different scale (B).

Sources of Uncertainty

Relative abundance indices need to be interpreted cautiously because the confidence intervals are relatively large and sources of uncertainty will need to be addressed in the future. In particular, there is uncertainty as to whether the density of capelin is horizontally homogenous in the CIL across the GSL, or if the densities in this habitat are lower when the CIL is found above higher depths in deep channels. Resolving this question would inform assumptions made when devising an abundance index. The in-depth analysis of the acoustic data collected during the bottom trawl surveys could be useful to validate the hypothesis of homogenous horizontal density in the CIL, and possibly lead to the development of an acoustic abundance index. The catchability of capelin did not appear to be greatly affected by predation indices or habitat characteristics sampled in the sGSL, but the analyzes did not allow this effect to be quantified for the nGSL survey (violation of model premises; Chamberland et al. 2022). Also, changes in the characteristics of the CIL have not been linked to the catchability of capelin in the surveys and could affect the abundance indices. Additional analyses would be needed to examine the

effects of these changes and reduce the uncertainties associated with possible variations in capelin catchability in the surveys.

There are different sources of uncertainty associated with the estimates of capelin importance in cod and turbot diets: digestion level affecting the identification of prey, criteria for excluding stomachs showing evidence of regurgitation particularly for turbot, and number of strata/stations/samples could be limiting in some years (Ouellette-Plante et al. 2022).

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

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

CONCLUSIONS AND ADVICE

The 2020-2021 4RST fishing seasons were similar to those of the last decade. The TAC was reached or slightly exceeded, most landings were made off the west coast of Newfoundland by the purse seine fleet, the timing of the fishery was within the range usually observed, and seiner performance indices and body condition of males and females in 2021 were above the long-term average.

The relative abundance indices in the sGSL were near or above the average since 2010, while the nGSL relative abundance indices were generally below the average since 2012. Because capelin have a short lifespan and populations consist of only a few age groups, the abundance of this species is generally characterized by large natural fluctuations. As these variations are mostly regulated by environmental factors, it is currently difficult to accurately estimate the impact of fishing on the 4RST capelin stock. However, plausible and cautious levels of the inferred exploitation rate from the fishery were at least five times lower than a reference exploitation rate that has allowed small pelagic stocks to increase in size. The low approximations of exploitation rate since 1998 and the composite index near the long-term average since 2016 indicate that any of the harvest levels attained over the last decade are unlikely to pose a risk to the 4RST capelin stock in 2022.

LIST OF MEETING PARTICIPANTS

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Bernier, Denis	DFO Science	X	X
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Boudreau, Mélanie	DFO Science	X	X
Boudreau, Sophie	DFO Science	X	X
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Smith, Andrew	DFO Science	X	X
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Thibault, Cynthia	Comité ZIP Côte-Nord	X	X
Van Beveran, Elisabeth	DFO Science	X	X

SOURCES OF INFORMATION

This Science Advisory Report is from the Regional Peer Review of April 20-21, 2022 on the Assessment of the Estuary and Gulf of St. Lawrence (Divisions 4RST) Capelin Stock. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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