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Study of the Arctic mesopelagic layer with vessel and profiling multifrequency acoustics

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ABSTRACT

The range limitation (> 200 m) for high-frequency echosounders does not allow for complete multifrequency studies of the mesopelagic layers from vessel-mounted echosounders. The layers of mesopelagic fish and zooplankton in the Arctic region north of Svalbard (Spitsbergen) were studied using vessel-mounted echosounders and a profiling acoustic probe, using 38, 120, 200 and 333 kHz. Volume density estimates of mesopelagic fish have shown to be marginally higher with the probing system in relation with measured from the vessel-mounted echosounders at 38 kHz. This shows that the swimbladder resonance phenomenon is not occurring in low density layers with limited vertical migration. The use of the profiling probe allowed densities to be calculated with an *in situ* measured target strength (TS). In depths > 200 m where high-frequency hull-mounted transducers cannot effectively reach, the profiling system measured a mixture of krill and amphipods down to 600 m. Vertical profiles of measured target categories, from vessel transducers and from the probing system are compared in relation to the biological sampling conducted during the survey. Profiling acoustics are shown to be a valuable tool to address some limitations in the current surveying methods for studying mesopelagic layers beyond the reach for high-frequency vessel-mounted systems.

1. Introduction

The Arctic has received increased international attention due to effects of rapid climate changes reported in scientific literature (Haug et al., 2017; Hollowed et al., 2013; Hollowed and Sundby, 2014). The sea-ice reduction has created potential for marine resource exploitation (Haug et al., 2017) and allowed access to an area greatly understudied (Van Pelt et al., 2017). Reports of ecosystem changes and climate vulnerability have kept the Arctic in the spotlight and have extended the debate beyond economic actors. Changes in the water column structure (Dalpadado et al., 2014; Lind et al., 2018) as well as at the ecosystem level have been published recently (Ardyna et al., 2014; Eriksen et al., 2017; Hollowed et al., 2013; Hollowed and Sundby, 2014). Monitoring of the Arctic ecosystems in relation to changing conditions is thus needed.

Similarly, the ocean mesopelagic layers are largely understudied (St. John et al., 2016), the Arctic being one of the most representative cases (Siegelman-Charbit and Planque, 2016), with mesopelagic fish biomass estimates being a subject of debate worldwide (Davison et al., 2015; Irigoien et al., 2014; Klevjer et al., 2016; Proud et al., 2018). Research on the mesopelagic fish community in high latitude ecosystems has been focused mostly on fjords, while only a few authors have focused on oceanic studies of this group (Geoffroy et al., 2019; Gjøsæter et al., 2017; Knutsen et al., 2017).

The mesopelagic layers, with depth ranges between 200 and 1000 m, present a challenge with currently available sampling methods. The combination of catch data with data from scientific echosounders provide an insight in the species composition and to the depth distribution of both fish and zooplankton communities. However, the limitations of echosounders with vessel-mounted transducers add to the challenge of obtaining reliable data for estimating biomass abundances. The reason for this is that among the frequencies normally utilized in scientific echosounders, only 18 and 38 kHz cover the mesopelagic ocean layer, since absorption of sound at higher frequencies hinders their use in target discrimination (Simmonds and MacLennan, 2005). Multifrequency analysis can be used for species identification and discrimination between zooplankton and mesopelagic fish (Holliday et al., 1989; Korneliussen and Ona, 2002; Proud et al., 2018). The new wide band generation of echosounders has the potential to substantially improve species identification (Andersen et al., 2013; Korneliussen and Ona, 2002; Lavery et al., 2017). However, the vessel mounted systems will still be limited in range at the higher frequencies, which are needed to separate and classify zooplankton. Wideband multifrequency data also presents challenges, namely the amount of

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Table 1
Echosounder specifications and settings used for the data sampling.

Frequency (kHz)	Vessel echosounders			Probe echosounders			
	18	38	120	38	120	200	333
Transducer							
Model	ES18-11	ES38B	ES120-7C	ES38B	ES120-7CD	ES200-7CD	ES333-7CD
Equivalent beam angle (10log Ψ [dB])	−17.0	−20.6	−21.1	−20.6	−20.7	−20.7	−20.7
Calibration							
Sphere	WC64	WC64	WC64	WC30	WC30	WC30	WC30
Range to sphere (m)	17	17	17	5	5	5	5
Sound speed [m/s]	1466	1466	1466	1466	1466	1466	1466
Absorption coefficient [dB/km]	3.1	10.4	31.3	9.97	38.09	53.48	78.9
Gain [dB]	23.15	26.25	25.28	23.2	28.0	28.0	24.45
Sa correction [dB]	−0.64	−0.65	−0.39	0.0	0.0	0.0	0.0
Beams							
Alongship half power opening angle[deg]	10.77	6.90	7.18	7.1	7.0	7.0	7.0
Offset Along. Angle [deg]	−0.11	−0.05	0.07	0.0	0.0	0.0	0.0
Athwartship half power opening angle [deg]	10.80	7.08	6.96	7.1	7.0	7.0	7.0
Offset Athwart. Angle [deg]	−0.16	−0.05	−0.01	0.0	0.0	0.0	0.0
Survey Settings							
Pulse duration [ms]	1.024	1.024	1.024	0.512	0.512	0.512	0.512
Electrical Power (W)	2000	2000	500	2000	250	120	40

data produced during a survey and increased effort in the interpretation. Acoustic profiling can thus be an important supplementary tool for studying vertical distributions of species such as mesopelagic fish and macrozooplankton.

We here present detailed analysis of data from an acoustic probe which was used in profiling mode to inspect the different backscattering layers at short range. The data are compared with the results from the vessel-mounted acoustic system. Zooplankton backscattering, which cannot be measured deeper than about 220 m from the vessel, is quantified and to some extent compared with the catch data obtained on the same survey. A methodology for improved quantification and separation of zooplankton is furthermore proposed.

This paper aims to address the following questions: i) Can we obtain reliable density estimates, with *in situ* measured target strength (TS) from mesopelagic fish targets and from macro- and mesozooplankton? ii) Will estimates of fish densities be the same using both acoustic sampling systems? iii) Will it be possible to use TS-probe data to estimate the abundance and vertical distribution of krill and amphipods, which are out of reach of the vessel transducers?

2. Methods

2.1. Sampling area

This study focuses on the area northwest of Svalbard, from 79.6°N to 82.2°N. The data were collected under the 2015 SI_ARCTIC/Arctic Ecosystem survey with *R/V Helmer Hanssen*, between 17 August and 7 September 2015 (Ingvaldsen et al., 2016). The coverage included the Yermak Plateau, northern Fram Strait and areas northwest of Svalbard.

2.2. Acoustic data collection

A profiling acoustic probe, referred to as TS-probe, mounted with sideways observing transducers, was operated like a CTD in profiling mode. The TS-probe was equipped with four scientific Simrad EK60 split-beam echosounders, operating at 38, 120, 200 and 333 kHz. In addition to the acoustic system, the probe was also equipped with a stereo-camera system with a strobe (Kubilius et al., 2015). The cameras were only used during the upcast of the probe system, since the downcast was to be used for data analysis. Onboard R/V *Helmer Hanssen*, a portable hydraulic winch with 1500 m electrical/optical cable was mounted on the side of the trawl deck and the probe was deployed over one of the A-frames on the starboard side of the vessel. Details on the TS-probe can be found in Thorvaldsen (2018). Profiles with the probe were taken on all major stations from 24 August on.

Acoustic data were collected from vessel-mounted Simrad EK60 split beam echosounders, operating at 18, 38 and 120 kHz frequencies. The transducers were mounted on the drop keel, which could be lowered from 3.5 m to 8.5 m below the sea surface (Korneliussen et al., 2008; Ona and Traynor, 1990). The vessel acoustic data were collected at a speed between 9 and 11 knots along pre-defined transect lines. The vessel mounted echosounders were calibrated prior to the start of the survey, on 17 August. A WC 64 mm sphere was used for checking that the calibration of the vessel was correct and that the echosounders were working properly (Ingvaldsen et al., 2016). The echosounders on the probe were calibrated on 19 August using a WC 30 mm sphere. For the probe, new gains were computed and entered into the calibration file on the post-processing system Large Scale Survey System (LSSS) (Korneliussen et al., 2006). In repeated calibrations from the TS-probe system there are observed changes in the gain (G_0) of less than 0.5 dB over the depth ranges used in this study (Andersen et al., 2008). No corrections to the data were made since this study is not aiming to report an *in situ* mean target strength for a species. For detailed target strength measurements, the system calibration should be made at the measurement depth.

The data collection settings and echosounder specifications, both vessel-mounted and from the profiling probe, are summarized in Table 1.

Profiles from the water column were collected with the sideways operating transducers while lowering the probe. The probe was lowered close to the bottom or, in deep stations, to 600 m at a speed between 0.22 and 0.59 m/s. The actual depth and speed of the probe was measured with an accurate pressure sensor mounted on the transducer platform, and the variation in lowering speed is due to the manual operation of the winch speed. The probe echosounders were operated at maximum, fixed ping repetition frequency (PRF) to a range of 50 or 100 m from the probe. The first 10 m from the transducers were excluded from the analysis of backscatter. Data from 20 stations were analyzed (Table 2). On each station, CTD, trawl, plankton and bottom fauna sampling gear were used sequentially. Due to this strategy, matching the timing was not always possible when making comparison of vessel data and probe data. In some stations, there could be several hours between the nearest valid vessel and probe data. With respect to total abundance at each station this should not be very different, but the vertical distribution of the backscattering organisms may have changed between the vessel data set and the probe data set (due to e.g. vertical migration).

Table 2
List of stations analyzed. The asterisk (*) indicates the stations for which there are images from the stereo camera.

Station Type	Station number	TS-probe data				Time 20-m grid	Vessel data		
		Date (2015)	Time	Sampling depth (m)	Bottom depth (m)		Date (2015)	Time	Bottom depth (m)
Hinlopen section	69	23.09	23:54	500	2227	00:01:02	23.09	12:27	2150
Hinlopen section	71	24.08	17:20	600	2226.84	00:00:37	24.08	15:19	2324
Slope crossing	72	25.08	21:26	500	510	00:00:41	25.08	19:21	1928
Hinlopen section	76*	27.08	05:49	650	2064.3	00:00:37	27.08	00:00	714
Ecosystem station	77*	27.08	16:51	650	1121.36	00:00:50	27.08	14:50	1235
Ecosystem station	78*	28.08	04:04	130	146.77	00:00:54	28.08	02:41	188
Ecosystem station	79*	29.08	22:50	450	464.31	00:00:46	29.08	05:41	546
Ecosystem station	81*	29.08	17:36	600	681.47	00:00:48	29.08	21:58	573
Yermak plateau	84*	30.08	19:47	650	742.25	00:01:31	30.08	16:15	842
Yermak plateau	85*	31.08	06:18	433	433	00:00:51	31.08	02:39	764
Fram Strait	86*	1.09	03:07	600	2430.01	00:01:03	31.08	21:48	1888
Fram Strait	87*	1.09	22:30	700	1540.28	00:00:36	1.09	14:13	2664
Fram Strait	88*	2.09	12:00	600	1092.29	00:00:34	2.09	07:36	1372
Fram Strait	89*	2.09	22:03	600	794.69	00:00:34	2.09	18:48	893
Fram Strait	90*	3.09	09:25	607	719.47	00:00:35	3.09	07:20	789
Fram Strait	91	4.09	01:32	450	486.89	00:00:39	4.09	20:27	666
Fram Strait	92	4.09	06:49	406	407.88	00:00:37	4.09	07:18	555
Fram Strait	93*	4.09	19:09	270	279.11	00:00:38	4.09	16:57	358
Ecosystem station	94*	5.09	06:22	614	912	00:00:34	5.09	10:09	967
Ecosystem station	95*	5.09	15:21	500	524	00:00:44	5.09	13:10	565

2.3. Acoustic data analysis

LSSS version 2.6.0 (Korneliussen et al., 2006) was used for processing all acoustic data for this study. The acoustic categories defined prior to the data processing were: 0-GR (age-0 fish), PLANK (broad category used for all planktonic species detected in the 0-group layer), COPEP (copepods such as *Calanus hyperboreus* or *C. finmarchicus*), COD (which included both *Boreogadus saida* and *Gadus morhua* for simplicity, since none of these species were the targets for this study), MESFI (*Lampanyctus macdonaldi*, *Benthosema glaciale* and other Myctophiformes), KRIAM (euphausiids and amphipods), BOTT (other demersal fishes contributing to the acoustic backscatter), PELAG (pelagic fish species contributing to the acoustic backscatter), OTHER (group including jellyfish, cephalopods, other unidentified or other resonant non-target species). From the vessel data, only MESFI category was used for analysis. In the TS-probe data, copepods could only be isolated when layers could be identified. Otherwise, their contribution to the KRIAM category is expected to be small since TS for copepods is reported to be around −100 dB at 200 kHz for 30 mm copepods (Stanton and Chu, 2000).

The nautical area scattering coefficients (s_A, m^2/nmi^2) was allocated to each acoustic category. The allocation to categories was based on relative frequency response of individual targets or layers (Korneliussen and Ona, 2002) as well as on the catch data. Data was exported from LSSS to R (R Development Core Team, 2008, Version 3.5.0) for analysis and figures.

The natural output of integrated echo energy in LSSS is the Nautical Area Scattering Coefficient as defined by Foote and Knudsen (1994),

$$s_A = 4\pi(1852)^2 \cdot \int_{r_1}^{r_2} s_v\, dr \quad (1)$$

where s_v is the volume backscattering coefficient (m^2/m^3), r_1 and r_2 are the range to the top and bottom of the layer of integration respectively, and $4\pi\ (1852)^2$ a normalization factor.

Data were exported from LSSS using a -90 dB re 1 m^{-1} S_V threshold. s_A was converted to volume density (ρ_v, number/m^3) as described in Maclennan et al. (2002). s_A was converted to area backscattering coefficient (s_a in m^2/m^2) using the formula:

$$s_a = s_A/4\pi(1852^2). \quad (2)$$

The spherical scattering cross-section (σ_{sp}, in m^2) was converted from the backscattering cross-section (σ_{bs}, in m^2) as

$$\sigma_{sp} = 4\pi \cdot \sigma_{bs} \quad (3)$$

Thus, both area (ρ_a, fish/m^2) and volume densities (ρ_v, fish/m^3) could be calculated as

$$\rho_a = s_a/\sigma_{bs} \quad (4)$$

and

$$\rho_v = s_a/\Delta z, \quad (5)$$

where Δz is the thickness of the integration layer in meters.

2.3.1. TS-Probe data analysis

Only the downward profile data was analyzed for 38, 120 and 200 kHz frequencies. In LSSS, seconds were defined as the unit for the horizontal grid and the grid size was calculated individually for each station (Table 2). As LSSS is a software used primarily for scrutinizing vessel-mounted data, the TS-probe profile is visualized horizontally; as such, horizontal grids defined in LSSS correspond to the depth intervals from the profile. Average speed for each 20-m depth interval was calculated per station, based on the pressure-time data. These data were then used for further analysis and data export from LSSS.

The targets were identified based on the relative frequency response r(f) and the categories used for the s_A allocation were the same as used for the vessel-mounted system during the survey. The relative frequency response r(f), defined in Korneliussen and Ona (2002) as

$$r(f) = s_v(f)/s_v(f_{38\ kHz}) \quad (6)$$

allows for the evaluation of the volume backscattering coefficient for each of the used frequencies, relative to the backscattering at 38 kHz. The r(f) expected for each acoustic category, described in Korneliussen and Ona (2003, 2002) was used as a baseline for the allocation of s_A for each acoustic category. The high resolution of the TS-probe data allowed for isolation of single targets, and for separation from the remaining targets of the echogram. The 'school box' function was used for such separation. For these targets, all s_A inside the school box was allocated to the indicated category. The frequency response curve was used for allocating single targets to specific category. Single targets that neither corresponded to the expected r(f) for fish nor krill were also isolated with school boxes and categorized as OTHER. In case of high-density layers of fish, like for juvenile fish registered near the sea surface, a layer would be created and the backscattering distributed

between juvenile fish and plankton, based upon how they reacted on signal thresholding. Catches from these layers were used to corroborate the decisions made by the thresholding method. The applied thresholds to be used for removing weaker targets were typically close to $S_v = -70$ dB re 1 m^{-1}. If strong aggregations of 0-group fish were found, harder thresholding even to −65 dB could be applied. Trawl data were used to support the species allocation made in the interpretation procedure. The 0-group and plankton categories were separated from MESFI and KRIAM categories but were not used for further analysis or density distributions.

In the mesopelagic layer, backscattering from weaker targets would be allocated to KRIAM category. Dense layers of copepods were also defined at stations where these layers were identified. These relatively clean layers exhibit a straight Rayleigh scattering form (Simmonds and MacLennan, 2005) with limited possibility for individual TS measurements. No further analysis has been done with this acoustic category.

After interpretation, the data were exported from LSSS for 38, 120 and 200 kHz to the database using a threshold of $S_v = -90$ dB re 1 m^{-1}.

2.3.2. Target avoidance in TS-Probe sampling

Kloser et al. (2016) has suggested that avoidance of fish targets could represent a potential bias for density estimates using a profiling probe. Avoidance by mesopelagic fish targets was assessed using the method reported by Patel et al., (2004); Draštík and Kubečka (2005), who compared fish densities at different distances from the source, the TS-probe in this case. On three stations (89, 90 and 91), the used sampling range (10–50 m) was divided into 5 m bins and data was exported to investigate avoidance. These data were selected from the mesopelagic layer in one or two depths along the profile (80 m in st. 89; 320 and 340 m in st.90; 260 and 340 m in st.91). A total of five samples (locations) were selected to make the comparison of the mean s_A values over the sampling range. The sections chosen were the ones that had fish detections in most of the sampling range. The data were then tested with a one-way anova in R to see if there was a significant difference in the mesopelagic fish mean density (H_0: Mean density of pelagic fish did not differ over the sampling range).

2.3.3. Target strength analysis from the TS-Probe

Detected target strength (TS) from single targets were exported from LSSS in selected regions and for each category. For MESFI, TS were exported for 38 kHz only. TS data for fish in the mesopelagic layer were exported only for the schools defined as belonging to this category. For the KRIAM category, TS was exported for both 120 and 200 kHz. The settings of the single echo detector (SED) used are listed in Table 3.

The spherical scattering cross-section (σ_{sp}, m^2) was calculated as

$$\sigma_{sp} = 4\pi \ 10^{TS/10} \quad (7)$$

(Simmonds and MacLennan, 2005), where TS refers to beam-compensated TS measurements (TSC, in dB re 1 m^2). For density calculations of mesopelagic fish, a mean σ_{sp} was calculated for each station as there were not enough TS detections per each grid cell. A minimum of 125 TS detections for mesopelagic fish targets was aimed, as described in Scoulding et al. (2015).

Estimating abundance of krill and amphipods, with *in situ* measured TS, was also one of the goals from this work. The species composition from KRIAM category have varied with depth. This was observed by the different frequency responses of the targets along the profile. Calculating *in situ* TS could be done with the TS probe data and is demonstrated in this paper. Since the WP2 net was the gear used systematically for plankton sampling, it was not possible to obtain data on vertical zooplankton distribution, and thereby finding layers with single species to take TS measurements. As a compromise between detection range and avoidance, the data in a layer from 10 to 20 m from the probe was used to reconstruct the density vertical profile. When profiling at a high ping rate to 50 m range from the probe, the same layers are observed in horizontal mode, from one to 50 m away from the probe. TS data were extracted both at 120 and 200 kHz for three stations (station 69, 84, 90). From these stations, data were extracted for the entire water column and for a selected school box only at different depths (station 69: 240–300 m, station 84: 280–320 m, station 90: 440–480 m and 560–600 m).

Table 3
Single echo detector (SED) settings used in LSSS for the TS-probe.

Frequency	38 kHz	120 kHz	200 kHz
Target	Mesopelagic fish	Krill and amphipods	Krill and amphipods
Minimum TS	−65	−80	−80
Max Gain compensation	3	3	3
Pulse Length Determination Level	6	6	6
Min Echo Length	0.8	0.8	0.8
Max Echo Length	1.8	1.8	1.8
Phase Deviation Check	Yes	No	No
Max Phase Dev Phase Steps	8	–	–

2.3.4. Vessel data analysis

For the analysis of the vessel data, the backscattering data from a 5-nmi section of the survey were selected for each location to be used for comparison with the TS-probe data. This also correspond to the elementary distance sampling unit (EDSU) used in the regular survey data for this Arctic survey. The selected section could either be from before or after probing. Proximity in time and space were used as a selection criteria (see Table 2 for details on the stations). The data was further divided into five 1-nmi intervals for measuring variability within the selected transect. Only data obtained at surveying speed (≈9 knots) and processed during the survey have been scrutinized and used for comparison with the probe data. The relative frequency response r(f), as described for the TS-Probe data processing, was used for the allocation of backscattering for each acoustic category. Only 38 kHz frequency was used for the vessel data analysis. Acoustic backscattering allocation to acoustic categories is to some degree subjective, involving expert interpretation.

The processing of the vessel data, for each echogram, included:

(1) **Bottom corrections** and possible **noise removal**. The accumulator integrator line was observed to assess the contribution of backscatter from other sources than the target species. All frequencies were inspected for noise, and procedures for noise removal were used if necessary.
(2) **Definition of layers**. Visual inspection of the echogram at different threshold levels, inspection of the r(f), use of the target detector function in LSSS to be able to discriminate between layers with different sized targets.
(3) **s_A allocation** for each layer. Allocation of backscattering was done based on the r(f) from the layer, on the catches and by sequential thresholding. In a layer which includes a mix of both fish and zooplankton targets, like for example a mesopelagic layer, sequential upper and lower S_V thresholding (moving the lower threshold gradually upwards while moving the upper threshold downwards, in −5 dB steps, with a minimum of 10 dB interval kept between top and lower thresholds) was done to determine the S_V at which each of the groups stopped dominating the scatters and the next one started. In the layers deeper than 220 m, the shift in the inclination of the r(f) graph was considered as an indication that another group was dominating the acoustic backscatter. For these layers, 200 kHz was not used. This sequential upper and lower thresholding was suggested by Korneliussen and Ona (2003) and refined by Uumati (2013). When measuring strong fish layers, like juvenile fishes (0-group) or dense mesopelagic fish layers, the s_A

Table 4
Categories used for grouping of the biological samples.

Category	Description
0-group	All fish species from the 0-age class
AMPHIPOD	Grouped of species from Amphipoda order (*Themisto libellula, Themisto abyssorum, Themisto, Gammarus wilkitzkii*)
CHAETOGNATHA	All specimens from Chaetognatha phylum (genus *Sagitta)*
CNIDARIA	Cnidarians from class Scyphozoa *(Cyanea capillata, Periphylla)*
CNIDARIA (HYDROZOA)	Cnidarians from Hydrozoa class (subclass Hydroidolina)
COD	All species from the Gadiformes order
COPEPODA	All species from Copepoda order
CRUSTACEA	Other species from Crustacea, excluding order Euphausiacea
DEMERSAL	Other demersal fish species other than Gadiformes
GASTROPODA	Pelagic species from Gastropoda *(Clione limacina, Limacina helicina)*
KRILL	Grouped of species krill from Euphasiidae family (genera *Meganyctiphanes* and *Thysanoessa*)
MESO	All fish species from Stomiiformes and Myctophiformes order
OTHER	Cephaopoda, Ctenophora
OTHER MESO	Mesopelagic fish *Arctozenus risso*
PELAGIC	Pelagic fish species

allocation was done at a lower threshold level than usual (S_V ranging between -65 to -75 dB re 1 m^{-1}) on each station. Since the high density of fish targets would otherwise 'mask' the presence of smaller targets (Logerwell and Wilson, 2004; McQuinn et al., 2013; Rudstam et al., 2008). To differentiate fish targets, like cod and mesopelagic fish, sequential thresholding of the weaker signals from the lowest S_v (-90 dB re 1 m^{-1}), in -5 dB steps was used, as described in Ingvaldsen et al. (2016).

(4) **Data export**. Data was exported from LSSS for further analysis and plotting in R.

(5) **Density calculations.** Density calculations for the acoustic category MESFI was done as described by equations above and was based on TS from *Benthosema glaciale* given in Scoulding et al. (2015).

A paired *t*-test was used to test the difference in area densities between the vessel and TS-probe (H_0: Mean area densities did not differ between vessel and TS-probe stations).

2.4. Biological sampling

Fish sampling was conducted with a Harstad (Dingsør, 2005), an Åkra (Valdemarsen and Misund, 1994) pelagic trawls and a Campelen bottom trawl (Engås, 1994). These gears targeted the 0-group layer, mid-water and bottom layers, respectively. The Harstad trawl has a ≈20 m vertical opening, with an opening area of ≈400 m^2, and has 8 mm meshes in the codend. The Åkra trawl is a medium sized pelagic trawl, equipped with a multisampler (Engås et al., 1997; Wenneck et al., 2008), facilitating the sampling at different depths in the mesopelagic layer during the same haul. This net has an opening between 20 and 35 m, and 8 mm mesh size in the codend. The bottom trawl used was a Campelen 1800, which is a small shrimp trawl with an opening of 5 m. The trawl was equipped with a ground-gear (rockhopper type, with discs of 35.56 cm). The codend had 40 mm meshes and was equipped with a 24 mm mesh sized liner.

Trawling was done at an average speed of 3.2 knots and the geometry and depth of the trawl was monitored by SCANMAR sensors. The catch was sorted and identified to the lowest possible taxonomic level, counted and weighed. Additional data on length, maturity and stomach content were also collected (Gjøsæter et al., 2017; Ingvaldsen et al., 2016).

Several gears were used for zooplankton sampling. A frame connecting a WP2 net (56 cm diameter, 180 μm mesh) and a Juday net (36 cm diameter, 180 μm mesh) was used in most TS-probe sampling locations (Ingvaldsen et al., 2016; Knutsen et al., 2017). This system was used for sampling on 31 locations, with vertical tows from the bottom to the surface. At four stations, there was additional zooplankton depth-stratified sampling with a Hydro-Bios Multinet MIDI (0.25 m^2 size aperture), equipped with 5 nets with a 180 μm mesh. Since the multinet was not used in most stations, its data were not used to corroborate the acoustic findings. The data were, however, inspected to look for "clean layers" to extract TS data. Wenneck et al. (2008) describe the gear as well as the equipment operation.

For the analysis of the biological data, catches both from the fish trawl and zooplankton nets were grouped (Table 4) to the relevant categories to be used for scrutiny.

3. Results

3.1. Distribution of mesopelagic fish

Fish densities were relatively low for all surveyed stations. The station which registered the highest density in the profile was station 81, with about 3 fish/1000 m^3 (Fig. 1). This density was only detected by the TS-probe and not from the vessel. Station 91 recorded the highest density for the vessel data, with less than 2 fish/1000 m^3.

In five of the sampled stations, the mesopelagic fish layer could be detected as shallow as 100 m depth during night, while for the remaining stations the layer was observed below 200 m depth. In four of the sampling locations, the mesopelagic layer extended to depths between 500 and 600 m. In 10 locations the layer did not reach beyond 450 m depth (Fig. 1).

The mean summed area fish densities (fish/m^2) were higher for the probe data than for the vessel-based data at some stations (Fig. 2). In four of the stations (69, 72, 77 and 89), no mesopelagic fish was detected from the vessel echosounder, whereas some were detected with the probe. Most of the stations had similar densities with both observation systems. From the probe data, calculated density ranged between 0.01 and 0.41 (fish/m^2). For the vessel, the range was from 0.01 to 0.29 (fish/m^2). The highest mesopelagic fish densities were registered in the Fram Strait on both systems.

Stations 84 and 94 had a wider spatial distance between the two samples than the other stations. The TS-probe showed to some extent higher mean densities over most of the water column, with exception of the stations from the Yermak Plateau, where densities were extremely low for both TS-probe and for the vessel data. When analyzing station profiles from both vessel and probe, some stations showed a mismatch in the depth distribution as well as for the depth of the peak density (Fig. 1). Station 91 was the only location where the vessel data showed slightly higher densities than the TS-probe data. Grouping all the stations, the overall mean area density was 0.138 and 0.0455 for TS-probe and vessel, respectively. Vessel and TS-probe area densities were significantly different (paired *t*-test, $p = 0.3132$).

3.2. Vertical distribution of krill and amphipods measured with the TS-probe

Depth ranges and peaks in zooplankton density varied among stations. The difference between the two frequencies used for zooplankton (120 and 200 kHz) varied over the water column and between stations. In stations 69, 79 and 84, the difference between the two frequencies was not evident while in other stations the distributions varied at some depths (Fig. 3). For example, station 72 showed that targets at 120 kHz dominated between 100 and 300 m depth range. Stations 77 and 87 showed that in the upper 300 m, targets were detected both at 120 and 200 kHz, while below 300 m there was a dominance of targets detected at 200 kHz.

3.3. Target strength analysis

The number of TS detections for mesopelagic targets was enough (> 125 per station) to allow for calculation of mean TS for each sampling location. A tendency for the mean TS to increase with depth can be observed in some stations (Station 87, 89 and 91; Fig. 4).

For most of the stations, targets were detected between 200 and 500 m depth, with an overall tendency for larger targets to be detected at greater depths (Fig. 5). The histogram shows a detection peak for fish targets identified in the mesopelagic layer between −55 and −60 dB. Another peak is seen between −55 and −52 dB.

The calculated mean TS per station ranged between −55.0 and −60.3 dB (Table 5). The mean TS detected in most stations was between −55.1 and −56.9 dB, except for stations 87 and 89 which showed a lower average. All averaging shown in Table 5 was done in the linear domain. The minimum and maximum TS detections show that targets have been detected from −74.3 up to −50.1 dB. However, the interquartile range varied between 1.5 and 4.2 dB within the stations, showing a minor influence of the outliers.

Multinet sampling was only conducted in connection to three TS-probe stations. Thus, there is no depth stratified data available for zooplankton for most of the stations sampled. The availability of such data would be crucial to select depth intervals for TS data extraction. Good TS registrations for krill and amphipods were obtained in some locations, as seen in Fig. 6. When selecting TS targets from the whole profile, there is seen an overrepresentation of smaller targets which might be present at determined depths of the water column (Fig. 7). Since TS is measured in the logarithmic domain, the contribution of these weaker targets to an overall mean TS would be minor.

3.4. Biological sampling

Trawl sampling in the mesopelagic layer was limited to seven sampling locations. An overview of the catches are available in Table 1

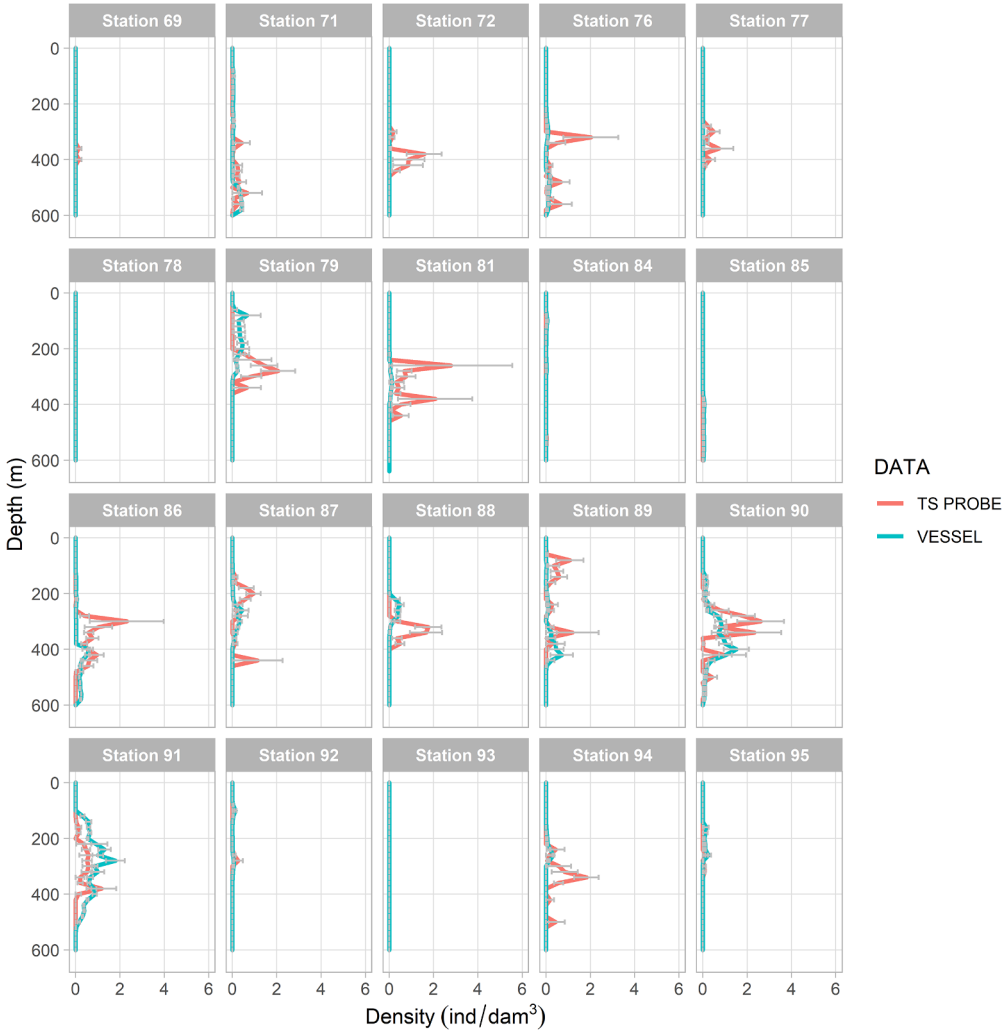

Fig. 1. Mesopelagic fish densities (fish per 1000 m^3) over depth for each sampled site, from 38 kHz data. Vessel (blue color line) and TS-probe (salmon color line) density profiles are shown with ± 0.95 confidence intervals (in grey). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

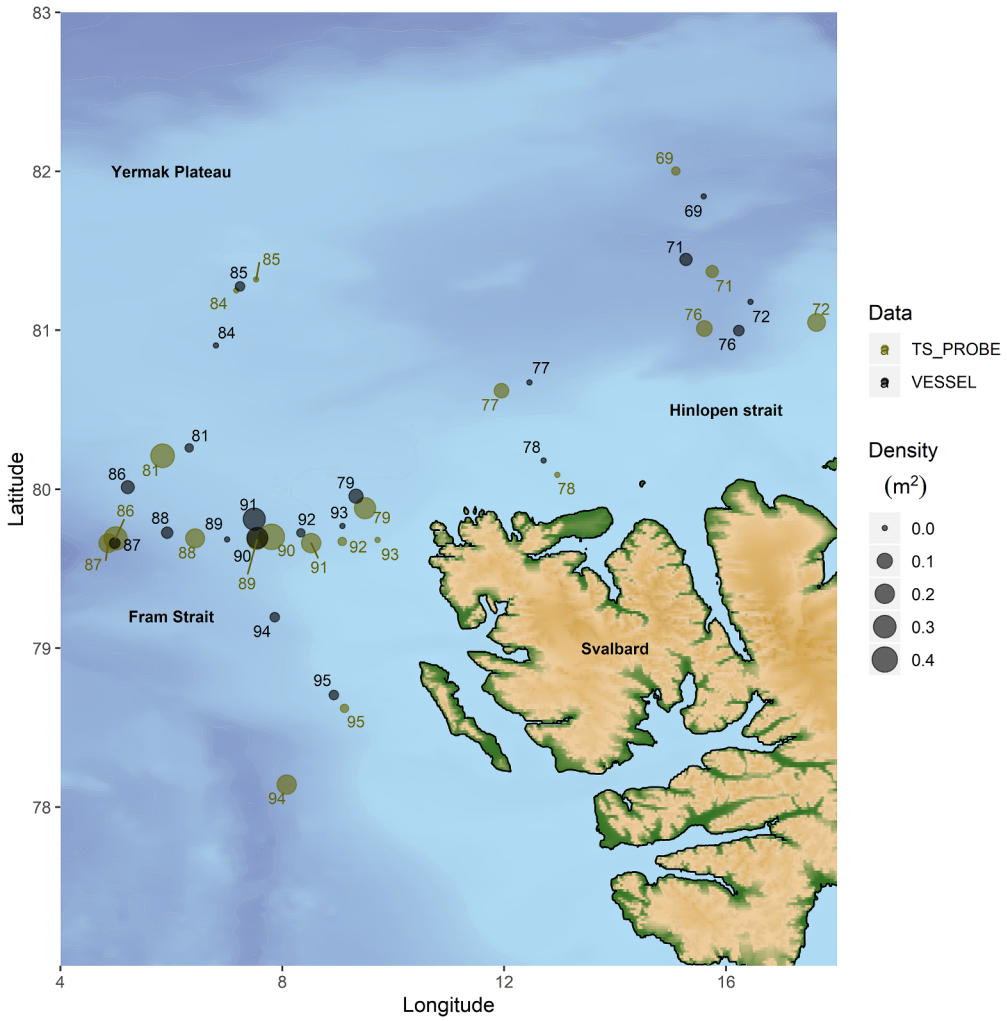

Fig. 2. Fish density (number per m^2) comparison. Green circles show the TS-Probe and black circles show the vessel density values. The radius of the circles is proportional to fish densities. Station numbers are shown next to the data. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(from data in brief). The dominant groups recorded varied among hauls, with the 0-group being the most representative in several hauls. Krill, amphipods and mesopelagic fish also dominated the catch in some hauls. Mesopelagic fish species were recorded in 13 hauls. From this group, *Benthosema glaciale* and *Lampanyctus macdonaldi* were identified, however in most stations, specimens from the group could not be identified to species level due to the lack of taxonomic expertise on-board. No mesopelagic fish specimens were taken for post-survey identification since this was not a focus of the survey.

0-group fish, cod, polar cod, amphipods and krill were caught at most stations. Length distributions for the most frequently caught fish species can be consulted in this article's data in brief (length frequency histograms). Krill was not recorded in four stations while amphipods were registered in all hauls, except for one. Chaetognaths were nearly absent from trawl catches, as expected due to mesh size. In the WP2 samples, however, Chaetognaths were present in all hauls except for station 93 (Table 2 from data in brief). Euphausiids were caught at 10 stations and amphipods were caught in all stations, except for one. Copepods were recorded with genera *Calanus* and *Paraeuchaeta* in most WP2 catches, except at stations 78 and 79. Siphonophores were recorded in nine of the trawl stations.

4. Discussion

Studies conducted in Arctic regions might provide an invaluable insight into the changes affecting Arctic ecosystems (Fossheim et al., 2015). Acoustic surveying has been widely used for observation and monitoring of marine ecosystems (Simmonds and MacLennan, 2005). These techniques are important tools for large-scale descriptions of prey and predator fish populations, as well as some important zooplankton components. In shallow areas (< 200 m), like the North Sea, Bering Sea, and parts of the Barents Sea, one may rely on standard multi-frequency methods for categorization and abundance estimation. When target categories, like bottom fish, pelagic schooling fish or zooplankton can be isolated on the acoustic records, directed sampling with suitable gear may be used for identification and biological sampling. In deeper ecosystems, sampling the deep scattering layers may be a challenge, and the density estimates may be strongly affected by the catch efficiency of different size groups. Studies have shown that catchability of deep-water nekton depends on the type of taxa targeted, when comparing different trawl gears (Heino et al., 2011). Thus, a potential exists for using the TS-probe to fill gaps and to assist the interpretation of acoustic backscatter, complemented with suitable gear sampling and optical tools.

4.1. Mesopelagic fish densities: Comparison between TS-probe and vessel echosounders

For this study, a hull-mounted echosounder and a TS-probe system were used to assess mesopelagic fish densities. Common to both systems

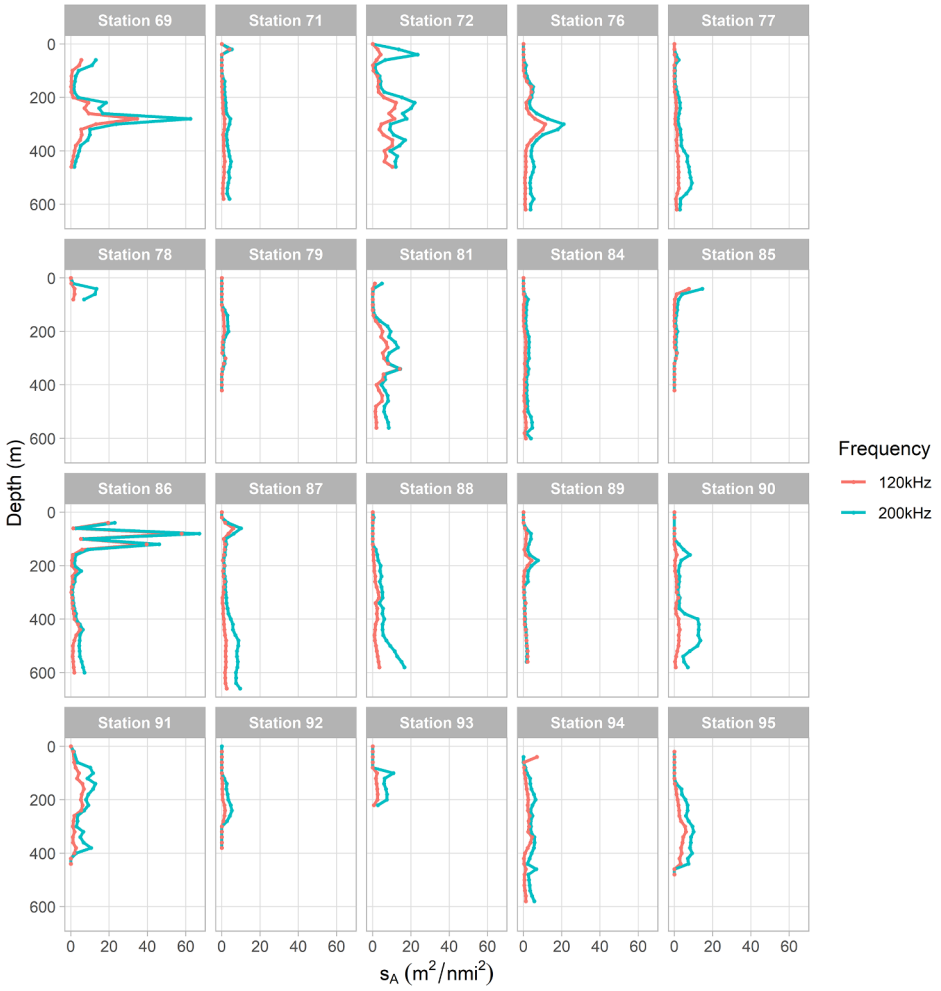

Fig. 3. Nautical area scattering coefficient (NASC, m^2/nmi^2) as a function of depth for krill and amphipods at 120 and 200 kHz at 20 profiling stations.

was that the measured fish densities were extremely low. This is in accordance with literature citing mesopelagic fish as virtually absent in the Arctic (Catul et al., 2011; Kaartvedt, 2008). *Benthosema glaciale*, *Lampanyctus macdonaldi*, and other Myctophidae were identified from trawl catches from 13 of the 20 stations surveyed for this study. Even though the catch data has been used to assist the interpretation of the echosounder data, mesopelagic fish have been identified also for stations where they had not been recorded in the trawl catches. For TS-probe and vessel data, mesopelagic fish were identified in 15 and 12 stations, respectively. The lack of trawl hauls inside the mesopelagic layer for some of the stations analyzed adds to the challenge of species identification during the acoustic post-processing. Bottom trawl hauls, despite not targeting the mesopelagic layer, were also used as an indication of presence/absence of mesopelagic fish. However, catchability of mesopelagic fish is known to be gear dependent, shown to be lower with Åkra trawl compared to a specialized macrozooplankton trawl (Heino et al., 2011). Similarly, avoidance from pelagic trawls by mesopelagic fish was reported by Kaartvedt et al. (2012).

The vertical distribution of the mesopelagic fish fauna could be calculated from both acoustic systems. Fish densities from both methods were low, with slightly higher mean values recorded with the TS-probe. The two samples have not shown a statistically significant relation. This is likely due to the combination of higher thresholding used in the vessel data and a better resolution from TS-probe data. When individual components have overlapping backscattering strength (S_v distributions), thresholding on a mixed aggregation involves a difficult compromise not to exclude a large percentage of the backscattering from one component in the aggregation. This is well illustrated in Uumati (2013) when trying to extract backscattering from jellyfish when mixed with small fishes. Since all the fish targets are well resolved with the TS-probe data, the entire target backscattering is included in this interpretation, whereas for the vessel data a compromise between the contribution to the total backscattering from the KRIAM and MESFI categories had to be reached. Vertical distributions also differed between methods at least for some stations. This may be attributed to the time lapse between the two samples. Only 'on track' (i.e. between stations) vessel data were chosen to be analyzed, opposite to TS-probe data which were obtained on station. This choice was made since the transect data are normally used for calculation of abundance indices, and therefore these data were the main goal for comparison with the probe measurements. Extensive survey sampling created, however, both spatial and temporal lags which might affect the observations of the vertical distributions. A limited diel vertical migration (DVM) of the Arctic mesopelagic scattering layer was reported by Gjøsæter et al. (2017), based on data from the same survey. Although the DVM varied between locations at all sites, the authors reported a difference between the depth of the mesopelagic layer during low and high light intensity. Stations 69, 79, 86 and 87 showed the largest temporal gap between the two sampling methods (11, 17, 5 and 8 h respectively). This could explain the distribution shift. Stations 84 and 94 had considerable spatial distance. In station 94, the probe recorded up to 2 fish per 1000 m^3 compared to < 1 fish per 1000 m^3 in the vessel data.

Possibly the TS used to calculate mean densities could also be a source of difference between the datasets. The vessel densities were converted to biomass using literature data on TS (Scoulding et al.,

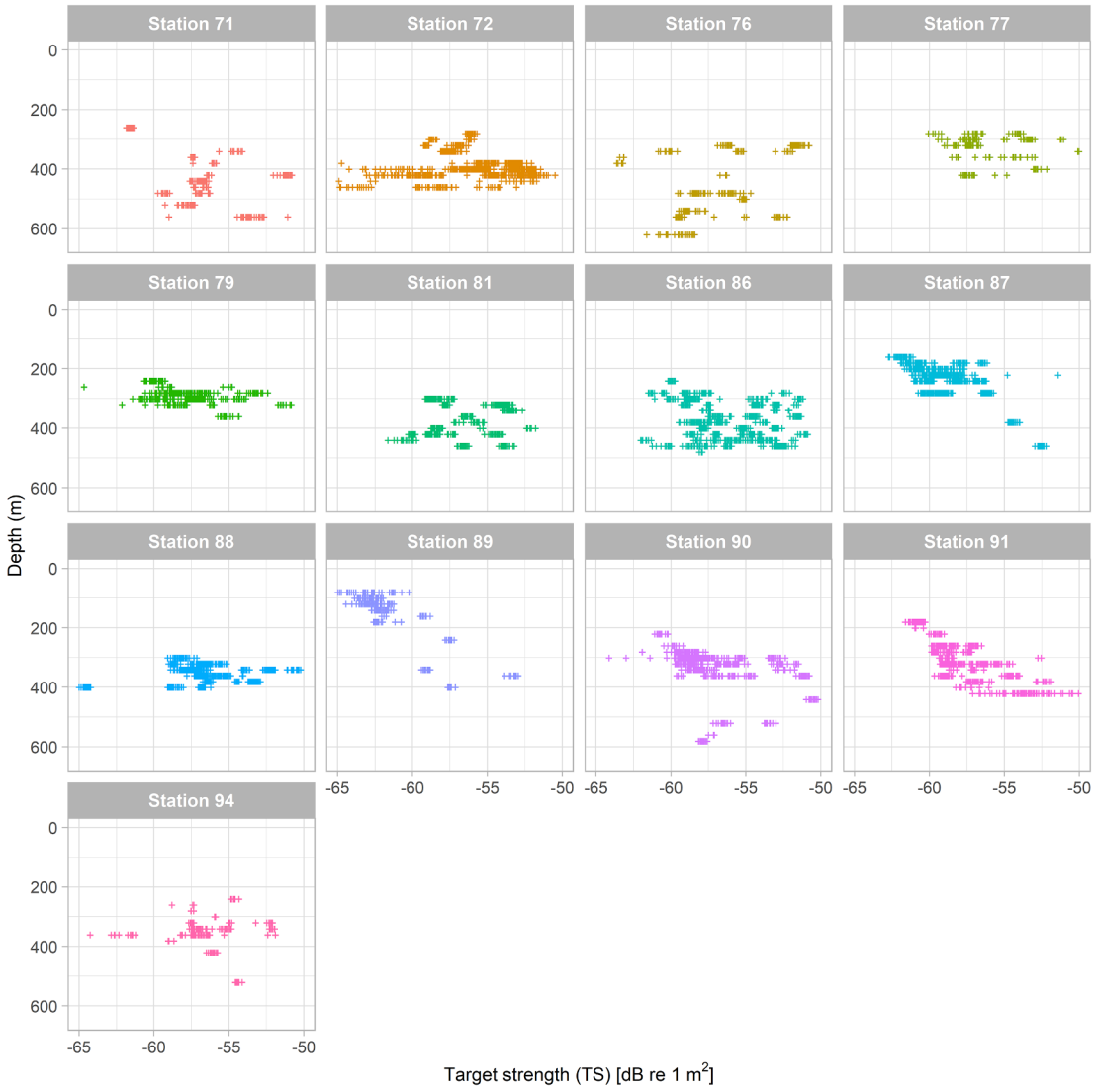

Fig. 4. Target strength (TS) detections for mesopelagic fish by Station. The plots show beam compensated TS (in dB re 1 m^2) over depth (m) for the stations that registered > 125 detections per station.

2015), while the probe data densities were converted with a direct mean *in situ*-measured TS, in the lateral aspect. We therefore believe that the probe data are a more correct measure for conversion to density for this group. Multifrequency analysis can be used in a more consistent manner with the TS-probe data as the inherent range limitation, an issue for higher frequencies in vessel-mounted echosounders, is non-existent in the probe data. This could also be regarded a factor responsible for inconsistency between the results from the two systems. Bias created by the fact that the TS-probe is sampling in lateral aspect, compared to the vessel echosounders, is dismissed as a cause for differences in densities. Since the sonar equations and density measurements are valid both for lateral and dorsal aspects, we believe that the lateral aspect does not bias the TS-probe observations. The literature target strength values used for density calculations of vessel data could on the other hand bias the results, since TS is known to be species-specific as well as size specific. The reference target strengths used for the vessel data were also collected in a Norwegian fjord, rather than in the Arctic. Differences in swimbladder volume and oil content in mesopelagic fish between the sites are likely creating physiological differences in mean target strength (Ona, 1990).

The contribution from other fish species to the mesopelagic fish densities, as to their TS measurements, could be expected due to the presence of *Boreogadus saida*, *Gadus morhua*, *Mallotus villosus*, *Arctozenus risso* or *Sebastes* species in the catches. 0-group fish, despite present in nearly all trawl catches, is not expected to be found below 60 m depth (Dingsør, 2005; Prozorkevich et al., 2018; Prozorkevich and Sunnanå, 2016), thus likely not influencing TS measurements from the mesopelagic layer. *Boreogadus saida* is reported to distribute from 20 to 500 m (Ajiad et al., 2011) and as such be potentially detected in the mesopelagic layer. However, their contribution has been deemed negligible since this species has been caught mostly in bottom hauls. As an example, from station 92 (trawl series number 2070), 14 individuals were recorded in the catch, whereas nearly no mesopelagic fish targets were identified with acoustics. Both stations 72 and 81 showed larger numbers of polar cod individuals than mesopelagic fish in the catches (series numbers 2026 and 2042, respectively). The incorporation of polar cod on the TS measurements, attributed to MESFI, is not likely since the interquartile range for MESFI TS measurements in those stations do not coincide with those predicted for polar cod. Predicted TS ranges for polar cod in stations 72 (Min TS: −52.4 dB; Max TS: 45.6 dB; Q25: −49.6 dB; Q75: −47.5 dB) and 81 (Min TS: −52.4 dB; Max TS: 45.9 dB; Q25: −52.4 dB; Q75: −50.4 dB), calculated by applying the target strength relation

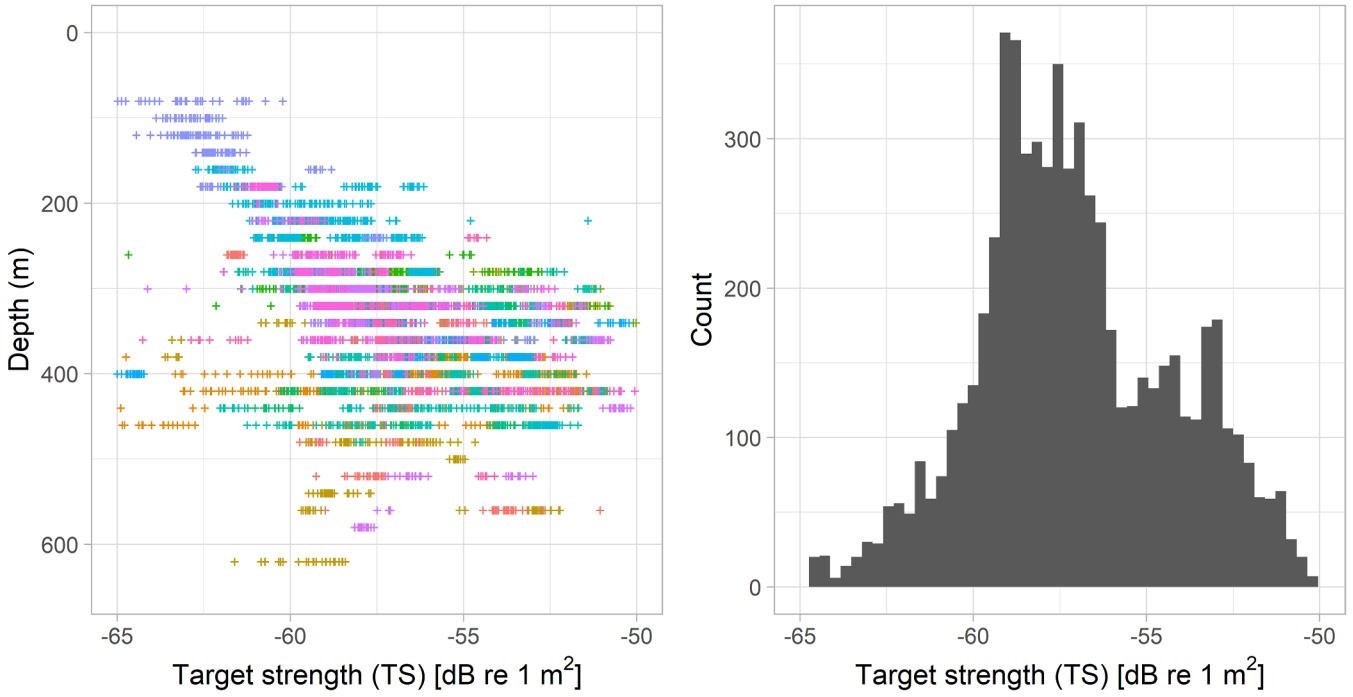

Fig. 5. Mesopelagic fish target strength detections (in dB re 1 m^2) grouped for all stations. Left y-axis shows depth (m) and right y-axis count. Left figure: Profile of the TS detections over depth, for all stations represented in different colors (from Fig. 4); Right figure: histogram of all TS detections.

Table 5
Summary of statistics of mean TS, confidence interval for the mean and Q25 and Q75.

Station	*n*	Mean	Median	Min.	Max.	Q25	Q75
TS_71	261	−55.61	−56.88	−74.30	−50.78	−57.78	−54.18
TS_72	854	−55.10	−55.75	−64.89	−50.47	−57.60	−53.32
TS_76	241	−55.85	−57.98	−63.61	−50.78	−59.10	−55.23
TS_77	205	−55.03	−56.83	−60.06	−49.83	−57.52	−53.74
TS_79	406	−56.91	−57.82	−64.67	−50.83	−59.26	−56.60
TS_81	443	−56.10	−57.13	−61.65	−51.80	−58.52	−54.27
TS_86	864	−55.26	−56.35	−62.03	−50.88	−58.27	−54.03
TS_87	805	−58.27	−59.26	−62.73	−51.41	−60.29	−57.88
TS_88	712	−55.79	−56.87	−65.00	−50.22	−57.99	−55.36
TS_89	237	−60.43	−62.28	−64.98	−52.95	−62.73	−61.19
TS_90	689	−56.24	−58.01	−64.12	−50.18	−58.92	−56.19
TS_91	580	−56.92	−58.39	−61.61	−50.06	−59.15	−56.55
TS_94	171	−55.82	−56.50	−64.26	−51.89	−57.42	−55.08

$$TS = 21.8 \ \text{Log} \ L - 72.7 \quad (8)$$

used in the assessments in the region (Prozorkevich et al., 2018) showed that the overlap between the TS of polar cod and mesopelagic fish is minimal (Table 5). The contribution of *Arctozenus risso* to the target detections of mesopelagic fish would be expected. Despite being recorded at nine stations, it is not likely to influence the data since the individuals caught ranged from 12.5 to 28 cm. *Mallotus villosus*, caught also at several stations, is also not expected to have biased the MESFI TS detections since it was only caught in the upper 60 m. *Sebastes* could in theory contribute to the TS detections since it is found in the Arctic mesopelagic fish assemblages. Since mostly 0-group *Sebastes* was recorded in the catches, it is not likely to have contributed to the TS detections of MESFI. The presence of one-year-olds *Sebastes* in the mesopelagic layer is however a hypothesis that cannot be rejected. However, in station 78 *Sebastes* was caught both from Harstad and Campelen trawls, including individuals with lengths up to 8.5 cm. However, no TS detections are registered at that station in the TS-probe system.

The presence of jellyfish in the catch of some stations could potentially influence the TS from the mesopelagic layer. Both *Cyanea* and *Periphylla* were caught at some stations. Still, the influence of these targets is considered negligible. When present in the layer, jellyfish are weak scatterers that can be separated in close range from gas bladder targets, using frequency response and target strength. Jellyfish acoustic identification has been described by Brierley et al. (2004) and Crawford (2016). They described the TS from jellyfish varying cyclically over a range of 15 dB and that the discrimination between fish and jellyfish was simplified by a repetitive pattern of varying TS attributed to the umbrella movement.

Since most of the backscatter from fish is caused by the gas contained in the swimbladder (Foote, 1980), the presence of gas bearing Siphonophores (Cnidaria: Hydrozoa) could potentially affect the estimates of mesopelagic fish (Davison et al., 2015; Proud et al., 2018). At frequencies near resonance for the gas bubble, these gas-bearing organisms can have a significant contribution to the backscatter if present. Siphonophores have been largely under sampled on routine fisheries surveys (Mapstone, 2014; Proud et al., 2018) and target sampling is still not done (Hosia et al., 2017). The catchability of this group is gear specific (Hosia et al., 2017) and the gear used to sample this group varies. Considering the fragility of these organisms, it is fair to assume that, if present in the water column, a large portion of these would not be retained in the trawl. However, it is expected that despite the low catchability, either higher proportions of siphonophores in the trawl, or more frequent presence in the pictures would reflect an increase in the density in the water column. WP2 data, trawl data and stereo-camera images were considered as indicative for the presence/absence of this group. Siphonophores were recorded in the mesopelagic layer in some trawl catches, namely at station 90 and 93 (at 400 and 100 m, respectively). At station 90, many siphonophores in WP2 catches were also registered. The pictures taken by the probe stereo-camera did not record siphonophores in the mesopelagic layer, neither from the two mentioned stations nor from any other station with optical recordings. From the screening of the stereo-camera's pictures, only chaetognaths were registered at nearly all stations. Backscatter from these are not expected to affect mesopelagic fish biomass, as they are not gas bearing organisms. It is still possible that siphonophores have some influence in

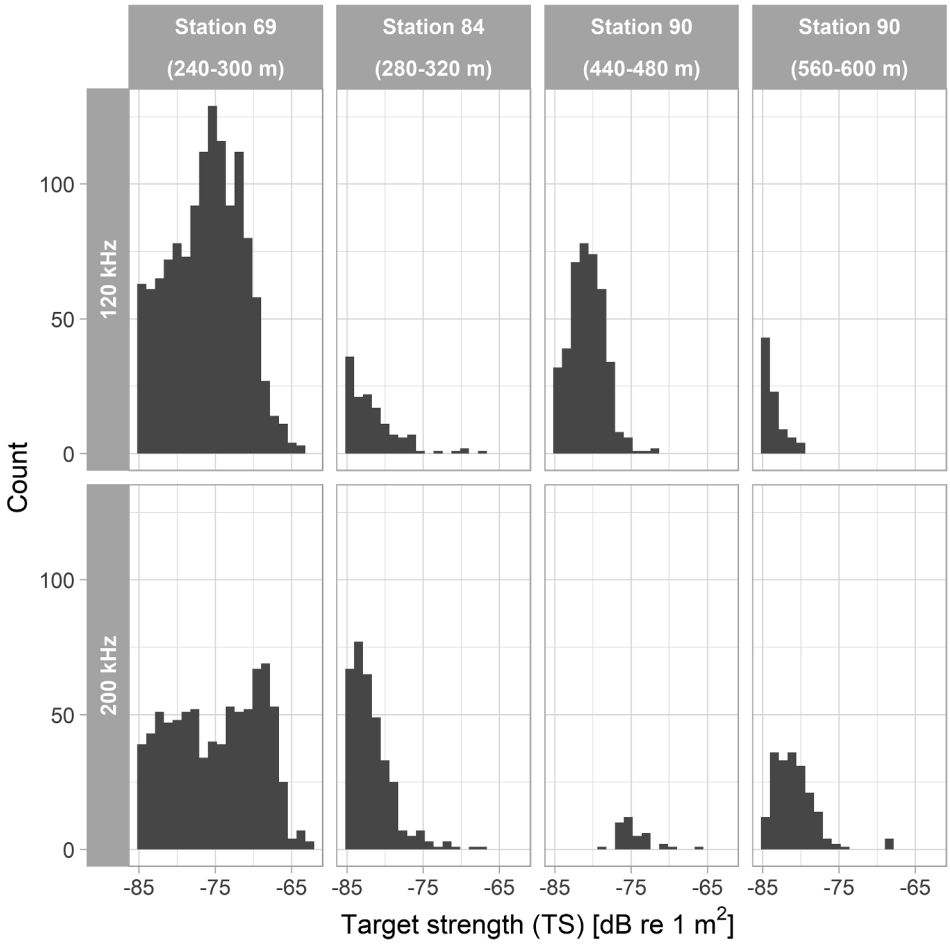

Fig. 6. Target strength detections (dB re 1 m^2) in regions interpreted as Krill and amphipods. TS data from school boxes from 3 selected stations; data extracted 10 to 20 m from the transducer. The depth interval from selected data with depths specified in the figure. Upper row shows data at 120 kHz and lower row at 200 kHz.

the densities in the mesopelagic layer registered by the vessel. According to predictions of TS values in Proud et al. (2018), TS of siphonophores can decrease more than 10 dB from resonant backscattering at 38 kHz to higher frequencies. Such large TS differences were not seen in these data. Since no such large differences were found in the mean TS of the assumed mesopelagic fish, the influence of siphonophores to the density of this group is assumed to be small.

Avoidance could be expected to influence mesopelagic fish densities estimated by an acoustic probe and is listed as a potential bias by Kloser et al. (2016). However, the results from one-way anova assessing differences between the mean densities over the sampling range (Fig. 3 and Table 3 from data in brief) showed no significant differences in densities with range between 10 and 50 m from the probe. Thus, there is no evidence of avoidance when the targets are located more than 10 m from the probe. Avoidance from mesopelagic fish within 10 m from the probe is expected, as described by Ona and Pedersen (ICES, 2012). Since the analysis for this paper only considered the 10 to 50 m range, any influences of avoidance behavior recorded in the TS-probe data are considered negligible.

Depth-dependent resonance is indicated as a potential factor for overestimating mesopelagic fish abundance (Davison et al., 2015; Proud et al., 2018). Diel vertical migration is reported to influence the backscattering from mesopelagic fish species due to swimbladder resonance, with highest influence at lower frequencies (Godø et al., 2009). The authors differentiate between shallow migrating layers and deep-scattering layers (DSL), which showed different patterns of resonance. The shallower DSL was composed mostly by *Maurolicus muelleri* which had higher resonance at higher depths. The non-migrating layer, mostly composed of species from the Myctophidae family, also indicated some resonance, although considerably lower (Godø et al., 2009). The present study does not indicate resonance among mesopelagic fish at 38 kHz from the vessel-mounted system. Presence of increased resonance with increasing depth would have estimated much higher densities at increasing depth compared to the probe system since a constant TS was applied when converting from backscatter intensity to fish density.

The use of multifrequency analyses for target identification in the mesopelagic layer is limited by the depth range from high frequencies (Simmonds and MacLennan, 2005). For traditional acoustic surveys, only data from 18 and 38 kHz frequencies can be used to cover the mesopelagic layer, with a good signal to noise ratio at mesopelagic depths (Davison et al., 2015; Godø et al., 2009). This hinders the refinement of target identification for organisms below the epipelagic layer. Such limitation applies to broadband systems as well. The use of a profiling acoustic probe addresses this limitation, as suggested in Proud et al. (2018). Obtaining good TS data *in situ* is important for profiling acoustic systems, either using the transducers in dorsal or lateral observing modes. In the present paper, some limitations in the data collection made it difficult to record good TS data from krill and amphipods. However, for mesopelagic fish, it was possible to collect enough data to calculate a mean TS for each sampling location. Combined mesopelagic TS-detection histograms showed a bimodal distribution, which could either be an indication of more than one species of mesopelagic fish being detected, such as *Benthosema* and *Lampanyctus*, or bimodal length distribution of a single species (or a mix thereof). The increase of TS with depth could also support the indication that either

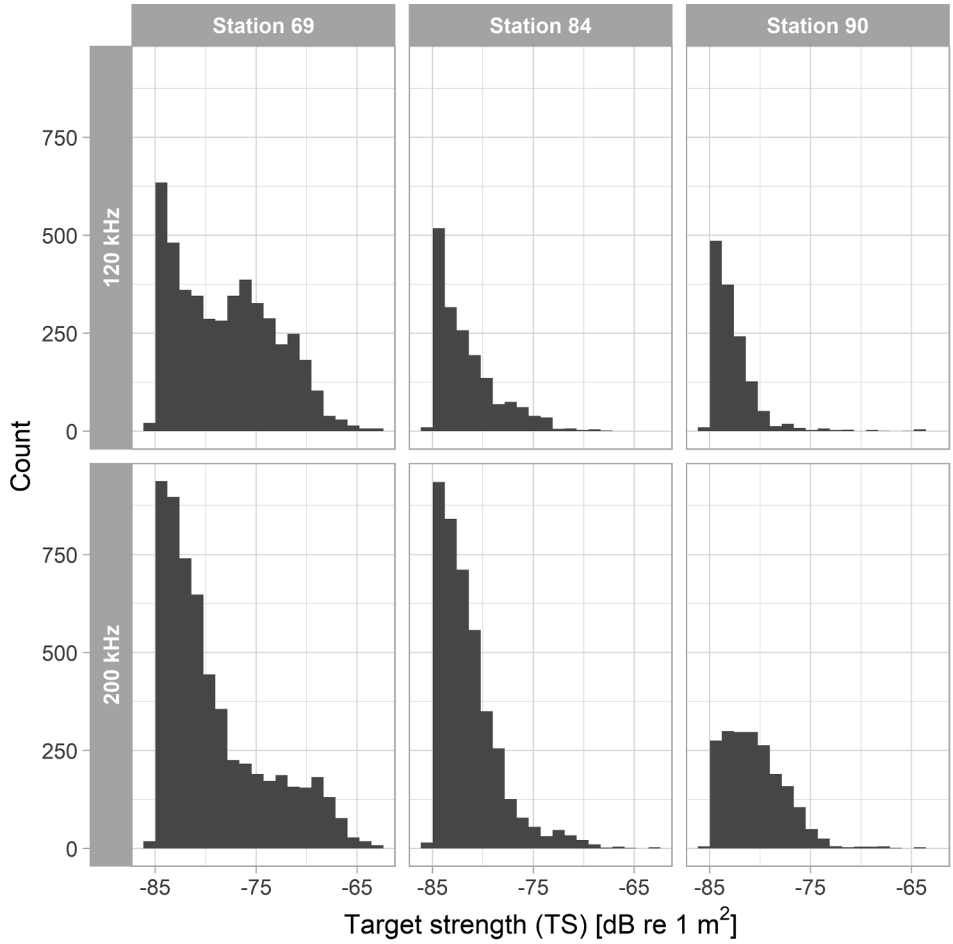

Fig. 7. Target strength detections (dB re 1 m^2) interpreted as Krill and amphipods. Plots show histograms for the entire KRIAM vertical distribution.

more than one species of mesopelagic fish was recorded or that different length sizes were present. The taxonomic identification of mesopelagic fish, up to species level, was only possible in 3 of the stations where mesopelagic fish was recorded, making it difficult to draw any conclusions.

4.2. TS detections of krill and amphipods

The density of krill and amphipods is possible to calculate using a profiling probe, since TS data extraction was demonstrated at three stations. However, in this study densities of krill and amphipods were not estimated due to limitations in the biological data collection. Thus, these data were not used to its full extent. When inspecting the echograms for zooplankton, it was possible to detect some layers of apparent single species (see Fig. 6). When comparing the data from the selected layers with the data from the entire water column (Fig. 7), the detection of other organisms, like chaetognaths or copepods, could be pulling the TS distribution towards a lower value.

The detection of clear copepod layers in the probe data, namely at 200 kHz, shows that this group can be detected by the TS-probe. The TS detections demonstrated in this paper were considered to be representative of larger zooplankton as they were in accordance with the range reported by Klevjer and Kaartvedt (2006), which reported TS values ranging from −68 to −77 dB for *Meganyctiphanes norvegica*. Targeted net samples, together with the development of a consistent method for the analysis of recordings by the stereo cameras, are potentially useful tools for discrimination and ID of plankton targets. The different gears used for zooplankton sampling have different catchability for the various zooplankton groups. The use of the TS-probe shows a potential for measuring zooplankton densities *in situ*. Nonetheless, the sampling must also be directed towards better quantification of the zooplankton scattering layers by target net hauls in these distinct layers, to corroborate acoustic or optic sampling tools. Systematic use of multiple opening and closing sampling gear, like Multinet (Hydro-bios) should be considered.

4.3. Vertical distribution of krill and amphipods

For some stations, the vertical profiles of s_A varied between the two frequencies used (120 and 200 kHz). Other stations appear to be relatively stable over the water column with consistent with respect to the difference or ratio between the frequencies. The contribution of copepods for this profile cannot be ruled out but according to Stanton and Chu (2000), individual copepods are expected to be 100 times weaker (TS between −100 and −110 dB re 1 m^2), and their contribution to the scattering in this interpreted profile is not expected to be large. Automatization of acoustic classification based on frequency response has increased potential for high-resolution data like those coming from the TS-probe. This possibility is further enhanced by the potential offered in new broadband systems. Zooplankton is an important player in the trophic chains of marine ecosystems. The lack of plankton sampling data with vertical resolution limits conclusions on the vertical distribution of the various zooplankton groups for this study. However, there is potential for using the profiling probe for describing zooplankton species distribution and furthermore divide these into different taxonomic groups (e.g. krill and copepods) based on differences in TS and frequency response. Further work needs to be done, especially in close-range target strength and response measurements in clean

concentration of krill and amphipods. Such work could benefit from improved camera methods both inside trawls (Rosen et al., 2013) and on the probe, with extended range resolution (Kubilius et al., 2015).

5. Conclusion

We have shown that the densities estimated by the vessel's 38 kHz echosounder give valid description of the true densities and the vertical distributions of mesopelagic fish in the Arctic region. There is potential for using the TS-probe, possibly complemented with suitable gear sampling and optical tools, for filling gaps and assisting in the interpretation of acoustic backscatter in the upper 1000 m of the water column. Mesopelagic fish were easily discriminated by the probe, producing clear single target conditions over the entire observation range from 10 to 50 m from the probe at all depths. Furthermore, avoidance of fish due to the probe was not observed outside a range of 10 m from the probe. The use of a profiling acoustic probe addresses the limitations of multifrequency acoustics on vessel mounted systems and limitations in present fish and zooplankton sampling methods. The contribution from siphonophores and from resonance at 38 kHz to the mesopelagic backscatter are considered minor in this survey.

Author contributions

IB wrote the first draft of the manuscript and produced most of the figures and tables. EO contributed to the study design, acoustic data analysis and have contributed to the text throughout the manuscript. HG contributed to collection and data analysis of the vessel data, and to the overall text.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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