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Assessment of Capelin (*Mallotus villosus)* in SA2 + Div 3KL in 2017

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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

Information from spring acoustic surveys, larval surveys, distribution patterns, biological characteristics and spawning behaviour were used to inform the status of Capelin in NAFO Divisions 2J3KL up to and including 2017. Following a period of increased abundance in 2013-2014, the acoustic index of Capelin abundance declined unexpectedly in 2015 and further in 2017 falling to levels typical of the period of low abundance seen in the 1990s and early 2000s. These declines were accompanied with poor spring condition of Capelin, delayed roe development and late spawning times. The 2017 age composition from the acoustic survey was strongly dominated by age 2 fish, although the proportion of Capelin first maturing at age 2 remained lower than during other periods of low abundance. More capelin were found on the shelf break during spring surveys, and reduced diel vertical migration observed. Fall distributions determined from bottom trawl survey catches were centered further south than in the four preceding years. Larval indices suggest that 2016 and 2017 cohorts will be below average. It is expected that the spawning stock biomass of capelin in 2018 will be low, although composed of a larger size fish due to the presence of virgin age 3 spawners.

INTRODUCTION

Capelin (*Mallotus villosus*) is a small, short-lived pelagic schooling species with major populations occurring in the Northwest Atlantic, waters around Iceland, the Barents Sea, and Northern Pacific. Historically DFO Newfoundland and Labrador Region has provided assessments and advice for 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 (i.e. meristics, tagging studies) it was recommended that Capelin in NAFO SA 2 + Div. 3K and in Div. 3L be considered one stock complex. This is the only Newfoundland Capelin stock for which assessments are currently provided.

Historical (pre-1970) catches of Capelin for food, fertilizer, and bait in Newfoundland did not exceed 25,000 t. An offshore foreign fishery for Capelin occurred in the 1970s with a peak catch of 250,000 t in 1976. The offshore fishery was closed in Div. 3L in 1979 and in Div. 2J3K in 1992. An inshore fishery started in Div. 3KL in the late 1970s, with peak landings of about 80,000 t from 1988-90. Recent landings have been closer to 20,000 t (Fig.1).

Capelin are considered a key forage fish in Newfoundland waters and are eaten by many predators including seals, whales, Atlantic cod, Greenland halibut, salmon, and seabirds. Capelin provide a vital link between zooplankton production and the production of most commercial fish species.

NAFO Div. 2J3KL Capelin spend most of their adult life in offshore waters. Historically the center of this distribution changed seasonally, with Capelin generally found feeding further north (NAFO Div. 2J and 3K) in the fall, moving southward along the shelf break in the spring (NAFO Div. 3L) before turning in across the shelf and migrating back up the NE coast to spawn at beaches and deep-water sites close to beaches in the bays of NL in summer.

Over the years, a number of inshore and offshore indices have been used to describe the abundance and distribution of NL Capelin. Inshore data series have typically concentrated on Capelin abundance at or around the time of spawning (aerial surveys, inshore commercial fishery catch rates, egg depositions) and emergent and late larval Capelin production. Offshore Capelin data has included 0-group surveys, multi-species bottom trawl surveys, bycatch information, and, most importantly, directed offshore acoustic surveys.

Due to funding restrictions and the subsequent loss of many of these indices in the early 2000s (e.g., aerial surveys, egg deposition, 0-group surveys) not enough data sources were available to run the multiplicative model previously used to estimate Capelin cohort strength (Evans and Nakashima 2001). Consequently from 2002-07 Capelin research initiatives were directed principally toward ecological research. From 2008-14 stock status information has been provided on a biennial basis based on data from 2 main indices (i.e. spring acoustic survey and emergent larval index). Following recommendations stemming from the 2012 assessment, a limit reference point meeting was held in November 2013 (DFO 2013). During this meeting all currently available data sources and assessment methods were reviewed and a number of potential reference points were discussed. However, due to serious data limitations and the lack of adequate stock projection methodologies, no limit reference points were set. There should have been an assessment of stock status in 2016 based on the biennial schedule, but the assessment was delayed by a year as there was no acoustic survey in 2016. This document presents information on stock status up to and including 2017, and is the first in revived series of annual Capelin stock assessments.

DATA SOURCES

FISHERY

Due to the short fishing season, changes in fishery timing and exploitation methods, commercial catch rates have not been used as an index of abundance for this species since 1993. However biological data from commercial fishery samples collected during the season were used to provide data on the age-and size-structure of spawning stock removals. The Capelin integrated fishery management plan (IFMP) splits the quota between two gear sectors: mobile and fixed (DFO 2018). Limits on the window of time during which the fishery may occur are also set forth in the IFMP, but the actual opening date of each gear sector within each bay is determined annually in consultation with industry and is dependent on the availability and quality of Capelin. Prior to the opening of the fishery, test fishery permits are allocated to a few fishers in each bay to monitor the biological characteristics of available Capelin. In most cases industry will not request a fishery opened until the test fishery finds that the fish are of high quality (high roe content and low feed). 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. Although considered fixed gear, a tuck seine is a modified beach seine that is fished in the same manner as a purse seine. Tuck seines have accounted for an increasing portion of the fixed gear fishery effort since the early 2000s.

Samples from the commercial fishery were obtained from catches as they are unloaded at processing facilities. Ten samples composed of 200 fish were obtained from each bay. Samples processed were spilt among gear types and temporally over the course of the fishery, in proportion to their associated sector landings. Length, sex and maturity were ascertained for all fish and additional detailed information (weight, gonad weight, stomach fullness, and age (from otoliths)) was collected for 2 fish per sex, per 5 mm length class in each sample. Catch at age was calculated separately for each gear sector and NAFO Division. This paper presents age compositions for commercial catches up to and including 2017 as well as mean sizes (length and weight) of commercial catches.

SHRIMP FISHERY BYCATCH

The commercial fishery for Northern Shrimp (*Pandalus borealis*) is subject to a fishery observer program which, among other responsibilities, monitors bycatch of non-target species. The program has ~100% coverage of trawlers within the offshore fleet and ~7% coverage for trawlers in 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 was determined separately for the inshore and offshore fisheries in each division and the total number of sets was counted. To adjust for the 7% coverage of the inshore fishery, the total bycatch and total number of sets for the inshore fishery in each Division was divided by 7% in order to obtain an estimate of the total bycatch and number of sets within each Division.

CAPELIN ACOUSTIC SURVEYS

From 1982 to 1992 two acoustic surveys were conducted each year. The first survey of the year was conducted in the month of May and covered the majority of Div. 3L, an area of particular importance for juvenile Capelin. The main objective of this survey was to produce an estimate of immature Capelin that would be recruiting to the spawning population the following year. A second survey was conducted during the month of October in Divs. 2J3K. This survey was used to determine the size and number of maturing fish available for the following year. Together these surveys formed the basis of the stock assessment until 1992. However, following a dramatic decline in the fall and spring offshore acoustic abundance estimates accompanied by sudden changes in Capelin spawning behaviour and migration, the reliability of the offshore acoustic surveys as indices of Capelin abundance were called into question.

In an attempt to address these concerns the spring survey was briefly discontinued in 1993 in favor of an expanded fall survey covering all of Divs. 2J3KL (1993-94). However, this expanded fall acoustic survey failed to find the ‘missing’ offshore Capelin. No Capelin acoustic surveys were conducted in 1995 and only the spring 3L survey was conducted in 1996. There were no acoustic surveys conducted in 1997 and 1998. Since 1999, spring surveys have been conducted annually (with the exception of 2006 and 2016), but fall surveys ceased in 1994.

Spring surveys for Capelin have historically been conducted in the month of May; however, in two years (1992 and 2003) the survey was also repeated a second time in June. Surveys were conducted primarily in NAFO Div. 3L and since 1996 also in the lower portion of 3K (<50ºN). A stratified survey design was conducted each year, although the stratum boundaries and areas covered have changed over time. 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. 2). The methodology and original strata for each survey from 1982 to 1996 are presented in annual stock assessment documents (Miller 1985, 1991, 1992, 1997).

Transect design has also varied substantially 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 distribution patterns lead researchers to revert to the equidistant parallel line design in 1993, as it was decided that this design would have the greatest probability of intersecting Capelin aggregations. In the post-1999 survey design, the start point of the initial transect is randomly generated for each survey.

In the 1980s and early 1990s, transects were allocated within each stratum at a rate of one per 10 nautical miles of latitude. In subsequent years, it was decided that survey intensity was less important than maximal area coverage. In particular, there was interest in expanding the survey area northward and to the deep shelf edge waters. Consequently, transect spacing was increased to 15-30 nautical miles, and sampling intensity (effort) was adjusted in each stratum depending on its expected density ranking (based on the previous year’s survey findings) and upon total time available for the survey.

During acoustic surveys, backscatter was attributed to species using echogram characteristics and biological characteristics of the catches from trawls. Targeted fishing sets were conducted as required to investigate the species composition of the acoustic backscatter, and targeted fishing sets are also periodically conducted to confirm the absence of Capelin in the acoustic bottom deadzone’ (0.75 m). A minimum of one set was conducted every 12 hours during all surveys. Prior to 1996, a large mid-water trawl (Diamond IX) was used to collect biological samples. Since 1996, both mid-water IYGPT (1996-2015) and Campelen 1800 (1996-present) trawls have been used. Length-based selectivity corrections were made to all IYGPT catches to produce Campelen equivalents, as the IYGPT trawl catches significantly more small Capelin (<10 cm) and fewer large Capelin >14 cm (Mowbray 2001). Fishing sets have been completed both on the seabed and in the water column, targeting the observed backscatter signal. Using bottom trawls allowed for directed sampling of the bottom zone in the 1990s when Capelin tended to aggregate near the seabed. The duration of fishing sets ranged 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 each species caught was recorded in all years. Total length, sex, and maturity were recorded for a maximum of 200 randomly selected Capelin from each set. Additional detailed sampling (weight, gonad weight, scalar stomach fullness and otolith extraction) was conducted on 2 Capelin of each sex per 5 mm length group. Since 1999, stomachs have been collected from one set per stratum. Stomachs were removed from Capelin subject to detailed sampling. From 1999 to 2007, stomachs were preserved in 10 % formalin but since 2008 stomachs have been frozen. Since 1999, length measurements have also been recorded for all other potential acoustic targets including Arctic cod, Atlantic Cod, Atlantic Herring, Redfish, and Sandlance.

Changes in vertical migration patterns may affect the availability of fish to acoustic surveys. This can result from fish moving above the “effectively ensonified” portion of the water column (11-15 m from surface), staying within the bottom “deadzone” (0.75 m from bottom) or by dispersing to such a degree that Capelin cannot be detected or separated from background noise. In order to address these concerns, mesoscale studies investigating diel differences in Capelin detectability were conducted in 1987 (Miller, unpublished data) and 1999 (Mowbray 2001). During these studies, a small block (approximately 18.5 km x14.8 km) was repeatedly surveyed with equidistant parallel lines and the resultant backscatter integrated in 100 m horizontal bins. The mean area backscattering coefficient (*sa*) of Capelin on a transect was calculated each time the transect was surveyed. Minimum detectability was calculated as the ratio between the minimum and maximum average Capelin *sa* over the mesoscale survey area within a given 24-hour period. Results of these studies indicated that Capelin were consistently less available to acoustic surveys during the day, likely as a result of their proximity to the seabed.

Over the years changes in fall and spring acoustic surveys have occurred which may impact survey results and comparability. These changes include survey design/intensity, the acoustic technology used, calibration techniques, fish biology, and sampling gear used. Frank et al (2016) investigated the impact of spring acoustic survey design changes and found that the current transect design and spacing provided similar results to previous spring acoustic survey designs. In the previous assessment (Mowbray 2012), a statistical methodology to calculate the confidence intervals around the spring acoustic survey estimates was established in to incorporate variability associated with biological and technological changes in the spring acoustic survey design.

MULTISPECIES BOTTOM TRAWL SURVEYS

Catch rate information from multispecies bottom trawl surveys (hereafter bottom trawl surveys) was available since the trawl used switched to the Campelen bottom trawl. Capelin catch rates were available for fall surveys in NAFO Divisions 2J3KL since 1995 and spring surveys in NAFO Divisions 3LNO since 1996. For a detailed account of the methodology and design of these surveys see Brodie (2005). Limitations in the availability of Capelin to the bottom trawl surveys due to Capelin vertical displacement relative to the net and the selectivity of the trawl employed prevent the bottom trawl data from being used to estimate Capelin abundance (e.g., Mowbray, 2001). However the bottom trawl survey data were used to describe Capelin distribution and center of mass of the Capelin stock. Furthermore, the bottom trawl surveys provide the only source of information on Capelin distribution in the northern portion of the stock’s range. Samples of 200 fish (spring surveys) and 25 fish (fall surveys) collected during the bottom trawl surveys are frozen and later examined in the lab. Length, sex, and maturity are determined for 25 fish from each catch in the fall surveys and from one sample of 200 fish from each superstrata (group of consecutive similar depth strata) in the spring. Detailed sampling (weight, gonad weight, stomach fullness, and age from otoliths) is determined for 2 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 surveys.

BELLEVUE LARVAL SURFACE TOWS

Since 2001, surface tows for larvae have been conducted at 5 sites in nearshore waters (< 20 m) off Bellevue Beach. This survey was designed to sample larvae emerging from demersal Capelin spawning beds (Nakashima and Wheeler 2002) as well as larvae emerging from Bellevue beach and 4 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 fitted with 270 µm mesh nets and towed for a duration of 10 minutes at 2.1 knots at 5 stations (Fig.3) every 24-48 hours (weather permitting). Only one of the nets collects a larval sample. A General Oceanics 2030 Series mechanical flow meter positioned in the opening of one net measures the volume of water filtered. Capelin larvae are preserved in a 5% formalin and saltwater solution buffered with sodium borate. In the laboratory, when less than 500 Capelin larvae are present in a sample they are all enumerated, otherwise a sub-sampling technique is used (van Guelpen et al. 1982). From each sample, 50 larvae are measured and presence/absence of their yolk sac 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) summed over the sampling period is estimated using the trapezoidal integration method:

$$N = \sum (t_n - t_{n-1}) \, ½ \, [X(t_n) + X(t_{n-1})]$$

where t_n is the sampling day, t_{n-1} is the previous sampling day, X(t) is the number of larvae per m^3 on day t, and $X(t_{n-1})$ is the number of larvae per m^3 on day t_{n-1}. Only days when all 5 stations were successfully sampled are included in the 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 three or more days then the missing values are set to 0.

TRINITY BAY LARVAL SURVEYS

From 1982 to 1986 investigations into larval Capelin production and distribution were carried out in Trinity Bay (Dalley et al. 2002). This work consisted of a comprehensive monitoring of Capelin production on a monthly basis from July to October, covering the entire main bay. During these surveys 52 randomly chosen stations in 6 strata were repeatedly occupied and fished using a pair of 333 µm mesh nets fitted on a 61 cm diameter bongo frame. Catches from these surveys indicated that the center portion of the bay contained the highest densities of Capelin larvae and that catches in these center strata were correlated with catches in the other strata.

In 2002 a reduced version of this survey was reinstated. Objectives of the survey were to track larval production at the bay scale and investigating how later spawning times affected larval survival and growth. Since 2003, 19 stations (Fig. 4) in the central strata have been sampled 1 to 3 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.

From 2003, fixed sampling stations were established along 4 northwest lines 6 nmi apart; stations were placed at 3 nmi intervals along each of the 4 lines. All other equipment and methods were the same as Dalley et al. (2002). Constant bongo net descent and ascent rates are maintained at each station by real- time monitoring of gear depth using a net-mounted STD. Target descent rate is 20 m/min and the ascent rate is 10 m/min. The filtered volume of each net is monitored using mechanical flow meters (General Oceanics 2030 Series). The bongo nets are towed at a speed of 2-2.5 knots. At each station, one bongo sample is preserved in 2% buffered formaldehyde and the other bongo sample preserved in 99% ethanol.

CTDs casts of the entire water column are conducted at each of the 19 bongo stations, as well as across the head and mouth of the bay when time and weather conditions permit (Fig. 4). Since 2013, zooplankton samples have been collected at each bongo 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 CCG Vladykov using a FlowCam.

Following the survey, the 19 larval samples preserved in 2% formaldehyde are strained, soaked in freshwater and then reconstituted to 1L volume. Successive 50 ml aliquots of the reconstituted sample are sorted and all fish larvae identified to species. Aliquots are analyzed until a minimum of 50 Capelin are counted or half of the sample is sorted (500 mL). The number of individuals of each species is recorded, and all Capelin and herring larvae are measured for standard length. 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 filtered volume in m^3. The annual Capelin production index from Trinity Bay is the mean weighted 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 preserved in ethanol is not used for abundance estimation. Capelin larvae from these samples are used for larval age, growth and diet studies. Based on studies from Capelin larvae preserved in ethanol in 2002, 2006 and 2013, Capelin larvae are < 30 days old in the Trinity Bay surveys and experience interannual variability in growth rates, which may be related to prey availability (Murphy et al. 2018).

RESULTS

FISHERY

Participation in the Capelin fishery in Divs. 2J3KL depends largely on market conditions and processing sector capacity both for Capelin and alternative fisheries. Consequently, for the past 20 years few Capelin have been harvested in Conception Bay, as local industry preferred to fish crab during the time period allocated to the Capelin fishery. However, in Trinity Bay and in bays further north a greater proportion of licensed harvesters actively fish Capelin. In 2017, 71 of the 195 licensed mobile gear participants and 207 of the 1,259 fixed gear participants were active (DFO 2018).

In 2015-17 Capelin spawning was late and industry encountered difficulties isolating schools with both adequate maturity development and low levels of feed. In 2017 this resulted in the fishery closing before harvests in the northern portion of Div. 3K could occur. Extensive delays in landings could not be accommodated by processing plants, which had begun to process catch from other fisheries. As a result, landings in 2017 were atypically low with no harvests occurring in White Bay. A total of 23,282, 27,391 and 19,777 metric tons of Capelin were landed in NAFO Divisions 2J3KL in 2015-17 respectively. These amounts account for 76%, 90% and 65% of the overall Divs. 2J3KL annual TAC for these years, although some Division and sector quotas were achieved or exceeded in all years (Fig. 1). The sharing of the stock TAC among divisions is not designed to protect regional stock components, but rather to equitably share the resource among harvesters. If the TAC for a given region is not fished, fisheries management can reallocate it to be taken in other fishing areas. Catches broken out by NAFO division and gear sector are shown in Fig 5.

Between 2015 and 2017, the average length of Capelin taken in the fishery progressively decreased from a peak in 2014 to the smallest in the time series caught in 2017 (Fig. 6). These changes in average size were associated with an increase in proportion of mature age 2 fish caught in the fishery and a decreasing proportion of older age classes. In 2017, age 2 fish accounted for 75% and 77% of fish caught commercially in Div. 3K and Div. 3L, respectively while almost no fish over age 3 were caught (Fig. 7).

SHRIMP FISHERY BYCATCH

Bycatch of Capelin in the commercial shrimp fishery peaked at 364 metric tons in 1989 for NAFO Divisions 2J3K (Fig.8). More recently bycatch reached a high of 266 metric tons of Capelin in 2012, but has since declined to 4.8 metric tons in 2017. For Division 3L, Capelin bycatch peaked in 2010 at 505 metric tons but the shrimp fishery in 3L has since closed. The sector contributing the most to bycatch varies by year and Division. For Divs. 2J3K, the commercial shrimp fishery responsible for most Capelin bycatch frequently alternates between the inshore and the offshore. For Division 3L, typically the inshore shrimp fishery was responsible for the majority of Capelin bycatch, but since 2010 the offshore shrimp fishery has caught the most Capelin bycatch. While fishing effort plays a role in the amount of Capelin bycatch caught in the shrimp fishery, the relative abundance of Capelin and the degree of spatial overlap between Capelin and Shrimp also affect bycatch rates. For much of the observer time series in Division 3L, there is little difference between the mean fishing depths of all trawl sets versus those sets in which Capelin was caught as bycatch (Fig.9), indicating that Shrimp and Capelin are occupying similar depths. In contrast, for Division 2J3K, the mean depth of trawl sets that caught Capelin are shallower than the mean depth of all trawl sets since 2014, indicating that Capelin are occupying shallower depths than Shrimp in this Division.

DISTRIBUTION

All spring acoustic survey strata (Fig 2) were surveyed in 2015 and 2017, with the exceptions of Trinity Bay in 2015 and a portion of the inshore edge of strata C and E in 2017, which were inaccessible due to excessive ice coverage. Since fish densities in ice covered portions of strata C and E are usually similar to the rest of the stratum, strata C and E abundances were estimated using densities from the surveyed portions extrapolated for the whole stratum area.

During the 2015 acoustic survey, Capelin were found throughout the northern portion of the survey area, with densities in the northern strata an order of magnitude greater than those on the southern Grand Bank (Fig 10). Capelin were found in very low densities and were absent from large portions of the surveyed area in 2017; the highest Capelin densities occurred in strata consecutive to the shelf break in a narrow band around the 200m depth contour (Fig 10). The highest density of Capelin (stratum mean) observed in 2017 was approximately half of that observed in 2015. Recent spring distribution patterns are similar to those observed in the early 2000s, with Capelin located further offshore and in deeper water.

Fall distribution of Capelin tends to be centered in Division 3K. Generally low Capelin densities were observed in 2J in 2016 and 2017 (Fig.11). Buren et al (2019) used a centre of gravity approach that accounted for both inertia (i.e. spatial dispersion of the population around its center of gravity) and changes in fall bottom trawl surveys sampling effort (cf. Woillez et al. 2007). The centre of gravity trend in most decades was a pronounced shift along the north-south axis, with an exception in the 2000s when there was a westward shift in the centre of gravity (Fig. 12). In the 2010s, the CG was again offshore with shifts along the north-south axis, similar to the centre of gravity of the late 1980s. (Fig 12).

Historically Capelin underwent diel vertical migrations in all portions of the surveyed area; however, starting in the spring of 1991, these patterns changed suddenly with Capelin remaining much 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 much deeper in the water column than in the late 1980s. Since 2011 capelin have once again been observed in shallower water, but with little to moderate diel migration (Fig. 13).

BIOLOGICAL CHARACTERISTICS

Capelin are regularly sampled throughout the acoustic surveys. The trawls most extensively used to collect these samples (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 Capelin, which usually range from 5 to 8 cm total length in May. However, older Capelin are well sampled by both gear types (Mowbray, 2001).

Capelin captured in acoustic survey trawl sets range from 5 cm to 20 cm in length and are composed of ages 1 through 6, although ages 5 and 6 were present in only a few years since the 1990s and age 1 Capelin were largely absent from the survey in 2017. In most years, age 2 Capelin account for the majority of the catch, with age 3 Capelin the second most prevalent age class (Fig. 14, 29).

One of the most significant changes in the composition of the catch in Div. 3L has been the increase in proportion of maturing age 2 Capelin. This proportion was low during periods of high abundance during the late 1980s and high during periods of low abundance from the mid 1990s-2000s. A similar low proportion of maturing age-2 fish was found in 2011-13 when Capelin abundance improved to 25% of pre-1991 abundance estimates. While the Capelin acoustic index has since declined, the proportion of maturing age 2's has not yet reached the high rate observed in the period from 1996-2010 (Fig. 15).

Changes in age of maturity have been associated with larger size at age for younger Capelin (age 1 and 2), but similar or smaller sizes for ages 3 and older (Fig. 16). The proportion of age 2 fish maturing was positively related to fish length (Fig 17).

The somatic condition of Capelin (Fulton's K) was calculated for Capelin captured during the spring acoustic survey. Prior to 1996 weights of capelin captured during the survey were not recorded condition values are only available from 1996 onward. Condition was calculated for maturing females in order to investigate interactions between condition and gonad maturation. Trends in condition over time were similar among size classes. For most years, gonad development (i.e. roe content; % of body weight) tracked condition. In 2017 the condition of smaller (< 12 cm) Capelin was near the time series average, but declines in condition of larger fish (> 12 cm) approached the time series low . Roe content in 2017 was greater than the record low observed in 2015, but was still one of the lowest in the time series, particularly for the larger size classes (Fig 18).

In order to minimize the artifacts of energy re-allocation to gonads and mixed spawning histories that are more characteristic of females compared to males, fall condition was examined for male fish only. Individual lengths and weights of Capelin were used for this analysis and fish with weights greater than the 99th percentile were removed from the analysis as these were most likely keying errors. Age 1 and 2 fish were considered separately. Relative condition was estimated by performing a linear regression on the log10 transformed length and weight of individual males, then dividing the weight of each fish by the associated fitted value obtained from the regression. Note that only fish with relative condition between 0.7 and 1.4 were displayed.

Fall condition of Age 1 males was low in 3L (their main area of distribution) in 2015, but climbed to a time series high in both 3L and 3K in 2017 (Fig 19a). Fall condition of age 2 fish, declined from average values in 2015 to low values in 2016 in both 3K and 3L rebounding to a series high in these same areas in 2017 (Fig. 19b).

Samples of spawning Capelin were collected using a cast net once a week at Bellevue beach. Samples were also collected from several other beaches where local residents participate in the DFO Science spawning diary program. Samples are comprised of 25 males and 25 females which were randomly selected. These samples were used to examine within season variation in spawner composition.

A decline of approximately 20 mm in the mean size of spawning Capelin has been observed over the course of the spawning season in most years, including in 2017 (Fig 20). 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 little variation in spawner size was observed. The timing of sample collections also exhibited marked delays in 2009 and 2015-17 as a result of late spawning. The timing of peak spawning is available from 2 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 (e.g., 2004, 2011, 2013), overall delayed spawning continues, with the timing of spawning in 2015-2017 among the latest in the time series (Fig 21).

LARVAL INDICES

The Bellevue surface tow index was positively related to the age 2 recruitment index (2001-15; $y = 1.04x - 2.25$; $p = 0.017$; $R^2 = 0.42$; updated from Murphy et al. (2018)) (Fig 22). Since 2015, the Bellevue surface tow index has been low, with annual densities of 989 m^{-3} (2015), 416 m^{-3} (2016), and 1,115 m^{-3} (2017). These annual densities were below the long-term average of 1,717 m^{-3} and are similar to mean Capelin larval densities sampled in the early 2000s.

The Trinity Bay late-larval index, derived from bongo net tows, were not related to the age 2 recruitment index (2002-15; $y = -0.0004x + 1.17$; $p = 0.234$; $R^2 = 0.05$; updated from Murphy et al. (2018)) (Fig 23). This lack of a significant statistical relationship is likely due to the spatial and temporal contraction of the sampling protocol compared to the 1980s with only 19 of the original 52 stations sampled from 2003-17.

Continued sampling of late-stage larvae remains important as the remaining 60% of 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). Since 2015, the September Trinity Bay larval index has been low, with mean densities of 9.7 m^{-2} (2015), 13.6 m^{-2} (2016), and 8.8 m^{-2} (2017). These mean densities are below the long-term average of 28 m^{-2}.

Each of the three indices (Bellevue surface tows, Trinity Bay bongo tows, and age 2 recruitment) for the 2002-17 year classes were standardized to the mean of the 2003-16 year classes (Fig 24). The Bellevue surface tow and age 2 recruitment indices track together through the time series, while the Trinity Bay bongo tow index does not. In the past 4 years (2014-17), the Bellevue larval index is below average, as is the 2015 year class in the acoustic survey. The September Trinity Bay bongo tow index was above normal in 2014 and below average for 2015-17. Our larval indices suggest that the 2016 and 2017 year classes will be below average.

ABUNDANCE

An index of Capelin abundance within the surveyed area was generated from the May acoustic survey. The associated variance for the survey area was calculated using a Monte Carlo approach (Mowbray 2012). This approach incorporates potential variability derived from 4 factors: calibration values (associated with technological advances), target strength (TS) (resulting from variations in length composition and catchability), acoustic detectability (resulting from variations in vertical migration), and spatial variability (aggregation). Using this technique a re-sampled population of Capelin areal density estimates was derived for each stratum. To address issues of spatial autocorrelation, the survey track was divided into consecutive 2 km segments. For each segment, the species *sa* value was randomly selected from one of the 20 candidate 100 m horizontal bins. This value was 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 was repeated 1000 times for each 2 km segment within each stratum. The median value of the resultant distribution was 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 indices are generated from the spring acoustic survey, one for the offshore area (all strata except Trinity Bay) and one for Trinity Bay.

Mowbray (2012) found estimates derived using the new approach and a length-based target strength were well correlated with those previously published by Miller (1985, 1991, 1997), although slightly lower. During the 30 year spring acoustic survey time series, dramatic changes in the offshore abundance index have occurred (Fig 25). The Capelin abundance index from the spring survey area dropped by an order of magnitude from 400-600 billion individuals (4-7 million t) in the late 1980s to less than 30 billion individuals (200,000 t) in the period from 1991 to 2005. This diminished abundance persisted despite an increase in surveyed area from 2000 onward. Abundance in the surveyed area increased slightly from 2007 to 2009 with 22-29 billion individuals (260,000-300,000 t) surveyed, but fell in 2010 to less than 1 % of the historic high (400-600 billion individuals) with only 2 billion fish (23,000 t) surveyed. There were dramatic declines in the abundance index of 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 estimate is now considered to be an underestimation as the year classes seen in the 2010 survey were stronger than expected in the 2011 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 this year.

At the time of the last assessment (2013 and 2014), the index values were the highest observed since 1992, although still below levels documented in the late 1980s. The trend of a higher abundance index continued in 2015, although the 2012 and 2013 year classes were lower than expected based on the 2014 survey. In 2017, the Capelin abundance index in the survey area once again declined to levels typical of the early 2000s at 18.5 billion individuals (158 thousand t).

Because older maturing Capelin are not well recruited to the survey, year class strength over a number of ages cannot be tracked. However, it is possible to evaluate relative year class strength at ages 2 and 3. It should be noted that the slope and variability associated with this relationship is impacted by changes in the age of first maturity, as post-spawning mortality is nearly 100% in males and may be as high as 75% in female Capelin maturing at age 2 (Flynn et al. 2001).

In the spring acoustic survey, 60% of the variability in age 3 abundance was explained by the abundance of the same cohort at age 2 abundance (P=0.01, R^2 = 0.60) (Fig 26). The largest outlying values were associated with the 1988 and 2008 year classes. In both these cases it was likely that Capelin availability to the survey was reduced; either due to ice restricting the survey area in 1991 (impacting the availability of the 1988 year class to the survey), or changes in Capelin migration/distribution in 2010.

When year class strength is compared across ages 1-5, the poor recruitment of age 1, 4, and 5 to the survey is notable. The 2011, 2012, 2013 and 2015 year classes at age 2 were relatively strong in comparison to the last 25 years. Equally noteworthy is the unprecedented decline in the 2012 year class at age 3. The number of fish at age only increased from one year to the next twice – the 2008 and the 2010 year classes, both times appearing stronger at age 3 than at age 2 (Fig 27). Based on the 2017 survey, the abundance of the 2016 year class (age 1) is one of the lowest in the time series, while the 2015 year class (age 2) is of moderate strength. Because age 1 Capelin are not fully recruited to the survey, it is not clear how to interpret the extremely low numbers of age 1's in the 2017 survey, although this finding is consistent with this year class's strength as larvae.

DISCUSSION

The spring acoustic survey, which targets the age 2 immature portion of the Capelin stock, is the main offshore fishery-independent abundance index used in the Capelin stock assessment. There have been persistent questions regarding the efficacy of this offshore survey due to the discord in the inshore and offshore Capelin indices in the 1990s (e.g., Carscadden and Nakashima 1997, Frank et al. 2016). To address these questions on the potential spatio-temporal mismatch of Capelin abundance and the May acoustic survey post-1991, repeat acoustic surveys were conducted in June in 1992 and 2003 (Mowbray 2014). The lack of a significant difference in Capelin abundance between the two months (Mowbray 2014) suggests that timing is not the main driver of survey results. This finding is consistent with that of Frank et al. (2016) which found the probability of the acoustic survey missing peak offshore Capelin abundance in 25 successive years was 22% (Frank et al. 2016). There has also been high internal consistency within the spring acoustic survey, with the abundance of the age-3 cohort highly correlated with the abundance of the age 2 cohort of the previous year. Cohort tracking in the acoustic survey failed in only 2 years (1990 and 2010), and affected all ages rather than just the age 2 and age 3 cohorts (Mowbray 2014).

Another hypothesis for the discord between the inshore and offshore indices post-1991 was that the Capelin stock did not collapse but instead moved inshore post-1990 and remained there for the subsequent 3 decades and was unavailable to the spring offshore acoustic survey (Frank et al. 2016). The collapse and non-collapse hypotheses were tested using multiple independent data sets, which included both fishery-dependent (inshore commercial catch) and fishery-independent (spring and fall acoustic and fall bottom trawl surveys, Capelin larval indices, aerial surveys, predator diet and behavior) data, and diverse statistical methods. The weight of evidence approach led to the rejection of the non-collapse hypothesis and the authors concluded that the Newfoundland Capelin stock did collapse in 1990-91 with minimal recovery over the subsequent three decades (Buren et al. 2019). Therefore, based on all available data, this assessment assumed that the spring acoustic survey provides a robust index of the immature portion of the Capelin stock in NAFO Div. 3L.

Since no stock-recruit relationship has been found for the NL Capelin stock (Carscadden et al. 2000), research has focused on the early life history stages of Capelin as survival in the larval stage has been shown to be related to recruitment (Frank & Leggett 1981, Leggett et al. 1984, Dalley et al. 2002, Murphy et al. 2018). However, a minimum number of spawners (B_{lim}) would be required to spawn in order to replace themselves in the population. The B_{lim} is currently unknown. Since the Capelin fishery is based on a market for spawning females with roe, large females are removed before they spawn at beach and/or demersal sites. While the precautionary approach for the NL region states that 10% of Capelin spawning stock biomass (SSB) can be harvested for sustainable management of the fishery (DFO 2000), there is no estimate of SSB for the Capelin stock in NAFO Div. 2J3KL, so we are unable to determine if 10% of the SSB is harvested each year. This is an important research question that should be addressed in subsequent stock assessments.

In contrast to the NL region, the Barents Sea and Iceland have both set a B_{lim}. This is due to extensive acoustic surveys that cover the entire distributional area of Capelin and the use of Virtual Population Analysis (VPA) models. A Norwegian–Russian acoustic survey for the whole Barents Sea stock area (absolute biomass estimate) is conducted in the fall (September or October) to estimate a forward projection of SSB for the following April, taking natural mortality and the fishery into account (Carscadden et al. 2013; Gjøsæter et al. 2015). If the SSB estimate is below 200,000 tonnes (B_{lim}), than the fishery is closed. In this case the B_{lim} is based on the SSB of 1989, the lowest SSB that has produced a good year class. The Capelin stock in Iceland-East Greenland-Jan Mayen area has been assessed by acoustic surveys annually since 1978. The surveys take place in autumn (September-December) and in winter (January-February). The current year's advice is based on the advice rule established by ICES in 2015 (ICES 2016) for setting an initial quota on immature abundance (ages 1–2) in the autumn acoustic survey 16 months earlier than the winter survey used for the final TAC. ICES recommends that the initial quota is revised based on in-season acoustic survey information in autumn (intermediate quota), with the final TAC being set on the results of the winter survey (final quota). An index abundance trigger point of 50 billion immature fish is used, with a cap on the initial quota of 400 kt. The final TAC is based on a model which takes into account uncertainty in acoustic surveys and predation from cod, haddock, and saithe on Capelin to ensure that the advised catch will result in a less than 5% chance of SSB going below B_{lim}, which is 150 000 t. In the NL region, an absolute estimate of SSB cannot be obtained due to ice conditions in May precluding coverage of the entire stock area. However based on a strong, positive relationship between the larval index at Bellevue beach and the age-2 recruitment index (Murphy et al. 2018), and similar positive relationships between environmental (spring ice conditions) and acoustic abundance (Buren et al, 2014), a forecast model was developed (Lewis et al. 2019).

CONCLUSIONS

At the last assessment in 2015 (DFO 2015), 3 strong year classes (2011-13) comprised the bulk of the Capelin abundance index. Due to the strength and persistence of these year classes, it was expected that the acoustic index in 2015 would continue to increase, followed by a decline in 2016 and potentially low abundances in 2017, as the weak 2014 and 2015 year classes (based on larval indices) recruited into the survey and ultimately the fishery. Instead, the 2015 acoustic index was lower than expected due to a dramatic decline in the 2012 year class between the ages of 2 and 3, in addition to a sharp decline in the 2011 year class (Fig 27). Biological parameters of Capelin sampled in 2015 in both the spring acoustic and fall bottom-trawl surveys exhibited unusual characteristics, including record late sexual maturation, which was associated with poor condition in the spring. Fall condition in 2015 was also the poorest in the time series for both age 1 and age 2 Capelin (Fig 19). Since no spring acoustic survey was conducted in 2016, the fate of the 2014 year class at age 2 is unknown, although the year class was weak at age 3 in 2017 (Fig 27). The 2015 year class, which made up both the bulk of the spawners and commercial catches in 2017, was relatively strong at age 2. Given that only about half of this 2015 year class matured at age 2, a large proportion of this year class should be available to spawn in 2018. However, the 2016 year class is likely small and may contribute little to spawning in 2018. Consequently, it is expected that the spawning stock biomass in 2018, although composed of larger mean size virgin age 3 spawners, will be low.

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FIGURES

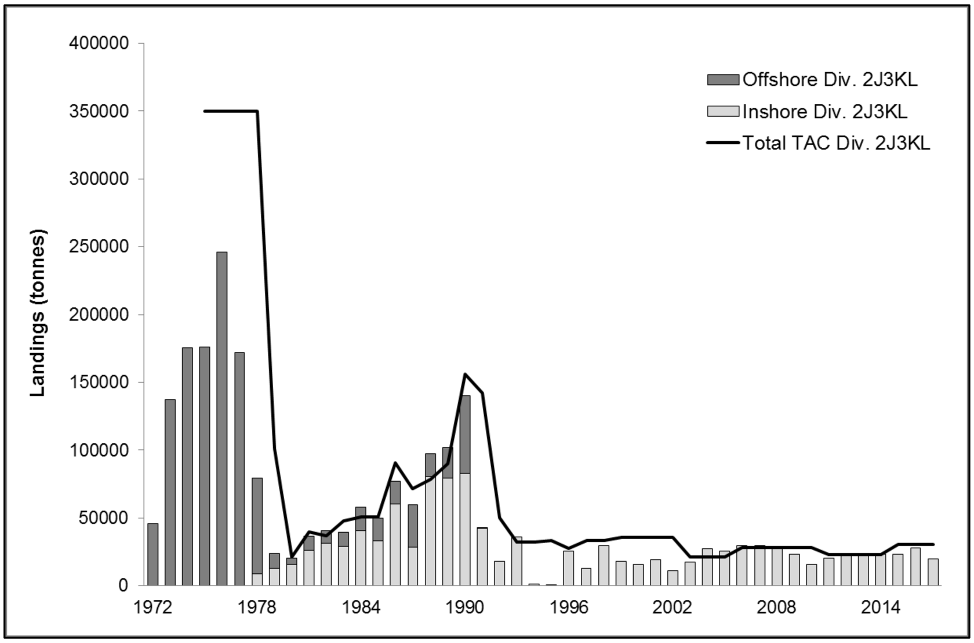

Figure 1. Capelin landings (tonnes) in NAFO Divisions 2J3KL from offshore (dark bars) and inshore (light bars) gear sectors from 1972-2017. Solid line indicates total Capelin TAC for the combined sectors. *2015-2017 landings preliminary.*

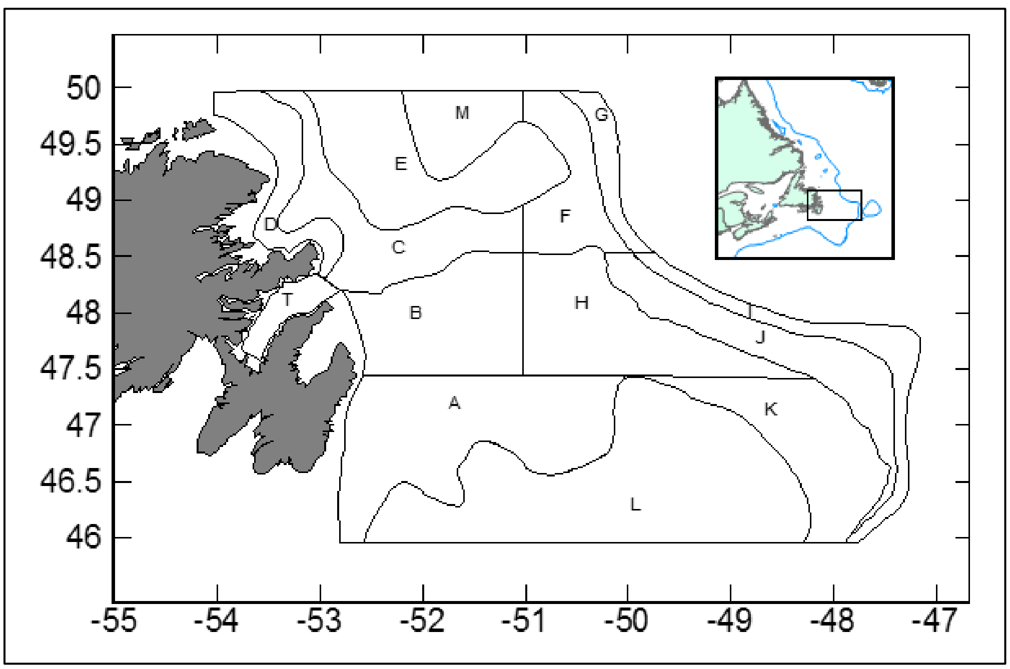

Figure 2. Map of survey area showing boundaries of depth-delimited strata used in the spring acoustic survey since 1999.

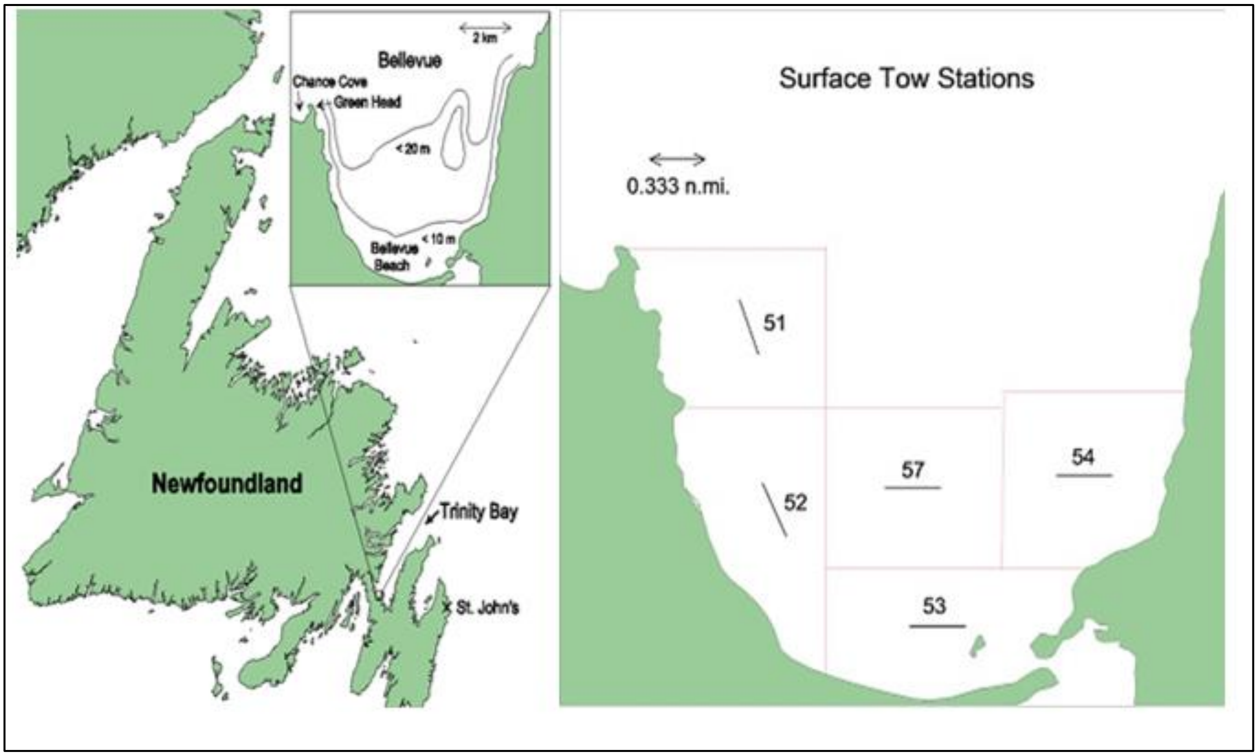

Figure 3. Map of Newfoundland and Bellevue Beach (left) and transects conducted during larval capelin tows (right).

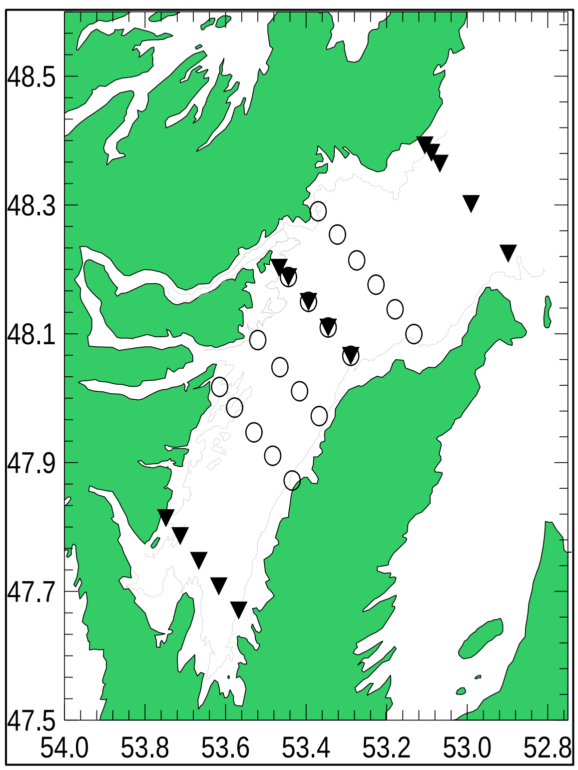

Figure 4. Positions of late-larval index tow stations in Trinity Bay.

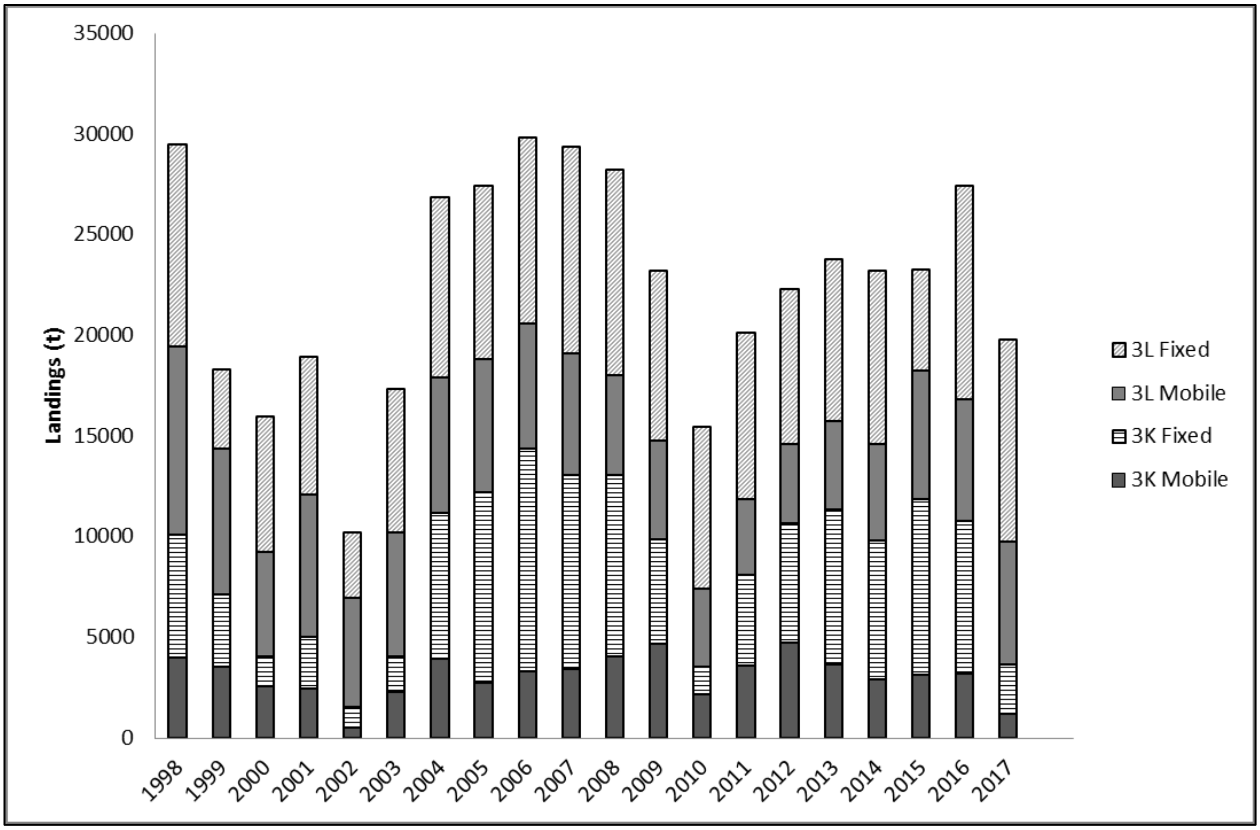

Figure 5. Landings of Capelin by NAFO division and gear sector. Mobile gear solid bars, fixed gear hatched bars.

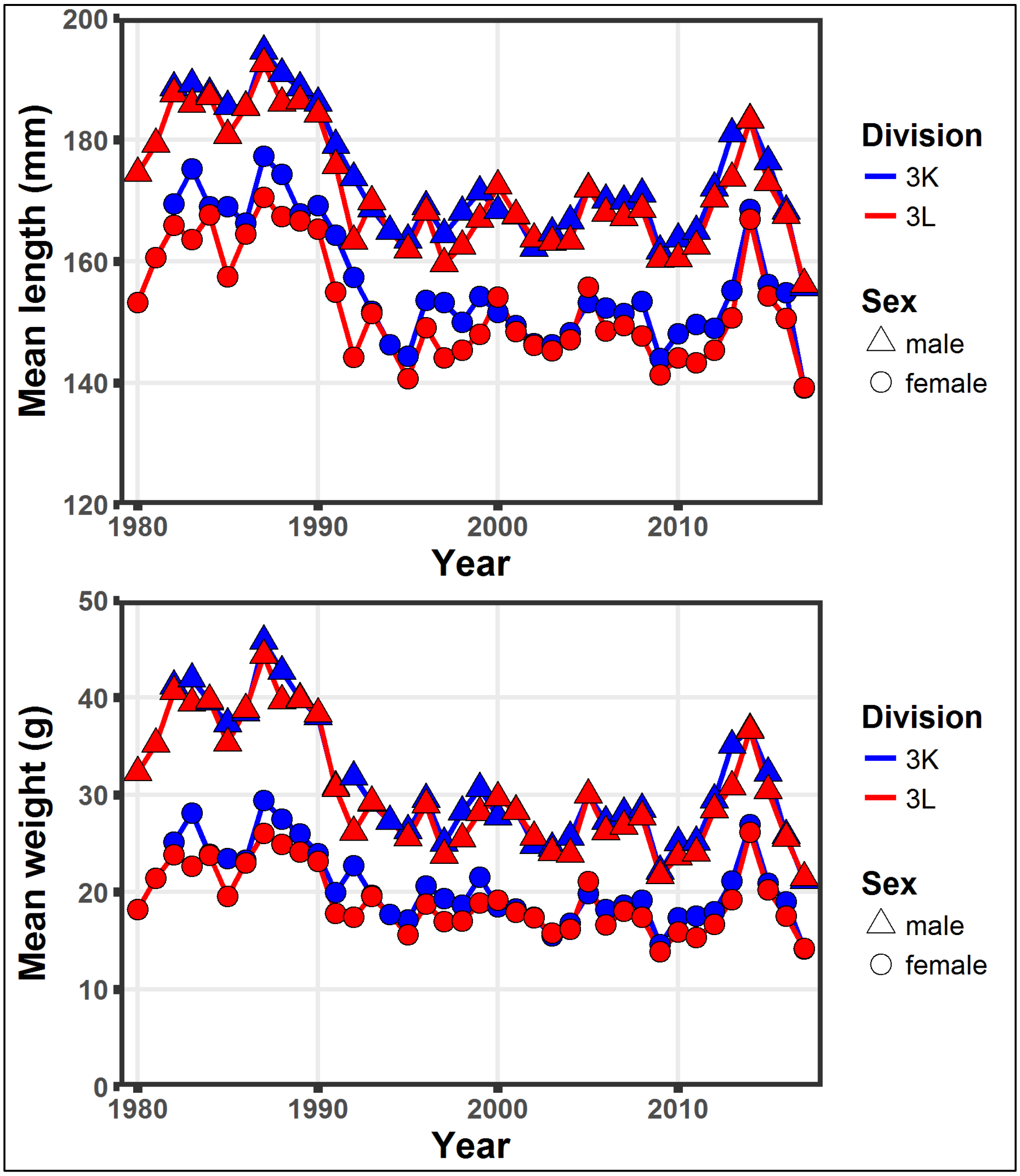

Figure 6. Mean length (Upper panel) and mean weight (lower panel) of Capelin caught in Divisions 3L and 3K in inshore commercial fisheries from 1980-2017. Symbols: females-circles, males- triangles, Division 3L- red, Division 3K -blue).

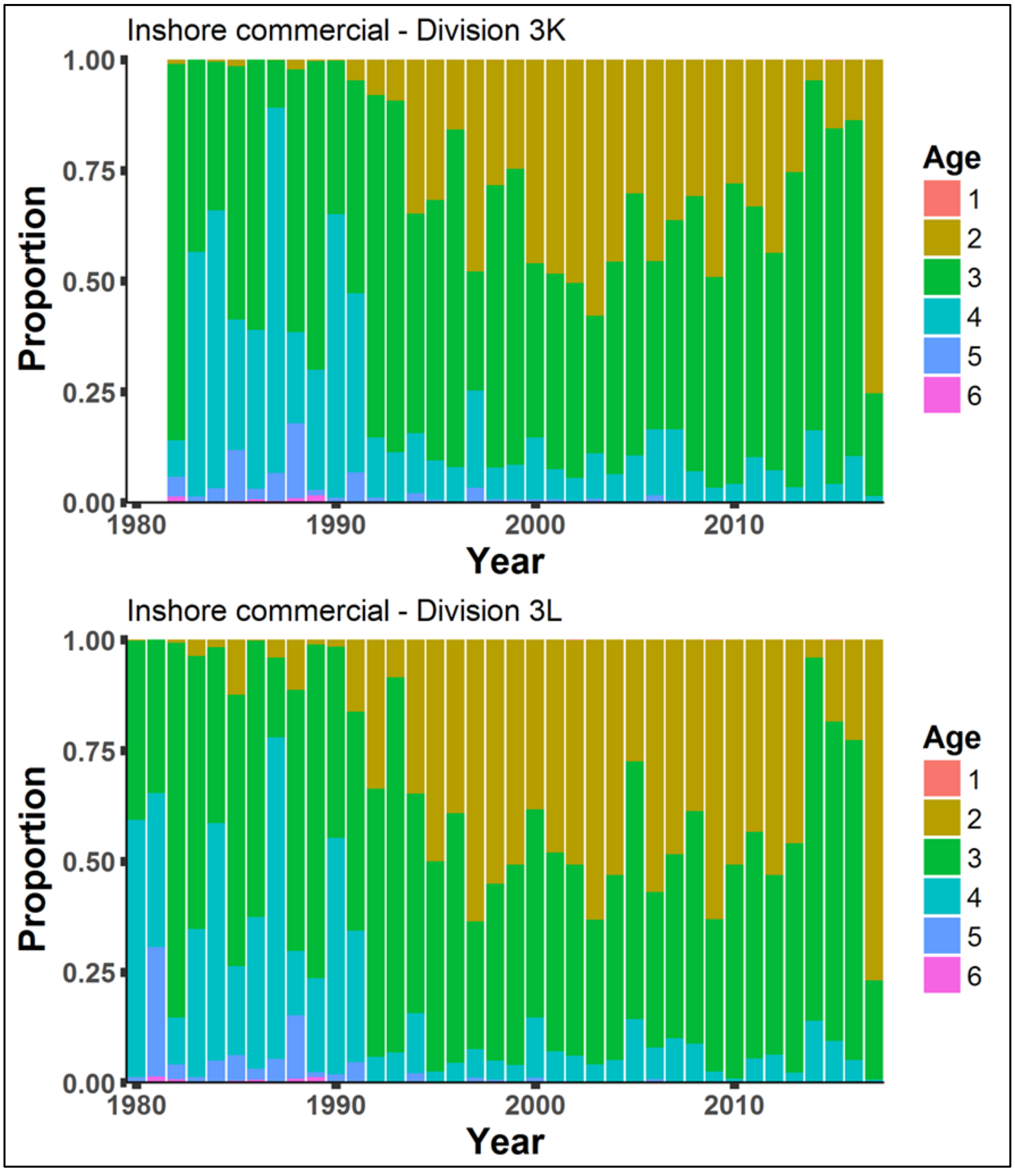

Figure 7. Age composition of capelin caught in the commercial fishery.

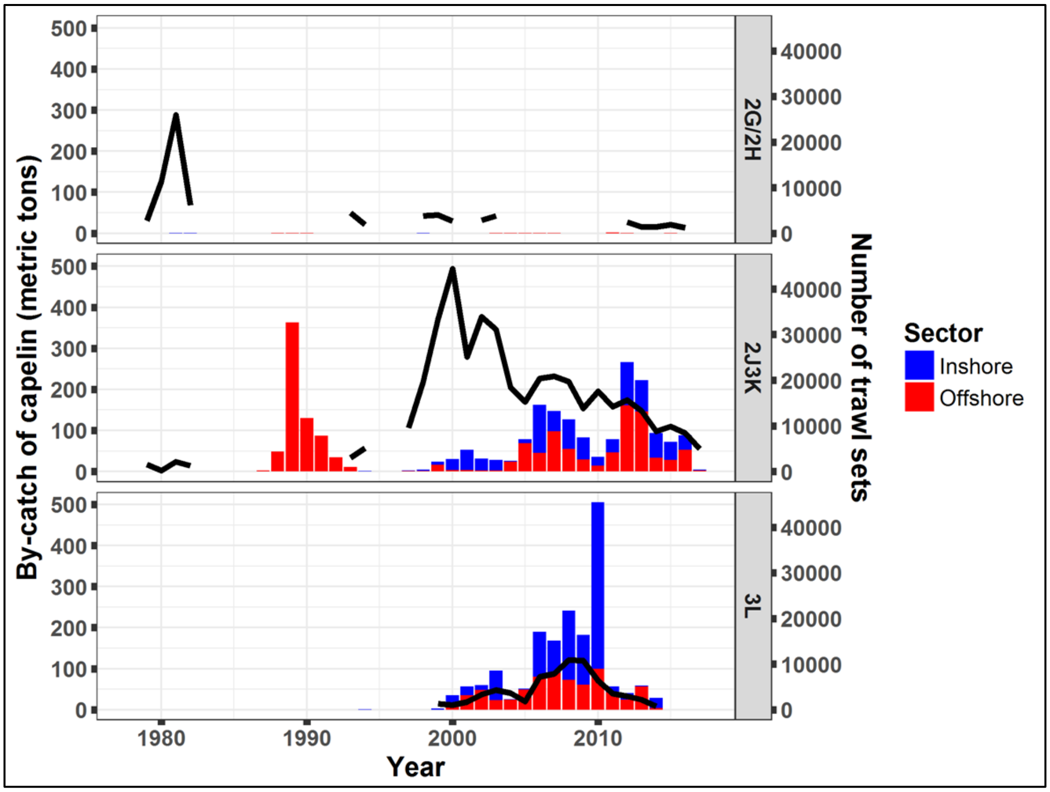

Figure 8. Bycatch of capelin by the commercial shrimp fishery in the inshore and offshore areas of Divisions 2G/2H, 2J3K, and 3L. The estimated number of trawl sets for each Division is shown with black lines.

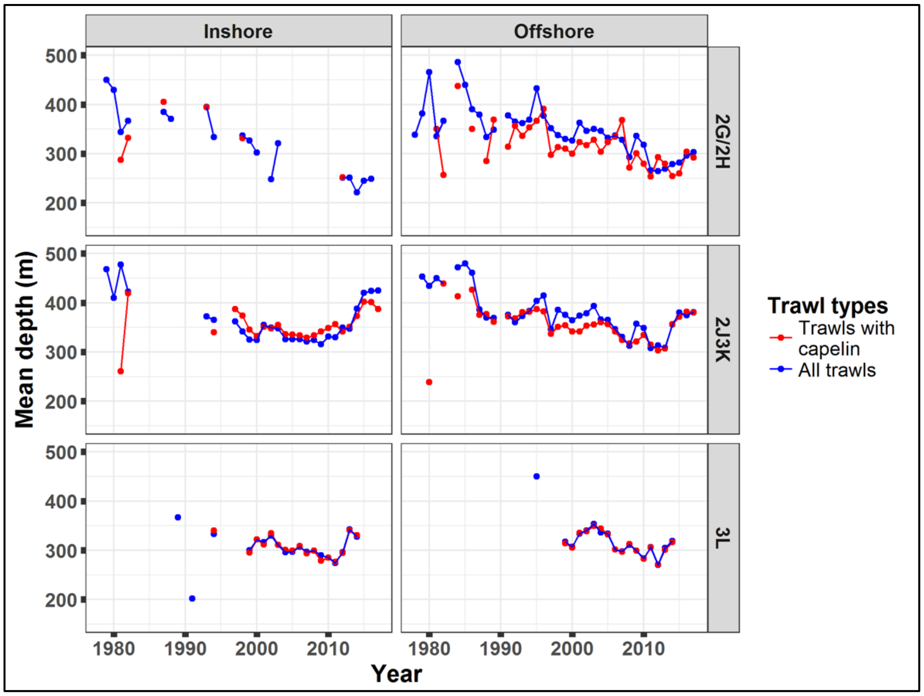

Figure 9. Mean trawling depths of all observed commercial shrimp trawl sets and all observed shrimp trawl sets that caught capelin for Divisions 2G/2H, 2J3K, and 3L.

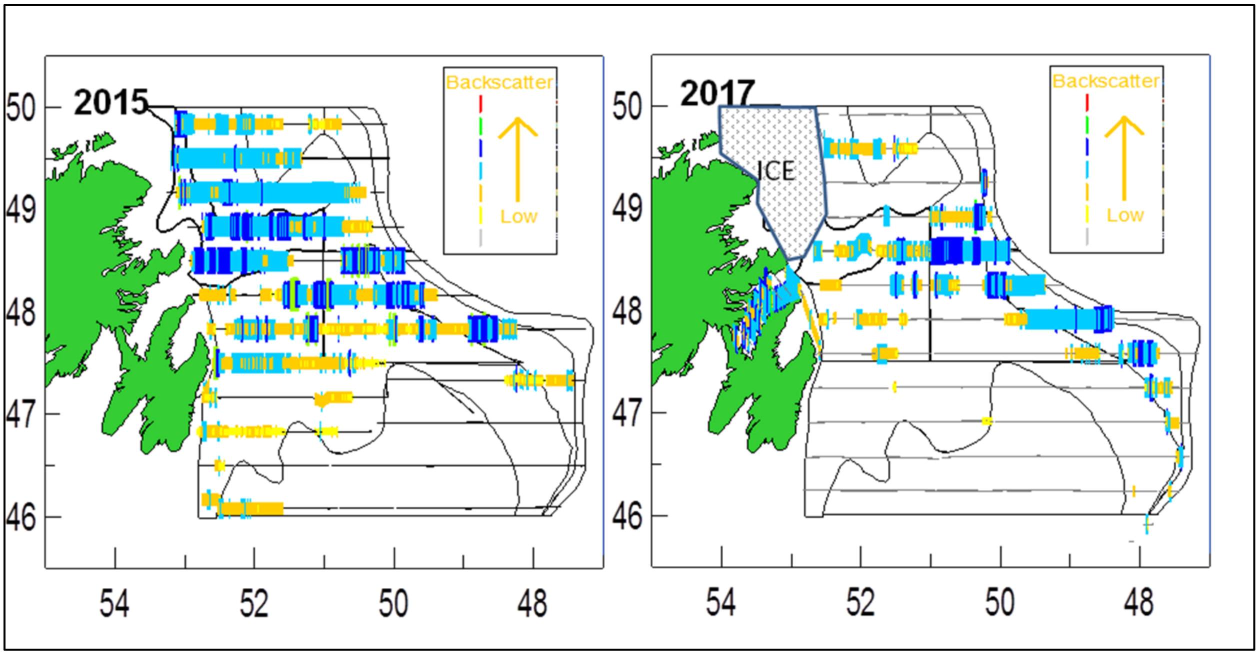

Figure 10. Distribution of capelin backscatter during spring acoustic surveys in 2015 (left panel) and 2017 (right panel). Consecutive color increments indicate an order of magnitude difference in backscatter quantity. Note, no survey was conducted in 2016.

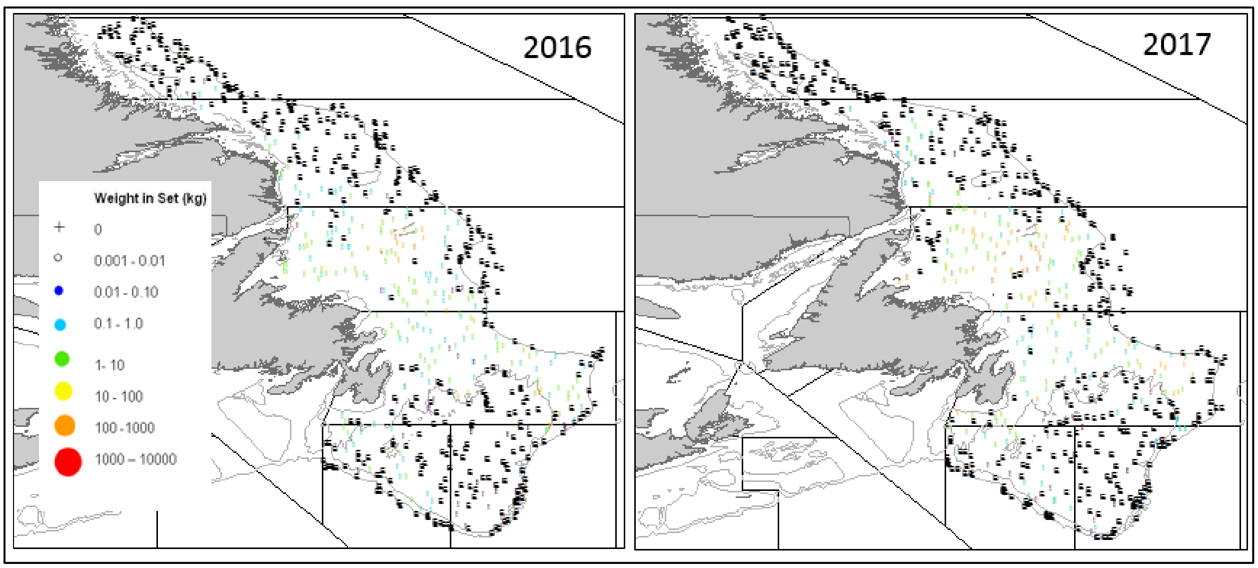

Figure 11. Distribution of capelin catch during annual fall bottom trawl surveys in Division 2J3KLNO in 2016 (left panel) and 2017 (right panel).

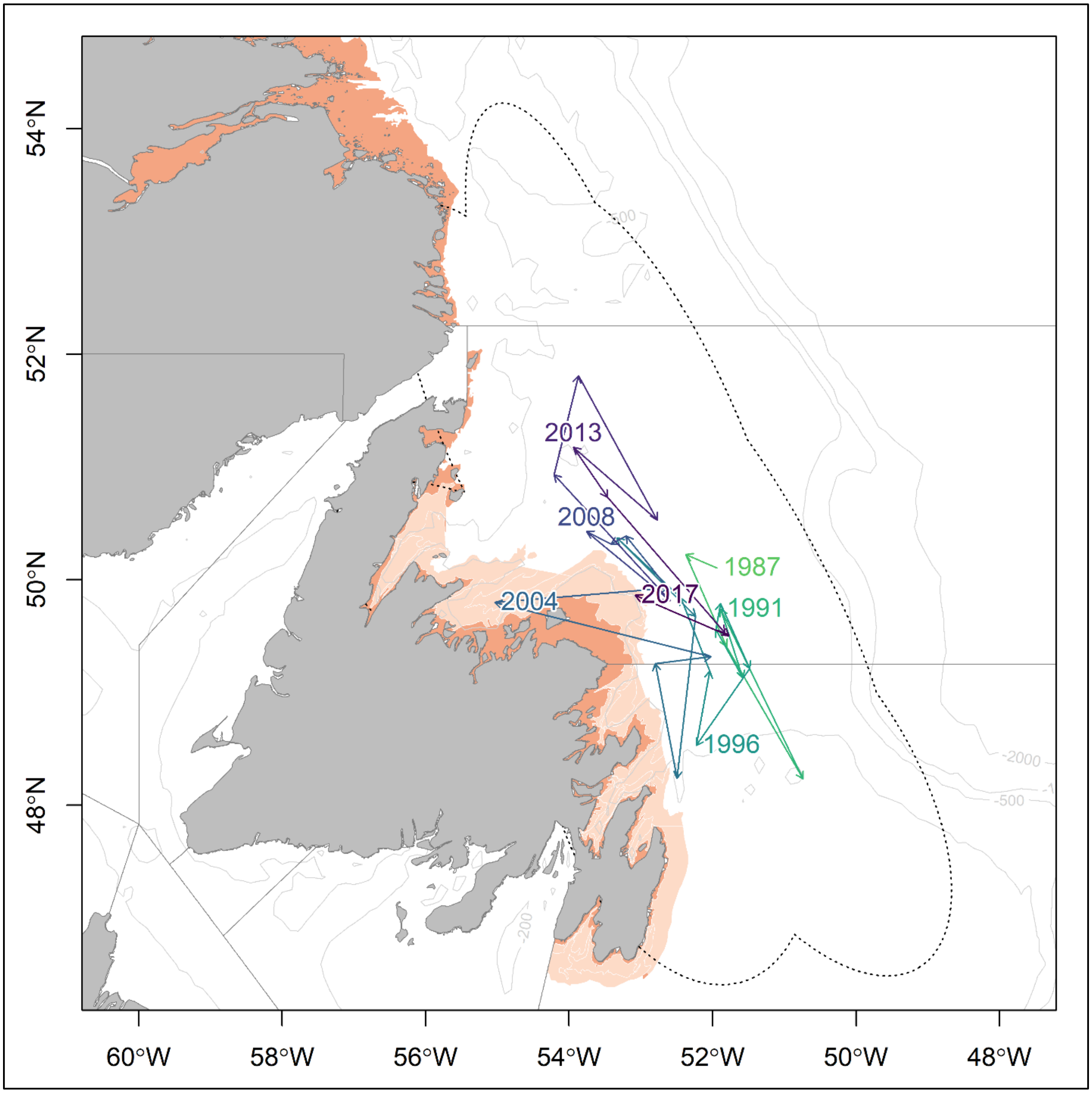

Figure 12. Center of gravity of capelin caught during fall bottom trawl surveys in NAFO divisions 2J3KL from 1987-2017. Dark red shaded areas are not occupied by the survey and peach colored areas are only occupied in some years and hence are excluded from in the analysis.

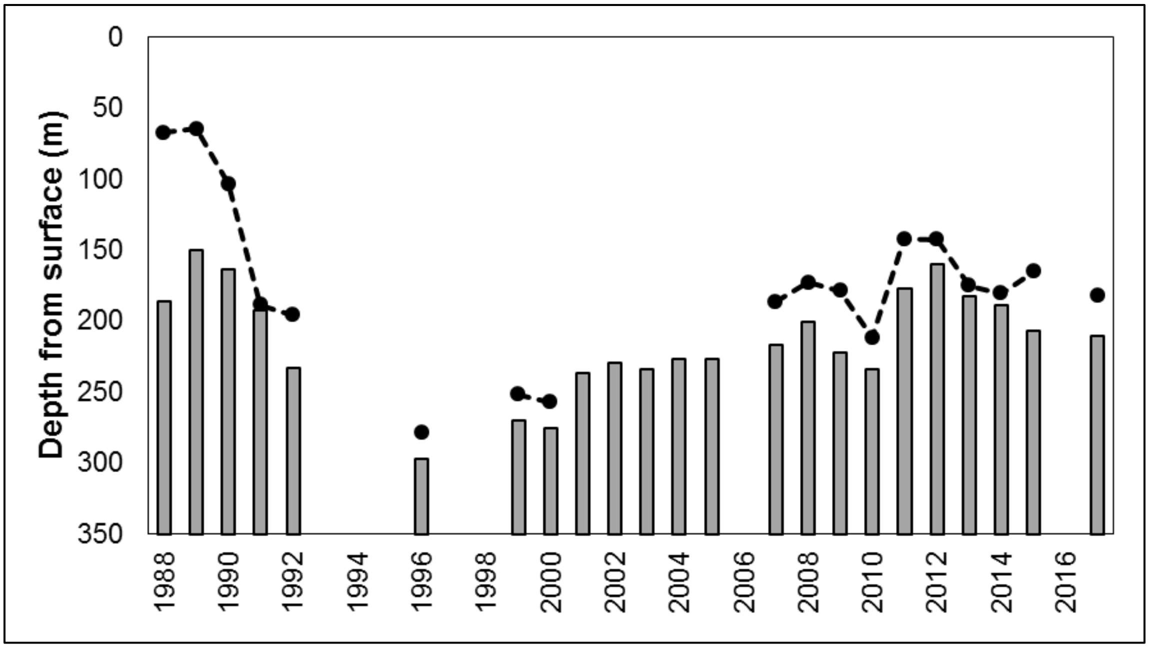

Figure 13. Mean bottom depth (bars) and mean weighted depth of capelin (points) during spring acoustic surveys 1988-2017.

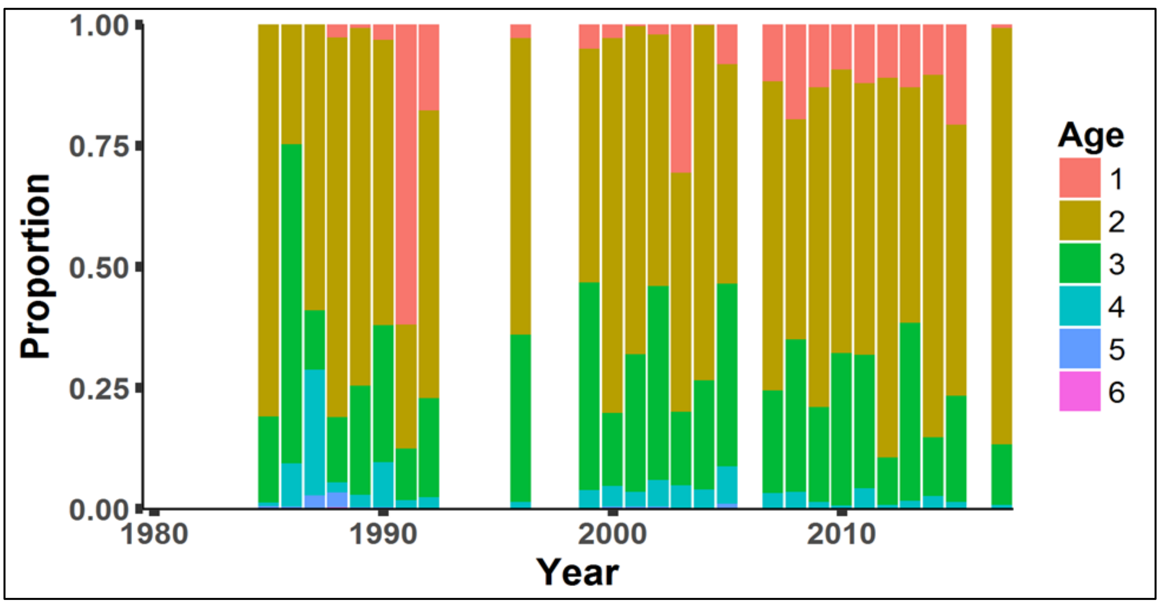

Figure 14. Age distribution of capelin sampled during spring acoustic surveys.

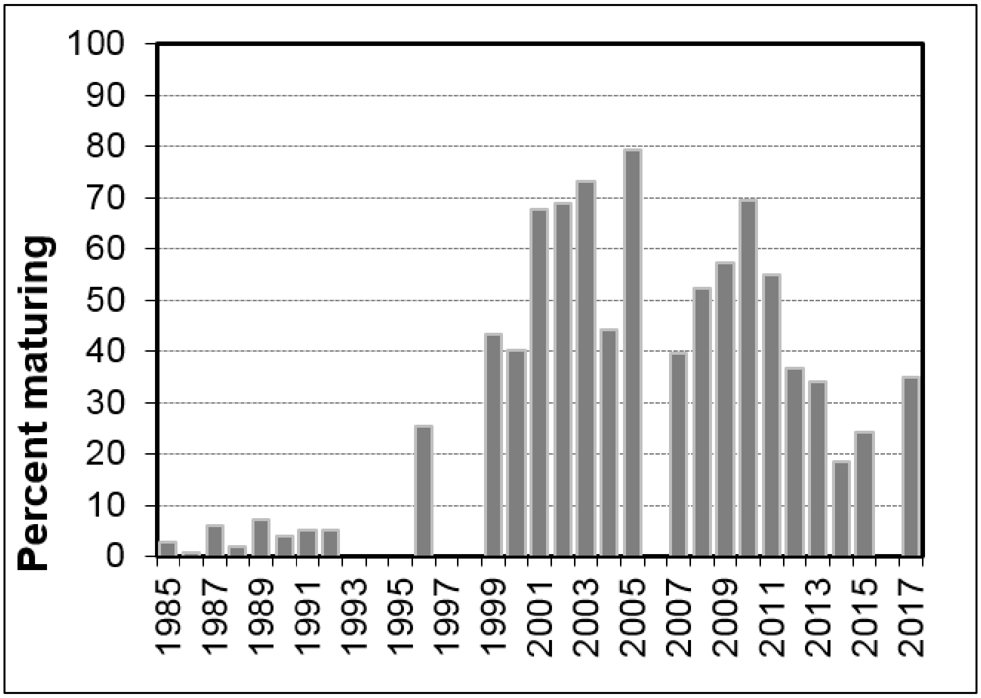

Figure 15. Proportion of maturing age 2 capelin sampled during spring acoustic surveys 1985-2017.

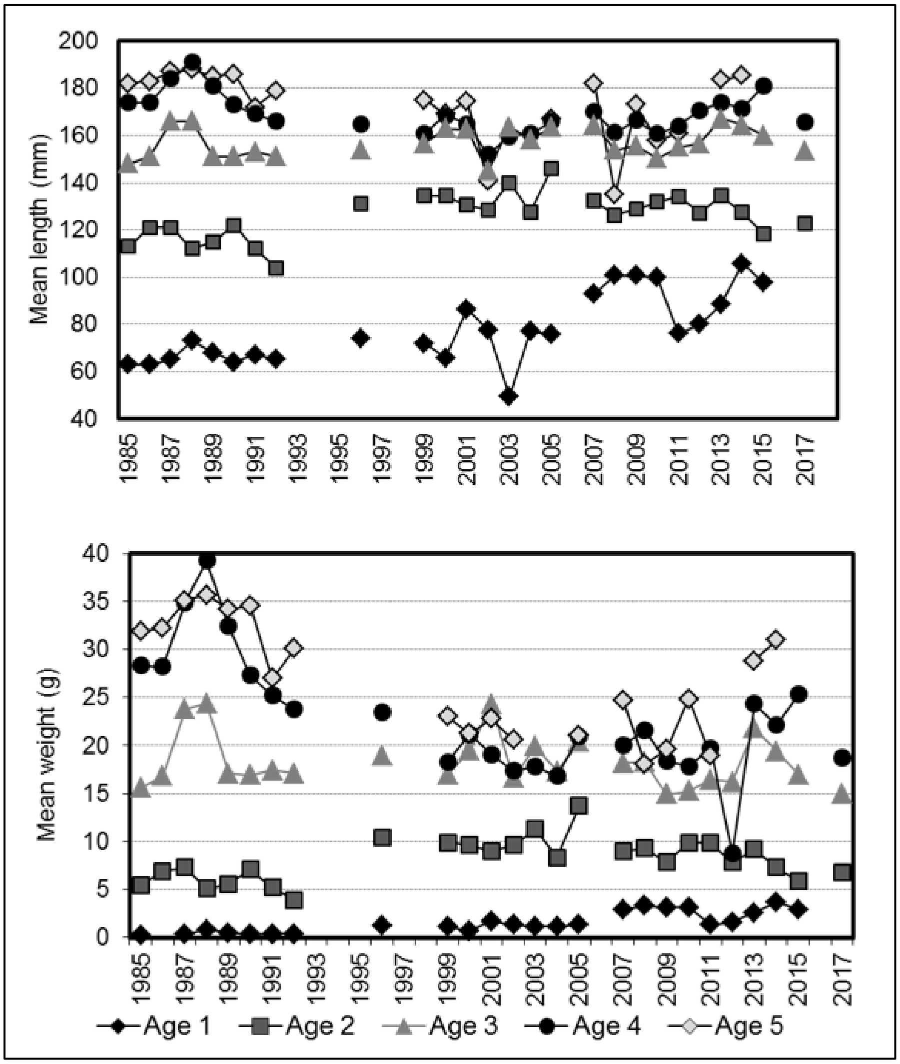

Figure 16. Mean length (upper) and weight (lower) of capelin captured during spring acoustic surveys 1985-2017.

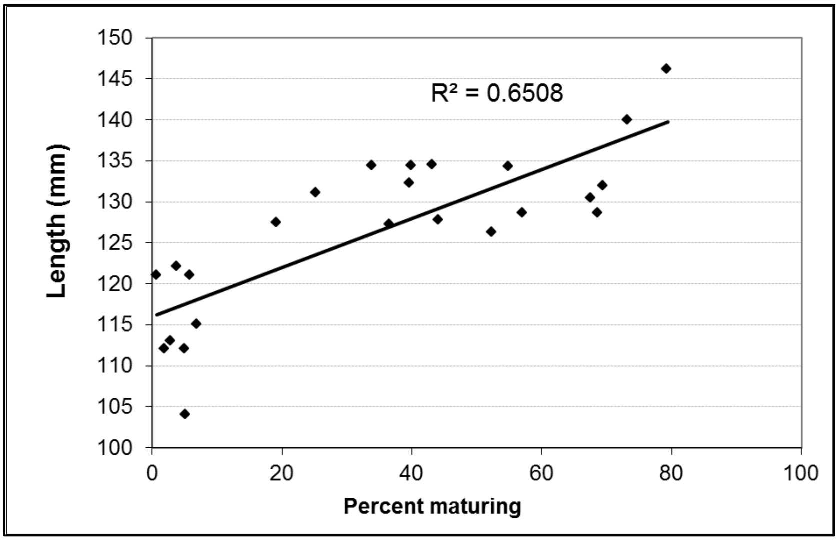

Figure 17. Relationship between length and percent maturing for age 2 capelin taken during spring acoustic surveys 1985-2017.

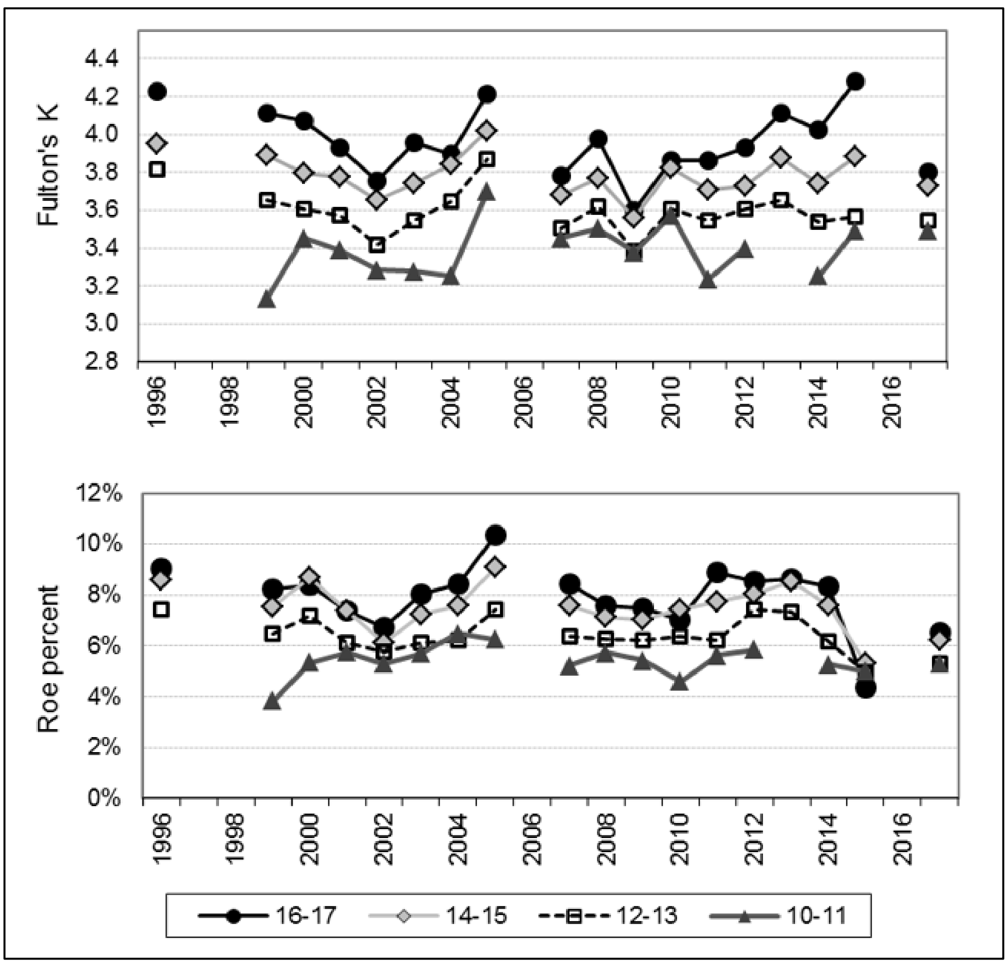

Figure 18. Fulton's condition (upper) and percent roe content (lower) of female maturing capelin sampled during spring acoustic surveys between 1996 and 2017 by size class (mm).

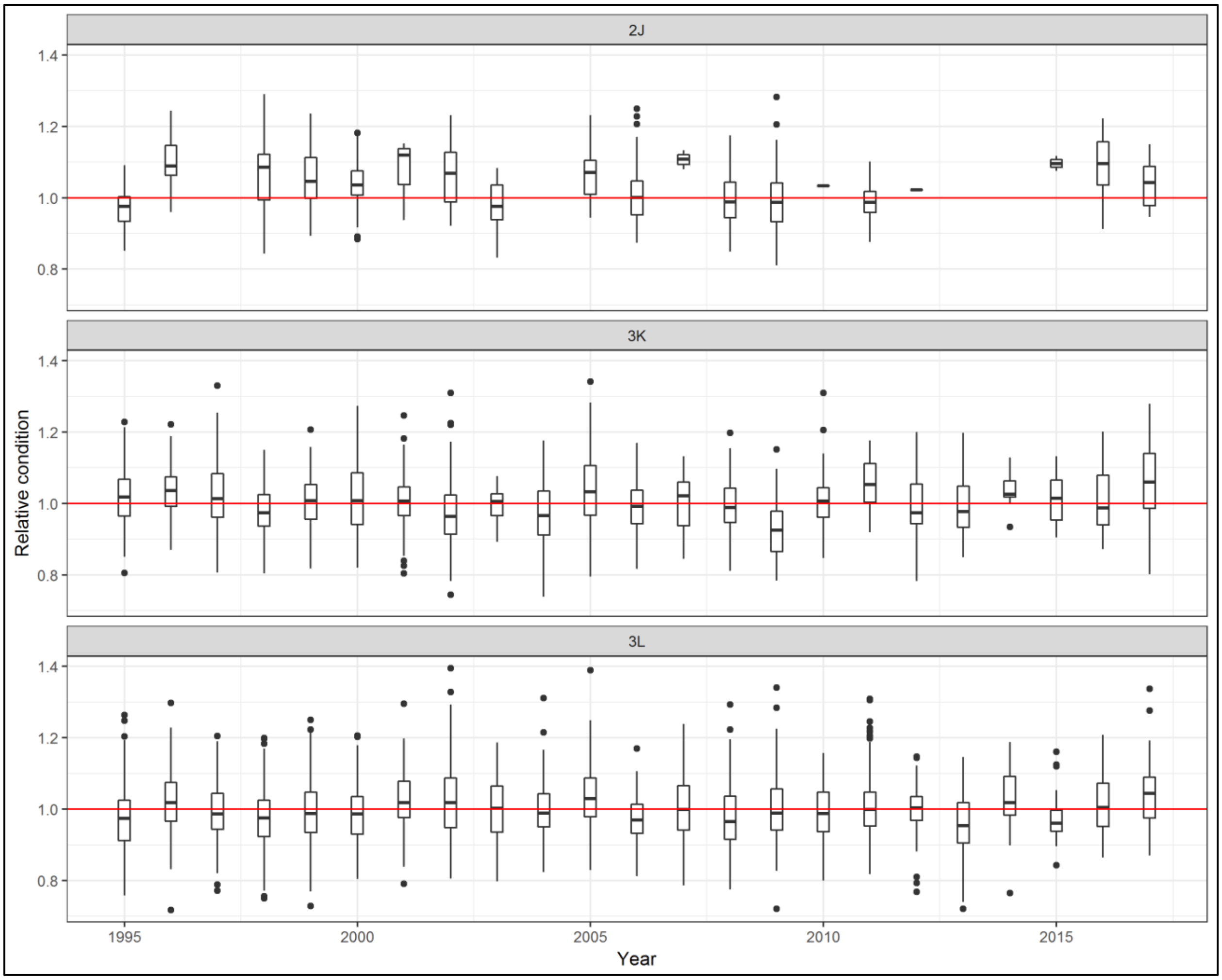

Figure 19a. The relative condition of age 1 male capelin taken during fall bottom trawl surveys in NAFO Division 2J,3K and 3L between 1995 and 2017.

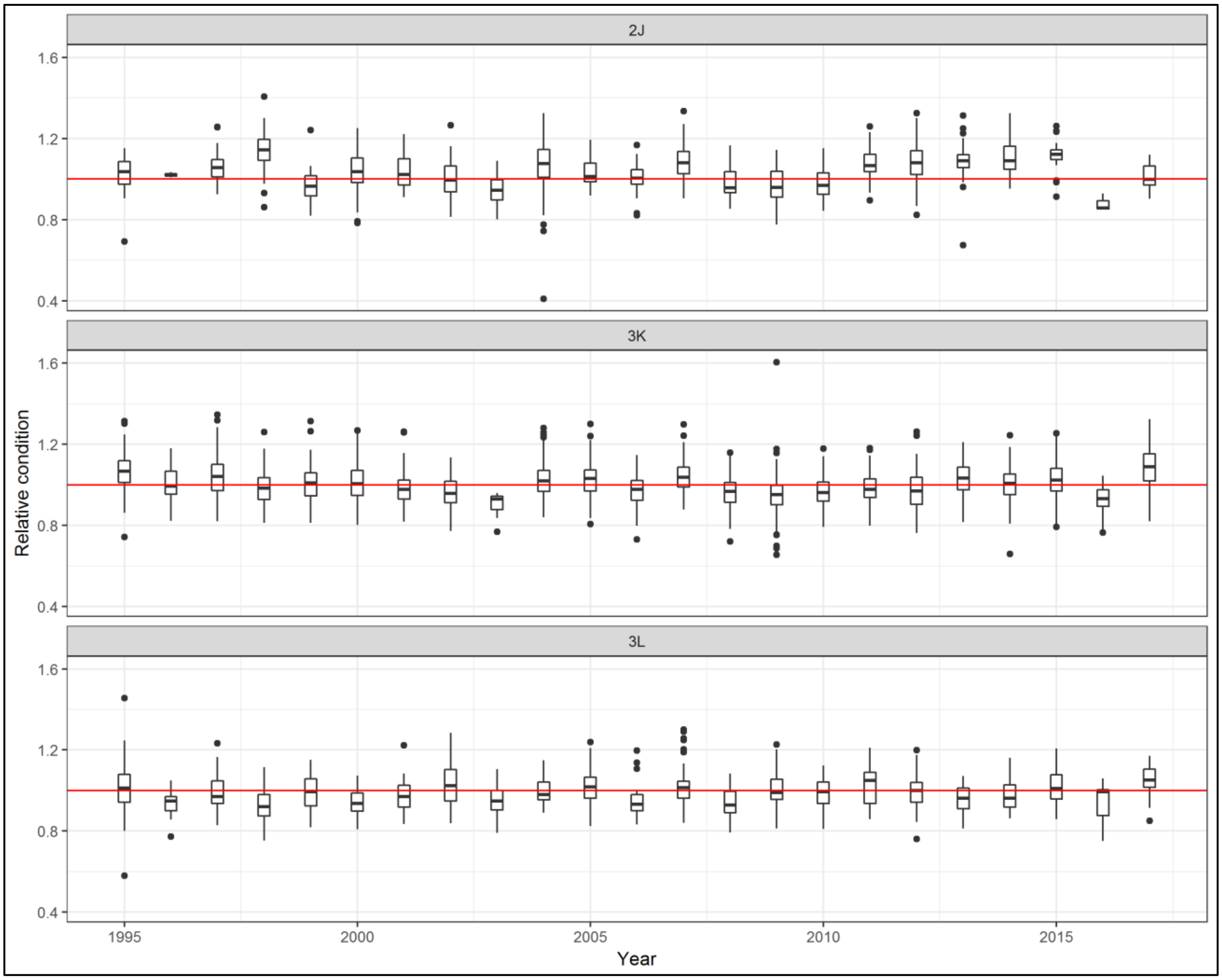

Figure 19b. The relative condition of age 2 male capelin taken during fall bottom trawl surveys in NAFO Division 2J,3K and 3L between 1995 and 2017.

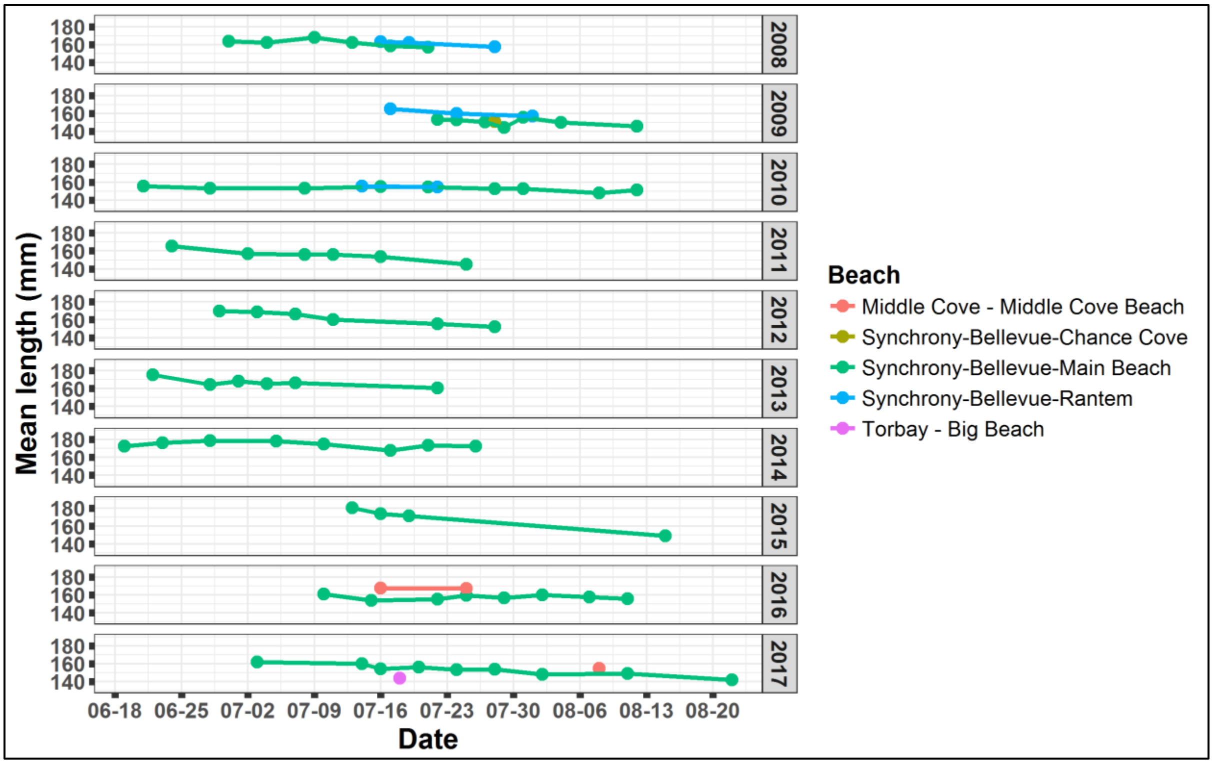

Figure 20. In-season variation in spawning capelin size at index locations on the Avalon Peninsula.

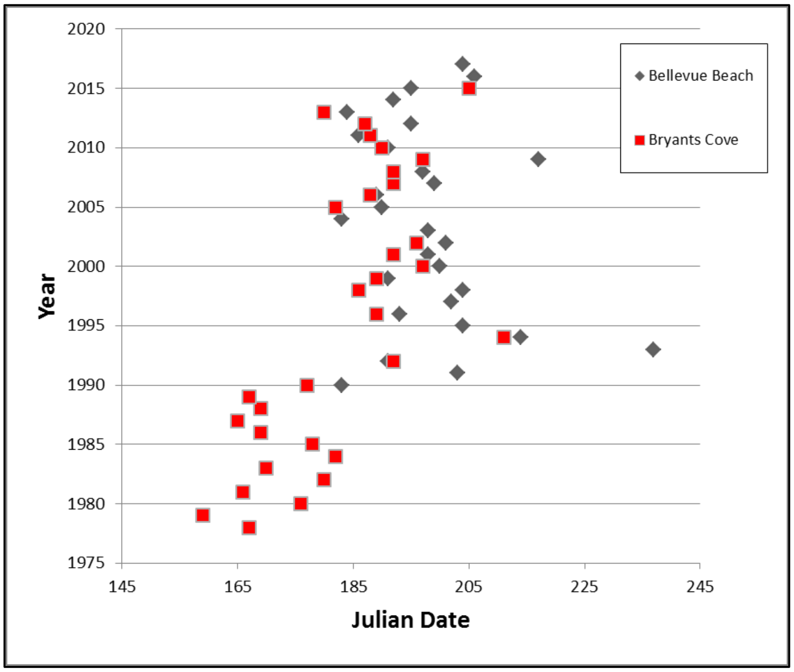

Figure 21. Timing of peak spawning of capelin at two beaches on the Avalon Peninsula, 1978-2017.

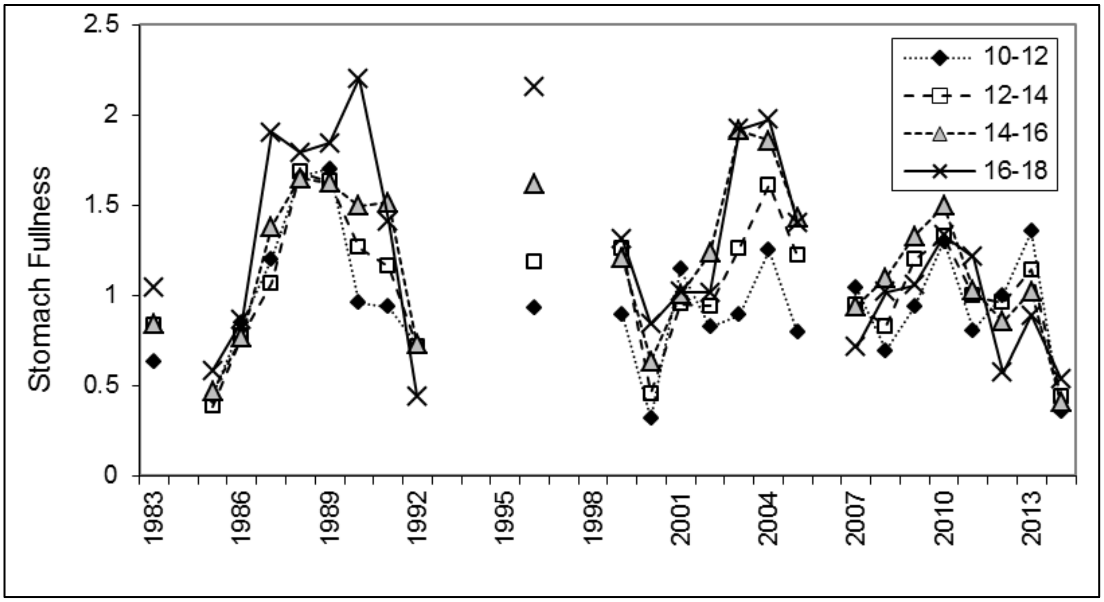

Figure 22. Stomach fullness index from spring acoustic survey by mm length class.

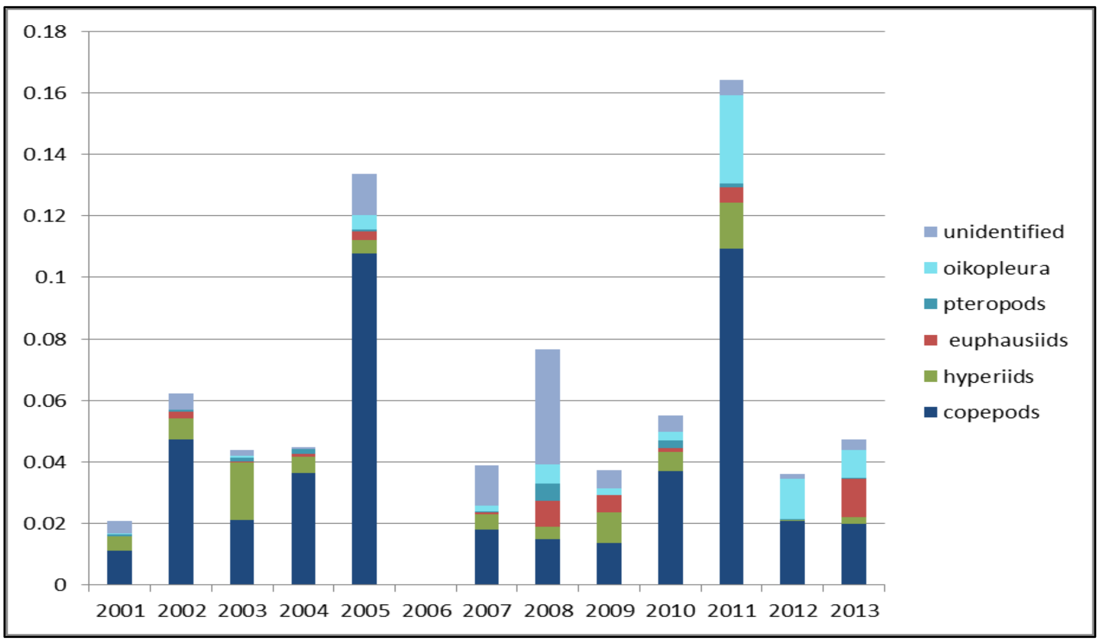

Figure 23. Prey composition from capelin stomachs by species.

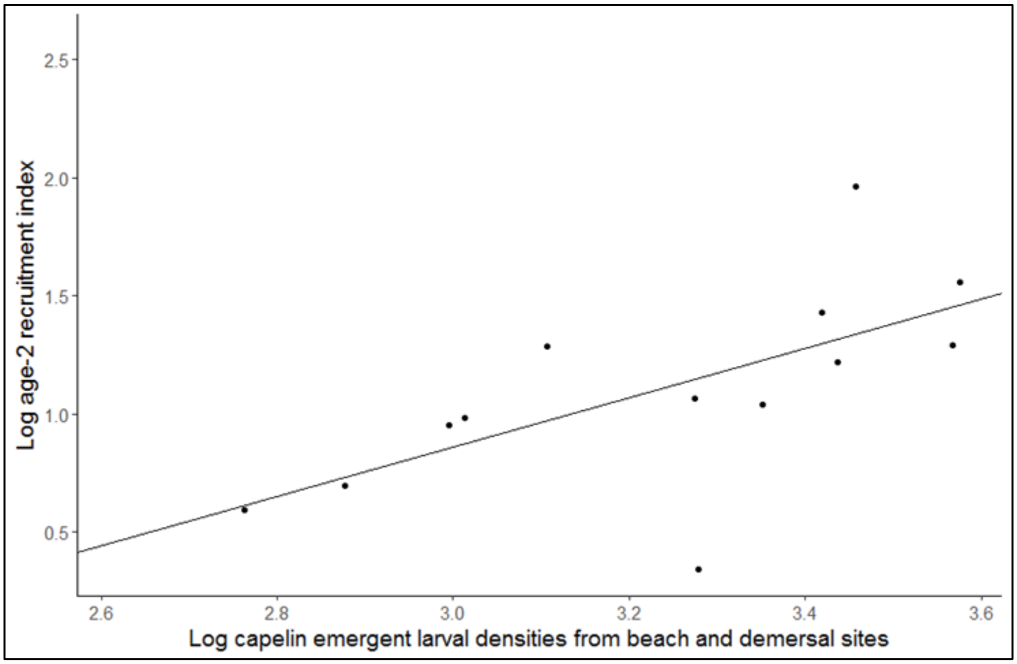

Figure 24. Relationship between emergent larval capelin densities in the Bellevue Beach area and the index of abundance of age 2 capelin two years later as estimated from the spring acoustic survey (2003-2017) tows.

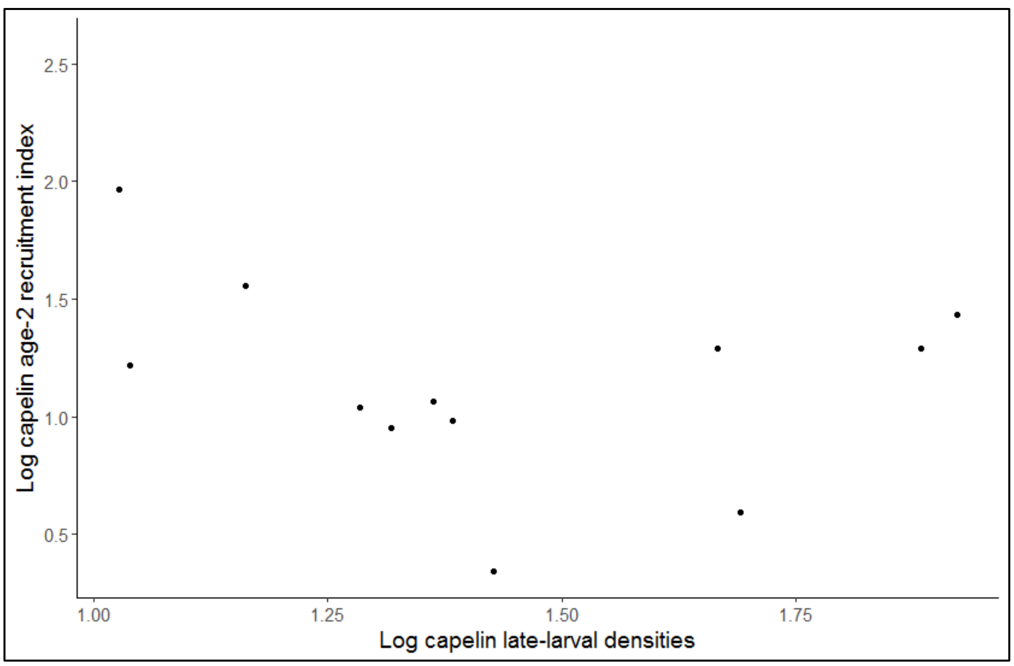

Figure 25. Relationship between late larval capelin densities in Trinity Bay area and the index of abundance of age 2 capelin two years later as estimated from the spring acoustic survey (2003-2017).

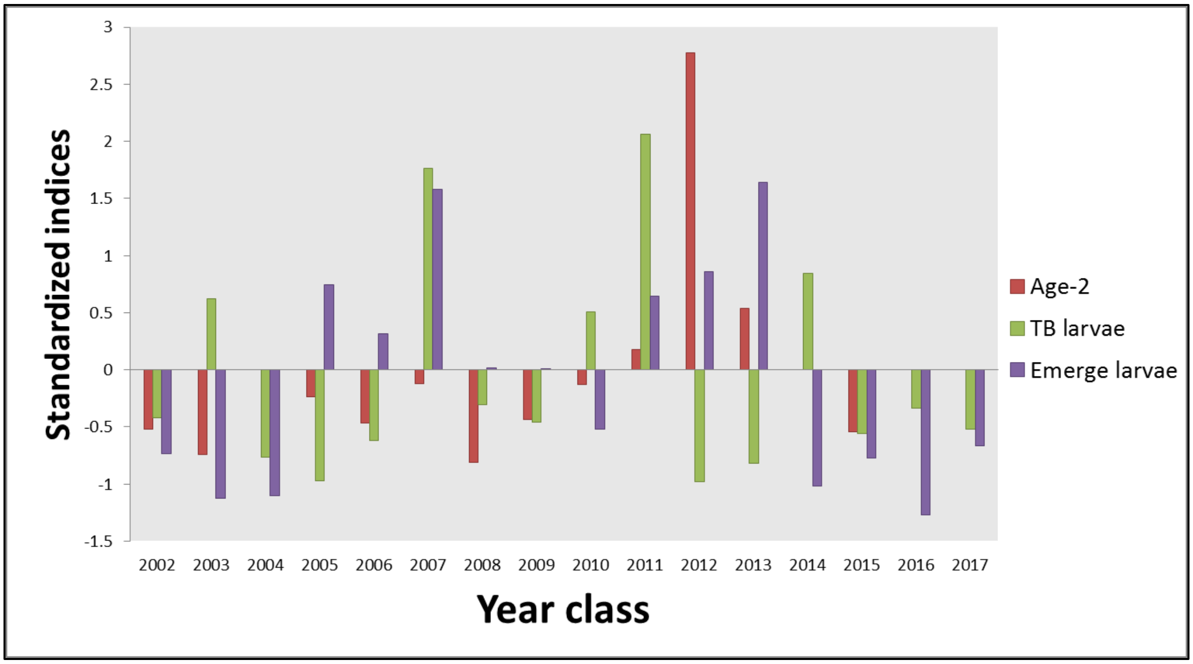

Figure 26. Comparison of standardized indices of cohort strength at three life stages, emergent larvae, late larvae and age 2.

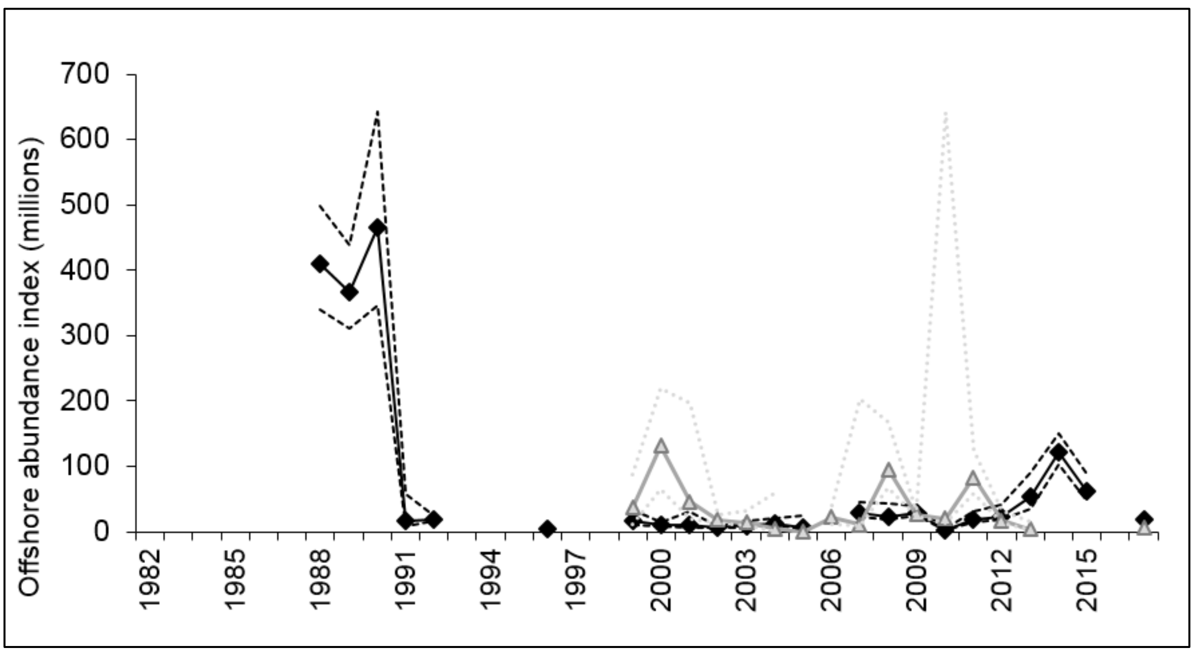

Figure 27. Index of Abundance of capelin enumerated in the spring offshore survey from the offshore area (black) and Trinity Bay (grey). Dashed lines give upper and lower confidence limits.

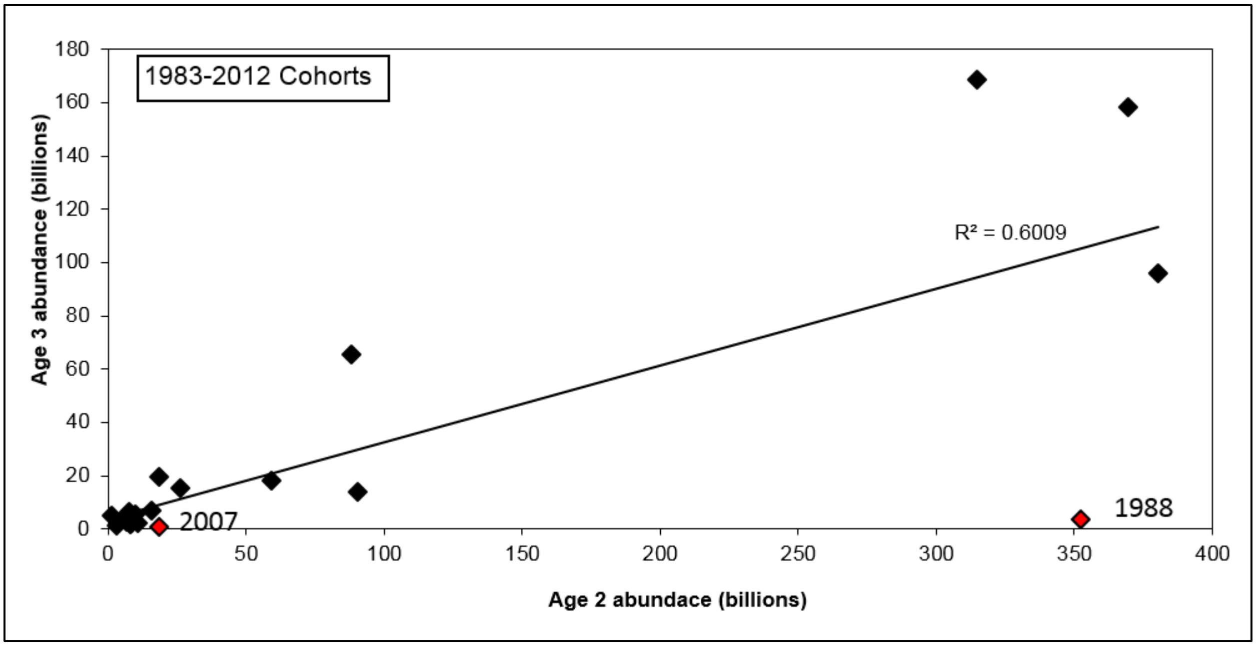

Figure 28. Relative abundance of capelin cohorts spawned from 1983 – 2012 at age 2 and age 3 as indicated from the spring acoustic survey. Cohorts for which the survey was impacted by ice or distribution shifts are indicated in red with the cohort year given.

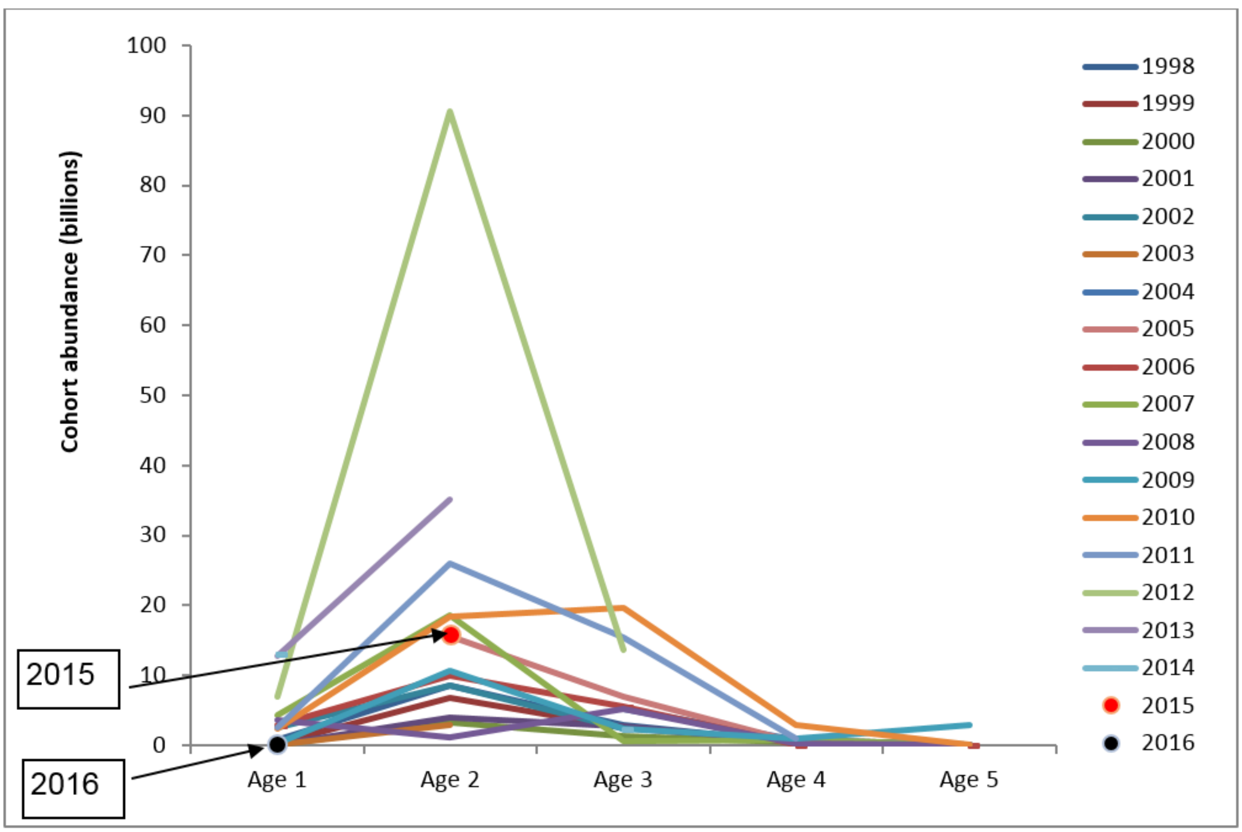

Figure 29. Progression of abundance of cohorts from 1998-2016 from spring acoustic survey.