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Survey report

FV *Vendla* and FV *Eros* 26.02-12.03.2021

Testing of trawl-acoustic stock estimation of spawning capelin 2021

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Content

Summary

This report describes the third in a series of 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. Echo sounders with frequencies from 18-333 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 88 539 tons, with a CV of 52%. The 5% lower and 95% upper confidence limits were 29 962 and 178 839 tons, respectively. The confidence bands overlap with the prediction from the autumn 2020, 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 like it was in this survey last year and which is common at low abundances. Capelin aggregations recorded north-east of Sørøya totally dominated in the estimate, these concentrations seemed stable from the first (eastward) to the second (westward) coverage. Very little capelin was recorded in the east. Mean length of the capelin was 15.9 cm, mean weight 18.8 g, and maturation had progressed further in the western than the eastern area which was the opposite of what was observed last year. Abnormal frequency response with increasing backscatter with increasing frequency was observed for many schools during the survey this year, and TS measurements on a capelin school revealed a lower TS than assumed. This potentially has significant effect on the biomass estimates and must be investigated further. A thorough evaluation of this survey series and its usefulness as input to the capelin advice will be prepared for the capelin benchmark next year (2022). We aim to add a fourth survey to the series in 2022 prior to the benchmark.

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, but also along the Russian coast. If there is opening for a fishery, it takes place on maturing 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 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 and second were carried out in 2019 and 2020. The third in the series is described in the current report.

Objectives

The main objective of this survey 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 12 March, respectively.

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 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, and was followed up in 2020 (see survey reports for details, for 2019 available at https://www.hi.no/resources/Toktrapport-loddetokt-mars-2019.pdf and for 2020 available at https://www.hi.no/hi/publikasjoner/toktrapporter/2020/testing-of-trawl-acoustic-stock-estimation-of-spawning-capelin-2020-nr.-2-2020). 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 and 2020, 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. Like in 2020, 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.

No scouting vessel was used like in 2019 and 2020. But information on recent capelin distribution was available prior to the survey, including information from fish plants reporting the presence of capelin in cod stomachs (See Appendix 1 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 the NSS herring spawning survey which finished off Tromsø on February 25. The available information did not point to specific areas where effort should be increased, so we allocated equal effort to each stratum.

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.

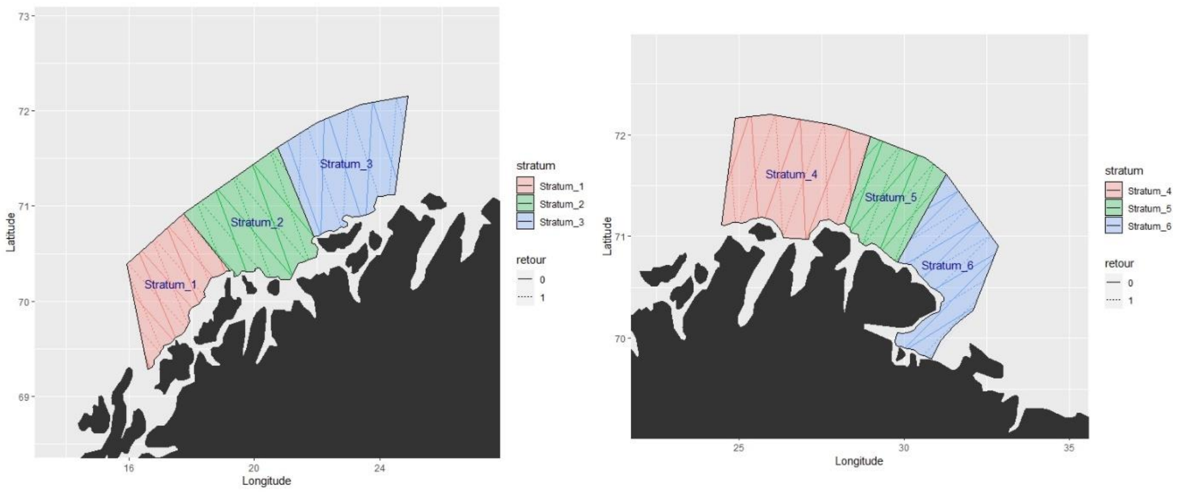

Fig. 1. Survey coverage for *Vendla* (west) and *Eros* (east) with 6 strata, zig-zag transects and equal coverage in each stratum.

Acoustic data collection and processing

Echo sounder

Acoustic data from calibrated Simrad EK80 echo sounders were collected at frequencies of 18, 38, 70, 120, 200 and 333 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^2nmi^{-2}). This output was used for the biomass estimation (see section below).

Sonar

Low frequency omni directional fisheries sonar (i.e. 14-24 kHz) are used by fishermen for long distance search of commercial fish aggregations. During surveying, the large sampling volume of the sonar can provide valuable information of the spatial distribution of fish schools. In particular this can be important if the schools have a patchy distribution and are low in abundance. The sonar can also provide valuable information about potential vessel avoidance or schools distributed shallowly in the echo sounder dead-zone.

Also, when schools are tracked at low vessel speed or for a long period, the direction and speed of the schools can be estimated, information that is particularly important for the capelin during the spawning migration towards the coast.

Sonar data from Simrad ST90 at a frequency of 20 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.

The ST90 sonars of Vendla and Eros were calibrated prior the start of the survey following the methodology proposed by Macaulay et al. (2016).

As in previous years, the methodology for the sonar data collection was the following: when a school was observed along the cruise line in the sonar and echo sounder, a trawl was performed to verify that it was capelin and for biological sampling. When schools were observed with the sonar outside of the track line, the vessel abandoned the transect once the school have been left to port or starboard side, and a detailed inspection with sonar and echo sounder was made. After the trawl for identification was completed, the survey was resumed in the point the transect line was left.

Biological sampling

Harstad trawls were applied on both vessels and rigged according to standard protocol (fig. A2_1 left, appendix 2). However, some changes were made since non-standard ET 15 m² 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. A2_1 right, appendix 2) which gave a lower trawl height compared to rigging with standard doors. Also, a split in the codend was made to protect the trawl and avoid large catches.

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 an RBR concerto[3] sonde. CTD-casts were spread over the survey area (See fig. 2).

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. The camera on board Vendla broke during first deployment due to a leakage.

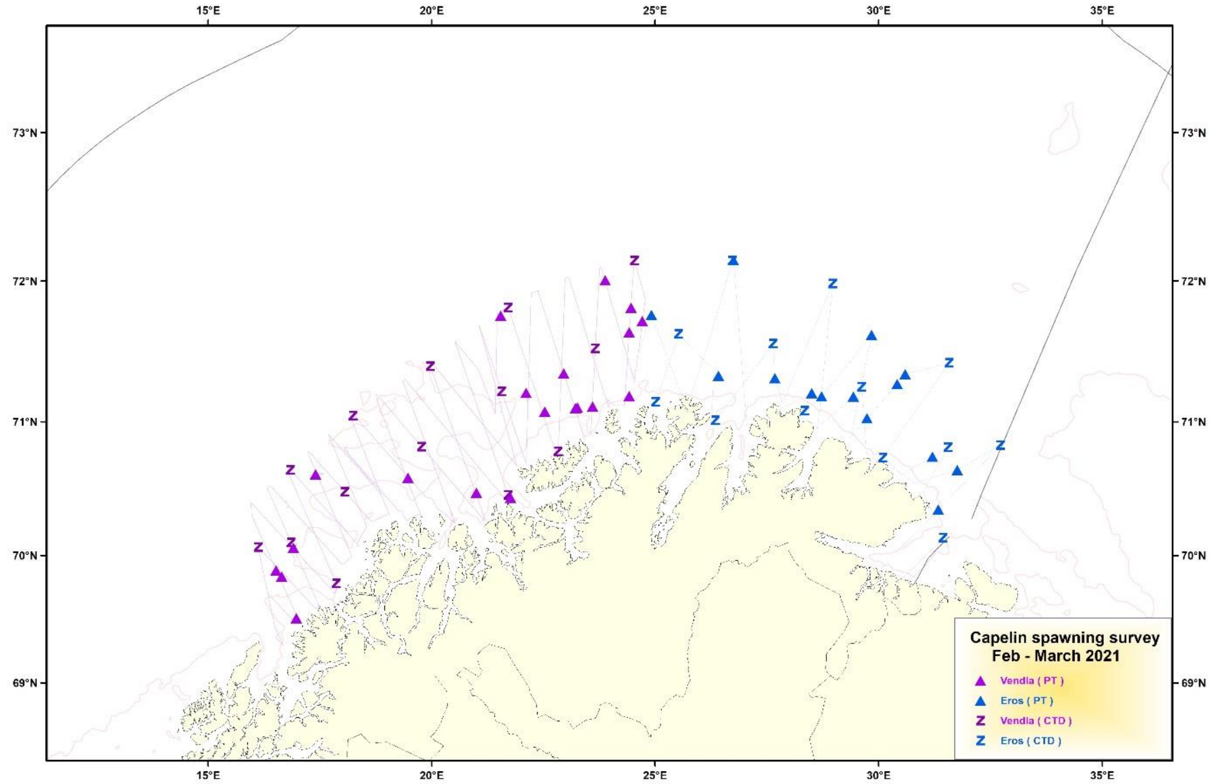

Fig. 2. Overview of cruise track and stations of Vendla (pink) and Eros (blue). PT indicates pelagic trawl, and Z indicates CTD-cast.

Biomass estimation

The Stox 3.0.0 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. The following target strength – length relationship was applied for the density (numbers/nmi^2) calculation (Dommasnes & Røttingen 1985):

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

Abundance of fish in numbers and biomass were estimated by stratum and age based on 500 bootstrapping iterations of biotic stations and acoustic transects. The results are reported in tables 1 to 4.

Results

Capelin biomass estimate

An overview of all transects and stations included in the biomass estimation is shown in fig. 3. The total biomass of mature capelin within the coverage area was estimated in to 88 539 tons (Tab. 1), with a relative sampling error or Coefficient of Variation (CV) of 52% (Tab. 1). 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 29962 and 178839 tons, respectively. Estimates of abundance and biomass by age with associated CV are provided in tabs. 2 and 3, respectively. Fish of age 3 was dominant. Mean length and weight by age are given in tab. 4. The confidence interval of the estimate is overlapping with the lower range of the confidence interval of the prediction from the 2020 autumn survey. However, the sampling error is large, in particular given the high sampling effort. The biomass estimate is completely driven by the biomass in stratum 3 and CV in this stratum was 0.55 (tab. 1). The results indicate a very patchy distribution of the capelin which can also be seen in fig. 4. Mean average biomass was higher when moving westward (return) than eastward, but the 90% confidence intervals between the two coverages are highly overlapping.

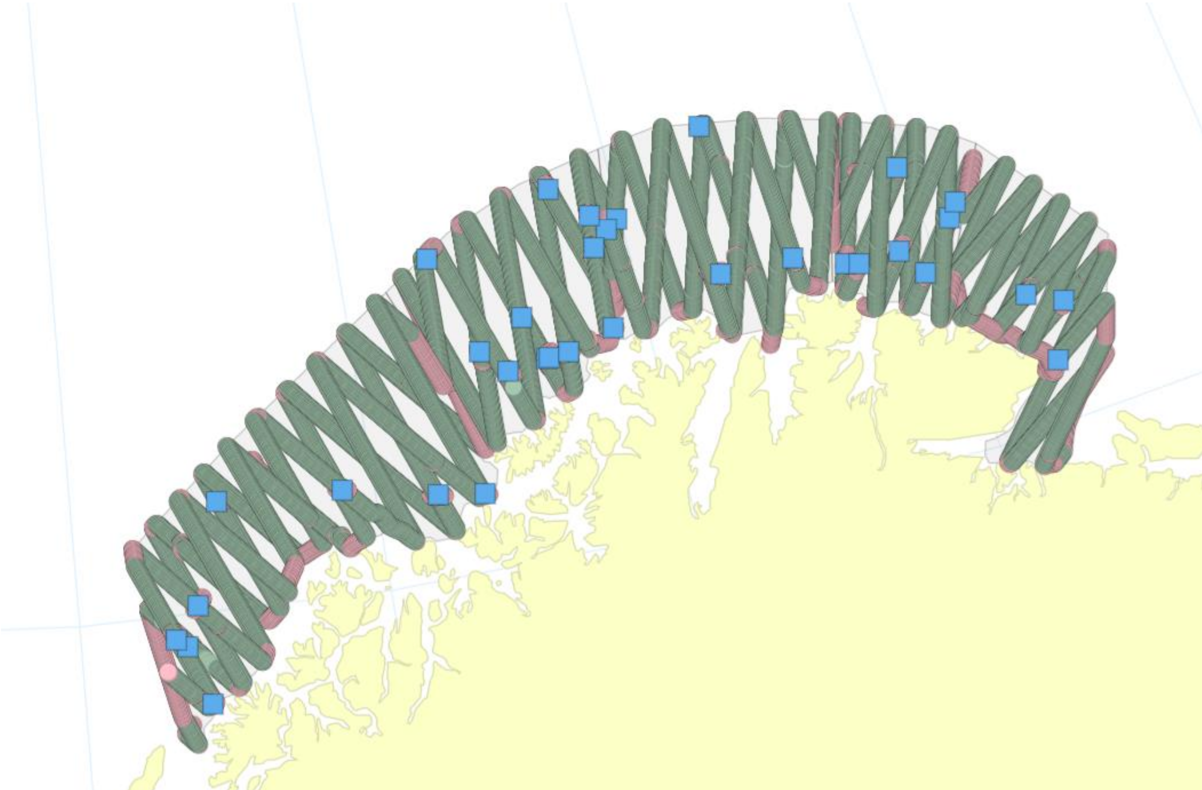

Fig. 3. Overview of transects (green: included in the biomass estimation, pink: not included in the biomass estimation). Blue dots mark trawl stations. The gray shaded areas mark the strata (1-6).

Table 1. Biomass estimation (BM, tons) output in tons by strata, area and westward/eastward coverage.

Stratum	Total (5-95% CI)		CV	Eastward (5-95% CI)		CV	Westward (5-95% CI)		CV
1	3081	(804-5677)	0.50	0		0	5203	(1817-9633)	0.436
2	0		0	0		0	0		0
3	82749	(24355-171659)	0.55	26609	(1445-67510)	0.700	144647	(30349-334008)	0.615
4	1678	(113-4321)	0.84	45	(0-125)	0.895	3286	(237-8410)	0.856
5	760	(304-1239)	0.37	609	(191-1178)	0.461	900	(49-1754)	0.519
6	271	(33-624)	0.68	365	(0-1052)	0.875	172	(8-346)	0.597
Survey	88539	(29962-178839)	0.52	27589	(2538-68837)	0.676	153848	(40800-345197)	0.578

Table 2. Abundance estimates (millions of individuals) of capelin at age during the spawning survey 26 February-12 March 2021, based on 500 bootstrap replicates.

Age	5th percentile	Median	95th percentile	Mean	CV
2	19	61	173	73	0.69
3	927	2785	5497	2886	0.52
4	420	1192	2405	1236	0.51
5	83	291	823	341	0.73
6	0	10	46	14	1.07
TSN	1547	4488	8721	4553	0.51

Table 3. Biomass estimates (tons) of capelin at age during the spawning survey 26 February-12 March 2021, based on 500 bootstrap replicates.

Age	5th percentile	Median	95th percentile	Mean	CV
2	249	795	2246	960	0.68
3	16838	52075	101409	53137	0.52
4	8183	23657	47632	24430	0.51
5	2171	8097	24810	9736	0.78
6	1	184	826	259	1.07
TSB	29962	87037	178839	88539	0.52

Table 4. Estimated length and weight of individual capelin at age during the spawning survey 26 February-12 March 2021, based on 500 bootstrap replicates.

Age	Mean weight	CV weight	Mean length	CV length
2	12.99	0.05	14.5	0.010
3	18.10	0.02	15.7	0.006
4	19.20	0.03	16.0	0.008
5	25.04	0.04	17.2	0.011
6	15.32	0.17	15.3	0.013

Acoustic recordings

Echo sounder

The distribution of acoustic backscatter used in the capelin biomass estimation, both coverages from both vessels, is shown in fig. 4. Echo sounder recordings from a small stretch to the north-east of Sørøya dominated the echo sounder recordings included in the estimate (See fig. 4). 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 low capelin recordings in the eastern coverage area.

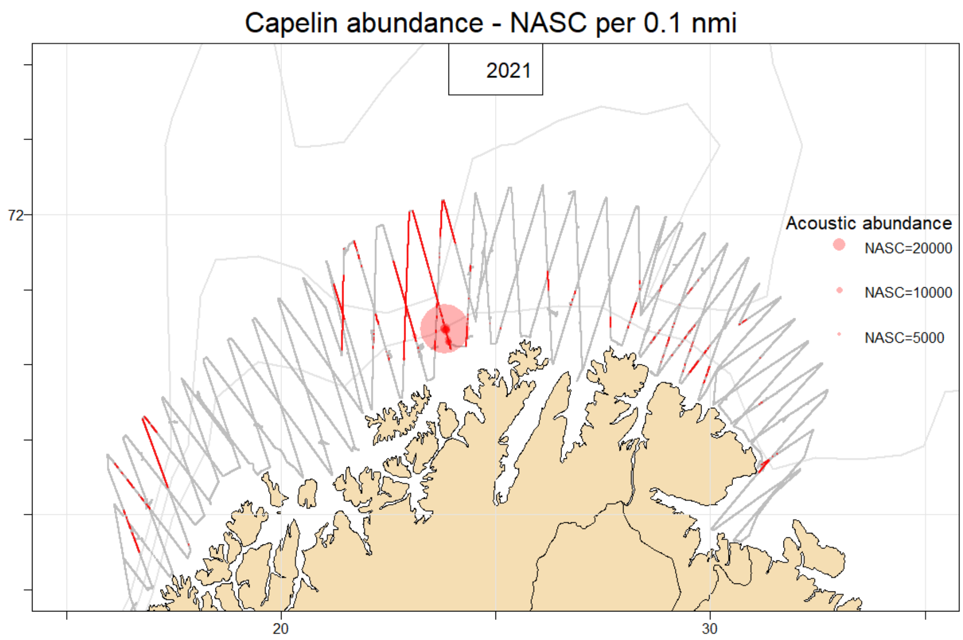

Fig. 4. Distribution of NASC (m^2nmi^{-2}) allocated to capelin and included in the biomass estimation. The size of the circle corresponds to NASC-value per 0.1 nautical mile.

Sonar recordings

The conditions for sonar observations of capelin schools were poor during the whole survey both in the west and east region. Most capelin schools were small and distributed deeper than 150 m, in addition they showed a low backscattering strength at the sonar frequency (i.e. 20 kHz) (see sections on TS and frequency response). In the eastern region, only two large schools were found, with 40 and 150 m height, respectively. The first one was only detected by the echo sounder, and the second was found when following a large number of whales close to the coastline.

No capelin schools were detected when processing the data from "Eros". The data from 'Vendla' have not been processed, and this work will not be prioritized due to the unfavourable conditions this year for sonar recordings of capelin schools.

Biology of the capelin

The mean length of capelin based on all biological samples was 15.9 cm and similar between western and eastern coverage areas (fig. 5). The length distribution supports the assumption in the stock prediction that capelin >14 cm are migrating to the coast to spawn. Mean weight was 18.8 g and also very similar between the western and eastern coverage areas. Length distributions by station are presented in Appendix 3.

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, some more in the eastern area. No capelin were found to be in stage 7 (spent).

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. 6. Roe percentage varied between 11 and 22, and most samples showed a roe percentage >16. No particular spatial or temporal trends in roe percentage were obvious (see fig. 6), but the capelin in the high concentration area in the west had percentages round 20, which corresponds with capelin getting close to spawning.

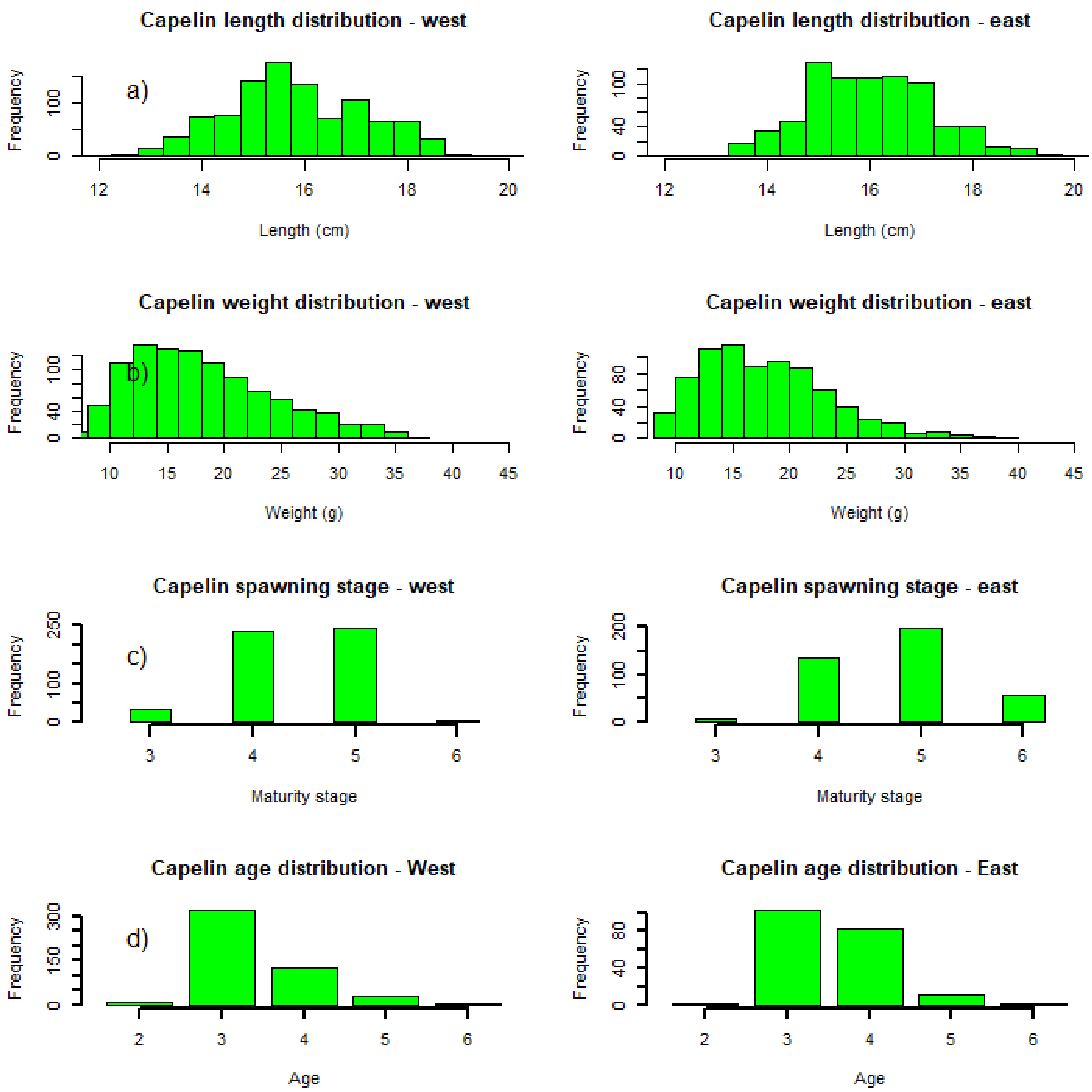

Fig. 5. Capelin a) length distribution b) weight distribution, c) spawning state and d) age distribution in the western (left column of panels) and eastern (right column of panels) coverage areas.

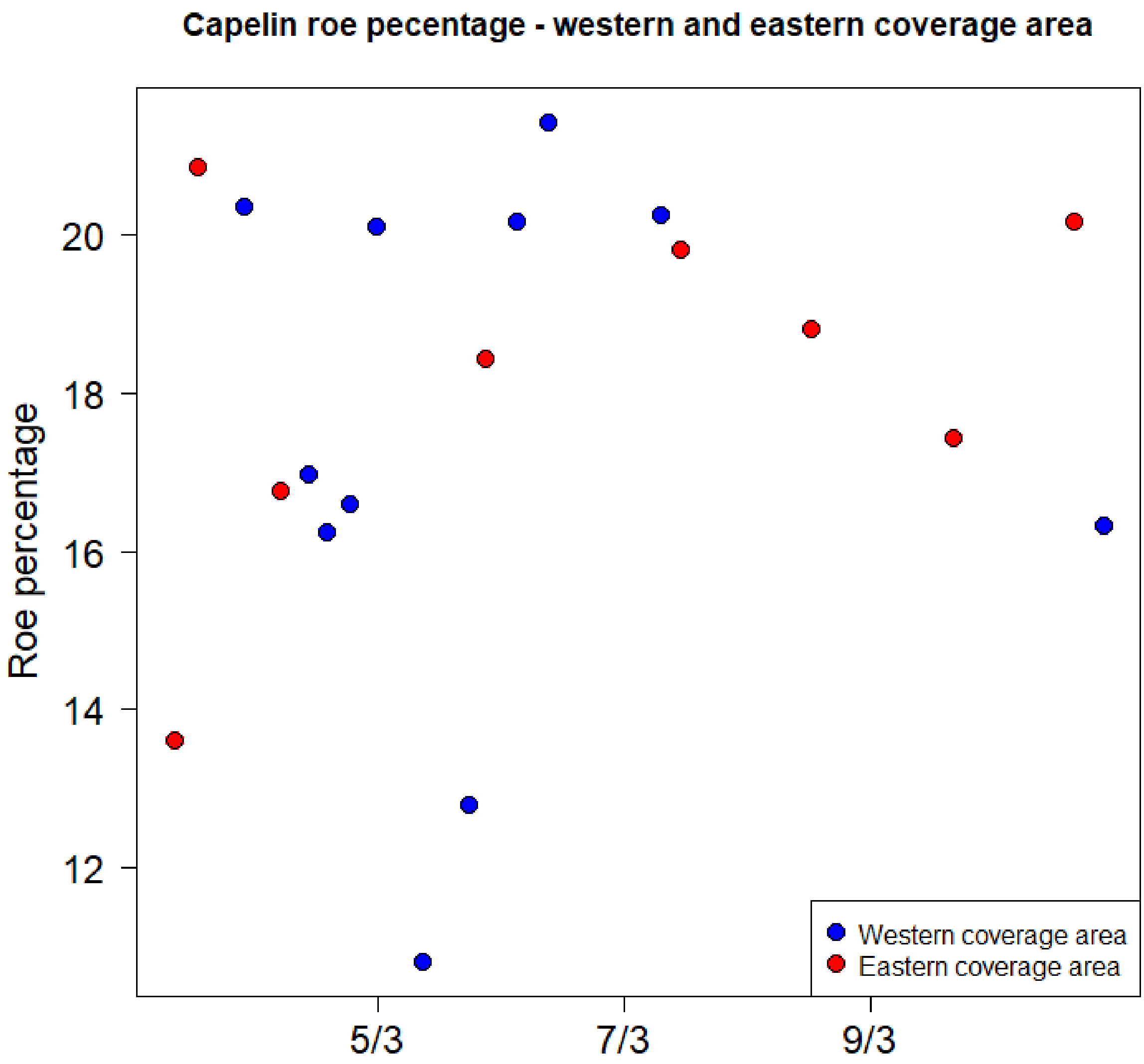

Fig. 6. Capelin roe percentage (Weight of roe in all sampled females divided by the total weight of those females) per station as a function of time. *Blue*: Stations from *Vendla* in the western coverage area, and *red*: stations from *Eros* in the eastern coverage area.

Norwegian spring spawning herring were present in the survey area, in particular in south-west, but also some in the eastern area. The herring sampled were dominated by the 2016-yearclass. More detailed information on herring distribution and biology are found in appendix 4.

Environmental data

The temperatures in the study area at different depths are shown in fig. 7. 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.

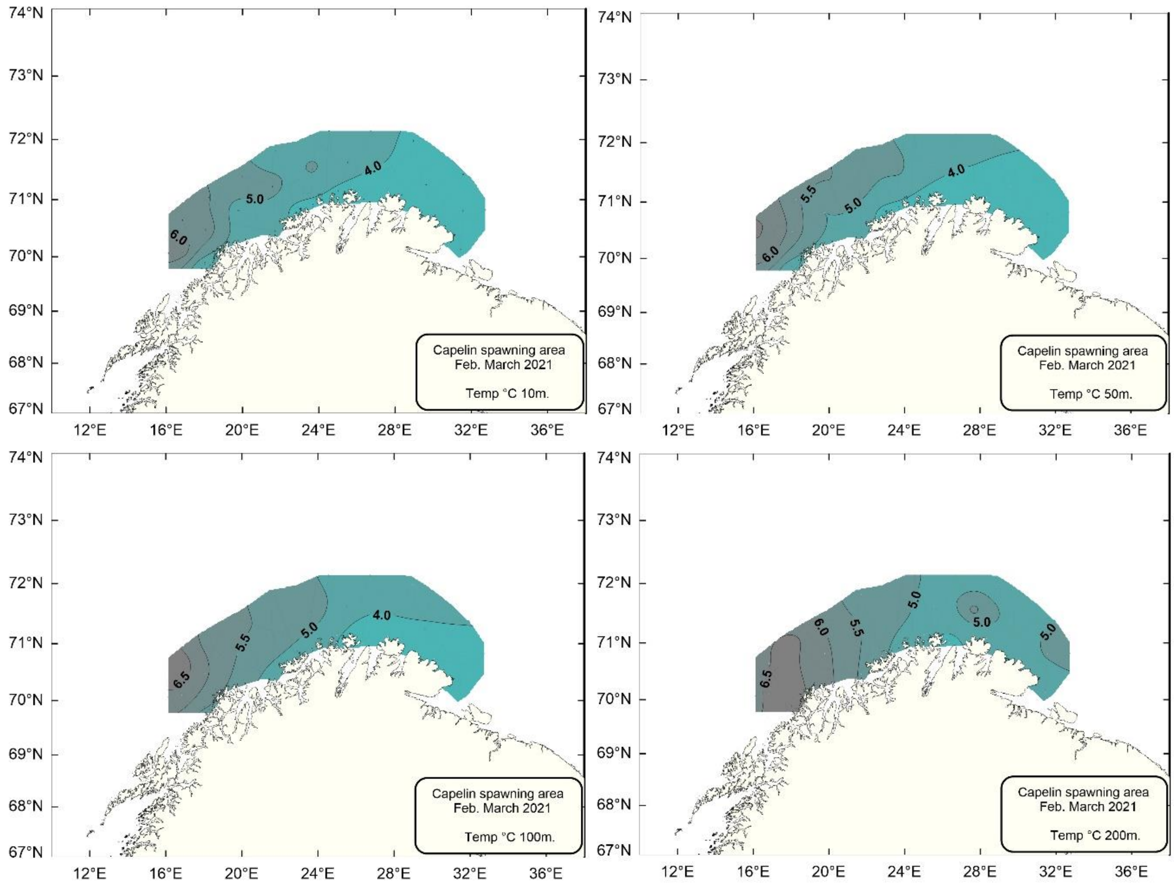

Fig. 7. Temperatures at 10 m (upper left), 50 m (upper right), 100 m (lower left) and 200 m (lower right).

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 or spawning capelin was observed in any of the stations.

Part B. Methodological investigations

Acoustic target strength investigations

TS measurements – Background

Fish target strength (TS) is a key parameter for abundance and 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 conversion is normally done through a target strength-length relationship which for Barents Sea capelin is defined as TS= 19.1 log(L)-74 at 38 kHz. This relationship is derived from ex-situ measurements of maximum TS of capelin and other species (Dalen et al., 1976) and theoretical corrections to convert it into a mean TS relation (Dommasnes and Røttingen, 1984). Therefore, in situ target strength measurements that reflects the acoustic backscattering of free-swimming capelin is needed, in particular from new survey situations like the spawning survey represents.

Measurements of single fish is required for deriving reliable estimates of TS. That is a challenge in schooling species like capelin, 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 measurements of single individuals. In the 2021 capelin spawning survey we used submersible independent transducers for TS measurements.

Data collection

Based in the experienced gained in the 2020 survey, a new system was used for collecting TS measurements from capelin. In order to detect single fish inside a capelin school it is required to have: high ping rate, a narrow beam and broad band transmission mode. The system used on board “Vendla” and “Eros” was an Simrad ES38D 7 deg opening transducer, operating at 38 kHz connected via 20 m transducer cable with a Simrad wide band transceiver (WBT). The transducer was mounted in a frame on board ‘Vendla’ (see Fig. 8) and a gimble frame on board ‘Eros’ to improve a vertical beam ensonification and lowered with a cable down to desired depth. The frame was submerged as close as possible to the capelin school, which had been detected with the vessel echo sounder. To avoid interference all transducers in the vessel echo sounder were turned into passive mode, only leaving the 200 kHz active. Once the frame reached the desired depth, the vessel was slowly maneuvered aiming to stay on top and in the borders of the school during the measurements. The vessel positioning was facilitated by the combined use of the sonar and vessel mounted echo sounder.

Fig. 8. Echo sounder mounted in a frame on board 'Vendla'.

Prior to departure the echo sounders were calibrated using the following settings: i) CW mode, 38 kHz frequency, 200 W power, 0.512 ms pulse duration and ii) FM mode, 34 to 42 kHz broad band, 1.024 ms pulse duration and 200 W power.

During deployment, data were collected with single band (CW) and broad band (FM), after which a pelagic trawl was carried out for biological sampling of the capelin.

After the deployment data were examined in EK80 software, and detailed analysis of single targets was done using post processing system LSSS and ad-hoc R codes. Single target data were filtered by range, cut-off angle and large non target species.

Results

One deployment was carried out on 'Eros' and two on 'Vendla' during the survey. "Vendla" had two deployments on March 6. One deployment at night-time 10 nmi north of Havøysund on schools displayed in Fig. 9. These were small, quite loose schools at 50-100 m depth. The second deployment was during daytime on aggregations shown in Fig. 17 in the frequency response section. These schools were more densely packed. In none of the deployments the transducer could come close enough to resolve single targets given the limited cable length.

The deployment onboard "Eros" was done on March 10, 15 nmi northeast of Magerøya. A large capelin school was found close to a group of whales away from the survey track. The school was dense and with a vertical extension of 20 to 150 m depth when first detected (Fig. 10). Due to the shallow distribution depth of the school, the transducer could be located at 2 to 3 m distance from the top of the school, allowing a narrow beam opening of ca. 1 m. The ping repetition rate was 5 pings per second. Under these conditions, single targets were possible to isolate using the setting parameters shown in Fig. 11. The main change to the default settings of the single target detection, for both CW and FM data, was the reduction in the "Minimum echo length", from a default of 0.8 to 0.3.

Echograms of data used for single target detections, are shown for CW in top panel and FM in bottom panel of Fig. 12, with single targets indicated as black dots.

To ensure that the best data were used for the target strength estimation, both data sets (CW and FM) exported from LSSS were filtered by the following criteria:

1. Minimum range was adopted to 4 m, i.e. about 2 times the transducer near field
2. Maximum range 13 m, after which TS values become unrealistic
3. Cut-off angle was 2 deg, after which targets are not distributed as expected inside the beam

The resulting distribution of TS values differed somewhat between CW and FM mode with a mean value of -70 dB from the broadband data and -68 dB from the CW data (Fig. 13). These values are much lower than expected from capelin.

Discussion

The use of a deployable 7 deg 38 kHz transducer connected to a frame which could be submerged using a cable allowed for collection of target strength data from single individuals when the targets were close to the surface. When distributed deeper, the length of the cable limited close range measurements. "Eros" successfully measured TS at close range of a capelin school distributed at shallow depths. The distance between the fish and the transducer was down to 3 m, allowing a narrow beam opening, fast ping rate and broadband transmission favoring the detection of single targets. The only unfavorable condition in that case was the high density of the fish inside of the school. Despite this, single targets were detected, and a detailed analysis was performed. The results showed TS values much lower than expected, both from the narrow and broadband data, with values of -68 and -70 dB, respectively. These values are about 18 dB lower than expected when using the standard TS length relation (TS=19.1 log(L)-74), which corresponds to a TS of -51 dB assuming a fish mean length of 16.4 cm (based on trawl samples).

It is proposed that the lower TS we observed correspond to capelin that had released gas from the swimbladder, perhaps as a strategy to keep control of the buoyancy while escaping from predators. Without the gas, the fish backscatter is dominated by the flesh and bone structures, and is dramatically reduced at lower frequencies, in particular at 18 and 38 kHz, and relatively stronger at higher frequencies (i.e. 200 kHz). The same backscattering pattern is observed and well documented in the Atlantic mackerel, which does not have a swimbladder.

A discussion about the implications of this fish behavior in the abundance estimation is made in the capelin frequency response section of this cruise report.

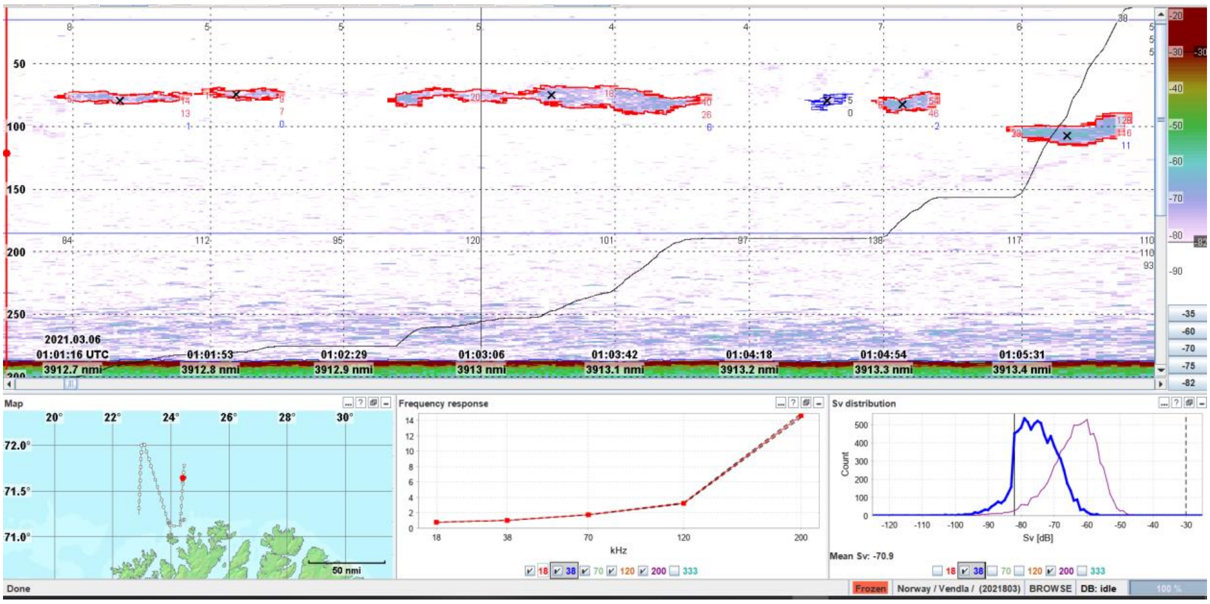

Fig. 9. Echogram of broad band (FM) data collected with the hull mounted 38 kHz transducer onboard "Vendla" on March 6. Top panel showing the echogram with the capelin schools between 50 and 100 m.

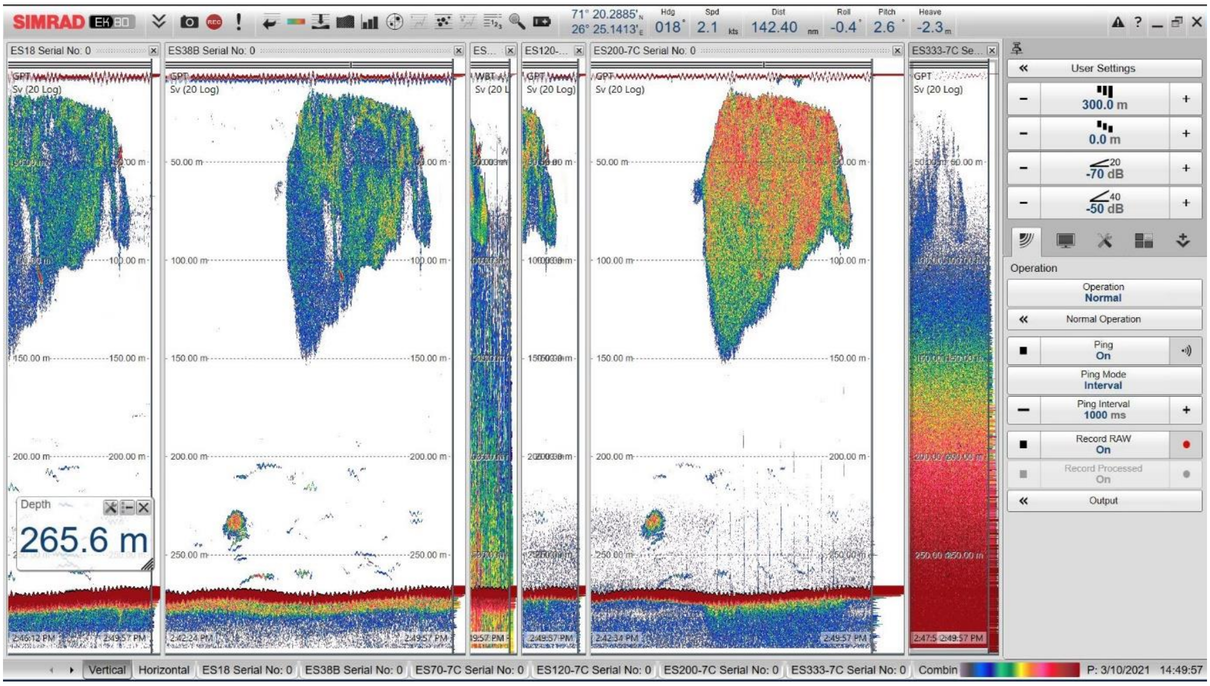

Fig. 10. Screen dump from the EK80 software showing the capelin school used for measuring TS onboard "Eros" on March 10. The school was measured by the multifrequency echo sounder, and the stronger backscattering at 200 kHz than 38 kHz is obvious.

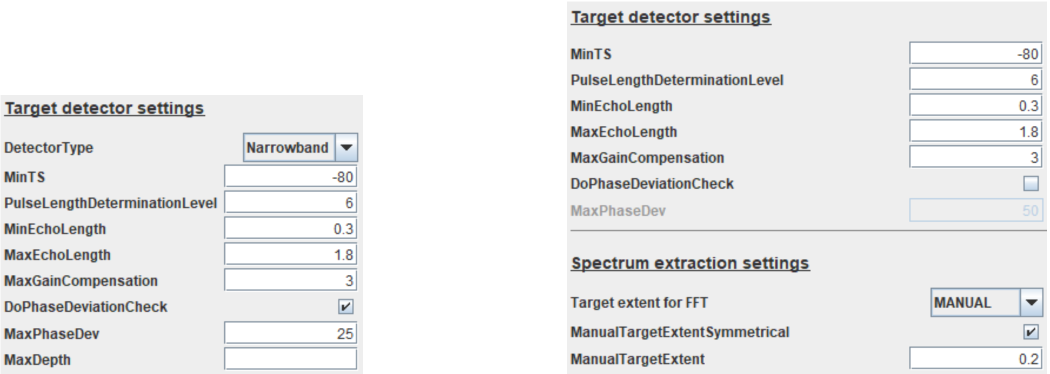

Fig. 11. Target detection settings in LSSS software used for narrow band (left) and broadband (right).

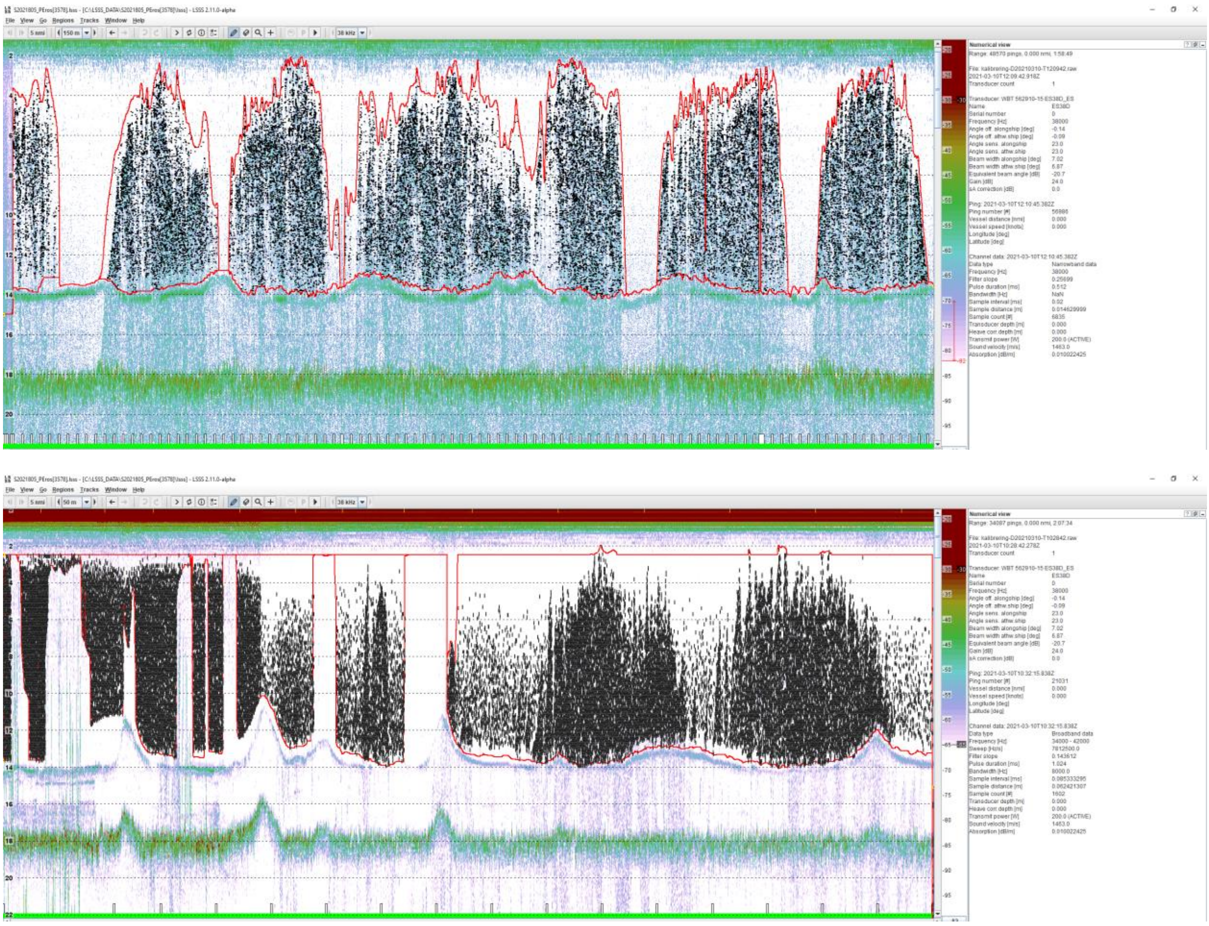

Fig. 12. Echograms of data sets from narrow (top) and broadband (bottom). Regions with noise and large targets were excluded.

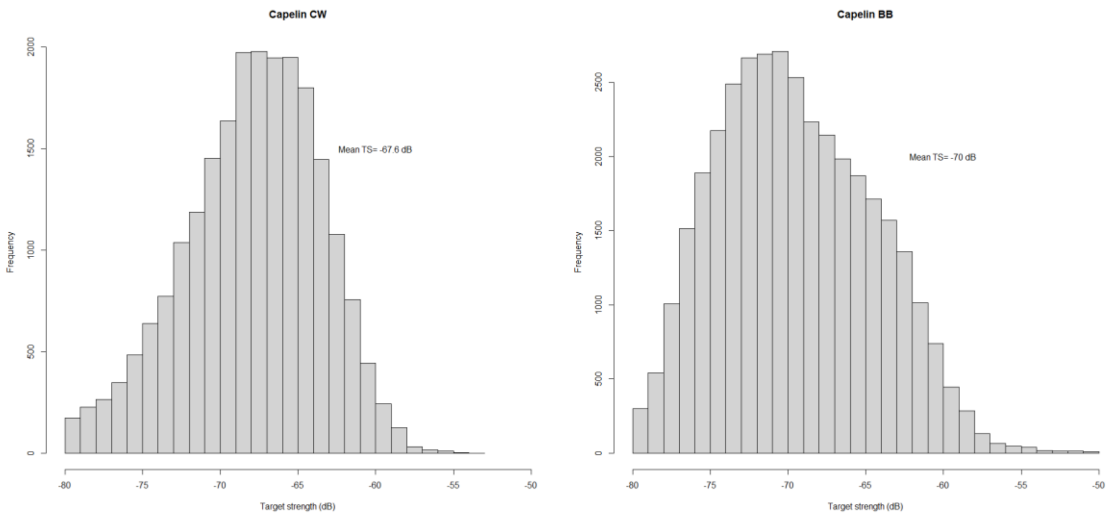

Fig. 13. Capelin target strength distributions and mean values from narrow (left) and broadband data (right).

Capelin acoustic frequency response

Introduction

Capelin has a physostomous swimbladder, with a connection to the esophagus, with no capacity to secrete gas (Fahlén, 1968). The swimbladder is typically contributing 90-95% of the backscatter from fish that poses one (Foote, 1980). Swimbladder fish display a characteristic frequency response in the frequency range used in fisheries acoustics (i.e. from 18 to 200 kHz), with strong backscattering at lower frequencies decreasing toward higher frequencies. Fish without swimbladder, like Atlantic mackerel, have stronger backscattering at higher frequencies decreasing at lower frequencies (Korneliussen, 2010). In the case of fish without swimbladder, the fish flesh and bone structures contribute most to the backscattering.

Normally, Barents Sea capelin is monitored during the autumn and display the classic frequency response of swimbladder fish. In this capelin spawning survey, we monitor capelin in a completely different state and situation, which potentially influences physiology and backscatter properties at various frequencies. Here we present some examples of the frequency response of capelin schools recorded during the 2021 survey, aiming to show the variability observed, and discuss potential implication on the survey results.

Methods

Multifrequency data was obtained from the EK80 calibrated systems onboard "Eros" and "Vendla", from 18 to 200 kHz. Schools along and outside the track line were sampled with the echo sounder, at survey speed (10 knots) or reduced speed for inspection or trawling. Capelin is reported to have little or no reaction to an approaching vessel (Jørgensen et al., 2004), making sampling with echo sounder a reliable measure of its acoustical properties.

Echo sounder data from various capelin aggregations (schools and layers) observed during the survey was inspected in the LSSS software and the frequency response was obtained.

Results

Echograms showing selected capelin aggregations and the frequency response are shown in Figures 14 to 19. The pattern of the frequency response is similar in the examples, with higher backscattering at 200 kHz, decreasing at lower frequencies. The strength of the backscattering at 200 kHz in the data from Eros is between 7 and 9 times higher than at the 38 kHz reference frequency.

In these examples, the depth of the capelin schools varied from closer to the surface to 200 m depth. The time of the day also varied, as well as the size from small (Figs 14, 15 and 19) to large (Figs. 16, 17 and 18). Predators (whales, dolphins and large demersal fish) were observed in various abundances around all schools, both visually and in the acoustic data (echo sounder and sonar).

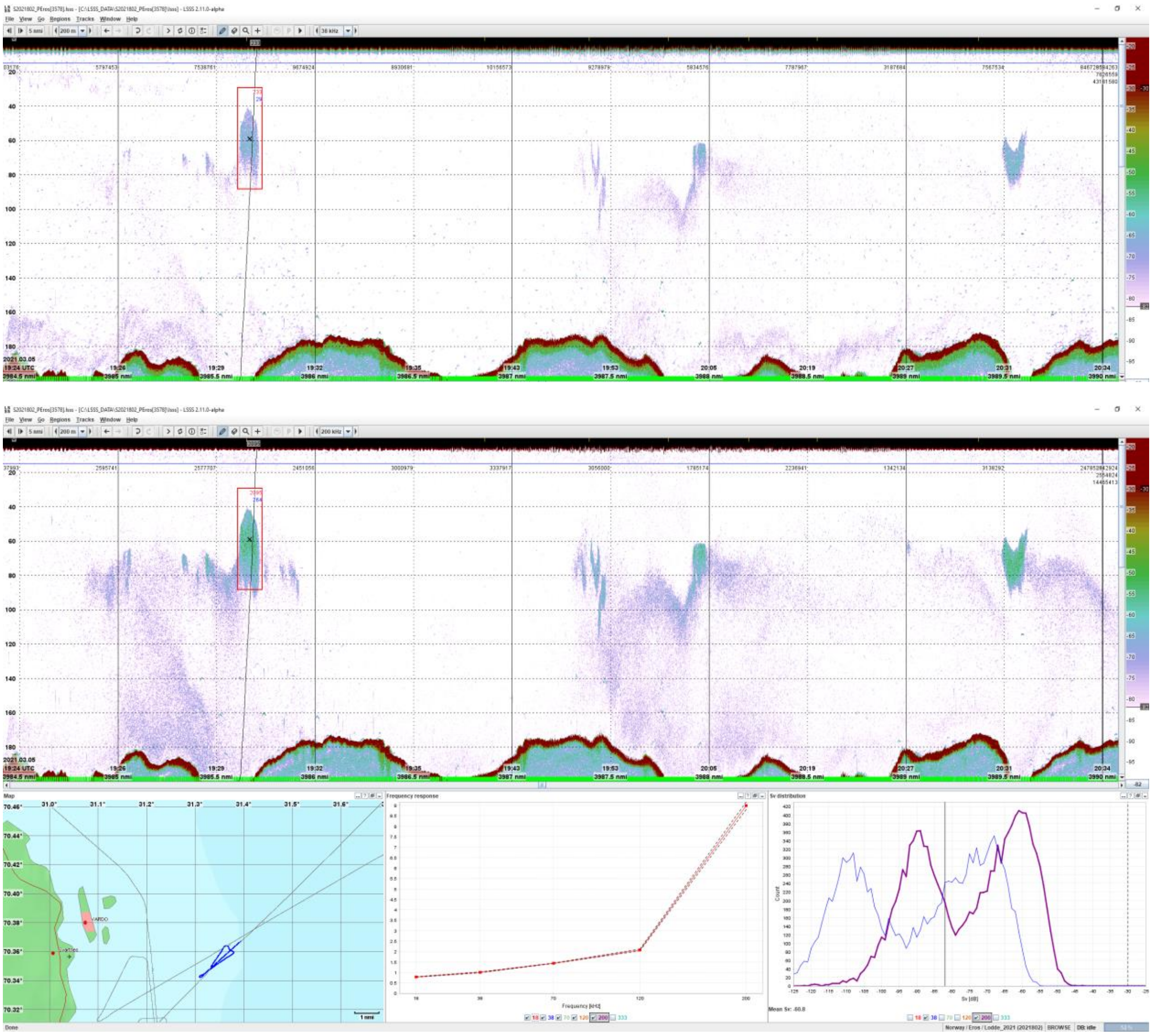

Fig. 14. Echogram from "Eros" of single capelin school (delimited inside a red square) on March 05, off Vardø at 19:30 hrs. at 38 kHz (upper panel) and 200 kHz (bottom panel). Frequency response from 18 to 200 kHz is displayed in the bottom center panel.

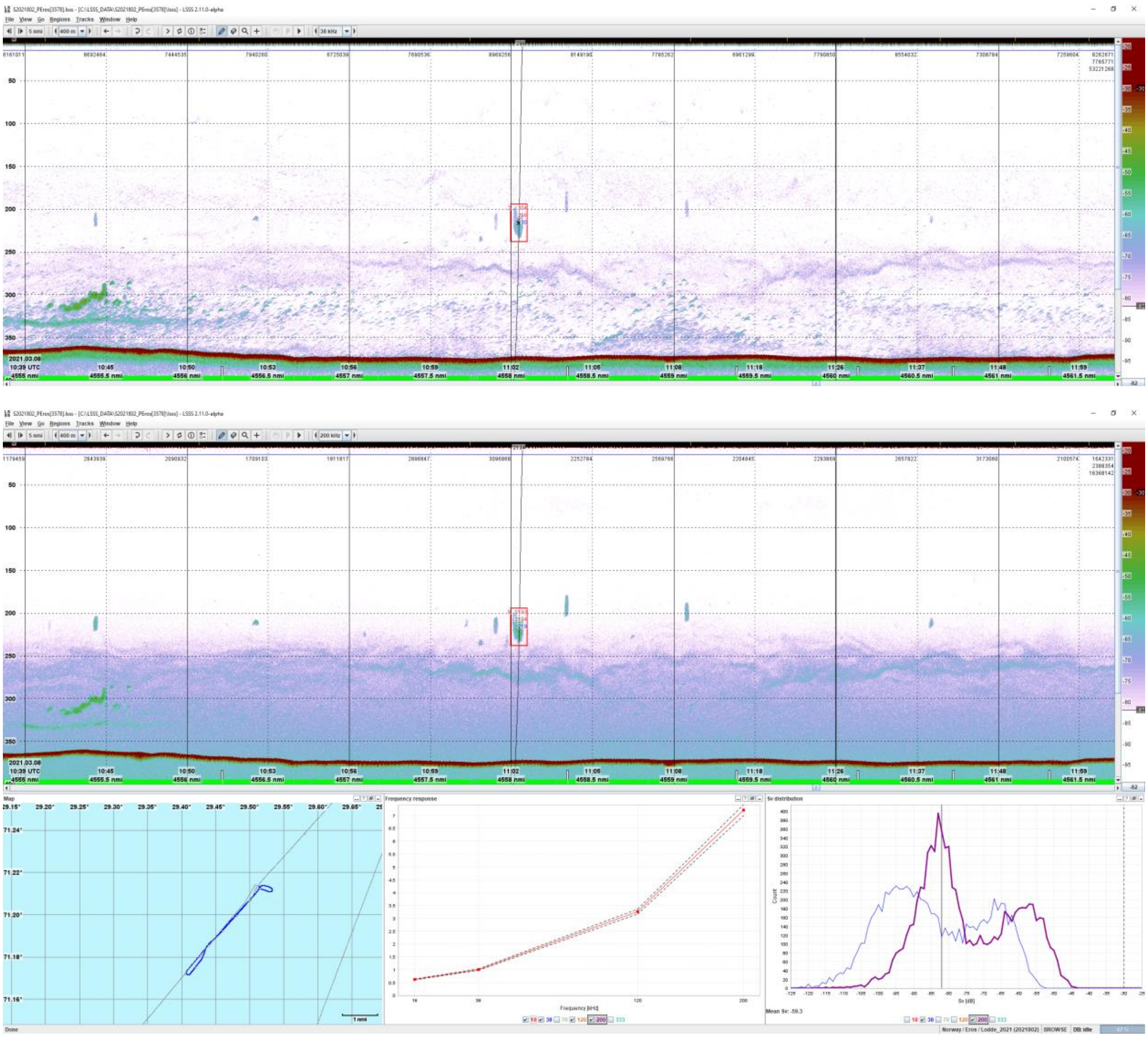

Fig. 15. Echogram from "Eros" of single small capelin school (delimited inside a red square) on March 08 at 11:00 hrs. at 38 kHz (upper panel) and 200 kHz (bottom panel). Frequency response from 18 to 200 kHz is displayed in the bottom center panel.

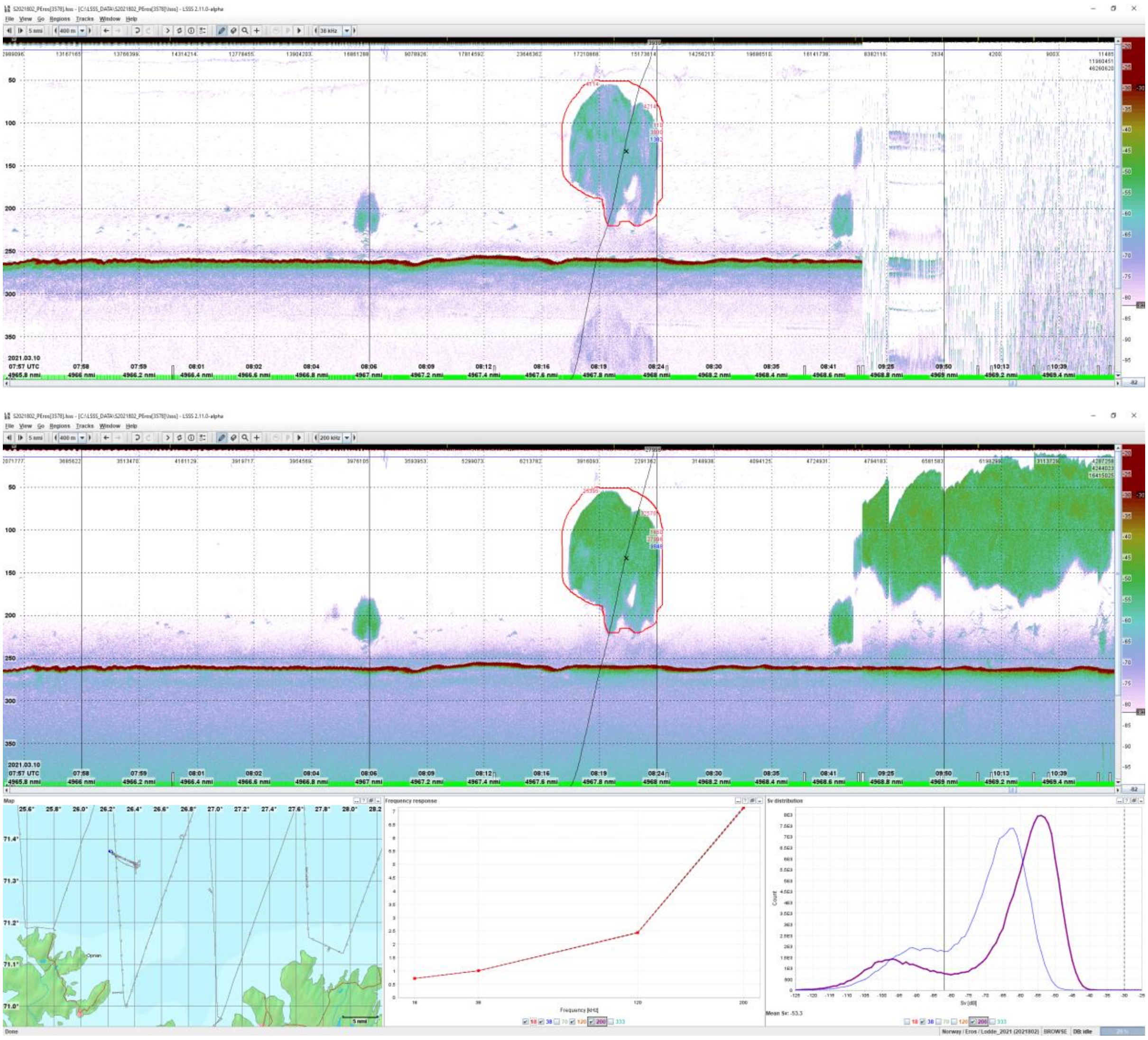

Fig. 16. Echogram from "Eros" displaying a large capelin school (delimited inside a red region) on March 10 at 08:24 hrs. at 38 kHz (upper panel) and 200 kHz (lower panel). Frequency response from 18 to 200 kHz is displayed in the bottom center panel.

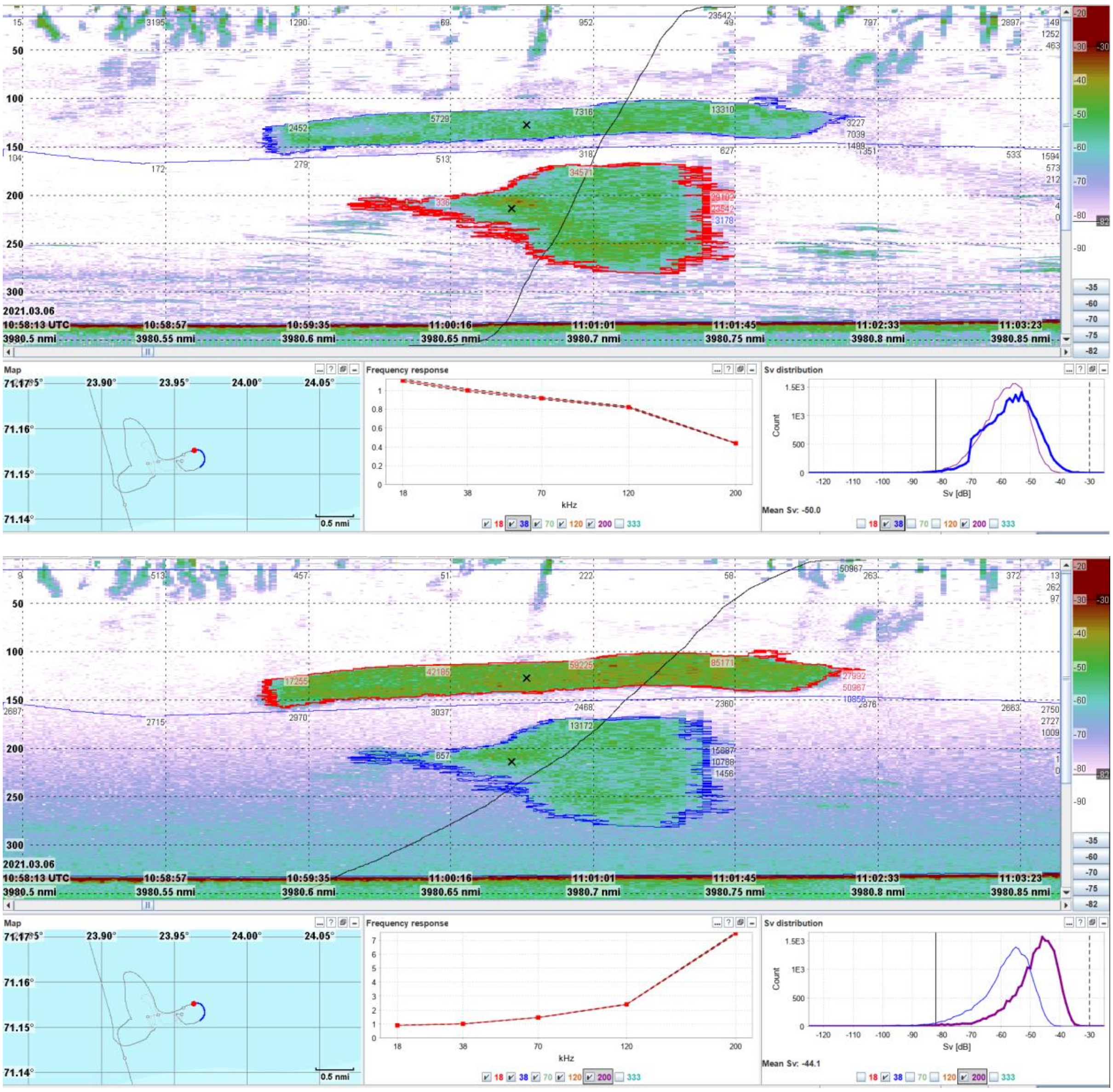

Fig. 17. Echogram example from ”Vendla” with two schools of capelin under heavy attack from whales from above and gadoids from below recorded ca. 11:00 UTC north of Fruholmen. The recordings are done at 4-5 knots speed during inspection. The upper panel displays the 38 kHz echogram showing the frequency response from the lower school (delineated by red line), and the lower panel the 200 kHz echogram showing the frequency response from the upper school. Frequency response from 18 to 200 kHz is displayed in the bottom center panel.

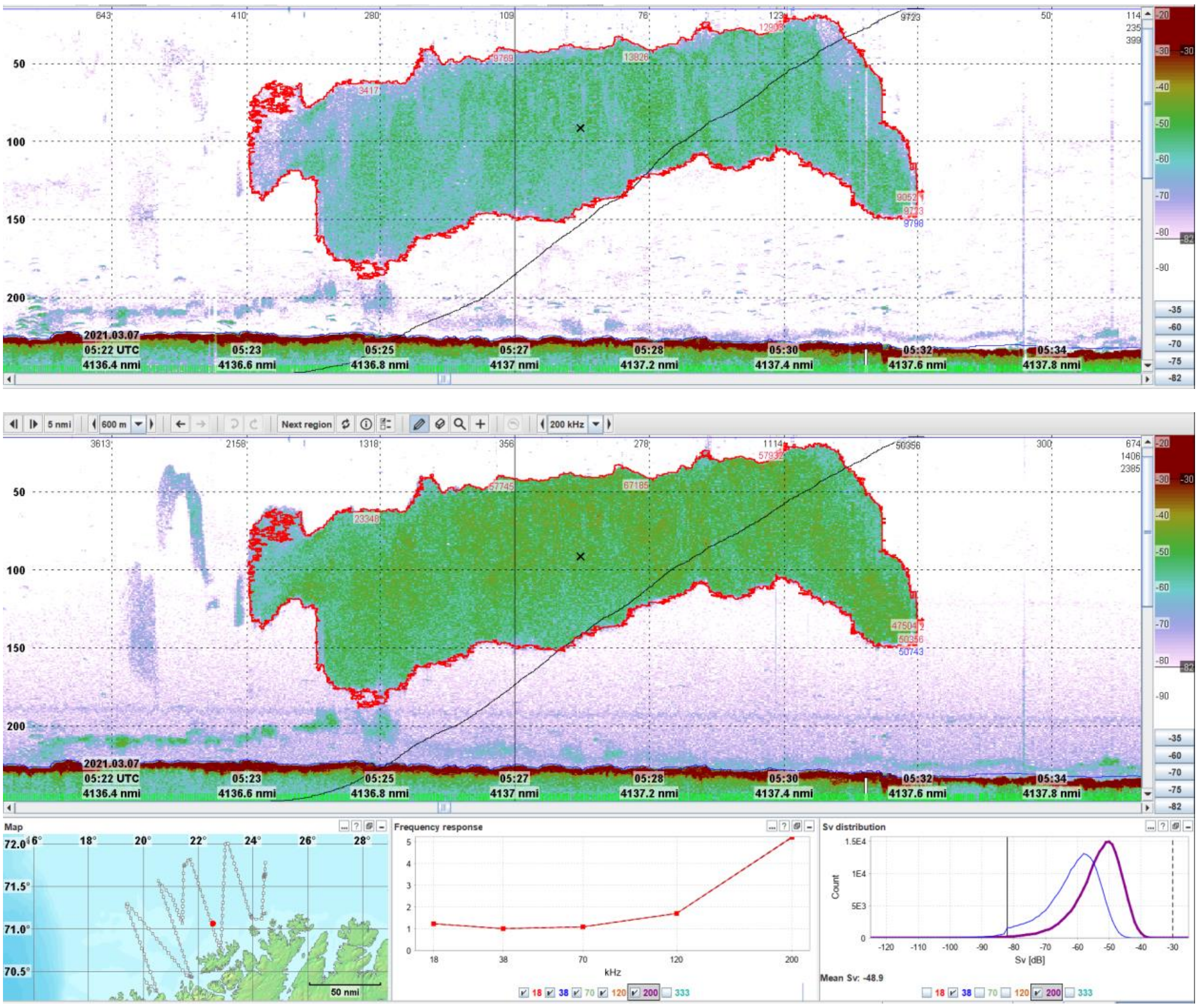

Fig. 18. Echogram example from ”Vendla” with big school of capelin and gadoid aggregations below recorded at 5:30 UTC north of Sørøya. The recordings are done at 7-8 knots speed. The upper panel displays the 38 kHz echogram showing the frequency response of the school delineated by the red line, and the lower panel the 200 kHz echogram. Frequency response from 18 to 200 kHz is displayed in the bottom center panel.

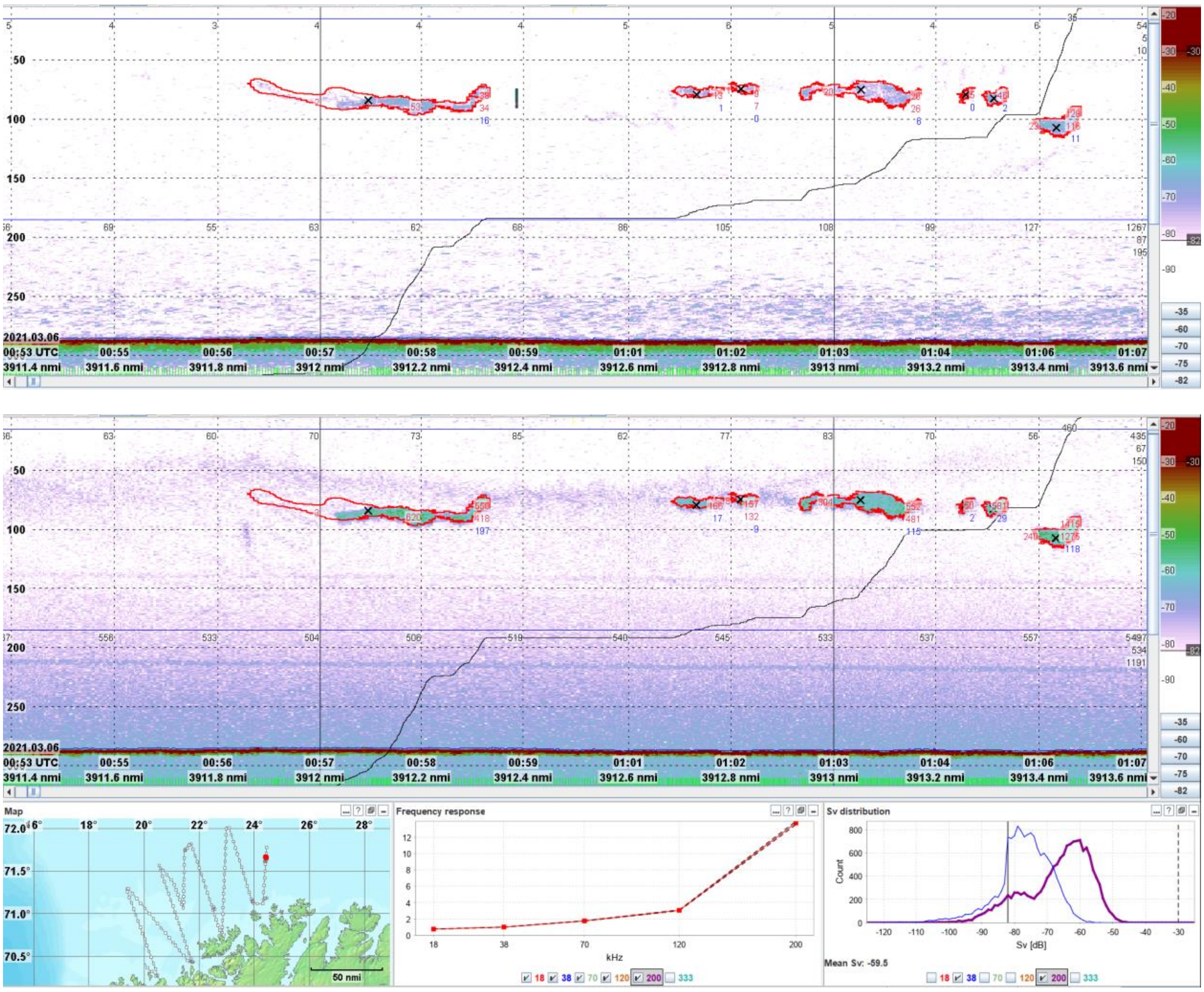

Fig. 19. Echogram example from "Vendla" with small schools of capelin at shallow depth recorded at 1:00 UTC north of Havøysund. The recordings are done at 7-8 knots speed. The upper panel displays the 38 kHz echogram showing the frequency response of the school delineated by the red line, and the lower panel the 200 kHz echogram. Frequency response from 18 to 200 kHz is displayed in the bottom center panel.

Discussion

The unexpected frequency response observed in capelin schools during the 2021 survey has previously been registered occasionally, but not quantified or investigated further.

We assume that the unexpected frequency response is due to the fish emptying or partly emptying the swimbladder under certain circumstances, which has also been observed in herring (Nøttestad et al. 1998). The resulting low backscattering at 38 kHz will have significant implications on the abundance estimation of capelin in such schools, since the conversion from acoustic backscatter to number of fish is assuming that fish have gas filled swimbladder (TS=19.1Log(L)-74). The target strength of a fish with empty swimbladder will be much lower, and a different formula for conversion should be used for such schools (see section on TS measurements).

Possibly the measured schools had emptied their swimbladder in response to predators, escaping vertically and releasing air and/or as a precautionary anti-predator strategy to reduce the risk of being detected by predators, in particular by marine mammals which use acoustics to localize their prey. The characteristics of the capelin swimbladder, with an opening to the esophagus support these hypotheses. In 2020, some schools attacked by demersal fish were observed acoustically to seemingly release gas (Fig. 20).

It will be important to quantify the extent of abnormal frequency response as a part of the evaluation of this survey time series, and a complete revision and analysis of the frequency response of capelin schools from the surveys from 2019 to 2021 will be carried out as a preparation for the 2022 capelin benchmark.

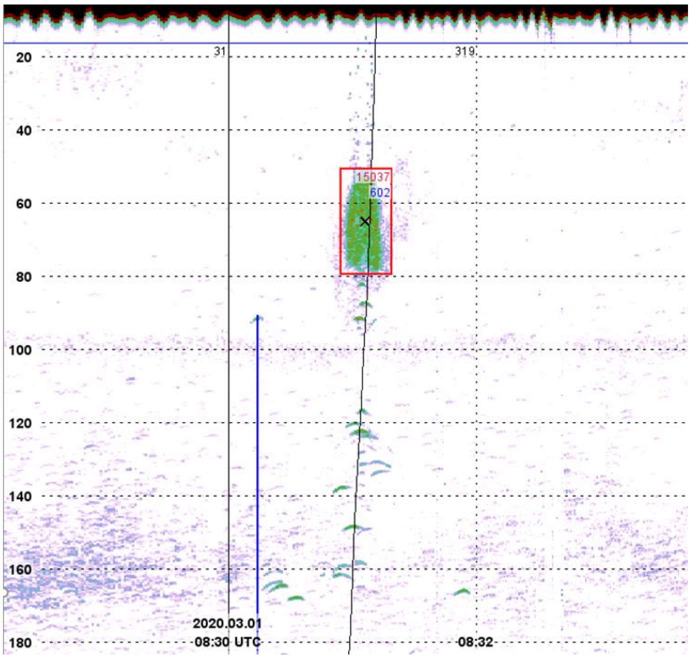

Fig. 20. Echogram showing a capelin school (delimited inside a red region) releasing gas, as green dots above the school all the way to the surface. Below the school it is possible to identify large demersal fish (as green arch shapes), most likely cod, attacking the school from deeper waters.

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Autonomous Sailbuoy

Introduction

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 has been tested both during the 2020 survey and 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. 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.

Deployment and retrieval

The Sailbuoy was deployed on 3th March in position N71 34.7' and E30 6' at 45 nautical mile distance from the coast, north of Tanafjord (fig. 21). The buoy was set to sail along a 15.8 nautical mile transect westward from the deployment position and parallel to the coast.
The drone was set up to go back and forth along the transect in a so called "fence mode" to monitor capelin migration towards the coast.
The Sailbuoy was retrieved after a little more than 5 days, just after midnight on the 9th March.

The weather was fair throughout the deployment period. Deployment followed standard procedures using a release hook from the stern of the drone. It was retrieved following the lasso approach described for the Sailbuoy. Both deployment and retrieval went smoothly.

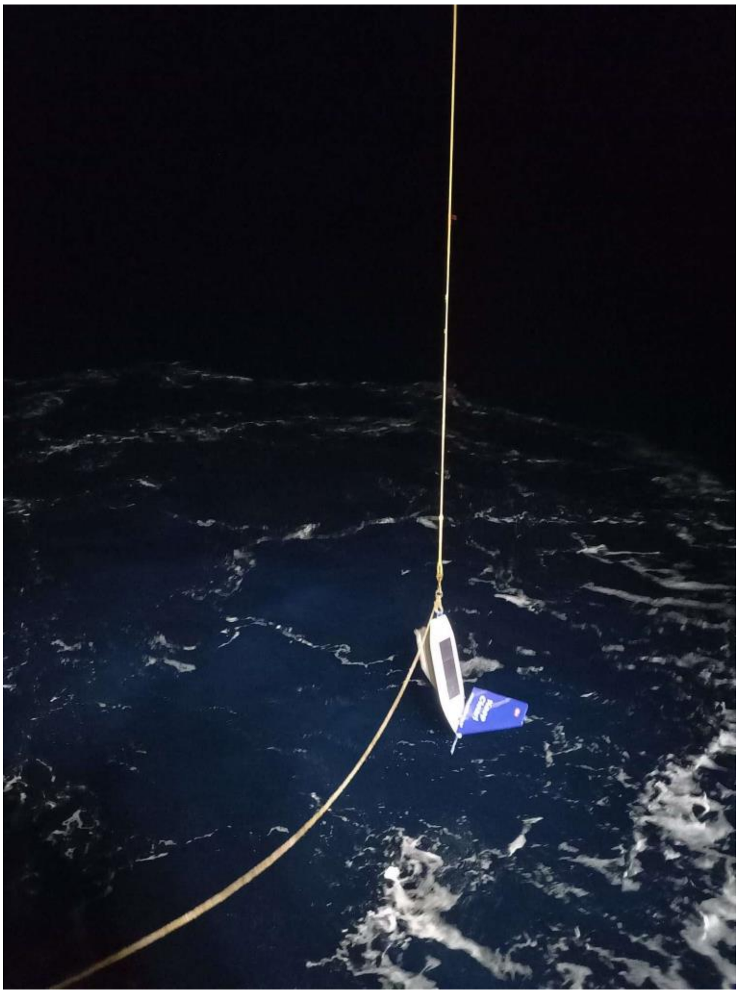

Fig. 21. Deployment of the buoy from the vessel crane

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 and limits the precision of the navigation.

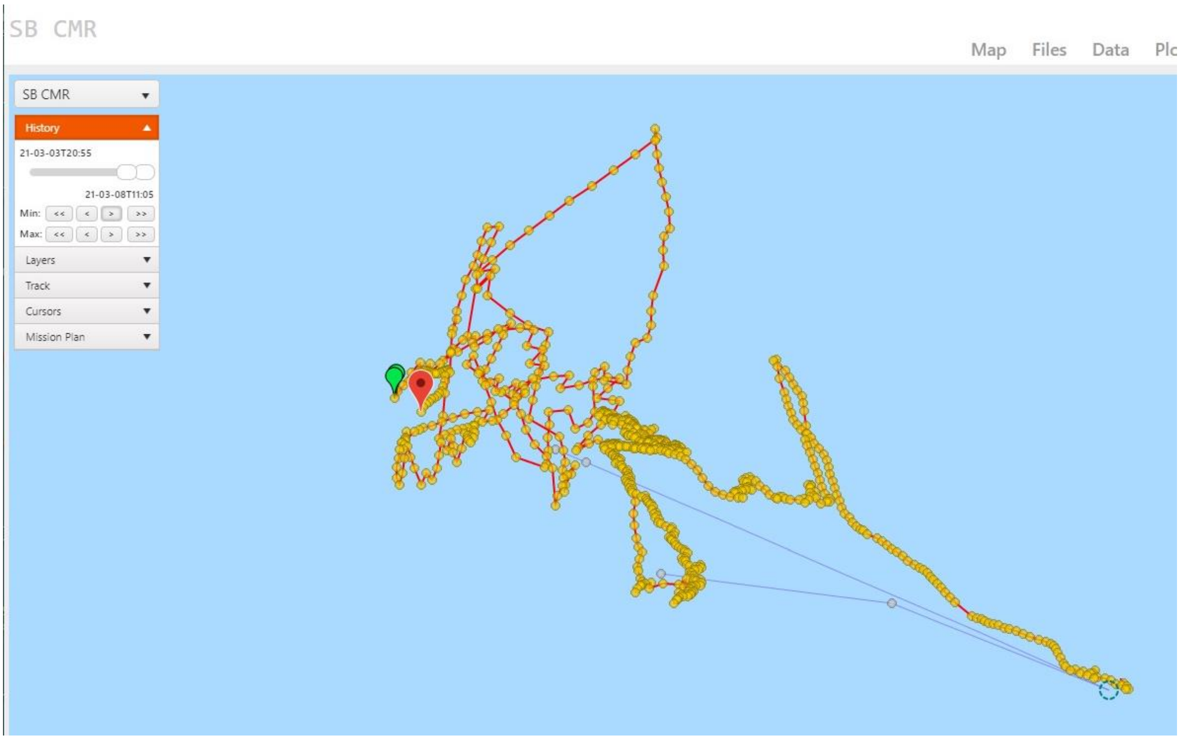

Fig. 22. Course track of the Sailbuoy along the transect.

During the 5-day deployment, the buoy only covered the 15.8 nm transect once. Most of the time was spent on detours around the western point of the transect (fig. 22). Following the advice from Offshore Sensing, the fence mode was aborted, and the new route functionality was applied. This did not have any positive effect. According to Offshore Sensing there may be technical issues with the servo for the rudder.

Due to the navigational issues, data from the buoy could not give any useful real time information that would benefit the survey execution. Consequently, no attempt was done to download acoustic data via satellite. The acoustic data will be retrieved after the survey.

Conclusions

Unfortunately, the navigational issues with the Sailbouy prevented us from gaining more experience on the potential usefulness of the drone to enhance survey results and operation.

Use of acoustic doppler current profiler (ADCP)

Introduction

The dynamics of predominant currents in the survey area is relevant to understand the spawning migration when capelin approach the coasts of Finnmark from the oceanic region of the Barents Sea. Models showing the prevailing currents are available (http://havstraum.no/), but space and time scales are not suited for the ones during the spawning survey. Therefore, is advisable to collect simultaneous echo sounder and ADCP data. The Simrad EC150-3C ADCP was available onboard Eros for a second year. In 2020 the ADCP was installed, but time synchronization and adequate motion reference unit (MRU) data were missing. Notwithstanding, current data was collected along the survey and selected periods during the transport along the coast in shallow waters was used for calibration. Calibration results were not satisfactory and ultimate ADCP data was processed by results considered not accurate.

For the current survey, actions were taken to solve MRU and time synchronization, calibration protocols were agreed, and survey time was allocated for ADCP calibration.

Data collection

A Meinberg Lantime M100 system was installed before departure for time synchronization between ADCP, MRU and GPS. Also, a new Kongsberg MRU was installed with the data output KM Binary required by the ADCP.

The ADCP calibration was done on March 01, inside Laksefjord, with wind speed of 16-19 ms^{-1} from the West. The data collection for ADCP calibration was following the protocol indicated in the EC150-3C instruction manual and repeated for CW and FM pulse transmission.

Results

Results from calibration showed inconsistent current direction when sailing direction was changed in 90 deg as indicated in the calibration protocol (Fig. 23). The same results were observed when using CW or FM modes.

In addition, results from the calibration showed a very large spread in the values of yaw (0.8), pitch (0.4) and roll (2.7), and cannot be used to update transceiver parameters. These indicated that data collected from ADCP had problems and needed to be investigated.

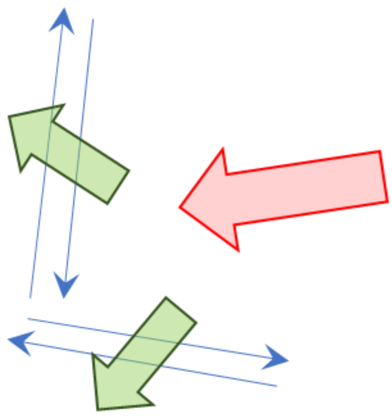

Fig. 23. Diagram showing the vessel direction (blue arrows) in the calibration transects, to North-South (top left) and East-West (bottom). The measured current direction is indicated with a large green arrow, with direction Northwest and Southwest. Prevailing wind direction is showed with a large red arrow.

After many efforts and direct contact and help from Simrad it was concluded that the time synchronization system was not working as expected (see example in Fig. 24), and there was a significant time delay in the information from the MRU and GPS that is delivered to the ADCP. This problem was not solved during the survey and will be followed up by Simrad and HI.

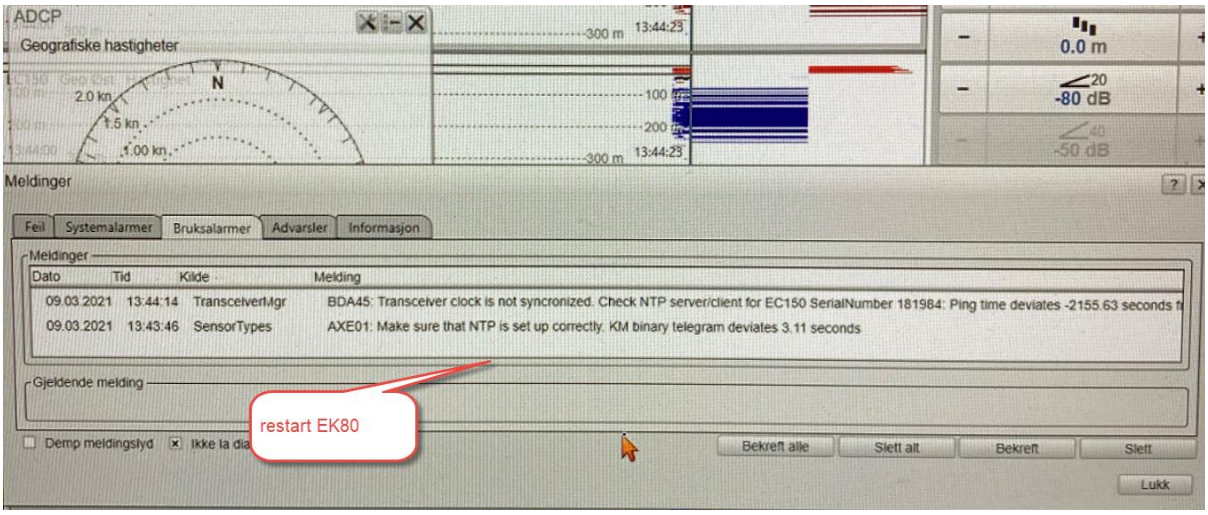

Fig. 24. Screen dump from the EK80 software indicating the time delay of 3.11 sec from the MRU (KM binary telegram).

Data collected during the survey was not processed and new calibration parameters, if possible, will be added in post-processing.

Concluding remarks about the survey

1. The total biomass was estimated at 85 751 t, with a sampling variance expressed as Coefficient of Variation (CV) of 49%. 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 a distribution was also observed last year and can be expected at low stock levels.
2. The dominating amounts of capelin were in the west similar as last year, and most capelin were recorded mostly in deep schools north-east of Sørøya. Very little capelin was recorded in the eastern part of the coverage area. Unlike last year, there were not significant differences between the first and second coverage.
3. This is the third year of conducting this survey and like for previous years the survey result overlaps with the lower range of the confidence band of the stock forecast based on the autumn survey. It is expected that the results are in the low range given the lack of coverage in the east, and the consistency in results despite the dynamics of the migration is promising for the use of such monitoring for advice purposes.
4. Multi-frequency recordings and TS measurements revealed unusual backscattering properties of the capelin which potentially can have significant impact on the abundance estimate. This must be taken into account and investigated further before the survey can be used to inform the advice.
5. The experience gained during the present survey, together with the surveys in 2019 and 2020 and the survey planned for next year 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 crew of FV *Vendla* and FV *Eros* are thanked for their excellent assistance and engagement during the whole survey.

Appendix

Appendix 1. 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. A1_1. The 2021 reporting started in week 2 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.

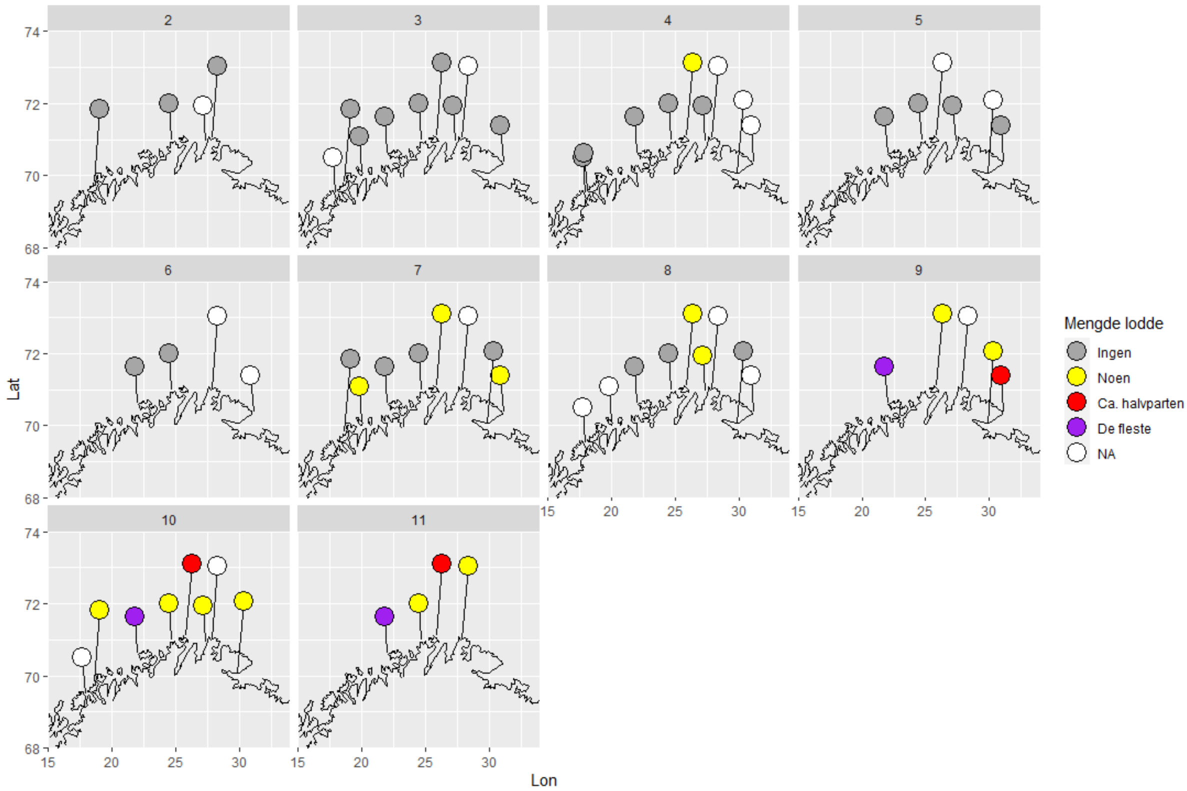

Fig. A1_1. Frequency of cod stomachs with capelin in them reported weekly from fish plants along the coast of Finnmark and Troms. Each panel represents a week (week 2- week 11). Grey circle: no capelin, yellow circle: capelin in some stomachs, red circle: capelin in ca. half of the stomachs, purple circle: capelin in most of the stomachs.

Appendix 2. Rigging of the Harstad trawl

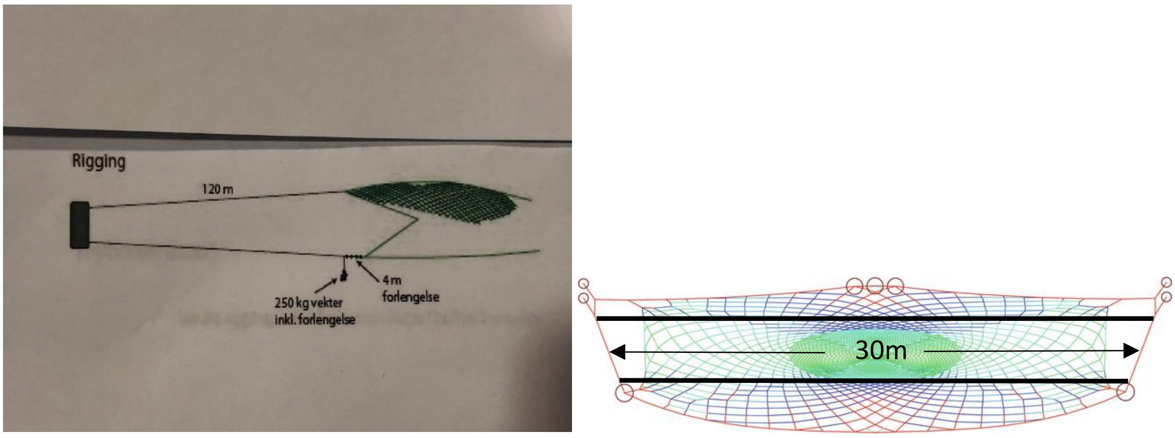

Fig. A2_1. Rigging of the Harstad trawl used during the survey (left panel) and detail of two 30 m security ropes attached to the net opening to protect the trawl from damage (right panel).

Appendix 3. Information about capelin distribution and biology

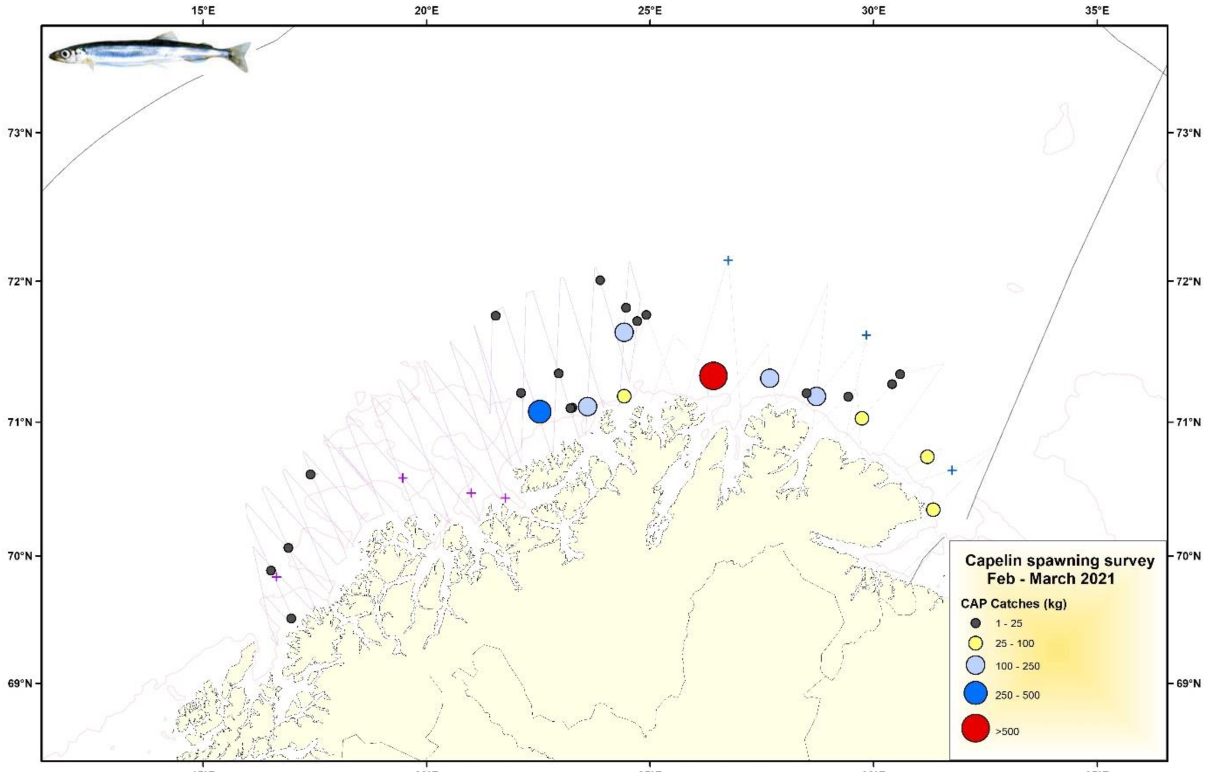

Fig. A3_1. Distribution of capelin samples by catch size. Note that all hauls are target hauls and the trawl was rigged with a split limiting catch size.

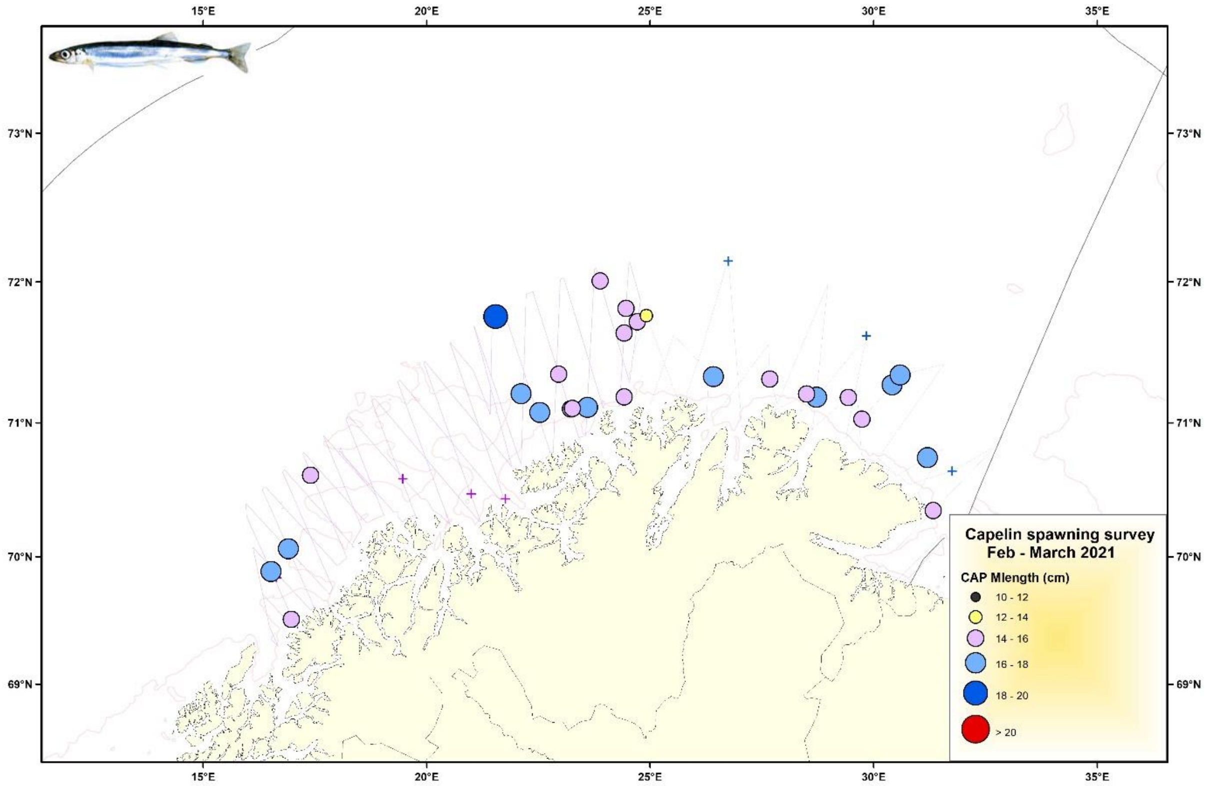

Fig. A3_2. Distribution of capelin mean lengths by station.

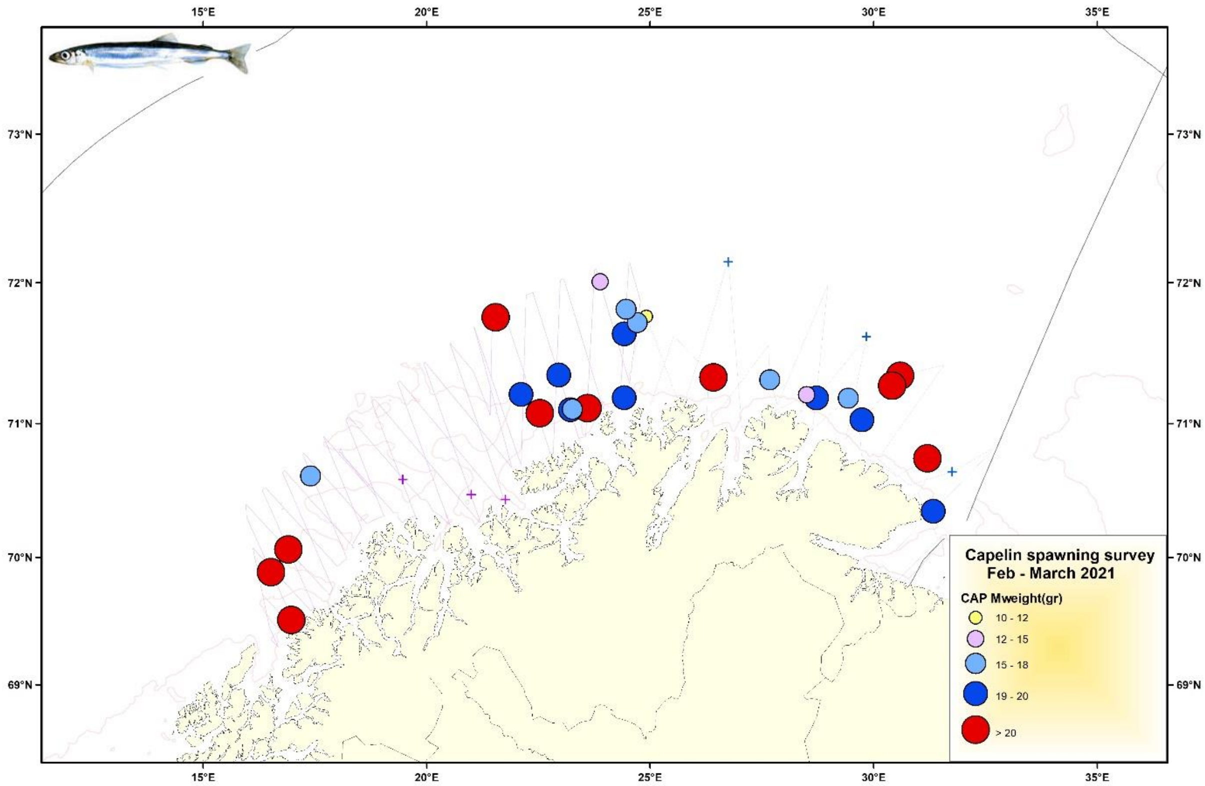

Fig. A3_3. Distribution of capelin mean weights by station.

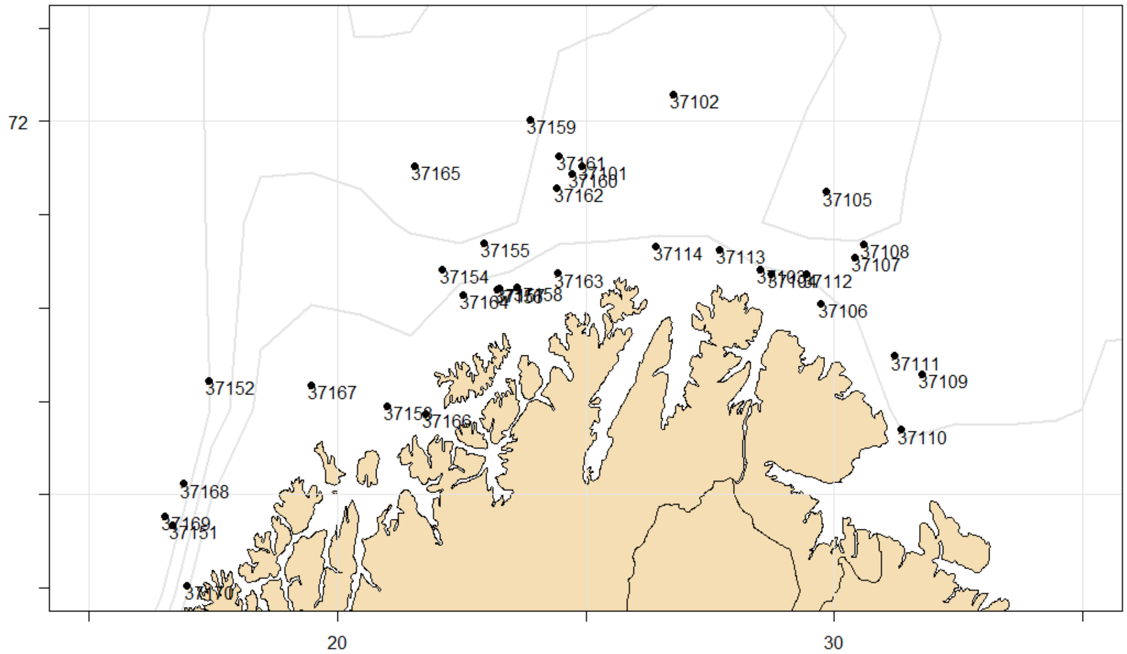

Fig. A3_4. Pelagic trawl stations with associated serial numbers.

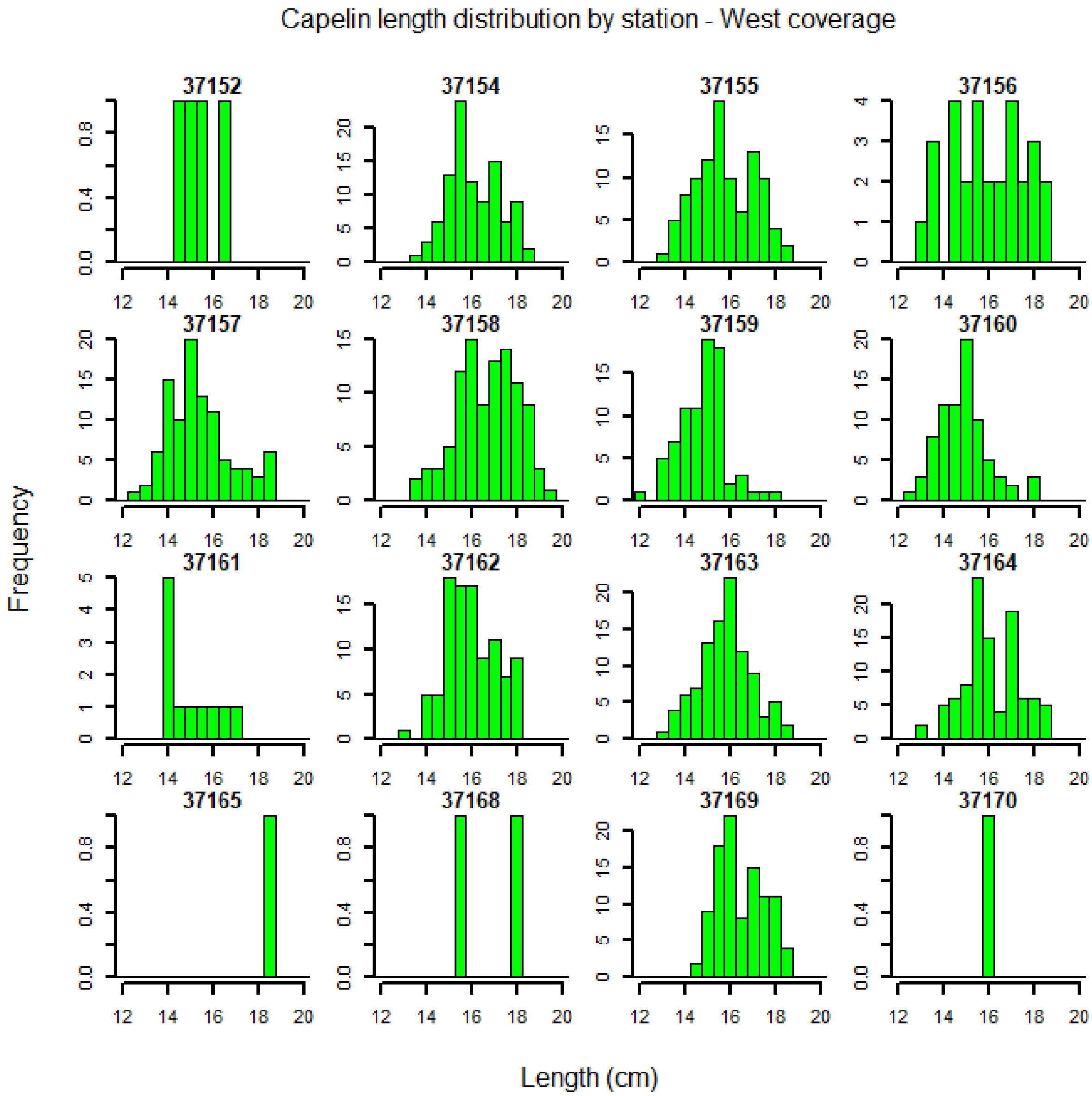

Fig. A3_5. Capelin length distribution by station; station serial number is given at the top of each panel (see fig. A3_4 for geographical position of the stations).

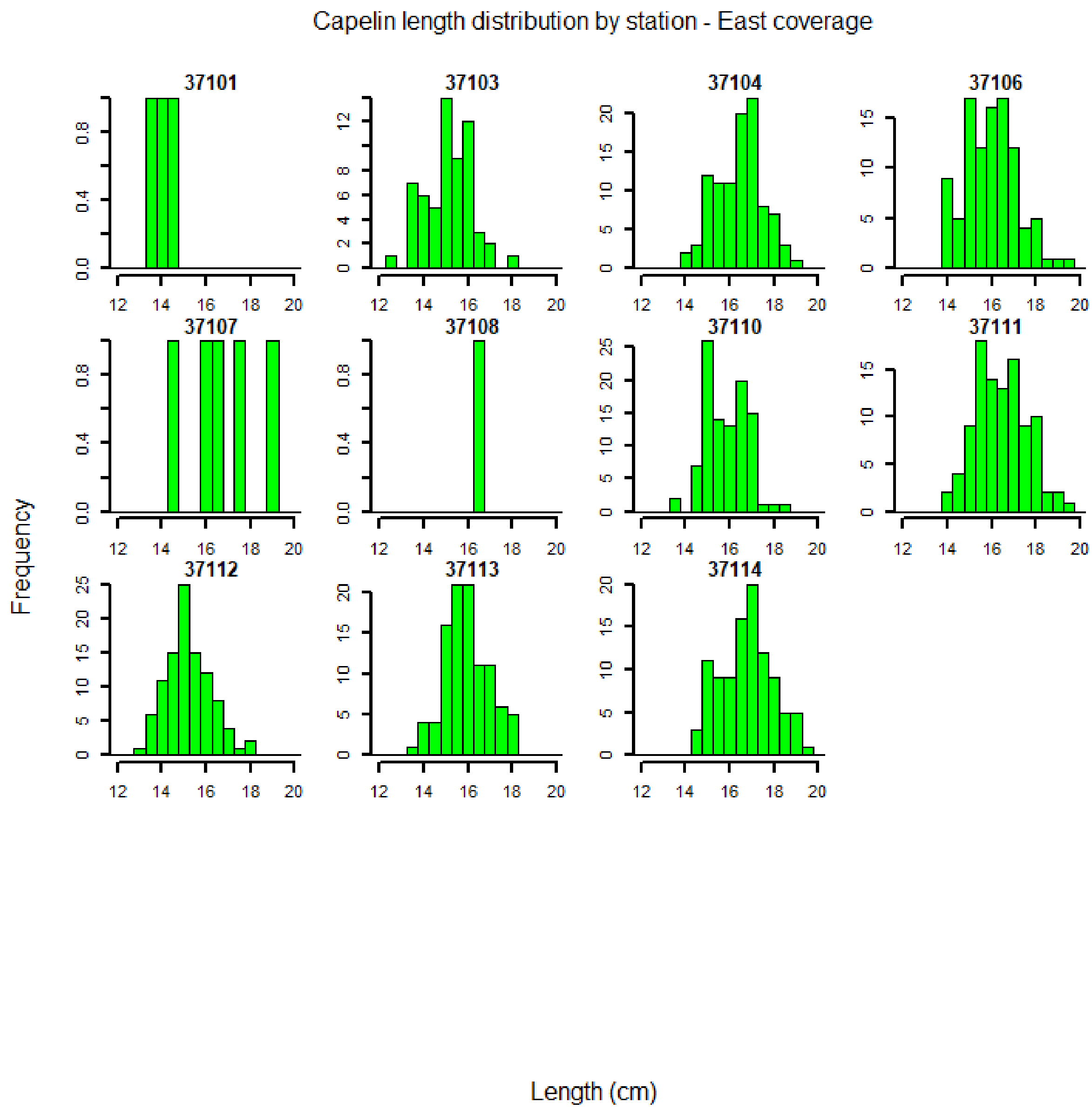

Fig. A3_6. Capelin length distribution by station for the east survey coverage; station number is given at the top of each panel (see fig. A3_4 for geographical position of the stations).

Appendix 4. Information about herring distribution and biology

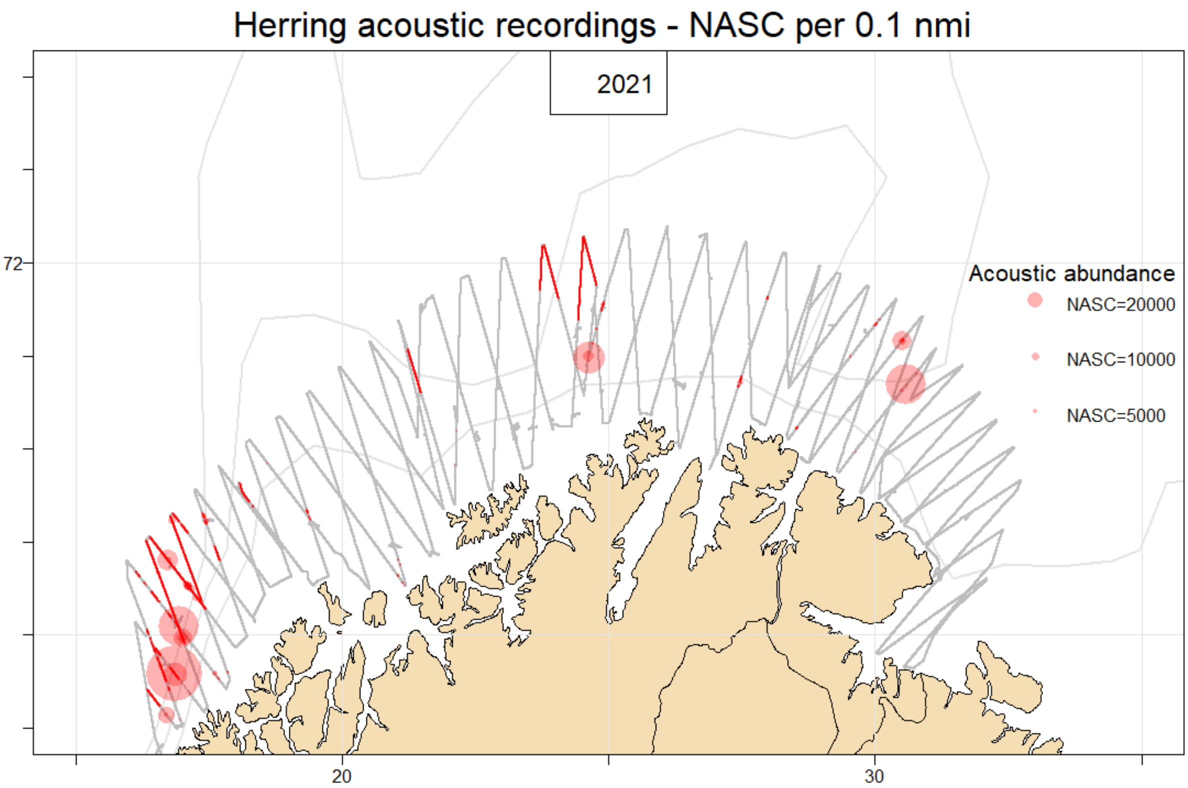

Fig. A4_1. Distribution of NASC ($m^2 nmi^{-2}$) allocated to herring. The size of the circle corresponds to NASC-value per 0.1 nautical mile.

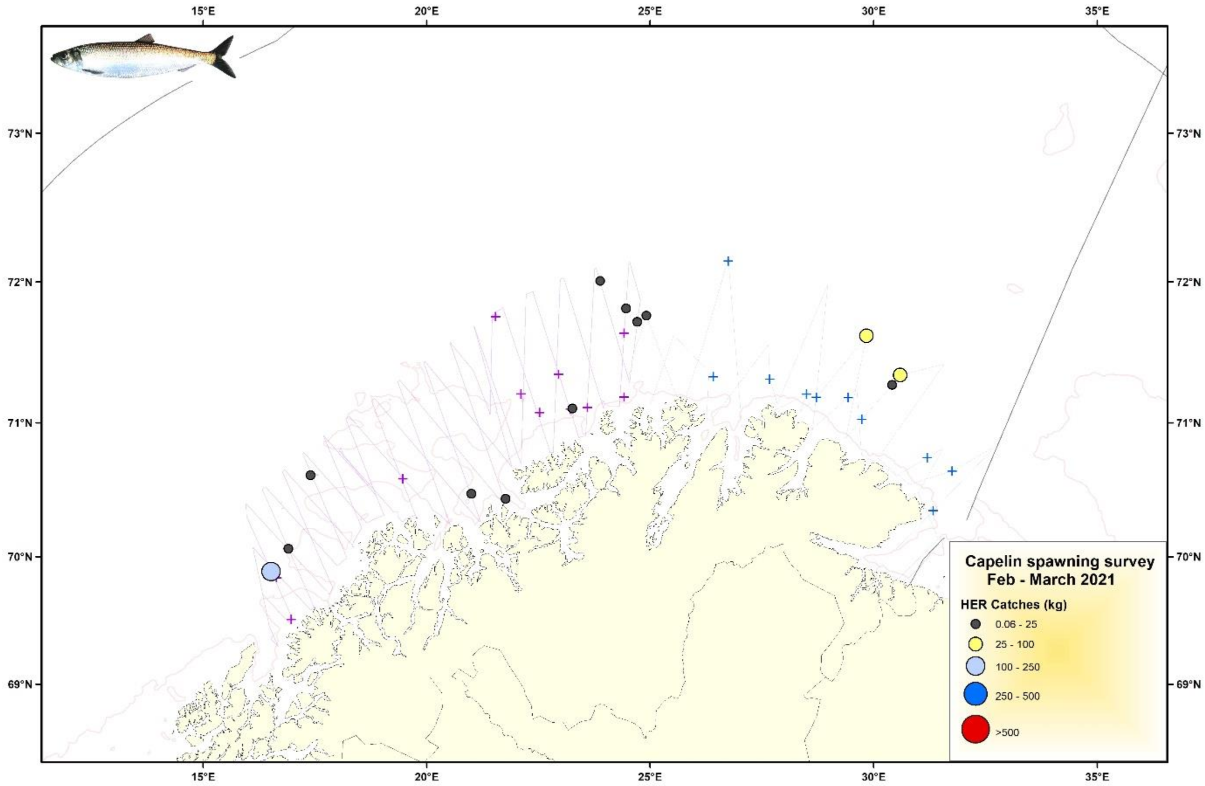

Fig. A4_2. Distribution of herring samples by catch size. Note that all hauls are target hauls and the trawl was rigged with a split limiting catch size.

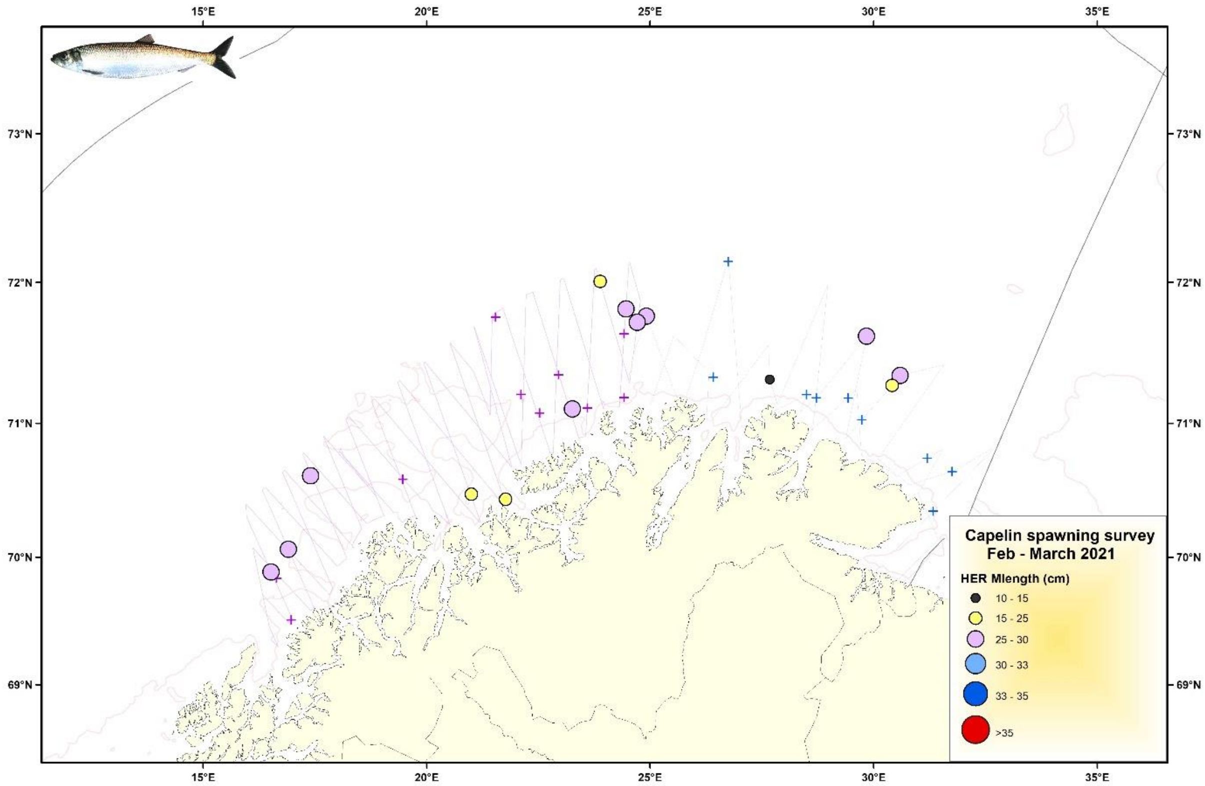

Fig. A4_3. Distribution of herring mean lengths by station.

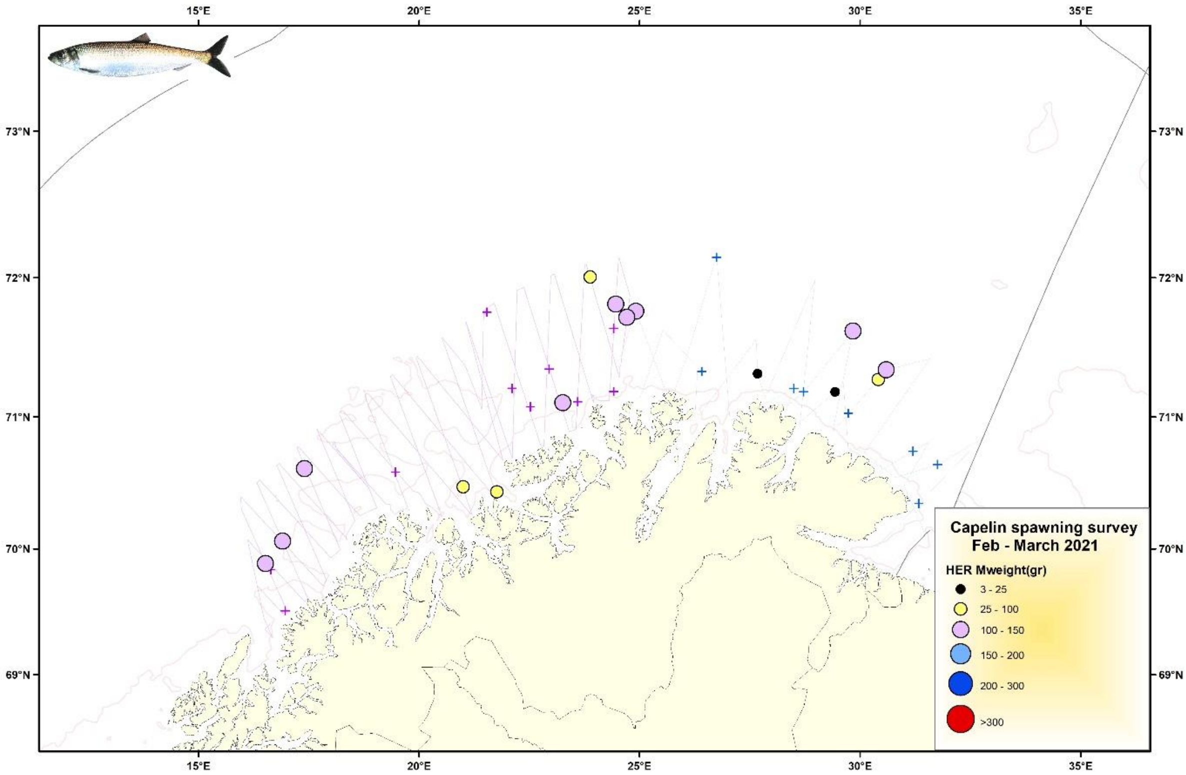

Fig. A4_4. Distribution of herring mean weights by station.

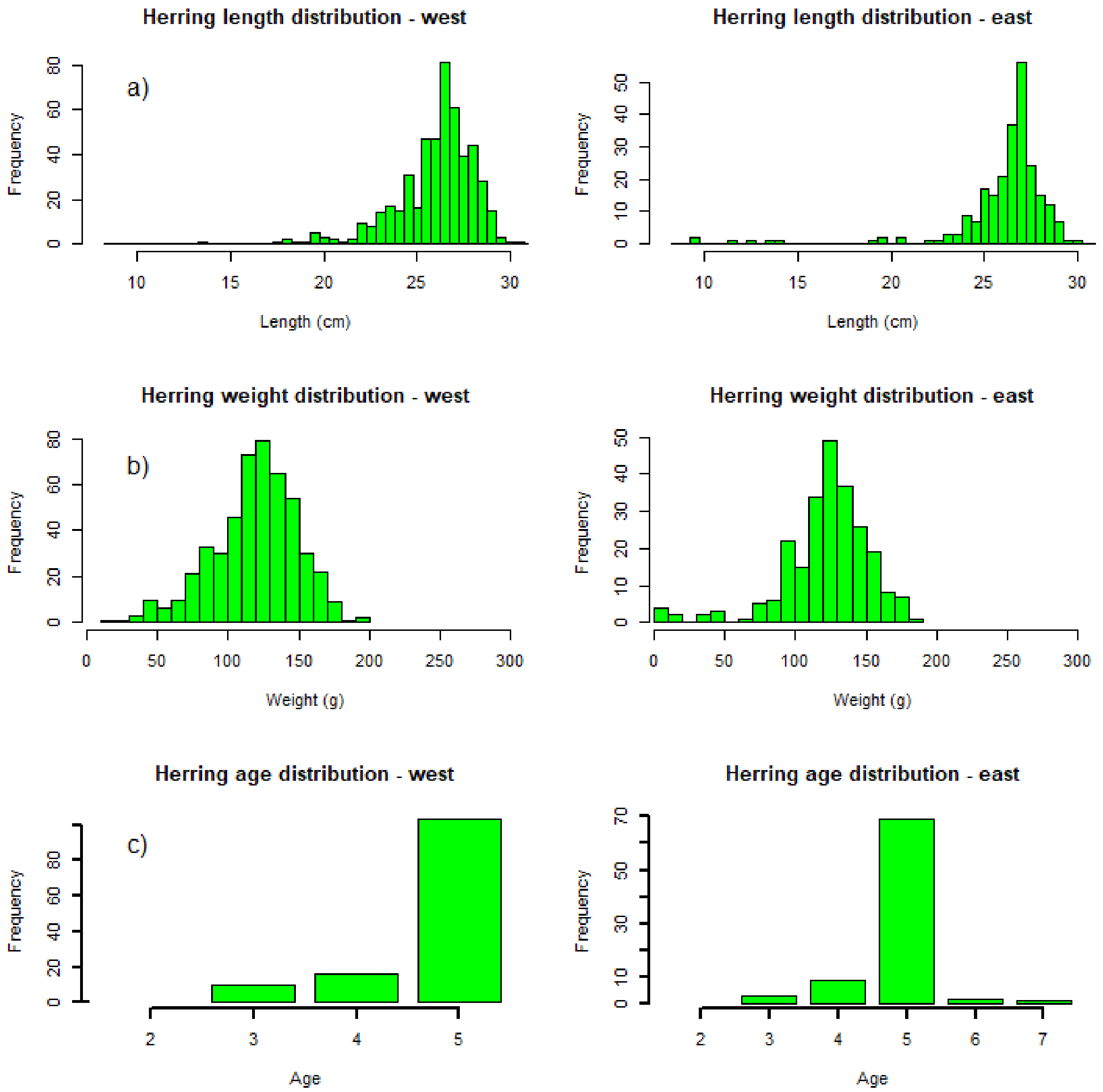

Fig. A4_5. Herring a) length distribution b) weight distribution, and c) age distribution in the western (left column of panels) and eastern (right column of panels) coverage areas.

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