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2022 STOCK STATUS UPDATE FOR CAPELIN IN NAFO DIVISIONS 2J3KL

Context

This Science Response Report results from the March 14–15, 2022 Regional Peer Review on the Stock Status Update of Divisions 2J+3KL Capelin (*Mallotus villosus*) as requested by Fisheries and Oceans Canada (DFO) Resource Management. A full Regional Peer Review meeting scheduled for March 8–11, 2022 was cancelled due to reduced spatial coverage in both the Capelin spring acoustic and fall multi-species bottom-trawl surveys in 2021. The resulting data limitations prevented DFO Science from conducting a full assessment of the stock. It was decided that the Centre for Science Advice (CSA), Newfoundland and Labrador (NL) Region would instead hold an internal DFO Stock Update.

This stock was last fully assessed in 2021 and included fishery-independent and commercial fishery data up to 2020, and a Capelin biomass forecast for the 2021 spring (May) acoustic survey. The basis of this update is new fishery-independent data and catch data from 2021.

Background

Since 1992, Capelin in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 2J, 3K and 3L have been assessed as a single stock complex (Fig. 1). There are two other assessed Capelin stocks in Canadian waters: the Gulf of St. Lawrence (Divs. 4RST) and the Southeast Shoal (Divs. 3NO; assessed by NAFO), and one unassessed stock on the south coast of Newfoundland (Subdivision [Subdiv.] 3Ps).

Capelin is a keystone forage fish species in the NL ecosystem. It spends the majority of its life offshore on the NL shelf but undergoes spring/summer spawning migrations to coastal areas in southern and northeastern Newfoundland to as far north as Labrador where it spawns on beaches and in nearshore deep-water habitats. The 2J3KL Capelin stock collapsed in the early-1990s with minimal subsequent recovery in the past 30 years (reviewed in Buren et al. 2019). The annual spring acoustic survey biomass index of largely immature age-2 Capelin declined by over an order of magnitude from the time series high of 6 million tonnes (t) in the late-1980s to less than 150,000 t in 1991. Since 1991, the index has remained low, on average 250,000 t over the past three decades. Historically, Capelin matured and spawned at ages 3–4. Following the collapse of the stock, immature Capelin experienced faster growth rates and matured earlier at ages 2–3, perhaps due to a compensatory response to less competition for food. During periods when immature fish have high growth rates, year-classes will mature and spawn at a younger age (Ricker 1981); and since the majority of NL Capelin are semelparous (Winters and Carscadden 1978, Shackell et al. 1994, Burton and Flynn 1998), increased immature growth rates and earlier maturation produces a spawning population that is both younger and smaller in length compared to fish maturing and spawning at older ages. When the stock collapsed, Capelin experienced an abrupt and persistent delay in beach spawning times, with spawning occurring approximately 18 days later in 1991–2019 compared to much of the 20th century (1919–90), and there has been minimal beach spawning in Labrador since the collapse in the stock (Murphy et al. 2021). Year-class strength is set early in the life history of

Capelin (Murphy et al. 2018), and weak year-classes are predicted to occur when spawning is later in the summer (Murphy et al. 2021).

Description of the Commercial Fishery

Historically, Capelin were harvested inshore on spawning beaches for food, bait, and fertilizer. A directed foreign large vessel offshore fishery for Capelin began in the early 1970s and was closed in Div. 3L in 1979 and in Divs. 2J3K in 1992 (Fig. 2). The peak offshore catch of 250,000 t occurred in 1976. During the late 1970s, a small vessel inshore fishery for roe-bearing female Capelin began. The inshore fishery is prosecuted using Capelin traps, purse seines, and to a lesser extent, beach seines. Since 1998, modified beach seines called “tuck seines” have been deployed to target Capelin in deeper waters. Peak inshore landings of approximately 80,000 t occurred from 1988 to 1990 (Fig. 2). Since 1991, annual landings have averaged ~25,000 t (Fig. 2). In some years, Capelin fishery effort and landings are negatively impacted by poor price, limited processing capacity, international markets (i.e., quota decisions in Iceland and Norway), and/or the relative profitability of competing fisheries such as Snow Crab. These factors may result in reduced participation in the fishery within particular bays, resulting in Total Allowable Catches (TACs) not being attained. In other years, the arrival of Capelin in specific bays may be later than expected resulting in fish plants switching to processing other species. For these reasons, the Capelin commercial catch rate is hyper-stable and may not reflect the status of the stock, so catch rate has not been used in the assessment of the 2J3KL Capelin stock since the 1990s.

Analysis and Response

Ecosystem Information

Capelin compose the middle trophic level of a ‘wasp-waist’ ecosystem (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 population dynamics (Buren et al. 2014a); and Capelin, in turn, play a vital role in the larger ecosystem by influencing the population dynamics of their predators (Buren et al. 2014b, Koen-Alonso et al. 2021).

The NL climate experiences fluctuations at decadal time scales, with potential impacts on ecosystem productivity. Since 2018, a warming trend has been observed, with 2021 being one of the warmest years on record (tied with 2010 and 1966) with a value of +1.3 Standard Deviation (SD) above the 1991–2020 average for the NL climate index (Fig. 3). While the impact of large-scale variations in ocean climate on Capelin is largely unknown, recent research found that the summer North Atlantic Oscillation and NL climate indices 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 hypothesized to influence adult Capelin and, by extension, biomass (Buren et al. 2014a).

There has been a general trend toward earlier onset of the spring phytoplankton bloom since the mid-2010s with mixed effects on total spring production (Fig. 4). Changes in zooplankton community structure were also evident during the same period, with an increasing trend in abundance of large, lipid-rich copepods (e.g., *Calanus finmarchicus*) and a decreasing trend in the abundance of small copepods (e.g., *Pseudocalanus* spp.), which resulted in an overall increase in total zooplankton biomass (Fig. 5; DFO 2021). These zooplankton community changes suggest improved foraging conditions for adult Capelin (Buren et al. 2014a) while larval foraging conditions may have declined (Murphy et al. 2018).

The fish community on the Newfoundland Shelf and Northern Grand Bank (NAFO Divs. 2J3KL) was dominated by finfishes (Capelin and groundfish) in the 1980s but these populations collapsed in the early 1990s while shellfish increased (Koen-Alonso and Cuff 2018, Buren et al. 2019). Even with the increases in shellfish since the 1990s, total biomass is far below pre-collapse levels. After the declines in the mid to late 2010s, there appears to be a moderate increase in biomass at the fish community level in Divs. 2J3K (no data for Div. 3L in 2021; Fig. 6A) with Capelin biomass in the bottom-trawl survey in 2021 the highest since 2014 (Fig. 6B). The 2021 fall distribution of Capelin extended northwards into Labrador (Div. 2J) which is typical of higher abundance years (2012–14; Fig. 6C). The abundance of age-2 Capelin in the fall bottom trawl survey was high in 2021. Based on previous years (2012–15), this trend suggests the possibility of high Capelin abundance in the spring acoustic survey in 2022 (Fig. 6D).

Capelin consumption by fish functional groups that are considered predators of forage species (i.e., medium and large benthivores, plankpiscivores, and piscivores) in Divs. 2J3K increased in 2020–21 compared to 2019 (Fig. 7A). The proportion of Capelin in the diet of its main predators, Atlantic Cod and Greenland Halibut (Turbot), increased to almost one quarter and one half, respectively, in Div. 2J in 2021 (Fig. 7B). Diet trends for Redfish are inconclusive due to small sample sizes. Diet changes were relatively minor in Div. 3K and there was no diet data from Div. 3L in 2021 (Fig. 7B). If predators' consumption and diets in the fall are an indicator of Capelin biomass the following spring, which our analyses suggest, an improvement in biomass in the 2022 Capelin acoustic survey would be expected.

Capelin biomass was predicted to increase in the 2021 spring acoustic survey relative to 2019–20 based upon models using the called stomachs (i.e., the two dominant prey items in sampled fish stomachs are recorded during the fall multi-species survey in Divs. 2J3K) of Atlantic cod and Turbot. These models link the Capelin acoustic biomass estimates and the average probability of Capelin in predator stomachs through a formulation derived from the functional response of the predator. The Atlantic cod model predicted a more modest increase compared to the Turbot model (Fig. 8; See Appendix 3 for model structure and diagnostics, and confidence intervals).

There is substantial uncertainty around each of the above analyses; however, the weight of evidence suggests positive signs for Capelin biomass in 2022.

Fishery

In 2021, the commercial fishery in Div. 2J3KL landed 13,945 t (96% of the 14,533 TAC for Divs. 2J3KL+ 3Ps; Fig. 2). Capelin TAC was reduced by 35% in 2018, with two subsequent reductions in 2020 (15%) and 2021 (24%).

Indicators of Stock Status

The Capelin stock assessment is based primarily on two fishery-independent data sources: an index of biomass of Capelin (primarily age-2) from the spring acoustic survey of Div. 3L and southern Div. 3K, and an index of larval Capelin abundance from Bellevue Beach, Trinity Bay (Div. 3L). Due to the COVID-19 pandemic, there was no spring acoustic survey in May 2020. In 2021, due to a lack of offshore research vessel availability, two 65' shrimp trawlers were contracted to conduct an acoustic survey of three offshore strata in Div. 3L in June (12 offshore strata are surveyed in a typical year; Fig. 9). These three core strata (strata A, B, C) typically contain ~60% of surveyed bi3omass each year. In 2020 and 2021, we were able to complete our typical sampling protocol at Bellevue Beach, as described in Nakashima and Mowbray 2014.

Additional data used in this Science Response Report are timing of beach spawning; Capelin biological characteristics (i.e., age, length, condition) from the modified spring acoustic and fall multi-species bottom-trawl (only Divs. 2J3K) surveys; and biological data of spawning fish from the commercial catch. The Capelin forecast model uses the Bellevue Beach larval index, summer *Pseudocalanus* spp. density, fall condition from the bottom-trawl survey in Divs. 2J3KL, and the timing of sea ice retreat. This model forecasts the Capelin biomass available to the spring acoustic survey in the current year and produces a partial forecast for the following year. Since we have had two consecutive years of missing or incomplete acoustic surveys, we are unable to refit the model with additional data and there are limited acoustic data available to 'ground-truth' the model forecasts for 2020 and 2021, which is considered best practice. Additionally, there are no fall condition data available from Div. 3L in 2021 due to the lack of fall multi-species survey coverage in Div. 3L. Thus, the Capelin forecast model will not be used to forecast Capelin biomass in the spring acoustic survey for May 2022 (in-season estimate) and May 2023. However, we will present results on how the partial acoustic survey results in 2021 fitted within the Capelin forecast model prediction interval for 2021 (DFO 2022), using updated data in the forecast model (e.g., known timing of sea ice retreat in 2021).

Beach Spawning Timing

Data on beach spawning timings were collected at Bellevue Beach (1990–2021) by DFO, and by a network of ~18 citizen scientists who checked their local beaches in Divs. 3KL+3Ps every 1–2 days in the summer (June–August) and recorded their observations of Capelin spawning behavior in a spawning diary (1991–2021) (Murphy et al. 2021). Peak spawning day at Bellevue Beach was June 20, 2021. Twenty beaches were monitored by the citizen science program in 2021 with three beaches recording no spawning behavior (one beach in 3Ps and two beaches in 3K) (Fig. 10). The median peak spawning day in 2021 was June 22, which is 17 days earlier than the 1991–2020 median (July 9). Spawning started first in Div. 3Ps (June 12; only 2 beaches monitored) followed by Div. 3K (June 19) and Div. 3L (June 27). It is atypical for spawning to occur in Div. 3K before Div. 3L. Early beach spawning in 2021 may bode well for the production of a strong 2021 year-class since early spawning predicts stronger year-classes (Murphy et al. 2021).

Bellevue Beach Larval Index

Age-2 Capelin recruitment was related to the Bellevue Beach larval abundance index for the years 2001–13 (Murphy et al. 2018). From 2001–21, the nearshore area adjacent to Bellevue Beach was surveyed every 1–3 days from the start to the end of larval emergence using surface plankton tows (Nakashima and Mowbray 2014). The Capelin larval index has been below average since 2014 and reached a time-series low in 2020. Even though there was earlier spawning at Bellevue Beach in 2021, the larval index remained below average (399 larvae m^{-3}, SE: ±106 m^{-3}; 2002–12 mean: 1,949 larvae m^{-3}). There have been eight consecutive low larval abundance years (2014–21) including all year-classes available to the fishery in 2022 (Fig. 11).

Spring Acoustic Survey Index

Spring (May) Capelin acoustic surveys have been conducted in their current form in most years since 1988: 1988–92, 1996, 1999–2005, 2007–15, 2017–19, and 2021 (partial coverage) (Fig. 12A). Following a period of very low biomass in the 1990s and early 2000s, the Capelin acoustic biomass index increased in 2007–12, with the exception of a record low value recorded in 2010. From 2013–15, the biomass index was at the highest levels observed since 1990. Since 2015, the biomass index is comparable to levels observed in the 2000s. The Capelin biomass index during the last complete acoustic survey in 2019 was 283 kt (95% confidence interval: 239–356 kt), which is similar to the average from 1999 to 2019 (272 kt), though remaining well below the average observed in the late 1980s (1988–90; 4,593 kt) (Fig. 12A). In 2021, the partial spring acoustic survey result in strata A, B, C was 474 kt (95% confidence interval: 319–578 kt) (Fig. 12B).

There are several important caveats to the 2021 Capelin acoustic survey results. First, the survey typically occurs in May, but in 2021 was conducted in June for the first time since 2003. Since spawning occurred in mid-June in 2021, the acoustic survey was conducted closer to spawning timing than any previous acoustic survey in the post-collapse period. This change in survey timing may have resulted in an increased availability of immature fish to the survey while the older, mature age-2+ fish may have been missed as they had already moved inshore to spawn. The high abundance of age-1 fish in the survey area may also be explained by a strong 2020 year-class and/or emigration of age-1 fish from the bays to offshore areas to avoid predation. The 1991 acoustic surveys, conducted in both May and June, also found a higher biomass of age-1 fish and a lower biomass of older fish in June (Miller and Carscadden 1991). Second, there were few Capelin samples collected during the acoustic survey, particularly in strata B and C (one sample from each of these stratum; Table 1), with only five trawl sets conducted compared to the typical 25–50 sets for the entire survey area. Capelin samples are used to determine age composition, calculate biomass estimates, and 'ground-truth' the acoustic signal as Arctic cod and Sand lance are also present in the surveyed area and it is important to confirm that the acoustic signal is from Capelin. Consequently, the June 2021 survey results should be considered with caution when comparing trends in biomass and biology to typical May surveys.

Biological (Age, Length, Condition) Characteristics

Due to the documented limitations of the June acoustic survey in 2021, only the age disaggregated survey results for immature age-2 Capelin are presented and analyses of age-1 and mature age-2+ fish are excluded from the Science Response Report due to potential migration to/emigration from the survey area. The immature age-2 biomass index was the second highest in the partial survey area (strata A, B and C) time series (2000–21) (Fig. 13), but still well below the age-2 biomass index from the late 1980s (not shown).

In 2021, the length frequency distribution of Capelin landed in the commercial fishery showed an increase in proportion of larger fish landed compared to 2020 and 2019 (Fig. 14). Capelin landed in 2014 and 2015 were the largest in the post-collapse time series (Fig. 14).

Relative condition (Le Cren 1951) of age-1 and age-2 Capelin collected during the fall bottom-trawl surveys is used in the Capelin forecast model and is hypothesized to correlate with adult over-winter survival (Lewis et al. 2019). Relative conditions were among the highest in the time series in 2020 and 2021 (Fig. 15). In 2021, relative condition in Divs. 2J3K was the highest of the time series, being marginally higher than in 2020. Relative condition for Divs. 2J3K in 2021 does not cover the entire Capelin stock area and should be considered with caution.

Capelin Forecast Model

The 2J3KL Capelin stock is typically assessed using actual and projected trends in the spring acoustic biomass index. Suitability of each Capelin forecast model projection (a suite of seven forecast models are run each year) is assessed using a combination of Deviance Information Criterion (DIC), Bayesian R^2, and the ability of each model to capture within its 95% credible intervals estimates of the Capelin biomass index from prior spring acoustic surveys. The impact of dropping a survey year when generating Capelin forecasts was examined during the 2021 Capelin stock assessment (DFO 2022). Forecasts missing the last 1 and 2 years of acoustic survey data were found to produce similar projection results to forecasts that were not missing these data, indicating that the forecast model is robust to short gaps in data availability for the period up to and including the 2019 survey (DFO 2022).

We were interested in evaluating how the partial acoustic survey results fitted within the Capelin forecast model prediction interval for 2021 to evaluate if there were significant increases or decreases in the Capelin stock since two years of full coverage acoustic surveys have been missed. We did not include a prediction for 2022 as the model could not be updated due to data limitations (i.e., lack of fall condition data in Div. 3L in 2021; not able to refit the model with 2020 and 2021 Capelin acoustic biomass estimates). The best model (based on DIC and Bayesian R^2) from the model suite run each year was the same one that was presented at the 2021 Capelin stock assessment, but with an updated value for the timing of sea ice retreat as it was now known. The observed biomass from the partial 2021 Capelin acoustic survey was above the median for the 2021 prediction interval and within both the 50% and 80% prediction intervals suggesting that were no unexpected increases or decreases in the stock in 2021 (Fig. 16).

Sources of Uncertainty

Two consecutive years of gaps in data collection due to the COVID-19 pandemic and research vessel availability limited our ability to provide science advice for this short-lived (typically 2–3 years) forage fish species.

Like all forage fish populations, Capelin is characterized by ‘boom-bust’ population dynamics, which are primarily driven by environmental factors. Capelin have been in a period of low productivity for 30 years (1991–2021). Climate change is associated with an increase in the magnitude and frequency of anomalies in environmental parameters, which has unknown ramifications for Capelin stock dynamics.

The Bellevue Beach larval index is based primarily on productivity from a single beach spawning habitat. The contribution of coastal deep-water spawning habitats to Capelin recruitment is currently unknown but is the focus of ongoing research.

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.

Conclusions

Due to offshore research vessel availability issues, the May 2021 acoustic survey could not be conducted. The results of a modified June 2021 spring survey were not directly comparable to May surveys conducted in prior years.

The 2021 partial spring acoustic survey index was within the forecasted prediction presented at the 2021 Capelin assessment, with no evidence of unexpected declines or increases in the stock. Due to data limitations, the Capelin forecast model could not be used to provide advice for the 2022 Capelin fishery.

The commercial fishery landed 96% of the Total Allowable Catch (TAC) for Divs. 2J3KL+3Ps in 2021 (13,945 t of the 14,533 t TAC).

Most analyses carried out for this update indicate a positive environment for Capelin production in 2021. This includes the earliest beach spawning since the 1980s, good fall Capelin condition, increased consumption of Capelin suggesting increased availability of Capelin, high numbers of age-2 Capelin in the partial acoustic and fall multispecies surveys, warming ocean trends, earlier spring blooms, and increased abundance of large copepods. However, low larval productivity, a key input in the forecast model, suggests continued low stock productivity.

Due to the uncertainty regarding 2021 stock levels and lack of projections for 2022, stock status could not be updated. Given this species' significant ecological role, a cautious approach to managing the fishery is advised.

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Appendix 1: Tables

Table 1. Biological sampling for strata A, B and C in Capelin spring acoustic surveys from 2000–21. (NA - not applicable). There were no spring acoustic surveys in 2006, 2016 and 2020.

Year	Strata	Samples (n)	LSM (n)	Length Mean (mm)	Std Dev
2000	A	14	1,826	136	30
-	B	0	0	NA	NA
-	C	0	0	NA	NA
-	**Total**	**14**	**1,826**	**136**	**30**
2001	A	4	214	150	15
-	B	3	404	148	20
-	C	7	692	144	26
-	**Total**	**14**	**1,310**	**146**	**23**
2002	A	2	384	138	17
-	B	3	127	125	23
-	C	5	893	123	30
-	**Total**	**10**	**1,404**	**127**	**27**
2003	A	0	0	NA	NA
-	B	6	731	149	14
-	C	3	161	146	26
-	**Total**	**9**	**892**	**148**	**17**
2004	A	5	823	125	27
-	B	3	497	125	20
-	C	4	677	133	21
-	**Total**	**12**	**1,997**	**128**	**24**

Year	Strata	Samples (n)	LSM (n)	Length Mean (mm)	Std Dev
2005	A	2	400	105	34
-	B	1	39	158	11
-	C	3	600	154	13
-	**Total**	**6**	**1,039**	**135**	**34**
2007	A	6	1,200	134	26
-	B	1	200	144	15
-	C	1	200	123	8
-	**Total**	**8**	**1,600**	**134**	**24**
2008	A	6	1,200	140	19
-	B	3	600	114	24
-	C	2	400	159	18
-	**Total**	**11**	**2,200**	**137**	**26**
2009	A	5	880	131	18
-	B	2	400	130	19
-	C	4	800	117	23
-	**Total**	**11**	**2,080**	**125**	**21**
2010	A	2	400	142	14
-	B	3	600	130	20
-	C	2	221	116	25
-	**Total**	**7**	**1,221**	**131**	**21**
2011	A	10	1,401	126	28
-	B	5	1,000	141	17
-	C	4	756	139	14

Year	Strata	Samples (n)	LSM (n)	Length Mean (mm)	Std Dev
-	**Total**	**19**	**3,157**	**134**	**23**
2012	A	6	1,061	138	21
-	B	2	400	128	14
-	C	4	682	125	14
-	**Total**	**12**	**2,143**	**132**	**19**
2013	A	6	880	127	39
-	B	4	672	137	24
-	C	3	600	150	19
-	**Total**	**13**	**2,152**	**137**	**32**
2014	A	5	1,000	128	15
-	B	3	530	115	13
-	C	1	200	128	17
-	**Total**	**9**	**1,730**	**124**	**16**
2015	A	4	617	118	18
-	B	2	400	112	19
-	C	3	600	126	29
-	**Total**	**9**	**1,617**	**119**	**24**
2017	A	4	71	145	19
-	B	2	192	128	18
-	C	3	409	124	15
-	**Total**	**9**	**672**	**128**	**17**
2018	A	3	469	127	19
-	B	3	600	126	17

Year	Strata	Samples (n)	LSM (n)	Length Mean (mm)	Std Dev
-	C	3	467	137	22
-	**Total**	**9**	**1,536**	**130**	**20**
2019	A	5	1,000	142	25
-	B	3	600	155	14
-	C	3	273	163	14
-	**Total**	**11**	**1,873**	**149**	**22**
2021	A	3	600	99	22
-	B	1	200	118	30
-	C	1	13	112	21
-	**Total**	**5**	**813**	**104**	**26**

Appendix 2: Figures

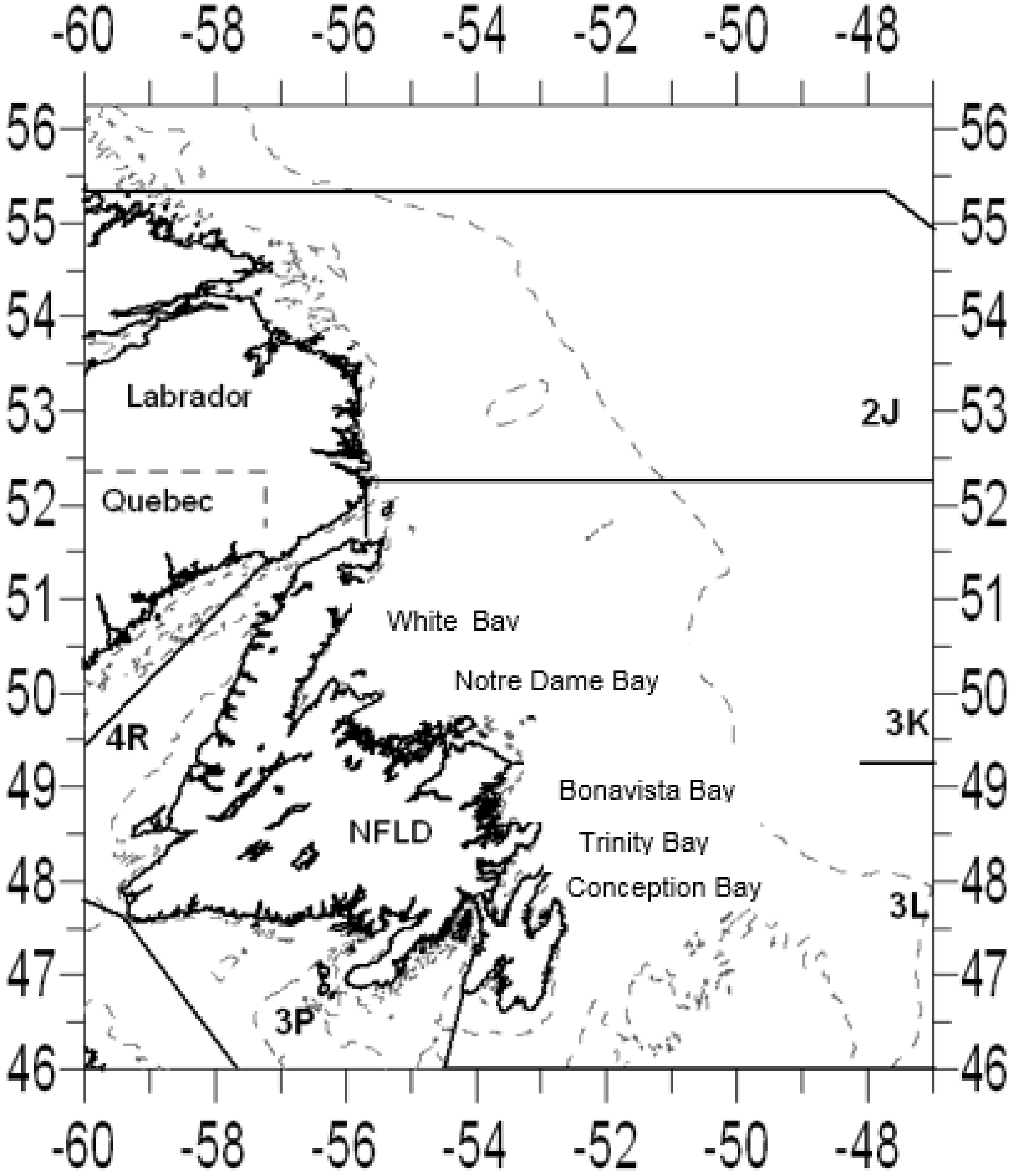

Figure 1. Capelin stock area in NAFO Divisions 2J3KL with 100 m and 500 m bathymetric contours.

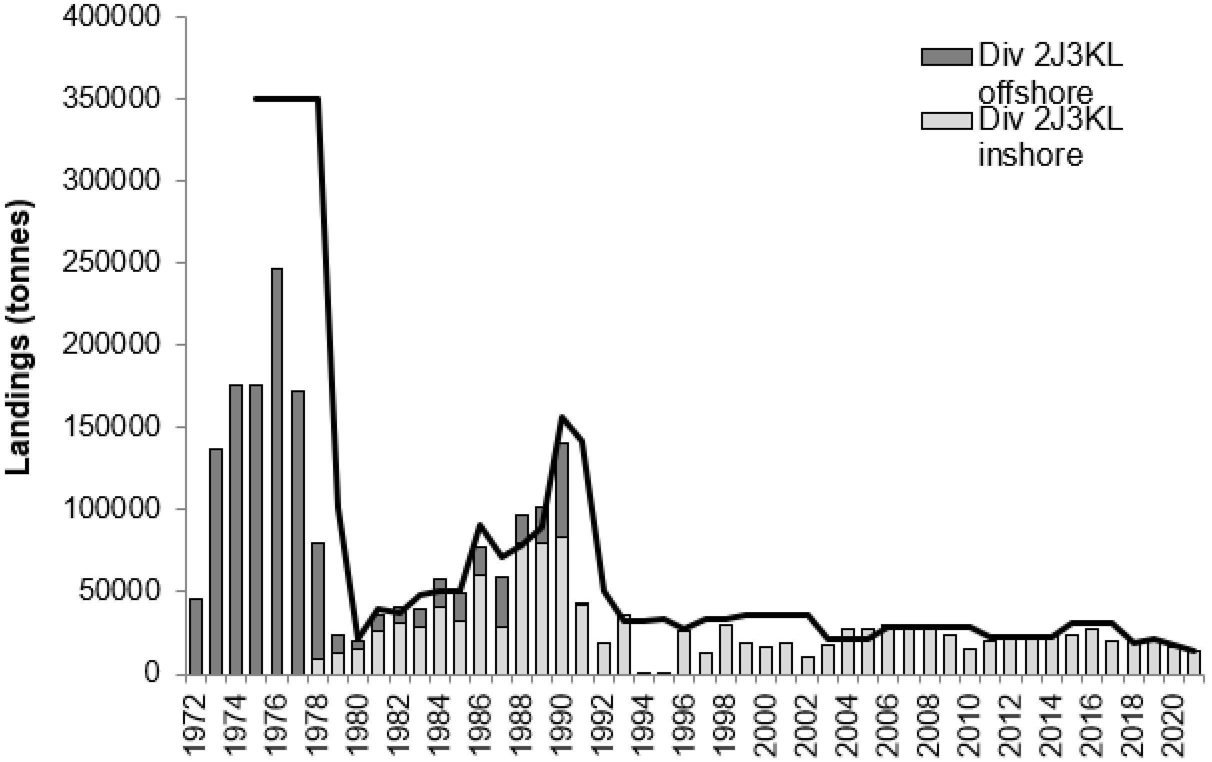

Figure 2. Inshore landings (light grey bars), offshore landings (dark grey bars) and Total Allowable Catch (TAC) (line) for Capelin in Divs. 2J3KL from 1972 to 2021. Note that annual inshore landings were likely greater than 0 t between 1972 and 1977, but they were not recorded prior to 1978.

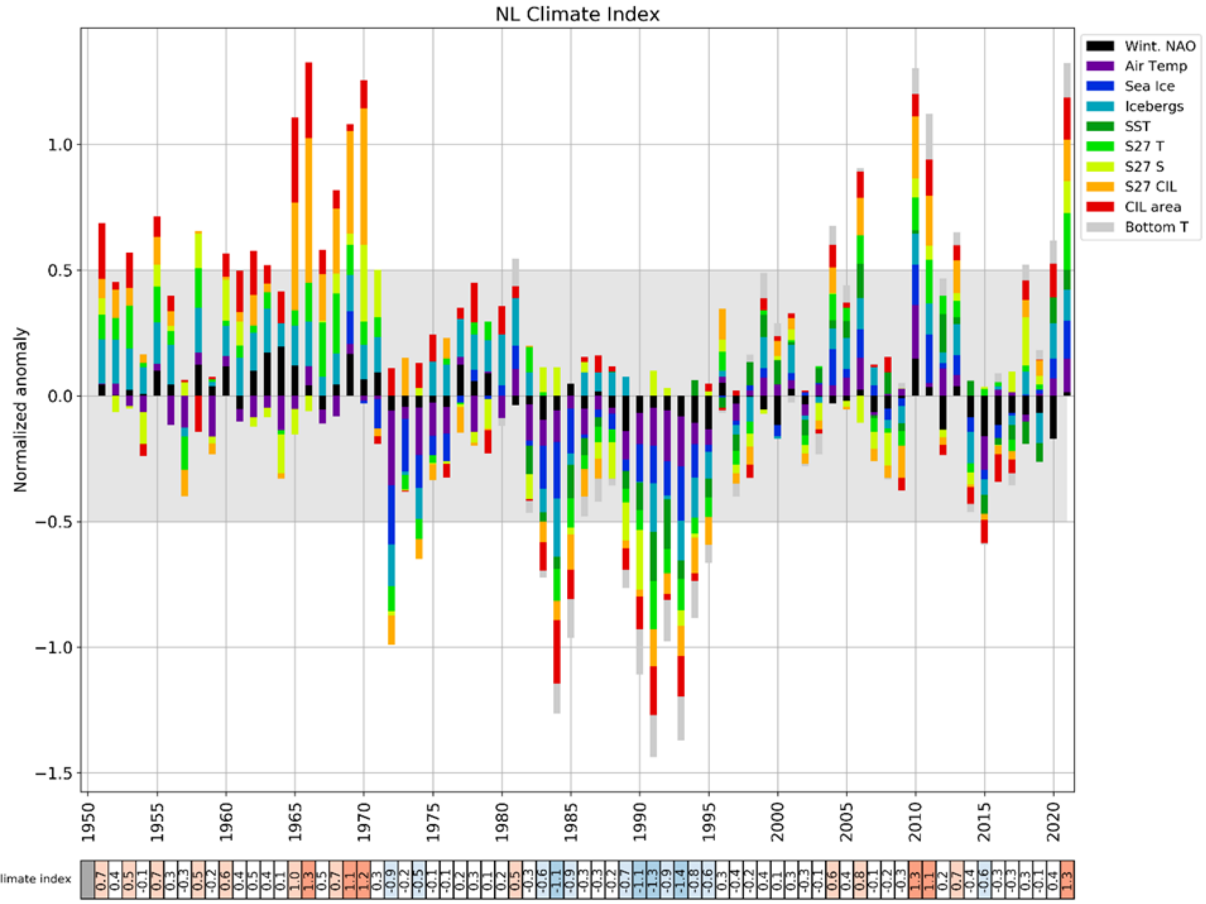

Figure 3. Newfoundland and Labrador (NL) Climate Index (Cyr and Galbraith 2021). This normalized index is made of the average of 10 sub-indices representing different aspects of the ocean climate (see legend). It aims to represent the general climate of the NL shelf and the Northwest Atlantic as a whole. A positive index is generally indicative of a warmer climate, while a negative index is indicative of a colder climate. Values within the gray area (±0.5 SD) are considered normal. See Cyr and Galbraith (2021) for reference to the data and methodology.

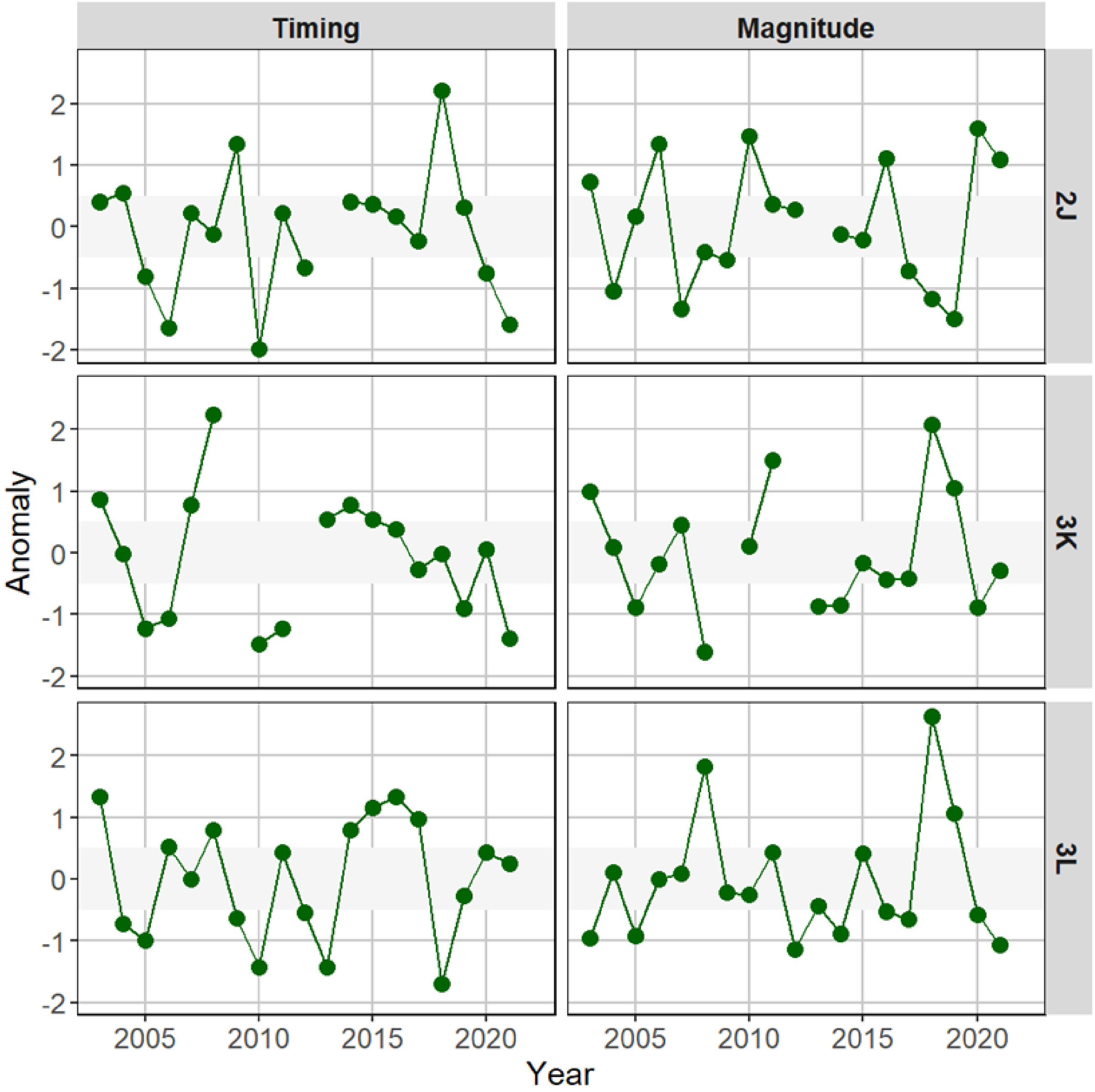

Figure 4. Standardized anomalies of the timing and magnitude (i.e., total production) of the spring phytoplankton bloom in NAFO Divisions 2J3KL. Anomalies were calculated using satellite surface chlorophyll a concentration derived from the MODIS sensor and a 2003–20 reference period. Anomalies within ±0.5 SD (grey band) indicate normal conditions.

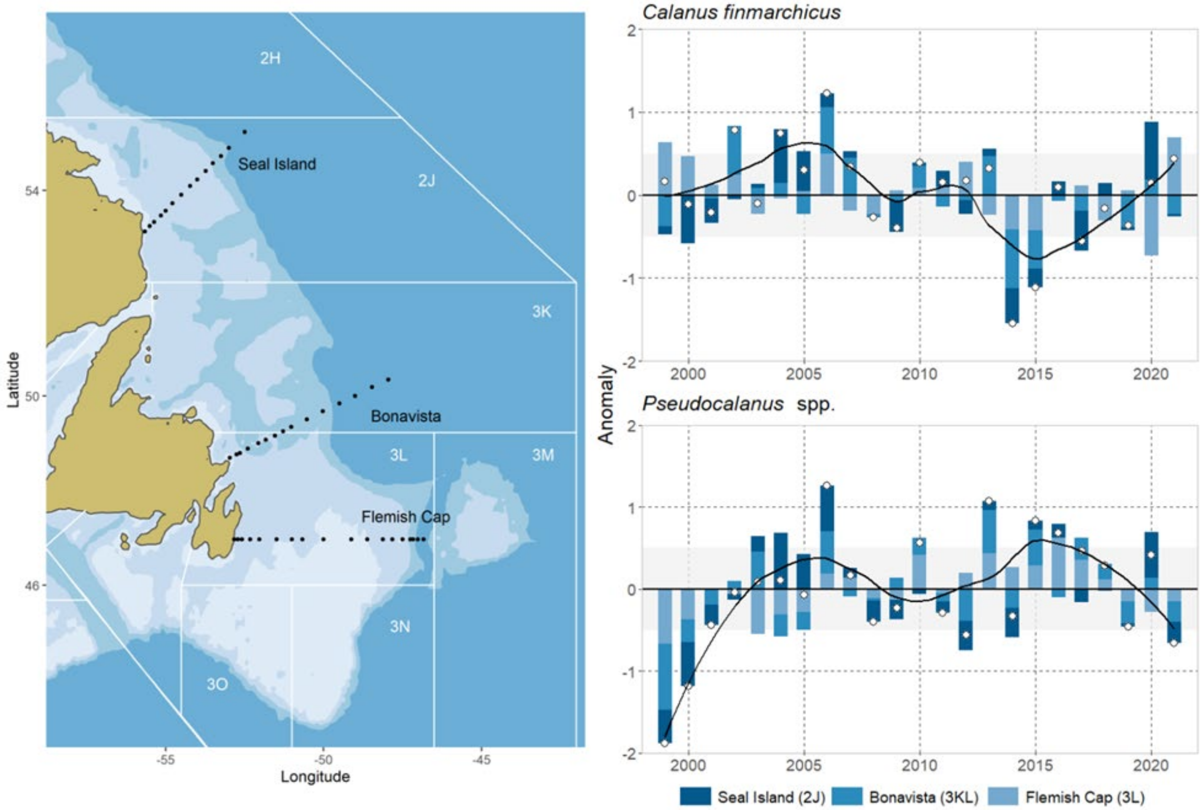

Figure 5. Location of the AZMP oceanographic sections and standardized anomalies for the abundance of large Calanus finmarchicus and small Pseudocalanus spp. copepods. Anomalies were calculated using copepod abundances derived from vertical net tows (full water column depth) carried out along standard AZMP oceanographic sections, and a 1999–2020 reference period. Open circles in the right panels indicate the mean anomaly in the Capelin assessment divisions (NAFO Divs. 2J3KL). Vertical coloured bars indicate the relative contribution of each oceanographic section to the annual mean anomaly. Black lines are LOESS regressions indicating the overall temporal trends in the abundance for each copepod taxa. Anomalies within ±0.5 SD (grey band) indicate normal conditions.

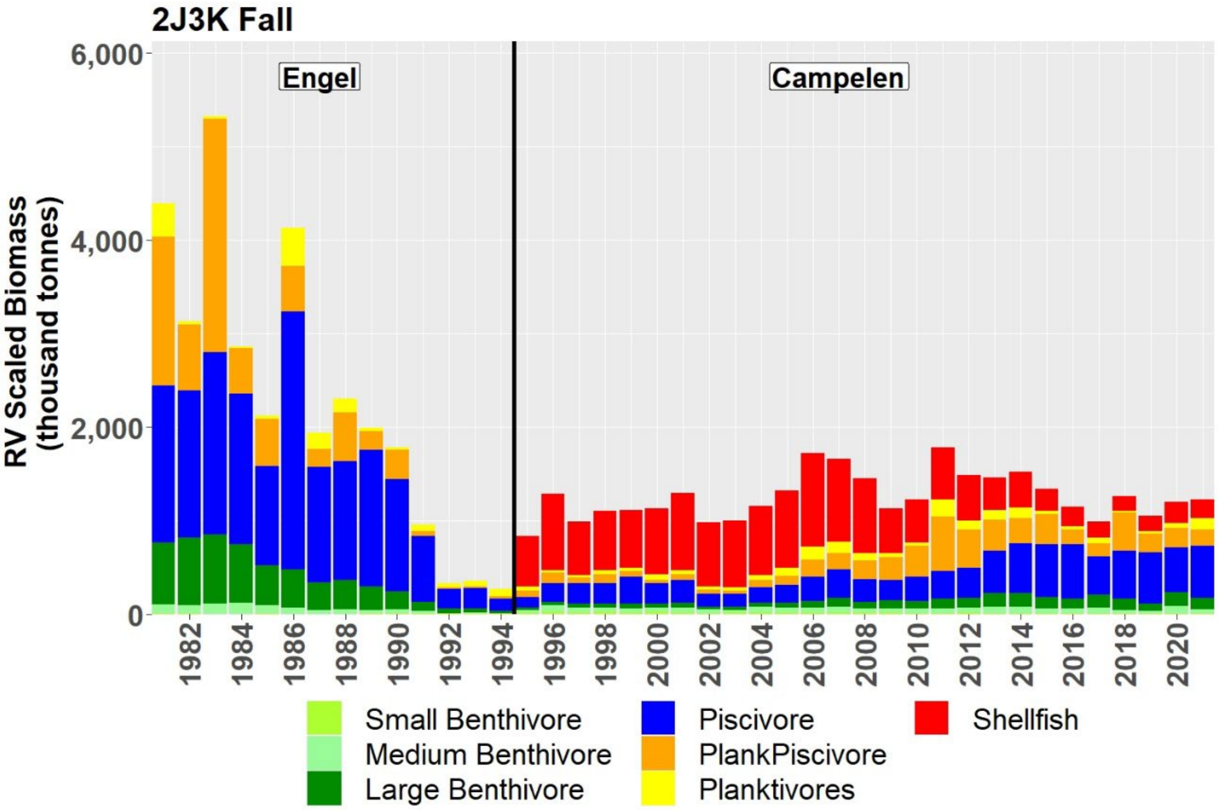

Figure 6A. Total Fall RV Biomass index trend of the fish community in the Newfoundland Shelf and northern Grand Bank (Divs. 2J3K) discriminated by fish functional groups. Indices for the Engel period have been scaled to be comparable to the Campelen series (Koen-Alonso and Cuff 2018). Shellfish data were not consistently collected during the Engel period so the index for this functional group is not available prior to 1995. Note that this figure does not include data for Div. 3L due to lack of survey coverage in this division in 2021.

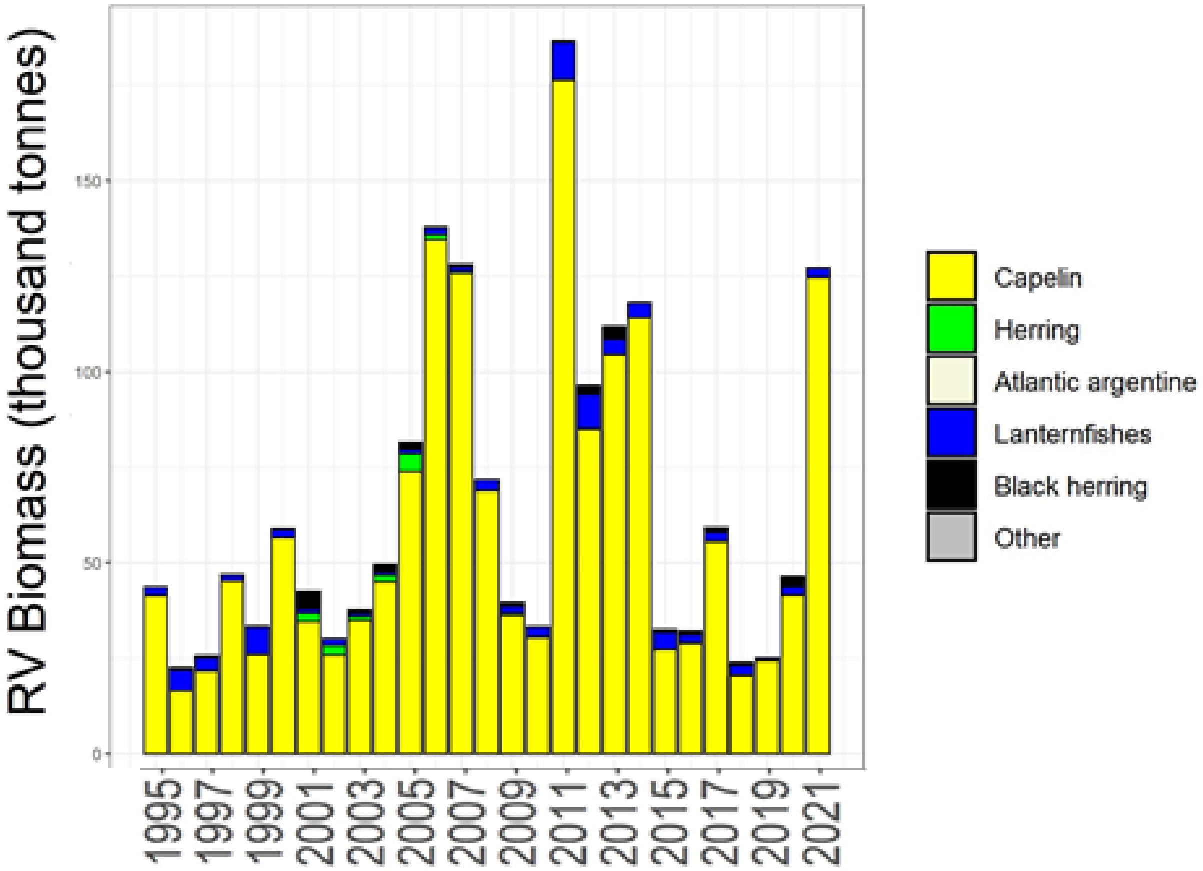

Figure 6B. Biomass of planktivores (i.e., Capelin, Herring) sampled during the Div. 2J3K fall bottom-trawl survey (1995–2021).

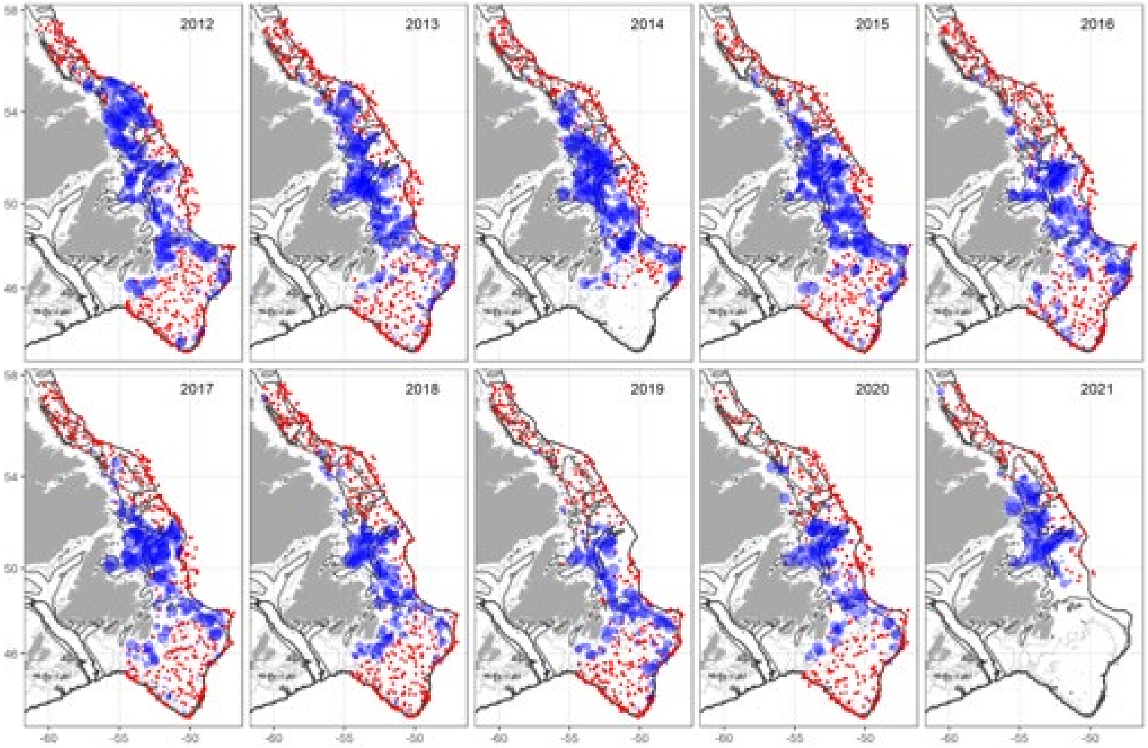

Figure 6C. Distribution of Capelin catches in the fall Divs. 2J3KL bottom-trawl survey (2012–21); note that there are no data from Div. 3L in 2021. Red dots are survey sets with no Capelin and expanding blue dots are catches of Capelin. The areas of the blue dots are proportional to the log (standardized catch [kg] + 1).

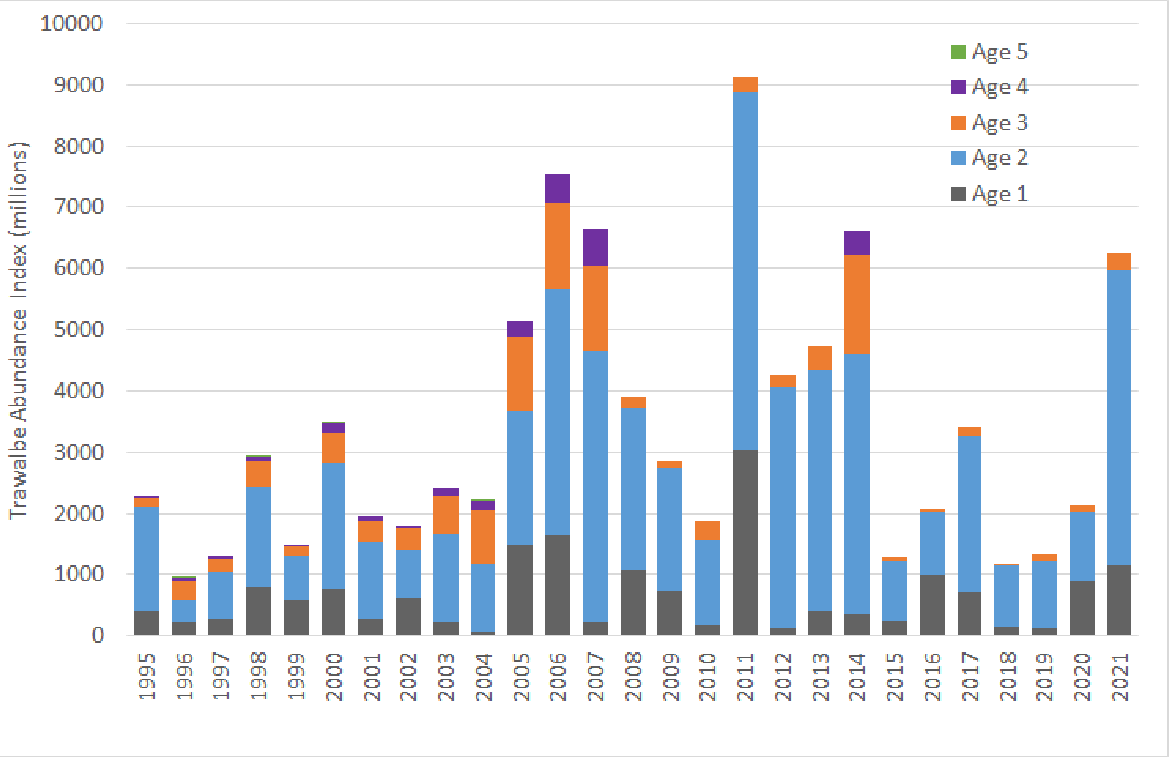

Figure 6D. Fall RV bottom-trawl Capelin abundance index in Divisions 2J3K, by age class.

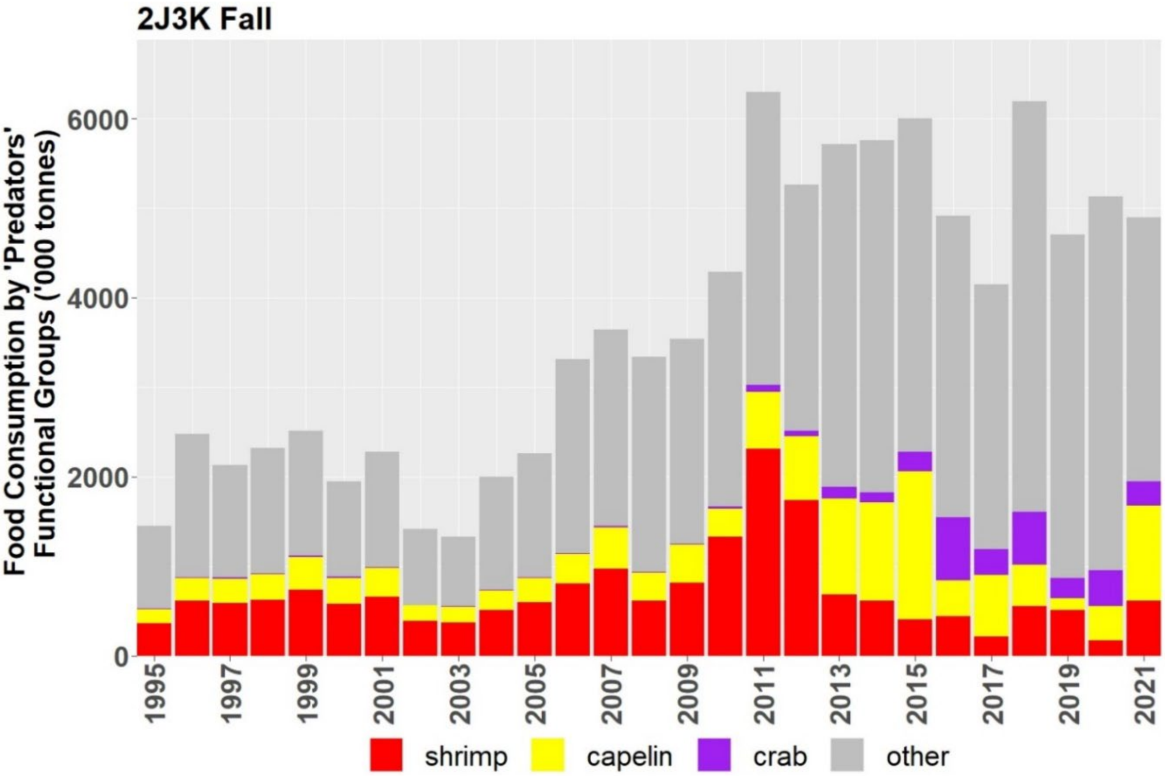

Figure 7A. Consumption of shrimp, Capelin and crab by fish predators in NAFO Div. 2J3K only (1995–2021; data from Div. 3L excluded based on lack of survey coverage in 2021).

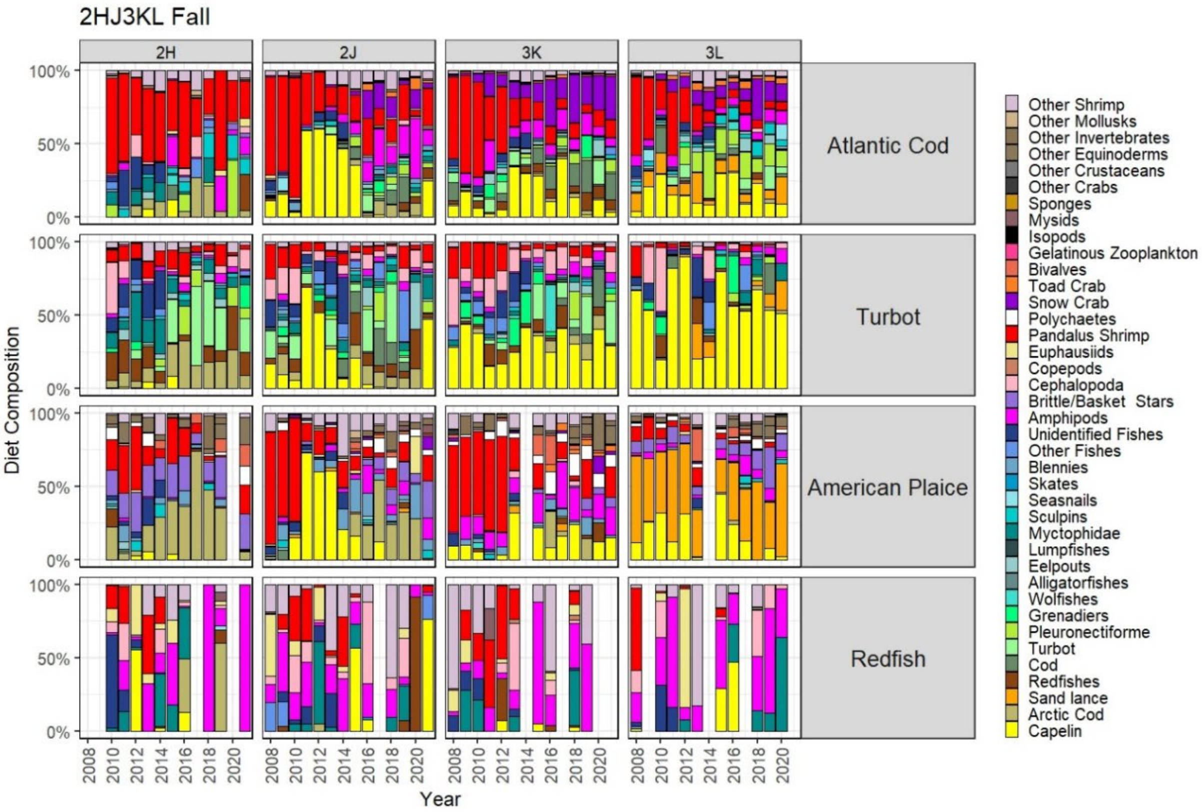

Figure 7B. Detailed diet of three main finfish predators of Capelin: Atlantic cod, Turbot, and American Plaice (2010–21). Note the lack of data in Division 3L in 2021.

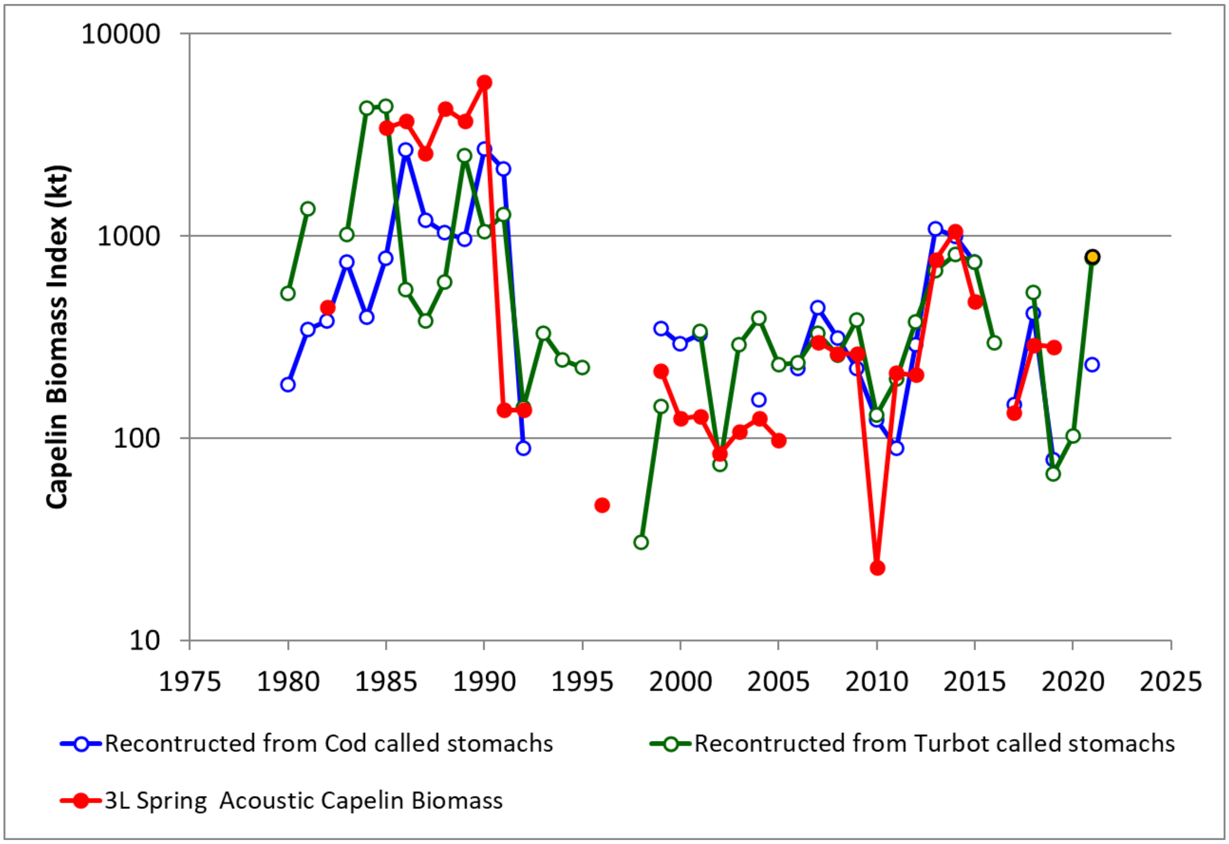

Figure 8. Called stomachs of Atlantic cod and Turbot (lagged by one year) are used to model Capelin biomass in the spring acoustic survey. Predictions of Capelin biomass are produced for 2021 from each predator. Yellow dot: the Turbot prediction is underneath the yellow dot, which is the scaled up 2021 acoustic survey and not used in the fit.

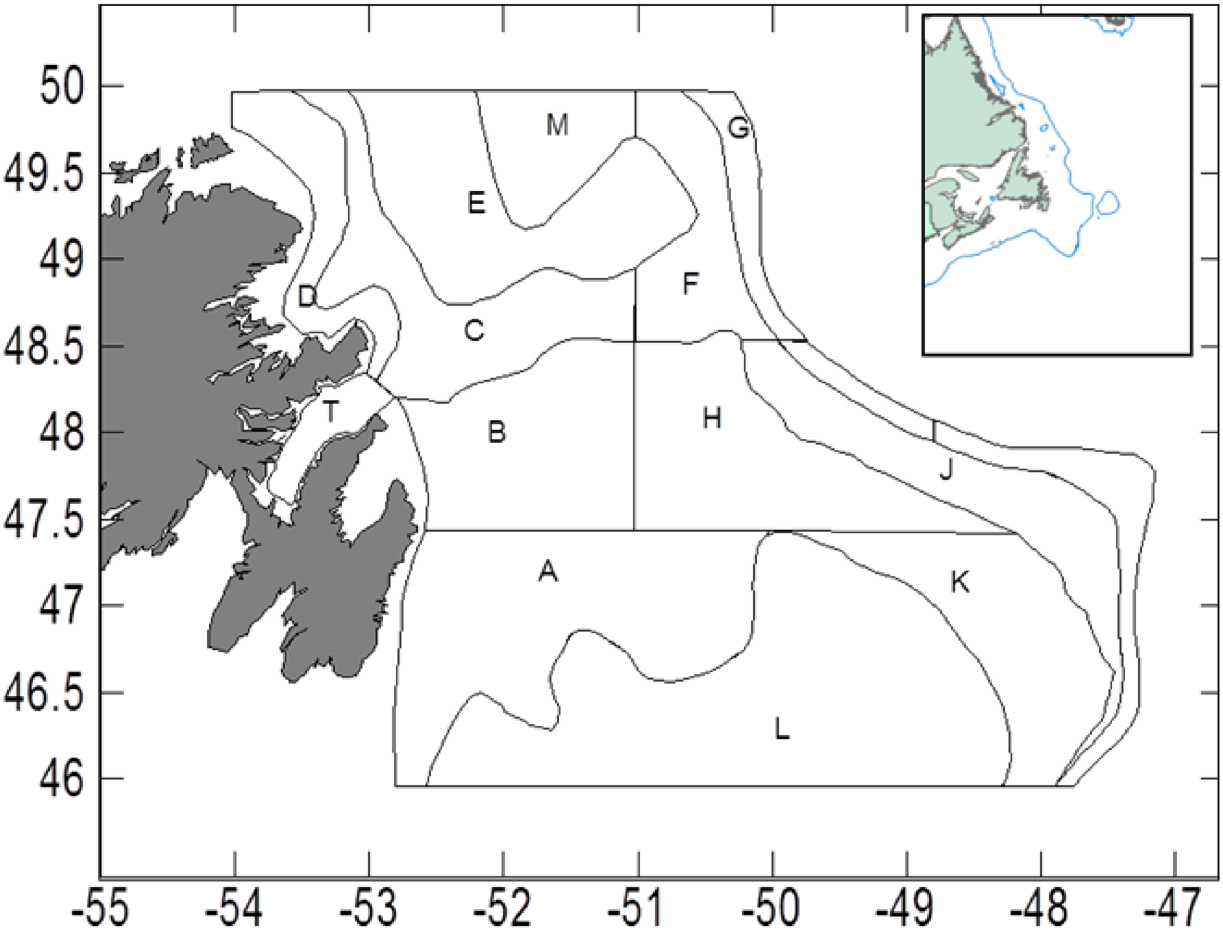

Figure 9. Capelin spring acoustic survey strata. Only strata A, B, and C were surveyed in 2021. In a typical survey year, all 12 offshore strata are surveyed.

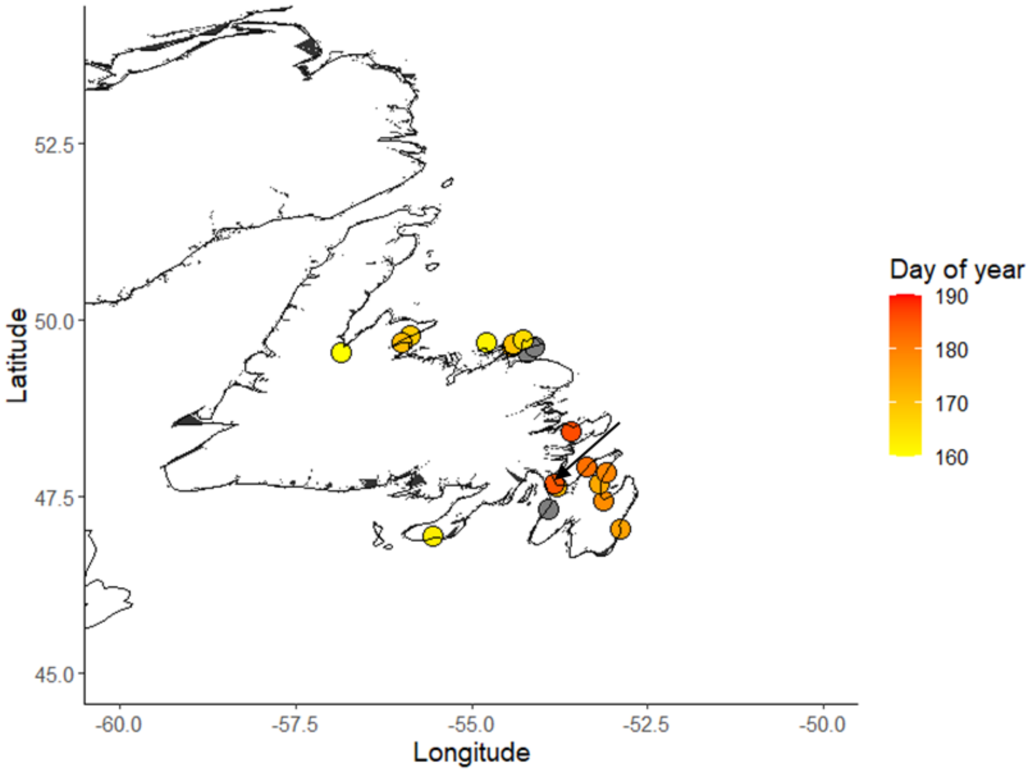

Figure 10. Capelin spawning timing in 2021 at the 20 beaches monitored in the Capelin spawning diary program including Bellevue Beach (indicated by the black arrow). Grey dots indicate monitored beaches with no spawning recorded in 2021. Note that there is an overlap of points on Fogo and Change Islands where 7 beaches were monitored (Div. 3K).

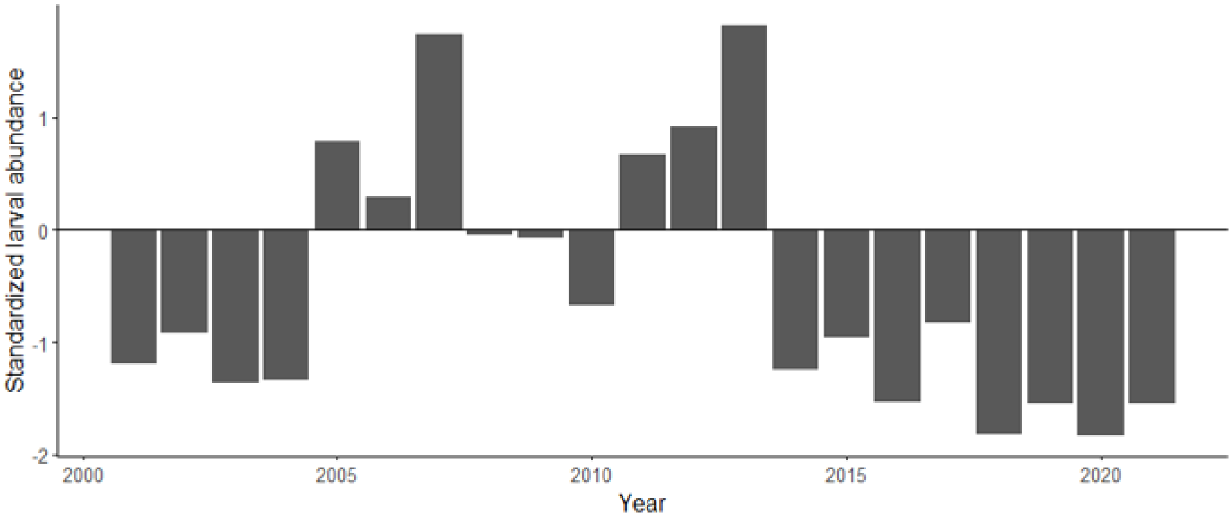

Figure 11. Standardized Capelin larval index from Bellevue Beach, Trinity Bay for the 2001 to 2021 year-classes. Negative anomalies indicate below average annual larval production. The reference period for standardization was 2002–12.

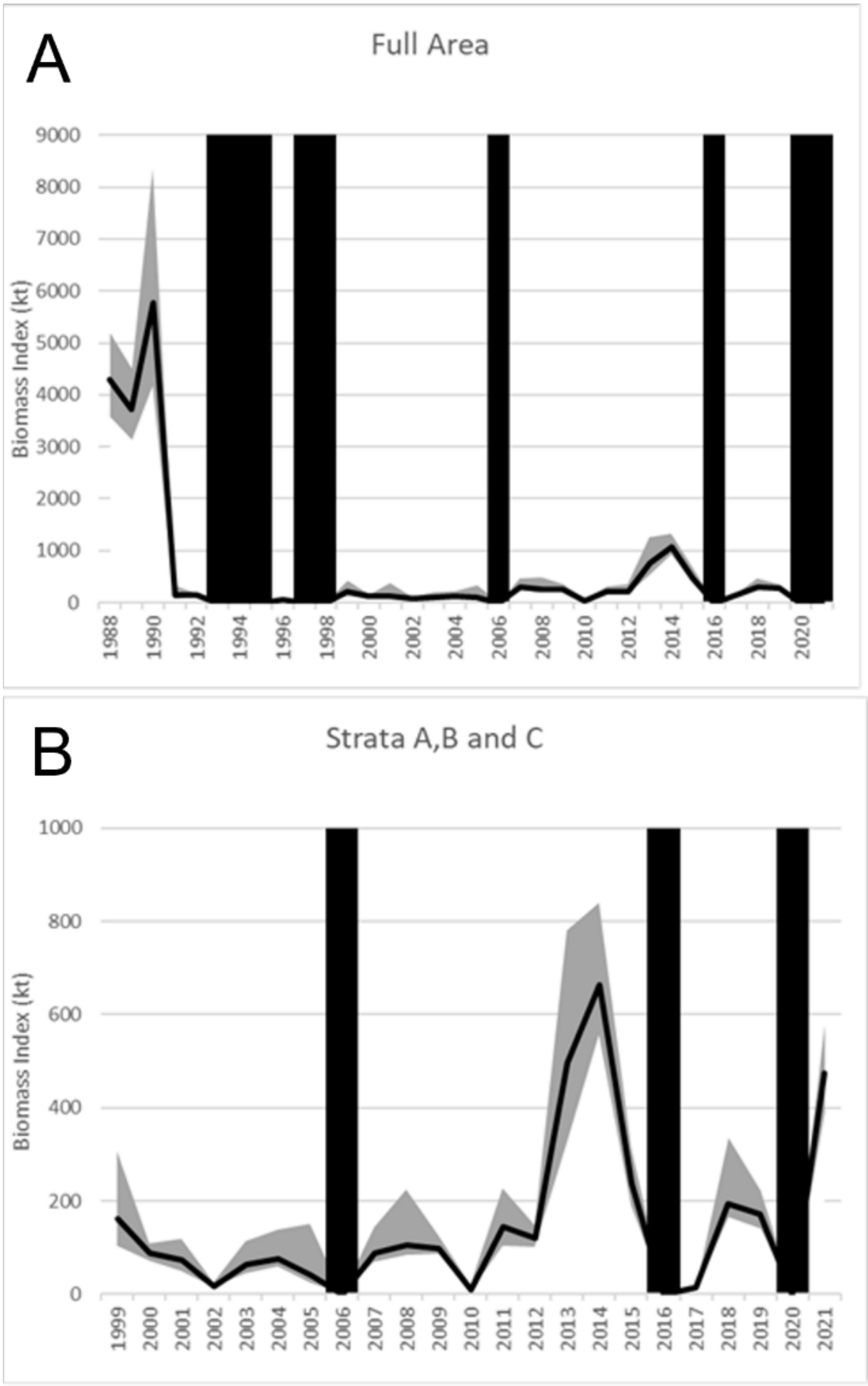

Figure 12. Acoustic survey biomass indices for (A) full survey area (1988–2021), and (B) strata A, B, C only (1999–2021). Black vertical bars indicate years when no data were available. Black line gives median values, grey shaded area indicates 90% confidence intervals. Note the difference in scales for the y-axis.

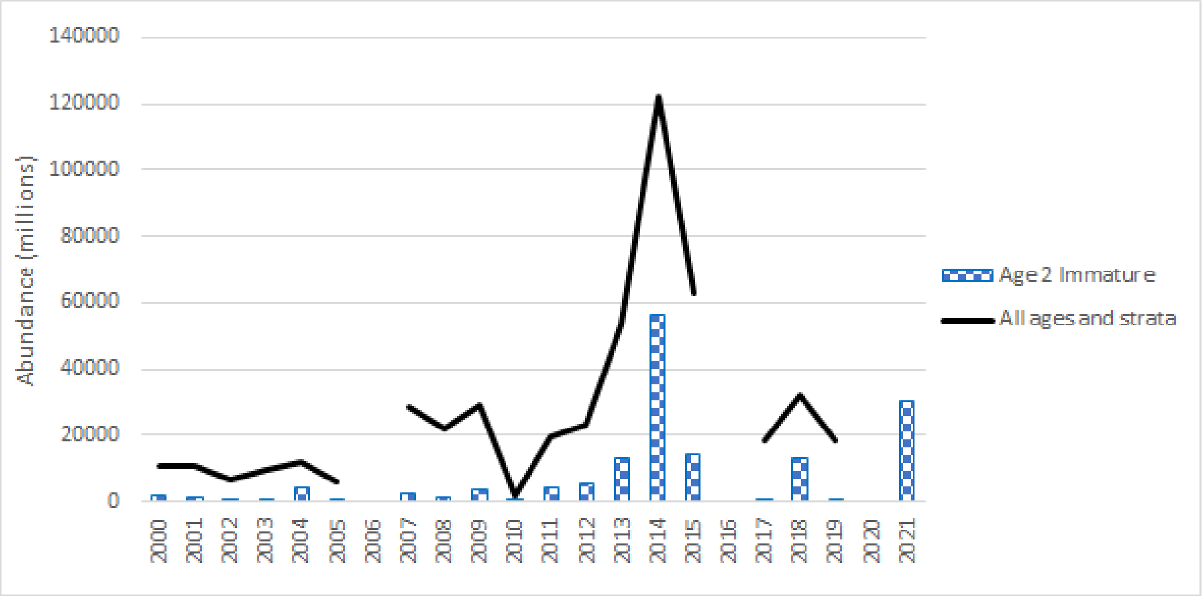

Figure 13. The Capelin spring acoustic survey abundance index for age 2 immature capelin in the reduced survey area (strata A, B and C) for the years 2000–21. Black line indicates total abundance for all age classes from previous years' spring acoustic surveys (full survey area with all 12 strata surveyed). No surveys conducted in 2006, 2016 and 2020.

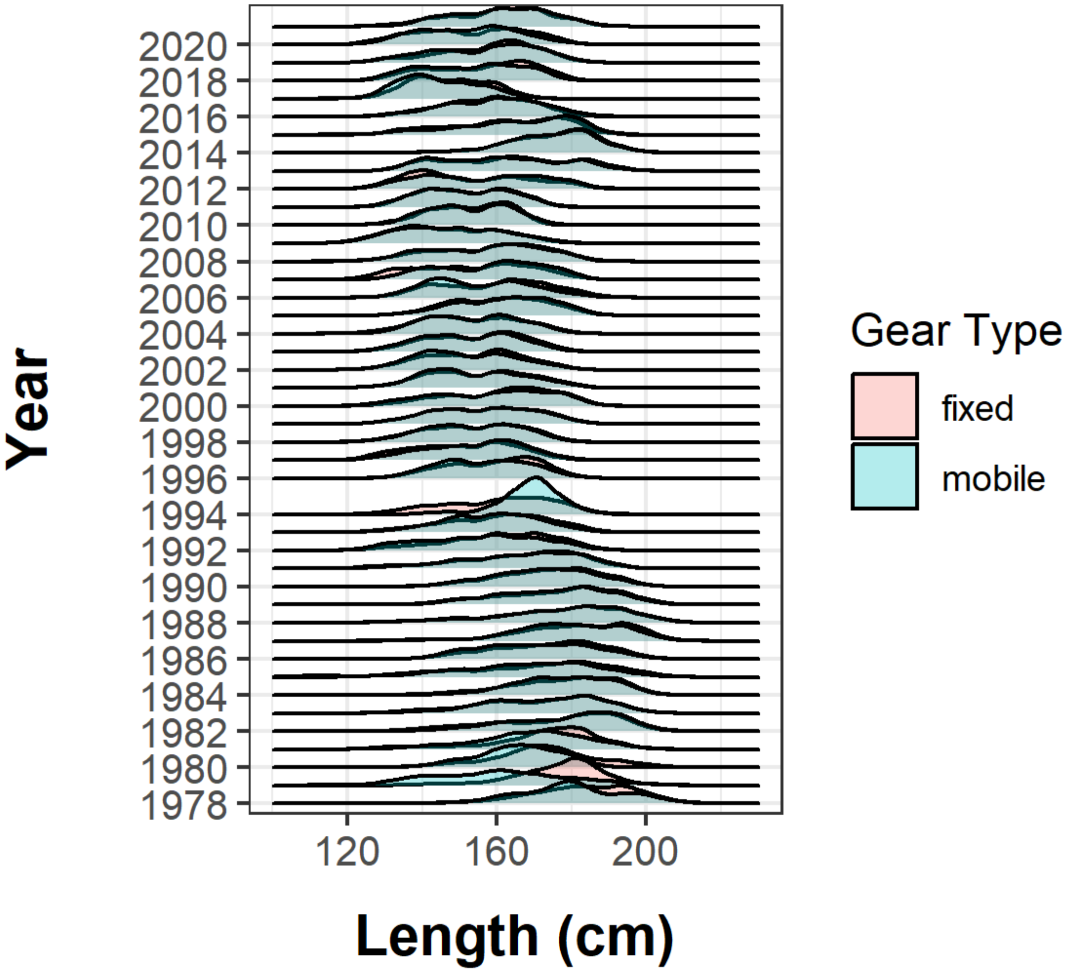

Figure 14. Length-frequency distribution of Capelin landed in the commercial fishery for the years 1978–2021. Length-frequency distributions are by gear type (mobile [purse seines] and fixed [traps, tuck seines]).

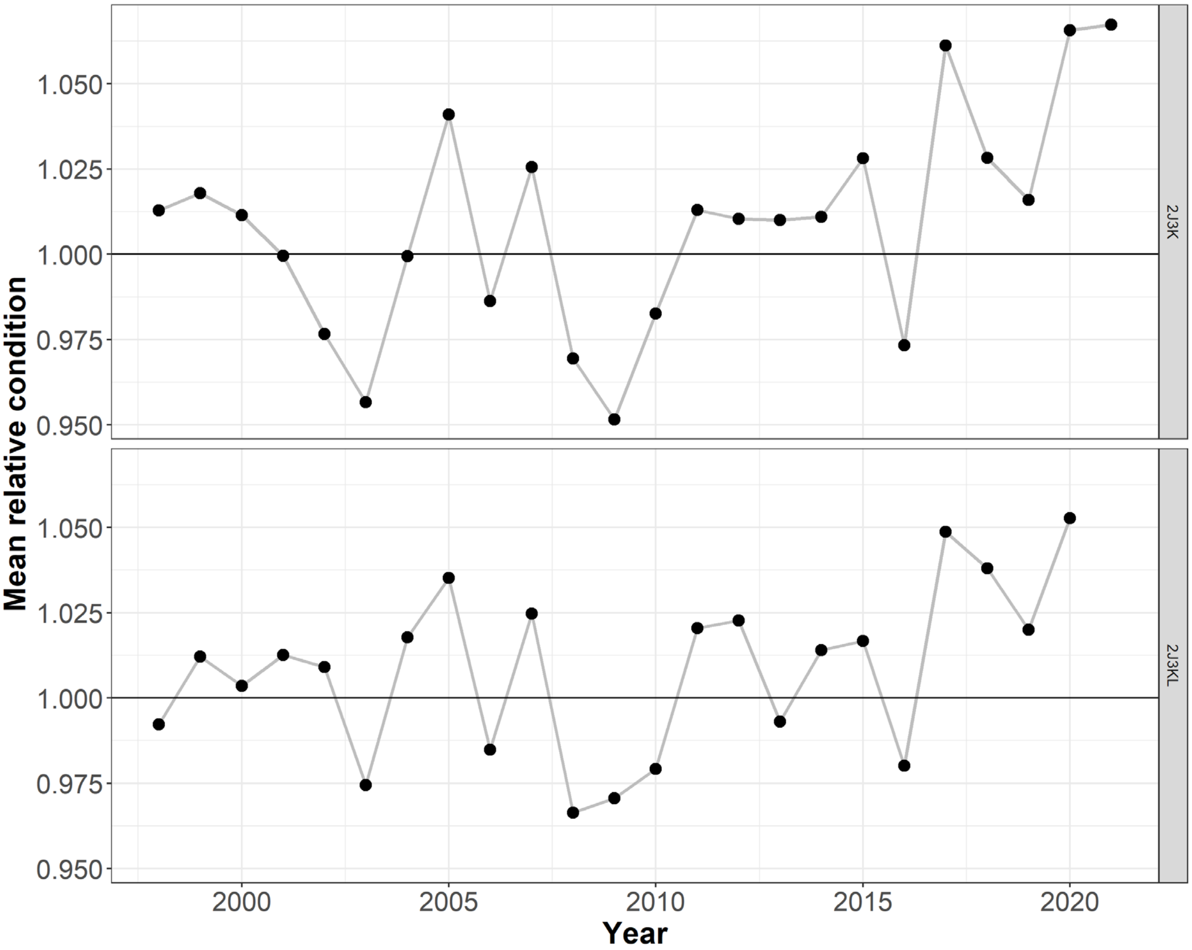

Figure 15. Mean relative condition of age-1 and -2 Capelin pooled by sex sampled in the fall multi-species bottom trawl survey by year (1995–2021) for NAFO Divisions 2J3K (top) and 2J3KL (bottom).

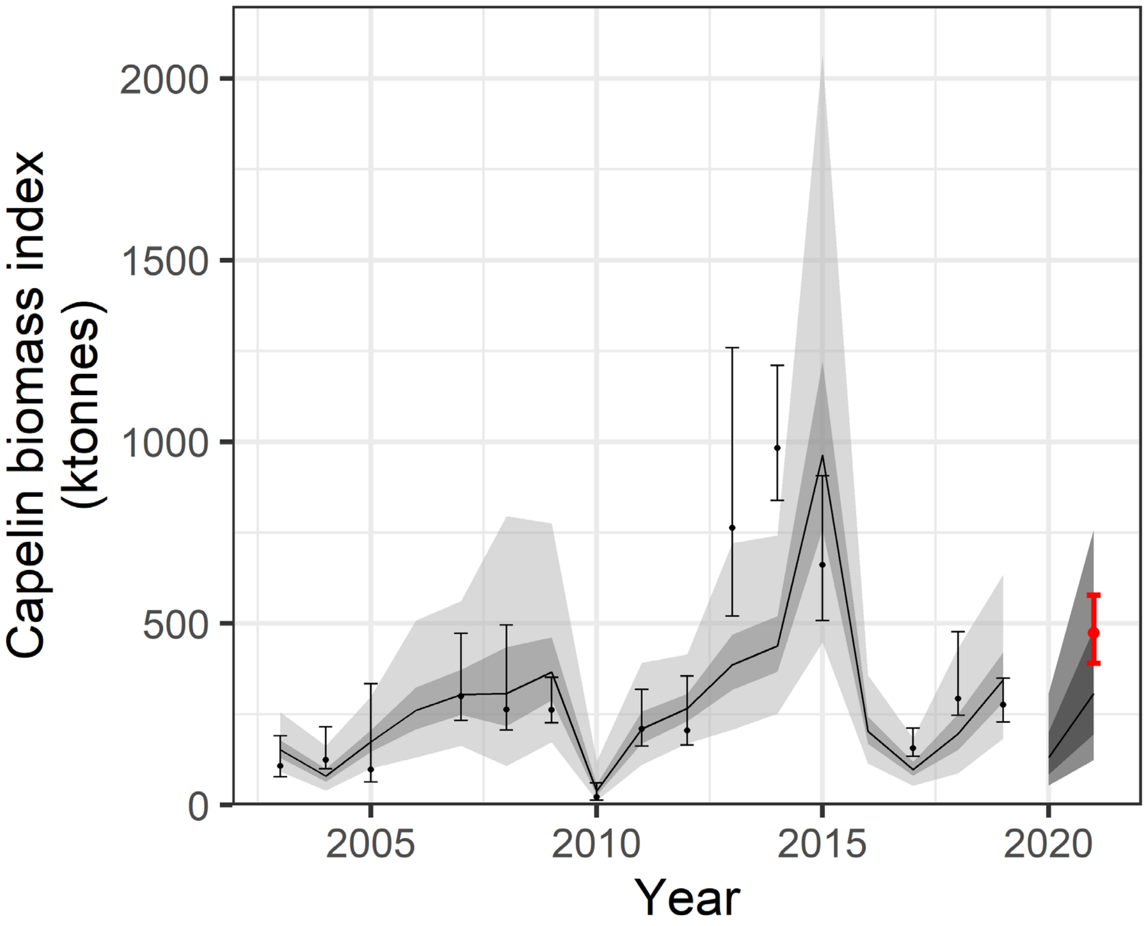

Figure 16. The Capelin forecast model presented at the 2021 Capelin stock assessment with an updated known value of timing of the sea ice retreat in 2021 (an estimated value was used in the 2021 Capelin stock assessment). The observed biomass from the 2021 June acoustic survey is show with the red point ± 95% confidence intervals. The 95% credible (light grey) and 80% prediction intervals (dark grey) for the expected values of Capelin biomass in the spring acoustic survey (solid line) and observed values (black point estimates with ± 90% confidence intervals).

Appendix 3: Model Structure and Diagnostics for the Called Stomach Models

The functional response of a predator (F) with respect to a single prey can be represented by (Koen-Alonso 2007):

$$F = J\frac{aB^b}{J + aB^b} = Jf(B)$$

where *J* is the maximum ingestion rate of the predator, *a* is the attack rate coefficient, *b* is the exponent that define the functional response type (e.g., *b*=1 corresponds to a classical type 2 functional response, *b*=2 corresponds to the standard -logistic- type 3 functional response), and *B* is the biomass of the prey (i.e., capelin).

In this formulation, the function *f(B)* varies between 0 and 1. This property allows assuming that the probability of finding capelin in a predator's stomach, *Pr(B)=p*, is proportional to *f(B)*. Under this assumption, the following equation can be constructed:

$$f(B) = kp \rightarrow \frac{aB^b}{J + aB^b} = kp$$

where *k* is a proportionality constant.

Solving the above equation for *B* renders:

$$log(B) = \frac{1}{b}\big(log(\alpha p) - log(\beta - p)\big)$$

where α and β are composite parameters that result from re-parameterizations done during the solution.

The called stomach models fitted for each predator were based on this derived equation and assuming a lognormal observation error (ε) structure:

$$log(B) = \frac{1}{b}\big(log(\alpha p) - log(\beta - p)\big) + \varepsilon$$

The model fits for the cod and turbot models, including approximated 95% confidence intervals, determination coefficients (r^2), and standardized residuals are presented below. The fitted models were also used to predict capelin biomass for those years when only called stomach data were available.

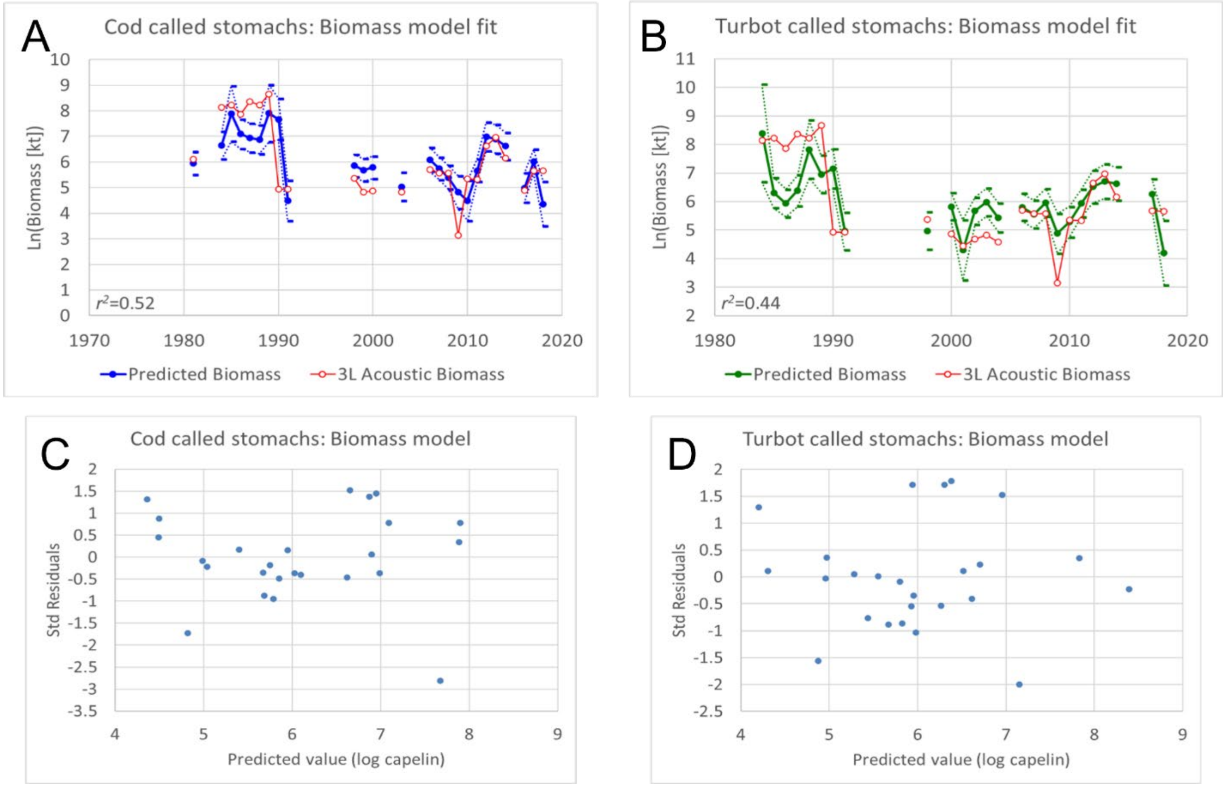

Figure A3 1. The model fits for the A) cod and B) turbot called stomach models, including approximated 95% confidence intervals, determination coefficients (r^2), and standardized residuals (C, D). The fitted models were used to predict capelin biomass for those years when only called stomach data were available.

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