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Assessment of Capelin (*Mallotus villosus*) in NAFO Divisions 2J + 3KL to 2024

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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

Fishery-independent (spring acoustic survey, larval survey, biological characteristics from the spring acoustic and fall bottom-trawl surveys, and citizen science beach spawning diary program) and fishery-dependent survey data were used to assess the status of Capelin (*Mallotus villosus*) in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Div.) 2J3KL up to and including 2024. In 2024, the biomass index was 647 kt which was higher than the 2018 to 2023 time period (median: 286 kt) and similar to recent time series highs in 2013 to 2014 but lower than the 1980s median. In 2024, a low proportion of female Capelin maturing at age-2 were observed; spawning timing was earlier than the post-collapse median; and the Bellevue Beach larval index was similar to the time series median. Capelin fall relative condition was similar to last year. The Limit Reference Point (LRP) for the 2J3KL Capelin stock is a spring acoustic biomass index of 155 kt. The Capelin stock in 2024 was above its LRP with a greater than 95% probability, and has been above the LRP since 2007, except for 2010 and 2017. Based on the Capelin forecast model, the Capelin acoustic biomass index in 2025 is projected to be lower than the observed 2024 biomass index, but above the LRP. The boundary between the Cautious and Healthy Zones has not been determined for this stock.

INTRODUCTION

Capelin is a small, short-lived pelagic schooling species with a circumpolar sub-Arctic distribution in the Northwest Atlantic, waters around Iceland, in the Barents Sea, and in the North Pacific (Gjøsæter 1998, Anderson & Piatt 1999, Carscadden et al. 2013) Capelin is the dominant forage fish species in the Newfoundland and Labrador (NL) ecosystem, providing a vital energetic link between zooplankton and numerous higher trophic level predators, including fish such as Northern cod (*Gadus morhua*), Greenland Halibut (*Reinhardtius hippoglossoides*), Atlantic Salmon (*Salmo salar*), as well as seals, whales, and seabirds (Templeman 1948, Carscadden et al. 2001, Davoren & Montevecchi 2003, Buren et al. 2014).

In 1992, as a result of accumulated biological evidence (Nakashima 1992), it was recommended that Capelin in Northwest Atlantic Fisheries Organization (NAFO) SA 2 + Division (Div.) 3K and Div. 3L be considered one stock complex (hereafter referred to as 2J3KL Capelin; Fig. 1). There are three other Capelin stocks in the Northwest Atlantic: NAFO Div. 4RST; NAFO Div. 3Ps; and NAFO Div. 3NO. Of these four stocks, the 2J3KL Capelin stock is the largest. 2J3KL Capelin spend most of their adult life offshore on the NL shelves. The center of Capelin distribution changes seasonally, typically with Capelin found feeding further north (NAFO Div. 2J3K) in the fall, moving southward along the shelf break in the spring (NAFO Div. 3L), and turning in across the shelf and migrating back up the northeast coast of Newfoundland into bays and northwards to coastal Labrador to spawn at beaches and coastal deep-water (demersal) sites in the summer. Capelin is facultatively semelparous.

The 2J3KL Capelin stock collapsed in the early-1990s with a slow, but modest recovery over the subsequent 30+ years (Buren et al. 2019, Murphy et al. 2024). Although Capelin stock biomass has increased since 2007, the population dynamics of this stock have remained relatively unchanged since the collapse. These include faster growth by immature fish and maturation subsequently occurring at a younger age; an age-truncated spawning population with few fish age-4+ compared to the 1980s; and an abrupt and persistent delay in beach spawning timing. Year-class strength is set early in the life history of Capelin (Murphy et al. 2018), and delayed spawning is predicted to produce weak year-classes (Murphy et al. 2021).

FISHERY

Capelin have been extensively harvested for food, bait, and fertilizer for multiple centuries in NL waters. An offshore commercial Capelin fishery started in 1972, and an inshore commercial fishery started in 1978. The offshore fishery closed in 1991, and the inshore fishery is the only ongoing commercial Capelin fishery. The inshore fishery uses mobile gear (purse seines) and fixed gear (traps and a modified bar seine called a tuck seine). Due to the short fishing season, changes in fishery timing, exploitation methods, and the effect of market forces on landings, Capelin commercial catch rates have not been used as an index of spawning stock biomass since 1993. However, biological data from commercial fishery samples collected during the season are used in the assessment to provide data on the age and size-structure of the spawning stock (see Mowbray et al. 2023 for more details).

Samples from the commercial fishery are obtained from vessels as catches are unloaded at processing facilities. In each bay with landings in the stock area, up to ten samples of 200 fish each are collected and frozen. A total of 20 of these frozen samples are processed each year, apportioned among gear sectors, bays and season (weekly) as a function of the total 2J3KL landings. Length, sex, and maturity are determined for all fish sampled and additional detailed information (weight, gonad weight, stomach fullness, and age from otoliths) is collected for 2 fish per sex, per 5 mm length class in each sample. Catch at age is calculated separately for each catch cell. A catch cell is defined as a unique combination of gear sector and NAFO Division. Age-length keys are determined for each combination of Year, NAFO Division and sex. These age-length keys are applied to the sexed length frequency (5 mm bins) of each sample, so that each fish is assigned an age based on length. Lengths are converted to weights using length-weight regressions calculated by year, division, and ex. Subsequent length and age frequencies from sampled fish are scaled to landings for each catch cell.

COMMERCIAL LANDINGS AND BIOLOGICAL CHARACTERISTICS

In 2024, the Total Allowable Catch (TAC) for the 2J3KL + 3Ps Capelin stock areas was 14,533 t of which 14,136 t was landed (representing 97% of the TAC; Fig. 2). The fishery was conducted in Div. 3KL with no landings in Div. 2J (TAC: 58 t) and Div. 3Ps (TAC: 968 t). Median annual landings in the fishery were 20,298 t from 1991–2023 (excluding 2022 due to the absence of a fishery that year). There has been a reduction in the TAC since 2017 to a low of 14,533 t in 2021–24.

The mean total lengths (TL) and weights of Capelin in the 2024 Capelin fishery were generally consistent with the values observed in the fishery since 2018. Males across NAFO Div. 3KL had an average TL of 173.2 mm and weighed on average 31 g while females averaged 150 mm TL and 19 g (Fig. 3). The average size of Capelin landed in the commercial fishery since their collapse in the early 1990s is smaller than pre-collapse sizes, but this is largely a reflection of the change in age distribution since the collapse. In the pre-collapse era spawning Capelin tended to be age-3 or age-4, while in the post-collapse era spawning Capelin tend to be age-2 or age-3.

SPAWNING

Since 1991, Capelin beach spawning timing has been monitored throughout the province by paid citizen scientists who check their local beaches in two Capelin stock areas (2J3KL + 3Ps) every day during the Capelin spawning period (June–August) and fill out a spawning diary with their observations of Capelin spawning behaviour (Murphy 2022). There has been consistent monitoring during this program, with each beach having been monitored on average five years (range 1–32 years). Participation in this program has varied inter-annually with an average of 18 beaches monitored each year, with most being in Div. 3L (Fig. 4). In 2024, 15 beaches were monitored, with six beaches recording no spawning behaviour (Fig. 4); furthermore, anecdotal evidence of deep-water spawning was recorded in the diaries from two beaches in Div. 3K. Median peak (high intensity) beach spawning was July 4, 2024, which is earlier compared to the post-collapse median (July 9 for years 1991–2023). Median first day of spawning was June 27, 2024, but spawning intensity was considered low to moderate by citizen scientists. The spawning period lasted on average 22.4 days (median duration is 11 days from 1991–2023). The 2024 year-class is predicted to be stronger than the post-collapse average based on earlier beach spawning timing (Murphy et al. 2021) (Fig. 5).

To complement the spawning timing data, spawners were collected at beaches to investigate their age and size distributions. In 2024, spawning Capelin were collected from one beach in subdivision 3Ps, six beaches in Div. 3L, and one beach in Div. 3K (n = 2473). Sampling took place between June 5 and July 29, and 12 samples were collected from these eight beaches. At all beach sites, approximately 200 fish were collected with a cast or dip net. In the laboratory, length, sex, and maturity were determined for all fish sampled, and additional detailed information (weight, gonad weight, stomach fullness, and age from otoliths) was collected for two fish per sex, per 5 mm length class in each sample. An age-length key (using *FSA* package in R) was constructed based on these 2024 data and was used to assign ages to unaged fish within each sample. Most of these sampled fish were male (76%), and only one female fish was sampled in 3K in 2024 (Fig. 6). There was a sex difference in age-structure of the spawning population, with most of the females sampled in Div. 3LPs being age-2 (~72% in both division/subdivision), and most of the males sampled in Div. 3KLPs being age-3 (range 54% - 64%). Females were on average smaller (142.8 mm TL ± standard deviation [SD] 14.6) than males (171.1 mm TL ± SD13.5), which reflects both sexual dimorphism and age distribution of spawning Capelin.

At Bellevue beach, Trinity Bay (Div. 3L) spawning fish were collected throughout the spawning period using a cast net. A total of seven samples were collected from July 3–August 5, 2024. At this beach, each sample was composed of a maximum of 25 females and 25 males (n = 341), and detailed sampling, including ages, was conducted on all fish collected. When considering each sex separately, females were predominately age-2 in both months (July: 48% of fish sampled; August: 83%) while males were predominately age-3 (July: 57%; August: 60%) (Fig. 7). Age-4 spawning fish made up a smaller percentage of the samples for both sexes (female: 5.4%; males: 28.5%). When compared to historic sampling at this beach (2016–23), 2024 is a typical year with a higher proportion of older fish arriving first followed by younger fish, and female spawners being made up of a higher proportion of age-2 fish compared to males (Fig. 7). The proportion of age-4 spawners sampled at this beach has increased since 2020 for females and 2021 for males. The spawning population being comprised of predominately female age-2 spawners is impacting the dynamics of this stock which is reflected in delayed spawning timing and age-truncation of the stock Buren et al. 2019).

EARLY LIFE HISTORY

BELLEVUE BEACH LARVAL INDEX

Larval surface tows using a 75 cm diameter ring net with 270 µm mesh have been conducted at five fixed stations in nearshore waters (<20 m) off Bellevue beach (BB), Trinity Bay (TB) since 2001 (Fig. 8; see Mowbray et al. 2023 for more details). This survey was designed to sample larvae emerging from a variety of sources including BB itself, nearshore deep-water Capelin spawning beds, and four smaller spawning beaches along the western shore of BB. Sampling takes place over a prolonged period (~6 weeks each summer) in order to cover the entire emergence period. The larval samples were predominately composed of newly emerged larvae with yolk sacs (4.77 ± SD 0.74 mm SL for the years 2001–16). While older larvae were occasionally sampled in the BB area, especially later in the summer, their densities were low, and their inclusion had a negligible impact on total annual larval density estimates (H. Murphy, unpublished data). Capelin larvae are preserved in a 5% formalin and saltwater solution buffered with sodium borate, and samples are processed in the laboratory, see Mowbray et al. (2023) for more details.

Annual densities of larvae per m^3 (N) are estimated using the trapezoidal integration method in equation 1:

$$N = \sum_{i=1}^{n} (t_i - t_{i-1}) \cdot 0.5\big(X(t_i) + X(t_{i-1})\big) \tag{1}$$

where t is the day of the year, n is the number of sampling days, i is the ith sampling day and X(t) is the daily average number of larvae per m^3 from the five stations sampled on day t. Only days when all five stations were successfully sampled were included in the analysis. If a station was missed on a sampling day for any reason (e.g., adverse sea conditions), the average of the estimates for that station on prior and next sampling days is substituted for the missed sample. If sampling was missed for three or more days, then the missing values are set to 0. This approach produces a conservative estimate of annual larval densities.

Variance of the annual densities of larvae (var(N)) is estimated using equation 2 based on Millar & Jordan (2013) and Irvine et al. (1992):

$$var(N) = 0.25 \sum_{i=1}^{n} (t_i - t_{i-1})^2 \cdot var(c_i) \qquad (2)$$

where var(c_i) is the variance of larval densities from the five samples per sampling day.

In 2024, the BB larval index was 968.8 ± standard error (SE) 208.7 individuals (ind). m^{-3} which was a slight decrease compared to 2023 and was similar to the time series median (1119.0 ind. m^{-3}; 2001–23) (Fig. 9). This suggests an average 2024 year-class relative to the post-collapse period. However, since peak spawning timing was earlier in 2024 relative to the post-collapse average, the 2024 year-class may be stronger than expected if there is improved larval survival due to earlier emergence into the nearshore habitat. This cohort will be caught at age-2 in the 2026 spring acoustic survey.

The age-2 recruitment index from the offshore spring acoustic survey, which was lagged by two years in order to compare survivors of the same cohort, was positively related to the BB surface tow index (Murphy et al. 2018). This linear relationship has weakened with the addition of additional year-classes to the model since there has been better-than-expected recruitment from low larval abundance years (Murphy et al. 2024). However, the BB larval index is a parameter in the most parsimonious forecast model (see Forecast Model section below), providing support for the importance of survival in the first few weeks of life in Capelin population dynamics.

TRINITY BAY LARVAL INDEX

The TB Capelin late-larval surveys began in 2002, building on prior work conducted in TB from 1982 to 1986 where 52 stations were sampled in July and August using oblique bongo tows (mesh 333 µm) to a maximum depth of 200 m (Dalley et al. 2002). In 2002, 52 stations were sampled across the bay, while in 2003–18, 19 stations were sampled in the center of the bay. In 2019–24, sampling effort increased once again, and 32 stations were sampled across the entire bay (Fig. 10). This sampling program occurs at a fixed date for one week in both August and September. During years when only one survey was conducted, it was targeted for September. For further details on this sampling program, see Mowbray et al. (2023).

In the laboratory, larval samples are sorted and Capelin density per square meter was calculated for each station using equation 3:

$$\rho_i = C_i * D_i / V_i \qquad (3)$$

where ρ is the density of Capelin larvae per square meter, i is the station, *C* is the number of Capelin caught, *D* is the maximum tow depth at station i in meters, and *V* is the filtered volume in m^3. Mean annual densities are calculated using only the 19 core stations.

The median 2024 TB late-larval index, pooled for month, was 5.8 ± SE 9.1 ind. m^{-2}, which was below the time series median (2002–23; 15.6 ind. m^{-2}). By month, the median August 2024 TB larval index was 17.7 ± 17.2 ind. m^{-2} , which was below the time series median (August 2008–23: 19.3 ind.m^{-2}), and the median September 2024 TB larval index was 2.4 ± 0.7 ind. m^{-2} , which was below the time series median (September 2002–23: 12.9 ind.m^{-2}) (Fig. 11). Only the September TB larval index was positively related to the BB larval index (linear regression R^2 = 0.20, p = 0.02; Fig. 12), which may be due to timing of the TB late-larval survey since larval emergence is still occurring in August at BB. The positive relationship between the BB and September TB indices supports the use of BB as an index beach for TB.

SPRING ACOUSTIC SURVEY METHODS

The acoustic survey is typically conducted in May and covers the majority of Div. 3L, an area of particular importance for juvenile and non-migratory age-1+ Capelin. Since 1982, the spring Capelin acoustic survey has taken place annually with approximately the same temporal and spatial coverage, except for 1983–84 and 2021, and there were no acoustic surveys in 1993–95, 1997–98, 2006, 2016, and 2020. Since 1996, the lower portion of Div. 3K (<50°N) has been included in the survey (Fig. 13). The inclusion of areas further north (>50°N) is precluded due to the presence of sea ice in May.

The spring acoustic survey produces a biomass index that is used as a proxy of stock status. Empirical support for the use of this index as a proxy is extensive (Murphy et al. 2018, Buren et al. 2019, Koen-Alonso et al. 2021, Regular et al. 2022). Interannual variability in the proportion of maturing age-2 fish since the stock collapse prevents the survey from being able to produce an estimate of the abundance of age-3 fish expected to recruit to the fishery the following summer. Details on the acoustic survey methods, sampling details, and calculation of abundance and biomass indices can be found in Mowbray (2013), Mowbray et al. (2023) and Murphy et al. (2024).

SPRING ACOUSTIC SURVEY ABUNDANCE AND BIOMASS

During the 2024 acoustic survey (conducted May 6–May 24), all core strata were surveyed (Fig. 14). Capelin distribution was most dense along the middle latitudes of Div. 3L (47°00’N – 49°00’N) with areas of very high concentrations in portions of coastal strata (B & T) and very high concentrations in portions of offshore strata (H, I & J). Capelin density diminished on the southern and northern extents of the survey area. This distribution is similar to 2017 and slightly different than the distributions observed in recent years where Capelin were generally aggregated in higher concentrations in coastal strata and along the shelf edge.

In 2024, the biomass index was 647 kt (90% confidence interval (CI): 408–1,111 kt), which was higher than the 2018–23 period (median: 286 kt) and similar to recent time series highs in 2013 (668 kt) and 2014 (779 kt) (Fig. 15). Since the collapse of the stock in 1991, the median annual Capelin acoustic biomass index is 202 kt (1991–2023), well below the pre-collapse 1982–90 median (3,697 kt). The spring acoustic abundance index in 2024 was 87.0 billion fish, which was higher than the 1991–2023 median (18.7 billion fish) (Fig. 16).

SPRING AGE, MATURATION, GROWTH, AND DIET

In the 2024 spring acoustic survey, age-2 fish dominated the catch (87%) followed by age-3 fish (8%) (Fig. 17). Age-1 fish are poorly recruited to the Campelen 1800 trawl and thus it is not a reliable index for this age group.

In 2024, ~20% of female age-2 fish were maturing and would have spawned that summer. This was a substantial decline from 2023 (~80%) and was the lowest percentage of age-2 females to be mature since shortly after the collapse of the Capelin stock in 1992 when 5.2% of age-2 females were mature. The most recent low for percentage of age-2 females being mature occurred in 2014 and 2015 when ~30% of age-2 females were mature. This low was associated with a short-lived surge in Capelin biomass that occurred from 2012 to 2015 (Fig. 18). A low percentage of age-2 fish maturing in the spring acoustic survey is typical of higher biomass index years. In the 1980s (1982–90) when Capelin biomass was at or near time series highs (Fig. 18), on average 3.7% of female age-2 fish were maturing in the spring.

Age at maturity for Capelin appears to be linked with Capelin growth rates (Murphy et al. 2024) with longer mean lengths at age-2 during the spring acoustic survey being associated with higher maturity rates. In the post-collapse period, age-1 and age-2 fish have been longer and heavier than ages 1 and 2 Capelin in the 1980s (Fig. 19, 20). In 2024, the mean lengths at age-2, -3, and -4 Capelin all declined compared to their mean lengths at ages in 2023. Mean lengths of age-1 Capelin in 2024 were about the same as in 2023 and are still near time series highs for mean length at age-1. Mean weights at age followed a similar pattern to mean lengths at age from 2023 to 2024. The decline in mean lengths and weights at age for ages-2, -3, and -4 Capelin is likely associated with increased density dependent competition with other Capelin given the large increase in Capelin biomass in 2024. The proportion of Capelin mature at age-2 continues to be strongly related to the mean length of the cohort at age-2 (beta regression, Pseudo $R^2 = 0.77$, $p < 0.001$) (Fig. 21).

From the spring 2024 acoustic survey, 387 Capelin stomachs were subject to detailed analysis, and fish ranged in size from 65–195 mm TL (mean: 139.3 ± SD 24.3 mm TL). Of these 387 fish, 33% had empty stomachs, which was similar to 2023 (28% empty) and lower than the post-collapse time series (1999–2022; 40% empty stomachs). For details on the methods of stomach content analysis, see Murphy et al. (2024). In 2024, Capelin diet composition was dominated by copepods, and to a lesser extent the appendicularian *Oikopleura* sp., for length bins between 100 and179 mm TL, while the largest fish (length bin 180 – 199) had high proportions of *Oikopleura* sp. and hyperiid amphipods (Fig. 22). There was no clear ontogenetic shift in diet composition, although the proportion of hyperiid amphipods in the diet increased from 140 mm TL. Other prey taxa in the diet were euphausiids, cirripedia, and pteropods. Mean percent stomach weight ($\%SW$) of Capelin was calculated as a measure of stomach fullness (equation 4).

$$\%SW_i = [WS_i/(WB_i - WS_i)] * 100\% \tag{4}$$

where WS_i is the weight of the stomach contents and (WB_i) and is the weight for an individual (g). In 2024, $\%SW$ Capelin mean was 0.38% (± SD 0.48%), which was a time series (1999–2023) low.

Frequency of occurrences (FO) of Capelin prey taxa were calculated using equation 5

$$FO = (S_i/S_{total}) * 100 \tag{5}$$

where S_i is number of stomachs containing prey taxa i and S_{total} is the total number of stomachs containing prey. In 2024, the top three prey taxa based on FO were copepods (84.1%), *Oikopleura* sp. (52.7%), and pteropods (primarily Limacina) (26.7%). This differs from the 2007–23 period where the top three prey taxa were copepods, *Oikopleura* sp., and hyperiid amphipods. In 2024, hyperiid amphipods were fourth most important (24.8%) followed by cirripedia (21.7%), and euphausiids (8.9%). The importance of *Oikopleura* sp., pteropods, and cirripedia in the diet in 2024 $\%SW$ was also low. For the period 2007–22, pteropods had a mean FO of 14.8% while cirripedia were largely absent (<1%). *Oikopleura* sp. is considered a low-quality prey taxa for Capelin in the Barents Sea and has been related to a lower stomach fullness index (Orlova et al. 2009, 2010).

The copepod category can be further divided: *Calanus finmarchicus* stages I–III and IV–VI; *C. glacialis* stages I–III and IV–VI; *C. hyperboreus* stages I–III and IV–VI; *Calanus* sp. (no species id); *Metridia* spp.; and Copepods (no species id). The Copepods (no species id) category includes small copepod species like *Pseudocalanus* sp. as well as copepod pieces. *Metridia* spp. had the highest FO (49.2%) followed by *C. finmarchicus* stage IV–VI (42.6%) and *C. glacialis* (39.9%) (Fig. 23). These diet data suggest that Capelin are feeding well on large copepods in the ecosystem, but their diet appears to be lacking in other prey taxa like euphausiids as they grow larger, which may be impacting their $\%SW$ and, more generally, the productivity of the stock.

FALL MULTISPECIES BOTTOM-TRAWL SURVEYS

Fall multispecies bottom trawl surveys (hereafter bottom trawl surveys) are conducted annually by the DFO NL Region in NAFO Div. 2GHJ3KLNO (Fig. 1). For a detailed account on the methodology and design of these surveys see Rideout & Ings (2018). Bottom trawl survey data are not used to estimate Capelin biomass due to pelagic distribution of Capelin and the selectivity of the trawl gear, which is biased against smaller sized fish, particularly those less than 10 cm (Mowbray 2002). Sampling of Capelin caught during the bottom trawl survey focuses on attaining samples from the full geographic distribution of the species (see Mowbray et al. 2023 for more details).

In 2024, the bottom trawl survey covered the entire survey area.

FALL CONDITION AND FEEDING

Fall condition in 2024 were calculated using data from all sets where detailed sampling was available. A condition index (LeCren 1951) was calculated by age class (ages 1 and 2) and the resultant values averaged. Capelin fall relative condition in 2024 was above the time series average and about the same as in 2023 but remained somewhat lower than the time series highs in 2021 and 2022 (Fig. 24). Capelin fall condition has been above average since 2017.

Fall Capelin stomach fullness is ‘called’ for fish when they are undergoing detailed sampling. Stomachs are categorized into five intervals: 0 (empty), 1 (¼ full), 2 (½ full), 3 (¾ full), and 4 (full). In 2024, the percentage of fish with food in their stomachs (fish with interval categories 1–4 divided by all fish sampled for stomach fullness) was 47%, which was lower than 2023 (59%).

FORECAST MODEL

The Capelin forecast model suite (Lewis et al. 2019) builds on two prior Capelin models (Buren et al. 2014, Murphy et al. 2018) by combining key features of the models within a common Bayesian framework which is then used to generate predictions of the Capelin biomass index from the spring acoustic survey. Three new models were added to the modeling suite this year which builds upon the CSAM1, CSAM2, and CSAM3 models which combine Capelin cohort strength models with Capelin mortality models. The new models (CSAM4, CSAM5, CSAM6) add a term for summer *Pseudocalanus* density from two years prior (Table 1). The most parsimonious Capelin forecast model for 2025 was the CSAM6 model which includes the BB larval index (LA) from two years prior; the day of year (DOY) of the most southerly position of contiguous sea ice (sea ice retreat; TI) which is related to the timing of the annual spring plankton bloom; the fall relative condition index (CO) of age-1 and age-2 Capelin (Lewis et al. 2019) from the preceding fall and summer density of *Pseudocalanus* from two years prior (Table 2). The fitted model (Fig. 25) had an R^2 of 0.62 which was substantially higher than the R^2 of the most parsimonious model presented at previous assessments (R^2 of 0.51; Table 2).

The model suite was fit with the most up-to-date data as of February 24, 2025. The actual timing of the sea ice retreat is not yet known. If the actual date of sea ice retreat is later in the spring, the projected biomass for the spring acoustic survey will increase over the current projection for retreat starting dates through the end of March before declining below the current projection for starting dates in April (Fig. 26). All sea ice retreat timing scenarios indicate that Capelin biomass in the spring acoustic survey in 2025 will decline from the observed biomass levels in 2024.

LIMIT REFERENCE POINT

The capcod model (Koen-Alonso et al. 2021) is the basis for the Limit Reference Point (LRP) for Capelin. This model accurately predicts Atlantic cod biomass in part based on Capelin biomass. This model was used successfully in both the NL and Barents Sea ecosystems. Northern cod serves as an indicator of finfish species in the NL ecosystem since the finfish community has a positive relationship with the status of Northern cod and Capelin. The capcod model estimated a Capelin LRP of 155 kt based on the acoustic biomass index (Fig. 27). Below this level, the Capelin stock is likely at risk of serious harm. This is also the level of Capelin in the ecosystem required to maintain Northern cod at its LRP. In 2024, the Capelin stock is currently above its LRP. The boundary between the Cautious and Healthy zones has yet to be determined for the 2J3KL Capelin stock.

ECOSYSTEM CONTEXT

From a food web perspective, Capelin corresponds to the middle trophic level of a ‘wasp-waist’ ecosystem structure (Cury et al. 2000) where a few forage species transfer energy from lower trophic levels (zooplankton) to higher trophic level predators. Capelin population dynamics are influenced by bottom-up drivers such as climate and zooplankton dynamics (Buren et al. 2014); and Capelin, in turn, play a key role in the larger ecosystem by influencing the population dynamics of its predators (Buren et al. 2014, Koen-Alonso et al. 2021).

The NL Ocean climate experiences fluctuations at quasi-decadal time scales that define warm and cold phases, with known impacts on ecosystem productivity. Warm phases appear associated with overall improvements in ecosystem productivity generally driven by improvements in Capelin and groundfish. The warm phase that started around 2020 has continued in 2024 (Fig. 28).

While the impact of large-scale variations in ocean climate on 2J3KL Capelin is not fully understood, recent studies have found that the summer North Atlantic Oscillation index and the NL Climate Index (NLCI) were predictors of Capelin spawning timing (Murphy et al. 2021), and inter-annual variability in prey availability associated with changes in the timing of the spring sea ice retreat was associated with changes in Capelin biomass (Buren et al. 2014). These relationships are indicative that the general ocean climate acts as an important regulator of biological processes and productivity of both Capelin, and the ecosystem at large.

Overall conditions of the past five years are indicative of improved productivity at the lower trophic levels in the NL bioregion (NAFO Divs. 2HJ3KLNOPs) (Fig. 29). This includes earlier phytoplankton blooms, higher nutrient concentrations, and above-average zooplankton biomass with a high abundance of both small and large energy-rich *Calanus* copepods. These zooplankton community changes suggest improved foraging conditions for larval (Murphy et al. 2018) and adult (Buren et al. 2014) Capelin.

Ongoing work has also uncovered a relationship between Capelin per capita productivity strength ($PS_t = B_{t+2}/B_t$, where B indicates the Capelin biomass index in a given survey) and the NLCI (3L Acoustic survey: Spearman Rho=0.39, p-value=0.013; 2J3KL RV Fall Survey: Spearman Rho=0.47, p-value=0.013). High NLCI values, indicative of a warm ocean climate, are associated with higher values of PS. Since PS can be considered as analogous to a recruitment per spawner signal, the relationship between PS and NLCI suggests that ocean climate conditions impact the survival of larvae during their first year, or the condition/effectiveness of the spawning adults in that year, or both. Irrespective of the exact mechanisms, when environmental conditions are favorable, Capelin per capita productivity strength appears to respond to these conditions quite consistently. While this response is evident on a per unit of biomass basis, a high enough spawning stock would be necessary to capitalize on these positive conditions at the stock level. The NLCI suggests that conditions for favorable Capelin per capita productivity strength will continue in 2025.

The ecosystems in the NL bioregion collapsed in the late 1980s and early 1990s associated with extreme cold ocean conditions and ecosystem overfishing. Declines in biomass of groundfish were not compensated for by increases in shellfish, with total biomass remaining below pre-collapse levels. Some recovery was observed between the mid 2000s and early 2010s, after which declines occurred.

While these ecosystems continue experiencing overall low productivity compared to the pre-collapse period, improvements have been observed in recent years. The total biomass of the fish community is showing a rebound from the mid-late 2010s declines and has reached in 2024 biomass levels around the post-collapse highs (Fig. 30). These increases have been largely driven by piscivores and plankpiscivores, notably cod and redfish. Given that spikes in redfish biomass in the RV survey are a well know feature, the persistence of the 2024 Total biomass level over time remains uncertain.

Both consumption estimates of Capelin by fish predators and predictions of Capelin biomass from the probability of Capelin in predators' stomachs indicate that Capelin has shown recent improvements from the late 2010s levels (Fig. 31, 32). However, these indicators differ in their expectations for 2025. The increase in the estimated consumption of Capelin by fish predators in the fall of 2024 (Fig. 31) suggests an increase in the expected biomass to be observed by the 3L Spring Acoustic survey in 2025. On the other hand, the prediction of Capelin biomass from models based on the probability of Capelin in the diet of cod suggests that Capelin would be expected to decline from the level observed in 2024 to around the 2021–22 level (Fig. 32). The reasons behind this discrepancy are under investigation, but they may be related to reduced and sparse sampling of the stomachs used for the estimation of the probability of Capelin in the diet. The sampling of the stomachs used for the estimation of consumption did not experience the same issues.

Despite the discrepancy indicated above, and taking into account that the consumption estimates show the same positive trend also observed in the 2J3KL RV Fall Capelin Biomass Index, together with the favorable ocean climate conditions expected for 2025, the overall weight of evidence would suggest a positive trend in Capelin in the 2025 Spring survey, but uncertainty around this expectation remains high.

SUMMARY AND CONCLUSIONS

The 2J3KL Capelin stock has shown modest signs of recovery from its collapse in 1991, while the stock is currently above its LRP, it is still only 10% of the 1980s high. Persistent changes in Capelin population dynamics post-collapse are likely due to density-dependent factors, resulting in fast immature growth and maturation at a younger age. In 2024, the growth of older Capelin slowed, likely as a result of increased Capelin abundance and biomass. However, the growth of young Capelin (age-1) remained high in 2024. Due to semelparity and early age at maturation, the stock is age-truncated compared to the 1980s. Post-1991, the 2J3KL Capelin stock is also characterized by delayed spawning and low recruitment. Spawning timing in 2024 was earlier than average, and the BB larval index was similar compared to the post-collapse time series median. This suggests that 2024 may have an average year-class strength compared to the post-collapse period, but earlier than average spawning timing could result in a stronger than expected year-class. Capelin fall relative condition was above average in 2024, but below the time series highs observed in 2021 and 2022. In 2024, the Capelin spring acoustic biomass index was near the recent stock high of 2013–14 but remains a fraction of the median biomass index observed during the mid-late 1980s. All timing of sea ice retreat scenarios for the Capelin forecast model predict that the Capelin acoustic biomass index in 2025 will be lower than the biomass index observed from the 2024 Spring acoustic survey. The 2J3KL Capelin LRP, based on the capcod model, is 155 kt in the acoustic biomass index. In 2024, the 2J3KL Capelin stock is above its LRP; however, the boundary between the Cautious and Healthy zones has not yet been determined for this stock. While the 2J3KL Capelin stock is above its LRP, the stock continues to face certain challenges such as post-collapse delayed spawning, maturation at earlier ages than in the pre-collapse period, and spawning by primarily age-2 fish. Furthermore, the stock remains below the 1982–90 productive period.

AREAS OF UNCERTAINTY

The spring acoustic survey does not provide an estimate of total spawning stock biomass, so the impact of fishing on the 2J3KL Capelin stock is unknown.

The BB larval index may not be representative of larval densities from areas with a high proportion of deep-water (demersal) spawning. However, trends in larval indices were similar between a site in Notre Dame Bay with a high proportion of deep-water spawning and the BB larval index (Tripp et al. 2023). The BB larval index is included in the most parsimonious Capelin forecast model.

The estimated envelope of Capelin consumption by fishes remains large and is highly dependent on how well these species represent overall predation. While order of magnitude analyses indicated that fishes are the main consumers of Capelin, consumption of Capelin by marine mammals and seabirds remains an important source of uncertainty.

The impact of fishing mortality on the Capelin stock is not quantified and is generally poorly understood, particularly its targeted impact on pre-spawning, egg-bearing females that have already survived predation and other sources of natural mortality.

There are currently limited abundance and biomass data for age-1 Capelin from the spring acoustic survey. Using a smaller meshed pelagic trawl on the spring acoustic survey may increase data on this life stage and potentially fine-tune the recruitment forecast from the larval stage to age-2.

RESEARCH RECOMMENDATIONS

The following recommendations for research were identified during the 2025 2J3KL Capelin assessment. They were either identified as knowledge gaps in the current assessment of data products or potential research topics for further investigation.

- Determine the age structure data for the commercial fishery to provide detailed age information for the season.
- Provide a table or figure of survey timing and fishery timing.
- Determine confidence intervals for condition estimates and spring maturation.
- Investigate the maturity data within the schools and strata to see if there are differences in maturity levels.
- Investigate methods to apply geostatistical analysis on acoustic survey data to improve accuracy and reduce confidence intervals.
- Update the documentation to clarify how changes to the Northern cod LRP impact the LRP for Capelin.
- Revisit the percentage of repeat spawners and report on pre-2016 beach spawning ages.
- Investigate incorporating more variables into the forecast model.
- Examine patterns in the forecast model residuals and investigate ways to minimize them.
- Provide more detail on the variables used to determine the confidence intervals for the acoustic biomass estimate.

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TABLES

Table 1 Statistical models within the Capelin forecast modeling suite with variables used to explain and forecast Capelin biomass (CB). Parameters are in Greek letters and are slopes unless otherwise specified (α = intercept, the error term is not shown). LA: larval abundance; ZO: zooplankton biomass (larval food); TI: timing of ice retreat (t_{ice}); CO: Capelin condition; time (year) is shown with the subscript t and is used to indicate the time lag for each of the variables.

Model family	Model abbreviation	Formal model
Cohort strength (CS)	CS0	$CB_t = \alpha + \beta \times LA_{t-2}$
	CS1	$CB_t = \alpha + \beta \times LA_{t-2} + \gamma \times ZO_{t-2}$
Adult mortality (AM)	AM0	$CB_t = \alpha + \delta \times TI_t \times (1 - TI_t / \eta)$
	AM1	$CB_t = \alpha + \delta \times TI_t \times (1 - TI_t / \eta) + \theta \times CO_{t-1}$
CS/AM	CSAM1	$CB_t = \alpha + \beta \times LA_{t-2} + \theta \times CO_{t-1}$
	CSAM2	$CB_t = \alpha + \beta \times LA_{t-2} + \delta \times TI_t \times (1 - TI_t / \eta)$
	CSAM3	$CB_t = \alpha + \beta \times LA_{t-2} + \delta \times TI_t \times (1 - TI_t / \eta) + \theta \times CO_{t-1}$
	CSAM4	$CB_t = \alpha + \beta \times LA_{t-2} + \gamma \times ZO_{t-2} + \theta \times CO_{t-1}$
	CSAM5	$CB_t = \alpha + \beta \times LA_{t-2} + \gamma \times ZO_{t-2} + \delta \times TI_t \times (1 - TI_t / \eta)$
	CSAM6	$CB_t = \alpha + \beta \times LA_{t-2} + \gamma \times ZO_{t-2} + \delta \times TI_t \times (1 - TI_t / \eta) + \theta \times CO_{t-1}$

Table 2. Summary fit statistics for the models tested as a part of the Capelin forecast modeling suite. Reported statistics include the deviance information criterion (DIC), delta DIC (the difference between the lowest DIC and the DIC for a tested model; dDIC), and the Bayesian variance explained (R^2; Gelman et al. 2019).

Model	**DIC**	**dDIC**	**R^2**
CSAM6	36.98	0.00	0.62
CSAM4	39.35	2.37	0.52
CSAM5	39.72	2.75	0.55
CSAM3	40.71	3.73	0.51
AM0	42.42	5.45	0.19
CSAM1	42.87	5.89	0.39
CSAM2	43.19	6.21	0.41
AM1	45.63	8.66	0.33
R1	46.19	9.21	0.28
R0	49.30	12.32	0.07

FIGURES

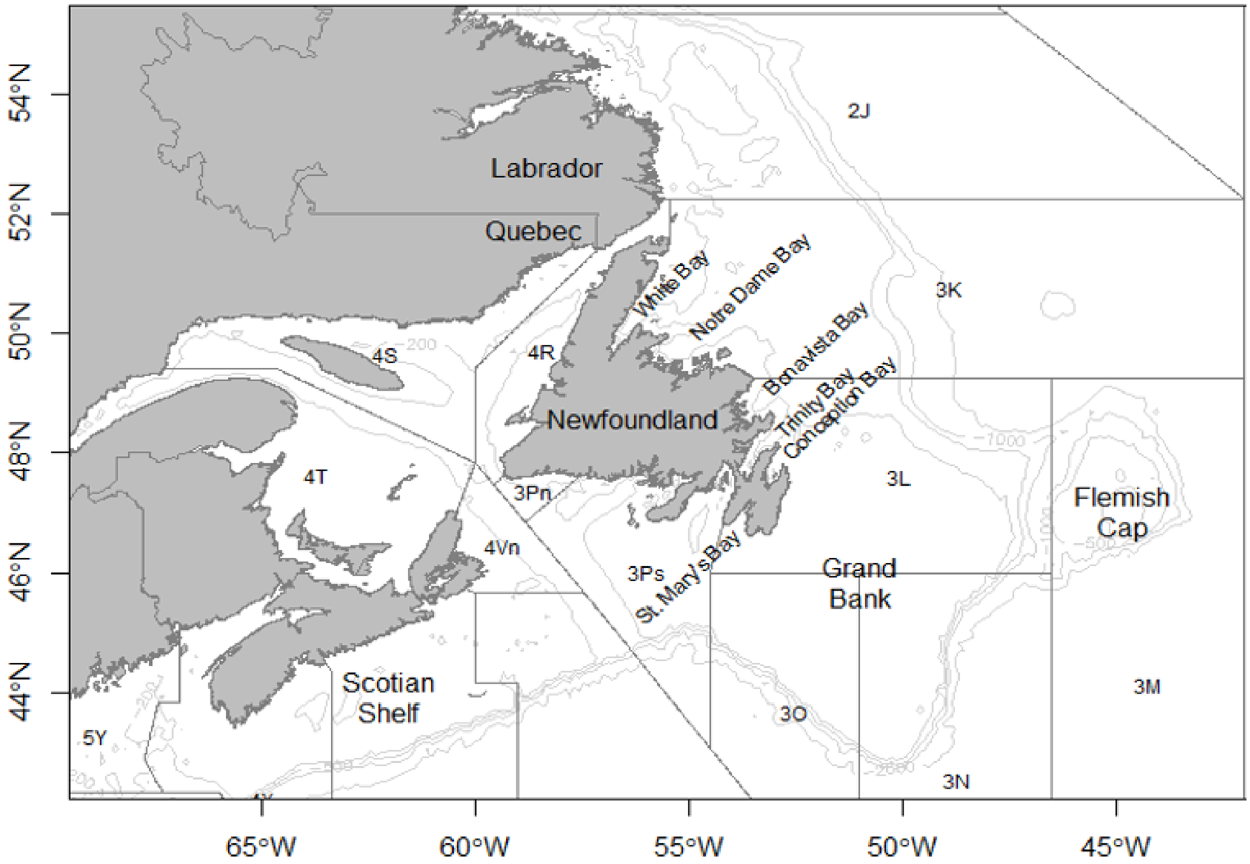

Figure 1. Stock area of NAFO Divisions 2J3KL Capelin.

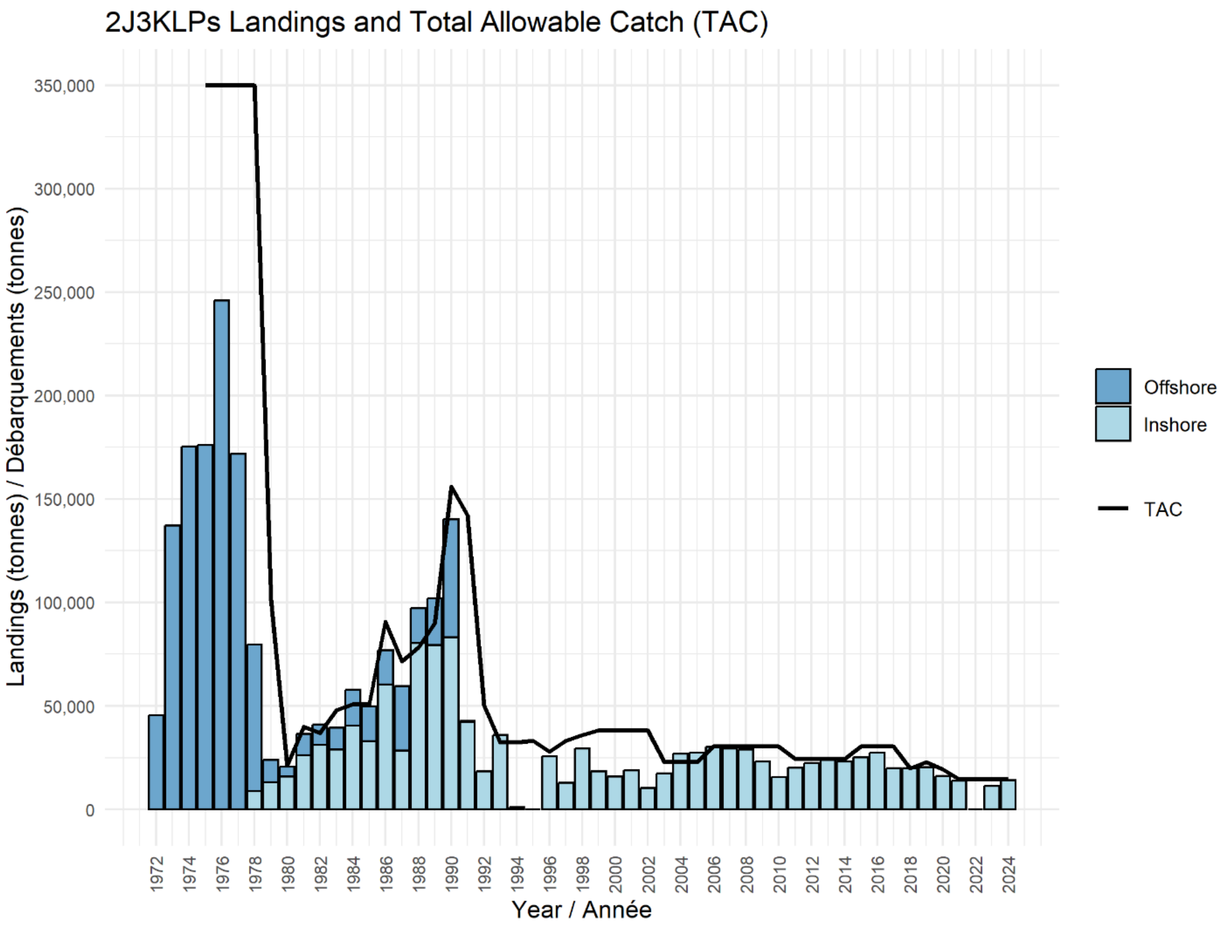

Figure 2. Inshore landings (light blue bars), offshore landings (blue bars), and Total Allowable Catch (TAC) (line) for Capelin in Divs. 2J3KL for 1972–2024. Note that annual inshore landings were likely greater than 0 t between 1972 and 1977, but they were not recorded prior to 1978. There was no commercial fishery in 1994, 1995, and 2022.

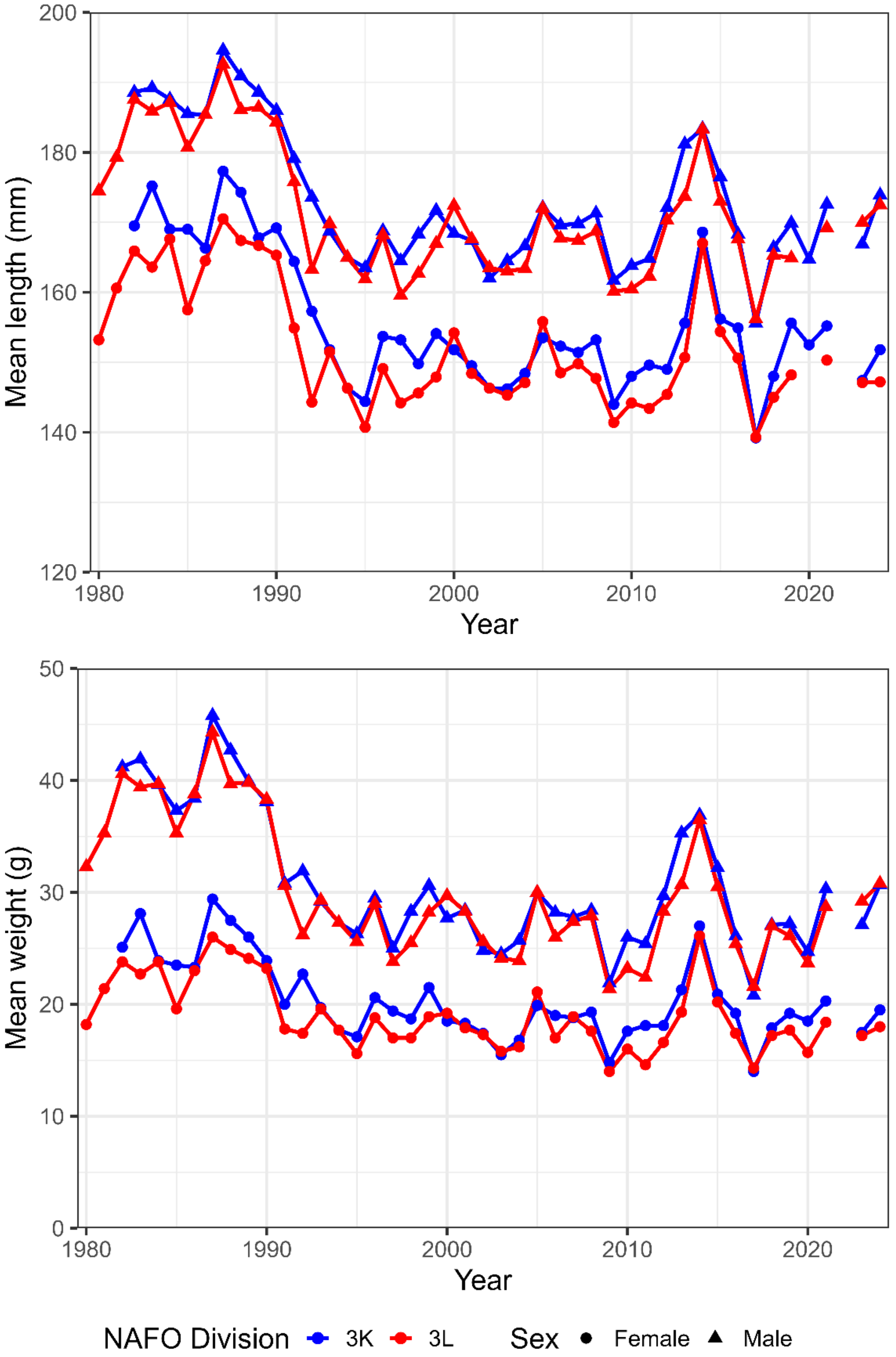

Figure 3. Mean length and weight of Capelin caught in NAFO Divisions 3K and 3L in inshore commercial landings from 1980–2024.

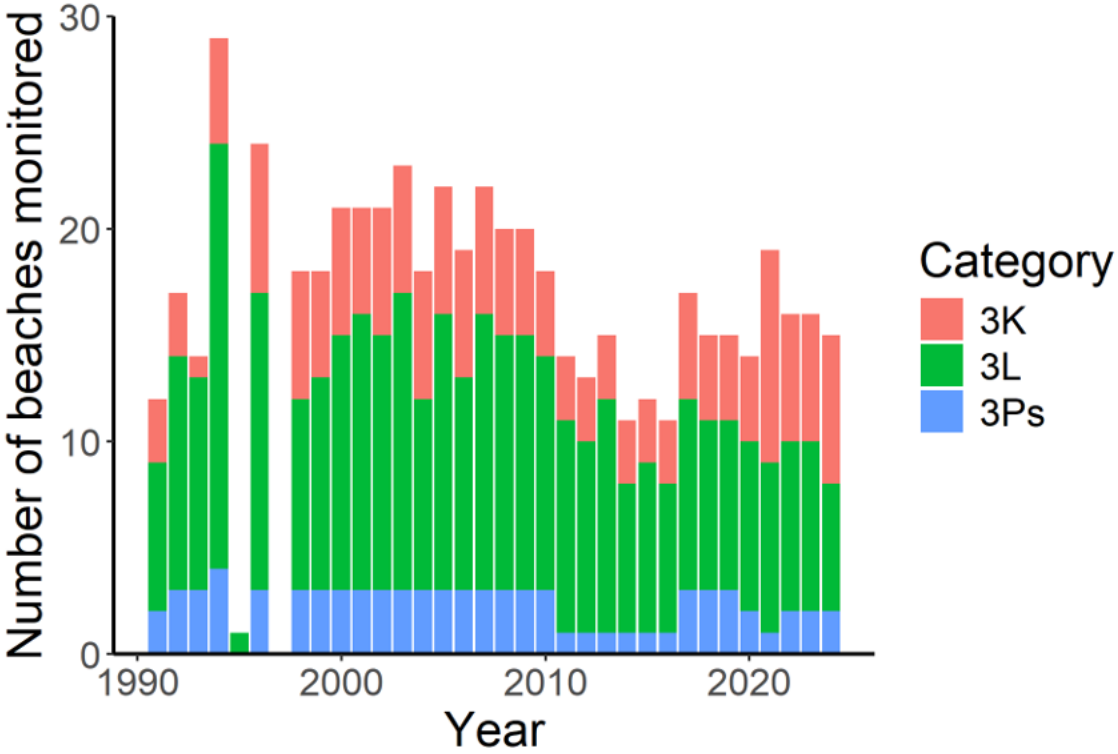

Figure 4. Number of Capelin spawning beaches monitored by Division by DFO's Capelin spawning diary citizen science program since 1991.

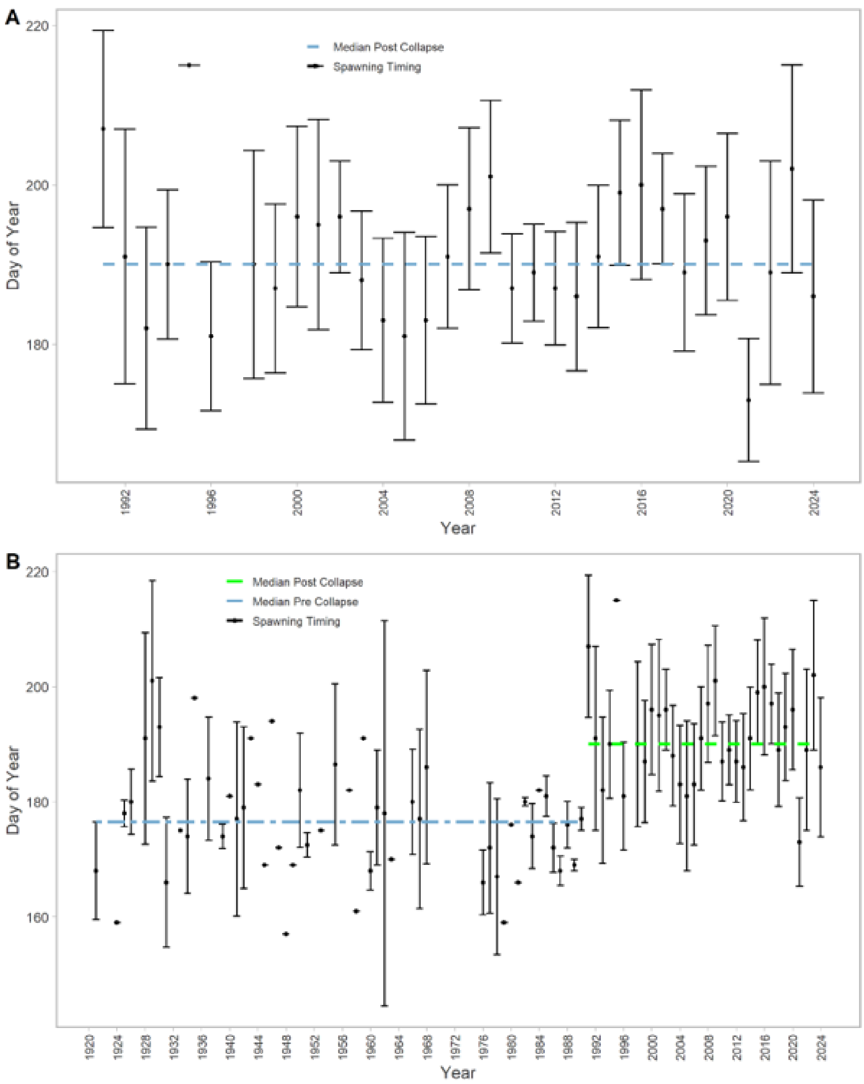

Figure 5. (A) Post-collapse median peak beach spawning timing for 2J3KL Capelin in 2024 was July 4 (Day of year [DOY]: 186) based on 15 beaches monitored in the Capelin citizen science spawning diary program. (B) The beach spawning time series. Blue dashed line is the median for the pre-collapse period (1919–1990: June 25, DOY 176; green dashed line is the median for post collapse period (1991–2023: July 9, DOY 190). The error bars are standard deviations. Based on Murphy et al. 2021.

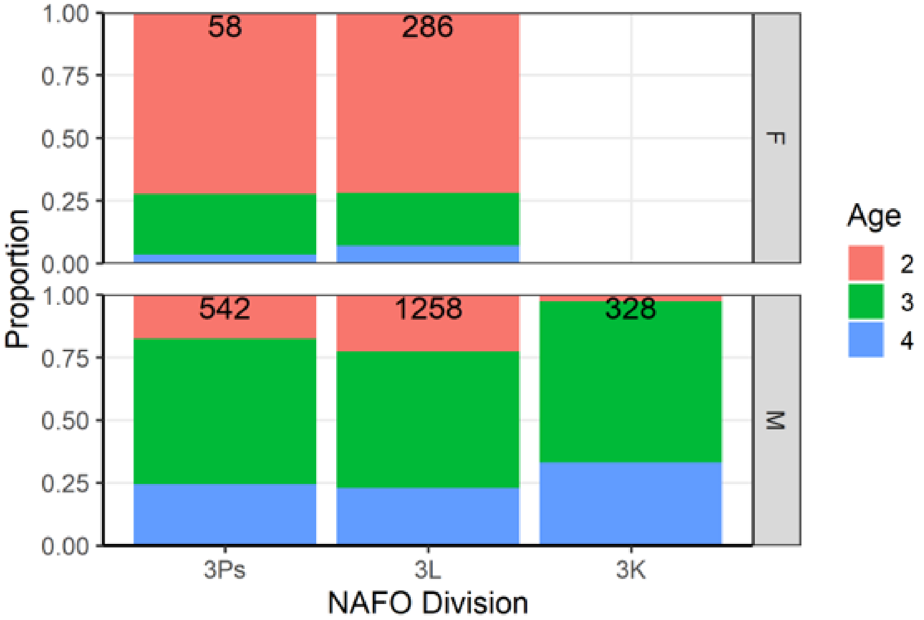

Figure 6. Age and sex composition of beach spawning Capelin at eight beaches in NAFO Divisions 3KLPs from June 5 to July 29, 2024 (12 samples collected over the two months). Fish were collected using a cast or dip net. Sample size is at the top of each bar for female (F) and male (M).

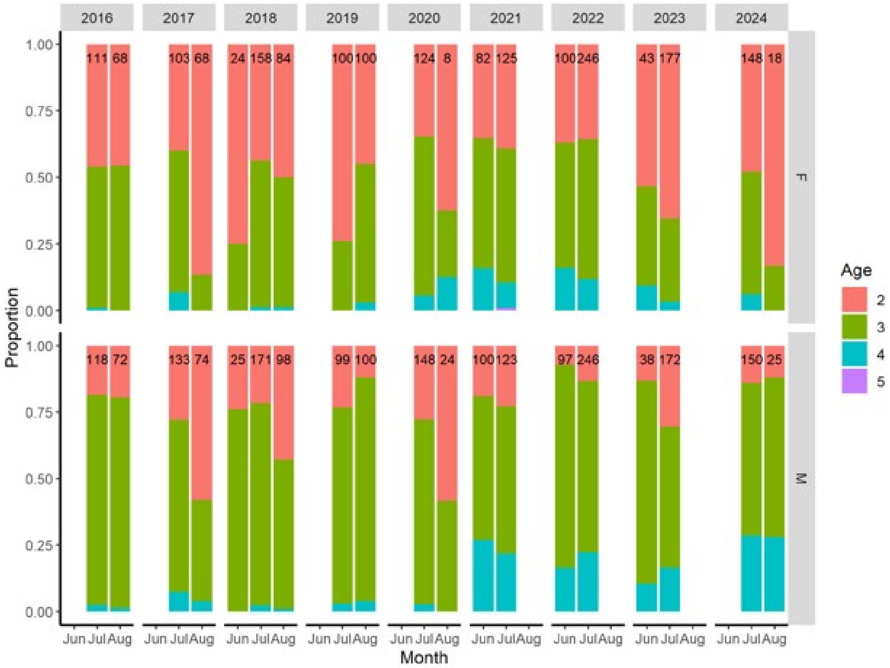

Figure 7. Age and sex composition of beach spawning Capelin at Bellevue Beach in NAFO Division 3L in June, July, and/or August 2016–24. Fish were sampled with cast nets. Sample size is at the top of each bar for female (F) and male (M).

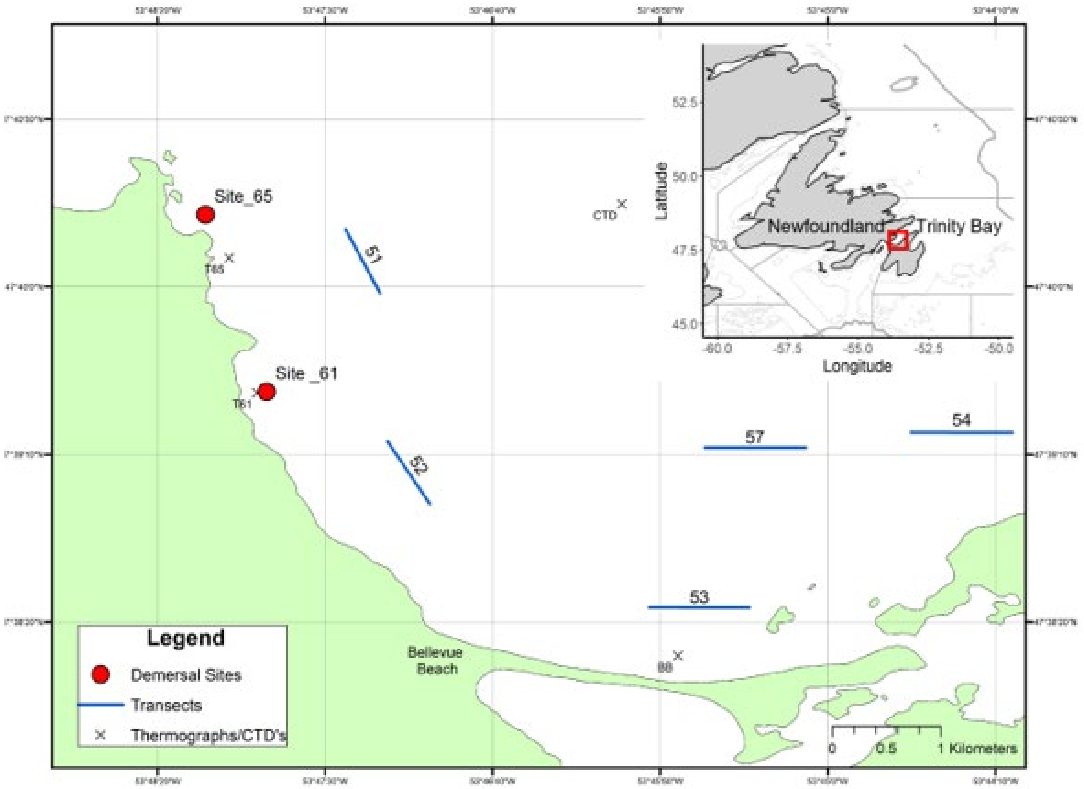

Figure 8. Bellevue Beach sampling area in Trinity Bay (Div. 3L). Demersal sites are in red (depths of 12–14 m). The numbered transects are fixed stations for larval surface tows. X indicates fixed stations for CTD data collected each sampling day. The red box in the inlay figure is the location of Bellevue Beach at the bottom of Trinity Bay.

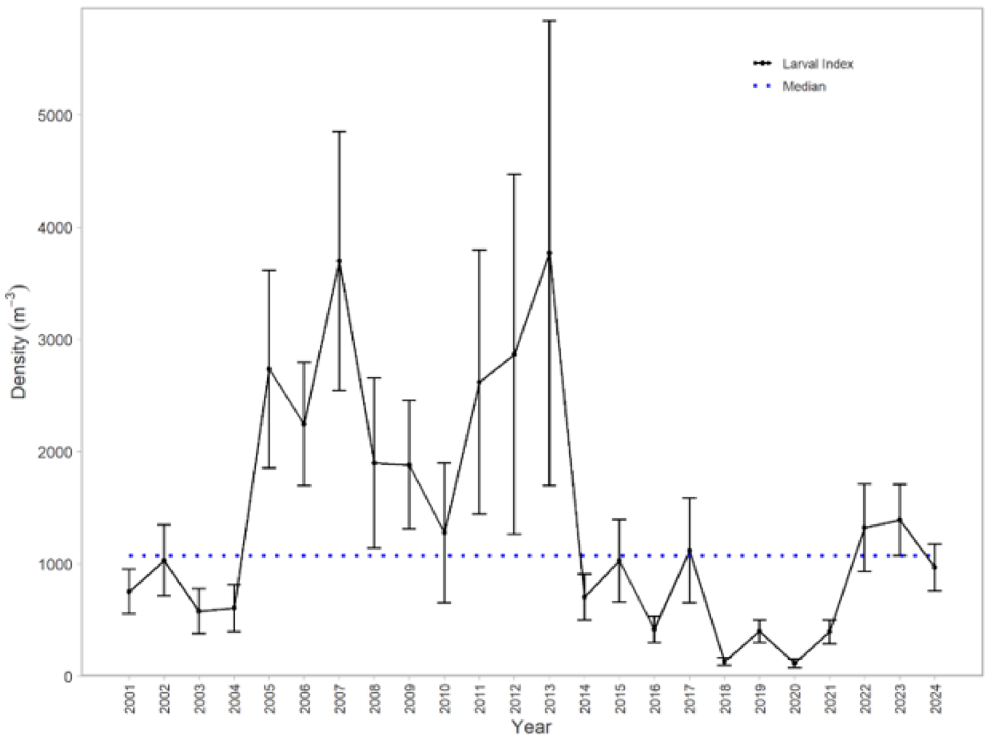

Figure 9. Bellevue Beach larval index (2001–2024) ± standard errors. The dashed line is the median larval abundance index (2001–23).

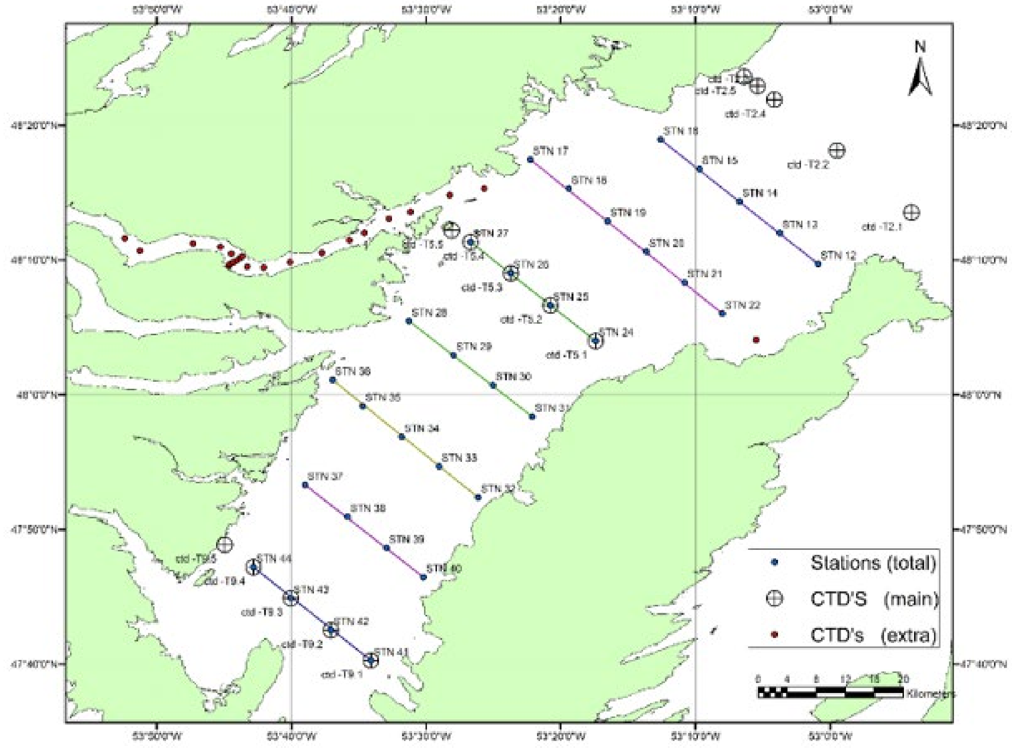

Figure 10. Trinity Bay larval survey. The core stations sampled are in the center of the bay (Stations 17–36).

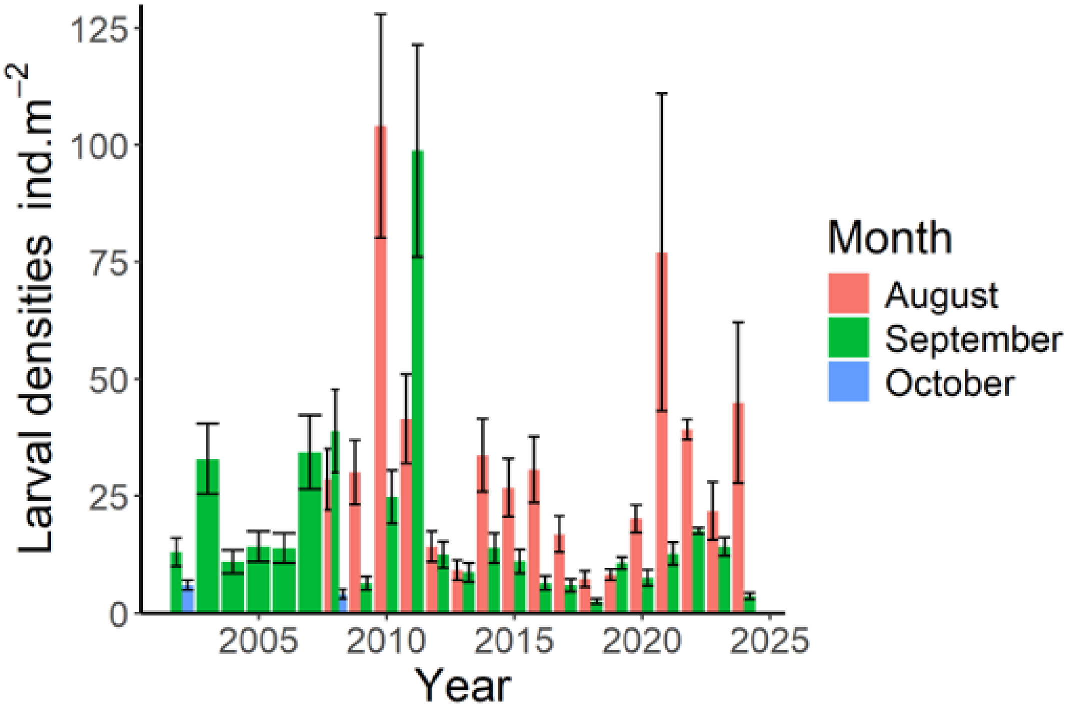

Figure 11. Trinity Bay (TB) larval densities sampled at 19 core fixed stations in the center of TB in August, September, and/or October 2002–24. Error bars are ±SE.

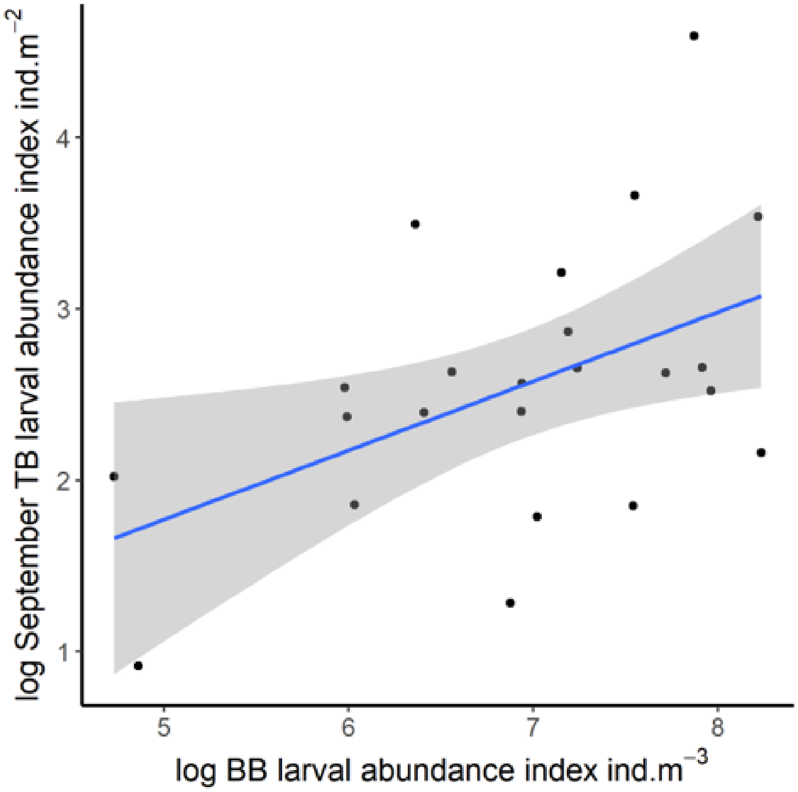

Figure 12. The Trinity Bay (TB) larval densities in September are positively related to the Bellevue Beach larval index sampled in July and August (2002–24; linear regression R2 = 0.20, p = 0.02).

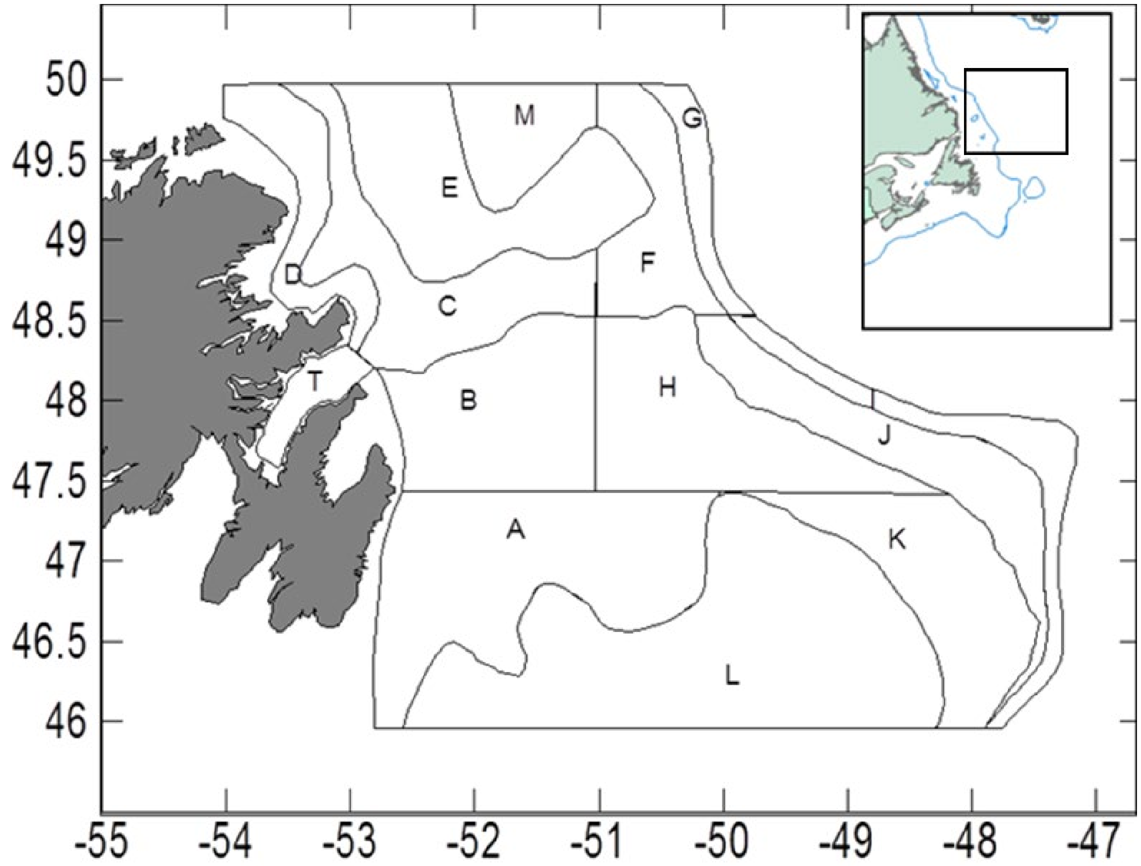

Figure 13. Spring acoustic survey strata in NAFO Divisions 3KL.

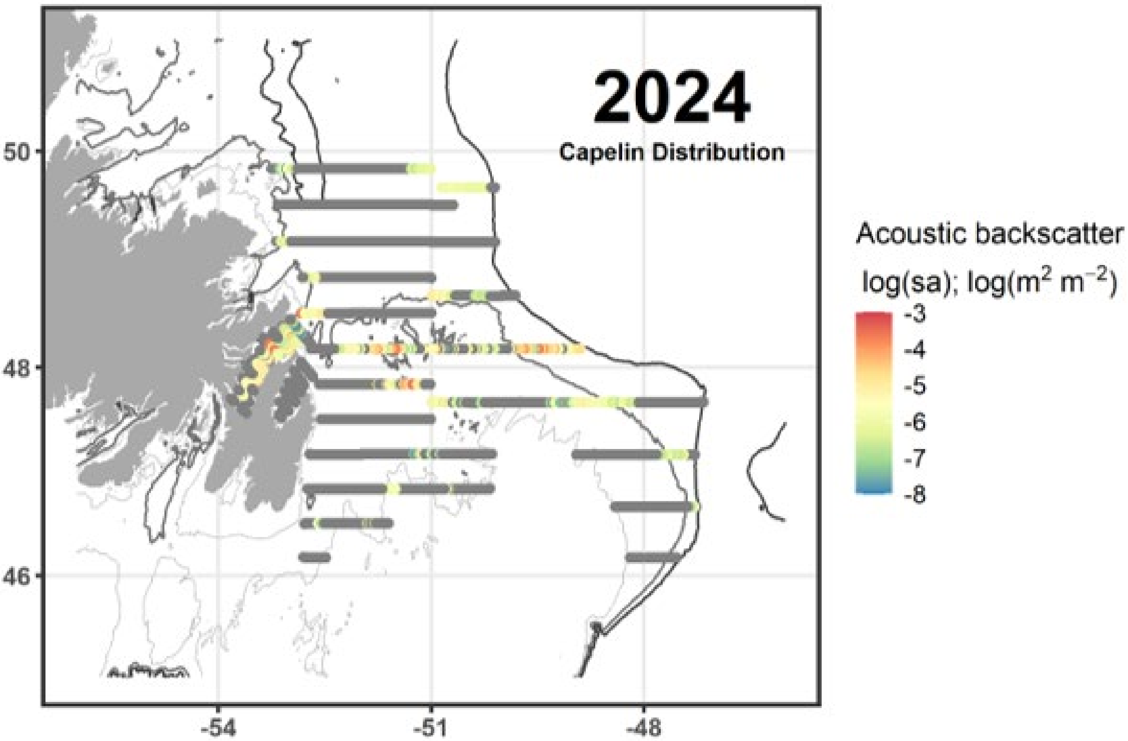

Figure 14. Spring acoustic survey tracks in 2024. Consecutive colour increments indicate an order of magnitude difference in acoustic backscatter with colder colours (blue) indicating lower acoustic biomass. Grey indicates no Capelin acoustic backscatter.

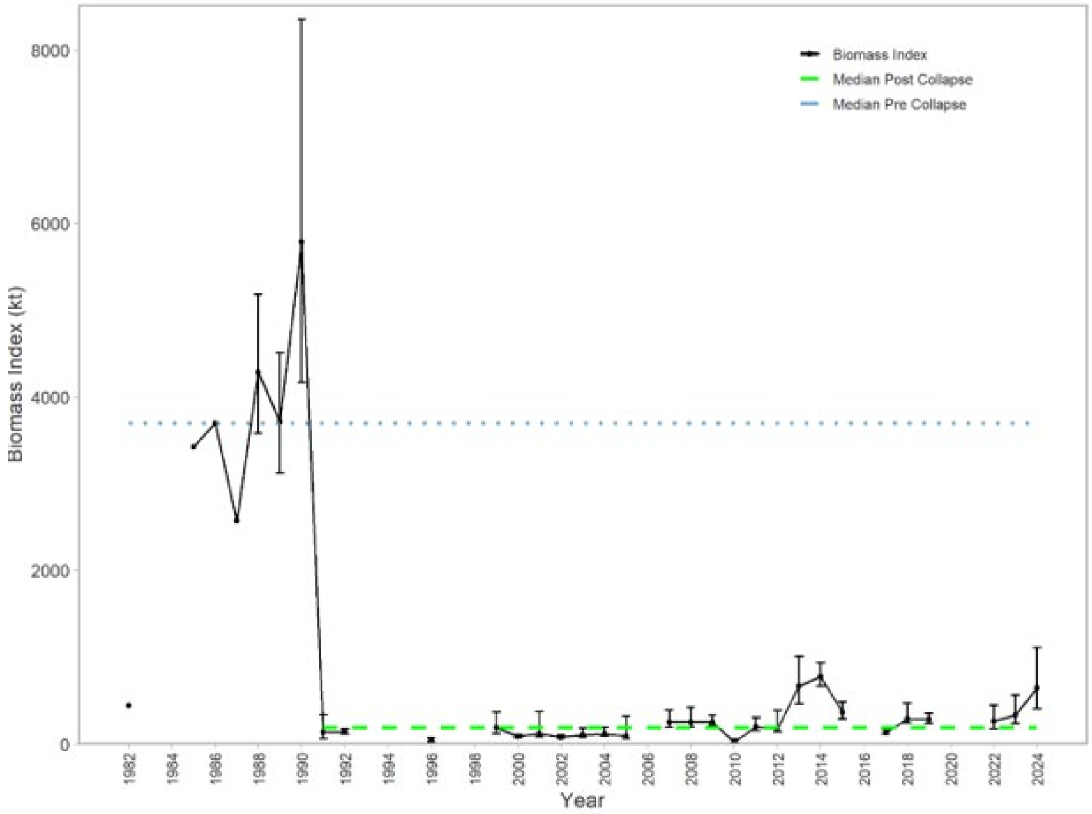

Figure 15. Capelin spring acoustic biomass index from 1982–2024. Error bars are 90% confidence intervals, ranging from the 5th to the 95th percentiles of the estimate. Error bars could not be calculated for 1982–87. The pre-collapse median (dotted blue) and post-collapse median (dashed green) are shown.

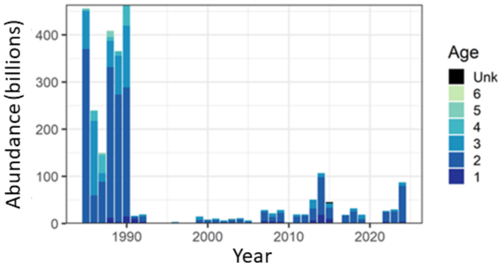

Figure 16. Capelin spring acoustic age disaggregated abundance index from 1985–2024.

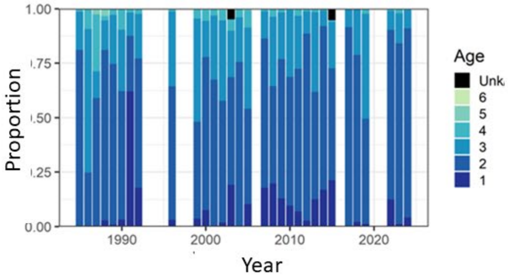

Figure 17. Capelin spring acoustic survey age composition from 1985–2024.

Unclassified - Non-Classifié

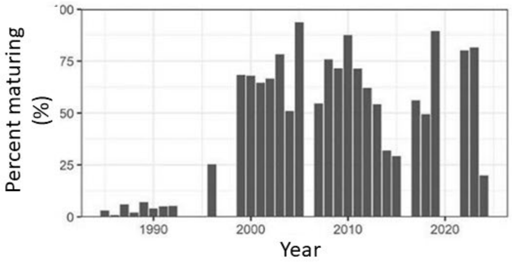

Figure 18. Capelin spring acoustic survey percentage of female age-2 Capelin maturing from 1985–2024.

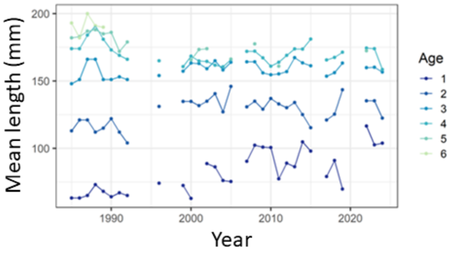

Figure 19. Capelin spring acoustic survey mean lengths at age (ages 1–6) from 1985–2024.

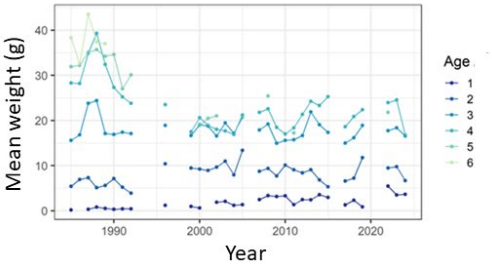

Figure 20. Capelin spring acoustic survey mean weights at age (ages 1–6) from 1985–2024.

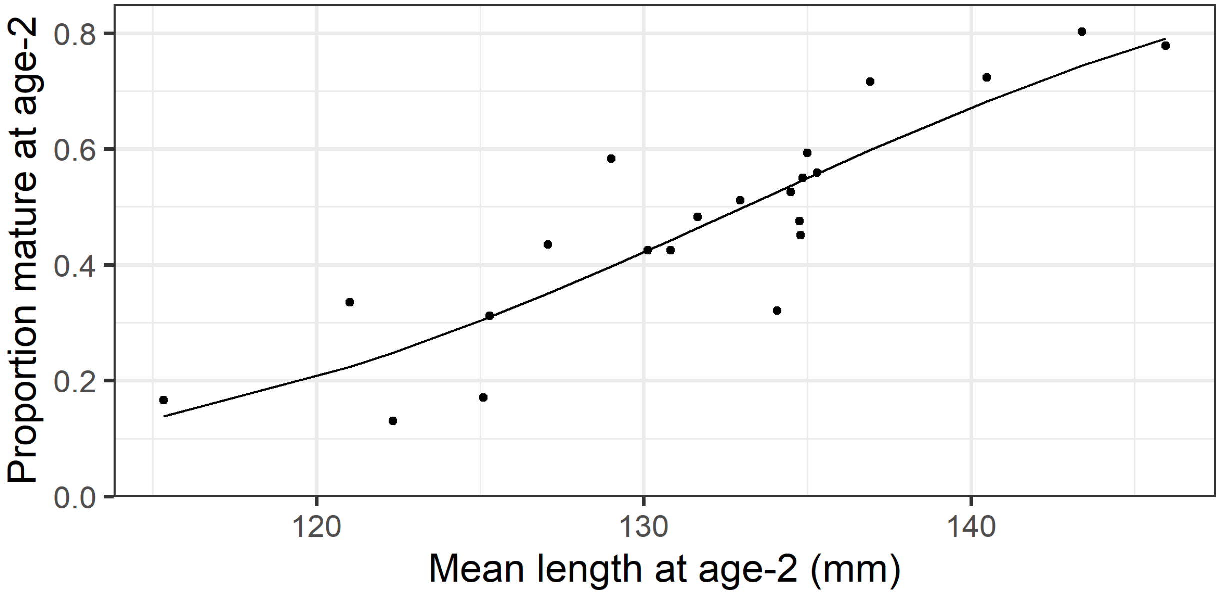

Figure 21. Proportion of Capelin mature at age-2 was positively related to mean length at age-2 (beta regression Pseudo R^2=0.77, p=0.001).

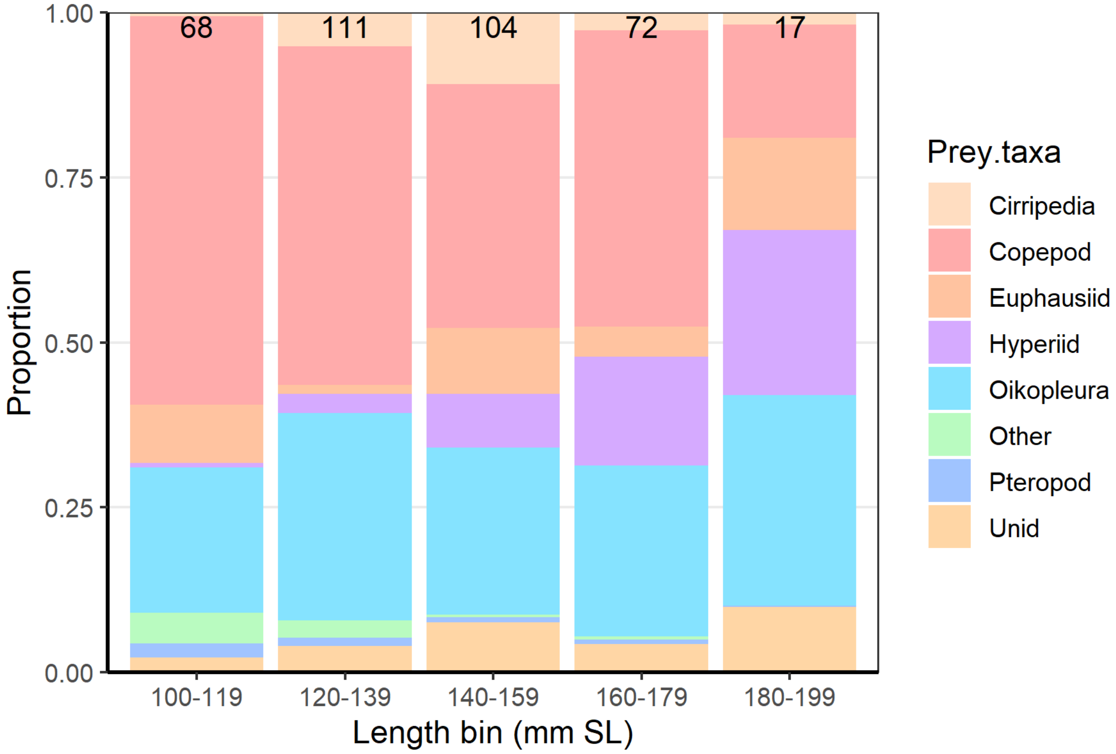

Figure 22. Proportion of prey taxa (based on weight) in the 2024 Capelin spring diet pooled by length bin. The number of fish included in each length bin is at the top of the stacked bar. The other category includes rare prey items like fish eggs and decapod larvae. The Unid category includes digested material and unidentified taxa.

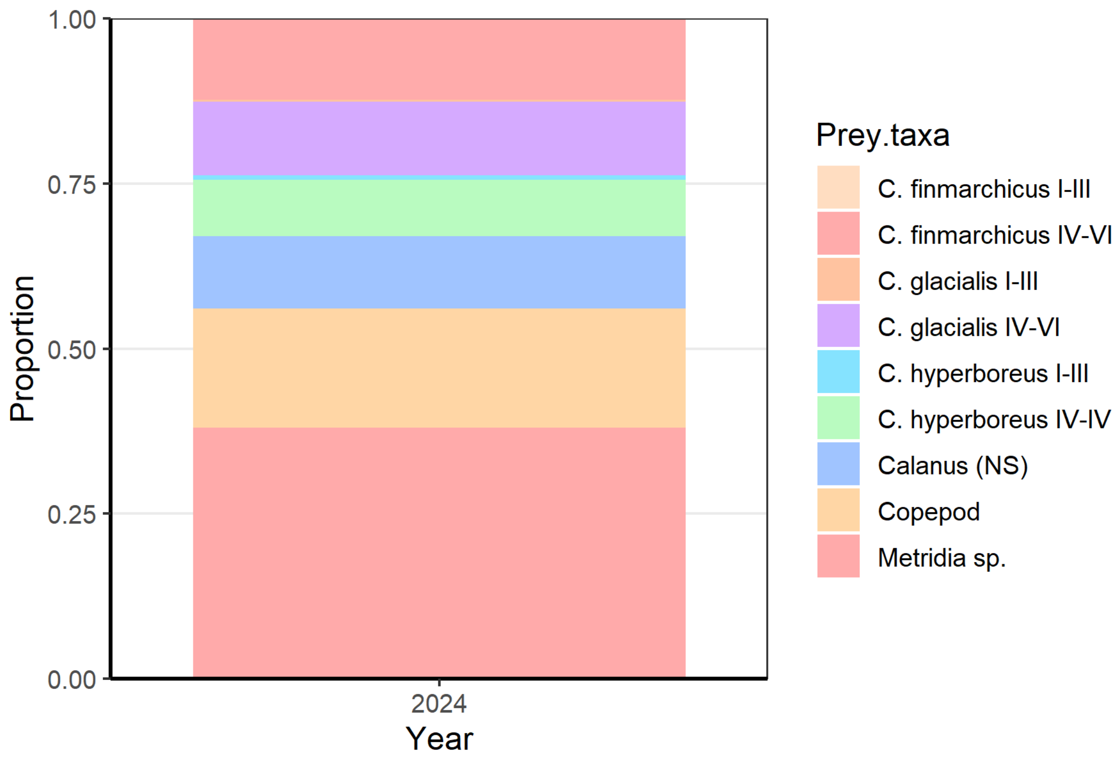

Figure 23. Proportion of copepod species (based on weight) in spring 2024 Capelin diet. Calanus (NS) category includes all unidentified Calanus species; the Copepod category includes small copepods like Pseudocalanus sp. and Oithona sp, as well as copepod pieces.

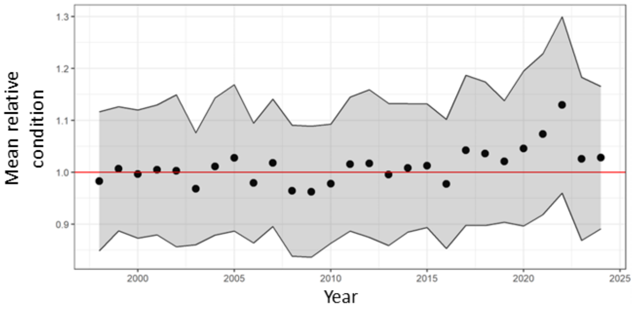

Figure 24. Mean relative condition of age-1 and -2 capelin with 95% confidence intervals (shaded region). The red line shows mean.

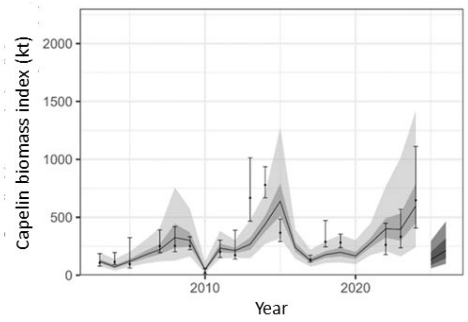

Figure 25. Results for the Capelin forecast model as of February 17, 2025, including the 95% credible (light grey) and 80% prediction (dark grey) intervals for expected values of the spring acoustic Capelin biomass index (solid line). Observed biomass index values (dots) with 95% confidence intervals are also plotted

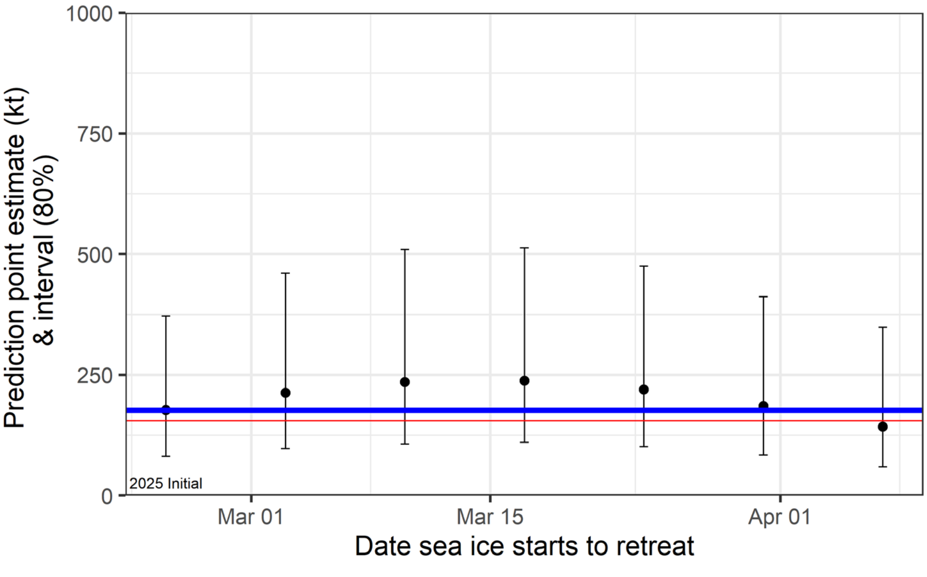

Figure 26. Sensitivity analysis for the CSAM6 model. The sensitivity analysis determines the impact of different dates for the start of sea ice retreat on the predicted biomass index value for the May 2025 spring acoustic survey. Weekly dates for the start of sea ice retreat ranging from Feb. 24, 2025, to April 7, 2025, were used. These dates were based on the timing of the weekly release of regional ice maps by the Canadian Ice Service. Points show the weekly median biomass index estimates while the lower and upper bars show the 10th to 90th percentile prediction interval. The solid blue line shows the median biomass estimate as of the capelin assessment while the solid red line shows the value of the Capelin LRP.

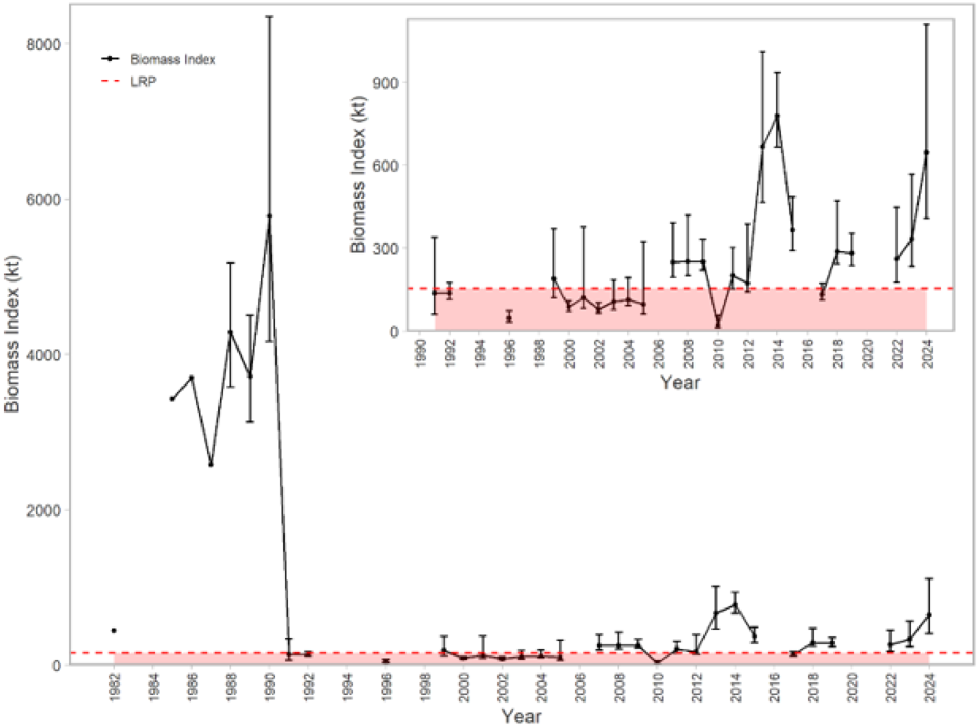

Figure 27. The Capelin LRP is 155 kt (red dashed) below which the 2J3KL Capelin stock and the Northern Cod stock are likely at risk of serious harm, i.e. in the Critical Zone (shaded red). Inset: Capelin biomass Index for the post-collapse years only (1991–2024). The Cautious and Healthy Zones have not yet been determined for this stock.

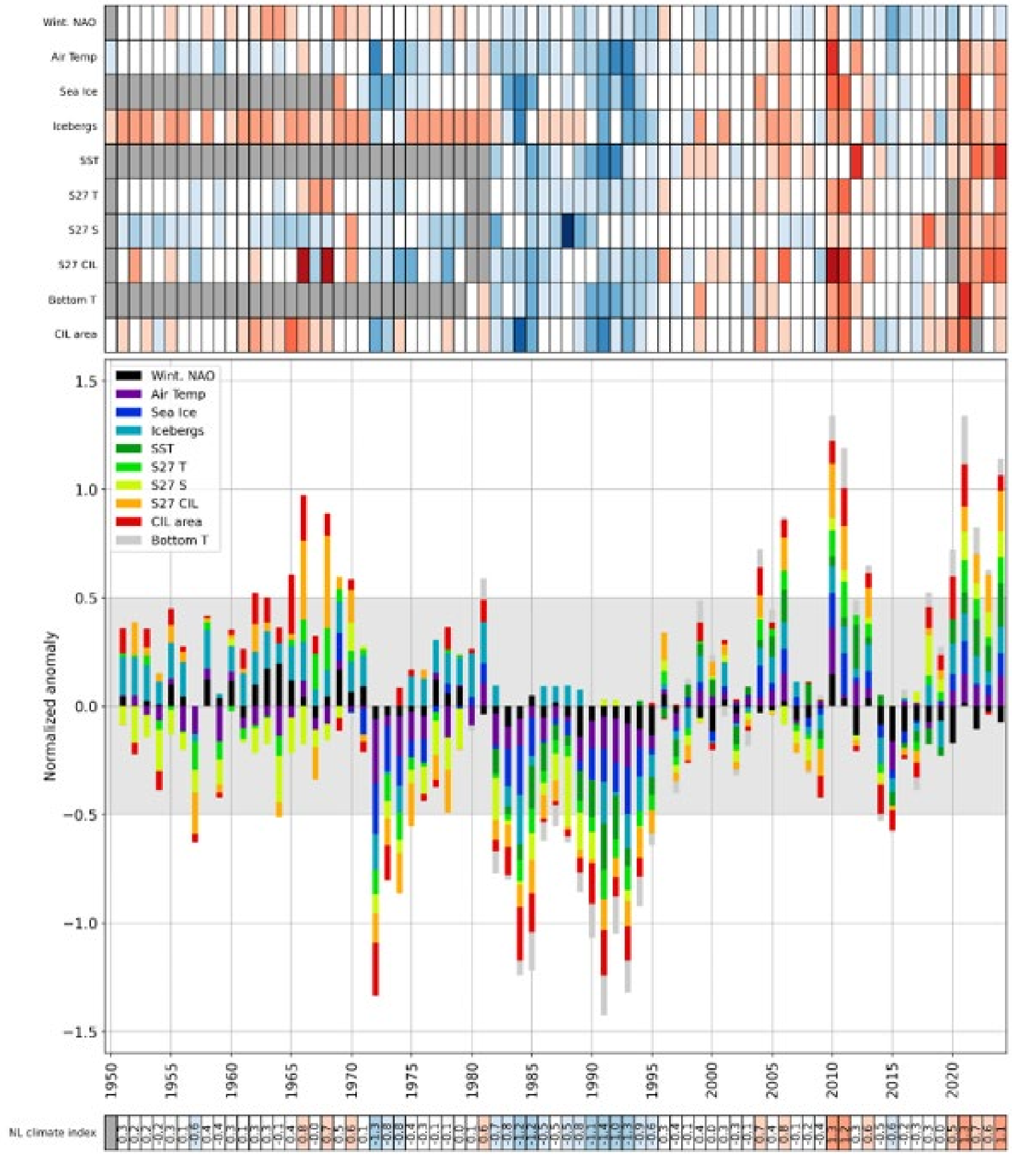

Figure 28. The Newfoundland and Labrador Climate Index updated to 2024. The index is made up of 10 subindices: winter NAO index; air temperature at five sites; sea ice season duration and maximum area for northern and southern Labrador and Newfoundland shelves; number of icebergs; sea surface temperatures in NAFO Divisions 2GHJ3KLNOP; vertically averaged temperature and salinity at Station 27; Cold Intermediate Layer (CIL) core temperature at Station 27; summer CIL areas in hydrographic sections Seal Island, Bonavista Bay, and Flemish Cap; spring and fall bottom temperatures in NAFO Divisions 3LNOPs and 2HJ3KLNO, respectively. The length of the stacked bar is the average of the respective subindices in which their relative contribution to the average is adjusted proportionally. The scorecard at the bottom of figure shows the colour-coded numerical values of the climate index (blue negative, red positive, white neutral).

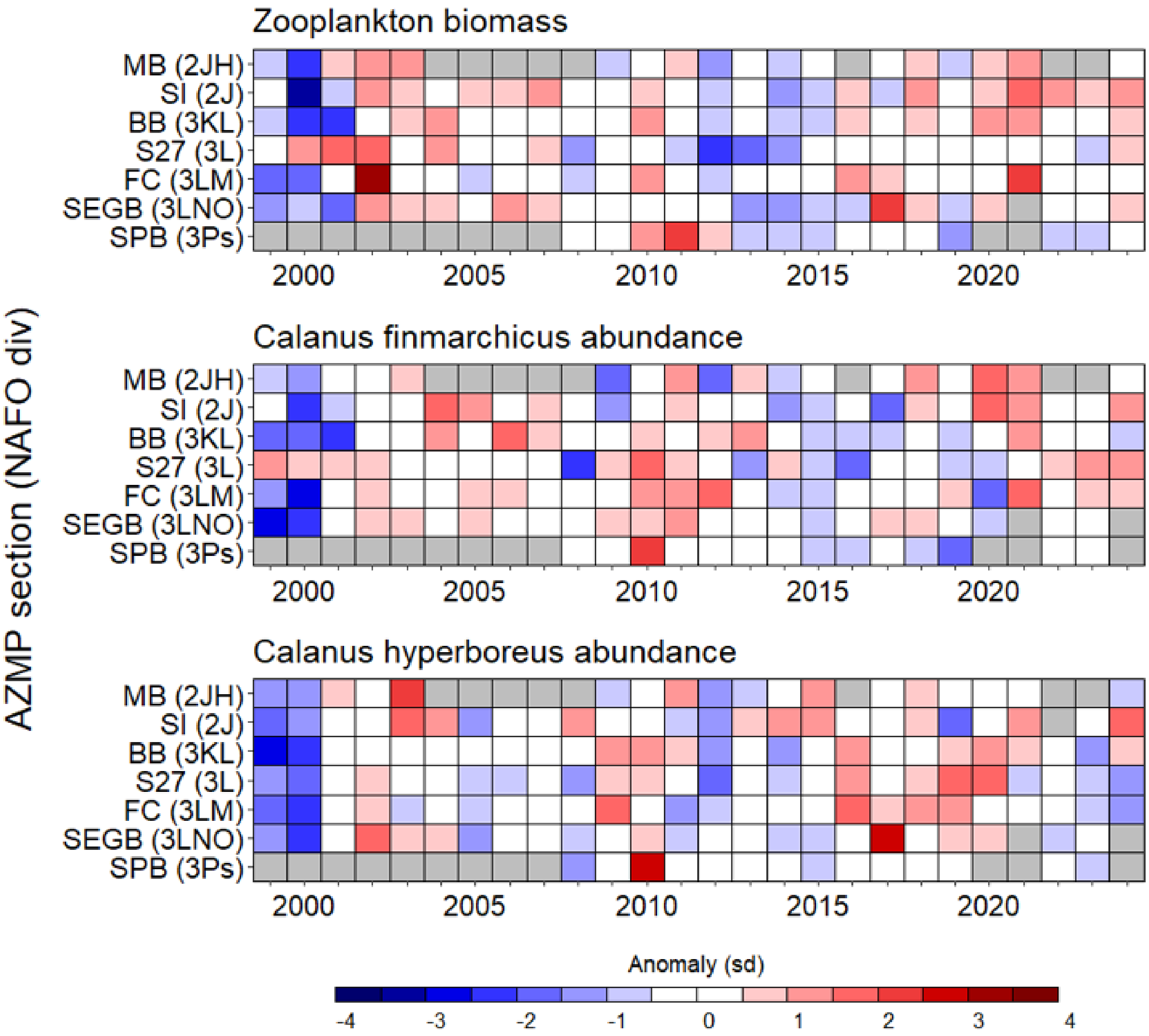

Figure 29. Anomalies (SD) for zooplankton biomass (top panel); Calanus finmarchicus abundance (middle panel) and Calanus hyperboreus abundance (bottom panel) from 1999–2024 divided by AZMP transect/NAFO Div. for Makkovik Bank (MB), Seal Island (SI), Bonavista Bay (BB), Station 27 (S27), Flemish Cap (FC), Southeast Grand Bank (SEGB) and St. Pierre Bank (SPB).

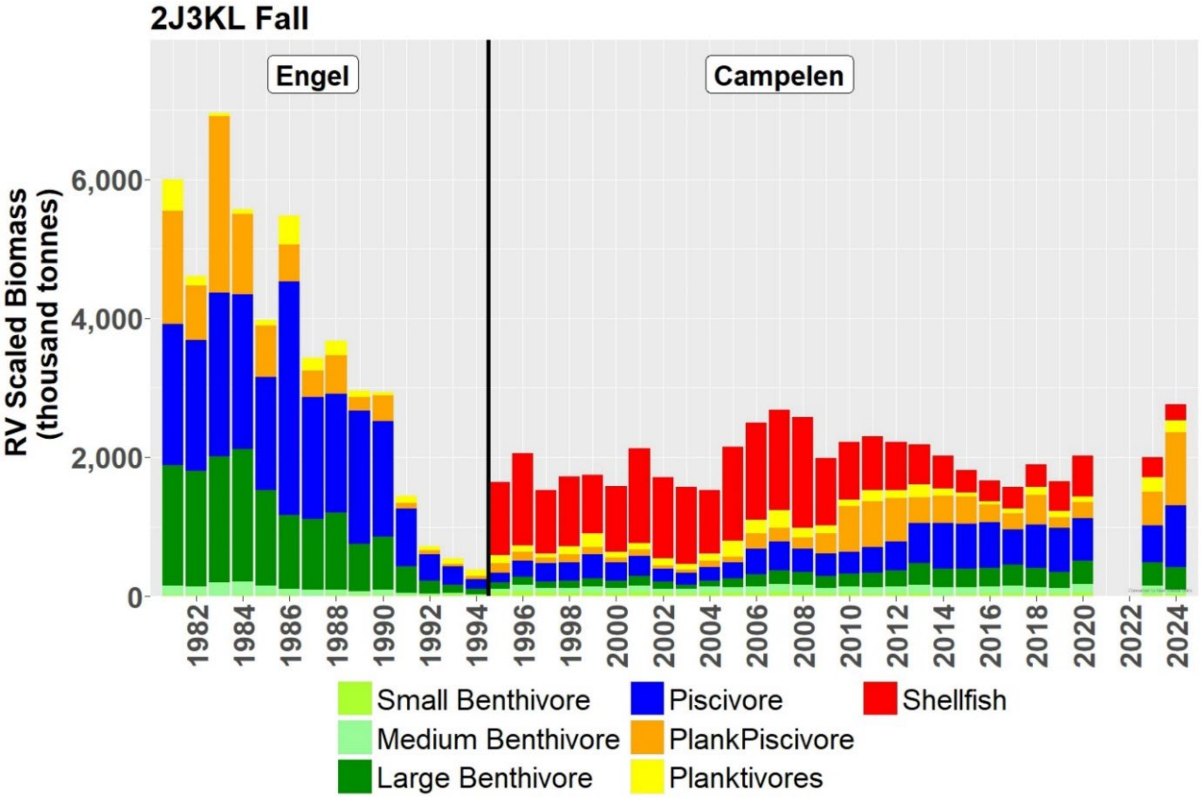

Figure 30. Total Fall RV Biomass index trend of the fish community in the Newfoundland Shelf and northern Grand Bank (Divs. 2J3KL) discriminated by fish functional groups. Indices for the Engel period (solid vertical line: 1981–1995) have been scaled to be comparable to the Campelen period (1996–2022) (Koen-Alonso and Cuff 2018). New Offshore Fisheries Science Vessels started operation in 2023 (vertical dashed line). Shellfish data were not consistently collected during the Engel period; the index for this functional group is unavailable before 1995.

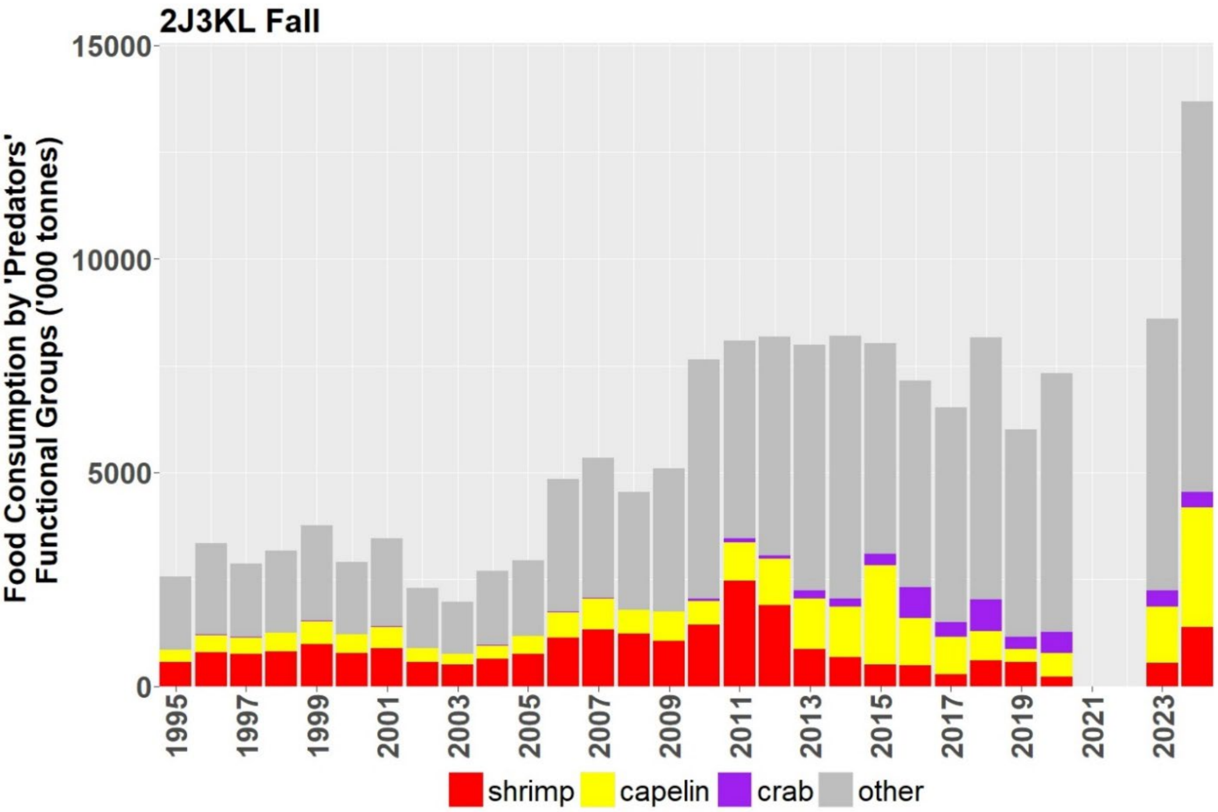

Figure 31. Consumption of Capelin, shrimp, and crab by fish predators in NAFO Div. 2J3KL in the fall (1995–2024).

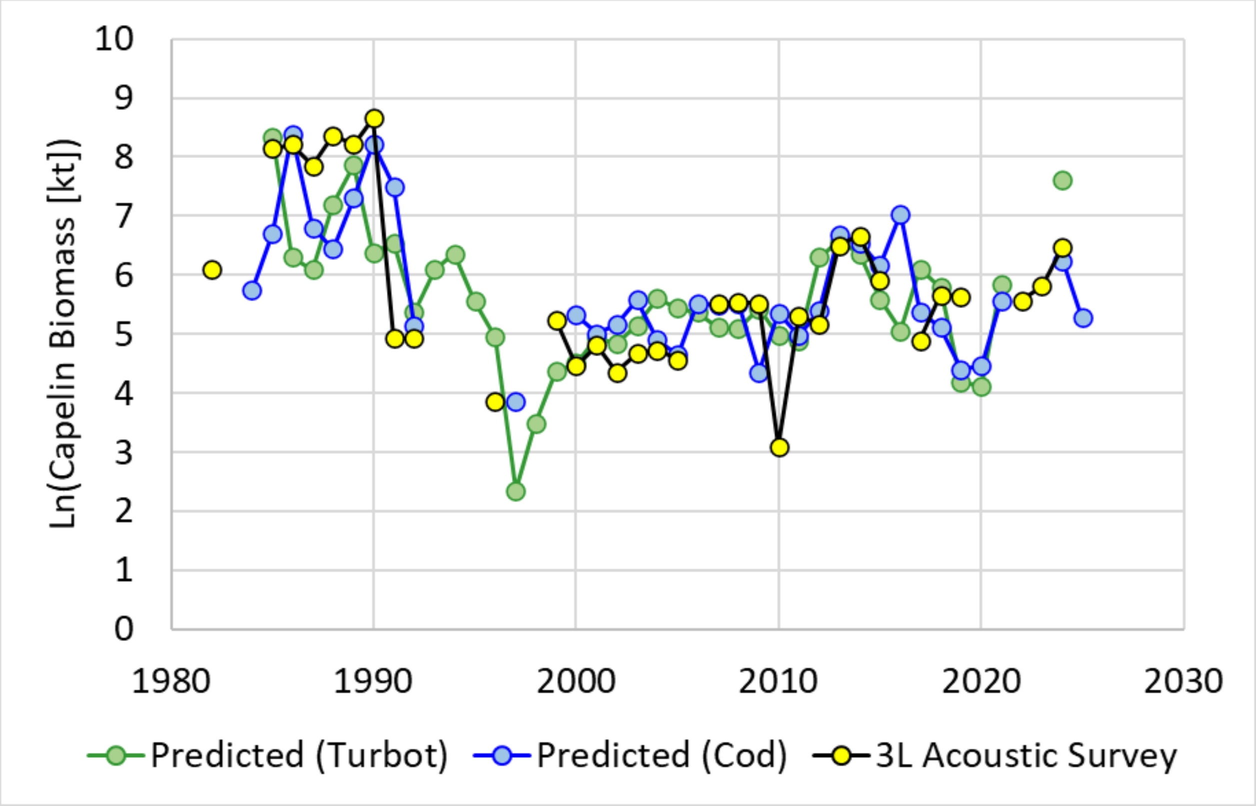

Figure 32. Capelin biomass Index from the 3L Spring acoustic survey index, and model predictions from two independent models of 3L Capelin Biomass Index as a function of the probability of Capelin in the diets of Cod and Turbot in NAFO Div. 2J3KL in the fall (1982–2024). Due to availability of data on the probability of Capelin in the diet, only the Cod model could be used to predict the expected Capelin Biomass Index in 2025, which shows a decline from the 2024 level.