10.4 Sonar recordings on board the RV “G.O. Sars”

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Background and objectives

Active sonars transmit and receive sound pulses. By custom, the term “echo sounder” is sonar that is essentially vertically oriented sonar, and the term “sonar” is used within fisheries acoustics if the beams are essentially horizontally oriented. Here, we use the term “echo sounder” if the beams are within ±30° from vertical, and sonar if the beams are 30° - 90° from vertical (i.e. 90° is horizontal). Echo sounders are typically used for abundance estimation during monitoring surveys for pelagic fish, also for Barents Sea capelin. With developing technology, sonars must be evaluated as supplements or even in some cases alternatives to conventional echo sounders. Sonars have the advantage over echo sounders that they sample a considerably larger volume of water including volumes usually inaccessible to echo sounders like surface waters.

The RV “G.O. Sars” is equipped with echosounder and two sonars, all manufactured by Simrad (Kongsberg). For both the echo sounder and the sonars there is now opportunity to log data and post-processing software available.

The main objective of applying the EK60 echo sounder is abundance estimation.

The main objective of applying the MS70 sonar was to find out whether it can be used as a supplement or even an alternative to conventional echosounders to quantify capelin biomass, in particular in cases where capelin are distributed close to the surface.

The main objective of running the SX90 sonar was to quantify swimming direction and speed of the capelin to evaluate whether there was systematic migration during the survey potentially biasing the survey estimate.

Application and methods

<u>EK60 recordings</u>

The scientific echosounder EK60 is modular by means of one GPT (General Purpose Transceiver) and one transducer for each frequency controlled by a common PC using MS operating system. The EK60 onboard RV “G.O. Sars” are connected to transducers at the frequencies 18-, 38-, 70-, 120-, 200- and 333-kHz in a tightly packed configuration for optimal spatial overlap with the purpose of reliable species identification.

EK60 was used during all of the survey. The data were processed by means of LSSS to remove noise and do automatic species detection. The EK60 data were scrutinized daily during two sessions. The official capelin abundance is based on the EK60 results. Capelin was also automatically identified from multi-frequency and pre-processed EK60 data by means of LSSS.

The EK60 data were processed in sequence the following way prior to scrutinizing: (A) Remove spike noise, e.g. due to unsynchronized instruments; (B) Correct for transducer geometry; (C) Detect bottom; (D) Remove ambient noise; (E) Remove unnecessary data; (F)

Detect school-candidates; (G) Suggest acoustic categories (i.e. do "species identification"). See Appendix A for details.

MS70 recordings

The Simrad MS70 is the first quantitative, high resolution multibeam sonar (Korneliussen et al. 2009). It is designed to provide output which can be used to quantify echo backscattering and hence estimate fish biomass. The MS70 uses 500 beams distributed equally over 20 fans to insonify a volume corresponding to 60 degrees horizontally and 45 degrees vertically in each ping (Figure 10.4.1). The sonar transmits in the frequency range of 75 to 112 kHz with a gradually increasing frequency with depth for each of the 20 fans; 75 kHz in the fan parallel with the surface, and 112 kHz in the lowest fan (pointing 45 degrees downwards). Although MS70 covers the frequencies 75 – 112 kHz, the frequency span is not very wide, so the sonar is considered to be essentially single frequency. The frequency span is a technical solution used to avoid interference between the vertical fans.

The sonar was operated with port-oriented beams, and pulse duration of 2 ms. Sonar transmission was synchronized with the echosounder, but due to the slower processing speed of the sonar ping-rate was usually one half or one third of the echo sounder, i.e. pinging every second or every third time the echo sounder transmitted. The sonar was calibrated in Norwegian waters following Ona *et al.* (2007), using 75- and 84-mm diameter spheres made from tungsten carbide (WC) and 6% cobalt binder. The sonar data were processed using the PROMUS module of the Large Scale Survey System (LSSS) (Korneliussen et al., 2006, www.marec.no, Bergen, Norway)

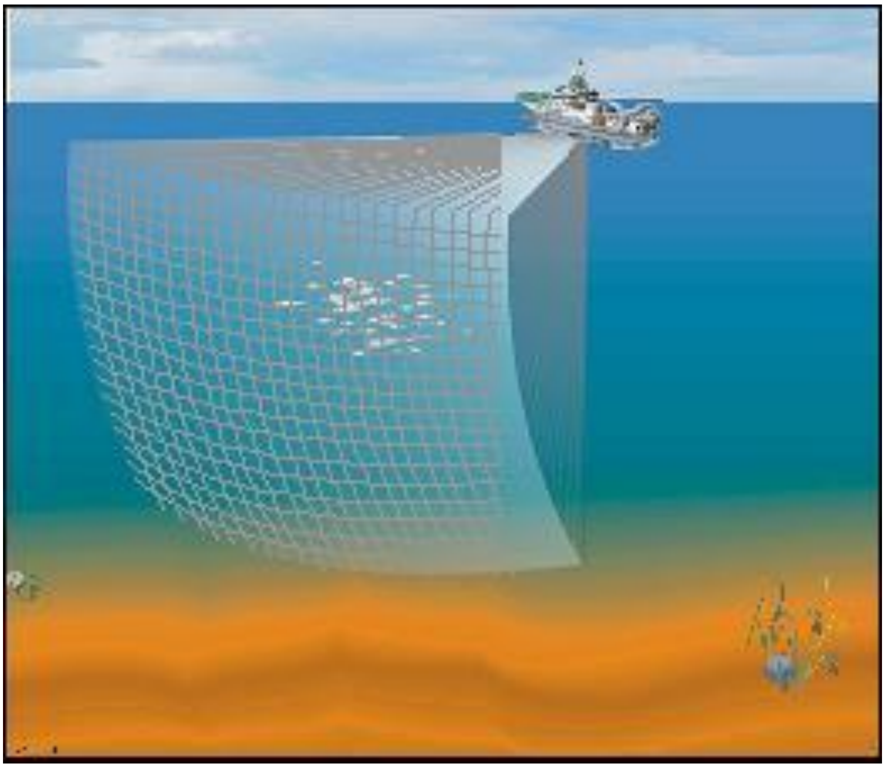

Figure 10.4.1. Illustration of MS70 (courtesy of Hans Petter Knudsen).

Application of MS70 during the survey

MS70 was used during all of the survey. The data were processed by means of the LSSS module PROMUS to remove noise and to make semi-automatic school-detection easier. The MS70 data were scrutinized daily simultaneously with the EK60 data during two sessions, i.e. the scrutinizing of pre-processed MS70 data and pre-processed EK60 data was done during the same operation. The results of the MS70 data were intended to make an abundance estimate of capelin independent of the EK60 data.

During the first 2/3 of the cruise, the MS70 data were scrutinized simultaneously with the EK60 data. However, some of the necessary processes to scrutinize the MS70 data were increasing the time needed to scrutinize all data to well beyond the 2 hour goal for 24 hours of collected acoustic data. It was especially the time needed to read the raw-data and store the scrutinized MS70-data into the database that were time-consuming. Therefore it was decided to postpone the scrutinizing of the MS70 data. After the survey, effort was put into removing those bottlenecks, and they are now removed. In fact, the reading and storing of processed MS70 data are now faster than EK60.

Further, it was decided that only a subset of the cruise-tracks should be used to compare the abundances based on MS70 data and EK60 data. A nearby area where significant amounts of capelin were found during an earlier period of the cruise was selected. Cruise-tracks were designed for a mini-survey (see below), and those cruise tracks should be covered during 30 hours to account for diel variations. Several trawl-hauls and other biological samples were intended together with CTD-samples. Unfortunately, RV “G.O. Sars” had to return to shore after 17 hours, from January 21 19:00 UTC to January 22 12:00 UTC. Although a full diurnal coverage was not done, the survey-tracks were covered 3 times, and two trawl-stations were carried out in the survey area, one pelagic and one bottom. The survey-grid is shown in Figure 10.4.2.

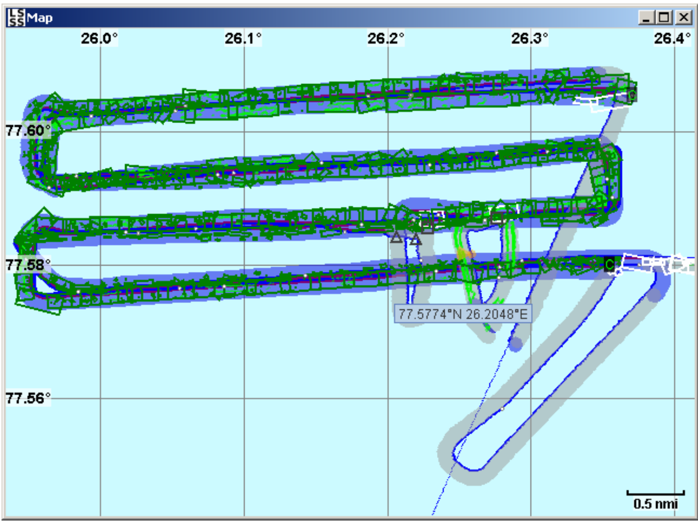

Figure 10.4. 2. Survey-grid covered three times. The grey proportions are excluded, e.g. due to trawling. The thin dark blue show cruise-lines covered by EK60, the thick lighter blue lines show what MS70 covered (and to which side of the cruise-line), the small black triangles mark start and stop of pelagic trawl, the black squares mark start and stop of bottom trawl. The green “blobs” are school-candidates detected by the K-means algorithm. The green boxes are accepted and scrutinized schools.

<u>MS70 processing prior to school-detection and scrutinizing</u>

The MS70 quantitative 4-dimensional sonar suffer from both spike-noise and ambient noise, so massive pre-processing to improve the data is necessary. Further, the MS70 generates so much data, that there had to be a selection of filters to keep the processing time down. The processing modules were used in sequence prior to scrutinizing. The processing modules do the following: (A) Remove spike noise, e.g. due to nearby fishing vessels, unsynchronized instruments, or problems in the MS70; (B) Remove ambient noise; (C) Remove unnecessary data, i.e. reduce the amount of data; (D) Do school-candidate detections for visualisation in a map; and (E) Compress data. In addition, the data after (C) are branched, and (F) phantom echograms (i.e. echograms generated from MS70 data) were generated better semi-automatic detection of schools. See Appendix B for details.

<u>Scrutinizing EK60 and MS70 data</u>

Figure 10.4.3 shows the interpretation interface for scrutinizing both MS70 and EK60 data. The echogram windows show approximately the same depth range. Figure 10.4.4 shows automatically detected acoustic categories. In this case, essentially all schools were identified as capelin, which is in accordance with the manual scrutiny. Thus, the scrutiny was in this case simple.

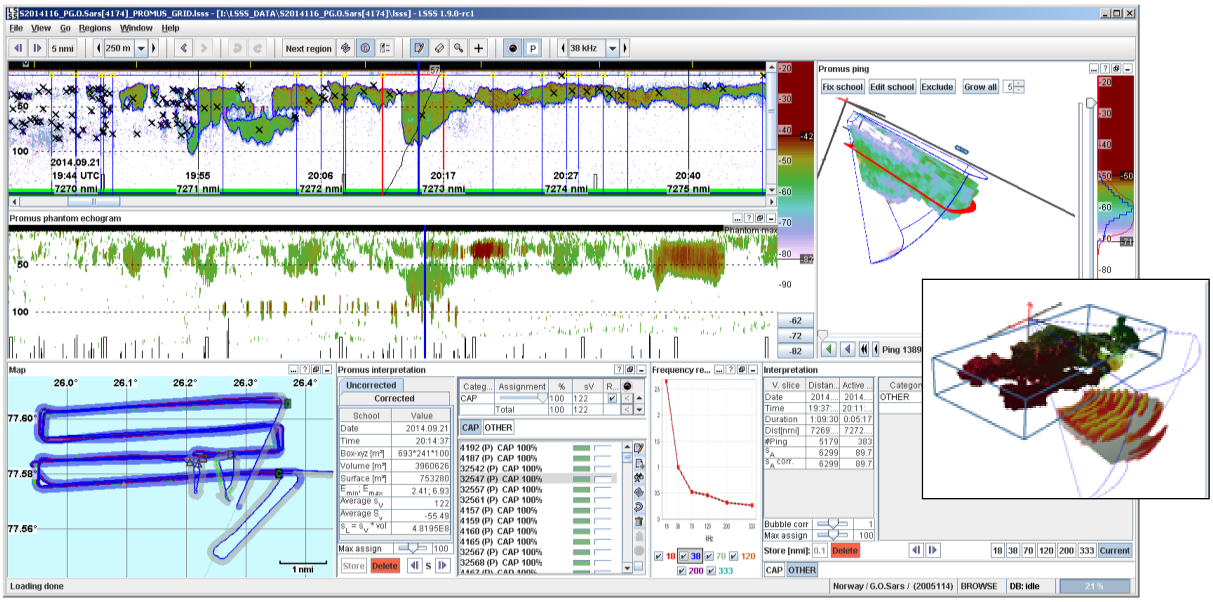

Figure 10.4.3. Example of echosounder and multibeam sonar (MS70) capelin recordings. Upper left: echogram displaying capelin recordings. Middle left: the same section with capelin as above, here as recorded with the multibeam sonar and visualized as a phantom echogram. Lower left: map showing the transect which was covered three times. Upper right: three dimensional representation of a single capelin school as observed with the MS70 (250 m range), with the bottom is seen in the lower part. Middle right: capelin shoal also showing the bottom (400 m range). The lower middle to right windows show: MS70 interpretation windows, frequency response of capelin recordings, EK60 interpretation window.

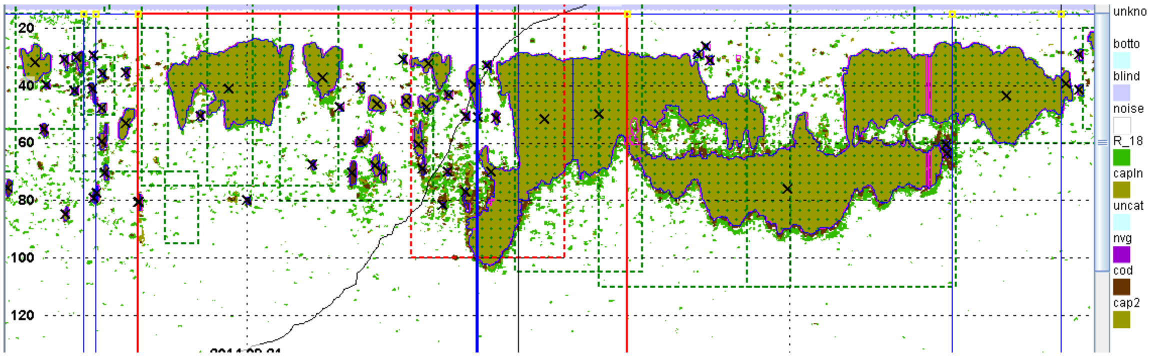

Figure 10.4.4. Automatic detection of species from multifrequency EK60 data show almost pure capelin for the schools (brownish spotted regions). The most relevant of the tested acoustic categories were in addition to capelin, also herring (Norwegian Spring Spawning herring) and cod (Norwegian Arctic cod).The stippled lines show the extent of schools detected from MS70 data. Those are schools accepted by the scrutinizer to really be schools, e.g. not only school-candidates.

The dorsal TS, i.e. the TS to be used with echo-sounder data, is well known, but the target strength (TS) for sonar data is in principle unknown. Dorsal side, capelin is expected to have tilt 0°±13°, while side aspect is more likely to be 0°±90°. Thus, the side aspect TS is smaller than dorsal side TS at the same frequency provided there is no reaction from capelin to the ship.

SX90 recordings

The Simrad SX90 is an omnidirectional fisheries sonar which operates at 20-30 kHz. The sonar can be operated in different modes deciding which volume is sampled. Here, we operated in 'Bow up/vertical' mode which alternates every second ping between transmitting a 360 degrees horizontal fan (64 beams), and a vertical fan (See Figure 10.4.5). We used a pulse repetition rate of 1 Hz, recorded to 600 m range with a tilt of 4 degrees, targeting schools at depths of 0–50 m. Unprocessed data were stored for each ping from the sonar-control computer to an external hard drive. Sonar data were post-processed using the software "Processing system for omnidirectional fisheries sonar" (PROFOS), which is a module of the Large Scale Survey System (Korneliussen et al., 2006, www.marec.no, Bergen, Norway). The sonar data were displayed as a circular image with the vessel at the centre and a diameter equal to the sonar operational range (i.e. 400 m).When a school was visually detected, a mouse click on top of the centre of each school ("to seed a school") told the software to automatically find the adjacent cells, where uncalibrated volume backscattering strength (S_v) ranged from -10 to -50 (dB re m^{-1}), and group them into one school ("growing a school"). This growing procedure was repeated for the ping where the school was seeded and for consecutive pings (i.e. 5 to 10 pings before and after the seed) until the school was no longer detected in the sonar (Pena et al. 2013). For each detected school, the geographic position, date, time, mean SV, and school area (m^2) were computed.

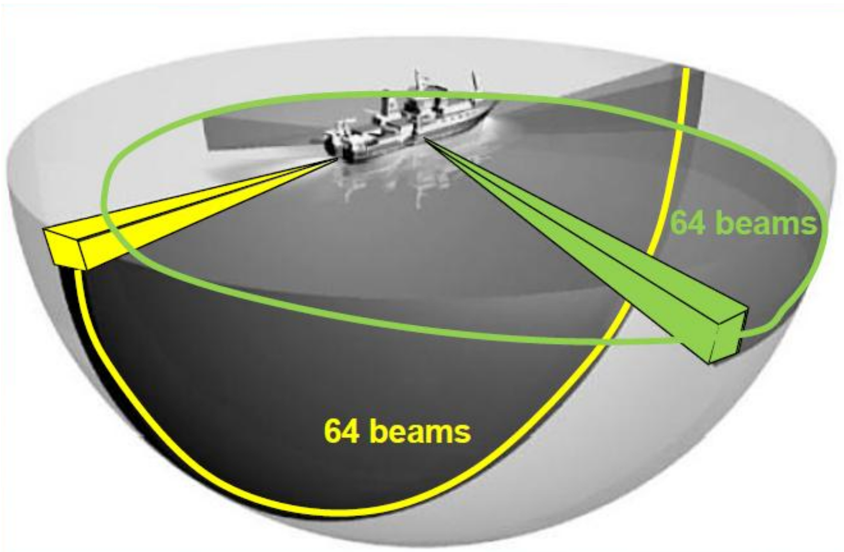

Figure 10.4.5. Example of a Simrad SX90 omni directional sonar modified from Simmonds and MacLennan (2005). The two transmitted beams forming conical shells are in this case pointing forwards and tilted slightly downwards (green) and vertically in the fore-aft plane (yellow). Tilting and rolling the sonar head can modify the sampling volume.

<u>ADCP recordings</u>

Data from both the 75 kHz and 150 kHz Acoustic Doppler Current Profiler (ADCP) on board were logged. They provide information about the vertical current pattern which is important when interpreting migration speed and direction. These data have not yet been processed.

Preliminary results

<u>MS70 abundance estimation</u>

The data were stored at a resolution of 0.1 nmi horizontally. The official TS-relation for capelin at 38 kHz does not consider compression of the swimbladder with depth:

Dorsal TS at frequency f: TS(f) = TS(38) + 10 Log(r(f))
The r(f) of capelin-schools in library: r(38)=1; r(70)=0.55; r(120)=0.42; r(200)=0.44;

Dorsal TS at 38 kHz: TS = 19.1 Log L -74.0 [dB];
Dorsal TS at 70 kHz: TS = 19.1 Log L -76.6 [dB];
Dorsal TS at 94.2 kHz: TS_{94}*≈19.1 Log L -77.2 [dB] (suggested), 3.2 dB from 38 kHz*
Dorsal TS at 120 kHz: TS = 19.1 Log L -77.8 [dB];
Dorsal TS at 200 kHz: TS = 19.1 Log L -77.6 [dB];

	Date	Hour	Log		Date	Hour	Log
Coverage 1:	2014.09.21	19:33	7269.1	-	2014.09.22	1:05	7294.2
Coverage 2:	2014.09.22	1:10	7294.4	-	2014.09.22	5:57	7322.4
Coverage 3:	2014.09.22	5:59	7322.4	-	2014.09.22	9:35	7346.4

	MS70	[kHz]	[DEG]	EK60_38	*EK60/MS70*
Coverage 1:	1253	93533	111.8	6525	5.2 (7.2 dB)
Coverage 2:	497	93613	112	3544	7.1 (8.5 dB)
Coverage 3:	213	95491	114.7	1055	5.0 (7.0 dB)

Due to the difference in target strength when insonified from the dorsal side or lateral side (see above), the EK60/MS70 ratio is expected to be >1. However, further work is needed to investigate whether these results are within the range of expectancy. The frequency difference (EK60 38 kHz and MS70 95 kHz) explains 3.2 dB of the difference. The difference in tilt is expected to explain 3 – 6 dB difference (although this is not clear yet.

Results from the SX90

Altogether 146 schools were detected using the SX90 (Figure 10.4.6). The main swimming direction was towards north-east, while a significant proportion also headed due north or due south (Figure 10.4.7). Only a very low proportion had a westerly swimming direction. This preliminary result indicates a non-random swimming direction of the capelin, with a main migration direction towards more northerly feeding areas, and a component heading south. The swimming speed was generally quite low and peaked between 0.1 and 0.2 m/sec (Figure 10.4.5).

The distribution of the capelin was such that the conditions for distinguishing schools with the fisheries sonar were often not ideal during the survey. Typically, when distributed close to the surface, capelin was found in layers more than distinct schools. Under such conditions, there is a risk that school detections by the sonar reflect local high-density patches in a layer, rather than distinct schools. Only schools that were clearly visible for more than 20 pings were therefore included. The distribution in layers could in itself be an indication of quite stationary behaviour, since schooling behaviour is expected during migration. This is confirmed by the generally low swimming speeds (Figure 10.4.8). On several occasions capelin were also distributed below the detection range of the sonar. These were found in more distinct schools, but swimming speed and direction could not be investigated by underway sonar monitoring.

There were some technical issues during the logging of the data. It seemed as if the data logging was corrupted when logging over the Ethernet. Even though the size of the files indicated that data were logged appropriately, only echo from two beams had actually been logged. The problem disappeared when logging to a local disc.

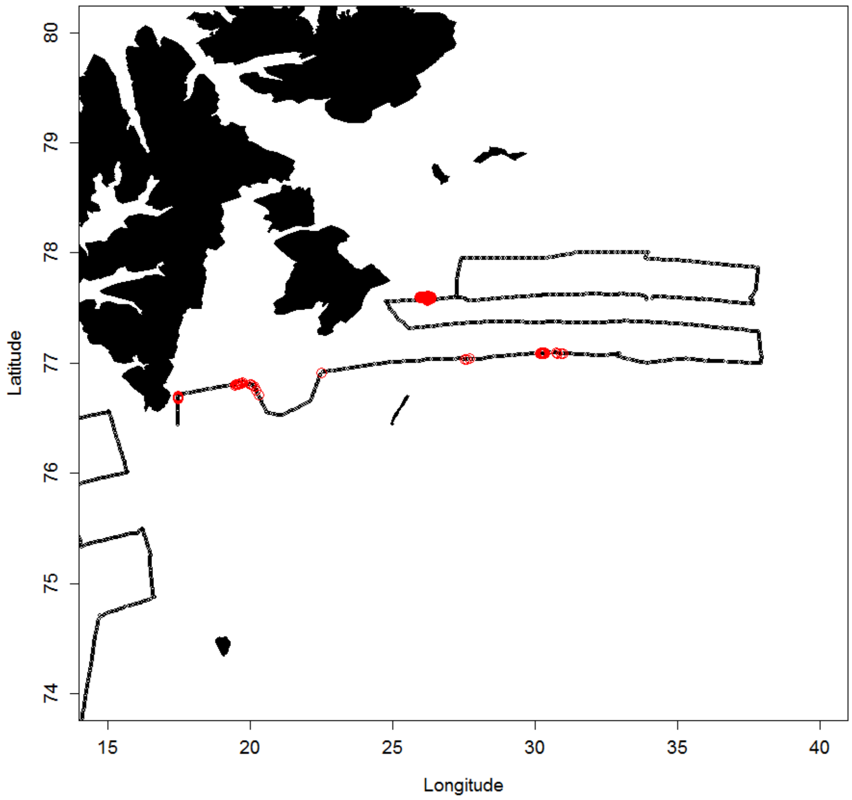

Figure 10.4.6. Positions with school observations marked in red.

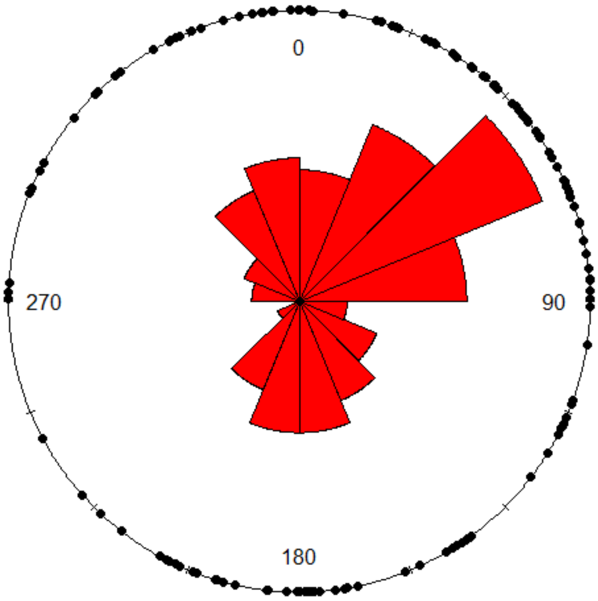

Figure 10.4.7. Rose plot indicating main swimming directions of the 146 detected schools. The range of the red sectors is proportional to the number of schools with net swimming direction indicated by the given sector. The points indicate single school detections.

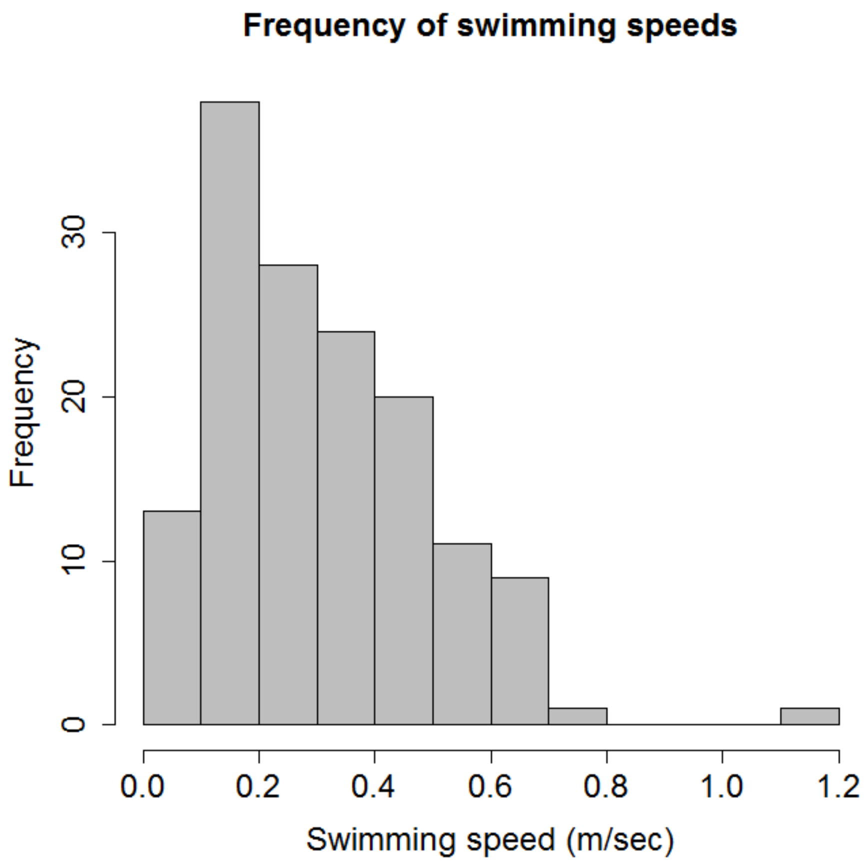

Figure 10.4.8. Frequency histogram showing swimming speed of the 146 detected schools.

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Appendix A. Processing steps of EK60 prior to scrutinizing

1)	SpikeFilterModule	- Remove spikes above 100 m
2)	SpikeFilterModule	- Remove spikes between 90 m and 250 m
3)	SpikeFilterModule	- Remove spikes between 240 m and 2500 m
4)	FillMissingDataModule	- Duplicate previous ping if a ping is not exixting for a frequency
5)	SpotNoiseModule	- Remove noise in a sample
6)	BubbleNoiseModule	- Correct for bubble-blocking of ping above 100 m
7)	BubbleNoiseModule	- Correct for bubble-blocking of ping between 90 m and 250 m
8)	BubbleNoiseModule	- Correct for bubble-blocking of ping between 240 m and 2500 m
9)	HorizontalOffsetCorr.Module	- Correct for horizontal transducer geometry
10)	VerticalOffsetCorr.Module	- Correct for vertical transducer geometry and for EK60 system delay
11)	TemporaryCompBeginModule	- Start of temporary computations. Discard data from until "Comp.End"
12)	SmootherModule	- Smooth horizontally with a Gaussian 50 m diameter kernal
13)	DepthModule	- Detect bottom on the smoothed data
14)	*TemporaryComp.EndModule*	- End of temporary computations: discard smoothing, but keep bottom.
15)	SmootherModule	- Smooth above detected bottom. Gaussian kernel: 8 m x 0.5 m.
16)	SmootherModule	- Smooth below detected bottom. Gaussian kernel: 8 m x 0.5 m.
17)	NoiseQuantificationModule	- Quantify noise parameters by using primarily data below bottom.
18)	DataReductionModule	- Remove data beyond useful range (e.g. beyond 300 m at 200 kHz)
19)	NoiseRemoverModule	- Correct data for noise (quantified abovs)
20)	*TemporaryComp.BeginModule*	- Start of temporary computations. Discard data from until "Comp.End"
21)	ThresholdModule	- Set data >-20 dB = -20 dB (due to weakness in RegionModule)
22)	ThresholdModule	- Set data <-120 dB = -120 dB (due to weakness in RegionModule)
23)	SmootherModule	- Smooth above detected bottom. Gaussian kernel: 35 m x 0.5 m.
24)	ExpressionModule	- Calculate synthetic channel: average data at 18, 38, 120 and 200 kHz
25)	RegionModule	- Detect school-candidate extent
26)	*TemporaryComp.EndModule*	- End of temporary computations: keep extent of detected schools only.
27)	*TemporaryComp.BeginModule*	- Start of temporary computations. Discard data from until "Comp.End"
28)	SmootherModule	- Smooth inside school-candidates. Gaussian kernel: 10 m x 1 m.
29)	CategorizationModule	- Calculate acoustic-category candidates of pixels (volume-segments)
30)	SchoolCategorizationModule	- Calculate acoustic-category candidates of school-candidates
31)	*TemporaryComp.EndModule*	- End of temporary computations: keep categorization only.
32)	PlanktonInversionModule	- Calculate zooplankton-model candidate

Appendix B. Processing steps of MS70 prior to scrutinizing

The processing modules do the following: (A) Remove spike noise, e.g. due to nearby fishing vessels, unsynchronized instruments, or problems in the MS70; (B) Remove ambient noise; (C) Remove unnecessary data, i.e. reduce the amount of data; (D) Do school-candidate detections for visualisation in a map; and (E) Compress data. In addition, the data after (C) are branched, and (F) phantom echograms (i.e. echograms generated from MS70 data) were generated better semi-automatic detection of schools.

I. 4-dimensional data:

1) TransducerDepthModule - Set transducer depth to 7.5 m (erroneously not set prior to operation)
2) MedianSpikeFilterModule (1) - Detect and remove spikes across beams, i.e. "walls" commonly generated by sonars from nearby ships of unsynchronized instruments on own ship. Require: sample >-45 dB and >10 dB of search window. The sample is replaced by the median of the search window.
3) MedianSpikeFilterModule (2) - Detect and remove spikes along beams. This may be caused by MS70-instrument problems. Require: sample >-45 dB and >10 dB of search window. The sample is replaced by the median of the search window.
4) SpotNoiseModule - Detect and remove noise in a single sample. This may be caused by MS70-instrument problems. Reqiure: sample >15 dB of search surrounding samples, and replace it by the median of the surroundings.
5) NoiseQuantificationModule - Ambient noise quantification. For each of the 500 beams: use samples the 175 m outermost data of 3 consecutive pings to calculate histograms of power-samples, and extract noise-parameters. The results of the noise calculations are estimated for (A) Moving average values of the noise-parameters for 3 running pings; (B) Minimum values of the noise-parameters for each file (that is commonly approximately 150 pings; (C) Minimum values for the noise-parameters for each day (here: January 21 and 22); (D) Minimum values of the noise-parameters for the whole survey.
6) BeamSmootherModule - For each of the 500 beams: smooth the samples by means of a 8 m diameter Gaussian kernel. The smoothing reduces the sample variance. The "mean noise" of smoothed data remain unchanged while "high noise" will be reduced. The BeamSmootherModule is placed after NoiseQuantificationModule to keep a slightly high estimate of "high-noise".
7) DataReductionPromus - Remove all samples at shorter range than 20 m and greater range than 250 m from the transducer, and vertical fans at the edges of the beam. The inner data are removed to avoid the transmission pulse, near-field effects and near-ship reactions of the fish. The removal of the data outside 250 m is somewhat arbitrary: it could have been 350 m based on the highest frequency (112 kHz), but horizontal beams bends due to hydrography and 250 m is thought to be a "safe" range to avoid problems like beams hitting the surface or large deviations of calculated depth and real dept of each beam.

   There are 25 vertical fans, and the 4 leftmost and 3 rightmost fans are removed. The leftmost and rightmost vertical fans are removed due to visual impression of noise in the data combined with the fact that the average values are used to calculate abundance. Removing 7 vertical fans means that the averages are based on 18 vertical fans instead of 25.

   The DataReductionModule is placed after the NoiseQuantification Module to allow for calculation of file, day and survey values even if the calculations for all beams are not used. Further, the 8-m smoothing diameter extends slightly outside the range-extents (by 4 m on each side).
8) NoiseAcceptanceModule - Decides which of the calculated noise-parameters that should be used ((A) running; (B) file; (C) day; or (D) survey). Due to massive amounts of capelin in the complete measured horizontal extent, the noise-

		parameters are extracted from the day-files (B). The noise parameters based on running values may be too high, and possibly also the al-file-minimum noise-parameter values, therefore the noise-parameters for the day-values (C) are used.
9)	NoiseRemoverModule	- Remove ambient noise based on the calculated noise-parameters selected in the NoiseAcceptanceModule. Noise is removed according to Korneliussen, 2000: power-samples smaller than “high-noise” is set to zero, power-samples larger than “high-noise” is reduced by the value “mean-noise”.
10)	DataReductionPromus	- Remove the uppermost fan that is always noisy. Keep other fans for optimal spike removal (MedianSpikeFilterModule (3) - point 11 below).
11)	MedianSpikeFilterModule (3)	- Detect and remove spikes in horizontal fans. This may be caused by MS70-instrument problems. Require: sample >-70 dB and >20 dB of search window. The sample is replaced by the median of the search window.
12)	MedianSpikeFilterModule (4)	- Detect and remove spikes along beams, similar as MedianSpikeFilterModule (2), but testing smaller values after smoothing and ambient noise removal, and requiring spikes to be 20 dB stronger than the surrounding signals. Require: sample >-70 dB and >20 dB of search window. The sample is replaced by the median of the search window.
13)	MedianSpikeFilterModule (5)	- Detect and remove spikes in small 4D surrounding each sample (3x3x3x3). Require: sample >-70 dB and >20 dB of search window. The sample is replaced by the median of the search window.
14)	DataReductionPromus	- Remove the two uppermost fans, i.e. one in addition to those previously removed. Also remove data more than 200 m below the sea surface.
15)	MedianSpikeFilterModule (6)	- Detect and remove spikes from ping to ping (“time-spikes”). This may be caused by MS70-instrument problems. Require: sample >-120 dB and >50 dB of search window. The sample is replaced by the median of the search window.
16)	ThresholdModule	- Set all samples weaker than -70 dB to -120 dB. This is done to make data compression (see below) better. Capelin-schools are expected to be stronger than -70 dB.
17)	ThresholdModule	- Set all samples stronger than -25 dB to -120 dB. This is done to make data compression (see below) better. Values stronger than -25 dB is expected to be wrong.
18)	*Temporary branch calculations*	- *Used to calculate phantom echograms for school detection. Not relevant here – see below.*
19)	SchoolClusterModule	- Detect school-candidates to be visualised in map.
20)	EchoLineExtractor	- Compress data.
21)	DepthModulePromus	- Detect bottom. First candidate is at same depth as detected by the echo-sounder.

22) Phantom echograms: This was done in under point 18 above:

1-17)	...	- The data processed under points 1 – 17 above were.
18-A)	TemporaryComp.Begin	- Start temporary calculations that will be disregarded when ended
18-B)	DataReductionPromus	- Remove all but the vertical fan number 16
18-C)	WriterModule	- Write results to sub-dir. “TMP” under the MS70Processed directory.
18-D)	TemporaryComp.End	- Stop temporary calculations and disregard all calculations since the TemporaryComputationsBeginModule, but keep all telegrams. Here the important piece is the data reduction and followed by saving for further processing.
22)	PhantomModule	- Generate synthetic echograms based on MS70 data. The data are taken from vertical fan 16 that points 277 degrees (7 degrees forward) where 0 degrees is the cruise directions.
23)	ThresholdModule	- Set all samples stronger than -57 dB to -200 dB. This is done to only show strong schools.
24)	SpikeFilterModule	- Remove spikes in phantom echograms: use median of surrounding samples instead.
24)	SpotNoiseModule	- Remove noise in single samples: use median of surrounding samples instead.