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Assessment of Capelin (*Mallotus villosus)* in 2J3KL to 2018

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The assessment of the 2J3KL Capelin (*Mallotus villosus*) stock considered data to the fall of 2018. Data from the commercial fishery, inshore larval surveys, multispecies bottom trawl surveys, Capelin acoustic survey and oceanographic monitoring were used to provide biological information and update a Capelin forecast model (Lewis et al. 2019). Following the collapse of this stock in the early 1990s, the spring acoustic survey abundance index declined by an order of magnitude, the size at age of younger Capelin increased, and the average age at maturity decreased from three to four years to predominantly age-2. There has been minimal recovery in the stock since the collapse, although the spring acoustic abundance index increased in 2012-2014 to approximately 25% of the pre-collapse levels. In 2018 the index increased relative to 2017, however it was still only approximately 25% of the post-collapse high of 2014. Most Capelin continue to mature early and the age structure of the stock has become truncated, with substantially fewer fish in older age classes (4-5) and no age-6 individuals being observed in recent years. The forecast model, which incorporates the Capelin larval abundance index, adult Capelin condition in the fall, and the timing of sea ice retreat, predicted that the spring acoustic abundance index would increase in 2019 but likely decrease in 2020, as the larval abundance index has been low for five consecutive years.

STOCK STRUCTURE

Capelin (*Mallotus villosus*) is a small, short-lived pelagic schooling species with major populations occurring in the Northwest Atlantic, in waters around Iceland, in the Barents Sea, and in the North Pacific. Historically, Fisheries and Oceans Canada (DFO) Newfoundland and Labrador (NL) Region assessed and provided advice on three Newfoundland Capelin stocks: Northwest Atlantic Fisheries Organization (NAFO) Subarea (SA) 2 + Division (Div.) 3K; NAFO Div. 3L, and NAFO Div. 3NO. In 1992, as a result of accumulated biological evidence, it was recommended that Capelin in NAFO SA 2 + Div. 3K and Div. 3L be considered one stock complex (hereafter referred to as 2J3KL Capelin). This is the only Capelin stock that DFO Newfoundland and Labrador Region currently assesses.

Capelin are a key forage fish in the Newfoundland ecosystem, providing a vital energetic link between zooplankton and numerous higher trophic level predators, including seals, whales, Atlantic Cod, Greenland Halibut, salmon, and seabirds. NAFO Divs. 2J3KL Capelin spend most of their adult life in offshore waters. The center of Capelin distribution changes seasonally, typically with Capelin found feeding further north (NAFO Div. 2J and 3K) 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 to spawn at beaches and deep-water (demersal) sites close to beaches in the summer.

FISHERY

FISHERY OVERVIEW

Capelin have historically been an important part of the Newfoundland inshore fishery and culture, with fish gathered from spawning beaches largely being used for food, bait and fertilizer. Total removals prior to the 1970s were estimated to be about 25,000 tonnes (DFO 1994). In the early 1970s, an offshore fishery began in Div. 2J3KL which peaked at nearly 250,000 tonnes in 1976; an inshore commercial fishery began in the same areas in 1978, peaking at 71,000 tonnes in 1990 (Fig. 1). The offshore fishery was closed in Div. 3L in 1979 and in Div. 2J3K in 1992; the inshore fishery has continued through the 1990s through to today with recent landings of between 20,000 and 30,000 tonnes (Fig. 1). Due to the short fishing season, as well as changes in fishery timing and exploitation methods, 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 fishery removals.

Participation in the Capelin fishery depends largely on market conditions and processing sector capacity both for Capelin and for other species. Currently, the Capelin Integrated Fishery Management Plan (IFMP) splits the overall quota between mobile and fixed gear sectors (DFO 2019). Limits on the window of time during which the fishery occurs are set forth in the IFMP, but opening dates for each gear sector within each bay are determined annually in consultation with industry and are dependent on the availability and quality of Capelin in respect to size, proportion of roe-to-body size, and percentage of fish with empty stomachs. Prior to the opening of the fishery, test fishery permits are allocated to monitor the biological characteristics of Capelin. In most cases, industry will not request a fishery be opened until the test fishery finds that Capelin are of high quality. The mobile gear sector opens 24 hours in advance of the fixed gear sector. The mobile sector is comprised solely of purse seiners, which are permitted to harvest quota throughout the stock area. The fixed gear component consists of traps, cast-nets, dip-nets and tucks seines. Fishers holding fixed gear licenses are limited to harvesting within one Capelin fishing area.

Samples from the commercial fishery are obtained from vessels as catches are unloaded at processing facilities. Ten samples of 200 fish are obtained per bay. These samples are split among gear types and over the course of the fishery in proportion to their associated sector landings. Length, sex and maturity are determined for all fish and additional detailed information (weight, gonad weight, stomach fullness, and age [from otoliths]) is collected for two fish per sex, per 5 mm length class in each sample. Catch at age is calculated separately for each gear sector and NAFO Division.

COMMERCIAL LANDINGS AND BIOLOGICAL CHARACTERISTICS

Following the 2018 stock assessment (DFO 2018), the overall TAC was reduced by 35% from 30,496 to 19,823 tonnes, all of which was landed in 2018 (Fig. 1). Fixed gear continued to account for the majority of landings in 2018 (Fig. 2). Landings were up in Div. 3K in 2018 compared to 2017, as no fishery occurred in White Bay in 2017 due to issues with timing of Capelin migration along the northeast coast and processing capabilities (Fig. 3). Landings were down in Div. 3L in 2018 compared to 2017 (Fig. 3).

Between 2014 and 2017, the average total length (TL) of Capelin taken in the fishery progressively decreased from 175.9 mm to 147.2 mm, the lowest value in the time series; in 2018, average length increased to 156.6 mm (Fig. 4). Mean weights showed a similar trend (Fig. 4). The average size of Capelin in the commercial fishery is largely a reflection of the age distribution of the catch. There has been a higher proportion of age-2 Capelin in the commercial fishery since the early 1990s, with coinciding declines in the proportion of older age classes (ages 4-6) (Fig. 5). From 2014 to 2016, there were relatively few age-2 Capelin in the catch and correspondingly high percentages of age-3 and 4s compared to more recent years, which resulted in a high average length of fish caught in the fishery during those years. In contrast, 2017 had the highest proportion of age-2 Capelin in the fishery for the time series (75% and 78% in Divs. 3K and 3L, respectively), leading to a time series low for average sizes (lengths and weights) in the commercial fishery (Fig. 4). The percentage of age-2 Capelin in the commercial fishery decreased in 2018 (40% and 58% in Divs. 3K and 3L, respectively), with the remainder of the catch comprised of age-3 fish (Fig. 5).

SHRIMP FISHERY BYCATCH

Newfoundland and Labrador's commercial Northern Shrimp (*Pandalus borealis*) fishery occurs throughout the year and consists of inshore and offshore sectors in Divs. 2J3KL, both of which catch Capelin as bycatch to varying extents. The fishery has an observer program which, among other responsibilities, monitors bycatch of non-target species. The program has 100% observer coverage of trawlers in the offshore fleet, but ~5% observer coverage for the inshore fleet. Data collected on individual trawl sets includes the location and depth fished, the set duration, the bycatch species caught, and the weight by species of the kept and discarded bycatch. The sum of discarded and kept Capelin bycatch is determined separately for the inshore and offshore fisheries in each division and the total number of sets counted. To adjust for the ~5% coverage of the inshore fishery, the total bycatch and total number of sets for the inshore fishery in each Division are divided by 5% in order to obtain an estimate of the total bycatch and number of sets per Division.

In Divs. 2J3K, Capelin bycatch since 1991 reached a high of 266 tonnes in 2012, but has declined since to less than 10 tonnes in 2017 and 2018 (Fig.6). In Div. 3L, Capelin bycatch peaked in 2010 at 505 metric tons (Fig.6). The sector (inshore or offshore shrimp fishery) with the highest Capelin bycatch varies by year and Division. For Divs. 2J3K, both the inshore and the offshore commercial shrimp fishery are responsible for Capelin bycatch. For Div. 3L, the inshore shrimp fishery was responsible for the majority of Capelin bycatch; however, that fishery has been closed since 2010. While fishing effort plays a role in determining the amount of Capelin bycatch caught by the shrimp fishery, the relative abundance of Capelin and the degree of horizontal and vertical spatial overlap between Capelin and shrimp also affects bycatch rates. For much of the observer time series in Div. 3L, there is little difference between the mean fishing depths of all trawl sets versus those sets in which Capelin is caught as bycatch (Fig.7), indicating that Capelin were present at most depths targeted for shrimp. In contrast, in Divs. 2J3K, the mean depth of trawl sets with Capelin bycatch are shallower than the mean depth of all trawl sets since 2014, indicating that Capelin are occupying shallower depths than shrimp in these Divisions.

MULTISPECIES BOTTOM TRAWL SURVEYS

METHODOLOGY AND BIOLOGICAL SAMPLING

Multispecies bottom trawl surveys (hereafter bottom trawl surveys) are conducted by the DFO NL Region each fall in NAFO Div. 2J3KLNO and each spring in NAFO Div. 3LNOPs. For a detailed account on the methodology and design of these surveys see Brodie (2005). Bottom trawl survey data are not used to estimate Capelin abundance due to the diel vertical distribution of Capelin and the selectivity of the trawl gear (Mowbray 2001); however, the bottom trawl survey data are used to describe Capelin distribution, diet and biological characteristics.

Capelin caught during bottom trawl surveys are collected at sea and later processed in the laboratory to determine length, sex, and maturity. Detailed sampling (weight, gonad weight, stomach fullness, and age from otoliths) is completed for two fish per sex per 5 mm length class in each sampled catch in the spring survey and from a maximum of 25 fish from the set with the highest catch in each superstrata from the fall.

Each year approximately 500 Capelin stomachs are collected and analyzed from the fall bottom trawl survey. Total stomach content weight is recorded and the dominant prey type is identified and its proportion of the total stomach contents recorded. Since 2009, one in every 10 stomachs has been subjected to a detailed prey weight analysis, where the first non-empty stomach in every group of 10 stomachs is examined in detail from each set. Prey is classified to species level where possible and total prey weight is recorded.

DISTRIBUTION

The spring bottom trawl survey covers the southern portion of the stock range, with Capelin generally distributed throughout the survey area (Fig. 8). The fall bottom trawl survey occurs from September to December while Capelin are feeding and overwintering, when distribution is generally centered to the north. In 2018, fall distribution was centered in Div. 3K, and, similar to previous years, low densities were observed in 2J (Fig.9). Buren et al. (2019) used a center of gravity (CG) analysis that accounted for both inertia (i.e. spatial dispersion of the population around its center of gravity) and changes in sampling effort (Woillez et al. 2007). The CG trend in most decades was a pronounced shift along the north-south axis rather than the east-west axis, with an exception in the 2000s when there was a westward shift in the CG. From 2010-2016, the CG was offshore with shifts along the north-south axis, similar to the CG of the late 1980s. In 2017 and 2018, the CG was orientated toward the inshore with a westward shift in distribution similar to what was observed in the 2000s (Fig 10).

FALL CONDITION

Fall condition (Le Cren 1951) is calculated only for male Capelin collected during the bottom trawl survey, as the effects of energy re-allocation to gonads and mixed spawning history can make interpreting female condition during the fall post-spawning season problematic. Male Capelin with weights greater than the 99th percentile are excluded from the analysis, as they were considered anomalies due to sampling error, and age-1s and 2s are considered separately. Le Cren's condition was estimated by first fitting a length-weight regression to the $\log_{10}$ transformed length and weights of male Capelin across the dataset (1995 to 2018). The observed weight of each fish was then divided by its predicted weight given the observed length and the fitted length-weight regression equation. The relative condition index of age-1 male Capelin varied across years. In Div. 3L (their main distribution area) median male age-1 condition reached a time series low in 2015, whereas time series highs were reached in 2017 and 2018 for both Divs. 3K and 3L (Fig 11a). In 2018, the relative condition index for age-2 male Capelin was at a time series high in Div. 3L, was average in Div. 3K (their main distribution area), and above average in Div. 2J (Fig. 11b).

FEEDING

Stomach fullness is recorded using a scaler value of 0-4, where 0 is empty, 1 is ¼ full, 2 is ½ full, 3 is ¾ full, and 4 is full. Stomach content analysis in the fall of 2017 and 2018 found that the proportion of empty Capelin stomachs was at time series lows, as was the proportion of empty stomachs in spring 2018 (Fig. 12). This could indicate either good feeding conditions for Capelin or limited competition for prey due to a small Capelin population size.

SPRING ACOUSTIC SURVEY

SURVEY METHODOLOGY

The spring Capelin acoustic survey has generally taken place annually since 1982, except in 1993-95, 1997-98, 2006 and 2016 (Mowbray 2012). The acoustic survey is typically conducted in May and covers the majority of Div. 3L, an area of particular importance for juvenile Capelin. Since 1996, the lower portion of Div. 3K (<50ºN) was also included in the survey. The main objective of the spring acoustic survey is to produce an abundance estimate of the immature, non-migratory portion of the Capelin stock (primarily age-2s) that will be recruited to the spawning population the following year. Since the collapse in the Capelin population, the spring acoustic survey also surveys pre-spawning, mature age-2 fish, and the proportion of immature/mature fish is determined using these data.However, the spring acoustic survey does not provide an estimate of the total spawning stock biomass because the surveyed area only covers a portion of the population range of Capelin, primarily a juvenile nursery area, and the spatial distribution of Capelin within that range varies from year to year. All age classes acoustically surveyed are included in the annual index of Capelin abundance, even though age-1 fish are poorly recruited to the trawl due to their small size, and age-3 and age-4 fish may be further north and/or undergoing their spawning migration so are under-sampled by the trawl. However, cohorts track well in the spring acoustic survey with the abundance index of age-3 fish correlated with abundance index of age-2 fish from the previous year (DFO 2018).

A stratified survey is conducted each year, although the transect design, stratum boundaries and areas covered have changed over time. Prior to 1989, transects were laid out in equidistant parallel or zigzag patterns. From 1989 to 1992, randomly spaced parallel transects were surveyed following protocols set out in O'Boyle and Atkinson (1989). A randomly spaced transect design was thought preferable as it would allow for calculation of variance on abundance estimates based on transect means. However, a decline in offshore Capelin densities and a change in distribution patterns led researchers to revert back to the equidistant parallel line design in 1993, as it was felt that this design would have the greatest probability of intersecting Capelin aggregations. Since 1999, the start point of the initial transect has been randomly generated for each survey. Prior to 1999, strata were generally rectangular and extended from the coastline across the shelf, but not as far as the shelf break. Since 1999, stratum have been depth-delimited (Fig. 13). The methodology and original strata for each survey from 1982 to 1996 are presented in annual stock assessment documents (Miller 1991, 1992; DFO 1997).

The spring acoustic survey only surveys Div. 3L and the southern portion of Div. 3K as these areas are normally ice-free during spring. This area also corresponds with the main juvenile nursery area for Capelin, which provides an index of the immature stock that is expected to spawn in the following summer. In years when the sea ice coverage extends south into 3L, portion of transects will remain un-surveyed. Estimates of Capelin biomass in each strata are estimated using bootstrapping (i.e. using data from with the same strata to estimate the Capelin missed in the un-surveyed portion of the transect). Extensive sea-ice coverage limited the survey area in 1991-92, and 2007.

During acoustic surveys, backscatter is attributed to species using echograms and biological characteristics of the catches from fishing trawls. Targeted trawl sets (both bottom and mid-water) are conducted as required to investigate the species composition of the acoustic backscatter and to confirm the absence of fish signal. A minimum of one trawl set is conducted every 12 hours. Since 1996, a Campelen 1800 trawl has been used on the acoustic survey. The duration of trawl sets ranges from 15 to 120 minutes, depending on the mode of deployment (bottom or mid-water) and the intensity of the backscatter to be verified. The total number and weight of all species caught during the spring acoustic surveys is recorded. When Capelin are caught, the length, sex, and maturity for a maximum of 200 randomly selected fish per set is recorded. Additional detailed sampling (weight, gonad weight, stomach fullness, and age from otoliths) is conducted on two Capelin of each sex per 5 mm length group. Since 1999, stomachs have been removed from each fish for prey content analysis. From 1999 to 2007, stomachs were preserved in 10% formalin; as of 2008, stomachs were frozen until diet analysis could be performed. Since 1999, length measurements have also been recorded for all other potential acoustic targets including Arctic cod, Atlantic Cod, Atlantic Herring, Redfish, and Sandlance to assist with classifying mixed aggregations.

A Capelin abundance index is generated from the survey using acoustic data (echograms) and biological samples. The associated variance of the abundance index is calculated using a Monte Carlo approach which incorporates potential variability in Capelin abundance derived from four factors: calibration values (associated with technological advances); target strength (TS) (resulting from variations in length composition and catchability); acoustic detectability (resulting from variations in Capelin vertical migration); and spatial variability (aggregation). Using this technique, a re-sampled population of Capelin areal density estimates is derived for each stratum. To address issues of spatial autocorrelation, the survey track is divided into consecutive 2 km segments. For each segment, the mean area-backscattering coefficient (s_a) value of Capelin is randomly selected from one of the 20 candidate 100 m horizontal bins. This value is then transformed into Capelin density by incorporating randomly selected values for 3 parameters: calibration correction factor, TS (derived from a range of lengths), and a detectability correction. This process is repeated 1,000 times for each 2 km segment within each stratum. The median value of the resultant distribution is then used to estimate the areal density of fish in each stratum while the 5th and 95th percentiles were used as upper and lower confidence limits (Mowbray 2012). Two abundance indices are generated from the spring acoustic survey, one for the offshore area (all strata except Trinity Bay) and one for an inshore area (Trinity Bay).

2018 SURVEY AREA AND CAPELIN DISTRIUBTION

In 2018, a lack of dense sea ice combined with overall fair sea and weather conditions, allowed for all spring acoustic survey strata to be surveyed (including Trinity Bay) as well as Conception Bay, which was surveyed as there were reports from fishers in the area of large amounts of Capelin in the bay and other inshore areas (Fig. 14). During the survey, Capelin were found in high concentrations within Trinity Bay and Conception Bay, as well as in the coastal and northwestern portions of Div. 3L; high concentrations of Capelin were not detected along the shelf break as in prior years (Fig. 15). The additional surveyed area in Conception Bay was not included in the spring acoustic index derived for 2018.

Historically, Capelin underwent diel vertical migrations; however, starting in the spring of 1991, these vertical migration patterns changed, with Capelin remaining deeper in the water column throughout the day (Mowbray 2002). The mean weighted depth of Capelin surveyed during the spring acoustic survey reflects these changes, with Capelin in the 1990s and 2000s located deeper in the water column compared to the late 1980s. Diel vertical migrations were observed again to some extent from 2011-15, but reverted to near bottom distributions again in 2017-18 (Fig. 16).

AGE AND MATURATION

Capelin captured in the spring acoustic survey trawl sets range from 5 to 20 cm in length and have historically been composed of ages 1 through 6, although ages 5 and 6 have only been present in limited numbers in a few years since the 1990s. In most years, age-2s account for the majority of the surveyed Capelin, with age-3s being the second most abundant age group. The trawls used to sample Capelin during the spring acoustic survey (Diamond IX: 1982-96 and Campelen: 1999-present) are biased against smaller sized fish – in particular those less than 10 cm; this has resulted in a poor representation of age-1 (5 to 8 cm total length in May) Capelin in the survey. However, ages 2+ Capelin are well sampled by both gear types (Mowbray 2001). In 2017 and 2018, the number of age 1s sampled was very low (Fig. 17).

The spring acoustic survey was designed to sample the immature, non-migratory portion of the Capelin stock; however, the proportion of maturing age-2 Capelin sampled during the spring acoustic survey increased significantly since the early 1990s. Pre-1991, a period of high stock abundance, the proportion of Capelin maturing at age-2 was low (~4%) compared to ~40-80% of age-2 fish maturing post-1991. In 2012-14, when the acoustic survey abundance index improved to 25% of pre-1991 values, the proportion of maturing age-2s was less than 40%. In 2017 and 2018, the proportion of maturing age-2s has remained relatively low (~30%) even though the abundance index has decreased to a level similar to the 2000s (Fig.18 and 19).

Decreased age at maturity has been associated with increased size at age for younger (age-1 and 2) Capelin while the size of older fish has decreased. The trend of increased immature growth at smaller stock size has also occurred in the Barents Sea Capelin stock (reviewed in Gjøsæter 1998), and since timing of maturation is linked to growth, year classes with fast juvenile growth mature earlier. In 2018, size at age of age-1 and age-2 fish was slightly larger compared to 2017 (Fig. 20). The proportion of age-2 fish maturing was positively correlated (R^2 = 0.67) with fish length (Fig 21).

CONDITION, ROE CONTENT AND FEEDING

The spring somatic condition of Capelin (Fulton's K) for maturing females from the spring acoustic survey has been calculated intermittently since 1996. Only maturing females are used in this analysis as we are interested in the interaction between condition and gonad maturation. Trends in condition over time are typically similar among size classes. For most years, gonad development (i.e. roe content; % of body weight) tracked condition; however, since 2015, condition and roe content diverged with low roe content for a given body condition. This divergence was likely a result of a delay in the reallocation of somatic stores to gonad development. In 2018, the condition of smaller (10-11 cm) Capelin decreased compared to 2017 while condition of 12-13 cm fish increased compared to 2017 and was near the time series average. Larger fish (>14 cm) in 2018 had improved condition compared to 2017 with condition values in 2018 similar to the time series average (Fig. 22). Roe content was at its lowest values in the time series in 2017 and 2018, particularly for the larger size classes (Fig. 22).

As with the 2018 spring and fall bottom trawl surveys, there was a relatively low proportion of empty Capelin stomachs in the 2018 spring acoustic survey (Fig. 23). Stomach content analysis generally showed a diverse diet in terms of species and sizes, with copepods, amphipods (hyperiids), and oikopleura dominating in most years; in 2017 and 2018, copepods (large and small) were the dominant prey items (Fig. 24).

ABUNDANCE INDEX

The Capelin stock collapsed in 1990-1991, which was concomitant with a regime shift in the NL ecosystem (Buren et al. 2019). The Capelin abundance index dropped by more than an order of magnitude during and after the collapse from 400-600 billion individuals (4-7 million t) in the late 1980s to between 3.4 and 30 billion individuals (to a maximum of 200,000 t) during the period of 1991 to 2005 (Fig 19). The Capelin stock remained at low abundances during these years despite an increase in surveyed area from 2000 onward and a general warming in oceanographic conditions from 1995-2010 (Colbourne et al. 2016). Capelin abundance in the surveyed area was 22-29 billion individuals (260,000-300,000 t) during 2007 to 2009, but fell to less than 1% of the historic high in 2010 with only 2 billion fish (23,000 t) surveyed. The dramatic decline in Capelin in 2010 included a steep drop in the abundance index for 2 year classes (2007 and 2008), similar to the circumstances in the 1991 fall and spring acoustic surveys when the 1988 and 1989 year classes disappeared from the survey. The 2010 survey abundance index estimate is now considered to be an underestimate as the 2007 and 2008 year classes were stronger than expected in the subsequent 2011 spring acoustic survey. It should be noted that the within season trend in the length composition of spawners in 2010 was also anomalous, which may indicate a change in the distribution or migration pattern in that year. The spring abundance index was at its highest level since 1991 from 2013-15, ranging from 53.6 to 121.9 billion individuals, with a peak in the abundance index in 2014. This was the first time that the index reached the same magnitude as that of the pre-collapse years (i.e. 1980s). Since 2015, the Capelin abundance index declined substantially to 18.5 billion individuals in 2017 before improving to 32.2 billion individuals in 2018.

SPAWNING AND LARVAL SURVEYS

SPAWNER ATTRIBUTES AND TIMING OF SPAWNING

Samples of spawning Capelin are collected using a cast net once a week at Bellevue Beach, Trinity Bay (Fig. 25) and at other locations opportunistically during the spawning season. Samples are comprised of 25 males and 25 females that are randomly selected. These samples are used to examine within season variation in spawner size composition. Generally, larger Capelin spawn first and the observed sizes of sampled spawners decreases as the spawning season progresses. The major exception to this trend occurred in 2010, when the size of spawners increased at the end of the season, and to a lesser extent in 2013 when there was little variation in spawner size between the start and end of the spawning season (Fig. 26). The timing of sample collections was delayed in 2009 and 2015-18 as a result of the late commencement of spawning.

The timing of peak Capelin spawning is available from 2 reference beaches on the Avalon Peninsula: Bryants Cove, Conception Bay (1978-present) and Bellevue Beach, Trinity Bay (1991-present). A delay in spawning time occurred in 1991, and, although the timing of spawning was somewhat earlier in a few years since (e.g. 2004, 2011, and 2013), spawning has continued to be delayed since 1991, with the timing of peak spawning at Bellevue Beach in 2018 being among the latest in the time series (Fig. 27).

Since 1991, Capelin beach spawning has been monitored throughout the province by paid spawning diarists who check their local beaches every day during the Capelin spawning period (June-August). Participation in this program has varied inter-annually and has decreased in recent years. Generally, spawning occurs earlier in the south and later in the north with in the number of occupied spawning beaches for Div. 3L being reduced when spawning occurs later in the summer. Peak beach spawning occurred from mid to late July in 2016-2018. In 2018, more beaches were occupied by spawning Capelin than in 2016 and 2017 and there was very early (June) beach spawning on the west coast of the island (Fig.28).

BELLEVUE LARVAL SURFACE TOWS

Surface tows to monitor the annual abundance of emerging Capelin larvae have been conducted at five fixed stations in nearshore waters (<20 m) off Bellevue Beach, Trinity Bay since 2001 (Fig. 25). This survey was designed to sample larvae emerging from demersal Capelin spawning beds and off Bellevue Beach and four smaller spawning beaches along the western shore of Bellevue. Since 2003, this work has been conducted from a 27 foot fiberglass boat using two 75 cm diameter ring nets with 270 µm mesh that are towed for a duration of 10 minutes at 2.1 knots every 24-48 hours (weather permitting). Only one of the nets collects a larval sample, and the second net is used to stabilize the vessel while the nets are deployed. A General Oceanics 2030 Series mechanical flow meter is positioned in the opening of the in-use net. The plankton sample collected by the net is preserved in a 5% formalin and saltwater solution buffered with sodium borate. In the laboratory, all Capelin larvae are enumerated when fewer than 500 larvae are present in a sample, and a sub-sampling technique is used for samples containing more than 500 larvae (van Guelpen et al. 1982). For each sample with 50 or more Capelin larvae present, the lengths of 50 randomly chosen larvae are measured and the presence or absence of their yolk sac is recorded. If the yolk sac is present, then its diameter is measured. Capelin larvae sampled in this index range in age from newly emerged to <12 days. This estimate of age is based on the presence/absence of the yolk sac and larval length. Capelin do not form rings in their otoliths until approximately 12 days post-hatch (Ivarjord et al. 2008), and few of these larvae have formed rings in their otoliths at the time of sampling (Murphy, unpublished data).

Total annual production of larvae per m^3 (N) is estimated using the trapezoidal integration method:

$$N = \sum (t_n - t_{n-1}) \tfrac{1}{2} [X(t_n) + X(t_{n-1})]$$

where t is the Julian day of the year, n is the number of the sampling event (e.g. 1st, 2nd, 3rd,…), and $X(t_n)$ and $X(t_{n-1})$ are the number of larvae per m^3 on the day of the year of sampling events *n* and *n-1*. Only days when all five stations were successfully sampled are included in this analysis. If a sample was missed due to adverse sea conditions or for any other reason, the average of the estimates on the adjacent days is substituted. If sampling was missed for two or more consecutive days then the missing values are set to 0 rather than calculating a mean abundance for the missing days to prevent an overestimation of larval abundance.

Since 2014, the Bellevue surface tow abundance index has been below the long-term average of 1,629 Capelin larvae m^{-3} (2001-18), with recent annual production of 416 m^{-3} (2016), 1,115 m^{-3} (2017), and 129 m^{-3} (2018) (Fig. 29). The 2018 Bellevue surface tow abundance index is at a time series low. The age-2 recruitment index, which was lagged by two years in order to compare survivors of the same cohort, is positively related to the Bellevue surface tow index and preferred larval prey (*Pseudocalanus* spp.) density (Murphy et al. 2018).

TRINITY BAY LATE LARVAL SURVEYS

The Trinity Bay late larval Capelin surveys began in 2002, building on prior work conducted in Trinity Bay from 1982 to 1986 where 52 stations were sampled, covering the entire bay in July and August (Dalley et al. 2002). The objectives of the current survey are to track larval production at the bay scale and to investigate how later spawning times affect larval survival and growth. Since 2003, 19 stations (Fig. 30) in the center of the bay have been sampled one to three times per year during the months of August, September and/or October. During years when only one survey was conducted, it was targeted for September. The sampling stations are fixed along four northwest lines, spaced 6 nmi apart, with stations placed at 3 nmi intervals along each of the four lines (Fig. 30). Larvae are sampled using bongo nets with 333 µm mesh nets which are deployed using the same procedures as Dalley et al. (2002). The bongo nets are towed at a speed of 2-2.5 knots with a skewed “V”-shaped tow pattern. The nets are dropped to their maximum depth at a constant 20 m/min descent rate and are then retrieved at a constant 10 m/min ascent rate, with the ascent and descent rates tracked in real-time gear using a net-mounted STD. The volume filtered by each net is monitored using a mechanical flow meter (General Oceanics 2030 Series). At each station, one bongo net sample is preserved in 2% buffered formaldehyde and the other net sample is preserved in 99% ethanol or frozen. The different preservation methods are used to facilitate different types of analyses (e.g. counts vs measurements, etc.).

CTD casts through the entire water column are conducted across the head, center, and mouth of the bay when time and weather conditions permit (Fig. 30). Since 2013, zooplankton samples have been collected at each bongo net station using a 50 µm mesh net attached to the interior of one of the bongo nets. Starting in 2017, fresh zooplankton samples have been analyzed onboard the survey vessel using a FlowCam system.

Following the survey, the larval samples preserved in 2% buffered formaldehyde are strained, soaked in freshwater and then reconstituted to a volume of 1L. Successive 50 ml aliquots of the reconstituted sample are sorted and all fish larvae in each aliquot are identified to species. The number of individuals of each species is recorded, and the standard length of each Capelin and Herring larvae is measured. Aliquots are analyzed until either a minimum of 50 Capelin are counted or half the reconstituted sample volume (500 mL) is sorted. Capelin density per square meter is then calculated for each station as:

$$\rho_i = C_i * D_i / V_i$$

where ρ is the density of Capelin larvae per square meter, *i* is station, *C* is the number of Capelin caught, *D* is the maximum tow depth at station *i* in meters, and *V* is the volume filtered in m^3. The annual Capelin production index from Trinity Bay is the mean density of the 19 stations. Length frequencies of Capelin measured from each station are scaled to the station density and summed over the survey area.

The second bongo sample that is preserved in ethanol is used for Capelin larval age, growth and diet studies. Capelin larvae preserved in ethanol in 2002, 2006 and 2013 were <30 days old in the Trinity Bay surveys and experienced inter-annual variability in growth rates, which may be related to prey availability (Murphy et al. 2018).

Since 2015, the Trinity Bay late larval index has been low, with mean Capelin larval densities, pooled by month, of 25 m^{-2} (2016), 19 m^{-2} (2017), and 7 m^{-2} (2018). Since 2015, mean Capelin larval densities are below the long-term average of 30 m^{-2} (2002-18) with 2018 index value being the lowest in the time series (Fig. 29). The age-2 recruitment index is not related to the Trinity Bay larval index (2002-18; $y = -0.1753x + 1.63$; $p > 0.05$; $R^2 = 0.06$; updated from Murphy et al. [2018]). The lack of a significant statistical relationship is likely due to the spatial and temporal contraction of the sampling protocol since 2003 (19 of the original 52 stations sampled in one week in September from 2003-07, and one week in both August and September from 2008-2018). Continued sampling of late-stage larvae remains important as unexplained variability in age-2 recruitment may be explained by characteristics of the late-stage larvae, such as growth and diet (Murphy et al., 2018).

CAPELIN EARLY LIFE HISTORY

Each of the three indices (Bellevue surface tow [2001-18], Trinity Bay [2002-18], and age-2 recruitment [acoustic surveys in 2003-05, 2007-13, 2015-18; data lagged by two years]) were standardized to the mean of the Bellevue (2002-17), Trinity Bay (2003-17), and age-2 (2004-17) data series (Fig. 29). The different years for standardization was due to the different lengths of the time series available. Over the past five years (2014-18), the Bellevue larval index was below average; the Trinity Bay larval index was above average in 2014 and below average for 2015-18; and the age-2 recruitment index was below average for the 2015 year class (surveyed in 2017) and above average for the 2016 year class (surveyed in 2018) (Fig. 29). Our larval indices suggest that the 2017 and 2018 year classes may be below average; these year classes will be surveyed offshore in 2019 and 2020. It is noteworthy that the 2016 year class was predicted to be small based on the Bellevue surface tow index. However, the better than expected survival of the 2016 year class demonstrates that it is unlikely that a single variable explains the multiple stochastic processes that are affecting Capelin survival throughout their lifetime.

FORECAST MODEL

A Capelin forecast model (Lewis et al. 2019) was used for the first time in this assessment. The model builds on prior Capelin models (Buren et al. 2014, Murphy et al. 2018) by using a Bayesian framework to forecast the acoustic survey Capelin biomass index. The forecast model does not forecast the spawning stock biomass which is a limitation of the forecast model. The quality of model fit was evaluated using a combination of approaches including the leave one out jack knife method (Olden et al. 2002), examination of model residuals following Zuur et al. (2013), examination of deviance information criterion to choose between competing model formulations and examination of a Bayesian R^2 values (Gelman et al. 2019) to determine the portion of variance explained by the model. The selected model (CSAM3) was the most parsimonious model selected and had an R^2= 0.66. The indices used in the Capelin forecast model are the Bellevue Beach larval index, day of year (DOY) of the most southerly position of contiguous sea ice (sea ice retreat; t_{ice}) – which is related to the annual spring plankton bloom, and fall condition of adult Capelin (Lewis et al. 2019). The model uses a combination of timelags for the different indices in order to account for when the individual indices are expected to affect Capelin biomass for the year being forecast. The 2019 forecast is based on the 2017 larval index (a 2-year lag), 2018 adult fall condition index (a 1-year lag), and t_{ice} in 2019 (no lag). The 2020 forecast is based on the 2018 larval index (2-year lag), average adult fall condition index (to be updated with 2019 fall condition index), and average day of sea ice retreat (to be updated with 2020 t_{ice} when that data becomes available). The Capelin forecast model predicted approximately the same acoustic biomass estimate in spring 2019 as in 2018 and a decline in the spring 2020 acoustic biomass estimate compared to 2018 (Fig. 31). The 2020 Capelin forecast will be updated at the next assessment and a projection for 2021 will be provided.

CONCLUSIONS

A forecast model that incorporates the Capelin larval abundance index, adult fall Capelin condition, and the timing of sea ice retreat predicts that the spring acoustic biomass index will stay the same or slightly increase in 2019, but decrease in 2020 (Fig. 31). The results of the forecast model, in conjunction with the results of the spring 2018 acoustic survey, suggest that the amount of Capelin available to the fishery in 2019 may be similar to that of 2018.

The two main indices used to access the 2J3KL Capelin stock are low, which is likely attributable to environmental conditions (e.g., bottom-up processes) (Fig. 29). The importance of Capelin to the diet of northern cod is well-known (e.g., Rose and O'Driscoll 2002) and the continued low abundance of Capelin in the NL ecosystem may be inhibiting the recovery of this iconic stock.

AREAS OF UNCERTAINTY

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

Larval productivity in the Bellevue Beach inshore area may not be representative of larval production in other bays although previous work showed a correlation between Bellevue Beach and other bays.

Three bottom-up drivers of Capelin recruitment and survival have been identified and are being used in a Capelin forecast model; however, there is unexplained variability in the model and the influence of top-down processes on the Capelin stock have not been investigated

The impact of inter-annual variability in age-2 maturation on the Capelin stock is unknown

RESEARCH RECOMMENDATIONS

- Investigate post-spawning mortality rates particularly age-3+.
- Explore possible collaboration with harvesters to collect industry-based calibrated acoustic data to further investigate Capelin distribution and abundance in areas and/or times outside of the DFO spring acoustic survey.
- Consider using a fixed average/reference period for the condition indices and use a consistent method to calculate condition for both spring and fall (recommended to use Le Cren's condition index vs. using Fulton's in the spring).
- Use data collected at Station 27 multi-frequency echo sounder to extract seasonal information about pelagic fish and zooplankton dynamics.

- Create two indices from the acoustic survey: one for the percent of mature Capelin that will be spawning that year and the other for immature Capelin that will spawn the next year; this may require creating a maturity ogive.
- Investigate low percentage of Capelin roe in 2017 and 2018 acoustic survey and potential implications on fecundity, egg size and/or spawning time.
- Calculate condition for spawning Capelin.
- Adapt existing forecast model to integrate age composition and maturity data, splitting mature/immature components of the acoustic survey (high mortality of mature individuals) to better estimate biomass.
- Validate the forecast model estimates with results of the acoustics survey. Serves as a test for whether this needs to be peer-reviewed/undergo more extensive revision prior to use in the stock assessment.
- Incorporate fishery and predator mortality into the Capelin forecast model. Use the model to explore the effect of mortality of large gravid females on Capelin stock.
- Hold a Framework meeting in advance of the next Capelin assessment to review acoustic survey data analysis methodology.
- Set a Limit Reference Point or similar measure that can be used as a recommendation tool for management to provide advice based on either the forecast model or abundance/biomass trends. Despite gaps in Capelin data including an absolute abundance estimate and spawning stock biomass, there are modeling tools for data limited stocks that will be explored to set a limit reference point for this stock.
- Explore seasonal and spatial patterns in Capelin diet.
- Expand inshore drone work to include other northeastern bays of Newfoundland and, potentially, Labrador. Expand the geographic scope of targeted Capelin research north (into 2J), through the expansion of existing programs (index beaches, egg and larval sampling, Capelin diaries), and further analysis of existing data (e.g. spatial analysis of multispecies survey data).
- Reimplementation of fall Capelin acoustic surveys to capture entire stock area which will provide valuable data on absolute stock size for developing a limit reference point.
- Continue to evaluate current knowledge of Capelin genetics across the NL distribution and new genomics methodologies to determine if multiple stocks or species are present.
- Further research on demersal spawning versus beach spawning is warranted to estimate larval survival from both spawning modes.

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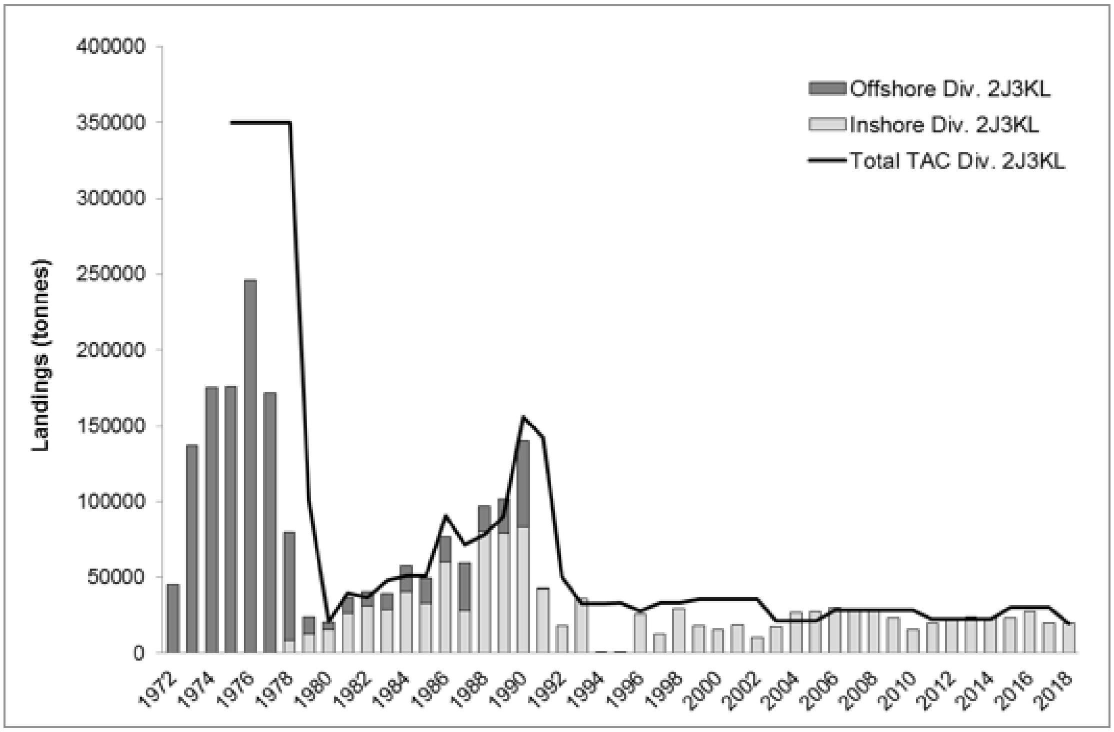
FIGURES



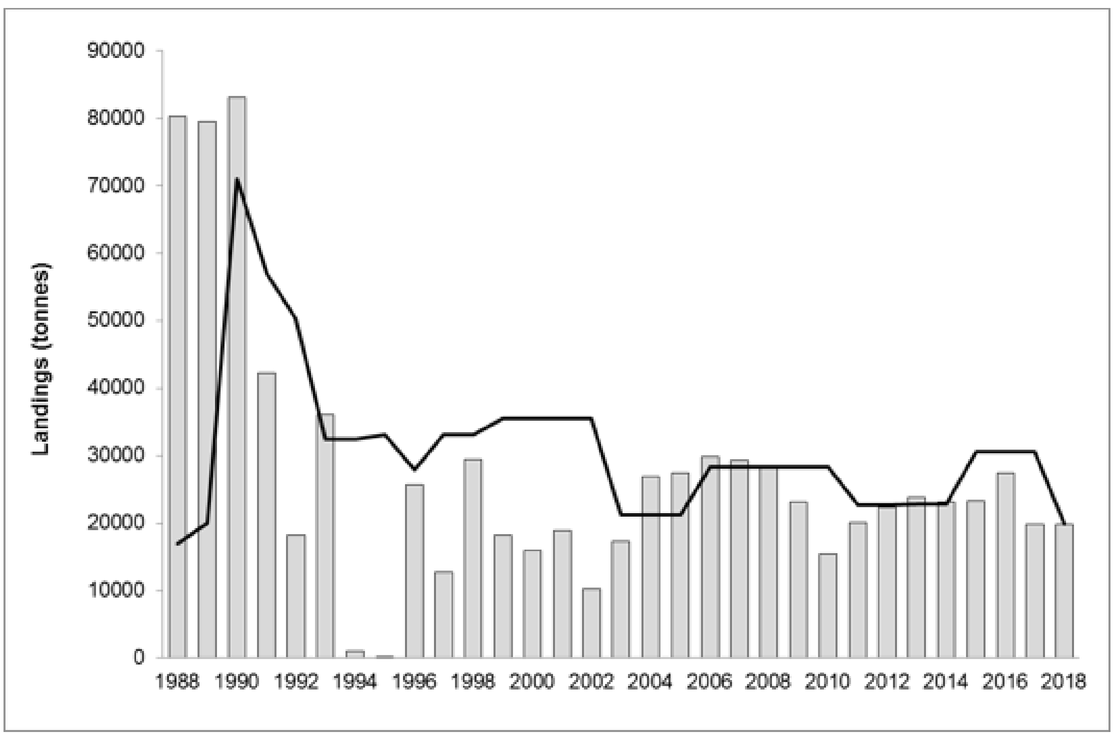


Figure 1: Capelin landings (tonnes) in NAFO Divisions 2J3KL from offshore (dark bars) and inshore (light bars) gear sectors from 1972-2018 (top panel) and inshore only from 1988-2018* (bottom panel). Solid line indicates total Capelin TAC for the combined sectors.*

**2016-2018 landings preliminary*

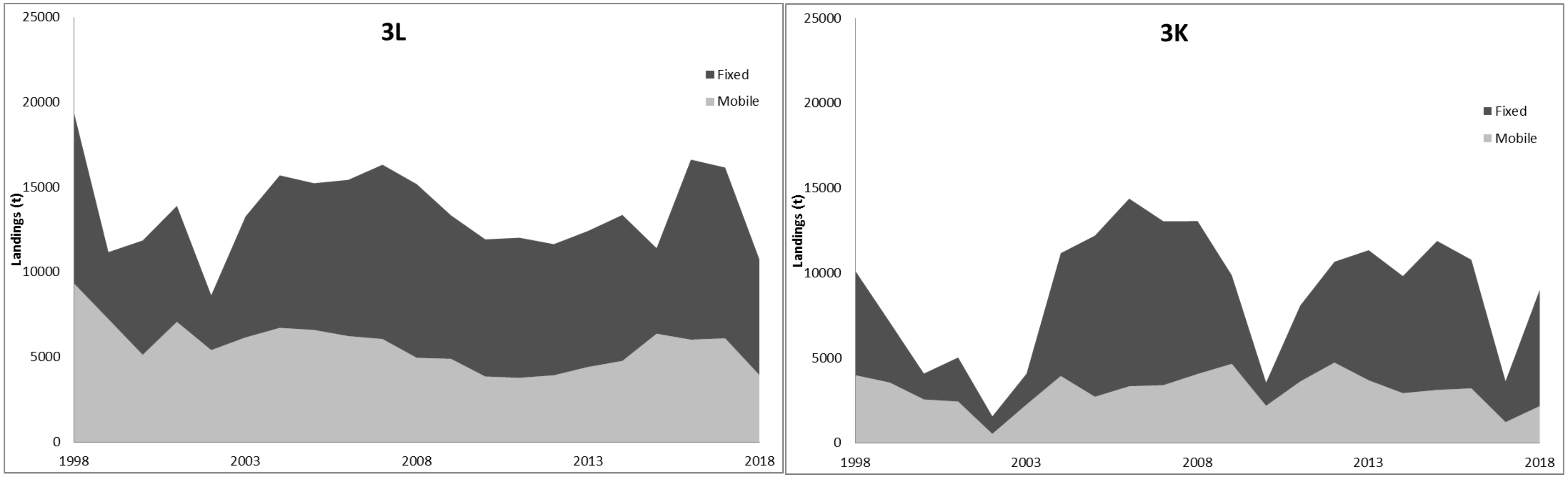


*Figure 2: Commercial Capelin landings by NAFO division and gear sector from 1998-2018.**

**2016-2018 landings considered preliminary*

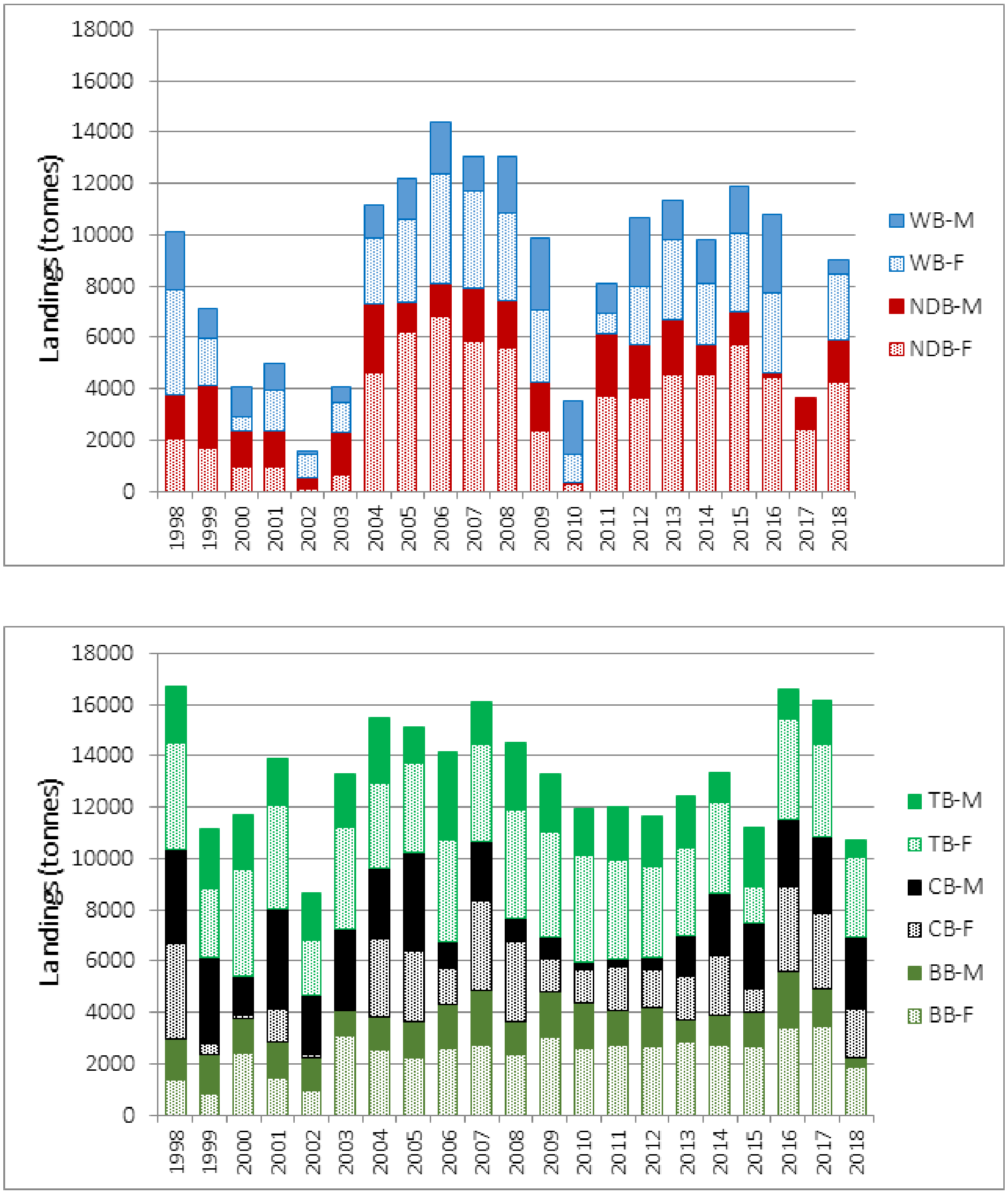


*Figure 3: Commercial Capelin landings by Bay (WB=White Bay, NDB=Notre Dame Bay, TB=Trinity Bay, CB=Conception Bay, BB=Bonavista Bay), gear sector (M=Mobile, F=Fixed) and NAFO Division (top panel=3K, lower panel=3L) from 1998-2018.**

**2016-2018 landings considered preliminary*

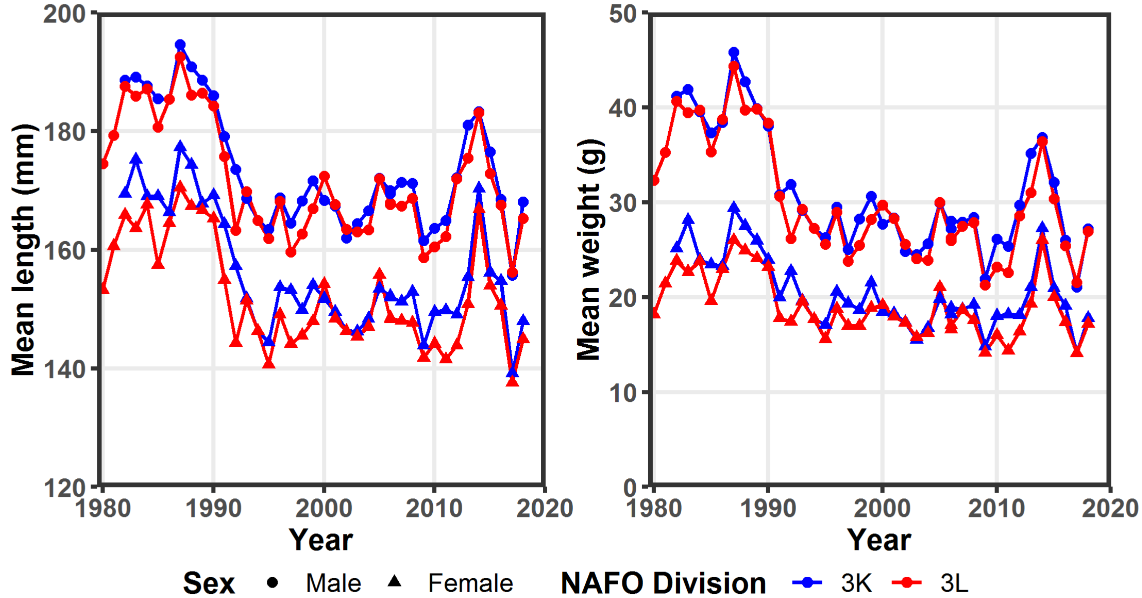


Figure 4: Mean length and weight of Capelin caught in NAFO Divisions 3K and 3L in inshore commercial fisheries from 1980-2018.

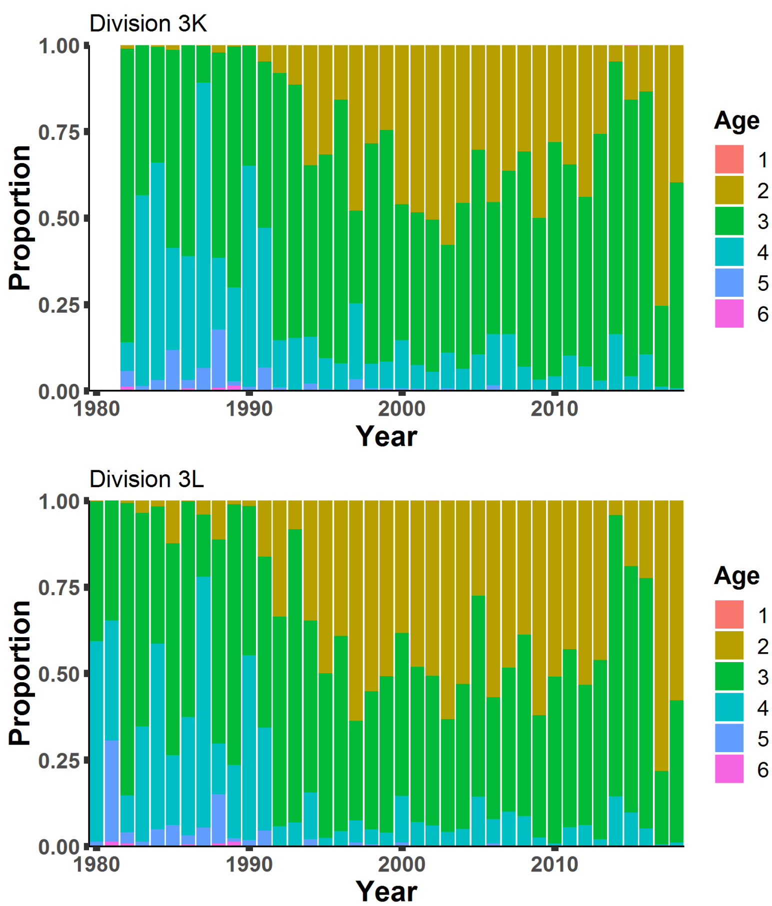


Figure 5: Age composition of samples collected from inshore commercial fisheries in NAFO Divisions 3K (top panel; 1982-2018) and 3L (lower panel;1980-2018).

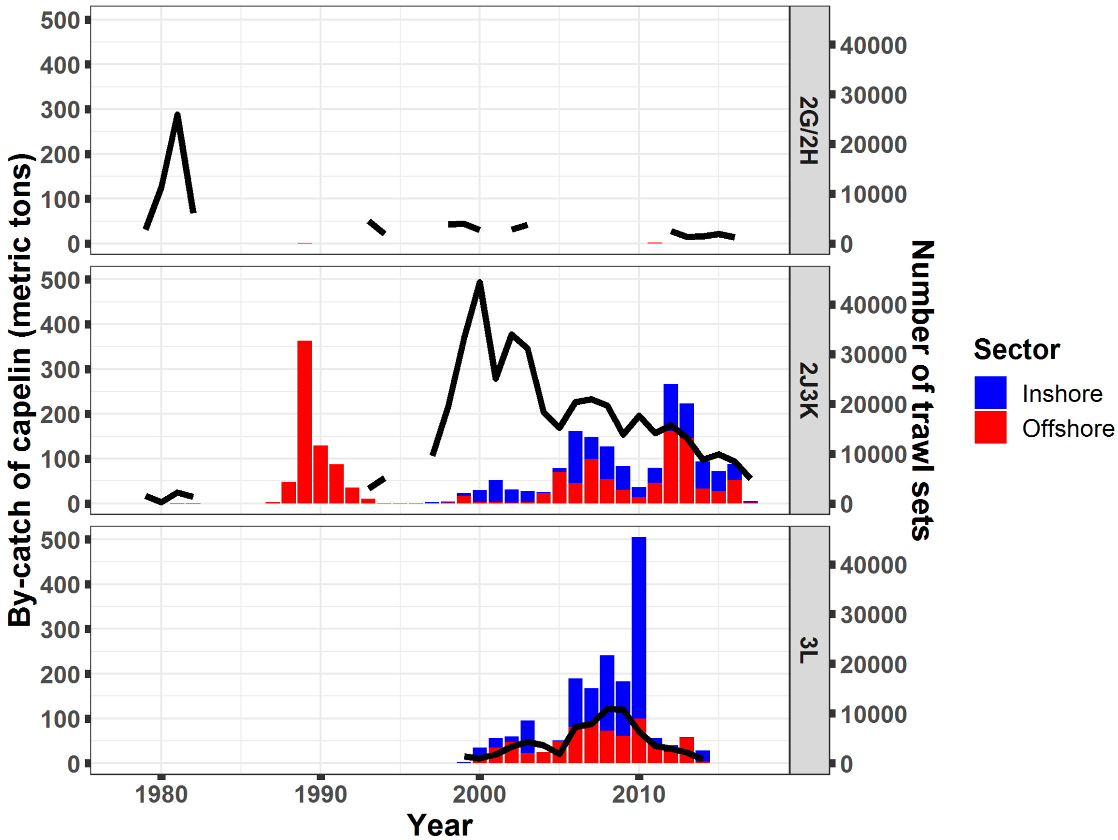


Figure 6: Bycatch of Capelin by the commercial shrimp fishery in the inshore and offshore areas of NAFO Divisions 2GH (top panel), 2J3K (center panel) and 3L (lower panel). Black lines represent estimated number of trawl sets.

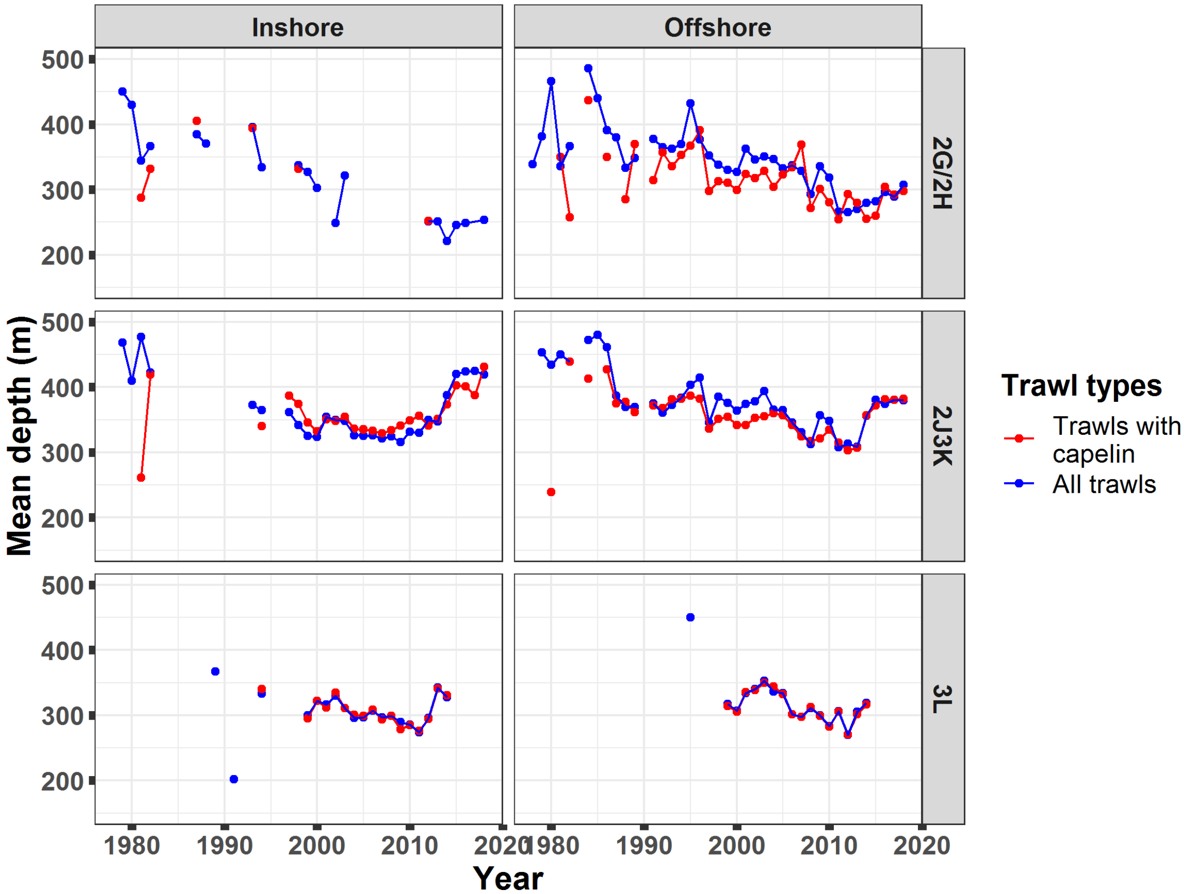


Figure 7: Mean trawling depths of all observed commercial shrimp trawl sets and the number of those sets that included Capelin bycatch for NAFO Divisions 2GH (top panel), 2J3K (center panel) and 3L (lower panel).

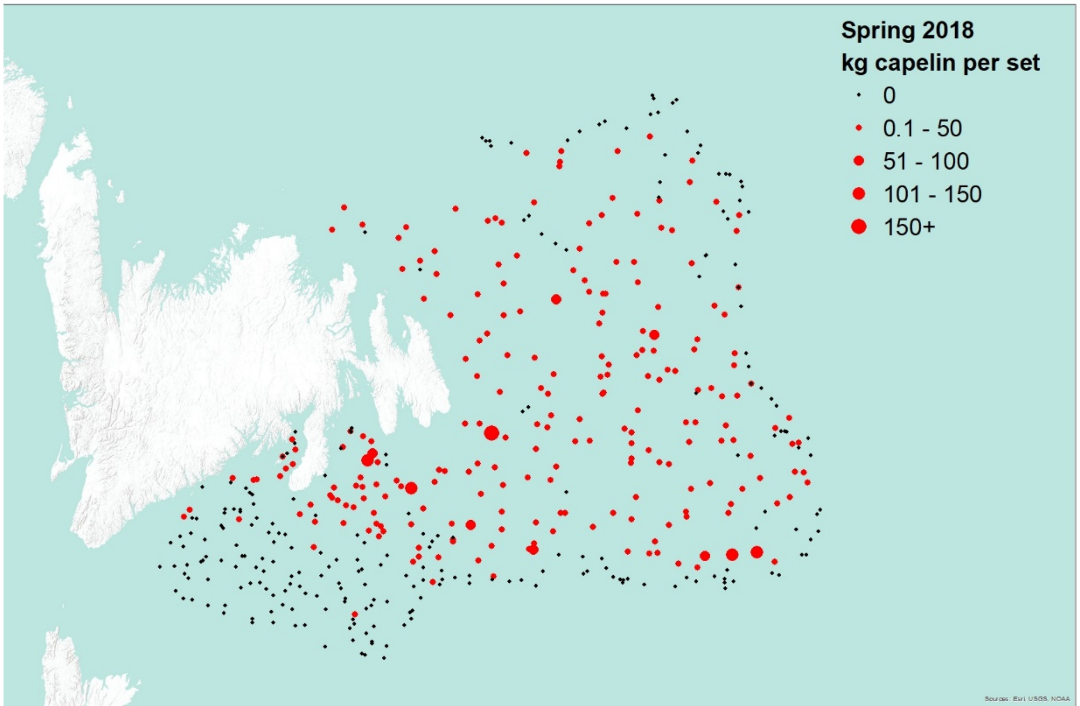


Figure 8: Distribution of Capelin catch from the 2018 spring (April – June) bottom trawl survey (black points are sets without Capelin; red points are sets with Capelin; red points are proportional to Capelin catch weight).

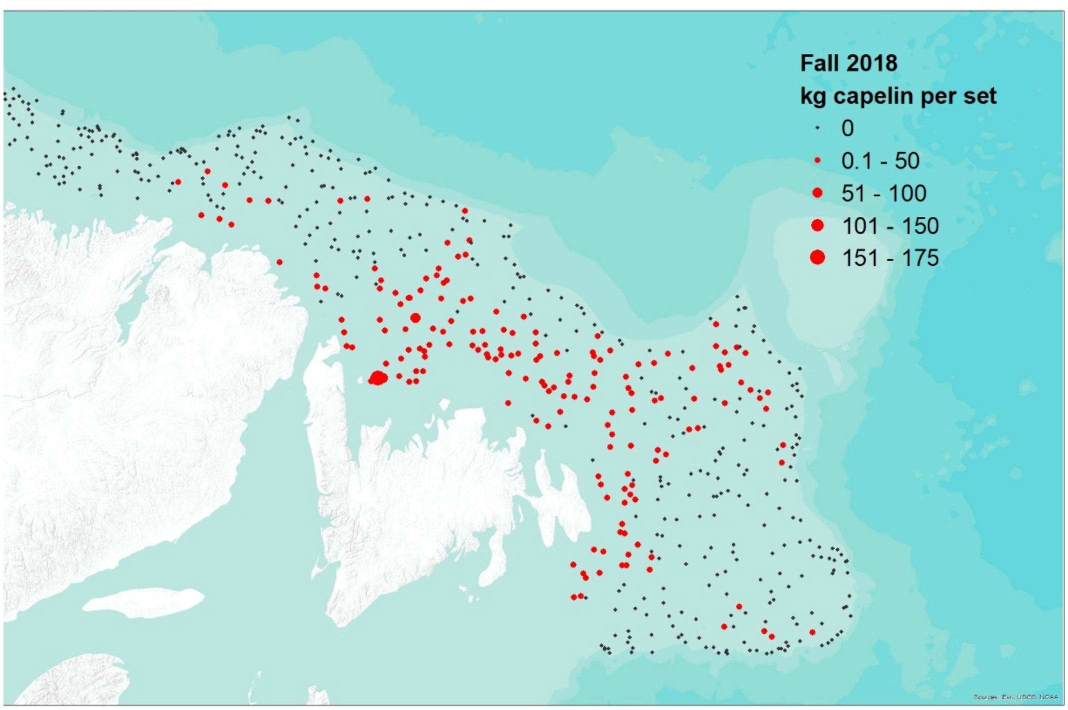


Figure 9: Distribution of Capelin catch from the 2018 fall (September-December) bottom trawl survey (black points are sets without Capelin; red points are sets with Capelin; red points are proportional to Capelin catch weight).

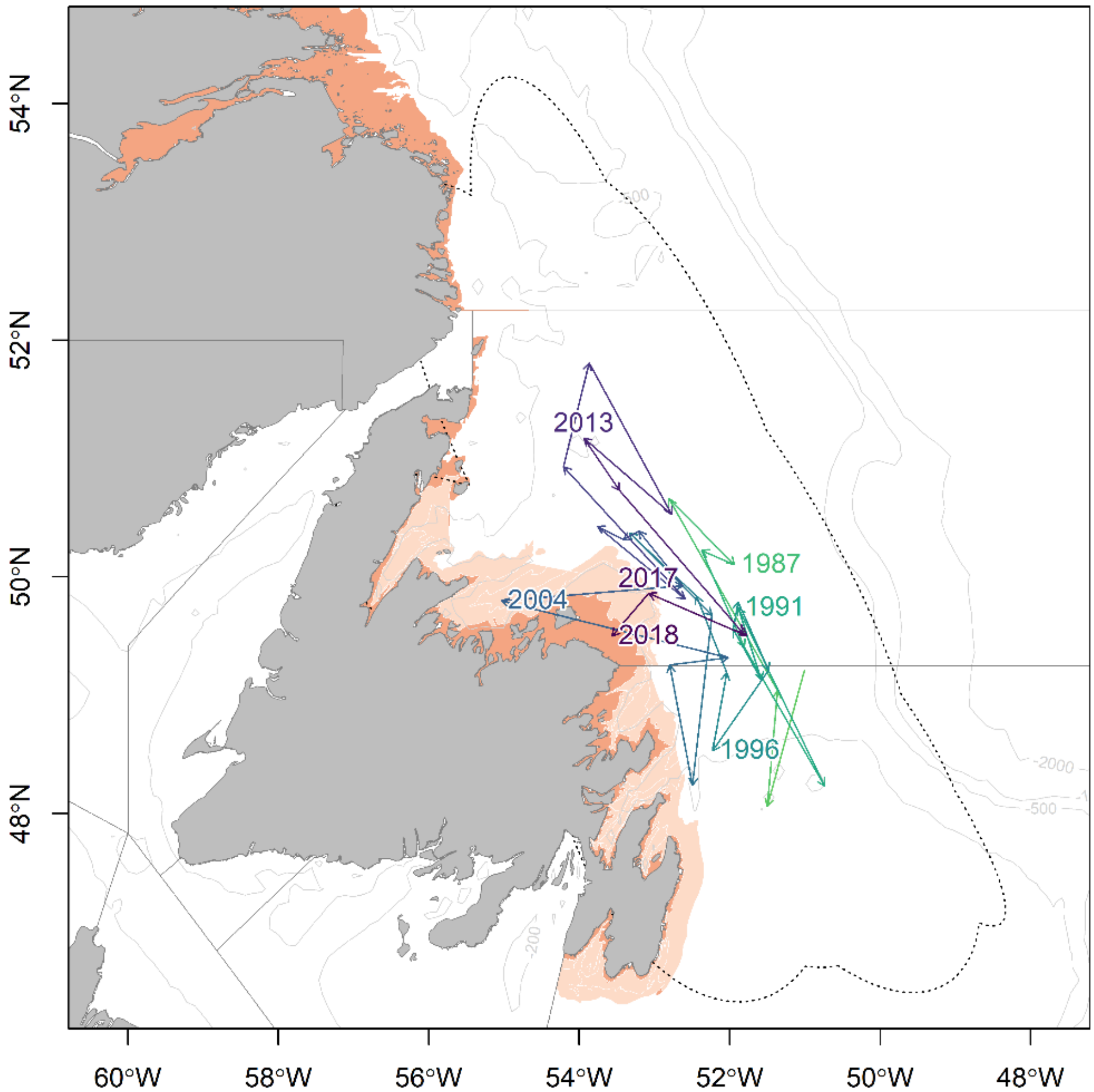


Figure 10: Center of gravity of Capelin from the fall bottom trawl surveys in NAFO Divisions 2J3KL from 1983-2018 (updated from Buren et al. 2019). Annual center of gravity estimates are connected by lines through time, and composite ellipses of deviation around these estimates (i.e. inertia) are indicated by the dotted black line. Center of gravity and inertia were calculated using equations found in Woillez et al. (2007). The red area indicates areas not covered by the survey and the light pink area indicates inshore strata that are poorly covered by the fall bottom-trawl survey.

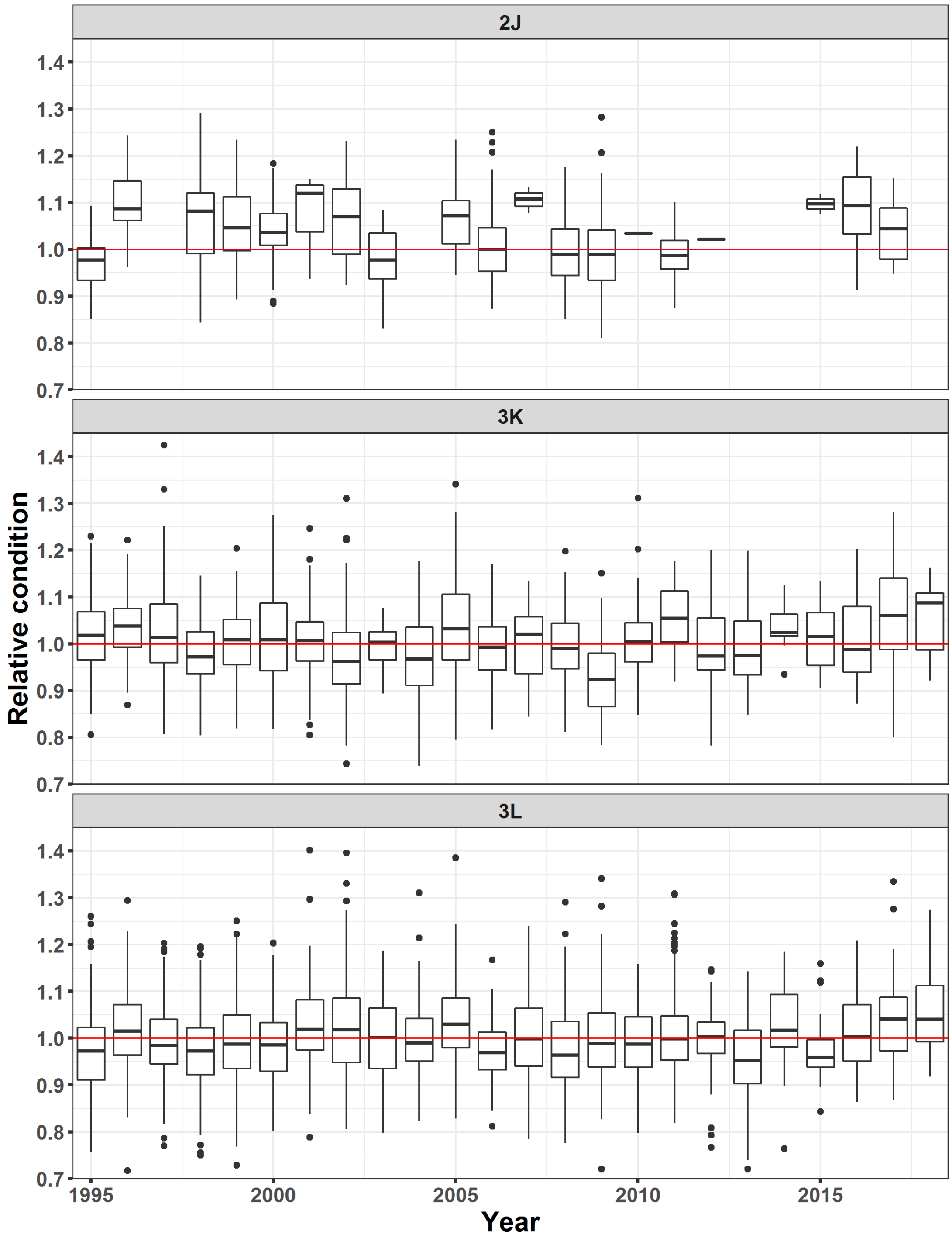


Figure 11a: Le Cren condition of age-1 male Capelin sampled during fall bottom trawl surveys in NAFO Divisions 2J, 3K and 3L from 1995-2018. Note that only fish with relative condition between 0.7 and 1.4 are displayed.

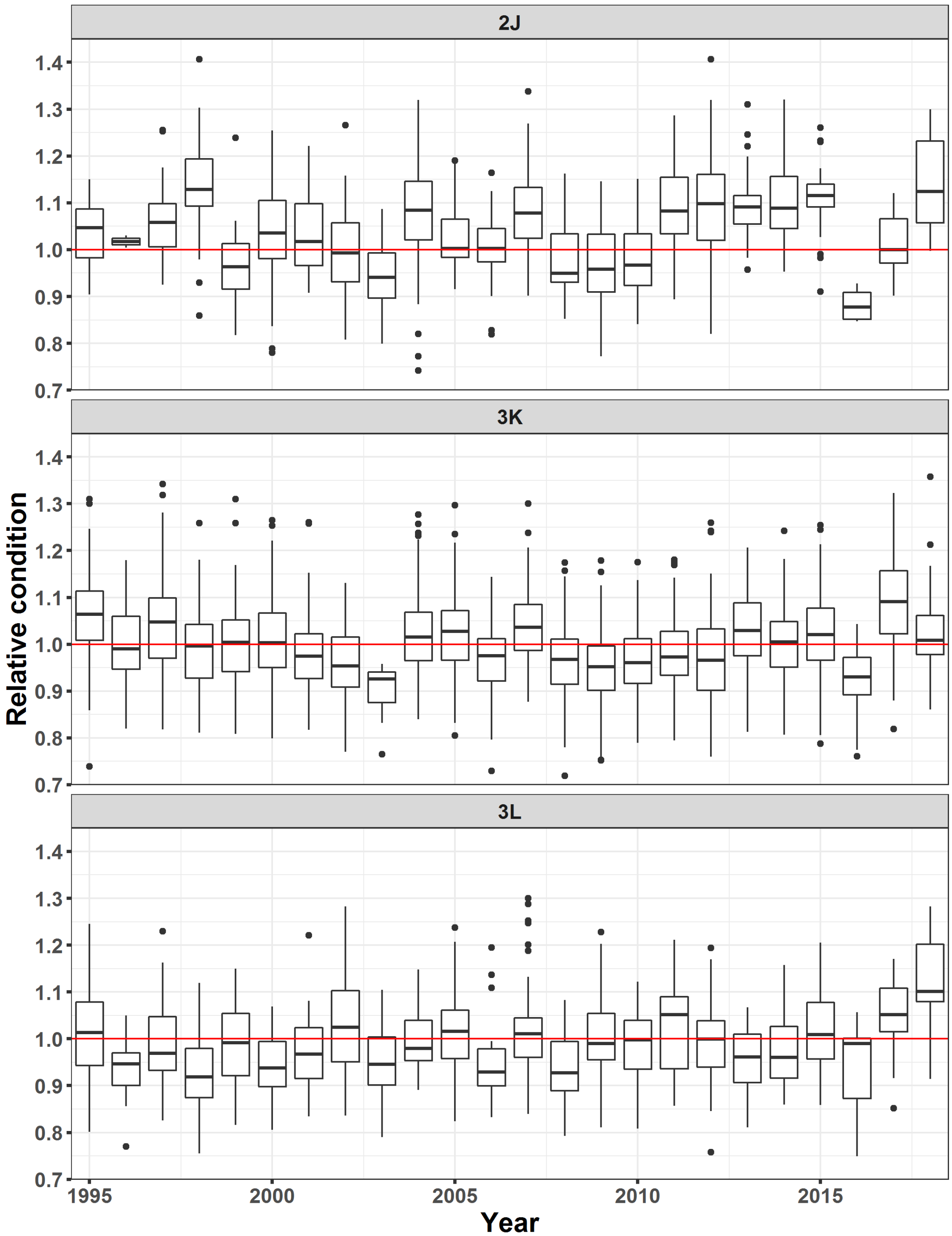


Figure 11b: Le Cren condition of age-2 male Capelin sampled during fall bottom trawl surveys in NAFO Divisions 2J, 3K and 3L from 1995-2018. Note that only fish with relative condition between 0.7 and 1.4 are displayed.

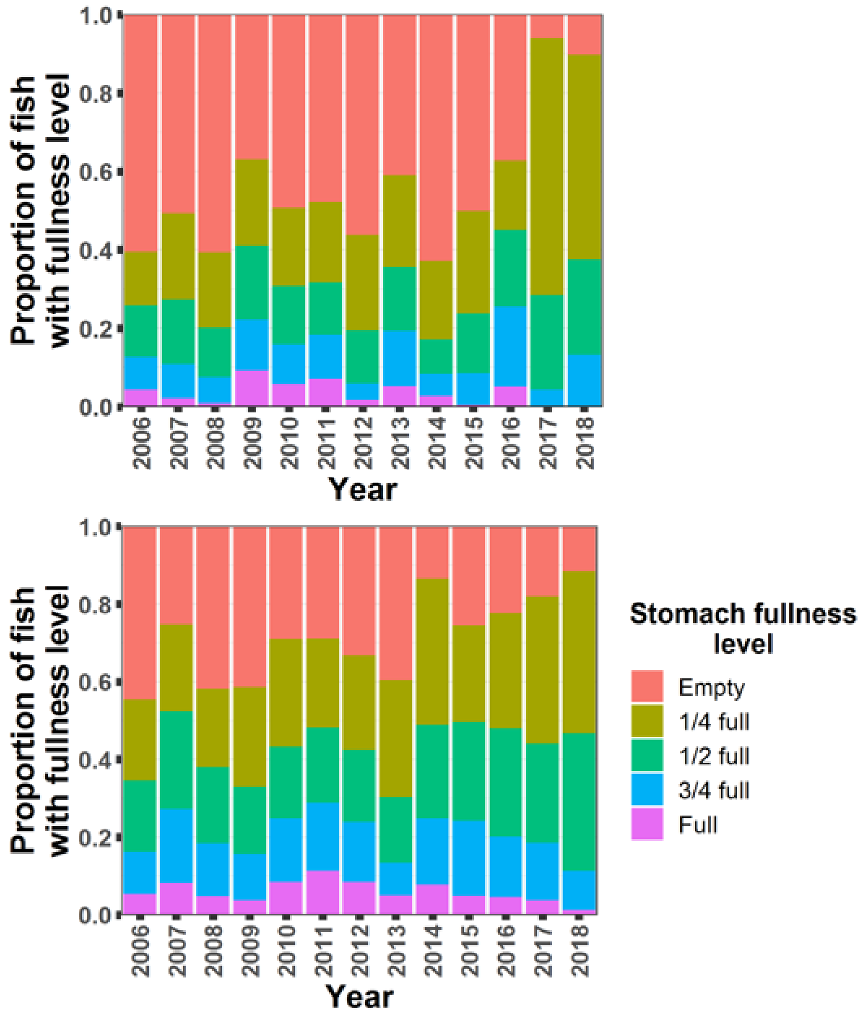


Figure 12: Stomach fullness proportion of Capelin sampled during fall multispecies surveys (top panel) and spring multispecies surveys (bottom panel).

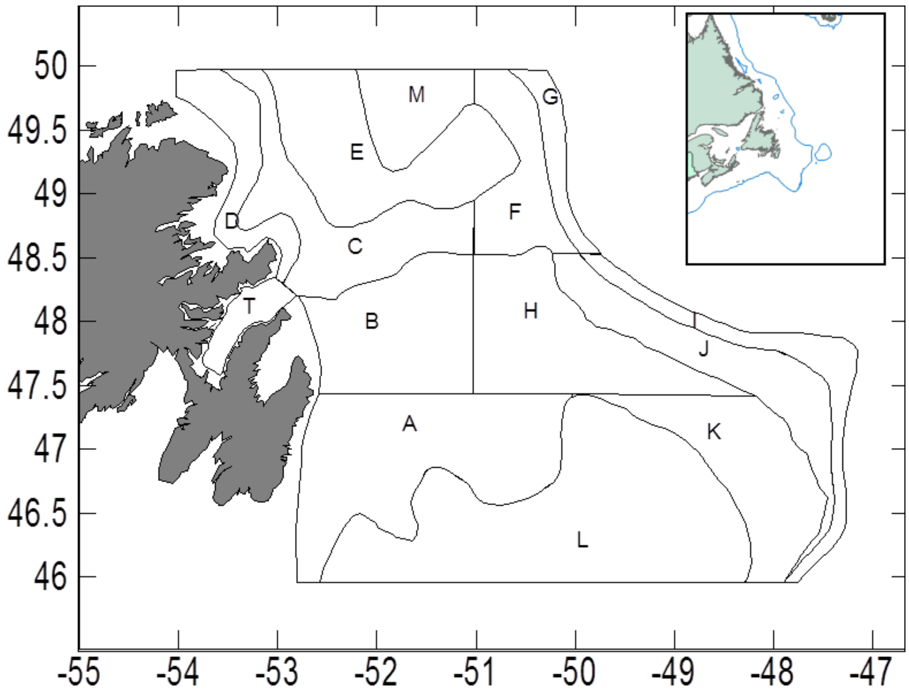


Figure 13: Map of survey area showing boundaries of depth-delimited strata used in the spring Capelin acoustic survey since 1999.

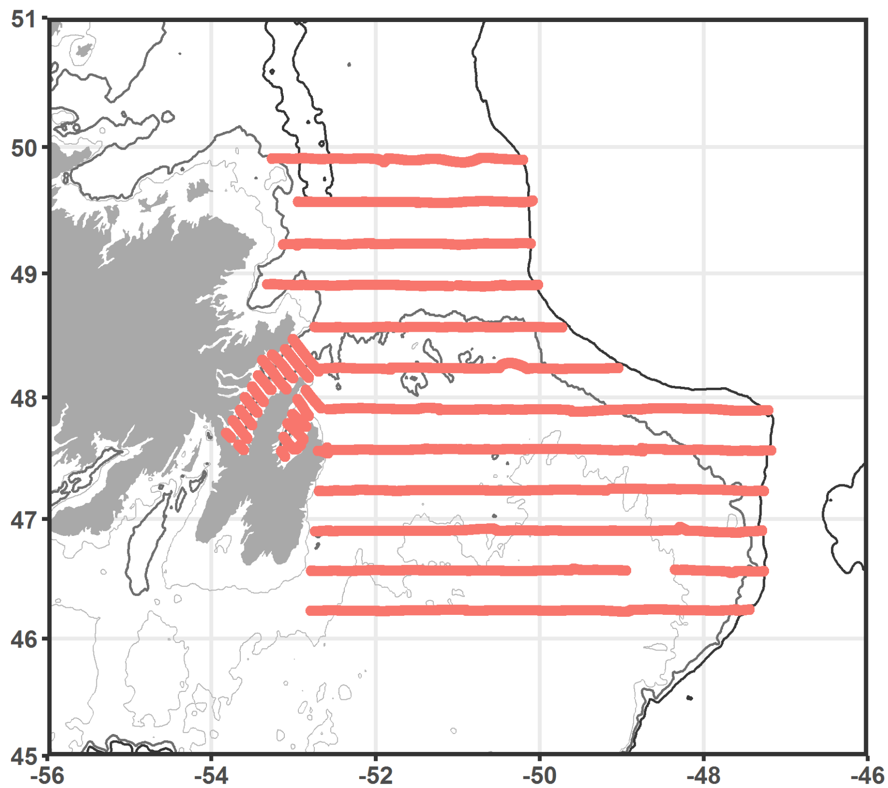


Figure 14: Transects completed during the May 2018 Capelin spring acoustic survey (note break in second line from bottom due to avoiding an oil rig).

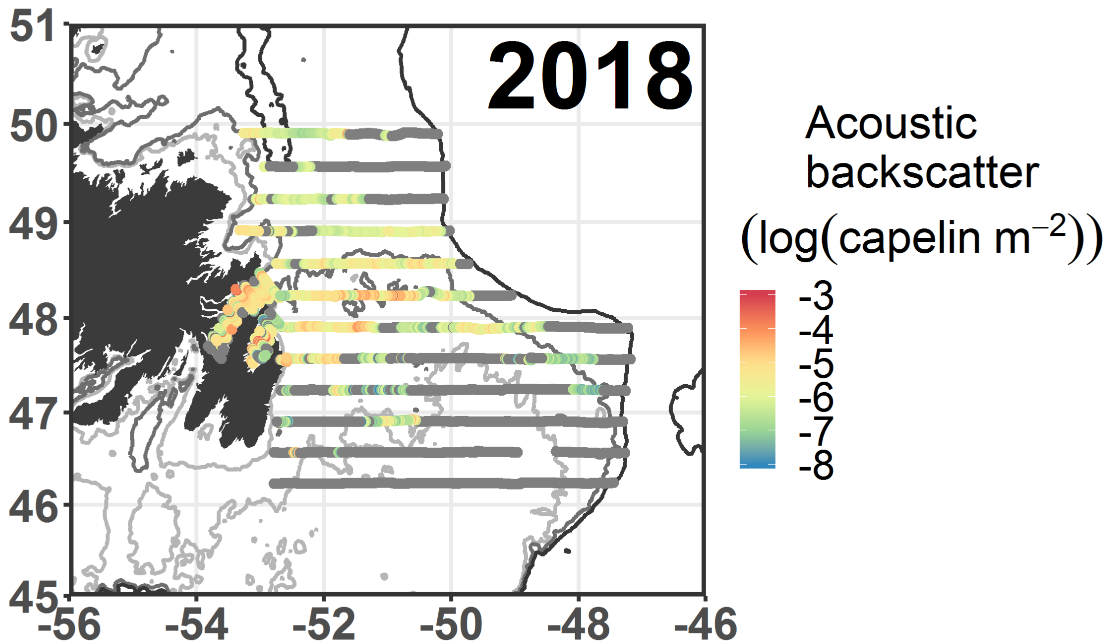


Figure 15: Distribution and intensity of Capelin backscatter during the 2018 spring acoustic survey.

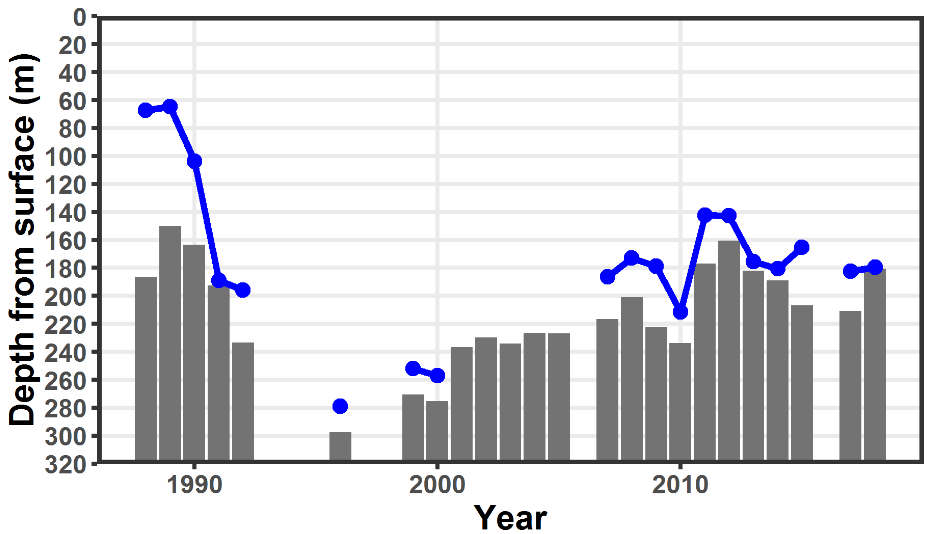


Figure 16: Mean bottom depth (bars) and mean weighted depth of Capelin (points) during the spring acoustic survey 1988-2018.

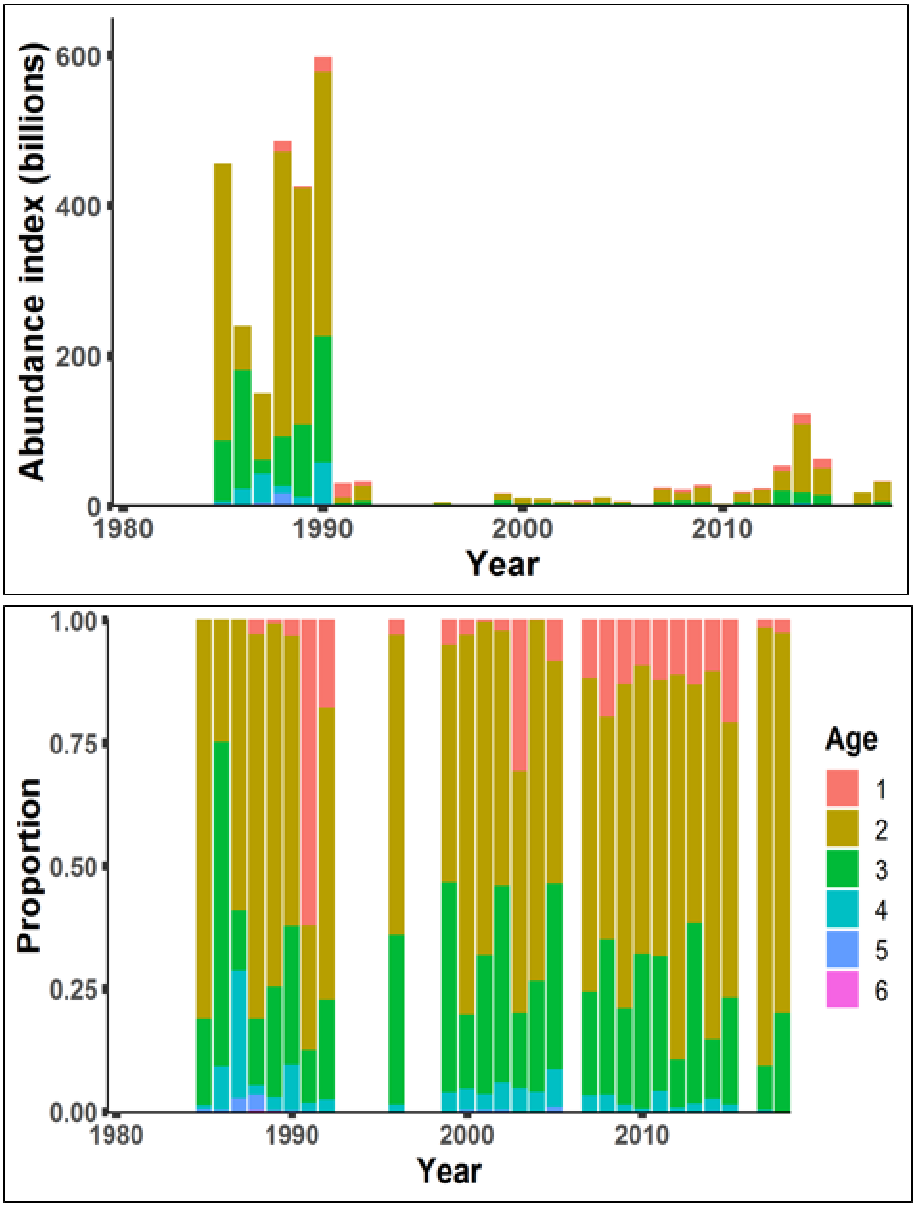


Figure 17: Age distribution of Capelin sampled during the spring acoustic survey by number (top panel) and proportion (bottom panel) to 2018.

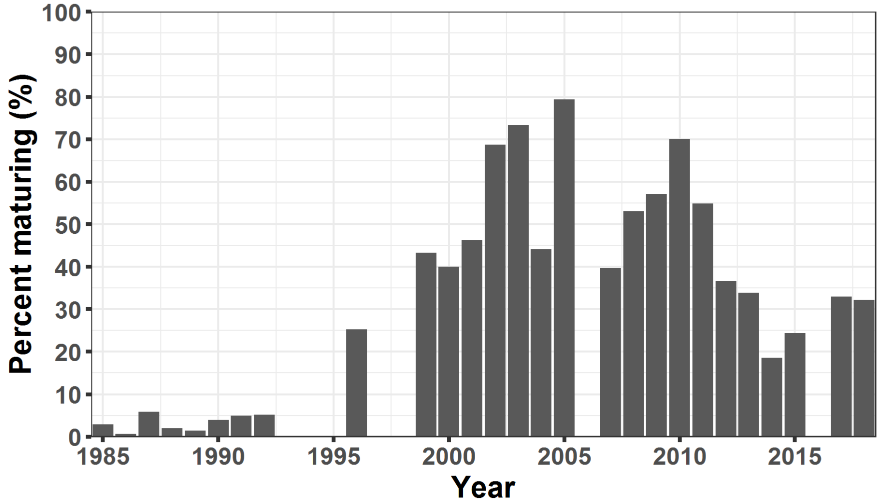


Figure 18: Proportion of age-2 Capelin sampled during the spring acoustic survey that were maturing.

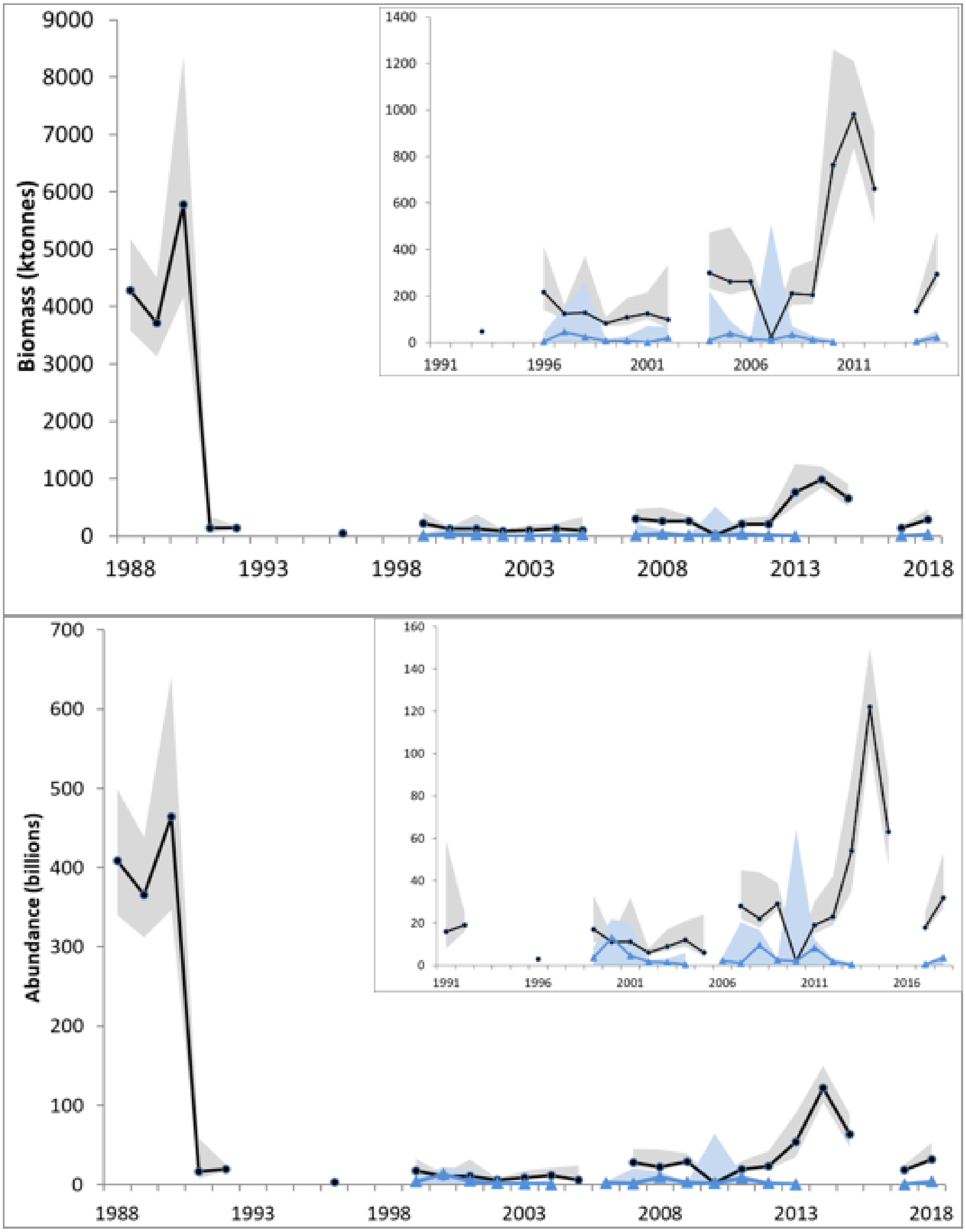


Figure 19: Index of estimated biomass (top) and abundance (bottom) of Capelin from the spring acoustic survey in the offshore (black) and Trinity Bay (blue). Shaded areas give upper and lower confidence limits, insets show post-collapse period (post 1990).

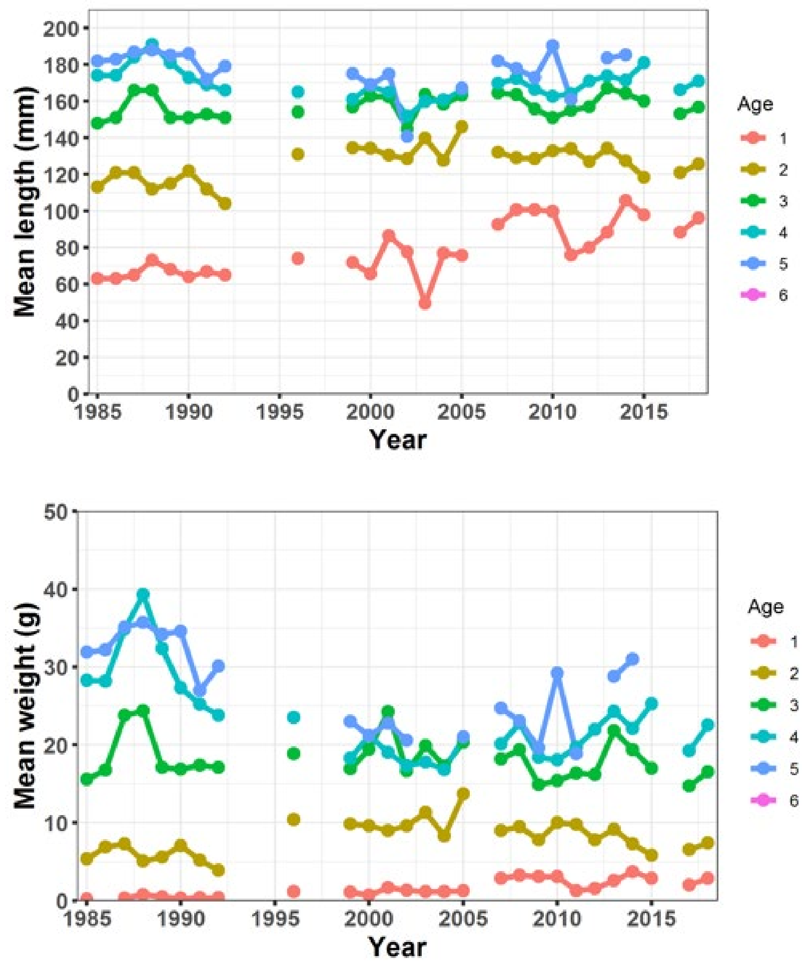


Figure 20: Mean length (top panel) and weight (bottom panel) of Capelin sampled during the spring acoustic surveys (1985-2018).

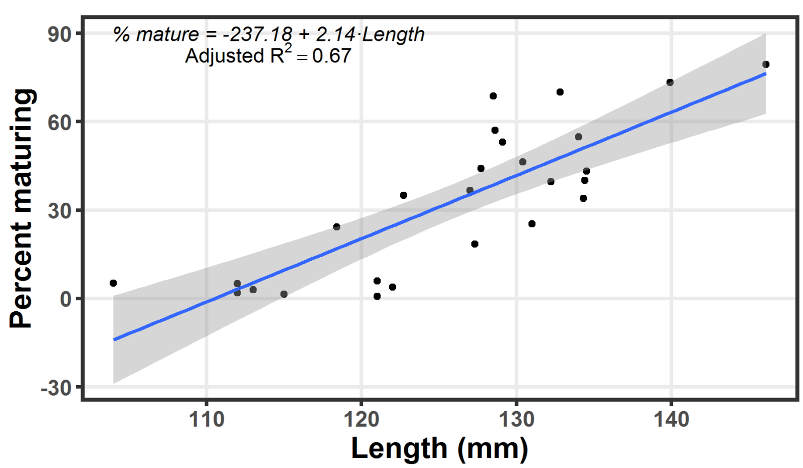


Figure 21: The percent maturing age-2 Capelin is positively related to length (mm) in the spring acoustic surveys 1985-2018.

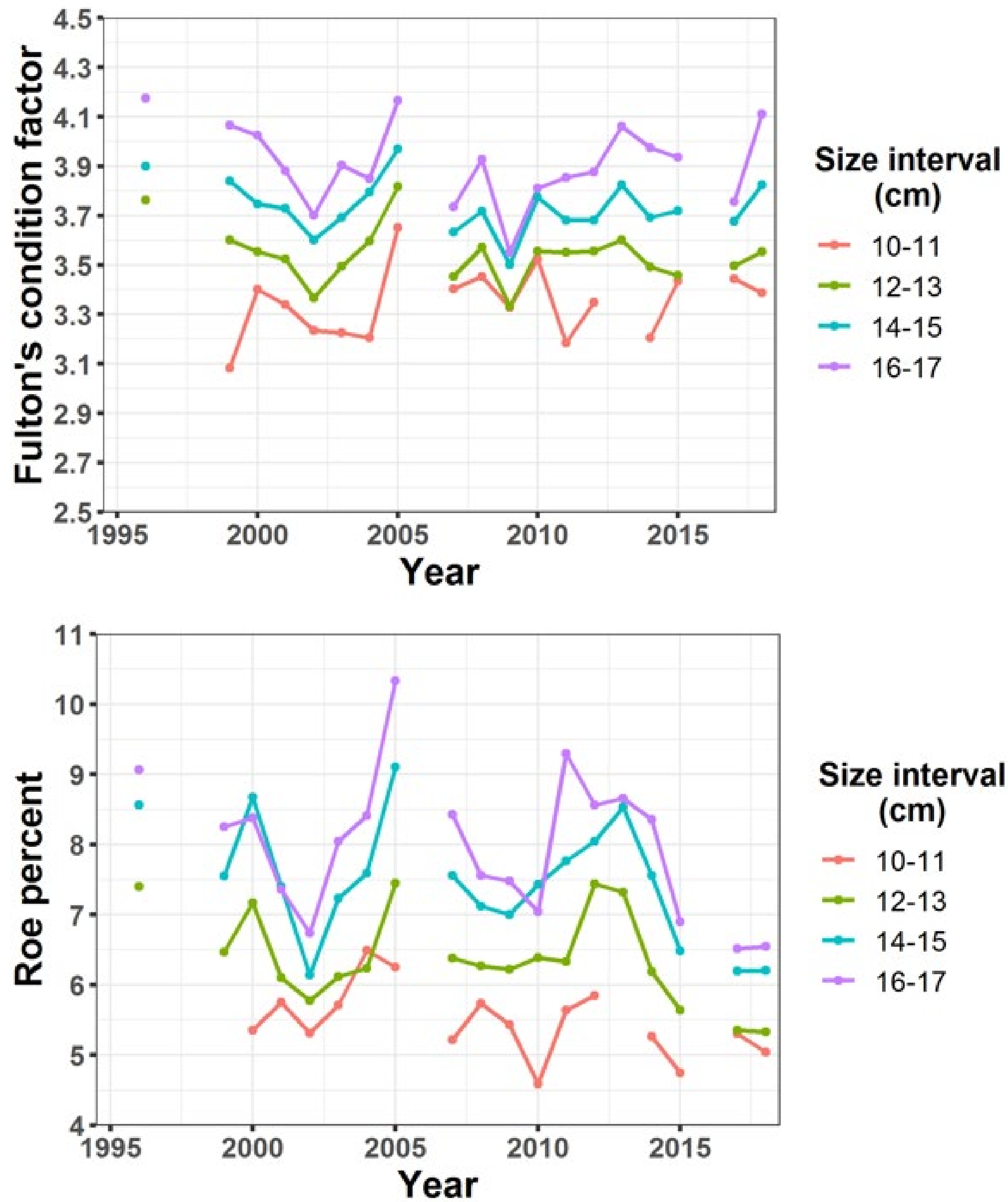


Figure 22: Fulton's condition (upper panel) and percent roe content (lower panel) of maturing female Capelin sampled during the spring acoustic surveys (1996- 2018) by size class (mm).

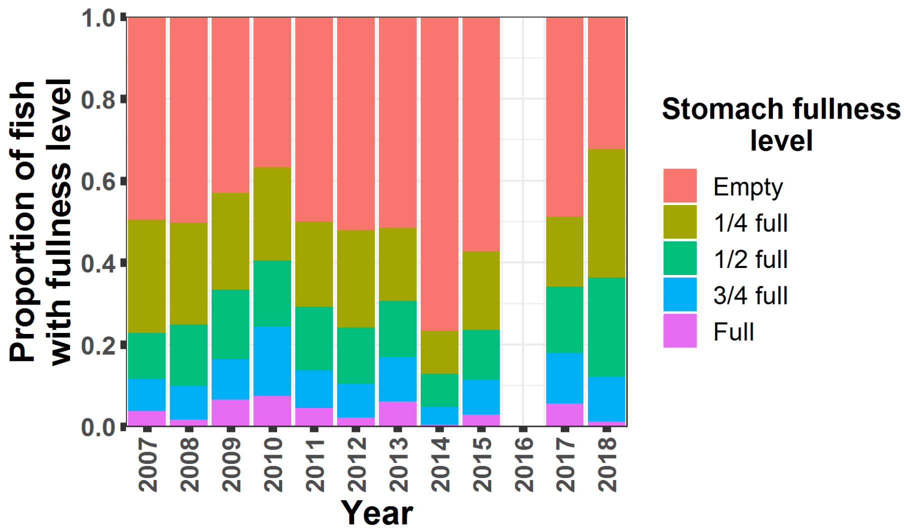


Figure 23: Stomach fullness proportion of Capelin sampled spring acoustic survey.

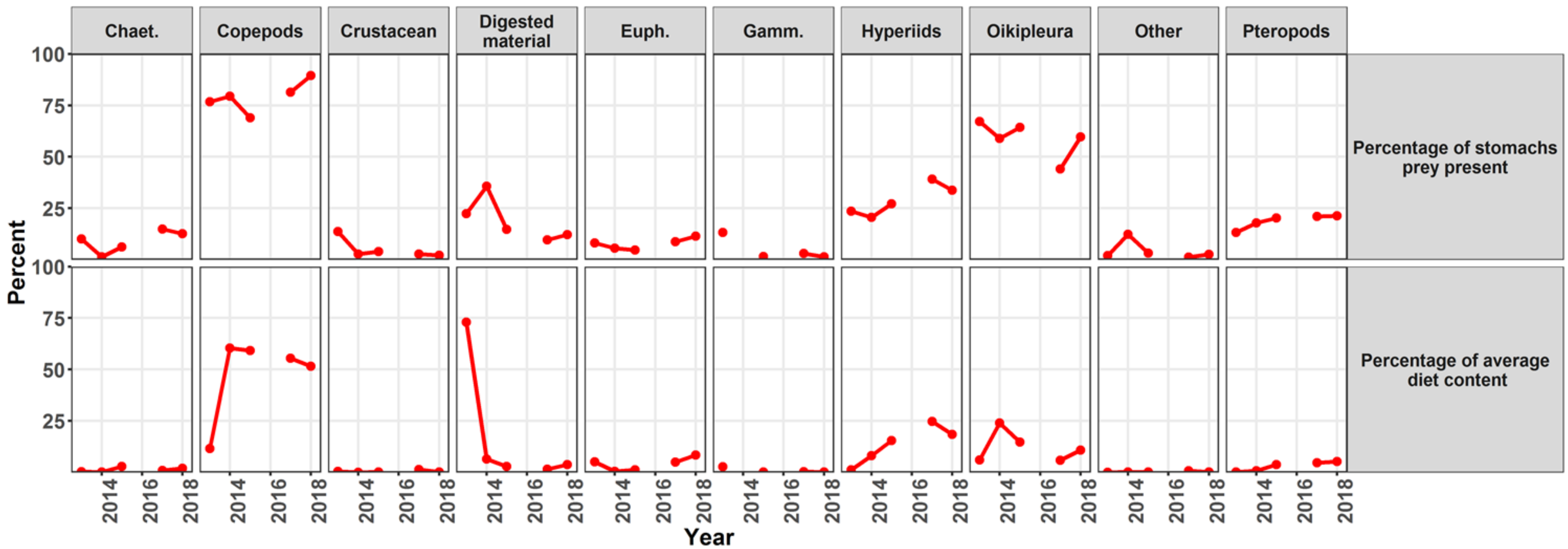


Figure 24: Percentage of stomachs with prey types present (top panel) and stomach content percentage by prey type (bottom panel) of Capelin sampled during spring acoustic surveys.

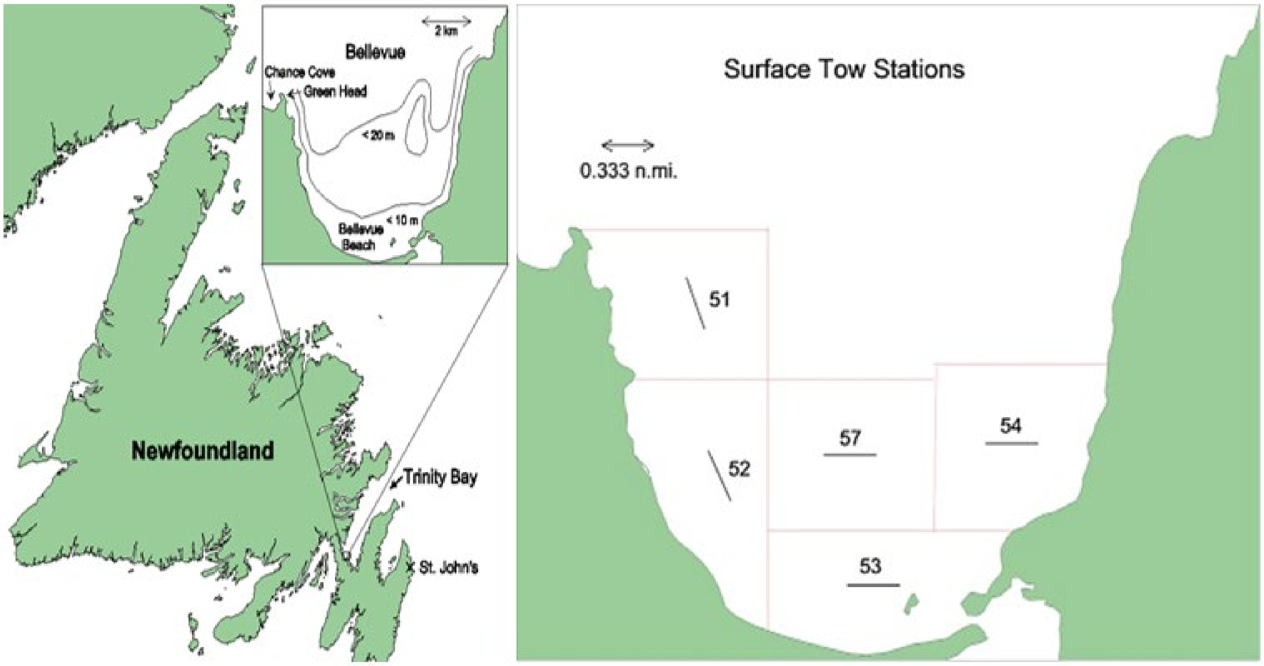


Figure 25: Map of Newfoundland and Bellevue Beach (left) and transects conducted during larval Capelin tows (right).

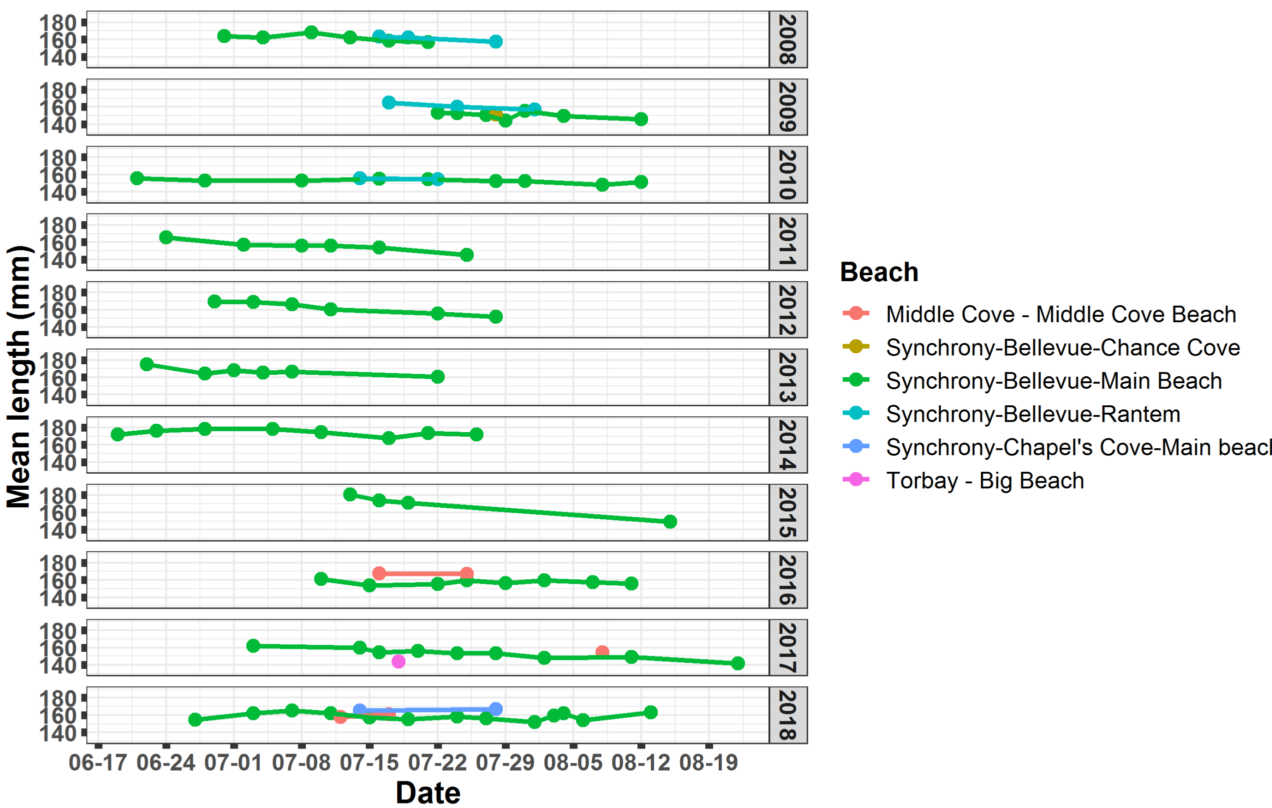


Figure 26: In-season variation in spawning Capelin length at index locations on the Avalon Peninsula.

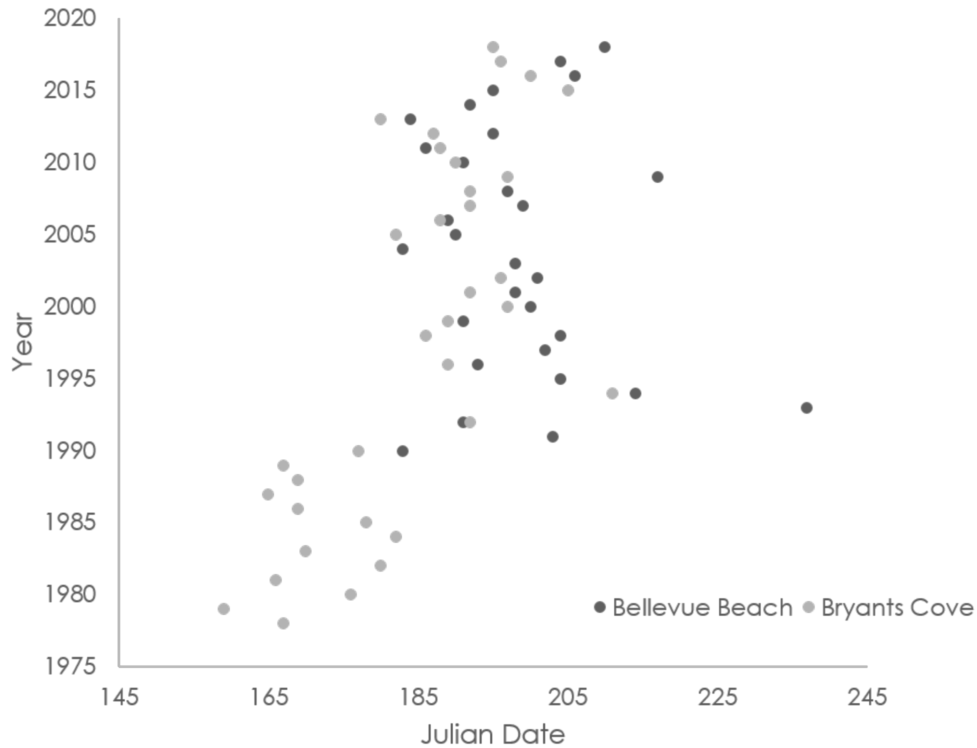


Figure 27: Timing of peak spawning of Capelin at two beaches on the Avalon Peninsula 1978-2018.

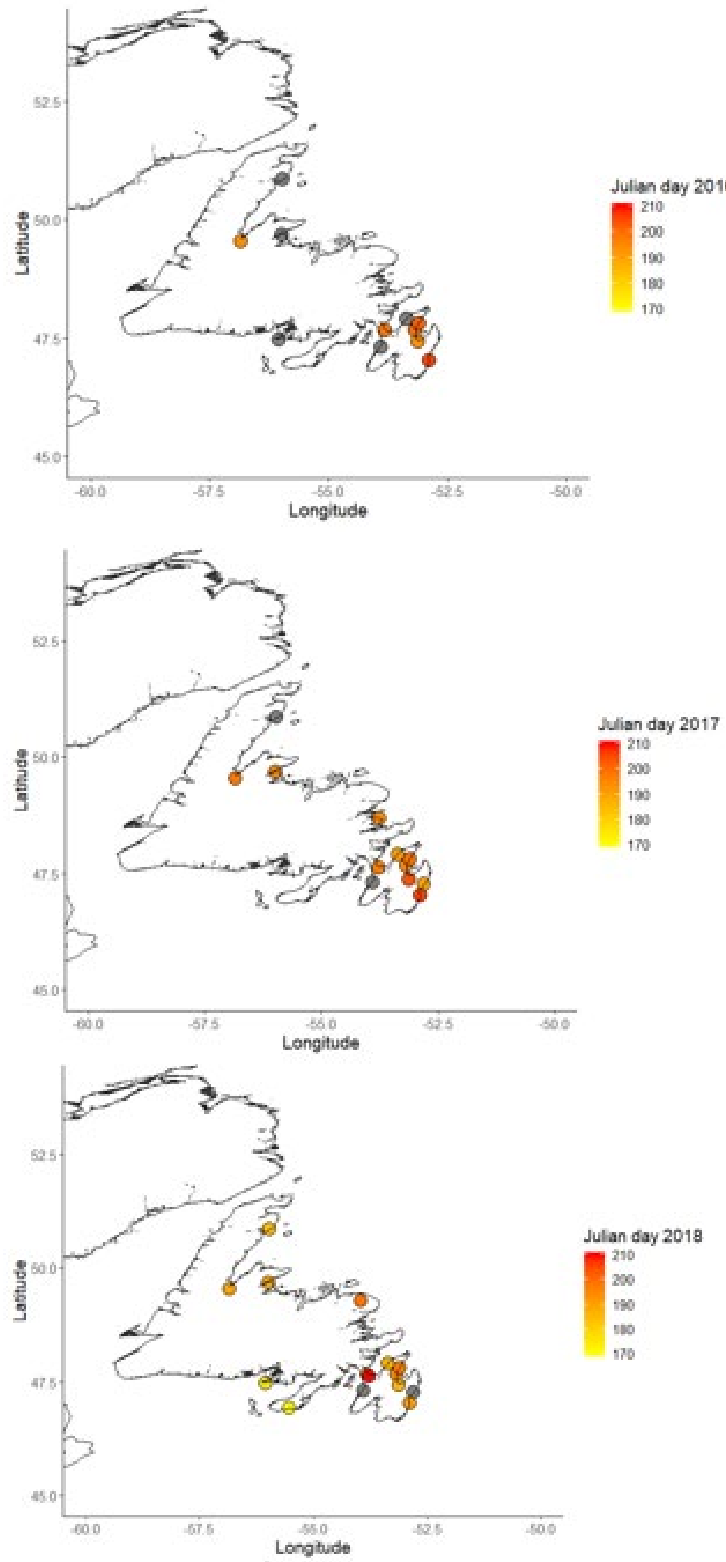


Figure 28: Timing of peak Capelin spawning on monitored beaches for 2016-2018.Grey circled indicated no recorded spawning.

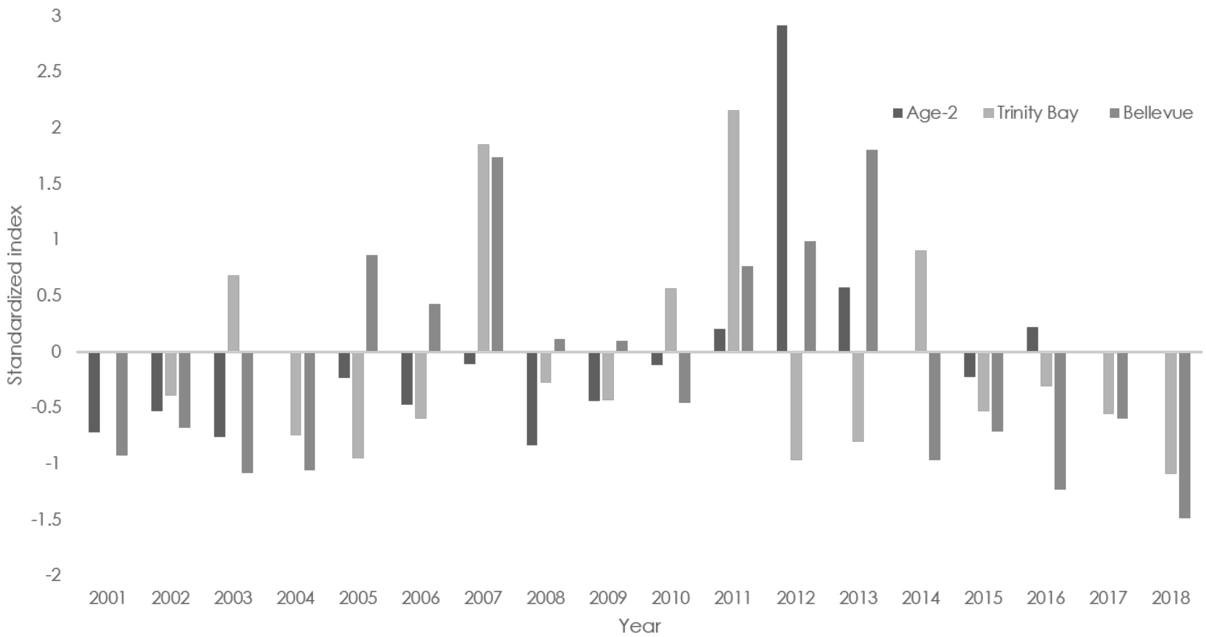


Figure 29: Comparison of standardized indices of cohort strength at all three Capelin life stages surveyed: emergent larvae, late larvae, and age-2. Note that the age-2 recruitment index is lagged by two years to compare survivors from the same cohort.

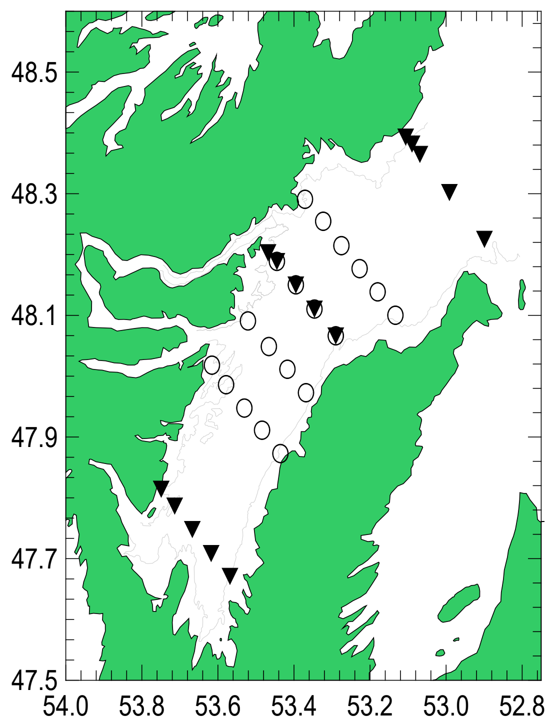


Figure 30: Positions of late-larval index tow stations in Trinity Bay. Open circles represent larval sampling stations, black triangles are CTD stations.

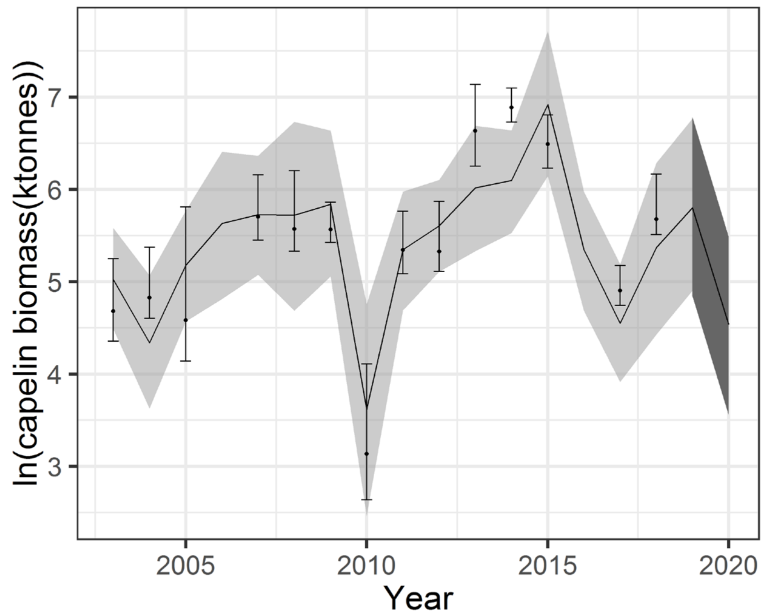


Figure 31: Results for the Capelin forecast model including the 95% credible (light grey) and 80% prediction (dark grey) intervals for expected values of Capelin biomass (solid line) and observed values (±95% confidence intervals).