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Survey report

FV *Vendla* and FV *Eros* 26.02-11.03.2020

Testing of trawl-acoustic stock estimation of spawning capelin 2020

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Content

Summary

This report describes the second in a series of three trawl-acoustic monitoring surveys of the spawning stock of capelin during the migration to the coast. The survey is a response to a proposal from the industry to evaluate the possibility of using winter monitoring of maturing capelin as an input to the capelin assessment and advice. The timing and geographic coverage of the survey are such that they would be relevant to use for advice given that the output is reliable. Pre-defined areas off the Troms and Finnmark coast were covered using two vessels, *Vendla* surveying the western part and *Eros* the eastern part. A stratified random transect design was adopted with two complementary zig-zag grids, the first going in a west-east and the second in an east-west direction over the same strata. The ultimate biomass estimate combines the two coverages, but evaluation about the mobility of the fish can be done by comparing the coverages. The final geographical allocation of survey effort was decided based on information from the scouting vessel *Hovden Viking* which covered the area a week prior to the main survey. Echo sounders with frequencies from 18-200 kHz were run together with sonars, and target trawls were carried out on significant pelagic aggregations. Capelin abundance was estimated using 38 kHz data. The total biomass of maturing capelin in the coverage area was estimated at 62 298 tons, with a CV of 38%. The 5% lower and 95% upper confidence limits were 26 655 and 104 305 tons, respectively. The result is in accordance with the prediction from the autumn 2019, but the high CV and wide confidence interval show that the survey result is uncertain. The high uncertainty despite the good survey coverage is likely due to the very patchy distribution of the capelin. In addition, in the western coverage area which had most of the capelin recordings, there was a big difference in both estimate and distribution in the return east-west coverage compared to the west-east. This underlines the high mobility of the capelin when it is in this state of migration. The strong dynamic was also evident last year and makes the monitoring of the capelin spawning migration challenging. Mean length of the capelin was 16.2 cm, mean weight 22.3 g, and maturation had progressed further in the western than the eastern area which was the opposite of what was observed last year. Methodological investigations including target strength measurements and testing of the autonomous Sailbuoy were carried out successfully and are described in the report. A thorough evaluation of the survey series and its usefulness as input to the capelin advice will be done after the third survey in this series is completed.

Introduction

In 2018, there was a proposal from the industry forwarded through FUR ('Faglig Utvalg for Ressursforskning'; Joint science/industry association for resource investigations), that funding from the Fisheries Resource Tax (FFA) should be spent on a winter monitoring of the Barents Sea capelin spawning migration to evaluate whether such monitoring could be used to improve capelin assessment and quota advice.

The main spawning of the Barents Sea capelin takes place in the period from late February to early April mainly along the coast of northern Norway between Tromsø and Varangerfjord. If there is opening for a fishery, it takes place on mature capelin off the spawning areas starting from late January. In the present assessment of the Barents Sea capelin stock, there is only one annual input to assess the biomass, and that is the estimate from the joint Russian/Norwegian Barents Sea monitoring in the autumn (ICES 2019, Prozorkevich & Meeren 2020). The quota advice is based on a forward projection of mature capelin biomass from the autumn survey the previous year to 1 April the present year, including associated uncertainty (Gjøsæter et al. 2002). Previous attempts have shown that winter monitoring of the capelin spawning migration is challenging (Ref: https://www.hi.no/resources/images/3_arig_rapport_gyteinnsig_lodde.pdf), both because the spawning region has a wide geographical extension and because the timing of the migration and hence availability to acoustic detection, is variable. Nevertheless, a reliable winter survey could potentially reduce uncertainty in the assessment of biomass of mature capelin and improve the advice. IMR therefore approved the proposal from the industry and took on to conduct a series of three winter monitoring surveys of which the first was carried out in 2019. The second in the series of three is described in the current report.

Objectives

The objective of this 3-year effort is to conduct a series of surveys with a timing and a design such that it could potentially have been used in an advice process. The surveys will form the main basis for an evaluation of the usefulness of such a monitoring in capelin assessment and advice. In addition, the survey will serve as a platform for selected methodological studies relevant for the capelin surveying during spawning including acoustic target strength measurements and trials with autonomous Sailbuoy. These are presented in part B of this survey report.

Part A. Monitoring of the capelin stock spawning migration

Methodology

Vessels

The fishing vessels FV *Vendla* and FV *Eros* were selected to carry out the acoustic survey, which started and ended in Tromsø, on 26 February and 11 March, respectively. The fishing vessel FV *Hovden Viking* was used as a scouting vessel and started its survey on February 19 and finished on February 26.

Survey design

We adopted a stratified random transect survey design with the allocation of effort reflecting the expected abundance of capelin within a given stratum. The initial strata and distribution of effort are shown in fig. 1 and were similar to the original strata system from 2019 which were based on a compilation of historical distribution data (see 2019 survey report for details, available at https://www.hi.no/resources/Toktrapport-loddetokt-mars-2019.pdf). It is important to underline that the survey area we have defined is a core area for the capelin spawning migration, and the survey period is adequate in the case an advice would have been provided, but this is not a complete coverage of the Barents Sea capelin spawning stock.

Like in 2019, we implemented a zig-zag transect design, which has the advantage of allowing more time spent on transects and less on transit compared to a design with parallel transects. Unlike in 2019, we adopted a design including a complementary return zig-zag going in the opposite direction (Harbitz 2019). We then get an abundance estimate by combining the two complementary directions, but an advantage with the two-direction design is that population mobility can be examined by comparing the two directions (Harbitz 2019). With two vessels available we could use this design in a western area comprising strata 1, 2 and 3 for Vendla and an eastern area comprising strata 4, 5 and 6 for Eros.

Strata boundaries were drawn using the software Stox (Johnsen et al. 2019), and allocation of effort within the strata was done using the "survey planner" function in the R package Rstox (https://github.com/arnejohannesholmin/sonR). The method used for generating the zig-zag transect plan was "Rectangular enclosure zigzag sampler" (Harbitz 2019). The starting point of the transects was random in all strata.

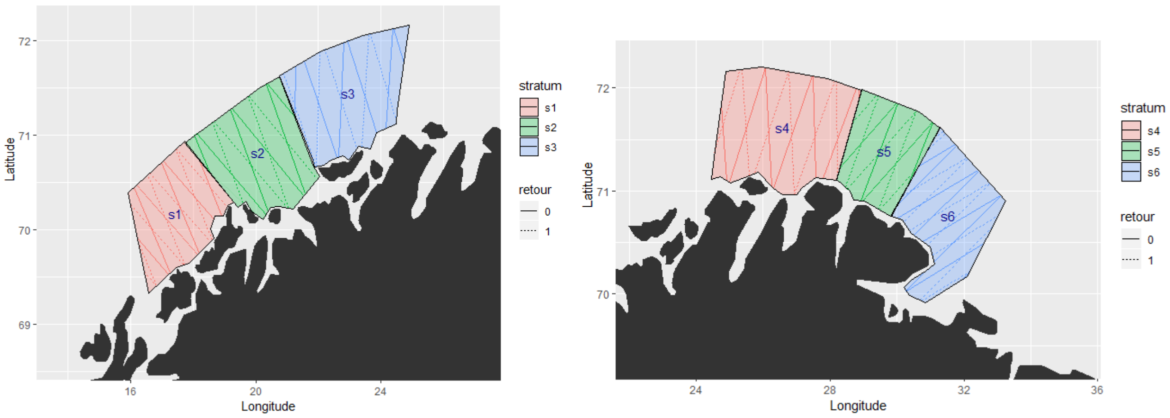


Fig. 1. Initial plan for survey coverage using *Vendla* (west) and *Eros* (east) with 6 strata, zig-zag transects and equal coverage in each stratum.

Similar to 2019, the final distribution of effort was made immediately prior to the survey based on updated information about capelin distribution. In particular, information from the scouting vessel RV *Hovden Viking* was important. Fig. 2 shows distribution of acoustic recordings from *Hovden Viking* and more detailed information can be found in Appendix 1.

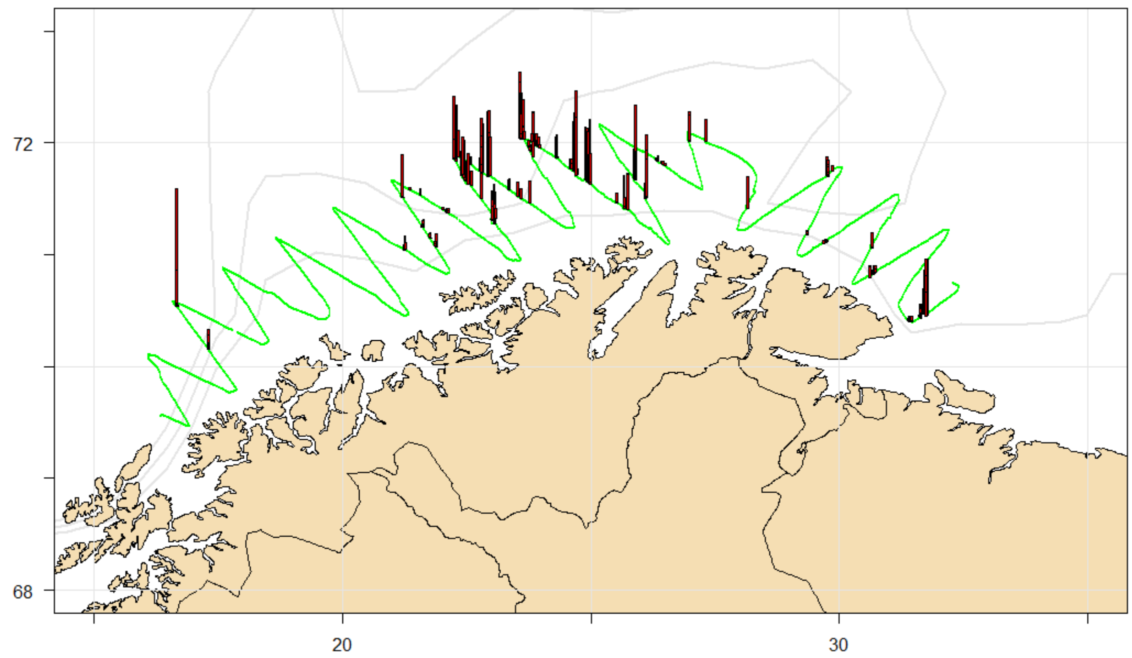


Fig. 2. Survey track (green) and echo sounder recordings from *Hovden Viking.* The relative height of the red bars corresponds to the strength of the recording. Note that there is no discrimination between acoustic targets done here (for instance between capelin and herring).

Other information on recent capelin distribution was also available prior to the survey, including information from fish plants reporting the presence of capelin in cod stomachs (See Appendix 2 for a summary of this information), data from the ground fish survey with RV Johan Hjort in the Barents Sea (the 'winter survey'), and acoustic and trawl data from NSS herring spawning survey which finished off Tromsø on February 25. The final allocation of transects to strata is shown in fig. 3. In addition to the 6 strata shown here, a 7th stratum north of the strata 4 and 5 was included somewhat ad hoc during the survey due to good progress (shown in fig. 5).

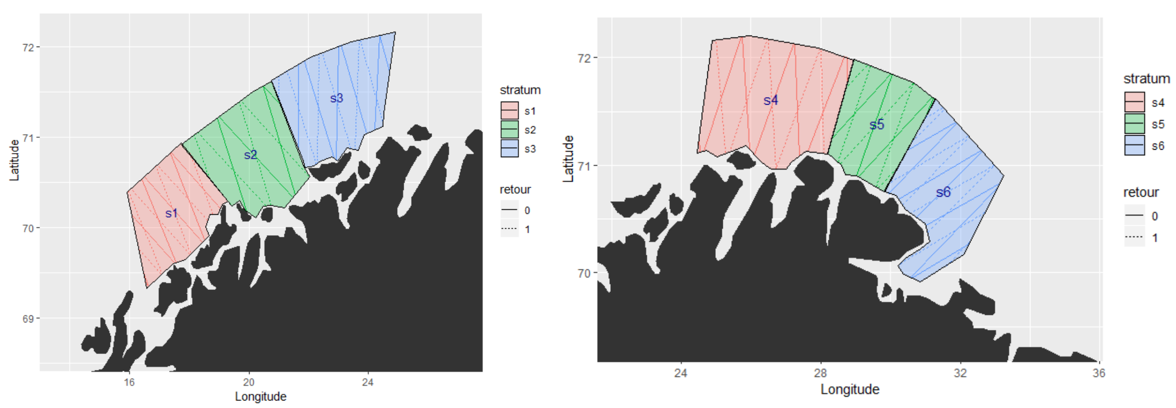


Fig. 3. Final design after adjusting the effort per stratum.

Acoustic data collection and processing

Echo sounder

Acoustic data from calibrated Simrad EK80 echo sounders were collected at frequencies of 18, 38, 70, 120 and 200 kHz on board both *Eros* and *Vendla*. Transducers were mounted in a drop keel 3 m below the vessel hull. Data were collected up to 500 m range and with a ping interval of about 1 second. Raw acoustic data were scrutinized daily using the LSSS software at 38 kHz to the categories ‘Capelin’, ‘Herring’, ‘Bottom fish’, and ‘Other’. The scrutinized data were stored at a resolution of 0.1 nmi horizontal and 5 m vertical and exported in units of Nautical Area Scattering Coefficient (NASC; $m^2 nmi^{-2}$). This output was used for the biomass estimation (see section below).

Sonar

Low frequency omni directional fisheries sonar (i.e. 20-30 kHz) are used by fishermen for long distance search of commercial fish aggregations. During surveying, the large sampling volume of the sonar provides valuable information of spatial distribution of fish schools. Moreover, if the schools are aggregated in a patchy distribution and in low abundance, sonar will more efficiently detect them than narrow echo sounder beams. Also, when schools are tracked at low vessel speed or for a long period, the direction and speed of the schools can be computed, information that is particularly important for the capelin during the spawning migration towards the Finnmark coast.

Low frequency sonars from Vendla (SX90) and Eros (SU90) were calibrated prior the start of the survey following the methodology proposed by (Macaulay et al. 2016). However, processing of calibration data has not been completed, and therefore uncalibrated data is presented in the present cruise report. Sonar data from Simrad SX90 and SU90 at a frequency of 30 kHz was collected continuously with horizontal beams up to 1500 m range with a tilt of -3 deg when surveying. Vertical beams were set across vessel track direction with a range of 600 m. Outside the survey transects, the tilt and range were adjusted to ensure a better sampling of the schools either for detailed inspection or during trawling. Data was scrutinized daily using PROFOS software and school’s properties were computed using ad-hoc R codes (geographical position, mean depth, mean acoustic strength, mean area, mean length along and across beams, average direction and speed).

When the schools were observed along the cruise line in the sonar and echo sounder, in most cases a trawl was performed for biological sampling and to verify that it was capelin. When schools were observed with the sonar outside the track line, the vessel abandoned the transect and a detailed inspection with sonar and echo sounder was made. After the inspection had been carried out and trawl haul made for identification, the survey was resumed at the point the transect was left.

Data presented in the present report includes sonar information only from *Vendla* and compares the data from the sonar and echo sounder up to a depth of 100 m, for each of the two coverages (eastbound and westbound) which included strata 1 to 3. Data from Eros will be analyzed at a later stage.

Combined echo sounder and ADCP

In addition, an EC150-3C transducer was used on board Eros. The transducer is operated using the EK80 and combines a wideband, narrow beam (3 degrees) echo sounder with an acoustic doppler current profiler (ADCP) for current measurements. The instrument has potential for quantifying for instance swimming speed and 3-dimensional direction of fish aggregations. Data were logged from the instrument, but the system is still under development and the data were not processed.

Biological sampling

Harstad trawls were applied on both vessels and rigged according to standard protocol (fig. A3_1 left, appendix 3). However, some changes were made since non-standard ET 15 m^2 trawl doors were used. They have a weight of 4800 kg and the spreading force of these large trawl doors must be compensated to prevent the trawls from being overspread or break. This was done by mounting 2 ropes of 30m length on top and bottom in the opening (fig. A3_1 right, appendix 3) which gave a lower trawl height compared to rigging with standard doors. Also, a split in the codend was made to protect the trawl when catches were large.

Only target trawl hauls were carried out, i.e. on significant pelagic aggregations that were thought to be capelin. In some cases, herring schools were difficult to distinguish from capelin schools. From every trawl haul, a maximum of 100 randomly selected capelin were sampled. Weight and length were measured for all, while age, sex and gonad stage was sampled for 50. In addition, roe weight was measured per specimen for the 50 individuals, but the scale was not precise enough to allow for quality measurements at such a fine scale so the weight of roe for all females among the 50 at each individual station was summed up and recorded. By dividing this roe weight with total weight of the females, roe percentage could be calculated. In addition, length and weight of 100 herring were sampled, and age from 25 of these. Length and total weight were recorded in case there was other catch.

Collection of CTD data

Conductivity Temperature Depth (CTD)-data were collected using a Seabird SBE 25 plus sonde. CTD-casts were carried out about twice a day in order to spread the distribution over the survey area (See fig. 4).

Video stations to ground-truth potential occurrence of capelin roe and spawning substrate

In order to investigate whether there was roe/dead capelin on the bottom indicating spawning, a photo rig was applied on each vessel. A Gopro 8 camera was mounted in a waterproof housing and mounted on a metal rig together with an underwater led flashlight. The rig was lowered down each time the vessel was at the innermost point of a transect. Thereby we got video footage of potential spawning products and spawning substrate at a set of random locations with adequate spawning depths (See fig. 4).

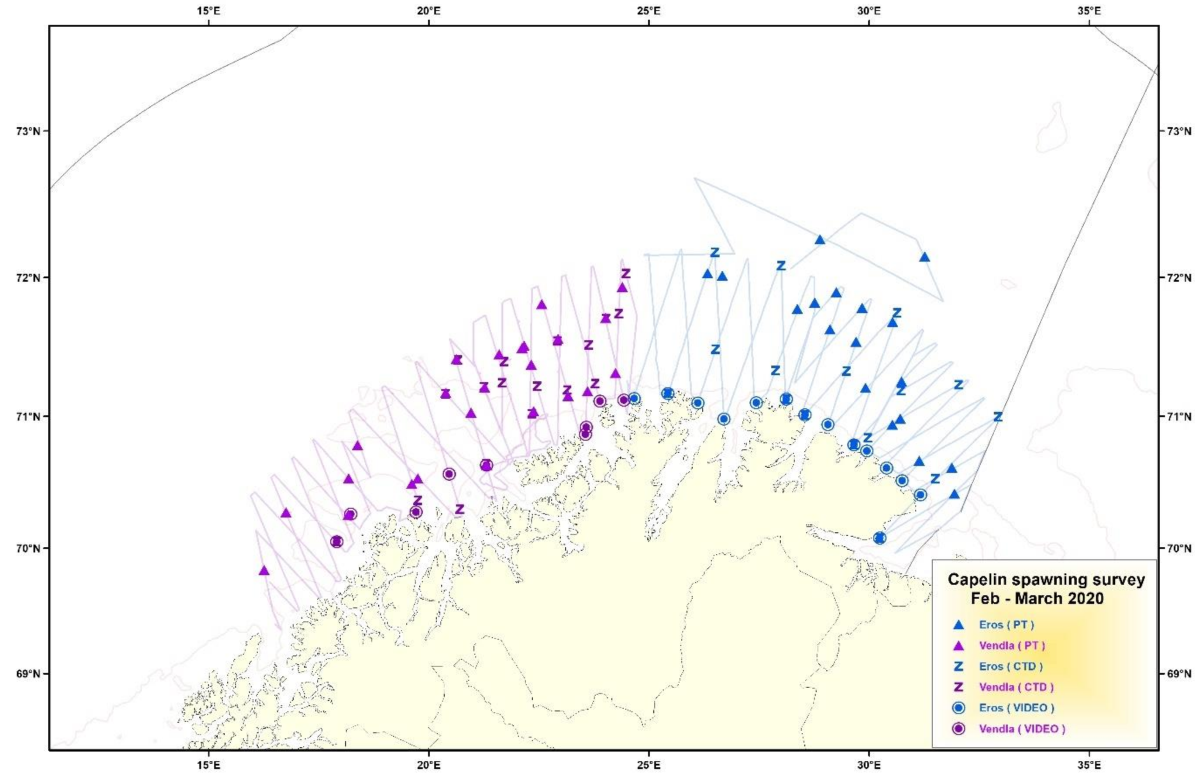


Fig. 4. Overview of cruise track and stations of Vendla (pink) and Eros (blue). PT indicates pelagic trawl, CTD is CTD-cast and the filled circle is a video station of bottom substrate.

Biomass estimation

The Stox application (Johnsen et al. 2019) was used to calculate a standard transect-based trawl acoustic estimate. Some main steps of the protocol can be mentioned: All acoustic recordings outside the transect lines (due to for instance trawling) were excluded from the estimation. All transects (from both coverage areas and survey directions) were combined. All the assigned biological stations were given equal weight when generating the total length distribution used in the estimation. Weighting according to NASC and according to sample size did not have significant impact on the estimate. The following target strength – length relationship was applied for the density (numbers/nmi^2) calculation (Dommasnes & Røttingen 1985):

$$TS = 19.1 \log L - 74$$

For the baseline estimate, abundance of fish in numbers and biomass were calculated by length. Finally, the R model was executed using 500 bootstrapping iterations of biotic stations and acoustic transects. The R-report model was run to output reports on sampling variance.

Results

Capelin biomass estimate

An overview of all transects and stations included in the biomass estimation is shown in fig. 5. The total biomass of mature capelin within the coverage area was estimated in to 62 298 tons (Tab. 1), with a relative sampling error or Coefficient of Variation (CV) of 38% (Tab. 2). This CV is based on bootstrapping with replacement of transects as well as bootstrapping of biological stations used in the assignment. A 5% lower and 95% upper confidence limit were calculated from 500 bootstrap replicates, and the lower and upper limits were 26 655 and 104 305 tons, respectively. Estimates of abundance by length and age with associated CV are provided in figs. 6 and 7, respectively. The estimate is within the uncertainty limits of the prediction from the 2019 autumn survey (ICES 2019). However, the sampling error is large, in particular given the high sampling effort. For a resample of acoustic data alone weighted by transect length and stratum, CV was 41%. The results indicate a very patchy distribution of the capelin which can also be seen in fig. 8. The estimate from the western coverage area was much higher when moving westward (return) than eastward (Tab. 3). Much of the difference is driven by the very high recordings in two 0.1 nmi segments north-west of Sørøya (see fig. 8). Such high recordings could be due to coincidence in otherwise similar situations, but the sonar which samples a much higher volume than the echo sounder indicated that the distribution had changed between the two coverages (see next section). In the eastern coverage area, the results from the eastward and westward coverage were more similar.

Estimated average individual weight of capelin was 20.57 g. Fish of age 4 was dominant, followed by 3-year-olds. Output tables by strata and uncertainty estimates by length and age are found in Appendix 4.

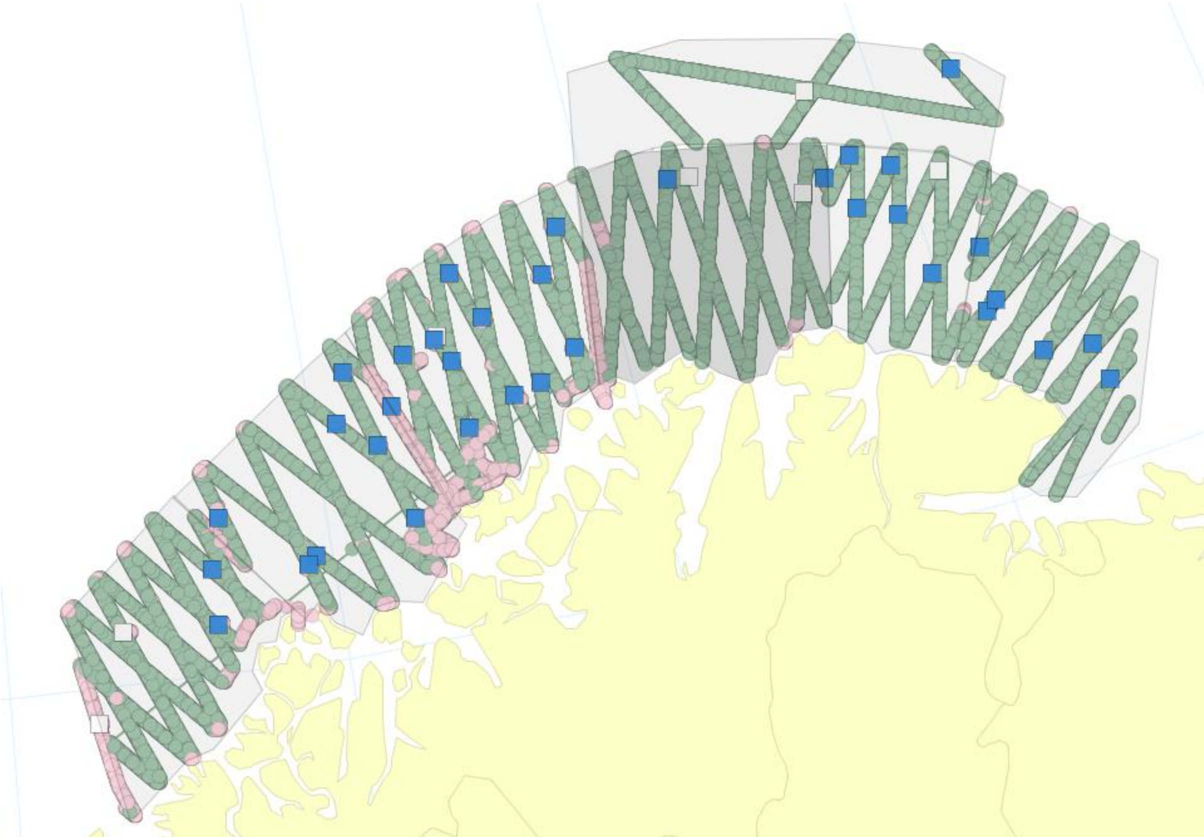


Fig. 5. Overview of transects (green: included in the biomass estimation, pink: not included in the biomass estimation). Blue dots mark trawl stations with capelin catch, white dots stations with no capelin catch. The gray shaded areas mark the strata (1-7).

Table 1. Results from the biomass estimation. Abundance and biomass of capelin by age and length from the entire survey coverage.

Variable: Abundance
EstLayer: 1
Stratum: TOTAL

LenGrp	age 2	3	4	5	6	Number (1E3)	Biomass (1E3kg)	Mean W (g)
12.5-13.0	2865	-	-	-	-	2865	22.9	8.00
13.0-13.5	3546	-	-	-	-	3546	29.0	8.19
13.5-14.0	8766	2375	-	-	-	11140	118.1	10.60
14.0-14.5	3141	49751	4166	-	-	57058	674.5	11.82
14.5-15.0	2712	186266	17216	-	-	206194	2703.5	13.11
15.0-15.5	1249	318103	71117	4487	-	394955	5770.7	14.61
15.5-16.0	1814	267480	196197	5302	-	470793	7923.2	16.83
16.0-16.5	6264	144274	309295	41891	2865	504588	9595.1	19.02
16.5-17.0	182	91879	258983	66881	-	417925	8966.3	21.45
17.0-17.5	-	83824	253642	24893	6446	368805	8783.1	23.82
17.5-18.0	-	4655	102147	92567	1539	200909	5470.8	27.23
18.0-18.5	467	21742	174838	22977	1001	221026	6644.6	30.06
18.5-19.0	-	10282	87865	33060	88	131295	4292.2	32.69
19.0-19.5	-	510	16073	15597	170	32351	1124.8	34.77
19.5-20.0	-	-	4352	-	-	4352	169.4	38.93
20.0-20.5	-	-	258	-	-	258	9.7	37.61
TSN(1000)	31006	1181141	1496149	307655	12111	3028062	-	-
TSB(1000 kg)	385.9	19767.8	33924.6	7932.6	287.1	-	62298.0	-
Mean length (cm)	14.26	15.47	16.65	17.19	16.95	-	-	-
Mean weight (g)	12.45	16.74	22.67	25.78	23.71	-	-	20.57

Table 2. Sampling uncertainty derived from bootstrapping of biological and acoustic input data to the biomass estimate and expressed as confidence levels and coefficient of variation.

	5% lower confidence level	95% upper confidence level	CV
Total stock biomass (tons)	26655	104305	0.38
Total stock number (10^6)	1313	5179	0.39

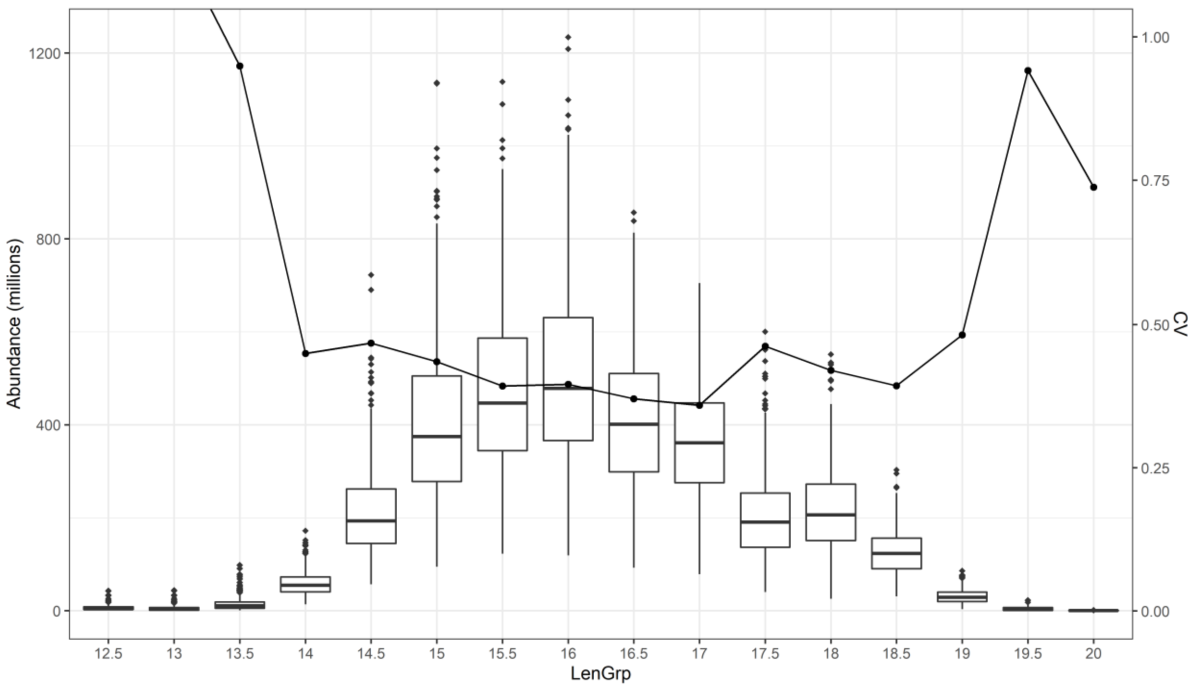


Fig. 6. Estimate of abundance (boxplot) and CV by length group.

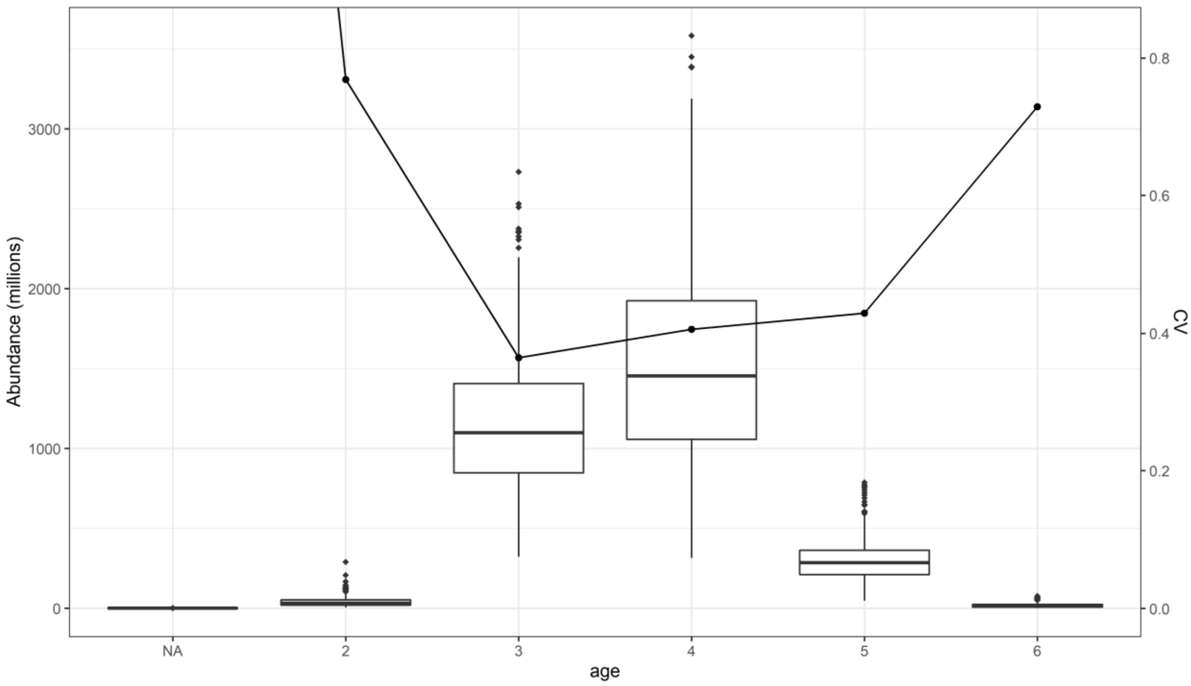


Fig. 7. Estimate of abundance (boxplot) and CV by age.

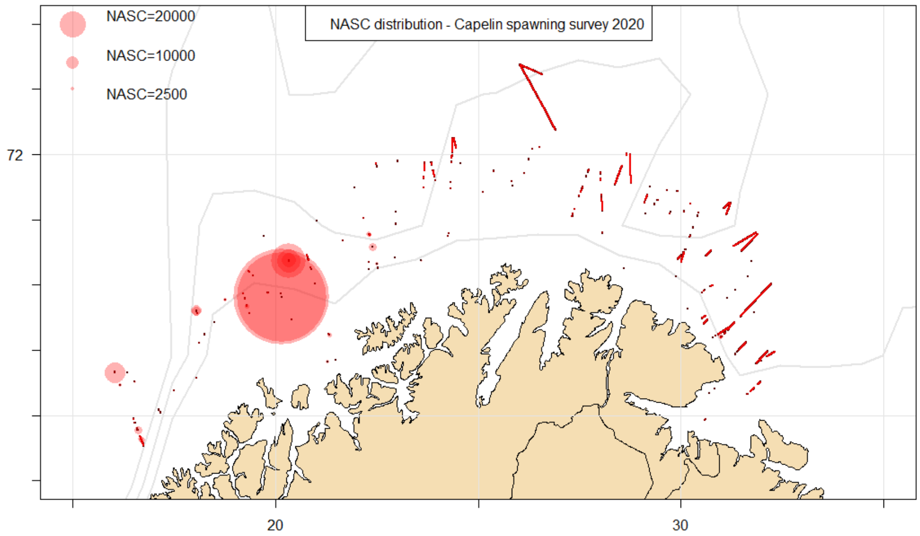
Table 3. Biomass estimation (BM, tons) output in tons by strata, area and westward/eastward coverage.

Strata	BM (tons) - eastward coverage	BM (tons) -westward coverage	BM (tons) - East + westward coverage
S1	29	14914	7810
S2	7104	75469	42083
S3	4193	3947	4066
S1 + S2 + S3	11326	94329	53960
S4	3225	465	1871
S5	1171	712	918
S6	4857	4844	4850
S4 + S5 + S6	9253	6021	7639

Acoustic recordings

Echo sounder

The distribution of acoustic backscatter used in the capelin biomass estimation, both coverages from both vessels, is shown in fig. 8. While the upper panel shows circles with size corresponding to NASC, the lower panel shows circle size corresponding to the fourth root of NASC, in order to get an alternative view of the distribution with less displayed difference between low and high values. Echo sounder recordings from a small stretch to the north-west of Sørøya dominated the echo sounder recordings included in the estimate (See fig. 8 upper). For pelagic fish, when abundance is low, the distribution is typically very patchy with long distance between large aggregations, and there is a low statistical probability of hitting the aggregations. In such situations you expect a high sampling variance (see previous section). There were mostly scattered capelin observations in the eastern coverage area, the only exception was the shelf edge on the north side of Varangerhalvøya where some more significant aggregations were observed (See fig. 8).



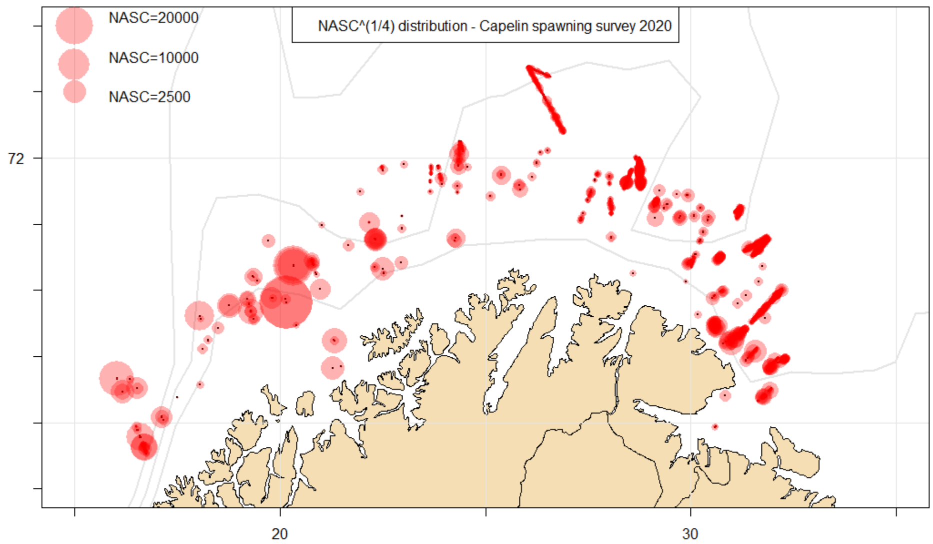


Fig. 8. *Upper:* Distribution of NASC (m^2nmi^{-2}) allocated to capelin and included in the biomass estimation. The size of the circle corresponds to NASC-value per 0.1 nautical mile. *Lower:* Distribution of *fourth root transformed* NASC ($NASC^{1/4}$).

Sonar recordings

In regions along the transects with depths larger than 100 m, schools were easy to detect at long range with the sonar settings used (fig. 9). However, in the coastal region in shallower waters, due to interference with bottom echoes, it was challenging to identify school echoes. School detection problems were also encountered in bad weather conditions at sonar ranges <200 m, with multiple echoes from air sweep down by surface waves.

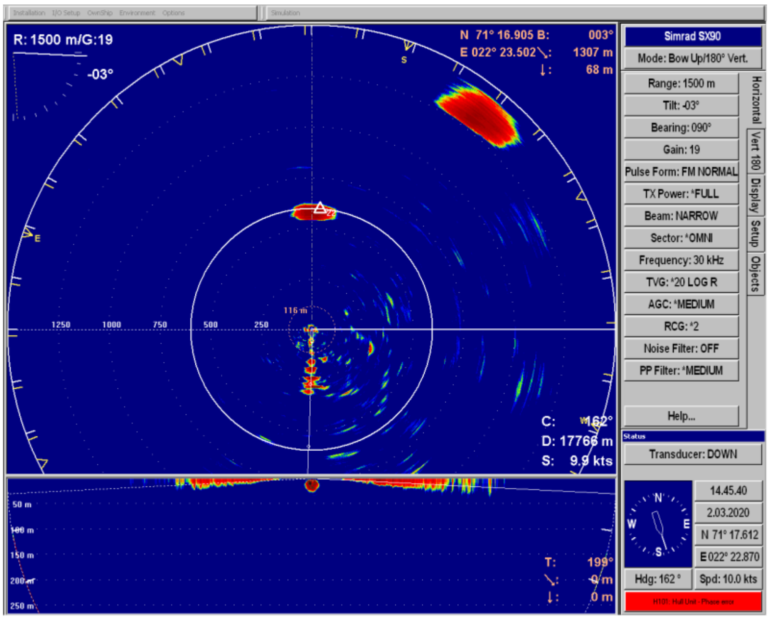


Fig. 9. Screen dump from SX90 sonar display during surveying. A capelin school is approaching the vessel at 600 m along the transect. A larger school is observed about 1200 m to starboard side.

An example of a capelin school observed both with the sonar and the echo sounder is shown in fig. 10. The school was located close to the surface with a vertical extension down to about 50 m. The echo sounder frequency response showed a decrease in higher frequencies (bottom right panel), which is expected.

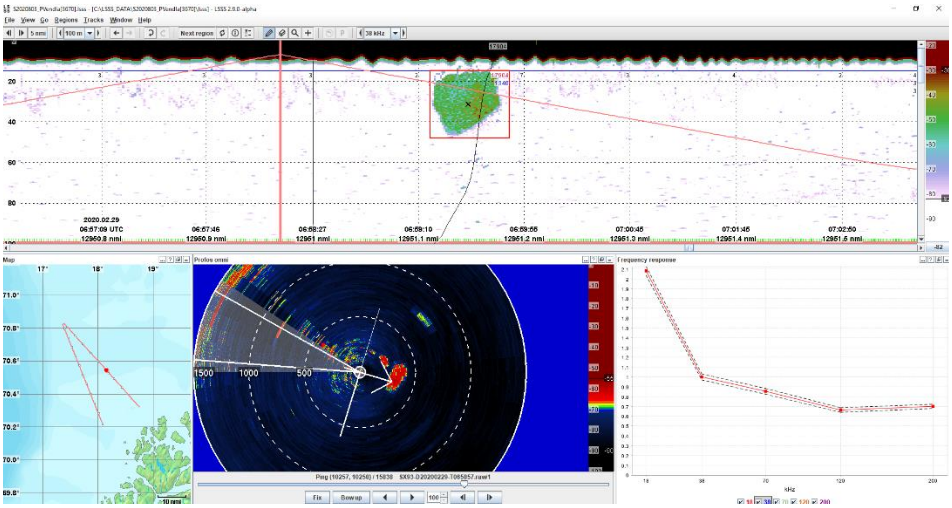


Fig. 10. Screen dump of the prost-processing system LSSS and PROFOS module, where sonar and echo sounder data are displayed simultaneously. The upper panel shows a capelin school measured by the echo sounder, which was previously detected by the sonar (center bottom panel).

The NASC distribution from the sonar recordings is shown in fig. 11. In the eastbound coverage, the highest recordings were from stratum 2 (central region), while the highest recordings came in stratum 1 during the westbound coverage. The results are only partly in accordance with the results from the echo sounder data. Partly, the discrepancy is probably due to different sampling volumes between echo sounder and sonar. But not all can be attributed to that, and there is ongoing to further analyze and interpret the sonar data.

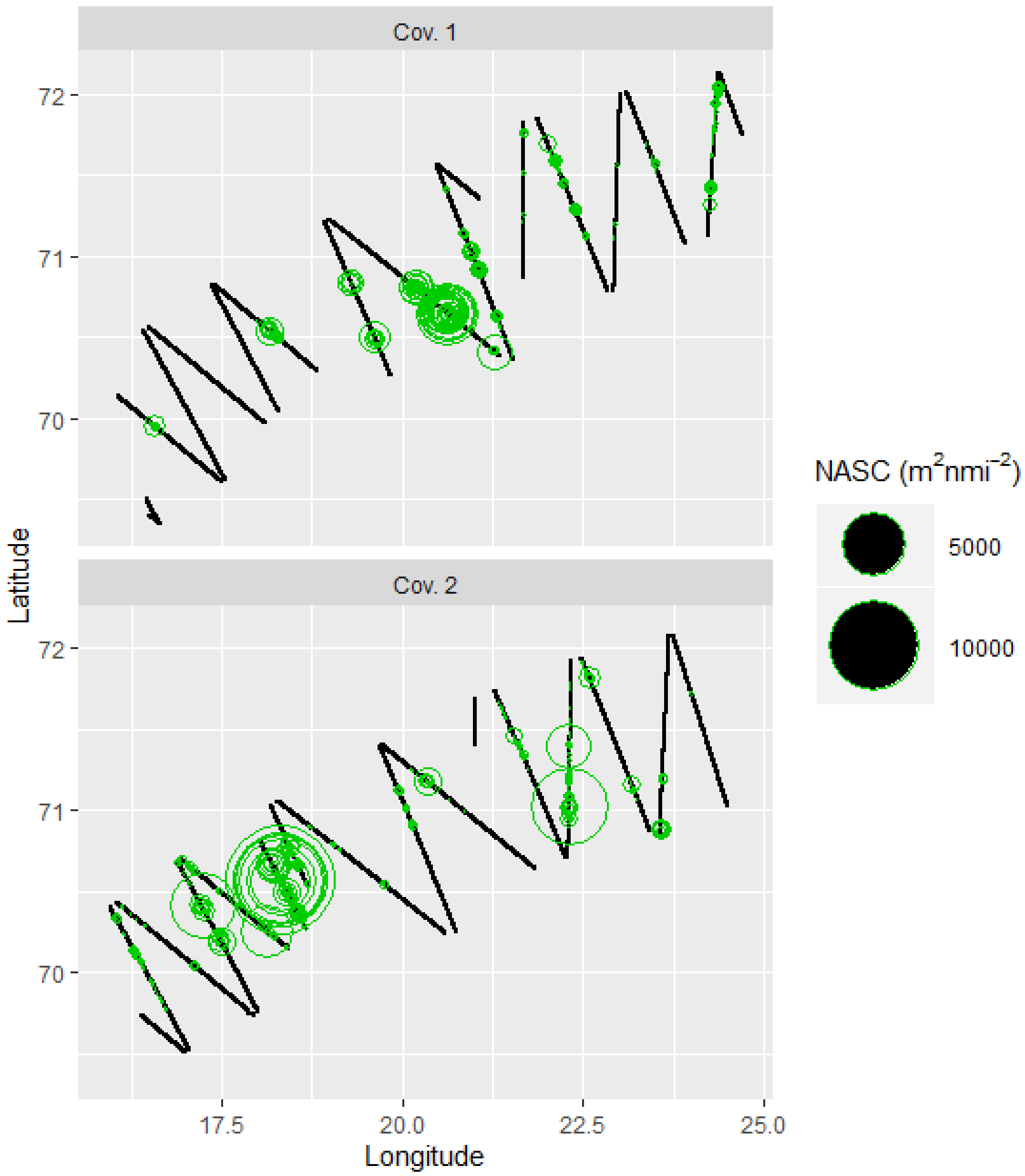


Fig. 11. Nautical area scattering coefficient (NASC, m^2 nmi^{-2}) for the sonar up to 100 m depth for the eastbound (upper) and westbound (lower) coverage.

The analysis of the schools with more than 30 detections in the sonar (about 2 minutes) indicated a general slow migration with a dominating direction towards the west, followed by east and south, with a mean speed of 0.2 knots.

Biology of the capelin

The mean length of capelin was 16.2 cm and similar between western and eastern coverage areas (fig. 12). Mean weight was 22.3 g and also very similar between the western and eastern coverage areas. Length distributions by station are presented in Appendix 5.

By far most of the capelin was in spawning stage 5, which is mature. A low proportion of the capelin in the western area was in stage 6 which is running or spawning stage. No capelin were found to be in stage 7. The situation was different compared to last year when spent individuals and also a higher proportion of running individuals were found to the east.

The roe percentage was calculated to get additional information on the maturation and spawning progress. It is calculated as the sum weight of roe in the individual samples divided by the total weight of females in the same sample. The results are presented in fig. 13. Clearly there was a generally higher roe percentage in the western than eastern coverage area. The roe percentage in the west also showed an increasing trend over the survey period, and the percentages towards the end of the survey period are corresponding with capelin in a state ready to spawn. The roe percentages of the capelin in the eastern area indicated that spawning was further ahead in time.

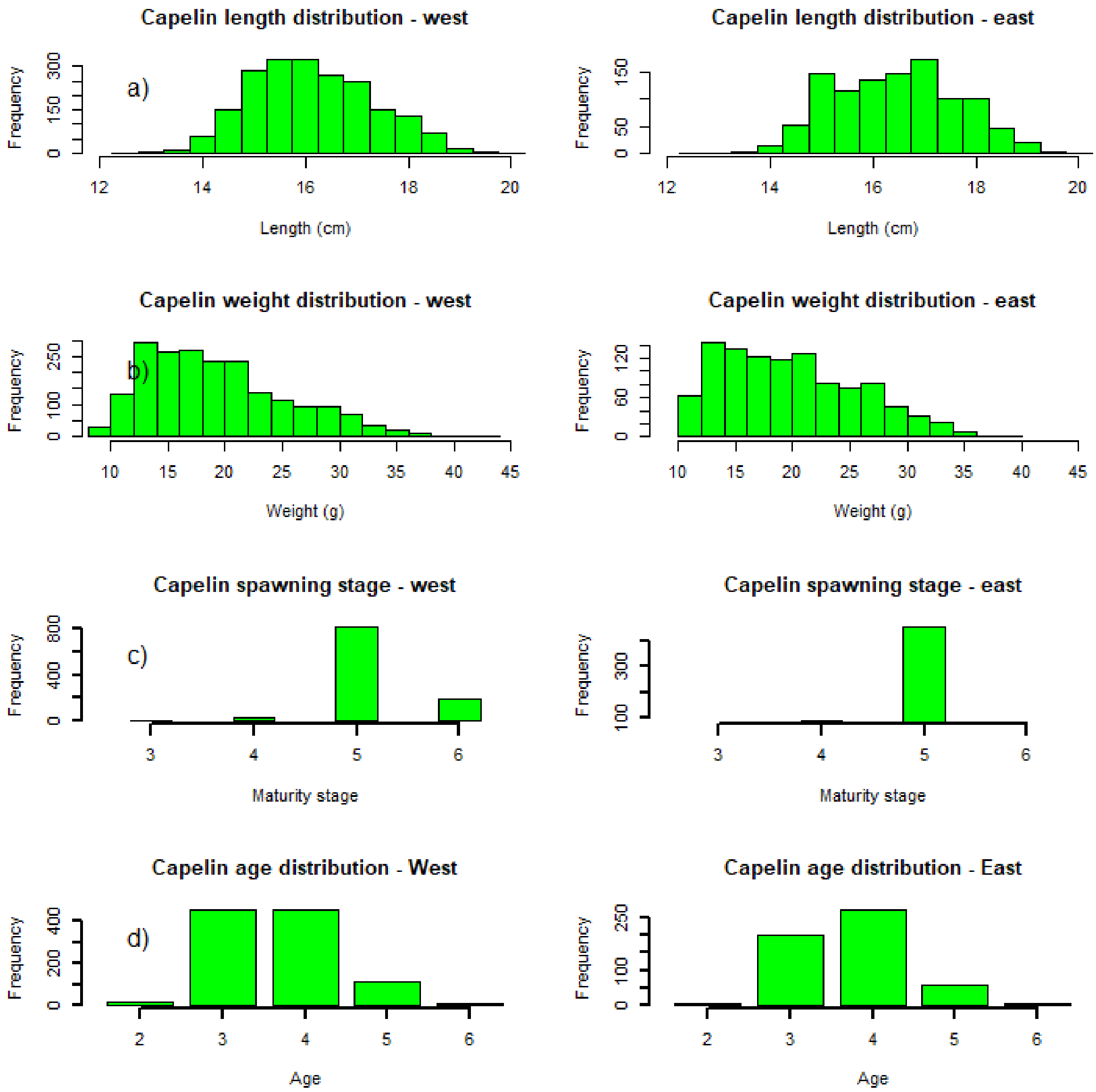


Fig. 12. Capelin a) length distribution b) weight distribution, c) spawning state and d) age distribution in the western (left column of panels) and eastern (right column of panels) coverage areas.

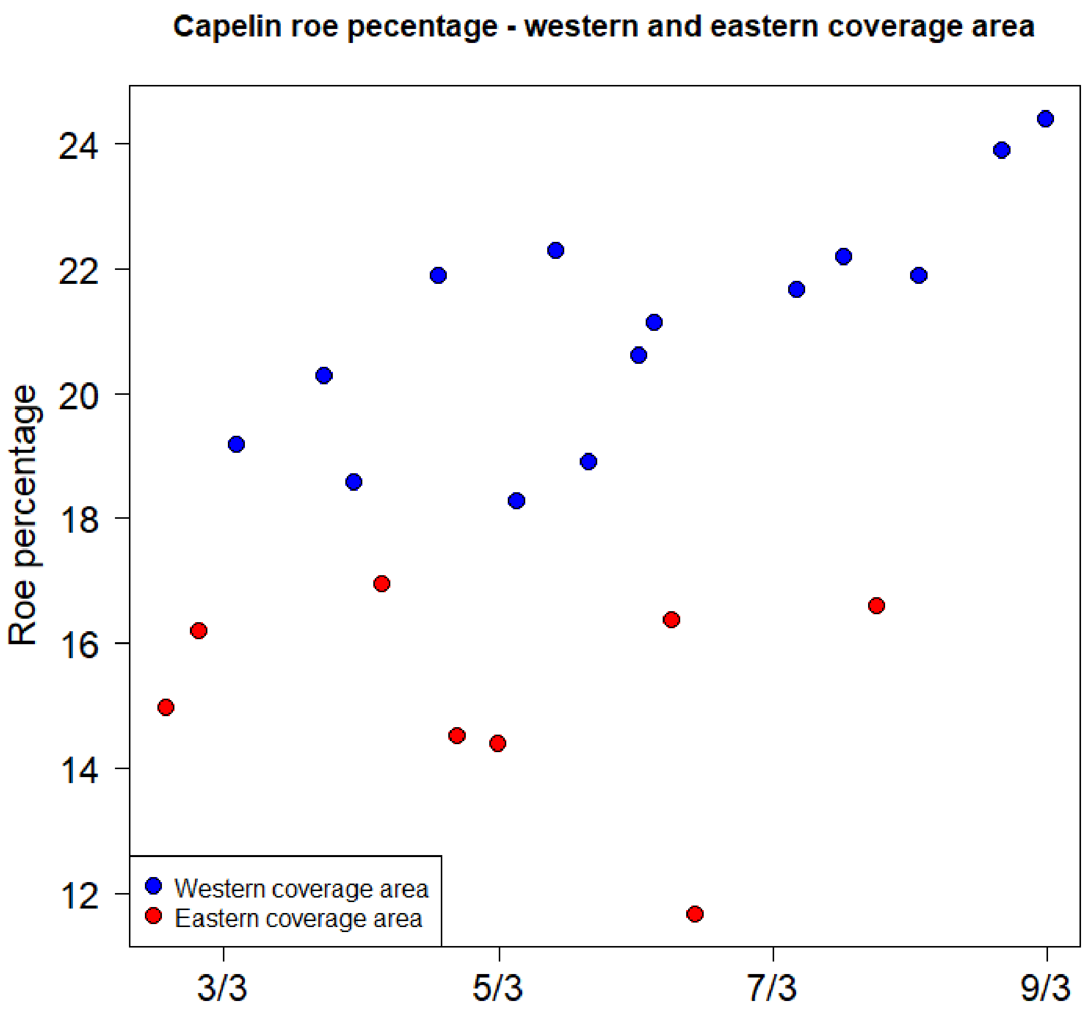


Fig. 13. Capelin roe percentage (Weight of roe in all sampled females divided by the total weight of those females) per station as a function of time. *Blue*: Stations from *Vendla* in the western coverage area, and *red*: stations from *Eros* in the eastern coverage area.

Herring were present in the south-western part of the western coverage area as well as the northern part of the eastern coverage area. The herring sampled were dominated by the 2016-yearclass. More detailed information on herring distribution and biology are found in appendix 6.

Environmental data

The temperatures in the study area at different depths are shown in fig. 14. In general, the temperature range was between 3 and 6 degrees which is appropriate for capelin spawning. The temperature in the western area was 1.5-2 degrees above the temperature in the eastern area. The temperature in the western area was also more even over the water column while the temperature in the east was typically increasing with depth.

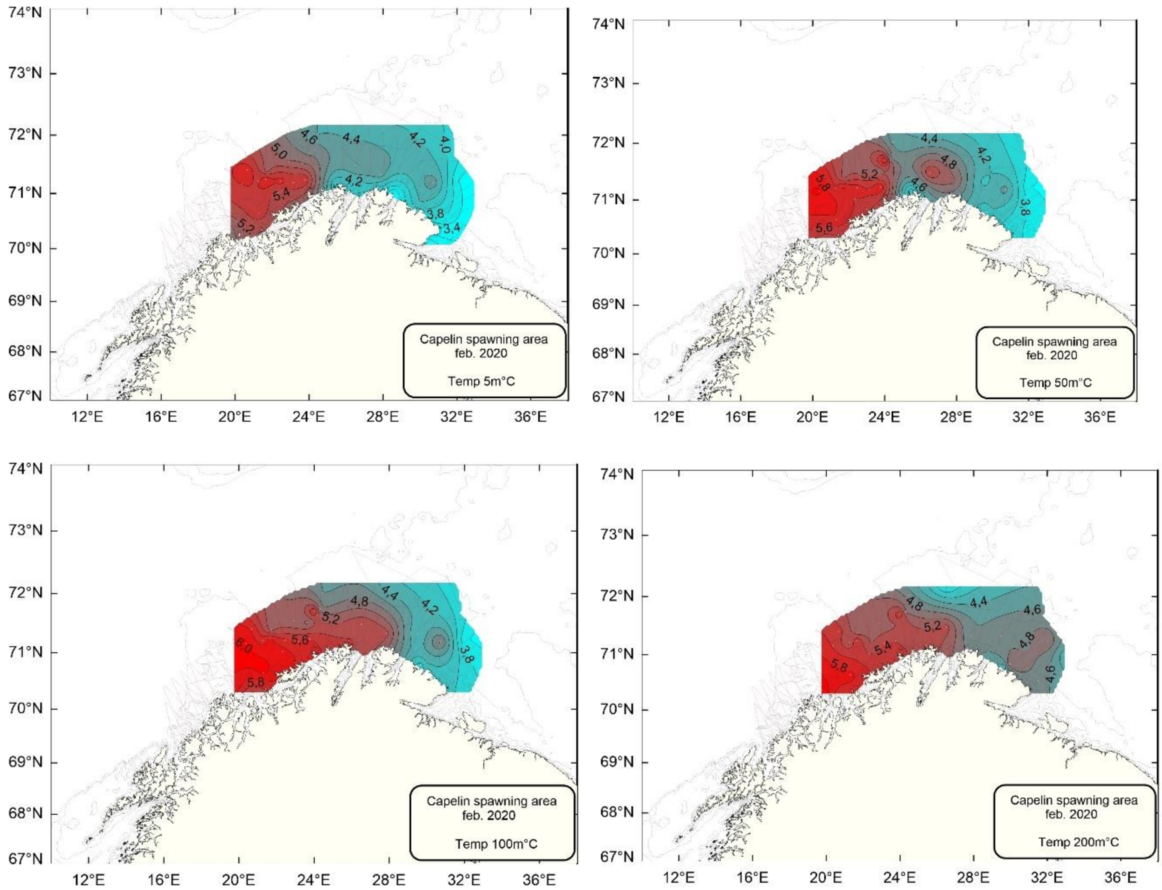


Fig. 14. Temperatures at 5 m (upper left), 50 m (upper right), 100 m (lower left) and 200 m (lower right).

Spawning products and spawning substrate

Several of the video station recordings revealed bottom made up of stones and gravel which are preferred bottom substrate for capelin, however, no capelin roe was observed in any of the stations. An overview of the substrate types in the different stations is found in appendix 7.

Part B. Methodological investigations

Acoustic target strength investigations using WBAT

TS measurements - Background

Fish target strength (TS) is a key parameter for biomass estimation of fish stocks when using the acoustic echo integration methods. The target strength represents the acoustic backscattered energy from a single fish and is used to convert the total energy measured with an echo sounder into number of fish. The target strength to length relation which is in current use for Barents Sea capelin, TS= 19.1 log(L)-74, is derived from ex-situ measurements of maximum TS of clupeid species (Dalen et al. 1976) and theoretical corrections based on different measurements to convert it into a mean TS-length relation (Dommasnes & Røttingen 1985). There has not been a proper evaluation of the TS-length relation since then (but see (Jørgensen 2004)), even though ad hoc studies indicate that factors like depth distribution, season and physiological state may influence the TS. Hence, *in situ* TS measurements that reflect the acoustic backscattering of free-swimming capelin are highly needed.

To obtain single fish measurements in schooling species from vessel mounted echo sounders is a challenge, especially during normal acoustic surveying. Deployment of an echo sounder close to the fish targets and use of broad band echo sounders will increase the chances of obtaining single school measurements.

TS measurements - Data collection

A Simrad autonomous scientific echo sounder (WBAT) was used onboard FV *Vendla* for TS measurements. The echo sounder system was equipped with a 38 and 70 kHz split beams transducers, both with beam width opening angles of 18 deg. Transducers were mounted to point downwards and the mission plan set alternated transmission of 100 pings for each transducer for the deployment period. The WBAT and transducers were mounted in a frame and lowered by a winch down to desired depth. The frame was submerged to ca. 5 m above the top of a capelin school, which had been detected and passed over with the vessel prior to WBAT deployment. Additional weights were used to ensure a vertical angle of the frame and echo sounders. Once the frame reached the desired depth, the vessel was slowly maneuvered aiming to stay on top and at the borders of the school during the measurements. The maneuver was facilitated by the combined use of the sonar and vessel mounted echo sounder. Because capelin schools have high fish density, schools and capelin aggregations with lower density were targeted for the TS measurements. However, only high-density schools were encountered during the survey period.

In different deployments, the WBAT was set to collect data from single band (CW) or broadband (FM). In broadband mode the frequency range used for the 38 kHz transducer was from 35 to 45 kHz, and for the 70 kHz transducer from 55 to 90 kHz.

Prior to each WBAT deployment a pelagic trawl was carried out for biological sampling of the capelin.

After each deployment, data was retrieved from the WBAT and examined in the EK80 software. A detailed analysis of single targets will be done at a later stage using post processing system LSSS and ad-hoc R codes. WBAT calibration was not possible before the survey and is planned as soon as possible.

TS measurements - Results

A total of 5 WBAT deployments were carried out with a variable duration between 0.5 to 1 hours (fig. 15). The first deployments showed problems related to the battery connection inside the WBAT, which motivated a change in the orientation of the WBAT unit from vertical to horizontal. Transducers were kept pointing downwards. The changes resulted in a normal operation of the WBAT and adequate data collection.

Preliminary analysis of the data collected with CW mode showed that no single fish were possible to isolate using the standard algorithms for single target detection in LSSS. On the contrary, in FM mode single targets were obtained in all deployments, because of the higher vertical resolution when using this transmission mode (ca. 4 cm with 38 kHz transducer).

An example of the FM data at 38 kHz from deployment No. 2 is shown in fig. 16. In the top panel the echogram shows a capelin school and the black dots represent the single targets detected. Only the upper 15 m were selected to avoid the denser parts of the school with the risk of measuring multiple targets as single fish. In deployment No. 5, the capelin school was denser (using same thresholds levels for displaying purposes), however, it was also possible to detect single targets in the shallower layer (fig. 17).

The processing of TS requires calibrated data to define the criteria for filtering and select the single targets. Therefore, no more results are presented in the present cruise report.

The preliminary analysis of the broadband data sets showed indications of suitable material to extract target strength measurements and derive in situ TS - fish length relations for capelin.

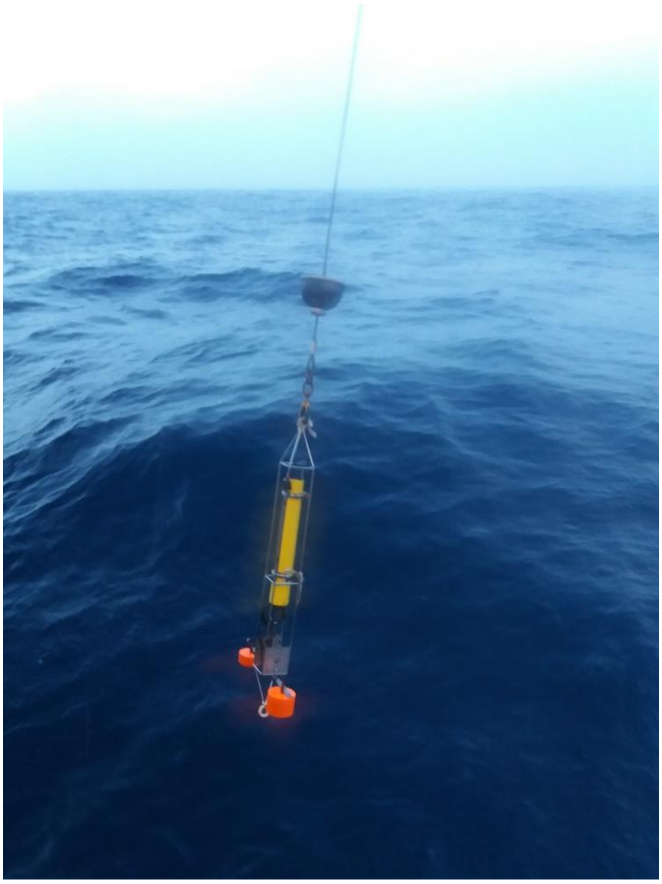


Fig. 15. Deployment of the WBAT equipped with 38 and 70 kHz transducers pointing downwards.

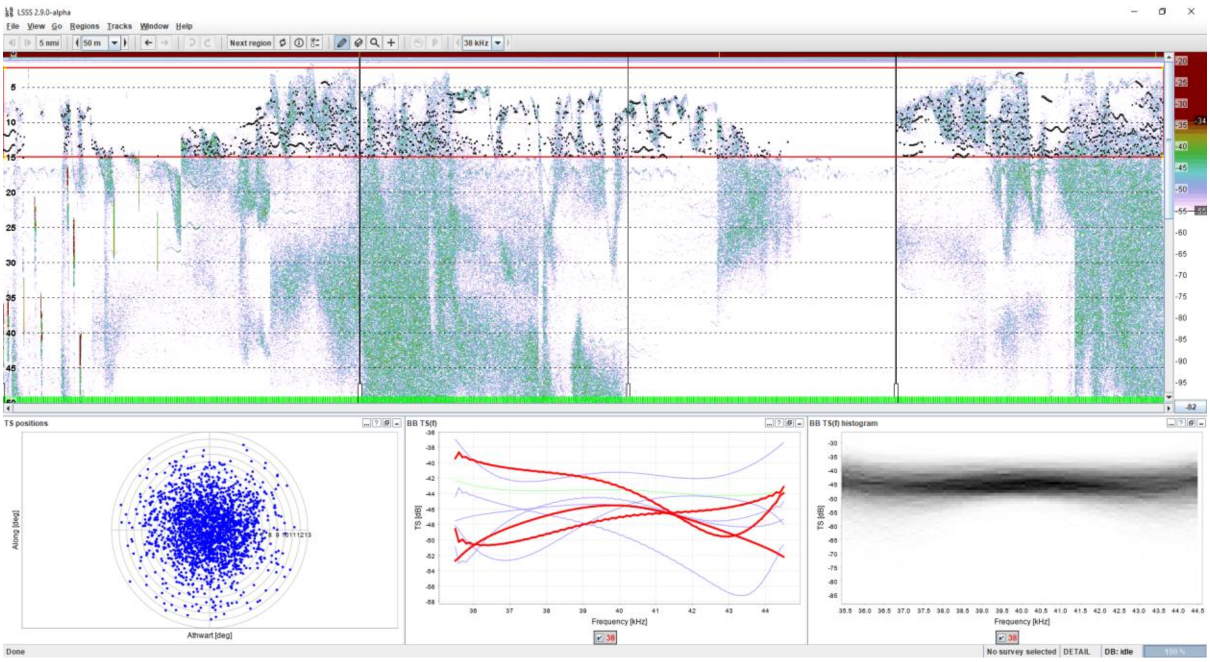


Fig. 16. Echogram of broadband (FM) data collected with the 38 kHz transducer in deployment No. 2. The top panel shows the echogram and detected single targets marked with black dots. Position of targets in the acoustic beam (bottom left panel) and histogram by frequency (35 to 45 kHz) of all targets in selected region (bottom right panel).

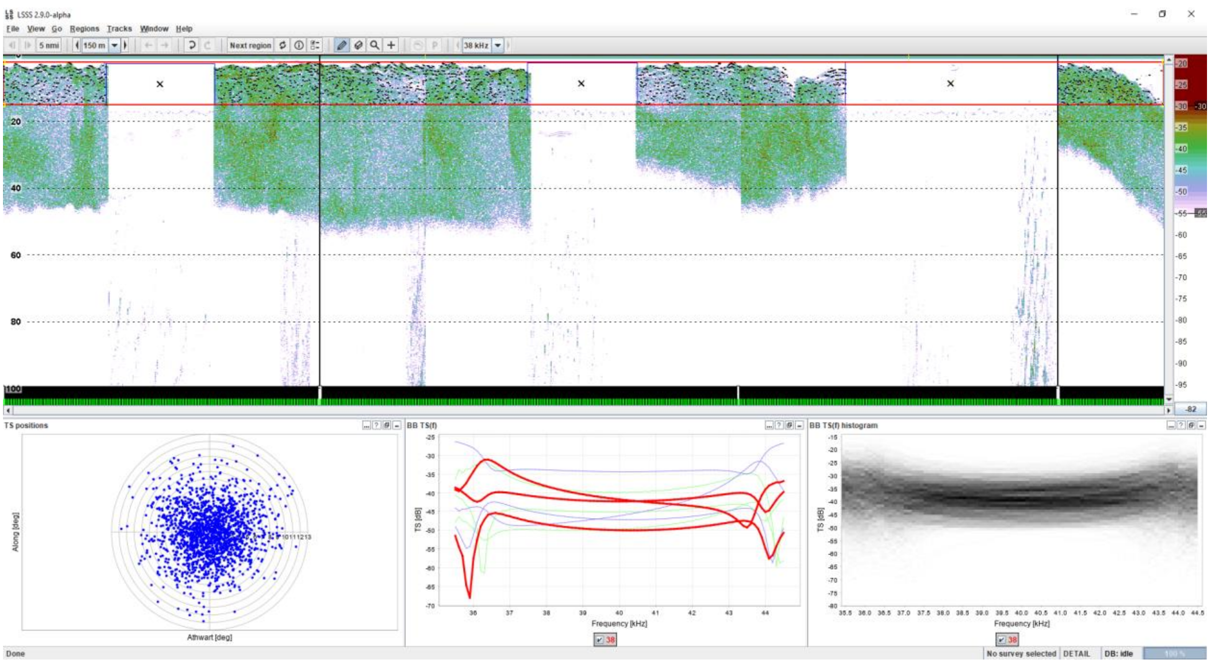


Fig. 17. Echogram of broadband (FM) data collected with the 38 kHz transducer in deployment No. 5. Otherwise, the explanation is the same as in fig. 16.

Testing of the autonomous Sailbuoy

Sailbuoy trial - Introduction

As described elsewhere in this report, the estimation of abundance of spawning capelin along the coast of Finnmark is challenging. This is mainly due to large interannual variation in timing and geographical location of the spawning. An adequate survey design is therefore not straight-forward to make.

The use of acoustic autonomous vehicles has been discussed as a mean to monitor the migration of capelin towards the coast in a cost-efficient way. Potentially, autonomous vehicles may enhance the quality of the surveys in the future. The Sailbuoy http://www.sailbuoy.no/, is such an autonomous vehicle which is relatively small (L x B x H= 225 x 61 x 135 cm), and constructed to be robust with long endurance. As part of the Norwegian Research Council Research and development project ‘Sailbuoy for krill’ (Project number 296183), the Sailbuoy was tested during the present survey. The project is a collaboration between Aker Biomarine AS (project owner), Offshore sensing AS, Liegruppen Fiskeri, NORCE Norwegian Research Centre AS and IMR. A key part of the project is a system for storing, processing, transferring and displaying acoustic data for remote monitoring of areas for commercial purpose (e.g. fishing grounds) and for the purpose of science and monitoring for potential use as input to assessment and advice. For IMR, the main interest and project task is to evaluate whether the Sailbuoy can be a valuable tool to improve the quality of the scientific monitoring in the future.

For the present survey, the Sailbuoy echosounder was not calibrated and the aim was not to include the acoustic recordings in any abundance estimation. This was only an initial test to get more insight into the potential of this novel technology.

Sailbuoy trial - Preparations

Several meetings were held between the project partners prior to the survey. During an *in situ* test and through discussions, the group identified challenges both with the sailing control and the remote, real time access to acoustic data since the Sailbuoy is currently not optimized for scientific monitoring. The deployment during the present survey must therefore be viewed as part of a process to improve and update the system as well as acquire valuable experience on this type of platforms.

Sailbuoy trial - Deployment and retrieval

The Sailbuoy was deployed on 4th March in position N71 34’ and E12 4’ at a 40 nautical mile distance from the coast, north of Hammerfest. This was the distance from the coast where much of the migrating capelin was found. The buoy was set to sail westwards along the coast. It was retrieved after 36 hours in a location 45 nmi to the west. The average speed between the deployment and retrieval points was 1.25 knots.

The wind varied a lot from close to dead calm to gale. The dominating wind direction was 170 degrees.

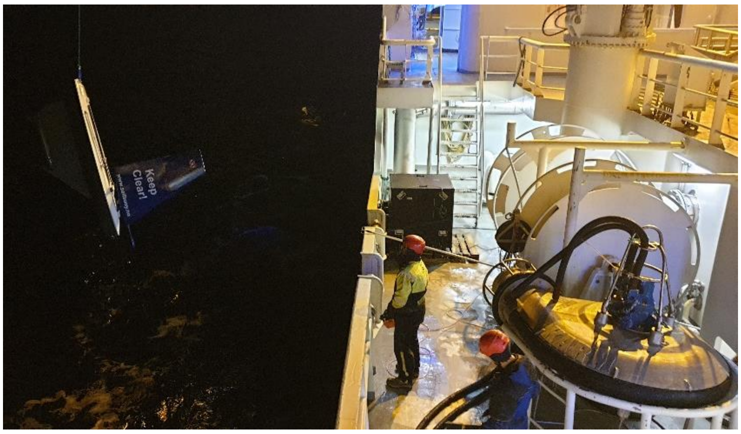


Fig. 18. *Upper:* Deployment of the buoy from the vessel crane. *Lower:* Retrieval of the buoy without putting out the workboat. A four-meter-long and thin floating rope was attached to the stern of the buoy.

Both deployment and retrieval went smooth (fig. 18). Especially the retrieval can be a challenge. The recommended approach of putting out a workboat is often not an option on this weather-torn coast. A four-meter-long and thin floating rope was therefore attached to the stern of the buoy. A loop was made at the end for lifting with the crane. This worked fine and the rope did not seem to have any negative impact on the steering of the buoy. A swivel should have been used to prevent winding the rope.

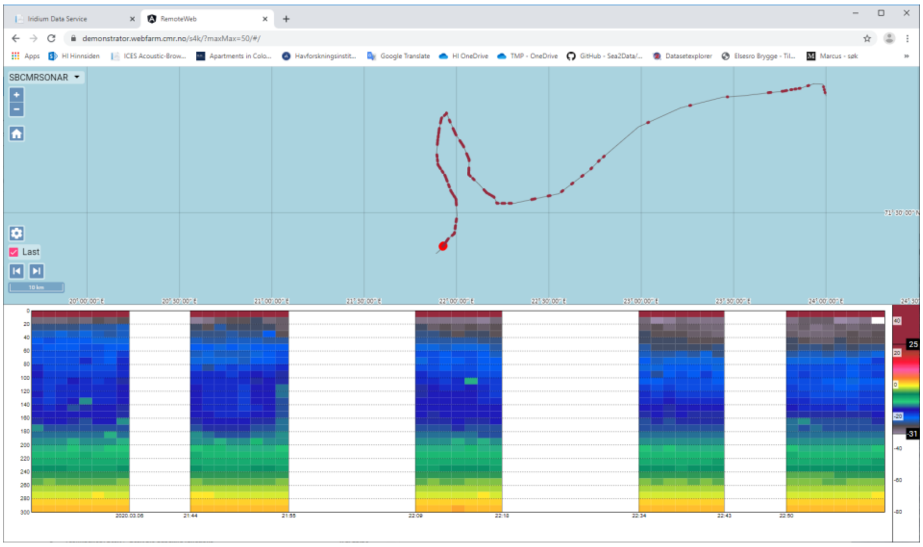


Fig. 19. Course track of the Sailbuoy shown in the upper part of the window. The lower part shows echograms transferred over the remote connection.

Sailbuoy trial - Operation and performance of the buoy

The Iridium connection to the buoy worked without any problems. At all times, we had connection with the buoy and knew the location and direction it was sailing. The sailing abilities of the buoy is limited to 4 predefined positions of the sail. This is most likely the reason why the buoy was struggling to go to the transect line and follow it (see fig. 19). The autopilot software in the buoy needed to be taken out of auto mode a few times and into manual steering control when the buoy was heading away from the desired route. Periods of little wind and strong currents may have been the reason at least for one of these occurrences.

The buoy can only go on auto along one transect. Either from start to stop position or back and forth in a so-called fence mode. More elaborated routes are presently not possible.

The original plan was to let the buoy go in fence mode to monitor the development of migration over time, past a transect parallel to the coast. This plan was aborted both due to the distribution of the fish (significant aggregations first present late in the survey), and due to navigational challenges and slow speed. The Sailbuoy was a side activity in the survey and extra time was not allocated for buoy experiments.

The real time echograms transferred during the operation were hard to interpret (fig. 19) due to the low resolution and the lack of reference thresholds (since the buoy was not calibrated). Development and refinement of the visual display as well as training in interpretation of such low-resolution echograms are needed to make full use of the buoy data for instance in an adaptive monitoring regime. The raw acoustic data stored inside the drone have not yet been evaluated as they will be downloaded after the buoy return to NORCE.

Sailbuoy trial - Conclusions

The practical testing of the Sailbuoy in the Barents Sea went relatively well. However, experience is needed for good piloting and the recovery is also not trivial when dependent upon a small-time window in open seas. We did not get enough deployment time or interpretable echogram displays that enabled us to make decisions on the monitoring based on remote data, but with more experience and improved visualization this could be possible. The Sailbuoy does not seem suited for conventional monitoring following transects replacing vessels in a classical design. However, the buoy could provide valuable information from zones unavailable to survey vessels, like the surface dead zone. It could also be used as a scouting vehicle or a long-term monitoring pod in a well-known system. It is likely that autonomous vehicles will play a role in such surveys in the foreseeable future.

Concluding remarks about the survey

1. Auxiliary information, especially data provided by the scouting vessel FV *Hovden Viking* helped to improve the original survey design by adjusting the coverage in some strata compared to the initial design.
2. The difference in the estimates and distribution from the first and second coverage in the western area underpins the huge temporal dynamic during capelin spawning migration which was also evident last year.
3. There was a different dynamic in the timing of the migration observed last year and this year. While the maturity state of capelin in the western area indicated that they were ready for spawning this year, the capelin in the eastern area still had some weeks left. This was opposite of what was observed last year.
4. The sonar provides a better overview than the echo sounder of the spatial distribution of capelin schools during the spawning period due to a larger sampling volume. At low abundance levels with few large schools, this aspect is very relevant. Sonar data will provide valuable information on the school spatial distribution which will improve an analysis of the accuracy of the echo sounder sampling.
5. The total biomass was estimated at 62 298 t, with a sampling variance expressed as Coefficient of Variation (CV) of 38%. The high CV despite the good coverage likely reflects a very patchy distribution where most observations are 0 or close to 0, but a few are very high. Such distributions can be expected at low stock levels.
6. Of the methodological work, the *in situ* target strength estimation showed promising results while new insight was gained into the strengths and weaknesses of the Sailbuoy.
7. The experience gained during the present survey, together with the surveys in 2019 and the next survey in the series will form the basis for a proper evaluation of the usefulness of a capelin winter monitoring as input to the stock assessment and advice.

Acknowledgments

The skipper and officers onboard FV *Hovden Viking* are thanked for they excellent cooperation and positive attitude during their participation in the scouting phase of the survey. The skipper and crew of FV *Vendla* and FV *Eros* are thanked for their excellent assistance and engagement during the whole survey.

Appendix

Appendix 1. Operation of the scouting vessel FV *Hovden Viking*

The scouting vessel Hovden Viking was instructed to follow the protocol below:

Survey along a pre-defined zig-zag track to cover the study region during a period of 7 days starting 19.02.20 off Tromsø and ending 26.02.20 off Varanger (fig. A1_1).

Keep vessel speed between 10-12 knots

Operate echo sounders and sonars continuously during the surveying using the most suitable settings for capelin search as defined by the skipper

Store data from the echo sounder (38 kHz) on an external hard drive for later processing

Synchronize the sonar and echo sounder clocks before the start of the survey

Write a log regularly with information about the results of the searching and navigation events

When important fish aggregations are found, the vessel can leave the transect and inspect the aggregations, collecting data from both the sonar and echo sounder. After the inspection the vessel should return and continue sailing along the transect

The log should contain the following information:

1. *Time when schools are observed with the sonar or echo sounder*
2. *Start and end of a transect line*
3. *Time when the vessel leaves the transect line to inspect a school*
4. *Time when the vessel returns to the transect line after school inspection*

When schools are detected with the sonar or echo sounder, a screen dump should be stored every 10 minutes until no more fish schools are observed

In the log, the "event" field should be completed indicating: school observations, start and end of transect, leave and return to transect. Any additional comments about school characteristics (depth, direction, speed, etc.) will be valuable.

Screen dump files need to be copied from the sonar and echo sounder PC to a PC with access to internet. The files should be loaded regularly into a shared folder which IMR has access to.

The 38 kHz echo sounder of the vessel was calibrated in Ålesund before the scouting started. While the vessel was at the pier, hard drives for data storage were installed, the sonar was set up for logging and waypoints discussed and technical and practical instructions given.

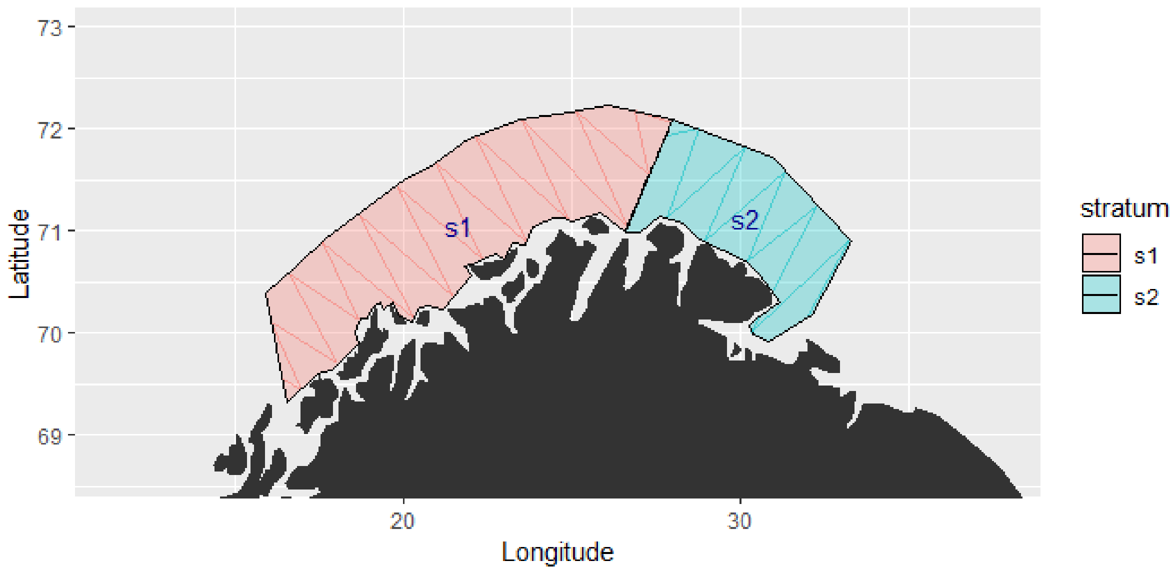


Fig. A1_1. Transects designed for the FV *Hovden Viking* scouting effort.

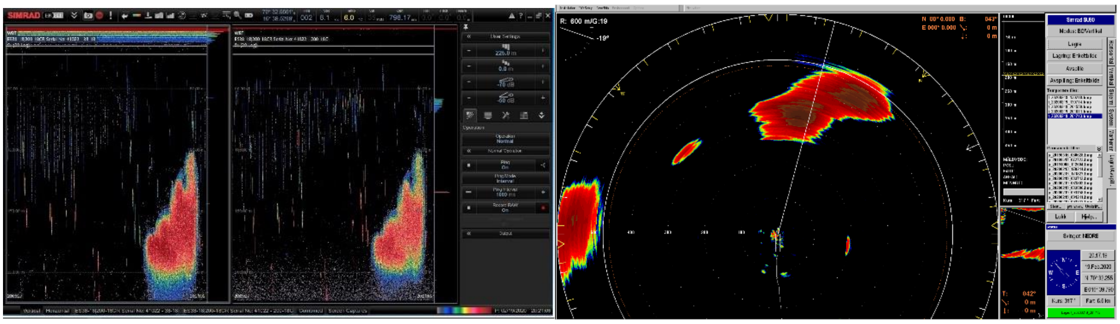


Fig. A1_2. Echogram (left) and sonar display (right) from *Hovden Viking* of schools around position 70°32N and 16°39E north-west of Tromsø. 20:15 UTC on the 19 Feb.

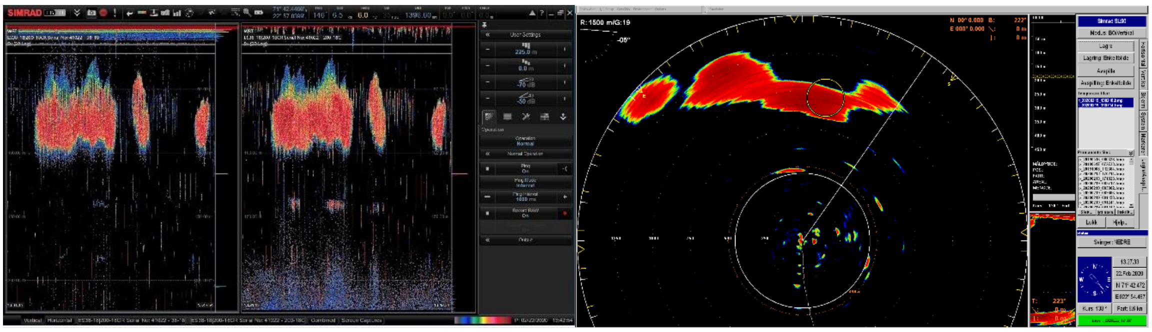


Fig. A1_3. Echogram (left) and sonar display (right) from *Hovden Viking* of good aggregations around position 71°42N and 22°55E north-west of Hammerfest. 13:30 UTC on the 22 Feb.

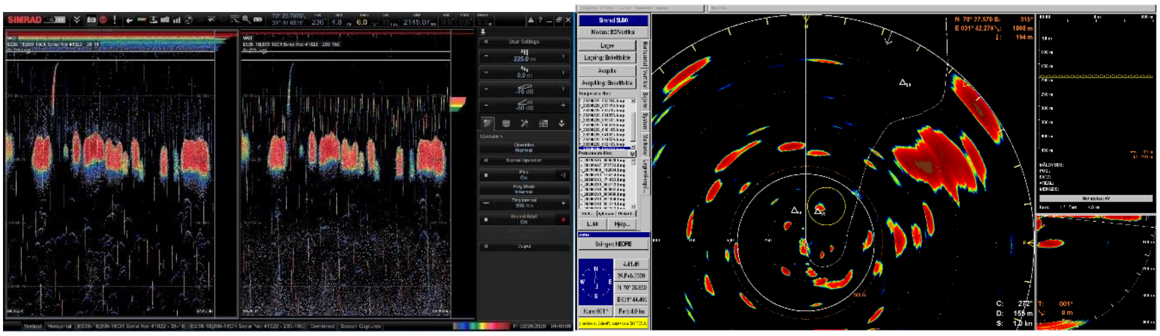


Fig. A1_4. Echogram (left) and sonar display (right) from *Hovden Viking* of a layer around position 70°26N and 31°38E north-east of Varanger. 03:31 UTC on the 26 Feb.

Appendix 2. Information from fish plants on capelin in cod stomachs.

Fish plants along the coast of Finnmark and Troms report weekly to IMR about frequency of cod stomachs with capelin in them. Not all plants report back each time, but the results from the plants which have reported are summarized in the fig. A2_1. The 2020 reporting started in week 3 and the last results included are from week 11. The scouting vessel started its surveying in week 8, and the main survey started in week 9 and ended in week 11.

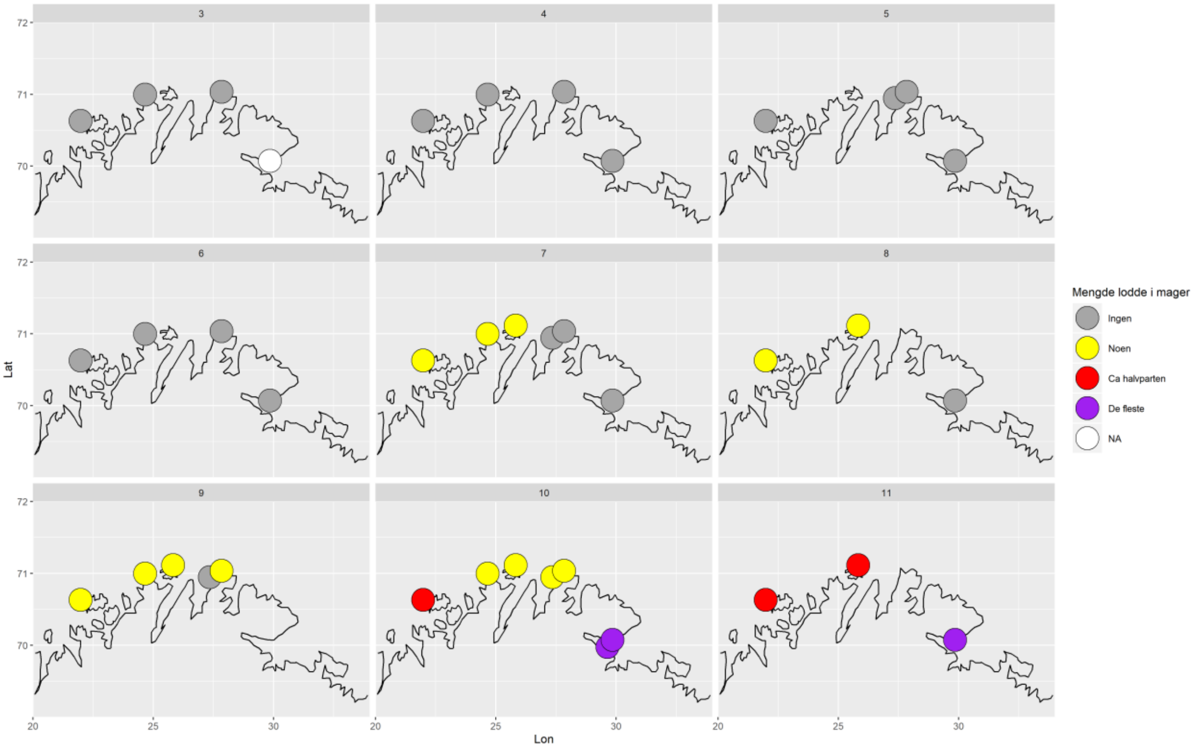


Fig. A2_1. Frequency of cod stomachs with capelin in them reported weekly from fish plants along the coast of Finnmark and Troms. Each panel represents a week (week 3- week 11). Grey circle: no capelin, yellow circle: capelin in some stomachs, red circle: capelin in ca. half of the stomachs, purple circle: capelin in most of the stomachs.

Appendix 3. Rigging of the Harstad trawl

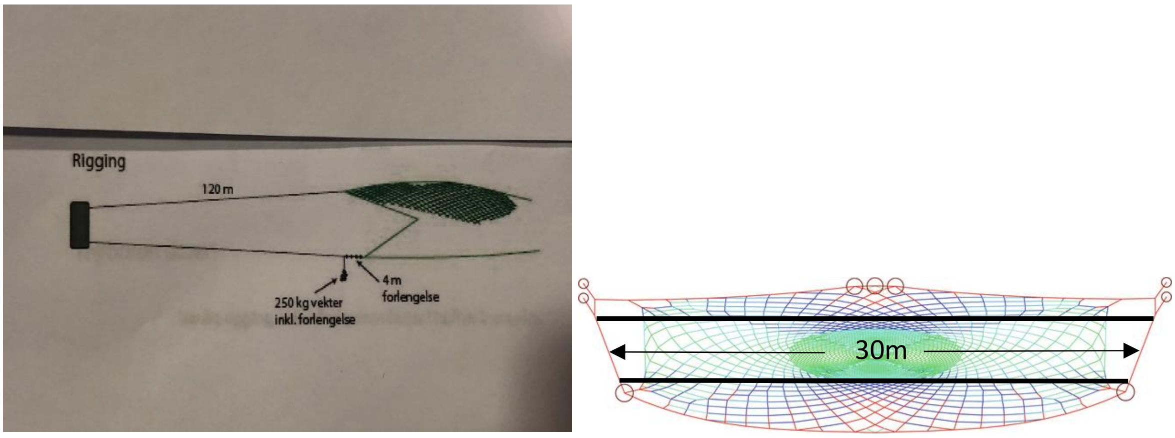


Fig. A3_1. Rigging of the Harstad trawl used during the survey (left panel) and detail of two 30 m security ropes attached to the net opening to protect the trawl from damage (right panel).

Appendix 4. Output from the abundance estimation

Table A4_1. Biomass estimate output table for stratum 1.

Variable: Abundance
EstLayer: 1
Stratum: s1

LenGrp	age 2	3	4	5	Number (1E3)	Biomass (1E3kg)	Mean W (g)
12.5-13.0	-	-	-	-	-	-	-
13.0-13.5	-	-	-	-	-	-	-
13.5-14.0	-	-	-	-	-	-	-
14.0-14.5	-	3917	-	-	3917	47.0	12.00
14.5-15.0	1959	21544	-	-	23502	313.4	13.33
15.0-15.5	-	43087	-	-	43087	630.6	14.64
15.5-16.0	-	50921	23502	3917	78340	1284.8	16.40
16.0-16.5	-	21544	70506	3917	95967	1876.3	19.55
16.5-17.0	-	9793	37212	9793	56797	1241.7	21.86
17.0-17.5	-	7834	29378	3917	41129	959.7	23.33
17.5-18.0	-	-	5876	5876	11751	305.5	26.00
18.0-18.5	-	5876	13710	3917	23502	689.4	29.33
18.5-19.0	-	-	1959	7834	9793	325.1	33.20
19.0-19.5	-	-	-	-	-	-	-
19.5-20.0	-	-	3917	-	3917	152.8	39.00
TSN(1000)	1959	164515	186058	39170	391701	-	-
TSB(1000 kg)	23.5	2761.5	4058.0	983.2	-	7826.2	-
Mean length (cm)	14.50	15.49	16.49	17.10	-	-	-
Mean weight (g)	12.00	16.79	21.81	25.10	-	-	19.98

Table A4_2. Biomass estimate output table for stratum 2.

Variable: Abundance
EstLayer: 1
Stratum: s2

LenGrp	age 2	3	4	5	6	Number (1E3)	Biomass (1E3kg)	Mean W (g)
12.5-13.0	2865	-	-	-	-	2865	22.9	8.00
13.0-13.5	2865	-	-	-	-	2865	22.9	8.00
13.5-14.0	8596	-	-	-	-	8596	91.7	10.67
14.0-14.5	2865	34383	2865	-	-	40113	475.6	11.86
14.5-15.0	-	111745	14326	-	-	126071	1661.8	13.18
15.0-15.5	-	206298	51574	2865	-	260738	3862.4	14.81
15.5-16.0	-	154723	148993	-	-	303716	5197.6	17.11
16.0-16.5	5730	77362	200567	34383	2865	320908	6143.1	19.14
16.5-17.0	-	48709	180511	45844	-	275064	5965.4	21.69
17.0-17.5	-	54440	171915	11461	5730	243546	5856.6	24.05
17.5-18.0	-	-	65901	74496	-	140397	3913.9	27.88
18.0-18.5	-	11461	131801	11461	-	154723	4721.9	30.52
18.5-19.0	-	8596	74496	17191	-	100284	3306.5	32.97
19.0-19.5	-	-	11461	14326	-	25787	905.4	35.11
TSN(1000)	22922	707716	1054411	212028	8596	2005673	-	-
TSB(1000 kg)	269.3	11925.2	24222.8	5535.7	194.8	-	42147.8	-
Mean length (cm)	14.00	15.44	16.66	17.19	16.67	-	-	-
Mean weight (g)	11.75	16.85	22.97	26.11	22.67	-	-	21.01

Table A4_3. Biomass estimate output table for stratum 3.

Variable: Abundance
EstLayer: 1
Stratum: s3

LenGrp	age 2	3	4	5	6	Number (1E3)	Biomass (1E3kg)	Mean W (g)
12.5-13.0	-	-	-	-	-	-	-	-
13.0-13.5	680	-	-	-	-	680	6.1	9.00
13.5-14.0	170	680	-	-	-	850	8.2	9.60
14.0-14.5	186	7829	373	-	-	8388	96.6	11.51
14.5-15.0	183	17198	-	-	-	17381	223.9	12.88
15.0-15.5	1071	24642	5178	-	-	30892	448.2	14.51
15.5-16.0	527	19486	10884	527	-	31423	526.3	16.75
16.0-16.5	533	12260	12793	3021	-	28607	549.4	19.20
16.5-17.0	182	8921	13472	3459	-	26035	561.1	21.55
17.0-17.5	-	5778	15709	3431	361	25280	612.9	24.24
17.5-18.0	-	1955	9242	5687	178	17062	475.2	27.85
18.0-18.5	-	1603	5521	3206	534	10864	334.8	30.82
18.5-19.0	-	-	2551	2381	-	4932	165.7	33.59
19.0-19.5	-	510	680	-	170	1361	48.3	35.50
19.5-20.0	-	-	170	-	-	170	7.5	44.00
20.0-20.5	-	-	170	-	-	170	6.8	40.00
TSN(1000)	3533	100863	76745	21711	1243	204096	-	-
TSB(1000 kg)	50.7	1689.9	1733.7	562.0	34.7	-	4071.0	-
Mean length (cm)	14.77	15.41	16.60	17.19	17.77	-	-	-
Mean weight (g)	14.36	16.75	22.59	25.88	27.92	-	-	19.95

Table A4_4. Biomass estimate output table for stratum 4.

Variable: Abundance
EstLayer: 1
Stratum: s4

LenGrp	age 3	4	5	Number (1E3)	Biomass (1E3kg)	Mean W (g)
12.5-13.0	-	-	-	-	-	-
13.0-13.5	-	-	-	-	-	-
13.5-14.0	-	-	-	-	-	-
14.0-14.5	-	-	-	-	-	-
14.5-15.0	6638	-	-	6638	86.3	13.00
15.0-15.5	6040	5177	-	11217	149.3	13.31
15.5-16.0	13022	1628	-	14650	229.5	15.67
16.0-16.5	4171	5214	-	9385	164.8	17.56
16.5-17.0	1373	5494	1373	8241	165.7	20.11
17.0-17.5	4326	10095	-	14421	336.0	23.30
17.5-18.0	-	10759	-	10759	251.9	23.42
18.0-18.5	-	3663	1373	5036	141.9	28.18
18.5-19.0	-	5580	3348	8928	268.9	30.13
19.0-19.5	-	2289	-	2289	76.5	33.40
TSN(1000)	35572	49898	6095	91564	-	-
TSB(1000 kg)	565.2	1140.8	164.8	-	1870.9	-
Mean length (cm)	15.51	17.02	17.94	-	-	-
Mean weight (g)	15.89	22.86	27.05	-	-	20.43

Table A4_5. Biomass estimate output table for stratum 5.

Variable: Abundance
EstLayer: 1
Stratum: s5

LenGrp	age 2	3	4	5	6	Number (1E3)	Biomass (1E3kg)	Mean W (g)
12.5-13.0	-	-	-	-	-	-	-	-
13.0-13.5	-	-	-	-	-	-	-	-
13.5-14.0	-	-	-	-	-	-	-	-
14.0-14.5	89	267	89	-	-	446	5.4	12.20
14.5-15.0	570	4563	-	-	-	5134	70.2	13.67
15.0-15.5	178	1599	533	711	-	3021	43.1	14.26
15.5-16.0	-	2130	888	-	-	3018	47.4	15.71
16.0-16.5	-	1951	2395	89	-	4435	79.2	17.86
16.5-17.0	-	1459	6484	1621	-	9564	186.4	19.49
17.0-17.5	-	1329	3278	2038	354	6999	159.1	22.73
17.5-18.0	-	885	2655	1062	-	4601	118.8	25.83
18.0-18.5	-	-	2390	1151	-	3541	100.1	28.28
18.5-19.0	-	-	1593	619	88	2301	68.3	29.69
19.0-19.5	-	-	796	-	-	796	27.7	34.78
19.5-20.0	-	-	265	-	-	265	9.2	34.67
20.0-20.5	-	-	88	-	-	88	2.9	33.00
TSN(1000)	837	14184	21454	7290	443	44209	-	-
TSB(1000 kg)	10.4	236.9	489.6	170.5	10.5	-	917.9	-
Mean length (cm)	14.55	15.53	17.02	17.04	17.30	-	-	-
Mean weight (g)	12.42	16.70	22.82	23.38	23.60	-	-	20.76

Table A4_6. Biomass estimate output table for stratum 6.

Variable: Abundance
EstLayer: 1
Stratum: s6

LenGrp	age 2	3	4	5	6	Number (1E3)	Biomass (1E3kg)	Mean W (g)
12.5-13.0	-	-	-	-	-	-	-	-
13.0-13.5	-	-	-	-	-	-	-	-
13.5-14.0	-	1694	-	-	-	1694	18.2	10.75
14.0-14.5	-	3355	839	-	-	4194	49.9	11.90
14.5-15.0	-	15411	2890	-	-	18301	228.8	12.50
15.0-15.5	-	36437	8654	911	-	46001	637.2	13.85
15.5-16.0	1288	18029	10302	859	-	30478	472.6	15.51
16.0-16.5	-	17819	17819	482	-	36120	635.7	17.60
16.5-17.0	-	12457	15810	4791	-	33058	662.6	20.04
17.0-17.5	-	10116	23267	4047	-	37430	858.9	22.95
17.5-18.0	-	1815	7716	5446	1362	16339	405.3	24.81
18.0-18.5	467	2803	17753	1869	467	23359	656.4	28.10
18.5-19.0	-	1686	1686	1686	-	5058	157.6	31.17
19.0-19.5	-	-	847	1271	-	2118	66.9	31.60
TSN(1000)	1755	121623	107583	21360	1829	254150	-	-
TSB(1000 kg)	31.9	1974.9	2279.6	516.5	47.1	-	4850.1	-
Mean length (cm)	16.17	15.58	16.61	17.17	17.63	-	-	-
Mean weight (g)	18.19	16.24	21.19	24.18	25.77	-	-	19.08

Table A4_7. Biomass estimate output table for stratum 7.

Variable: Abundance
EstLayer: 1
Stratum: s7

LenGrp	age 3	Number (1E3)	Biomass (1E3kg)	Mean W (g)
12.5-13.0	-	-	-	-
13.0-13.5	-	-	-	-
13.5-14.0	-	-	-	-
14.0-14.5	-	-	-	-
14.5-15.0	9167	9167	119.2	13.00
15.0-15.5	-	-	-	-
15.5-16.0	9167	9167	165.0	18.00
16.0-16.5	9167	9167	146.7	16.00
16.5-17.0	9167	9167	183.3	20.00
17.0-17.5	-	-	-	-
17.5-18.0	-	-	-	-
18.0-18.5	-	-	-	-
18.5-19.0	-	-	-	-
19.0-19.5	-	-	-	-
TSN(1000)	36669	36669	-	-
TSB(1000 kg)	614.2	-	614.2	-
Mean length (cm)	15.63	-	-	-
Mean weight (g)	16.75	-	-	16.75

Appendix 5. Information about capelin distribution and biology

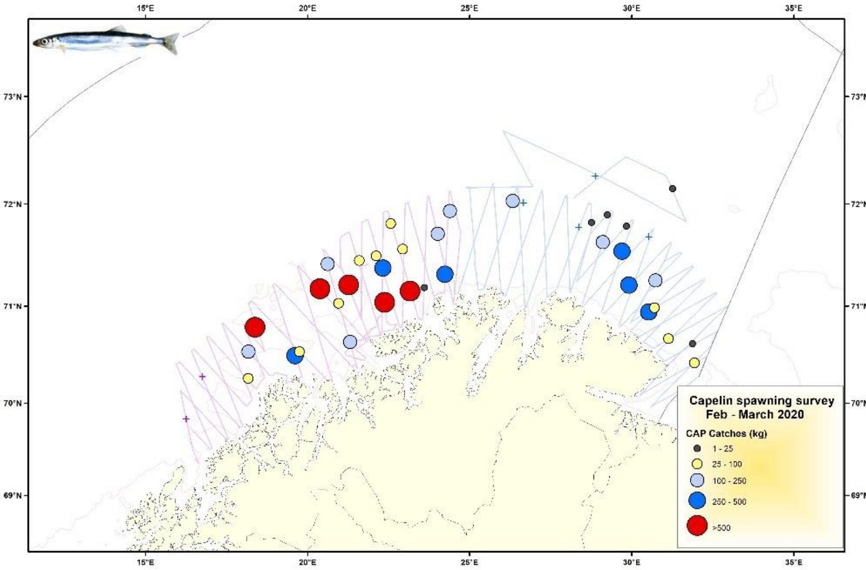


Fig. A5_1. Distribution of capelin samples by catch size. Note that all hauls are target hauls and the trawl was rigged with a split limiting catch size.

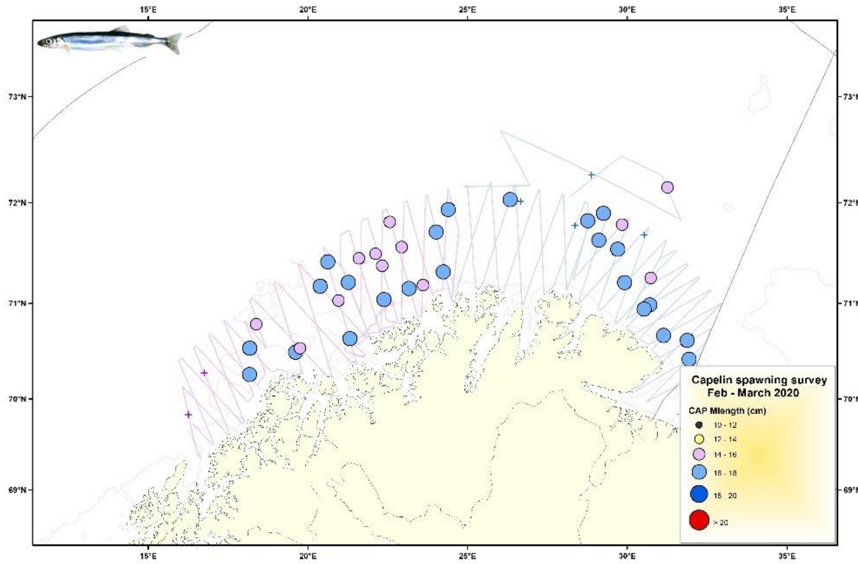


Fig. A5_2. Distribution of capelin mean lengths by station.

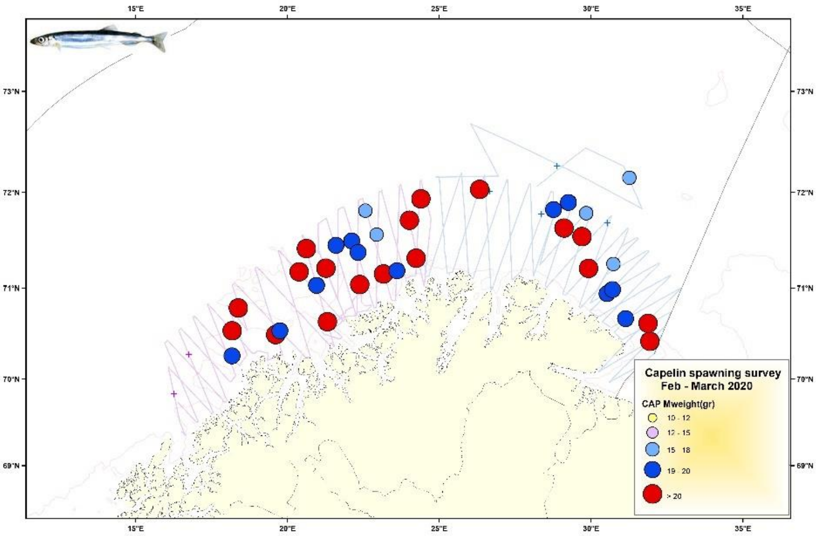


Fig. A5_3. Distribution of capelin mean weights by station.

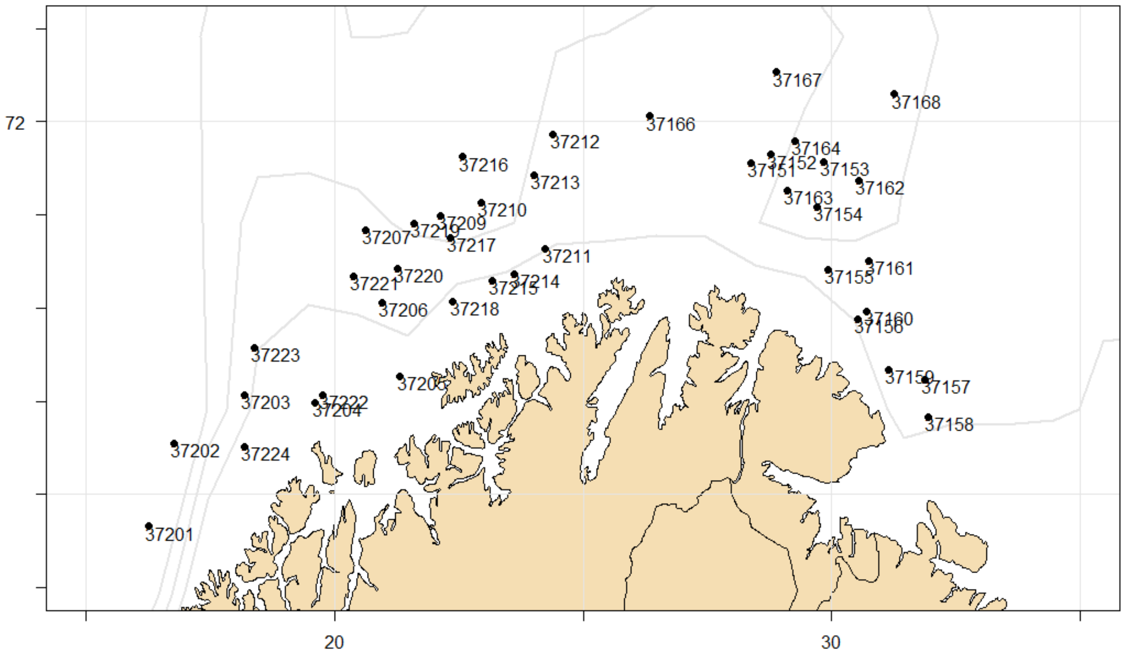


Fig. A5_4. Pelagic trawl stations with associated serial numbers.

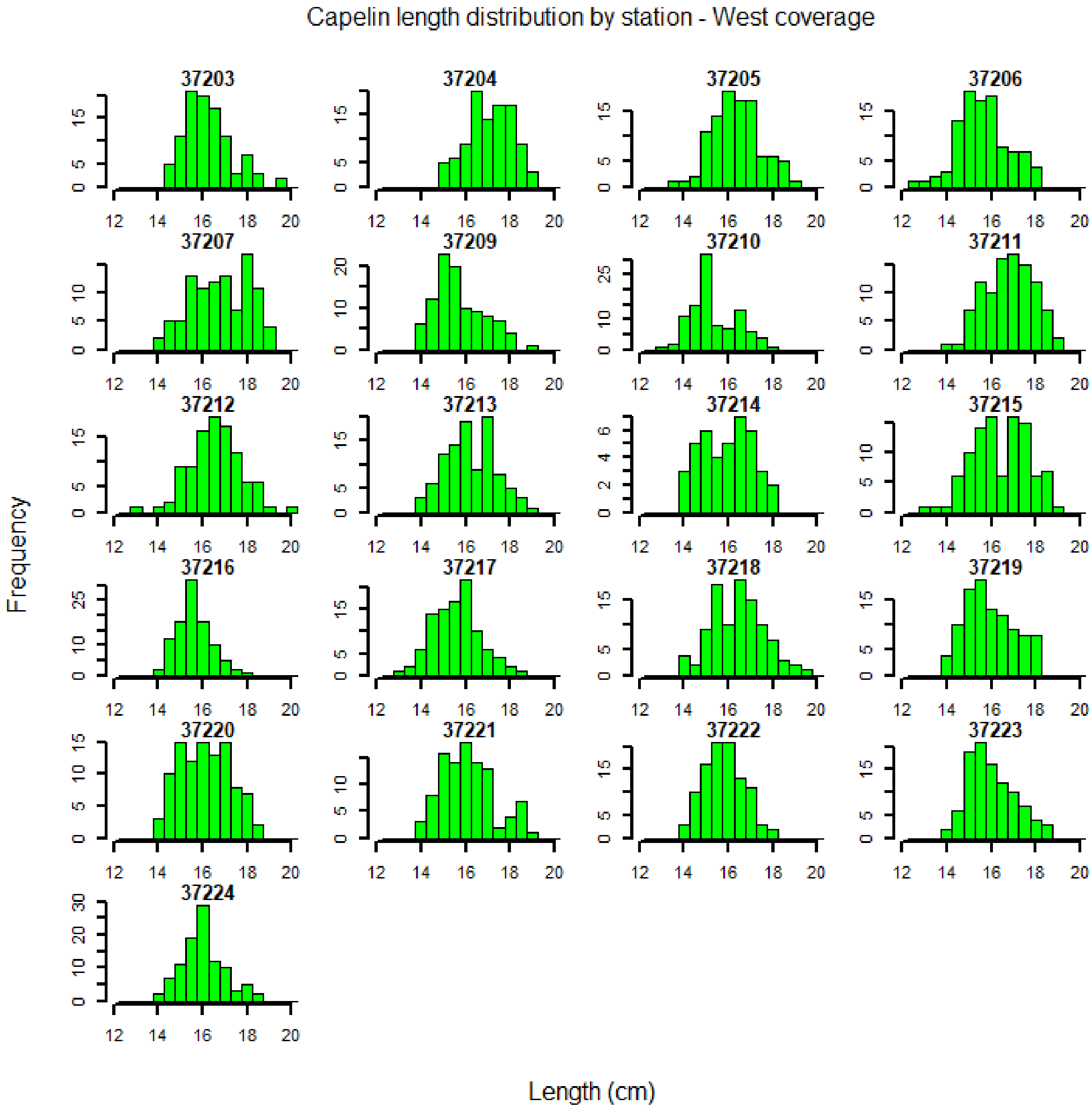


Fig. A5_5. Capelin length distribution by station; station serial number is given at the top of each panel (see fig. A5_4 for geographical position of the stations).

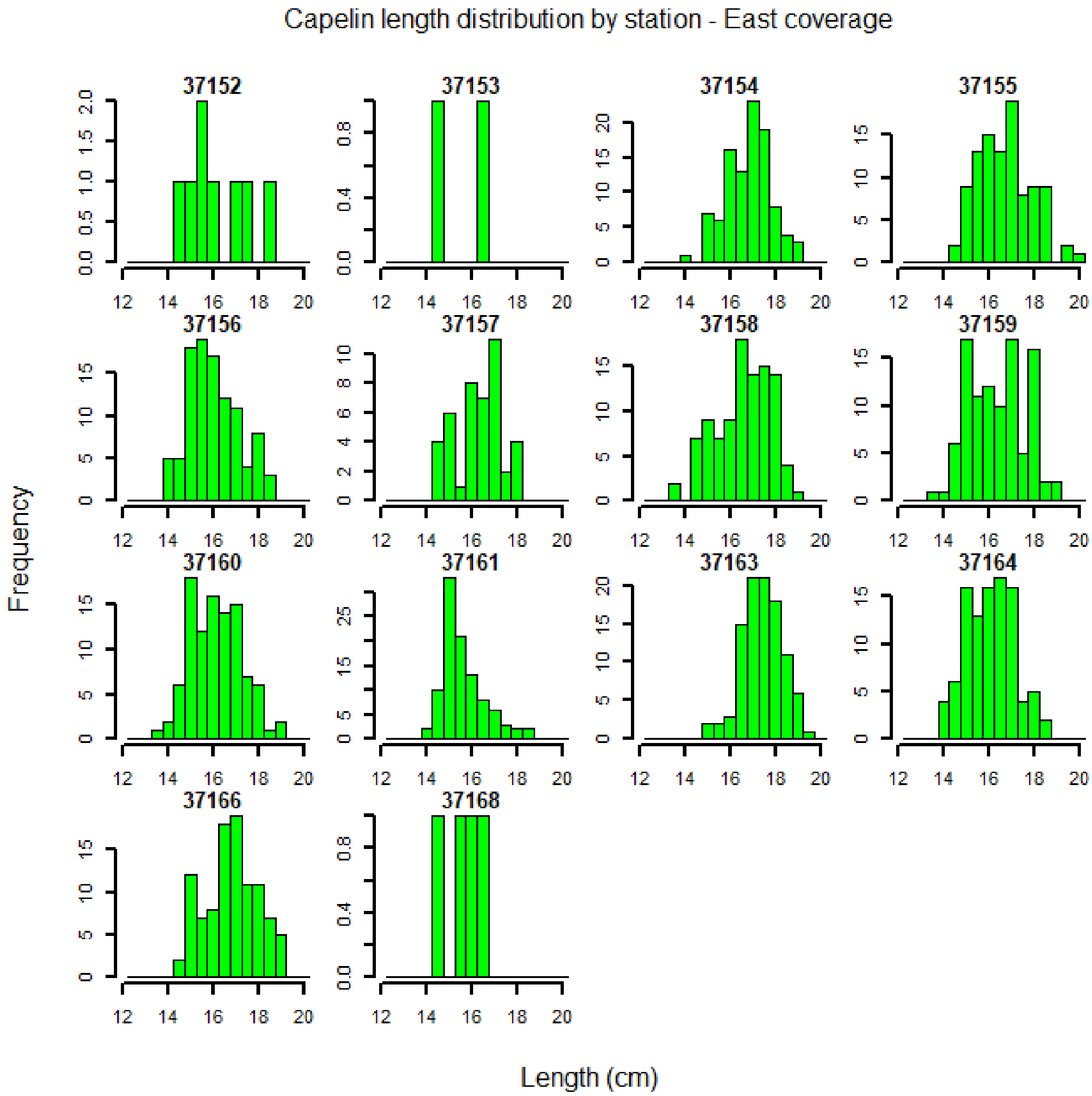


Fig. A5_6. Capelin length distribution by station for the east survey coverage; station number is given at the top of each panel (see fig. A5_4 for geographical position of the stations).

Appendix 6. Information about herring distribution and biology

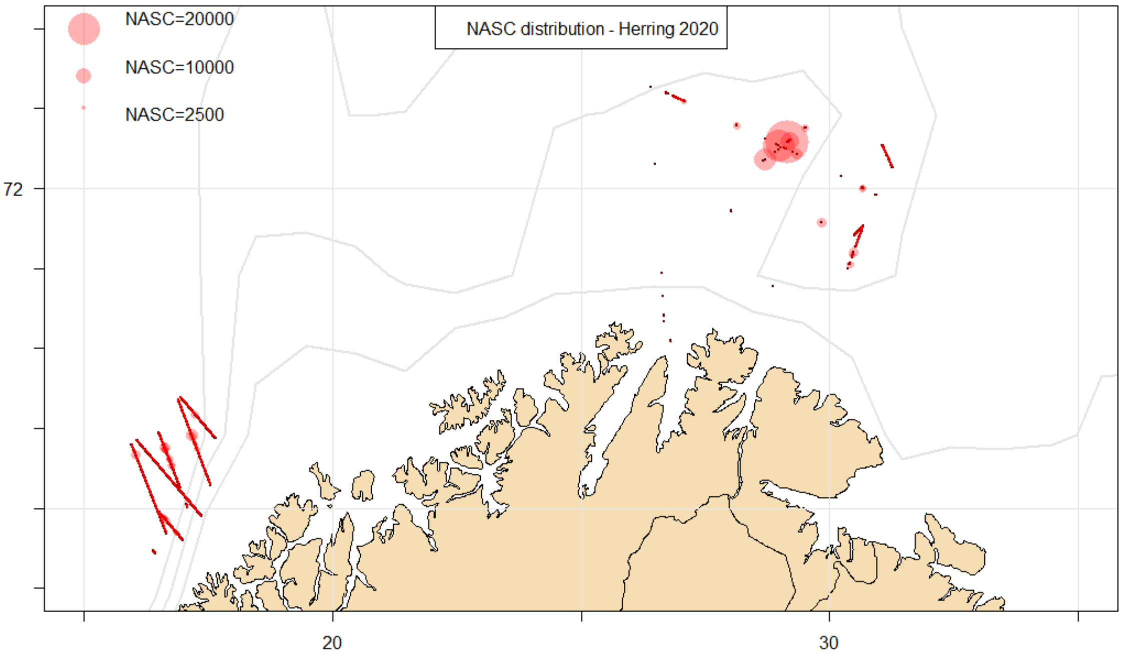


Fig. A6_1. Distribution of NASC (m^2nmi^{-2}) allocated to herring. The size of the circle corresponds to NASC-value per 0.1 nautical mile.

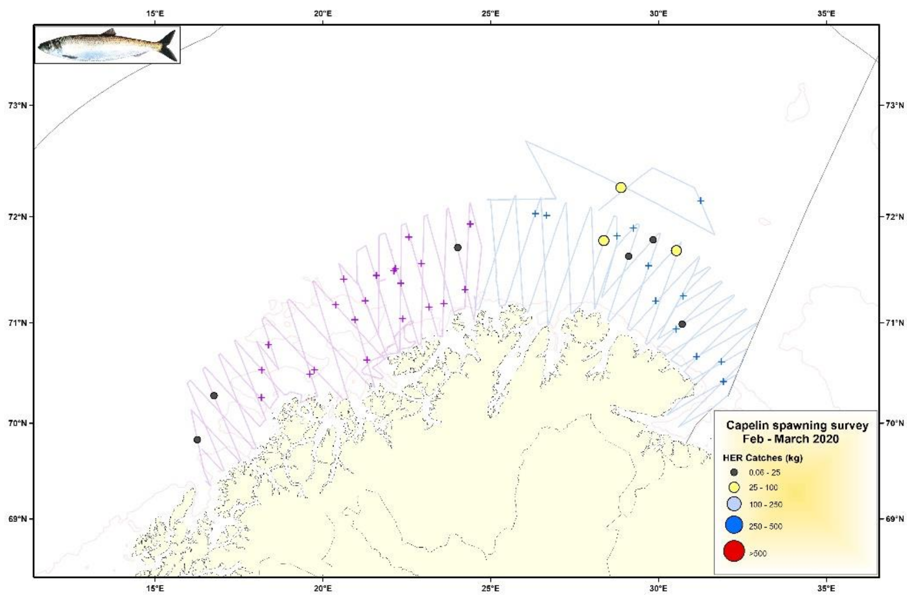


Fig. A6_2. Distribution of herring samples by catch size. Note that all hauls are target hauls and the trawl was rigged with a split limiting catch size.

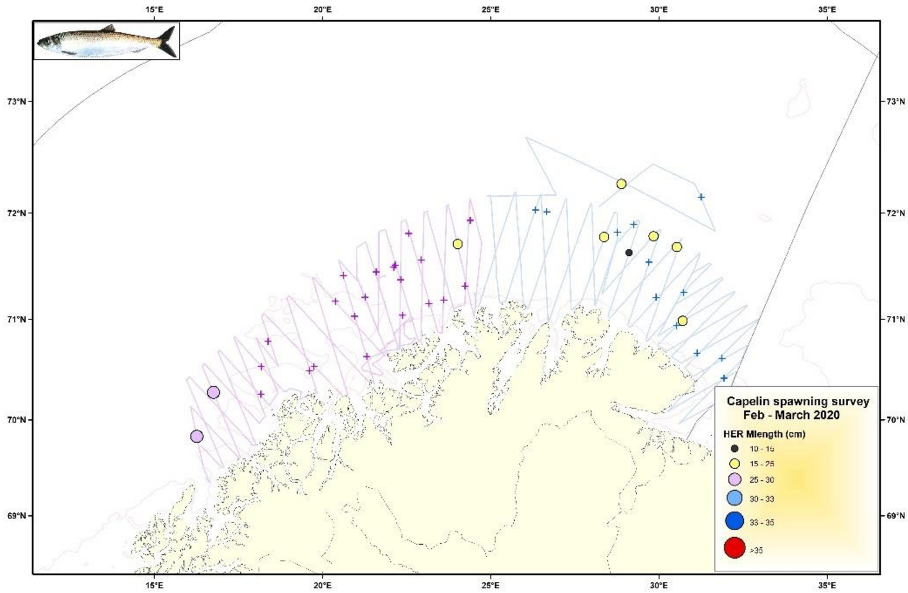


Fig. A6_3. Distribution of herring mean lengths by station.

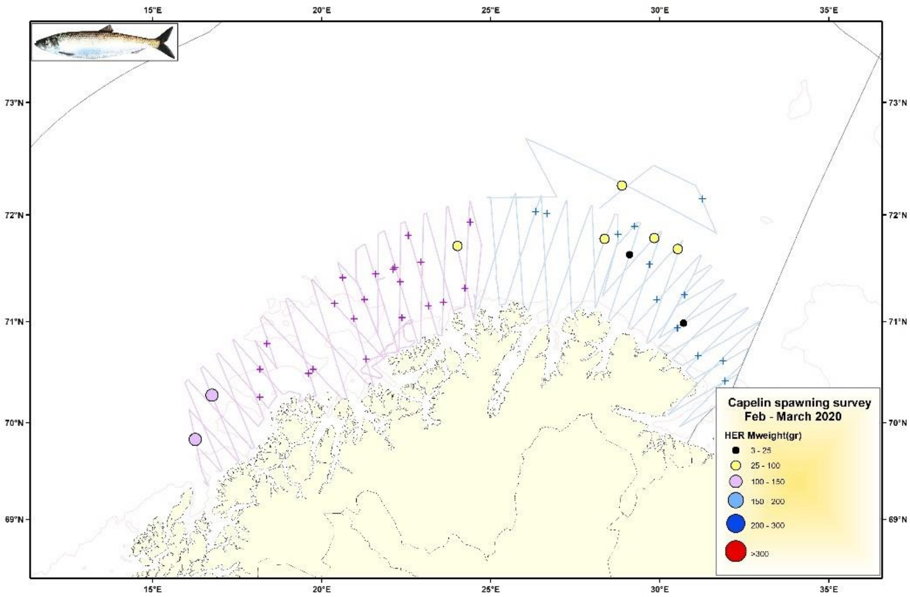


Fig. A6_4. Distribution of herring mean weights by station.

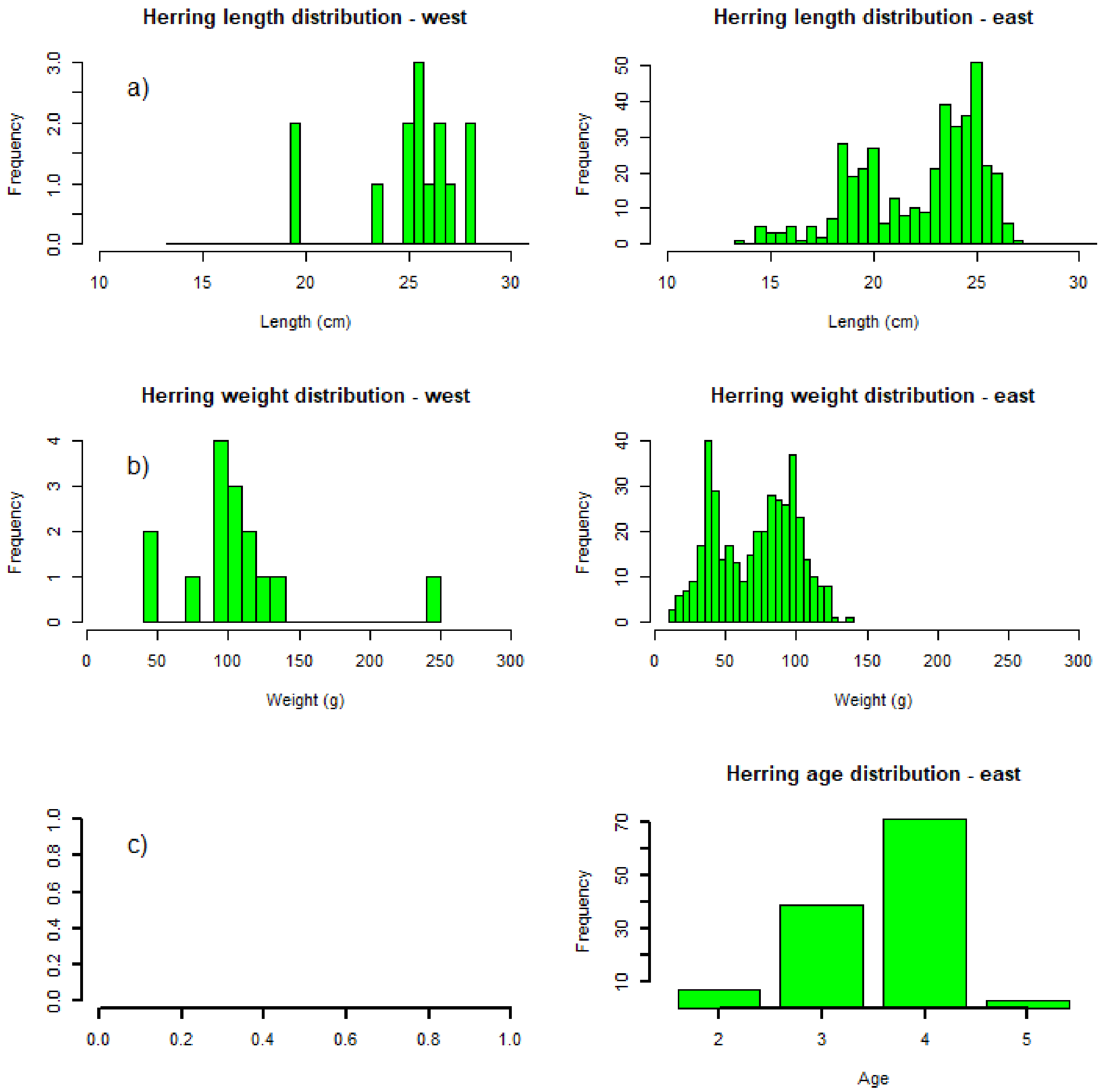


Fig. A6_5. Herring a) length distribution b) weight distribution, and c) age distribution in the western (left column of panels) and eastern (right column of panels) coverage areas.

Appendix 7. Substrate types

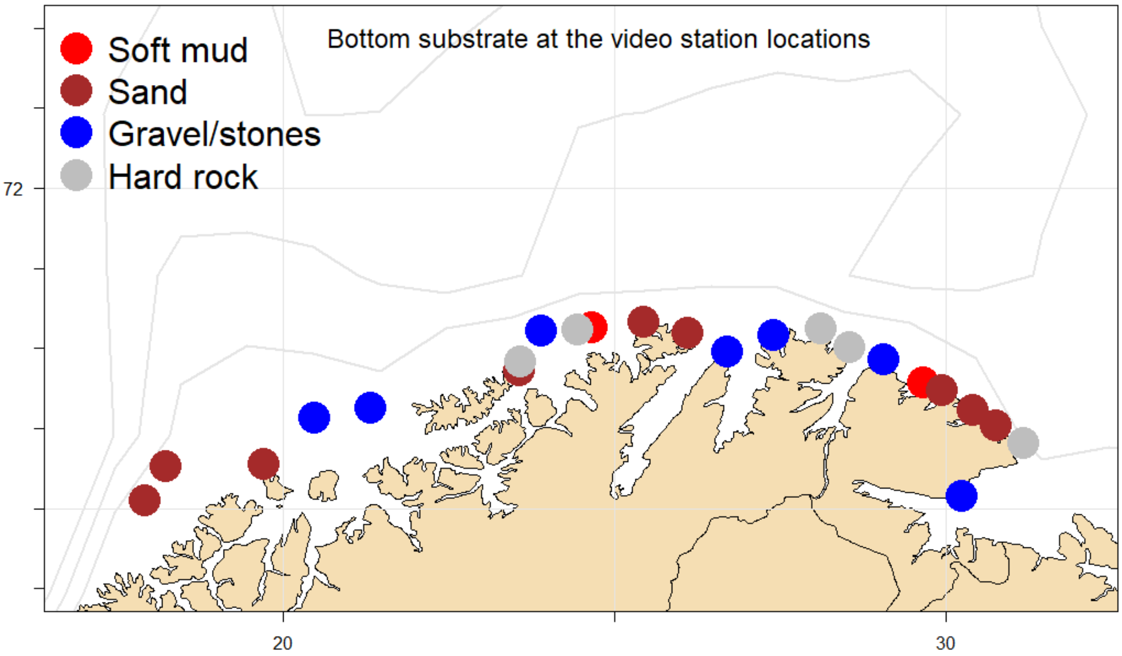


Fig. A7_1. Substrate types at the video station locations. Note that sand and stones/gravel in some instances occurred on the same spot, and they are then categorized to the dominating type.

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