Methods for acoustic identification and measurements of copepod abundance at specific North Sea sandeel grounds

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Abstract

In recent years there has been a decline in both size and the geographical distribution of the sandeel stock. The decline has been particularly profound in the Norwegian economic zone where the sandeel play an important part not only in terms of economic interests, but also in transferring energy from the planktonic society to the higher trophic levels. If there are not enough copepods to feed on, the sandeel along with several other animals would lose its basis of existence.

As a part of the IMR SMASSC (Survey methods for abundance estimation of sandeel (*Ammodytes marinus*) stocks) project it was decided to develop methods for acoustic identification and abundance estimation of copepods. This was done by comparing biological samples to acoustic abundance estimates using multi frequency methods with the operating frequencies 18, 38, 120 and 200 kHz collected in 2010. These data were to be compared with data collected in 2009 with six operating frequencies 18, 38, 70, 120, 200 and 333 kHz.
Results from these studies indicate that 333 kHz is required in most cases to identify copepods, and that the copepod distribution is far too heterogeneous for biological net samples alone to be reliable. Acoustic methods are better suited for mapping geographical distribution of copepods and may also be better suited for abundance estimation of copepods than the time consuming net sampling methods.
In addition, sandeel (*Ammodyte marinus*) digestion rate and gastric evacuation rate were monitored in a tankt. The digestion experiment implies that the sandeel leave the sand to feed once a day at the most. Also, it seems like light, more than the presence of copepods, is the decisive factor of motivation for the sandeel to emerge from the sand.

Symbols

s_v	Volume backscattering coefficient [m^3/m^3]
S_v	Volume backscattering strength (dB re 1 m^{-1})
s_a	Area scattering coefficient [m^2/m^2]
s_A	Nautical area scattering coefficient [m^2/nmi^2], equal to $4\pi\ (1852)^2 s_a$
σ	Acoustic backscattering cross section [m^2]
$<\sigma>$	Average backscattering cross section [m^2]
r(f)	Relative frequency response
TS	Target strength of one scatter, dB re m^2
ESR	Equivalent spherical radius, the radius of a sphere having the same volume as an irregular shaped object
g	Density contrast between an object and its environment [g/cm^3]
h	Contrast in sound speed within an object and its surrounding environment
ρ_A	Area density [$\#/m^2$], [$\#/nmi^2$]
ρ_v	Volume density [$\#/m^3$]
CML	Cube root mean of the length
CTD	Conductivity, Temperature and Depth
D	Simpson index
1-D	Simpson index of diversity

Contents

1. Introduction

The North Sea is the part of the Atlantic Ocean located between Norway and Denmark in the east, Great Britain in the west and Germany, Netherlands, Belgium, and France in the south. The 61th temperate latitude draws the border to the Norwegian Sea in the north. While Lindesnes-Hanstholm draw the border towards Skagerrak in the east, the south border is drawn from Calais-Dover at 51th temperate latitude. It is a typical semi-enclosed continental shelf sea (Howarth, 2003).

The North Sea is a productive area with an extensive primary production occurring in the upper 30 m of the water column. Nutrients are supplied by inflow from the Atlantic, the rivers, the sediments and the Wadden Sea. Nutrient concentration in the central part of the North Sea is increased by upwelling from the coastal areas during the summer. The upwelling enhances the primary production (Brockmann, 1990; Radach and Lenhart, 1995) and supports a large secondary production. The North Sea inhabits several important pelagic species like herring, mackerel and sandeel.

Secondary production in the marine environment is dominated by copepods. Copepods are usually the main herbivore organisms in marine waters and are the most important food supply for plankton predators (Levinton, 1995; Hay, 1995). According to marinespecies.org, more than 200 copepod species are registered in the North Sea. Copepods are the main food source for many important mid-trophic pelagic fish (Frederiksen et al., 2006). In the North Sea the lesser sandeel (*Ammodytes marinus* Raitt; hereafter sandeel) is such a fish and has been dominant in the mid-trophic pelagic region since the 1970's (Frederiksen et al., 2006).

The sandeel is one of the most abundant fish in the North Sea and considered as a key species in the ecosystem (Sparholt, 1990; van Deurs, 2009). The sandeel are an important link between the planktonic society and the higher trophic levels (Reay, 1986; Adlerstein, 2000) because of its high abundance and high caloric level (Hislop, 1991). Sandeel are also a key part of the diet for many different taxa ranging from sea birds and seal to predatory fish, but also of great economic interest to industrial fishery (Furness, 1990; Frederiksen et al., 2006). Sandeel fishery in the North Atlantic is almost exclusively located in the North Sea where

Norway and Denmark are the main actors (Jensen and Christiansen, 2007). The sandeel swims in large shoals and spends most of its time buried in the sand. Because of its sand dwelling behaviour it is exclusively found on sandy substrate. Sediments where the weight fraction of the fine particles silt (particles<0.09mm) and fine sand is larger than 10% will be avoided by the sandeel (Wright et al., 2000), and generate a patchy geographical distribution of sandeel.

While adult sandeel feed on copepods, sandeel larvae feed mainly on copepod larva and eggs along with apedicularians (Economou, 1991). If the copepod eggs are already hatched when the sandeel larvae is supposed to feed there will be little food available, and the risk of starvation increases rapidly when sufficient prey is not present soon after hatching (Arnott and Ruxton, 2002). Sandeel eggs hatch from February to May (Wright and Bailey, 1996) and the egg laying of *C. finmarchicus* peaks in March. The other abundant copepod *Calanus helgolandicus* maximizes its egg laying in May (Jonasdottir et al., 2005). Because of the difference in the egg laying period it is of great interest to (van Deurs, 2009) the sandeel with a dominance of *C. finmarchicus* rather than *C. Helgolandicus.* The lifecycle of the lesser sandeel seems to be adapted to and dependent on the egg laying period of the *C. finmarchicus.* Changes in the copepod community with respect to dominance, will affect top predators through a climate induced mismatch (Edwards and Richardson, 2004) in lifecycle between the sandeel and the copepod community (Frederiksen et al., 2006). A record high copepod feeding Herring stock (ICES, 2004) may perhaps also contribute to a decline in sandeel population.

A number of factors indicate a decline in sandeel abundance the past few years. In 2004 there was recorded an all time worst breeding season for seabirds in the north western North Sea (Frederiksen et al., 2006) on the east coast of Scotland. Also, a recruitment failure in the sandeel stock dated back to 2002 led to a 50% reduction in the commercial sandeel landings and a collapse in the sandeel stock in 2003 and 2004 (ICES, 2004). The collapse in 2003 was unexpected as the snadeel recruitment was very high in 2001.

Decline in the sandeel population has been related to possible climate induced changes in the copepod community (ICES, 2006). Records from continuous plankton recorder surveys show reduced copepod abundance, and as figure 1.1 (ICES, 2006) shows, there has been a

significant decline in the abundance of *Calanus finmarchicus* and an increase in *Calanus helgolandicus* and an overall decline in calanus abundance *(Heath, 1999).*

A change in temperature by 1°C over 40 years may seem insignificant, but it has none the less led to a change in the North Sea from a boreal to a temperate system (Beaugrand, 2008; 2009). When keeping in mind that each species has a certain temperature optimum, and that there is competition for recourses between the species, the preferred temperature interval for each species is probably smaller than experiments have shown (Bonnet, 2005; Helaoueet, 2007). This change in composition in the copepod community will definitely have a critical impact on the North Sea ecosystem.

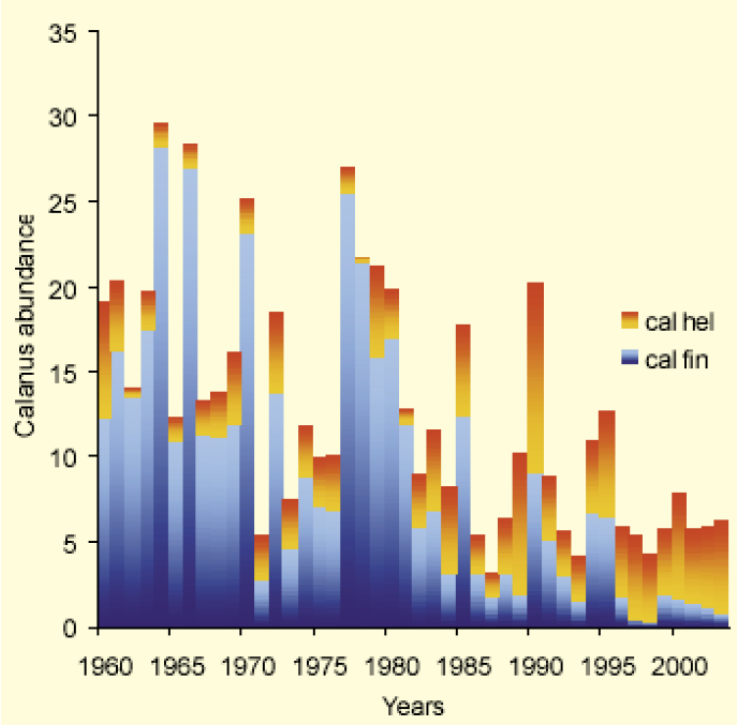


Figure 1.1(ICES, 2006): The C. finmarchicus , C. helgolandicus composition change relative to total calanus abundance in the North Sea from 1960-2003.The figure show a shift in dominance from C. finmarchicus to C. helgolandicus with an overall decline in the calanus population.

Today's estimates of copepod biomass are based on biological sampling. The biological samples provide precise information about species composition and developmental stages rather than reliable abundance estimations. The processing is very time consuming and the results are usually not available before months after the sampling period. Conventional sampling is also exposed to clogging and avoidance from larger zooplankton. There is also the possibility of a mismatch in sampling intervals and the spatiotemporal intervals of

zooplankton (Cassie, 1968; Greenlaw, 1979). Net sampling of zooplankton has been going on for approximately 200 years (Melle, 2004), while investigation of the acoustic properties of zooplankton first started in the 1970's (Greenlaw, 1979). Since then, in order to better understand sound scattering from these tiny animals there has been made significant progress in the acoustic modelling work (Stanton, 1994A, 1994B; Demer, 1995; Stanton, 2000).
To detect changes in the copepod community over a small spatiotemporal scale, a combination of biological and acoustic sampling will be well suited.

To be able to acoustically identify and perform acoustic abundance estimations of copepods it is a necessity to understand their acoustic scattering properties (Warren, 2001).
Zooplankton may be divided into three different categories based on their scattering properties; (1) gas bearing (e.g. Siphonophora), (2) hard elastic shelled (e.g. gastropods) and (3) fluid like scatterers, where the copepods are placed (Simmonds and MacLennan, 2005).
Because of the lack of both gas filled inclusions, a hard shell or bone, the echo reflected by fluid like organisms is much weaker than echoes from gas bearing organisms. In comparison, more than 90 % of the echo is considered to originate from the swim bladder in swimbladdered fish (Foote, 1980; Simmonds and MacLennan, 2005), where the rest of the echo is produced by bones, scales, tissues and fat. Echo from copepods is much weaker and more complex than the echo from swimbladdered fish, and about one million copepods in an ensemble are needed to produce about the same echo as one 10 cm swimbladdered fish (Korneliussen and Ona, 2000).

When there are many small targets like copepods in the acoustic sampling volume their individual echoes are combined, and it is almost impossible to resolve the individual targets. However, the total echo intensity can be used when measuring the biomass of the sampled volume. This measurement is defined as the volume backscattering coefficient (s_v) with a logarithmic equivalent called volume backscattering strength (S_v). The mean volume backscattering strength is commonly used when studying zooplankton. The s_v is defined as (Simmonds and MacLennan, 2005):

$$s_v = \frac{\sum \sigma}{V_0} \quad (1)$$

where the sum (Σ) of all contributing echoes (σ) from the sampling volume V_0 is included.

To identify insonified targets, the relative frequency response r(f) is an important feature. The relative frequency response is a measurement of the volume back scattering coefficient at a specific frequency relative to that of a reference frequency (Korneliussen and Ona 2002; Pedersen, 2009) . r(f) was defined by Korneliussen and Ona (2002) as:

$$r(f) = \frac{s_{v(f)}}{s_{v(38kHz)}} \quad (2)$$

Small targets such as copepods would be expected to create weak backscattering at low frequencies (18-120kHz) and according to Simmonds and MacLennan (2005) the strength of the echo from targets smaller than one wavelength should increase rapidly with the frequency and enter the Rayleigh scattering region. When knowing the characteristic frequency response of the target, the frequency response key can be used to identify the origin of the echo (Korneliussen and Ona, 2003).

There are two basic approaches used for acoustic estimation of copepods. One approach is based on the empirical relation between volume backscattering strength and biomass (Køgeler et al., 1987). The other is based on empirical and mathematical models (Anderson, 1950; Johnson, 1977; Greenlaw, 1977; Køgeler et al., 1987). The acoustic backscattering cross section (σ) predicted by these models is related to the target strength (TS) and rely on the density (g) and sound speed (h) contrast between the insonified organisms and the medium surrounding them, along with acoustic frequency. TS is the acoustic size of the insonified target measured in decibel (dB) (Simmonds and MacLennan, 2005). The TS-σ relationship can be expressed as(Ona, 1999):

$$TS = 10\log\left(\frac{\sigma}{4\pi r^2}\right) \rightarrow \sigma = 4\pi r^2 10^{\left(\frac{TS}{10}\right)} \quad (3)$$

σ is measured in square meters in SI units. r^2 is the reference area of 1 m^2.

The tilt angle and shape of the organism are also introduced in some models. However, the angular orientation is not considered very important for copepods. The importance of angular

orientation decreases with decreasing size because the difference in cross sectional area is less for small animals.

From a biological point of view one of the main problems with acoustic sampling is the lack of specimens of the insonified organisms (Greenlaw, 1979). By combining biological and acoustic sampling from North Sea sandeel grounds, the main aim is to identify and estimate the abundance of copepods and to use this information when investigating the copepod-sandeel interaction.

Do all the sandeel individuals leave the sand every day? This is an important and relevant question for the survey design used in the Norwegian acoustic sandeel surveys (Johnsen et al., 2009), where the sandeel schools are measured acoustically during daytime. The question is based on the assumption that the fraction of sandeel remaining in the ground during daytime is low.

Preliminary analyses of the stomach contents in the sandeels carried out in previous surveys suggested that the sandeel had a very rapid digestion (pers. comm. Tore.Johannesen@imr.no), and an experiment was conducted to test this hypothesis. Because hunger in fish (as compared to mammals) is assumed to be inversely proportional with stomach filling (Vahl, 1979) and sandeel are visual predators this could be an indicator for how frequent the sandeel have to leave the sand to eat. This knowledge could be of help when estimating the amounts of copepods the sandeel feeding require, and in acoustic abundance estimation of sandeel.

The main focus of this thesis will be to answer the following questions:

- Is it possible to acoustically identify copepods in the North Sea with today's survey equipment?
- Is it possible to do abundance estimation on North Sea copepods based on today's methods?
- Do the sandeel leave the sand every day to feed?

2. Materials and methods

2. 1 Materials

Selected sandeel grounds in the North Sea were surveyed with RV G. O. Sars from May 3 to May 24, 2009 and with RV Johan Hjort from April 18 to May 9, 2010. The data used in this study were collected during these two surveys. I participated and collected most of my material in the last of the two surveys. Below, maps (Johannesen and Johnsen, 2009; Gjertsen, 2010) of the sampling stations from both surveys are displayed chronological. The maps also show the location of the plankton and CTD stations.

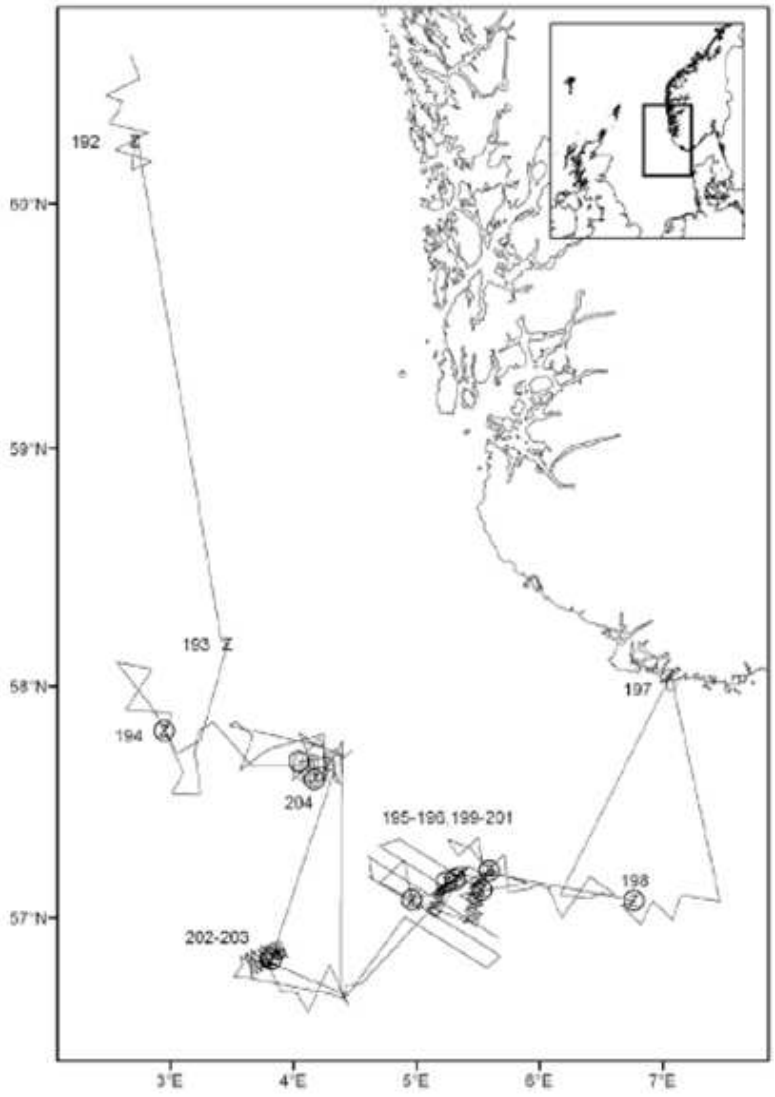


Fig. 2.1A Map (Johannesen and Johnsen, 2009)of the survey area from the 2009 sandeel survey. The lines represent the surveyed area, while O and Z illustrate the plankton and CTD stations.

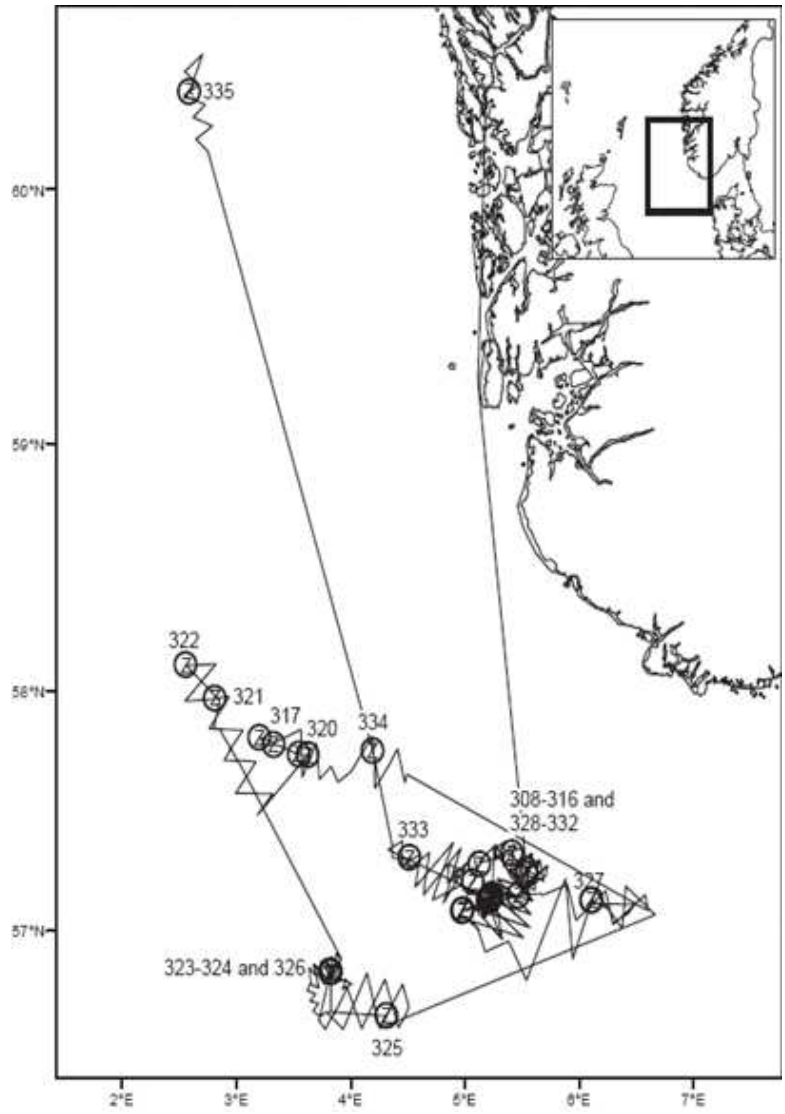


Fig. 2.1B Map (Gjertsen, 2010) of the survey area from the 2010 sandeel survey. The lines represent the surveyed area, while O and Z illustrate the plankton and CTD stations.

A good survey design should strive to minimize possible errors, and different designs are suitable for different species depending on their nature. The survey area was chosen based on satellite tracking data from the sandeel fleet, and trawl track information from two commercial vessels. The most important sandeel grounds (APPENDIX H) were covered by running parallel or zigzag transects (Fig. 2.1 a and b).

2. 2 Acoustic sampling

2. 2. 1 Echosounder

The echosounder used during the surveys was a SIMRAD EK60 split beam with 18, 38, 70, 120, 200 and 333 kHz in 2009 and 18, 38, 120, 200 kHz in 2010. The EK60 is a scientific echo sounder used for fisheries research (Bodholt and Solli, 1992; SIMRAD, 2004; Simmonds and MacLennan, 2005). The EK60 was running with a ping rate of $4s^{-1}$ (Johannesen and Johnsen, 2009). Ping rate is the number of sound pulses transmitted into the water column per second (Simmonds and MacLennan, 2005).

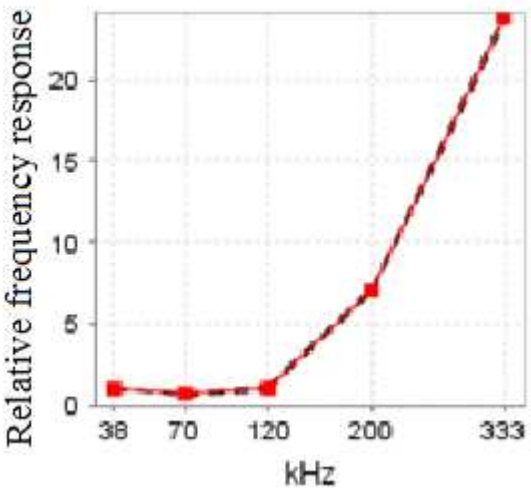
2. 2. 2 Calibration of the echosounders

Calibration of the echo sounder was performed according to standard methods (Foote et al., 1987) under good conditions and adjusted for split beam methods (Ona, 1999) prior to the 2009 survey and after the 2010 survey. More detailed information can be found in the calibration journals in APPENDIX F.

2. 3 Analysis

2. 3. 1 Analysis of acoustic data

LSSS, which is a post processing program for analysing acoustic data (Korneliussen et al., 2006) was used for analysis and scrutinizing. To detect zooplankton we used a frequency response key. Given the acoustic properties of the copepods and the difference in operating frequencies it would be expected from the 2009 data to show better and clearer response than the 2010 data, especially at 333 kHz. Figures 2.2a and b are good examples of what we were searching for as copepod backscattering in both surveys.



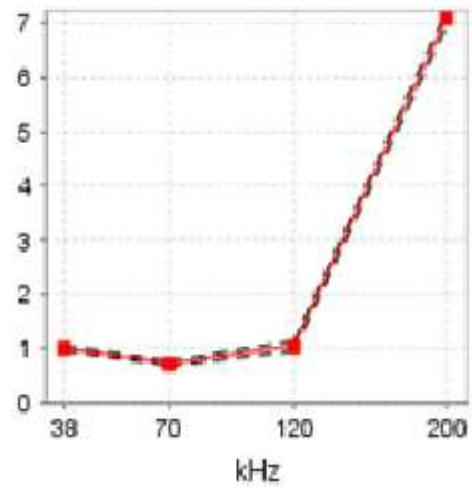


Fig. 2.2a: Desired relative frequency response in in 2009.

Fig. 2.2b: Desired relative frequency response response in 2010

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This example shows that the backscattering is low at 38-120 kHz compared to 200 and 333 kHz. It is respectively 7 and 30 times higher at 200 and 333 kHz than at 38 kHz.

Echograms were selected based on the plankton sampling stations which were the same as the CTD stations. This was done in order to compare the acoustic results with the biological samples. Each echogram ranged over 5 nautical miles (nmi). The sampling stations were placed the middle of this stretch and consequently there were 2.5 nmi on both sides of the stations. This part of the procedure was identical for the two surveys. We collected 12 zooplankton samples in 2009 (Fig. 2.1a), while in 2010 (Fig. 2.1b) we sampled from 28 different locations.

In the LSSS, the threshold of included volume backscattering strength (S_V) can be changed in order to remove unwanted acoustic backscatter from the echogram. When scrutinizing for copepods it is important to remove echoes with origin from organisms such as fish or hard elastic shelled animals which would out shadow the weak echo of small fluid like organisms. The unwanted backscattering from fish can be removed by narrowing the threshold interval. This is done by removing a part of the upper S_V interval. When narrowing the threshold interval all echoes with S_V outside the interval are removed. The echo from hard shelled organisms on the other hand might be more difficult to eliminate. Echoes from organisms

such as the gastropod *Limacina retroversa* are too weak to be removed by thresholding without removing copepod sound scatters as well.

When analysing the 2009 data the threshold interval was set to -50→-70 dB. The lower part of the threshold interval was changed from -70 to -80dB when analysing the 2010 data. This was done because a significant part of the 200 kHz frequency response seemed to be located in this interval (-70→-80 dB).

The acoustic density of copepods in a specific layer is measured through the nautical area scattering coefficient (s_A) or the area scattering coefficient (s_a). s_A for backscattering identified as copepods, was stored to category copepods. The nautical area scattering coefficient is defined:

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

with s_A in [m^2/nmi^2] and s_a in [m^2/m^2] (Simmonds and MacLennan, 2005).

Based mainly on the frequency response all the echograms were scrutinised with respect to copepod backscattering. In order to obtain a high resolution of the water column the data was stored with grid size set to 5m vertical and 0.1nmi horizontal before reports of the mean area backscattering coefficient were generated. The depth of initial top boundary was set to 10 m to avoid air bubble attenuation and the distance from bottom of initial bottom boundary was set to 0.5m.

Based on the knowledge of the expected backscatter characteristics of small fluid like organisms/objects the backscatter was isolated using multi frequency analysis. A layer of copepods of size 0.3-2.5 mm will enter the Rayleigh scattering region when insonified with frequencies between 18-333kHz (Korneliussen and Ona, 2000). If we look at copepods as small fluid like spheres this can be expressed mathematically as the echo area (σ) being proportional to the equivalent spherical radius (ESR) in the power of 3:

$$\sigma \sim ESR^3 \quad (5)$$

which means that for a fixed size, the backscattering will increase exponentially with $\sigma \sim ESR^3$
When the echograms displayed layers with weak smoke like features and exponential frequency response, it was possible to use the frequency response as a key for isolating copepods.

The depth profile of copepod backscattering calculated and illustrated using R. By calculating the mean backscattering value for each depth channels and plotting mean s_A against depth, the depth profile is illustrated (Fig. 3.9) by a box plot. This was done for all of the 12 sampling stations from the 2009 survey.

2. 3. 2 Target strength calculations

Target strength can be used to measure how strongly an object reflects sound. This also applies to zooplankton, but because of their small size and complex structure the methods used in abundance estimation of fish is not suiting for zooplankton, other than the those similar in size to the smallest fish (Simmonds and MacLennan, 2005).

Models by Stanton and Chu (2000) indicate very weak backscattering (Fig. 2.3) from copepods similar in size to what we found in our biological samples. Their models show a TS of approximately -135 dB for a 0.94 mm copepod with a cephalothorax of 0.65 mm (*Pseudodiaptomus coronatus*) when insonified with 333 kHz.
They also made controlled acoustic measurements from hundreds of freely swimming copepods. Their experiment indicated that their model calculations were correct.

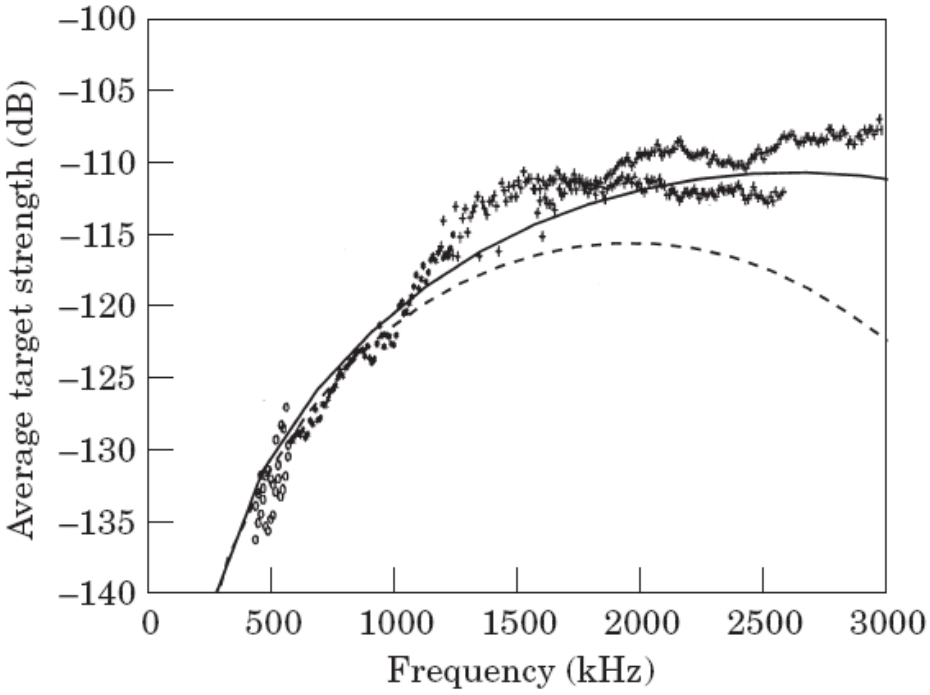


Figure 2.3 (Stanton, 2000): Comparison of TS models and laboratory data. The dashed line represent TS calculations based on the Andersons (1950)sphere model while the continuous line represent a deformed finite cylinder model. The copepods used in the experiment were the species Pseudodiaptomus coronatus with a total length of 0.94 mm, a 0.65 mm cephalothorax and a width of 0.234 mm. The angular distribution was 0°-10° and the density and sound speed contrasts in this study were set to g=h=0.01.

Our TS calculations were performed by Dr. Lucio Calise, a scientist at IMR, using a sphere model (Anderson, 1950). In a sphere model an irregular shaped fluid-like target is described as a sphere with equivalent volume to the irregular shaped target. From the theory, the scattering from a object is given by its size, form and acoustic impedance, which depends on the difference in specific mass density and sound speed between the object and the surrounding medium. Thus, an acoustic model can predict the scattering from individual fluid-like organism (target strength) where the acoustic frequency, size of the organism, density and longitudinal sound speed contrasts between the animal and its environment are the basic input to the model.

The body length ranged from 0.5 to 3 mm with step of 0.1 mm and the density and sound speed contrasts (g and h) (Table 2.1) between the target and its surroundings were obtained from Køgeler et.al.(1987)

The target strength calculations show a TS approximately 12 dB higher than found by Stanton and Chu (2000) (Fig. 2.3) for a similar sized copepod and with a frequency of 333 kHz. This difference in TS will part of the discussion.

From the TS we found the σ (Table 2.1) and the slope of the σ (Fig. 2.4) through the size distribution. From nonlinear regression we established that the σ is proportional to Length^3 (L^3). The relationship $\sigma = b_0 L^{b1}$ was found, and calculations (Table 2.2) show that there is a close to cubic relationship between backscattering and animal size at 333 kHz.

Table 2.1: Target strength calculated with a frequency of 333 kHz and backscattering cross section for copepods between 0.5-3mm. g and h are obtained from Køgeler et.al.(1987). σ in units of m^2. g and h are respectively the density and sound speed contrast to the surrounding water.

total length[mm]	estimated ESR[mm]	TS [dB]	σ [mm^2]	ρ [kgl^{-1}]	g	H
0.5	0.16	-139.6	1.39E-07	1.024	0.99805	1.021
0.6	0.20	-134.6	4.34E-07			
0.7	0.23	-130.5	1.12E-06			
0.8	0.27	-127.0	2.52E-06			
0.9	0.30	-123.9	5.09E-06			
1.0	0.34	-121.2	9.44E-06			
1.1	0.37	-118.9	1.63E-05			
1.2	0.41	-116.7	2.67E-05			
1.3	0.44	-114.8	4.15E-05			
1.4	0.48	-113.1	6.18E-05			
1.5	0.51	-111.5	8.89E-05			
1.6	0.55	-110.1	1.24E-04			
1.7	0.58	-108.8	1.67E-04			
1.8	0.62	-107.6	2.20E-04			
1.9	0.65	-106.5	2.82E-04			
2.0	0.69	-105.5	3.54E-04			
2.1	0.72	-104.6	4.36E-04			
2.2	0.76	-103.8	5.24E-04			
2.3	0.79	-103.1	6.19E-04			
2.4	0.83	-102.4	7.19E-04			
2.5	0.86	-101.9	8.20E-04			
2.6	0.90	-101.4	9.20E-04			
2.7	0.93	-100.9	1.02E-03			
2.8	0.97	-100.6	1.10E-03			
2.9	1.00	-100.3	1.18E-03			
3.0	1.04	-100.1	1.24E-03			

Table 2.2: The cubic relationship between length and backscattering $\sigma = b_0 L^{b1}$.

Parameter	Estimate	Std. Error	t-value	p-value
$\mathbf{b_0}$	3.047e-06	4.784e-06	8.143	2.30e-08
$\mathbf{b_1}$	3.247e+00	1.241e-01	26.020	< 2e-16

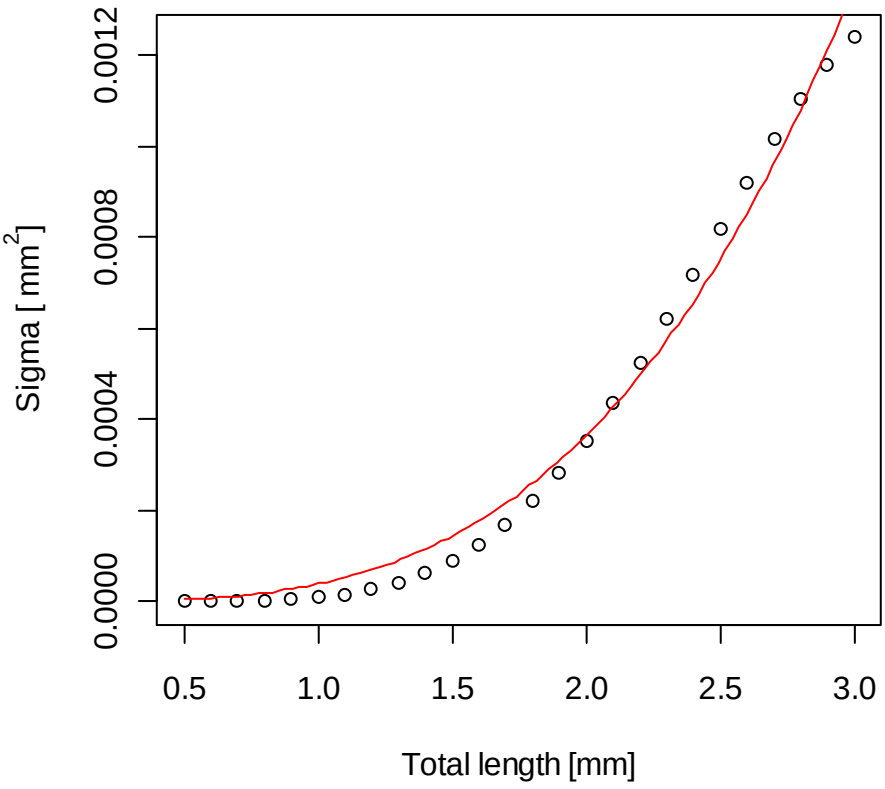


*Figure 2.4 show how the acoustic backscattering cross section increase with the size of the copepods. The regression line b0 * (length)*^{b1} *has a exponent(b1) of 3.247and an intercept (b0) of 3.047e-06.The real line forms a sigmoid curve as it approaches 3mm which means that this model is only suitable for copepods smaller than 3mm.*

2. 3. 3 Acoustic abundance estimation

If the copepods are heterogeneously distributed, the correlation between the area backscattering coefficient and the biological abundance estimates is expected to be reduced as

the distance from the sampling point increases. Therefore, to be able to validate the acoustic biomass estimates of copepods with biological net sample data, the change in correlation between the acoustical and biological abundance estimates over distance were examines. The acoustic abundance estimation was calculated from the working equation (Ona, 1999):

$$\rho_A = \frac{s_A}{<\sigma>} A_0 \quad (6)$$

where ρ_A is the area density in #/nmi^2, s_A is the nautical area backscattering coefficient [m^2/nmi^2] and <σ> is the mean backscattering cross section [m^2]. A_0 is the area of 1 m^2.

The density with respect to weight was found by multiplying the ρ_A (Eq. 6) by the average weight (<W>) of the copepod sample.

$$\rho_w = \rho_A < W > \quad (7)$$

where ρ_w is measured in g/nmi2

The weight was found from the length-weight relationship equation by Krylov (Cohen, 1981). This abundance estimate was used when comparing with the biological samples.

$$W = 0.292L^3\ 10^{-3} \quad (8)$$

W is weight in grams, and L is length in mm.

2. 4 Biological sampling equipment

For acoustic stock assessment of copepods to be reliable or even possible it is important to complement the acoustic data with biological samples. During the surveys we used a WP-2 net for plankton sampling while a trawl was used to collect Sandeel for this study.

2. 4. 1 WP-2

The WP-2 (Fig. 2.5) is a net designed for plankton sampling. It is used in stationary vertical hauls from the bottom and up. The mesh size used was 180µm and the WP2 had a diameter of 57cm. The WP-2 samples do not supply information about the vertical distribution of the catch. The WP-2 was deployed at all CTD stations.

Figure 2.5: This is not the exact same as we used but a WP2 from KC- Denmark

2. 4. 2 Trawl

The trawl in use was the Campelen bottom trawl 1800 (Engås, 1995). This is a standard survey trawl used for demersal trawling. This trawl is operated by both G. O. Sars and Johan Hjort. We used the Campelen 1800 to collect sandeel. Sandeel is not seen as a demersal species, but in order to avoid to big samples it is preferred over a pelagic trawl (pers comm. Egil.Ona@imr.no). The trawl door in use was Steinshavn W9, High type, area of 7.1m^2 and 2175kg. Se APPENDIX E for drawings.

2. 4. 3 CTD

CTD (Fig. 2.6) is an instrument used for measuring conductivity, temperature and depth. The CTD model used by IMR is SBE 911plus produced by Sea-Bird Electronics Inc. (Sea-bird, 2010). The CTD is lowered into the water column and records the water profile continuously at approximately 1ms^{-1}. The CTD data, temperature, salinity and density was recorded and plotted for all CTD stations (Fig. 2.1) from the two surveys. The data is transmitted via a long cable to a computer.

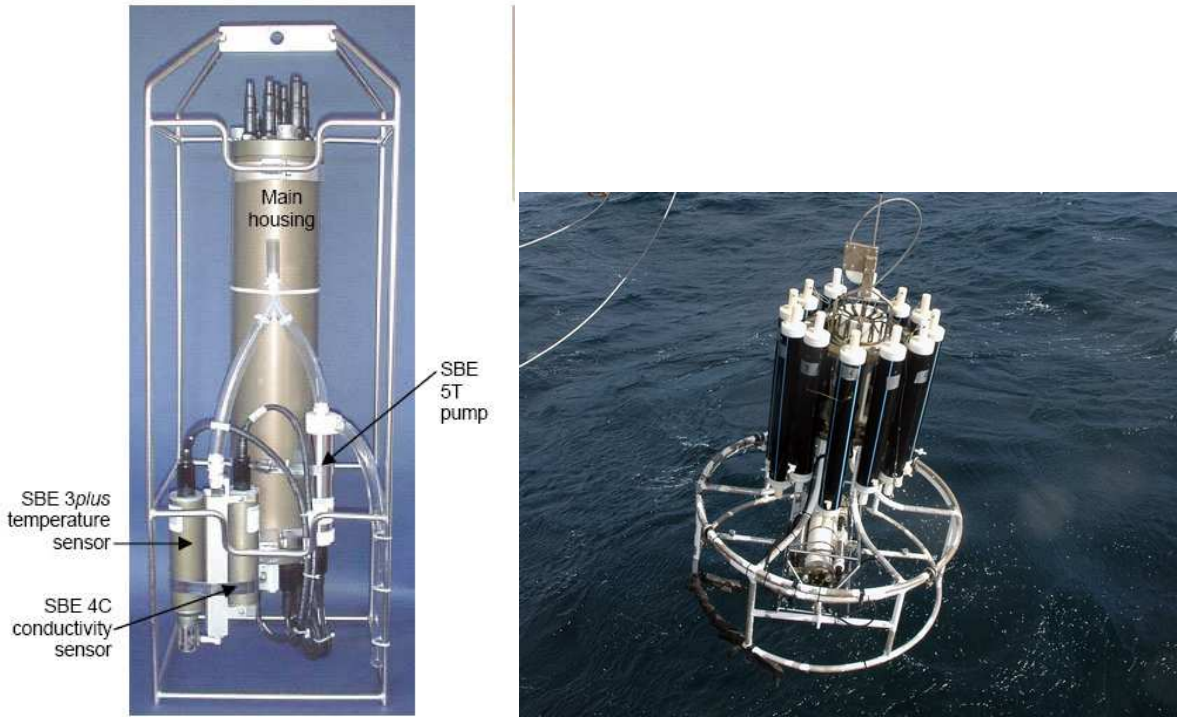


Figure 2.6: The CTD produced by sea-bird electronics inc. and used by IMR (IMR, 2009).The CTD probe record salinity, temperature and depth.

2.5 Processing of the biological samples

2. 5. 1 Onboard ship

The zooplankton samples were split in two with a Motoda plankton splitter. One half was fixed on 4% formalin (CH_2O) and buffered with borax ($Na_2B_4O_7 \cdot 10H_2O$) for later taxonomic analysis. This is the most common method used for fixing and storing zooplankton samples because it is cheap and the samples can be stored for several years (Kapiris et al., 1997).

The other half was filtered through 2000 µm, 1000 µm and 180 µm filters. The zooplankton measurements larger than 2000 µm were identified and measured and put on an aluminium dish for dry weight. The 1000 µm and 180 µm samples were put directly on dishes and put in a heating closet at 60°C for more than 24 hours to determine dry weight. The data recorded were uploaded to the IMR plankton web. This procedure was used onboard Johan Hjort. The samples from the 2009 survey were not split for biomass estimation but put directly on formalin as no specialist on zooplankton participated on the survey. The formalin fixated

samples had to be prepared for weighing in the laboratory at the High technology centre in Bergen.

2. 5. 2 At the IMR lab

The samples were further analysed at the zooplankton laboratory of the IMR. The zooplankton samples were processed in accordance with standard IMR procedure. First, the samples were sifted through an 180µm sifter and the formalin washed out with fresh water. With the help from a Motoda plankton-splitter the samples were further, stepwise split in halves until the sample was of countable size. By recommendations from the engineers at the IMR zooplankton laboratory, the splitting was restricted to 1/128 of the original sample. This was done in order for the subsample to be as reliable as possible when back-calculating to the original sample. This was not possible for all samples, as some of them were too numerous and had to be split down to 1/512 of the original sample.

When the splitting was done, the subsample was put in a counting chamber consisting of five cambers and analysed under a stereomicroscope of type Leika MZ7.5 (Leika, 2008). All the chambers were counted. After the counting was done the subsample was put back on borax-buffered formalin for scanning.
The total number in each catch was calculated by multiplying the number of animals counted in the subsample by the denominator of the fraction of the subsample.

$$N_{total} = N_{subsample}\, F_{denominator\ of\ subsample\ fraction} \tag{9}$$

Further the volume density was found by dividing the total catch by the volume filtered.

$$\rho_v = \frac{N_{total}}{F_{volume\ filtered}} \tag{10}$$

The dry weight from the 2009 samples had to be measured in the laboratory at the High technology centre in Bergen (HIB). The samples were rinsed in fresh water to remove formalin before they were split in half. One part was put back on 4% borax buffered formalin, while the other part was filtered through sieves of mesh size 2000 µm, 1000 µm and 180 µm.

The different size fractions were put in pre weighed aluminium dishes and placed in a heating cabinet at 60°C for 24 hours, or until the weight had stabilised.

The wet weight was calculated from the dry weight by multiplying with a factor of 5.0 (Mauchline, 1998) and by adding 20% (Omori, 1978; Champalbert, 1979) as a compensation for the expected weight loss from the formalin fixation. However, the accuracy from this procedure is not as good as for the 2010 material.
The area density was calculated from the area of the WP-2 (0.25^2) by multiplying the sampled volume by 4 for the m^2 density.

$$\rho_A = 4N_{Total} \tag{11}$$

2. 5. 3 Zooscan

The Zooscan is a waterproof scanner for identification and measurements of zooplankton. The plankton species identification software is yet to be perfected, and the scanner was used for length distribution only.

The subsamples were once again rinsed for formalin and flushed in boiled fresh water to remove potential unwanted buoyancy before they were poured onto the scanner. The zooplankton size distribution was obtained for 39 of the 40 samples, and the zooplankton was divided into desired taxonomic groups. Sample 206 was not measured for length distribution due to computer error. The size distribution within each of the taxonomic groups was not obtained because it would be too time consuming.

The length distribution was recorded for the fraction of the sample that was measured between 0.3- 3.0 mm. This was done because the organisms smaller than 0.3 mm would be competing with dust and other contamination in the scanner. In addition, this would further ensure that the animals used for the length distribution data were mainly copepods, and rule out potential contamination from animals such as apendicularians and chaetognats, which here would represent significant outliers.
From the scanning, total length and the equivalent spherical radius (ESR) which is the radius of a circle with volume equivalent to that of an irregular shaped object was found.

2. 6 Digestion experiment

During the survey it was suggested that the sandeel digested rapidly and within hours. This would seem reasonable if the sandeel left the sand every morning with an empty stomach to feed. This would also suggest that almost all of the sandeel left the sand during the day.
To test this, a sample of 330 *A. marinus* was collected from a trawl sample (station number: 195) and put in a tank where stomach filling and digestion rate were recorded from 10 individuals every hour. Before the experiment started we made sure that the sandeels in the catch were well fed. This was done by examining the stomachs of several sandeel as soon as a catch was on deck.

A 6 level scale was made were digestion rate ranged from 0-5; 0 being empty, 1 unidentified matter, 2 less than 25 % identifiable individuals, 3 25-50%, 4 50-75% and 5 being easy detection of 75-100% of the individuals. Also a 5 level scale concerning stomach filling were made, where 1 was empty, 2 modest, 3 half full, 4 full and 5 bursting. The sandeel was terminated and the otoliths preserved before it was gutted, examined and the stomach filling and digestion rate recorded.

Because of expectations of fast digestion it was decided to examine 10 individuals every 1 hour in the beginning of the experiment. The sampling started at t=0 and continued with t=1, t=2…t=7. After 7 hours it was decided to increase the interval. The stomach data was plotted against time to see how long it would take for the sandeel to digest the copepods and empty its stomach. The data for this experiment was recorded by 5 different technicians, and data recorded without me being present in the laboratory were removed to avoid subjective scale reading.

2.7 Statistics

All statistical analysis were performed in R (Team, 2008). When testing the correlation between the biological and acoustic abundance estimations simple linear regression was used.

The Simpson index of species diversity was used when comparing the diversity between the two years. The index is a measurement of the probability of two randomly picked species being different. The outcome of equation 12 give the Simpson index (D) where 0 is high

diversity and 1 is no diversity. By using the Simpson index of diversity (1-D) instead the index changes to a more logical scale where 0 represent no diversity and 1, high diversity.

$$D = \frac{\sum n(n-1)}{N(N-1)} \quad (12)$$

n represents the total number of organisms of a particular species and N the total number of organisms of all species.

Backscattering from copepods is size dependant and small copepods scatter sound more poorly than large. Non linear regression was used to find the relationship between σ and the length, and the backscattering-length relationship found at 333 kHz proved to be close to cubic. This information was used when calculating the mean size of the copepods with respect to the backscattering which is not the arithmetic mean but the cube root mean of the length (CML).

$$CML = \sqrt[3]{\frac{\sum n_i L_i^3}{\sum_{i=1}^{n} n_i}} \quad (13)$$

The weight-length relationship (Eq. 9) is similar to the σ–length relationship. The backscattering from a certain weight is therefore assumed to size independent. This means that 1 kg of small copepods will scatter sound in a similar manner as 1 kg of large copepods.

All graphical presentations and statistical calculations were performed in R (Team, 2008).

3. Results

3.1 2009 versus 2010 the biological samples

The animals collected with the WP-2 net (Fig. 2.1a and b) was identified to the lowest taxonomic level required for this study. The taxa recorded were *Calanus sp., Microcalanus, Psaudocalanus, copepod Naupilii, Metridia sp., Cyclopoid copepods, Apendicularia, Aglantha digitale, Temisto sp., Temora longicornis, Polychaeta*, Decapod larva, *Chaetognata, Limacina retroversa,* and some Hydrozooans other than *A.digitale.* There was some variation between the stations but calanoid and cyclopoid copepods were the dominant zooplankton in all stations. In 2009 at least 72% belonged to the order Cyclopoida and Calanoida while they contributed to 65% in the 2010 samples. At the most, 97 and 90% belonged to these to families in respectively 2009 and 2010, and the remaining taxa were represented by relatively few individuals. The taxonomic groups obtained from the biological samples were as expected from earlier North Sea surveys in the spring (Falkenhaug and Omli, 2010). Tables of the taxonomic analysis can be found in APPENDIX A.

Zooplankton taxa recorded during the 2010 survey were similar to the 2009 survey. The samples were dominated by early copepod stages belonging to the orders Cyclopoida and Calanoida. These two alternated as the most abundant order from station to station. Tables of the taxonomic analysis can be found in APPENDIX A.

The Simpson index of Diversity (1-D) reveals a higher diversity in 2010 (Table 3.1) than in 2009 with a mean index was 0.5 and 0.6 for the 2009 and 2010 data, respectively. A two sample Kolmogorov-Smirnov test of the index revealed a significant ($p=0.03$) difference in species diversity between the two years. The species accumulation curve (Fig. 3.1) shows that 10 samples should be sufficient to detect all species, meaning that the 12 samples from the 2010 survey is enough for the diversity index to be reliable.

Table 3.1: Simpson index of species diversity (D-1). The table explain the species diversity for all stations from 2009 and 2010. 0=no diversity, 1=High diversity. The values represent the probability of two randomly picked species being different from each other.

Stations 2009	D-1	Stations 2010	D-1
194	0.54	**308**	0.75
195	0.65	**309**	0.70
196	0.54	**310**	0.75
197	0.58	**311**	0.76
198	0.43	**312**	0.58
199	0.60	**313**	0.50
201	0.37	**314**	0.69
202	0.28	**315**	0.74
203	0.49	**316**	0.79
204	0.52	**317**	0.52
205	0.53	**318**	0.73
206	0.52	**319**	0.73
		320	0.69
		321	0.69
		322	0.60
		323	0.41
		324	0.34
		325	0.40
		327	0.68
		328	0.58
		329	0.57
		330	0.47
		331	0.67
		332	0.48
		333	0.43
		334	0.53
		335	0.73

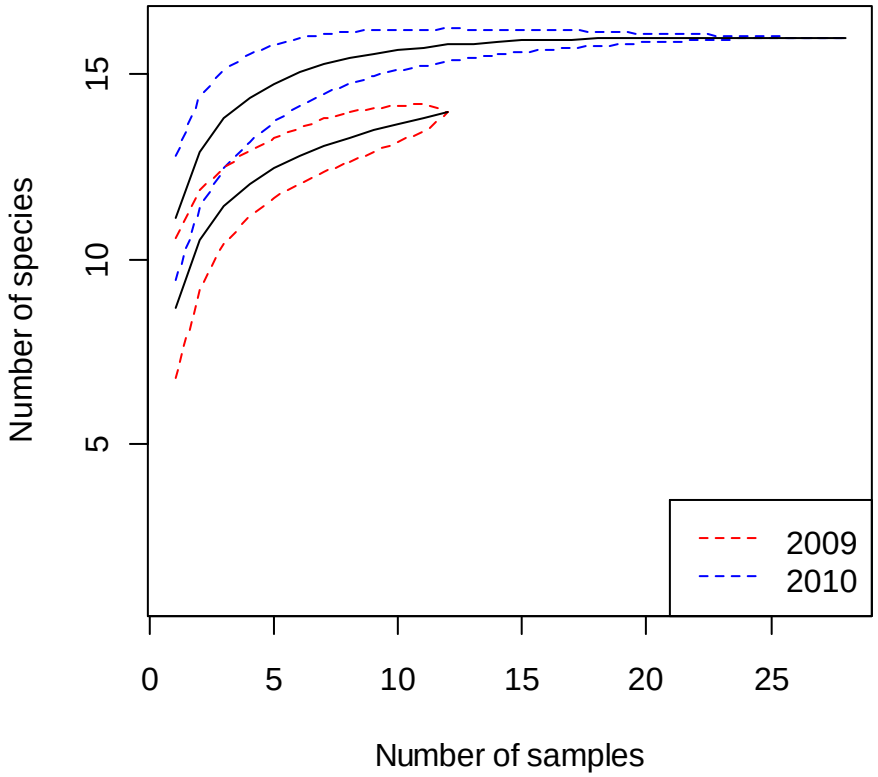


Figure 3.1: Species accumulation curve. Species accumulation models seek to estimate the number of unseen species. The figure demonstrates that the maximum number of species is reached after 10 samples in 2010 and that no new species were found in the rest of the samples. This suggests that 12 samples in 2009 are sufficient when comparing species diversity between the two years. The plotted values are the change in mean numbers of species with increasing numbers of samples. The colored lines show the 95% confidence intervals.

Abundance estimation for 2009 based on WP-2 sampling (Table 3.2) revealed a variation among sampling stations ranging from 10 to 36 g/ m^2 with an average of 20 g. About 99% of the sampled biomass was found in the 180-2000 µm filters, almost equally distributed between the smallest and the intermediate size intervals, 180-1000 and 1000-2000 µm. This shows that the copepods of size <1 mm were far more numerous than those larger than 1 mm.

Biomass estimations from the 2010 survey ranged from 0.4 to 40 g/m^2 with an average of 9 g/m^2. More than 60% of the sampled zooplankton was located in the 180-1000 µm interval and only 30% in the 1000-2000 µm interval. This suggests that the copepods were in average

smaller in 2010 than in 2009. Table 3.2 and 3.3 show all biomass calculations, including a conversion factor between dry weight and wet weight. The compensation factor of 20% used in 2009 to compensate for formalin induced weight reduction(Omori, 1978) is also indicated in the table.

Table 3.2: Biomass calculations for all stations from 2009. All weight calculations are in grams where DW is dry weight [g], WW is wet weight [g] and the corrected sum of 20% added due to formalin induced weight decrease(Omori, 1978). 180, 1000, and 2000 µm are the mesh size of the sifters used in the fractioning. Wet weight is calculated from dry weight by multiplying by a factor of 5 (Mauchline, 1998).The weight fraction >2000 µm does not contain copepods but mostly amphipods and decapod larva. The fraction 180-2000 µm consists mainly of copepods.

Stations 2009	$n10^5$/ sample	$n10^5$/ m^2	$n10^4$/ m^3	DW 180µm	DW 1000µm	DW 2000µm	DW sum	Weight correction	WW/ Sample	WW/ m^3	WW/ m^2	$WW10^{-5}$/ n
194	2.19	8.74	2.19	0.191	0.540	0.022	1.506	1.807	9.036	0.904	36.144	4.13
195	2.41	9.63	2.41	0.149	0.203	0.005	0.714	0.857	4.284	0.428	17.136	1.78
196	1.88	7.52	1.88	0.163	0.219	0.007	0.778	0.934	4.668	0.434	18.672	2.48
197	0.71	2.83	0.71	0.196	0.290	0.002	0.976	1.171	5.856	0.488	23.424	8.29
198	0.37	1.48	0.37	0.137	0.126	0.000	0.526	0.631	3.156	0.316	12.624	8.50
199	0.61	2.45	0.61	0.316	0.148	0.003	0.934	1.121	5.604	0.400	22.416	9.16
201	2.17	8.69	2.17	0.382	0.163	0.000	1.090	1.308	6.540	0.503	26.160	3.01
202	1.42	5.70	1.42	0.220	0.164	0.000	0.768	0.922	4.608	0.384	18.432	3.23
203	0.51	2.05	0.51	0.142	0.153	0.000	0.590	0.708	3.540	0.236	14.160	6.91
204	1.48	5.94	1.48	0.140	0.068	0.001	0.418	0.502	2.508	0.193	10.032	1.69
205	2.39	9.56	2.39	0.319	0.200	0.000	1.038	1.246	6.228	0.479	24.912	2.60
206	0.57	2.26	0.57	0.210	0.093	0.000	0.606	0.727	3.636	0.455	14.544	6.43

Table 3.3: Biomass calculations for all stations from 2010. All weight calculations are in grams where DW is dry weight [g], WW is wet weight [g] and 180, 1000, and 2000µm are the mesh size of the sifters used in the fractioning. Wet weight is calculated from dry weight by multiplying by a factor of 5 (Mauchline, 1998).The weight fraction >2000 µm does not contain copepods but mostly amphipods, decapod larva and some teleost larva while the fraction 180-2000 µm consists mainly of copepods and the 180-1000µm fraction contained large amounts of cyclopoid copepods.

Stations 2010	$n10^5$/ sample	$n10^5$/ m^2	$n10^4$/ m^3	DW 180 µm	DW 1000 µm	DW 2000 µm	DW Sum	WW/ sample	WW/ m^3	WW/ m^2	$WW10^{-5}$/ n
308	0.69	2.74	0.55	0.190	0.002	0.013	0.205	1.025	0.082	4.100	1.49
309	0.78	3.11	0.62	0.143	0.000	0.000	0.143	0.715	0.057	2.860	0.92
310	0.22	0.88	0.18	0.633	0.023	0.023	0.679	3.395	0.272	13.580	15.5
311	0.86	3.42	0.62	0.581	0.025	0.633	1.239	6.195	0.451	24.780	7.25
312	1.32	5.29	1.10	0.753	0.279	0.004	1.036	5.180	0.414	20.720	3.92
313	1.07	4.29	0.86	0.535	0.123	0.000	0.658	3.290	0.263	13.160	3.07
314	1.27	5.09	1.06	0.560	0.073	0.011	0.644	3.220	0.268	12.880	2.53
315	0.38	1.53	0.31	0.132	0.000	0.000	0.132	0.660	0.053	2.640	1.73
316	0.47	1.86	0.41	0.067	0.000	0.005	0.072	0.360	0.032	1.440	0.77
317	0.39	1.54	0.27	0.470	0.622	0.000	1.092	5.460	0.383	21.840	14.2
318	0.58	2.32	0.41	0.241	0.324	0.130	0.695	3.475	0.244	13.900	5.98
319	0.88	3.53	0.64	0.167	0.122	0.007	0.296	1.480	0.108	5.920	1.68
320	1.00	4.01	0.70	0.115	0.162	0.004	0.281	1.405	0.099	5.620	1.40
321	0.35	1.40	0.26	0.262	0.591	0.001	0.854	4.270	0.311	17.080	12.2

Table 3.3 continues:

Stations 2010	n10^5/ sample	n10^5/ m^2	n10^4/ m^3	DW 180 µm	DW 1000 µm	DW 2000 µm	DW Sum	WW/ sample	WW/ m^3	WW/ m^2	WW10^{-5}/ n
322	0.89	3.57	0.55	0.964	1.001	0.000	1.965	9.825	0.605	39.300	11.0
323	1.11	4.43	0.81	0.091	0.062	0.000	0.153	0.765	0.056	3.060	0.69
324	0.98	3.93	0.72	0.035	0.001	0.000	0.036	0.180	0.013	0.720	0.18
325	0.31	1.24	0.29	0.141	0.000	0.000	0.141	0.705	0.066	2.820	2.27
326	0.31	1.22	0.22	0.032	0.000	0.001	0.033	0.165	0.012	0.660	0.54
327	0.13	0.54	0.10	0.038	0.000	0.000	0.038	0.190	0.014	0.760	1.41
328	0.12	0.49	0.10	0.019	0.000	0.000	0.019	0.095	0.008	0.380	0.77
329	0.40	1.60	0.37	0.087	0.031	0.000	0.118	0.590	0.055	2.360	1.47
330	0.32	1.27	0.23	0.070	0.001	0.220	0.291	1.455	0.106	5.820	4.58
331	0.34	1.38	0.28	0.026	0.000	0.000	0.026	0.130	0.010	0.520	0.38
332	0.14	0.56	0.12	0.029	0.000	0.000	0.029	0.145	0.013	0.580	1.04
333	0.11	0.43	0.08	0.020	0.000	0.000	0.020	0.100	0.007	0.400	0.93
334	0.57	2.27	0.35	1.003	0.113	0.000	1.116	5.580	0.343	22.320	9.82
335	1.95	7.78	0.97	0.309	0.098	0.000	0.407	2.035	0.102	8.140	1.05

All animals with total length between 0.3 and 3.0 mm were measured by the zooscanner where measurements larger than 3.0 mm were excluded from the dataset to avoid animals other than copepods. Figure 3.2 shows the length distribution for all sampling stations from 2009 with a mean length of 0.80 mm. More than 60% of the copepods sampled in 2009 ranged between 0.375 and 0.625 mm, and more than 17 % were measured between 1 and 3 mm. Due to lack of length data from station 206, copepod data from this station will not be included in the rest of the study. Size distribution for the rest of the stations is presented in the APPENDIX B.

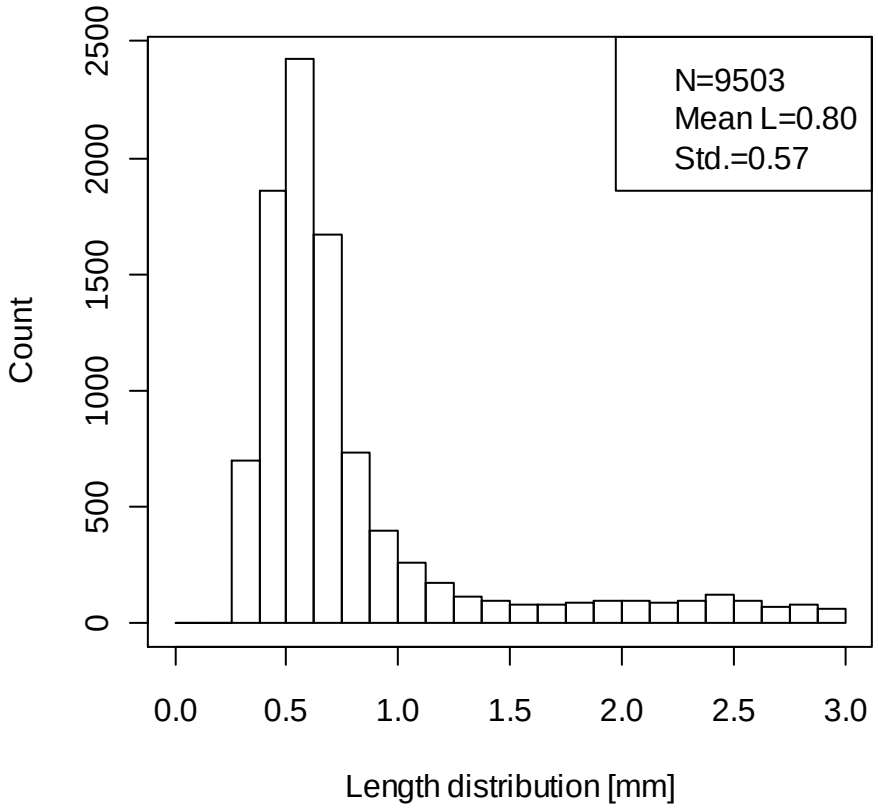


Figure 3.2: Histogram of copepod size distribution for all stations from 2009 with a mean length of 0.80 mm.

In 2010 a larger fraction of the sampled copepods ranged between 0.30 and 0.425 mm than in 2009 and only 12 % was measured between 1.0 and 3.0 mm. The length distribution of the copepods sampled in 2010 is shown in Figure 3.3 with a mean length of 0.75 mm. A two sample Kolmogorov-Smirnov test was used to test for equality in length between the two

years and revealed that the difference in size was highly significant with $p<0.001$. The Kolmogorov-Smirnov test is a non parametric analysis suitable to find out whether two data sets come from the same distribution.

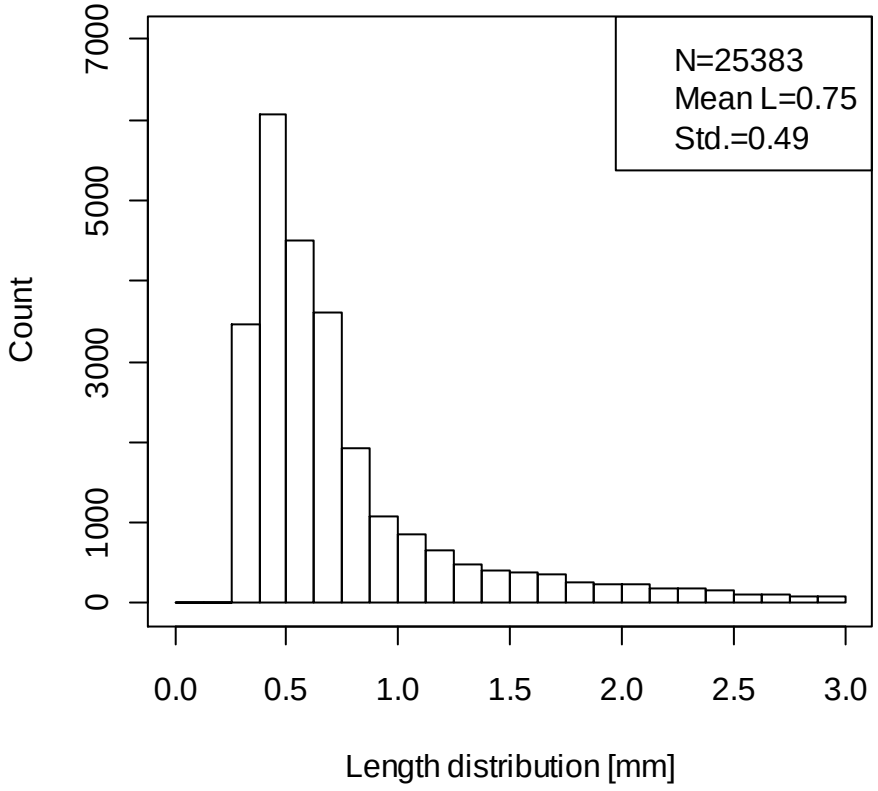


Figure 3.3 Histogram of copepod size distribution for all stations from 2010 with a mean length of 0.7 mm.

The copepods caught in 2009 were larger than those caught in 2010. The 2009 samples showed a mean size of 0.80 mm while the 2010 catch showed a mean size of 0.75 mm. When plotting each sampling station from both years (Fig.3.4) in the same plot it is evident that there is a general difference in size between the two years. The difference might seem small but considering the relative small mean size of the copepods a difference of 0.05 mm represents more than 6% difference in length.

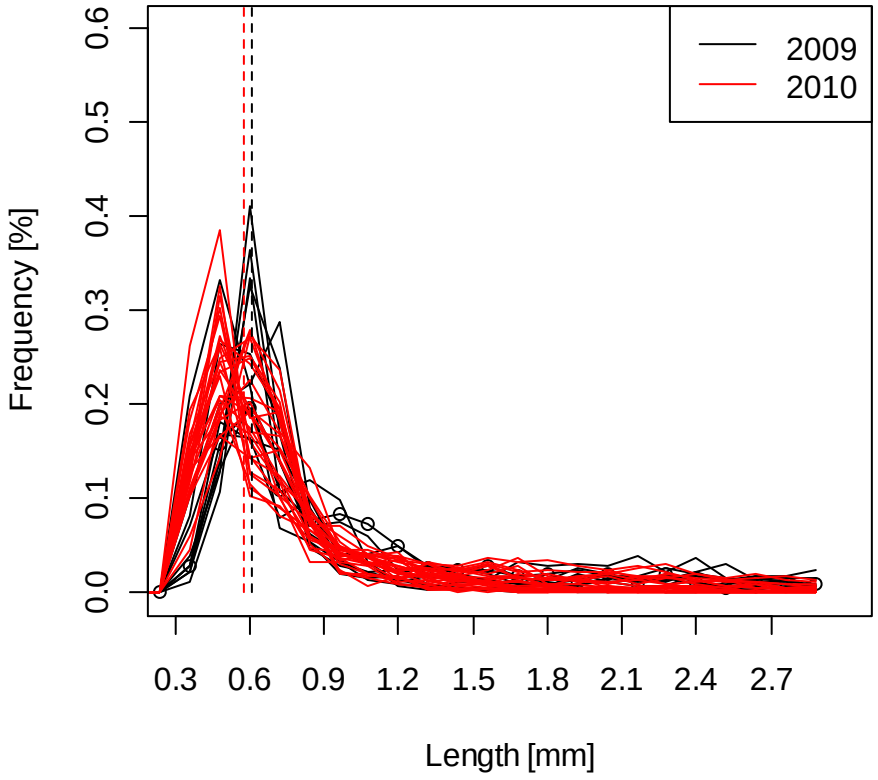


Figure3.4: Length distribution for all samples from both 2009 (black) and 2010 (red). The dotted lines represent the median length for the year with the corresponding colour.

3.2 Hydrography

Changes in hydrographical factors are probably one of the main reasons for change in the structure of plankton concentrations between different locations (Simmonds, 2005). A solar induced stabilizing of the upper layer of the water column is crucial for primary production to occur and thereby also vital for the secondary production. Increasing temperature affect the density of water and forces the low-density surface water to ride above the colder more dense water creating a stable layer (Levinton, 1995), and thereby facilitating the primary production. The layer where the specific density changes rapidly with depth is called the pycnocline and sets the boundary for were production can take place. The rapid change in density can be accredited the change in temperature and salinity.

During the G. O. Sars survey in 2009 the water temperature was well above 8°C in the upper 30 m of the water column while the CTD sampling from the 2010 survey showed temperatures no higher than approximately 6.5°C. Even though the time of the surveys was similar, the temperature was 1.5-2.5°C lower in 2010 than in 2009 (Fig. 3.5). The mean temperature during these years, for the North Sea surface temperature in April and May, are displayed in Figure 3.6. From the CTD profiles in Figure 3.5 the depth of the pycnocline can be observed for the stations 202 and 308 and it seems like the pycnocline was located at approximately the same depth in both years. The rest of the CTD profiles are listed in APPENDIX C.

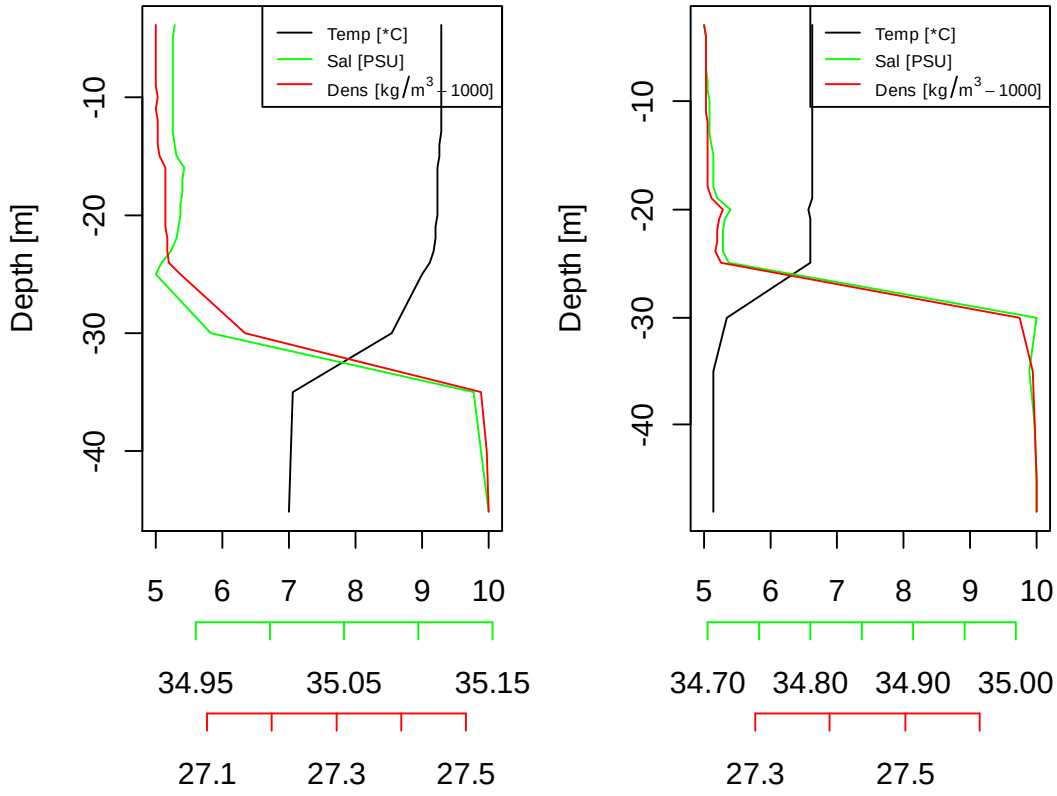


Figure3.5: Examples of temperature salinity and density for station 202 (left) from the 2009 survey and station 308 (right) from the 2010 survey. These stations are recorded at similar depth and the pycnocline is approximately the same for both years. Temperatures are measured in °C, salinity in practical salinity units (psu) and seawater specific density in kg/m^3 -1000.

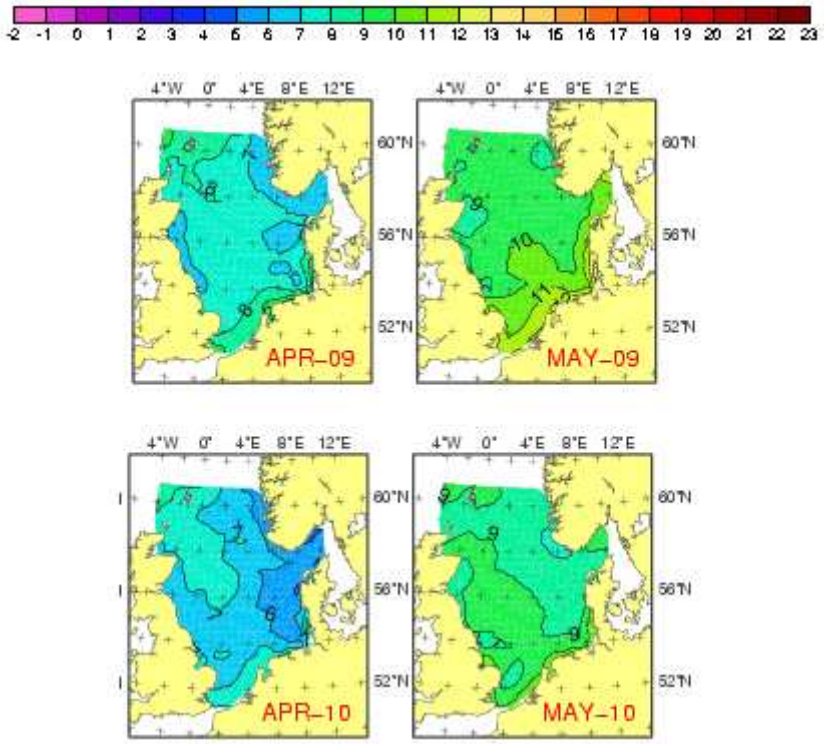


Figure 3.6 (BSH, 2011): Mean sea surface temperature for the North Sea for April and May 2009 and 2010.The mean temperature was lower in 2010 than in 2009.The bar at the top of the figure show the temperature scale. Mean surface temperature for April and May from 1990-2010 can be found in APPENDIX G.

3.3 Acoustic recordings

The sampled areas (Fig. 2.1a and b) in the two surveys was located far apart but was similar in depth and substrate so the probability of identifying copepods should be similar for all stations. In the data sampled in 2010 the frequency response was not strong enough on 200 kHz to positively identify copepods, or actually the frequency response was too strong on the lower frequencies (Fig. 3.7). The latter might be explained by the presence of the gas producing phytoplankton *Phaeosystis sp*. and is considered one of the limiting factors when measuring zooplankton acoustically in the spring bloom. Air bubbles are resonant or close to resonant at about 18-38 kHz which cause the frequency response to increase in this region and thereby making it very hard to isolate the characteristic echoes from copepods. Because the lower frequencies are more affected by the air bubbles than the higher ones the copepod frequency response gets 'shadowed' by the air bubble backscattering. Figure 3.7 shows an example of this from station 308 where the frequency response is higher for the lower frequencies than for the higher.

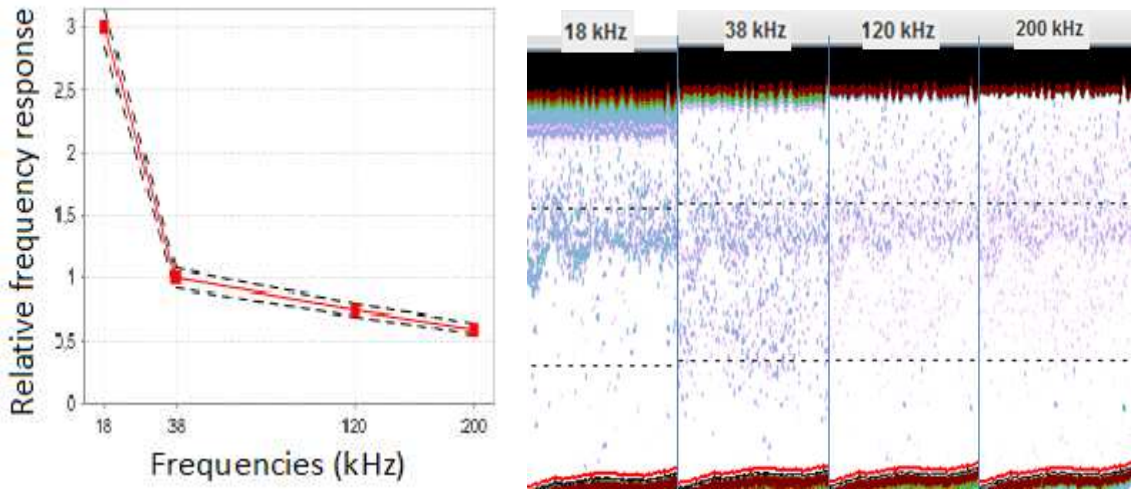


Figure 3.7: An example of the frequency response found in 2010 station 308 with 200 kHz as the highest operating frequency showing high backscattering at 18 and 38 kHz and low backscattering at 120 and 200 kHz. The echogram image from is also from station 308.

Even though copepods were found in the biological samples it was decided not to use the acoustic data collected during the 2010 survey because of the problem of identifying copepods acoustically without the 333 kHz echo sounder The acoustic equipment used in 2009 also included a Simrad EK60, operating at 333 kHz, which was less affected by the phytoplankton backscattering than the other frequencies.

Based on the echograms analysed, the copepod distribution showed a substantial variation between stations. Among the 12 different stations the mean backscattering coefficient at 333 kHz varied from 7 to 435 m^2 /nmi^2 over a 2.5 nmi distance from the sampling station. The difference in area backscattering within a short distance from the sampling stations also showed a large variability. Some of the echograms (Fig. 3.8) suggested a more heterogenic distribution of zooplankton across the horizontal while other suggested a homogenous horizontal distribution of the zooplankton layer.

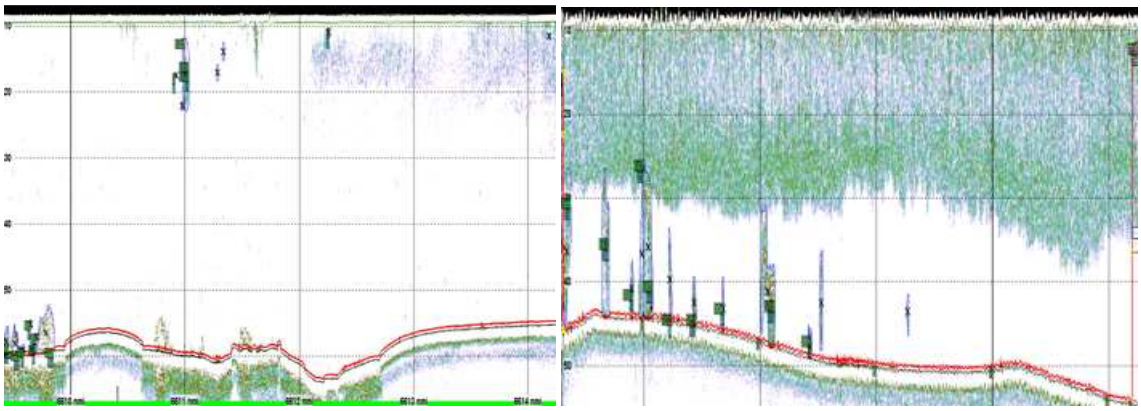


Figure 3.8: Difference in copepod distribution between 2 stations (203 to the left and 196 to the right) from the 2009 survey.

The vertical distribution of recorded backscattering was similar for most stations with a maximum at about 20m depth and with copepod backscattering located primarily in the 10-30 m depth interval. The box plot (Fig. 3.9) shows the vertical distribution and the range of backscattering in each of the 5 meter depth channels for all stations from 2009 well reflecting the variability in measured backscattering over the selected 2.5nmi distance. The variability in recorded NASC illustrated in Figure 3.9 support the idea of a highly heterogeneous copepod distribution.

The initial depth for echo integration was set to 10 m to avoid echo from bubbles caused by the interaction between the vessel and waves. In addition the drop keel and transducer near field create an acoustic blind zone which is the depth between the surface and initial depth of the echo integration. From Figure 3.8 it seems like the copepod distribution in station 196 extends all the way to the surface causing the density estimation to be an underestimate. This indicates that the copepod abundance on each station is an underestimate. If we assume that the density in the blind zone is the same as the uppermost layer it is possible to correct for this effect. On station 196, the correction would be approximately 5-10%.

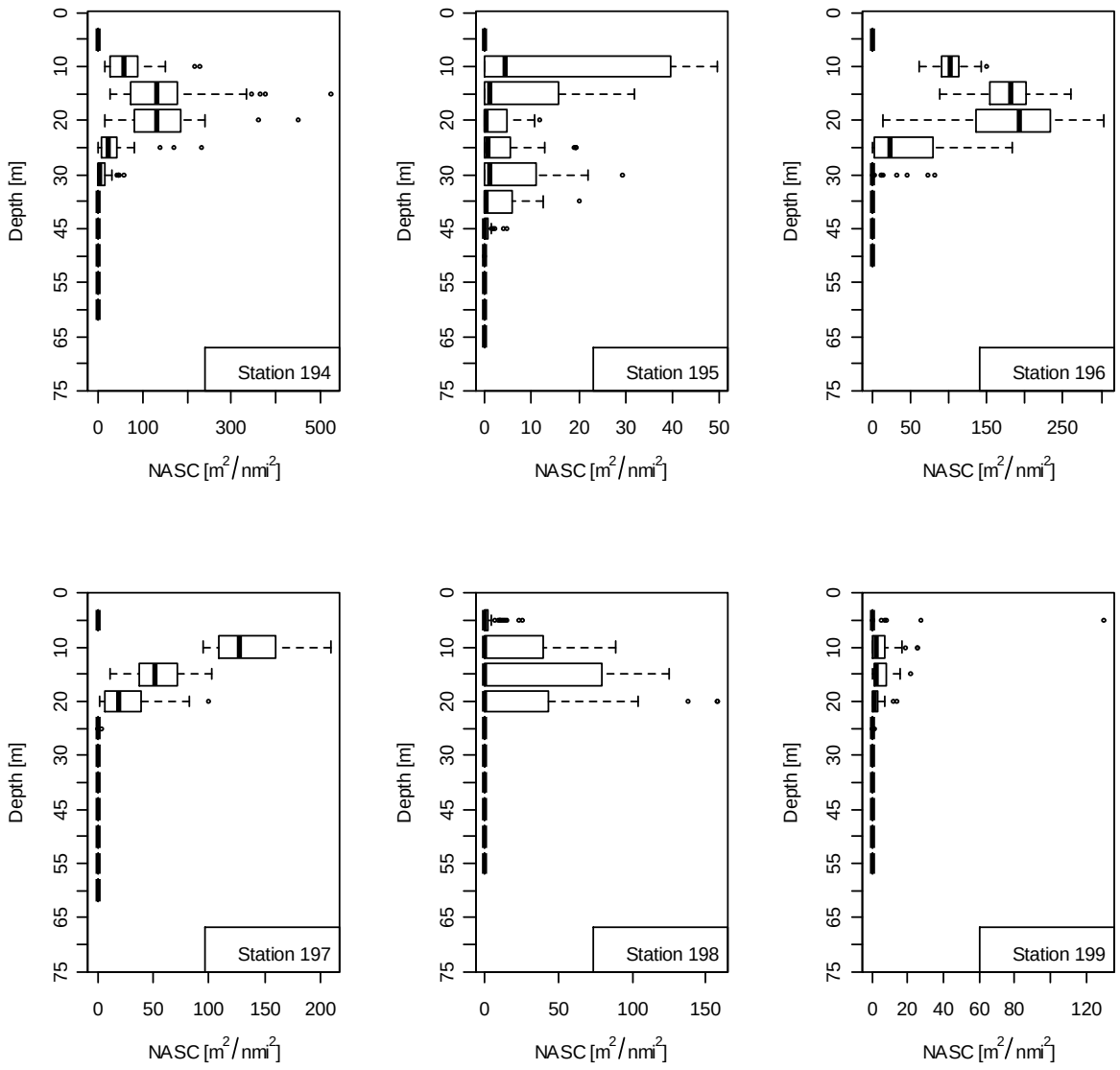
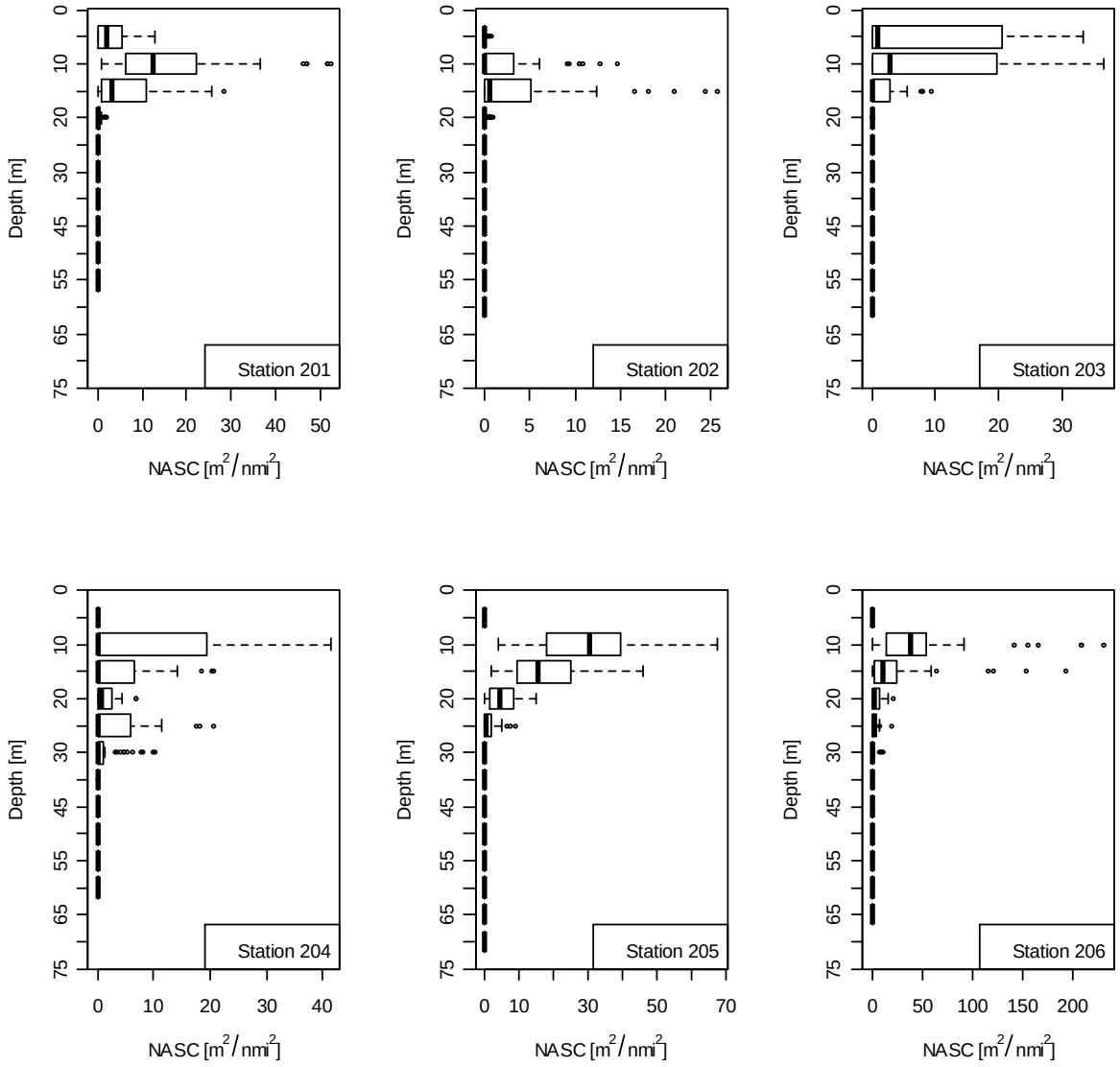


Figure 3.9: The vertical distribution of the nautical area scattering coefficient for all stations from 2009. The box represents the 25 and 75% quartiles split up by the median.

The dotted lines represent the upper and lower limits while the data points outside the limits represent rare extreme values (Løvås, 2004). The variability in NASC is illustrated over 5 nmi (2.5nmi on each side of the biological sampling station) with a resolution of 0.1 nmi across the horizontal and 5 m depth channels. Stations are listed chronological from left to right from 194-206. Station 200 does not exist. Stations 201-206 can be viewed on the next page.

Figure 3.9 continues:



3.4 Comparing zooplankton samples and acoustic abundance estimates

One of the main aspects of this thesis was to test the correlation between the acoustic and biological abundance estimates. To test this, it was crucial to understand how far from the sampling station the samples could be expected to show correlation. Figure 3.10 shows a decrease in correlation between copepod backscatter and biological abundance estimation as the distance from the sampling station increased. When performing a Pearson correlation test,

the correlation (r) drops rapidly from 0.56 to 0.45. In a distance of 2.5 nmi away from the sampling point, the Pearson product moment correlation coefficient is reduced to 0.30. The Pearson product-moment correlation is a measure of the linear dependence between two variables X and Y, giving a value between -1 and +1 (Bhattacharyya and Johnson, 1977).

In other words, the correlation decrease rapidly with distance and the reliability of the regression will decrease as the distance from the sampling point increase. This also strengthens the idea of the heterogeneous copepod distribution suggested by both the echograms (Fig. 3.8) and the box plots (Fig. 3.9). If the copepods were distributed homogenous across the 2.5 nmi the R^2 in Figure 3.10 would not decrease with form the biological sample point.

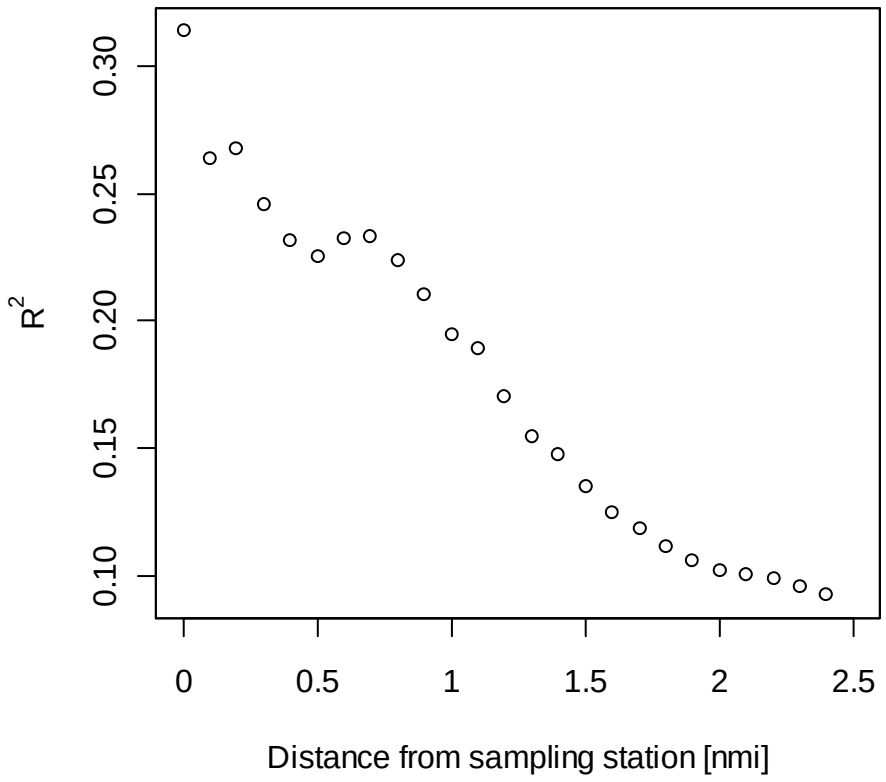


Figure 3.10: Decrease in correlation between NASC and biological abundance estimation over distance from the sampling point. This suggests a high degree of patchiness because the correlation would be much more stable with a low degree of patchiness.

Because of the expectations of rapid decrease in correlation when moving away from the sampling station the acoustic abundance estimation of copepods was correlated to the biological estimates only in the near vicinity of the sampling station. Figure 3.11 shows statistically insignificant correlation between the acoustic and the biological abundance estimation with r = 0.08. This lack of correlation can however be explained by some outliers, and will be further discussed. The outliers are represented by the red dots in figure 3.11.

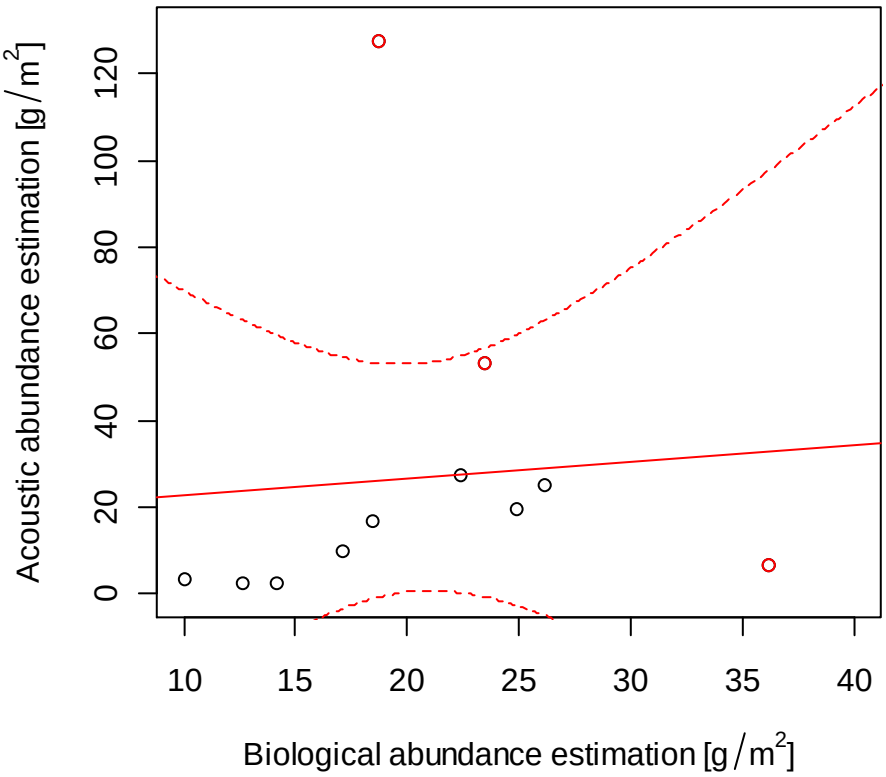


Figure 3.11: Correlation between biological and acoustic abundance estimation (gram wet weight per m^2). The red dots represent the outliers while the red dotted lines show a very large 95% confidence interval. The correlation is statistically insignificant (p=0.83).

Due to suspiciously deviant backscattering at three of the stations it was suspected that the samples might contain organisms with other backscattering properties than fluid like. For this reason the biological samples were analysed once more, to search for hard elastic shelled organisms. Hard elastic shelled organisms such as the gastropod *Limacina retroversa* reflect a

much stronger echo then fluid like organisms at high frequencies, and might “shadow” the weaker echo from fluid like organisms.

The suspicion proved to be well-founded, and the three samples 194, 196 and 197 contained more than 10 times the amounts of hard elastic shelled organisms compared with the rest of the samples. The removal of these outliers resulted in a highly significant correlation (Fig. 3.12) with r = 0.91.

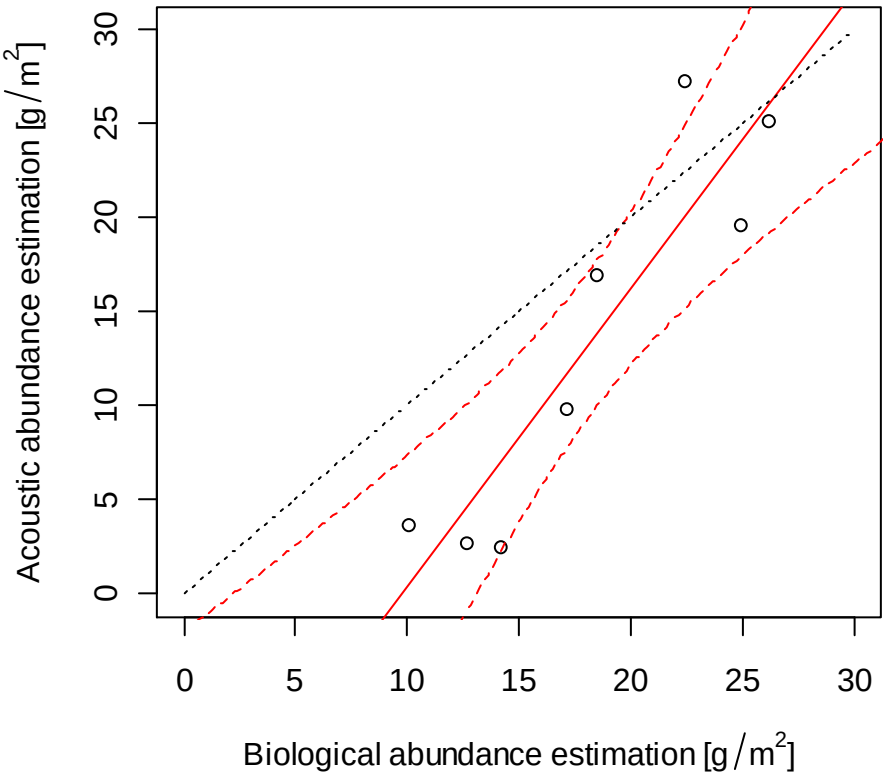


Figure 3.12: Correlation between acoustic and biological abundance estimation (gram wet weight per m^2) after removing outliers. In this case more than 76% of the variation is explained by the model. The regression line (red) has an intercept of -15.4 and a slope of 1.6. The red dotted lines are the 95% confidence interval, while the black dotted line is an imaginary line forced through origo.

The intercept in Figure 3.12 implicate that biological samples contain copepods even though copepods are not registered acoustically. This is not a surprise since the depth of initial echo integration was set to 10m and the fact that copepods probably occupy this part of the water column. Also, very low volume densities of copepods may fall under the threshold limit or the

detection limit of the echo sounder system. The relationship between the catch and the acoustics is very strong and the regression line (Fig. 3.12) shows that when the acoustic abundance estimation reaches approximately 25 g/m^2 there is close to a 1:1 relationship between the acoustic and the biological abundance estimations.

3.5 Digestion experiment

Because of the important role in transferring the energy from the plankton society to the higher trophic levels in the North Sea, accuracy in abundance estimation of sandeel is of great interest both commercial and ecological. To understand more of the sandeels sand burrowing behaviour it would be interesting to find out how often it has to leave the sand to eat. Since hunger in fish is inversely proportional with stomach filling this experiment could help answering this question. The information would also be of interest when trying to estimate the amounts of sandeel buried in the sand during the day.

The digestion speed was slow compared to the working hypothesis where the 50% gastric evacuation was expected to be reached in less than 24 hours. Nevertheless, it was first after 24 hours that noticeable signs of progress in digestion were recorded and another 10 hours passed before it was certain that the digestion had progressed to the next level of the scale used in this study. About 60 hours went by before the first sandeel with empty stomach was recorded. After 84 hours of testing, the majority of the fish was still not emptied out (Fig. 3.13 and 3.14). There was however a noticeable difference in time of digestion rate and gastric evacuation which will be discussed.

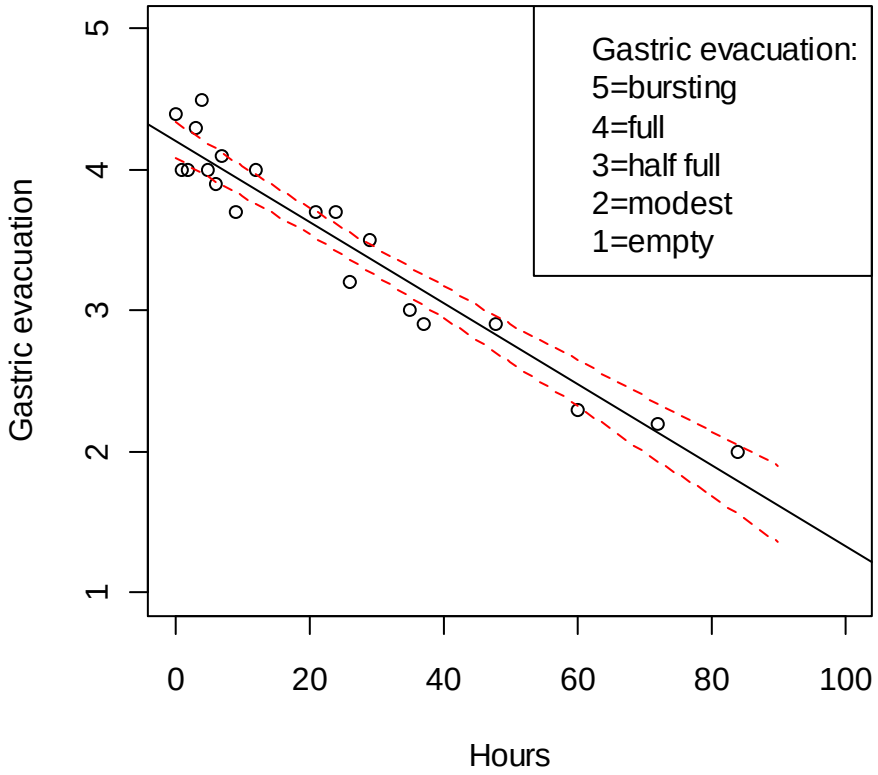


Figure 3.13: Time of complete gastric evacuation. The stomach seemed to be emptied out in about 60-90 hours. The red dotted lines represent the 95% confidence interval. In the regression line y=ax+b, the intercept is 4.21 and the slope -0.03. This model is only valid within the scale used in this experiment.

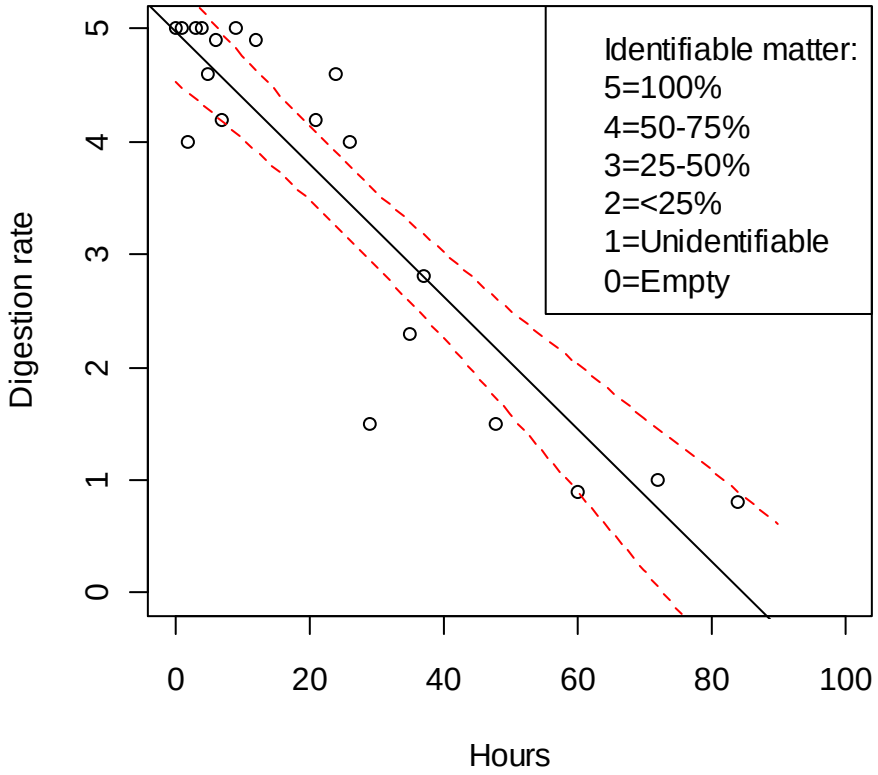


Figure 3.14: Digestion rate of the sandeel.The digestion rate seemed to progress much faster than the gastric evacuation. According to the digestion rate the the digestion took about 40-60 hours. The red dotted lines represent the 95% confidence interval. In the regression line y=ax+b, the intercept is 4.98 and the slope -0.06. This model is only valid within the scale used in this experiment.

According to the regression lines from Figures 3.13 and 3.14 half the food is evacuated and digested in respectively 40 and 33 hours. The digestion rate predicts a complete gastric evacuation in less than 90 hours while the regression for gastric evacuation predict complete gastric evacuation first after 107 hours. Because these results are collected from fish in a tank they might not reflect the digestion rates of sandeels in nature.

4. Discussion

The results from this study shed light on the problems and limitations concerning conventional biological sampling of zooplankton. When monitoring copepod abundance the main problem is the patchy heterogeneous distribution of copepods. The strong heterogeneity is evident both within and between stations. This variation is confirmed from several different angles. Echograms, vertical NASC profiles and the decline in correlation between NASC and biological abundance estimates over distance from the sampling station all point in the same direction, being that extrapolation of abundance estimates based on biological samples is most likely to give very imprecise estimates of the copepod biomass.

4.1 Target strength

For most zooplankton it is difficult to describe sound scattering with respect to its exact shape. To overcome this problem the use of geometrical approximations such as spheres, spheroids and finite cylinders have been used to describe the morphology of these small organisms. The sphere model dos not consider the irregulaity of the shape of the target, and because of the imagined spherical shape, the orientation is of no concern (Simmonds and MacLennan, 2005).

Wiebe et al. (1990) found significant devience in TS and attributed the devience to the irregularity of the morphology of the target. They suggested that elogated animals such as copepods scatter sound like elongated targets and not spherical ones. Even though Wiebe et al. (1990) claim the need for more sophisticated models, the sphere model represents an exact solution of the acoustic wave equation for a spherical shape. It can be considered a first-order approximation under some condition for a very complicated scattering process of animals with more complex shape (Traykovski et al., 1998).

TS models are very sensitive to the material property contrasts g and h. This sensitivity is profound, especially when the targets are close to the material properties of the surroundings, such as fluid like organisms in water. The density contrast (g) from Køgeler et al (1987) was based on a low count of animals without declared copepodite stage. Knutsen et al. (2001) found that for *C. finmarchicus* the density decreases as the stage increases until copepodit stage 5. The copepods in this study are small and perhaps a different g should have been

considered. Stanton and Chu (2000) found the TS to be 12 dB lower than the calculations used in this thesis. The use of a different g and h could explain this difference. From the results of this study it seems like the geometrical approximation model is sufficient for copepods of such small size, and the copepods used in the study by Wiebe et al. (1990) was indeed larger than the copepods used in this study.

Because the weight-length relationship is similar to the σ–length relationship, it was suggested that 1 kg of large copepods would give rise to the approximately the same echo energy as 1 kg of large copepods. This assumption proved to be incorrect for the copepods used in this study.

4.2 Sources of error and limitations to the material and methods

4.2.1 Taxonmy and length distribution

The taxonomic groups obtained from the biological samples were as expected from earlier North Sea surveys in the spring (Falkenhaug and Omli, 2010). Across the years the recorded taxa were similar, but the composition in terms of dominance was different.

In spite of the fact that the sampling was performed with a time lag of only 2 weeks, the copepods caught in 2009 were larger than those sampled in 2010. It could be that the time window is so small that 2 weeks could be considered a long time. However it is more likely that the growth rate of copepods is temperature dependent. This would be consistent with the results in the paper (Fig. 4.1) by Shin-ichi Uye (Uye, 1988) where temperature dependant growth rate is shown for several copepod species.

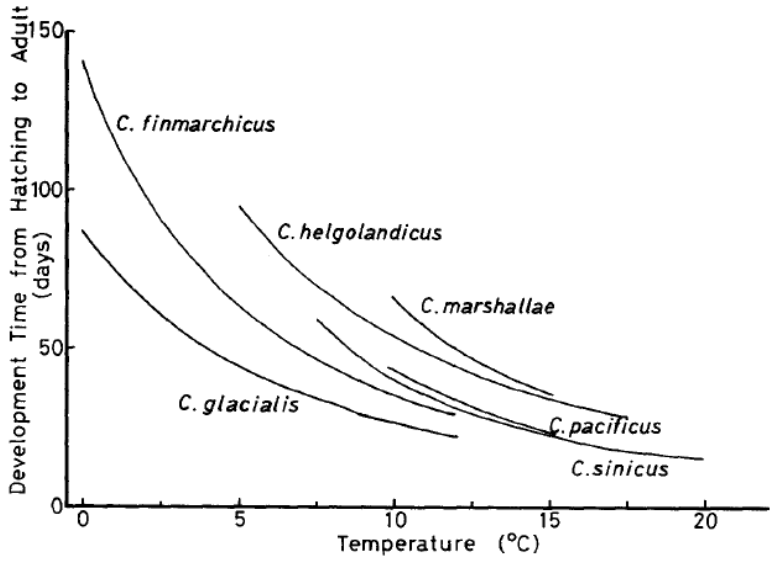


Figure 4.1: Temperature dependant growth rate of different copepod species (Uye, 1988). In this figure the growth rate of C. finmarchicus is affected by even a small difference in temperature.

According to Uye (1988), a decrease in temperature of 2 °C can slow down the development time from hatching to adult by approximately 10-20 days. If this is correct, the difference in size can be explained by the difference in temperature. Both difference in length and taxonomic composition can perhaps be explained by the difference in temperature. From inspections of historical data from the North Sea surface temperature (APPENDIX G), the difference in temperature can probably be accredited natural variation.

4.2.2 Acoustic and biological sampling

Sampling made with the WP-2 net provides no information about the vertical distribution of the catch, and is not ideal when the biological samples are to be correlated with acoustic data. In this study, the top boundary for echo integration was set to 10 m. Since the recordings on several stations reach all the way to the transducer depth, and maybe all the way to the surface, the acoustic abundance estimation would be expected to be an underestimate.

According to Williams and Conway (1980) a large fraction of the smallest *C. finmarchicus* copepodit stages are located in the upper 10 m of the water column at daytime, while the larger copepodit stages are spread more evenly throughout the water column. The lack of information on the vertical distribution from the biological sampling makes it impossible to find the amounts of copepods located in the upper 10 meters. However, NASC depth profiles

show a decline in backscattering when approaching the 10 m limit. This could indicate that if present, the copepod abundance should in most cases be lower in the upper 10 meters of the water column. To sample the copepods in the upper 10 m, it would be better to use a multinet which is a sampling device with 5 nets that can be programmed to open and close at predetermined depths. Information provided by the multinet would also give an opportunity to confirm the vertical NASC profile. The assumption of the vertical location of the copepod scatter is also strengthened by the hydrographical data on the depth of the pycnocline as no copepod backscattering was identified bellow the pycnocline.

The use of the frequency response for identification of copepods seems to work when the proper frequencies are used. From the 2010 survey we see that 200 kHz is not sufficient for identification of copepods. However, if the copepods are abundant and there is little interference from phytoplankton, Ona and Korneliussen (2000) found it to be sufficient. From the multi-frequency echograms from 2009 (APPENDIX D) it seems like 200 kHz might be adequate when identifying copepods given proper acoustic conditions. Station 202 is a good example of this. Data from 2009 show that when using 333 kHz, it is possible to identify copepods with a high degree of certainty. In most cases 333 kHz seems like a necessity.

When scrutinizing echograms with respect to copepods, one should be on the alert for large deviations in the frequency response. If r(f) above 20 is observed for the 333 kHz the scattering layer may contain hard elastic shelled organisms. The problem when scrutinizing echograms with backscattering from hard elastic shelled organisms is that even manual removal of all areas likely to contain hard elastic shelled organisms (HS) may lead to an extreme underestimation (station 194). On the other hand, if not removed, the unwanted backscattering leads to an extreme overestimation (station 196 and 197) of the copepod abundance. Because of this it was decided to remove all data most likely to contain this unwanted backscattering.

Before these scatterers were removed, the correlation between the biological and acoustic abundance estimation seemed to be poor. However, when the data from the three stations were removed, the correlation proved to be highly significant. Within the limited material presented with densities between x and y (Fig. 3.2), the acoustic density was quite close to the absolute abundance from the net sampling. This also means that the mean target strength of

the copepods must have been quite correct. This was not expected, since the modelling was based on g and h taken from the literature (Køgeler et al., 1987) and not measured. The target strength measurements were also nearly 12 dB different from data on *P. coronatus* by Chu and Stanton (2000). Fortunately, here, the acoustic densities and the catch data correspond well and the selected parameters from Køgeler et al. (1987) must be good.

4.3 Digestion experiment

The experiment suffered from many potential sources of error. Possible stress effects from handling and adaptation to the novel environment cannot be ruled out. For example, acute stress in rainbow trout (*Oncorhynchus mykiss*) caused cellular alteration in the gastrointestinal tract (Olsen et al., 2005). Stress factors such as handling, change of environment and the lack of sand are most likely to cause stress, and stress has been known to slow down the metabolism in fish, but also to catalyse the gastric evacuation (Talbot, 1985).

Gastric evacuation is dependent on temperature, and with a temperature of approximately 6.5°C it is likely that the evacuation would take about 40-50 hours (Pandian, 1985). The gastric evacuation in this experiment took a minimum of 55 hours while the digestion seemed to be done after a minimum of 45 hours. This difference could be explained with the possibility of some of the sandeel feeding on small particles and faeces during the experiment, and thereby making the digestion rate to be more correct than the gastric evacuation rate. This may explain the difference in time between 100% unidentifiable matter and complete gastric evacuation, also seen by Pandian and Vivekanandan (1985).

According to Pandian and Vivekanandan (1985), the evacuation rate is positively correlated with the feeding rate. As the sandeel in this experiment had no food available, the evacuation should slow down. On the other hand, Jobling (1981) found the gastric evacuation rate to be higher for a diet consisting of small particles than for a few large particles. Copepods are small and have a high surface to volume ratio, and the evacuation rate should therefore be catalysed. It may seem like the different factors exclude each other and that the digestion rate of the sandeel is as expected at such low temperatures for any other carnivore fish (Pandian, 1985).

The results from the digestion experiment are very interesting, as the digestion proceeded much slower than the working hypothesis predicted. With a complete gastric evacuation rate of 50-80 hours and a digestion rate of approximately 30-60 hours it is plausible that the sandeel can stay in the sand for more than 24 hours without emerging to feed and thereby being a source of error in the acoustic abundance estimation. The sandeel caught during the experiment seemed to follow a similar digestion rate as the sandeel used in the experiment. Sandeel caught subsequent to the experiment was empty, and continued to emerge from the sand for several days without the presence of copepods. This raises the question of why the sandeel do leave the sand? Are they triggered only by light and hunger? It might seem this way, seeing as similar amounts of sandeel were found in the water column both with and without the presence of copepods.

4.4 Conclusions and future aspects

The results from the digestion experiment strongly indicate that the sandeels emerge from the sand once a day at the most to feed, but that it might not have to leave the sand more than every second day. It may also seem like light intensity by far is the main factor causing the sandeel to leave the sand. To strengthen the results from this study, the experiment should be repeated with a better design and more replicates in order to get a more precise estimate. Evacuation rates should also be studied over time at one location with repeated dredge or grab sampling. Material for this kind of analysis was collected during the 2010 survey.

Traditional sampling methods alone are not suited for abundance estimation on a small spatio-temporal scale. However, by combining conventional techniques with acoustic methods this can be done with a reasonable degree of uncertainty. The methods used in this study seem promising, and should be deployed in future investigations for verification of the results and further development. One of the main focuses in the future should be the limitations due to the presence of hard elastic shelled organisms. One way to improve the method would be to gather information on the vertical distribution based on biological sampling equipment from a device such as the multinet. It would also be desirable to gather information from an acoustic lander, which is a tool developed for acoustic in situ measurements of fish and zooplankton. An acoustic platform can be placed on the ocean floor and gather information all the way to the surface while the survey can perform other tasks. This would make it possible to estimate the copepod abundance in the upper 10 meters.

5. References

ADLERSTEIN, S. A. S. 2000. Diel variation of stomach contents of North Sea cod (Gadus morhua) during a 24-h fishing survey: an analysis using generalized additive models. *Canadian Journal of Fisheries and Aquatic Sciences,* 57**,** 2363-2367.

ANDERSON, V. C. 1950. Sound Scattering from a Fluid Sphere. *The Journal of the Acoustical Society of America,* 22**,** 426-431.

ARNOTT, S. A. & RUXTON, G. D. 2002. Sandeel recruitment in the North Sea: demographic, climatic and trophic effects. *Marine Ecology-Progress Series,* 238**,** 199-210.

BEAUGRAND, G. B. 2009. Rapid biogeographical plankton shifts in the North Atlantic Ocean. *Global change biology,* 15**,** 1790-1803.

BEAUGRAND, G. G. 2008. Causes and projections of abrupt climate-driven ecosystem shifts in the North Atlantic. *Ecology letters,* 11**,** 1157-1168.

BHATTACHARYYA, G. K. & JOHNSON, R. A. 1977. *Statistical concepts and methods* New York, John Wiley & Sons,526-533.639

BODHOLT, H. & SOLLI, H. 1992. Application of th split beam technique for in situ target strength measurements. *World fisheries congress.* Athens.

BONNET, D. B. 2005. An overview of Calanus helgolandicus ecology in European waters. *Progress in oceanography,* 65**,** 1-53.

BROCKMANN, U. H. 1990. Cycling of nutrient elements in the North Sea. *Netherlands Journal of Sea Research,* 26**,** 239-264.

BSH. 2011. *Sea surface temperatures* [Online]. Bundesamt für Seeschifffahrt und Hydrographie. Available: http://www.bsh.de/en/Marine_data/Observations/Sea_surface_temperatures/anom.jsp#SSTJ [Accessed 24.03.2011 2011].

CASSIE, R. M. 1968. Sample design. *In:* TRANTER, D. J. & FRASER, J. H. (eds.) *Zooplankton sampling.* Paris: United Nations Educational, Scientific and Cultural Organization,.105-121.

CHAMPALBERT, G. 1979. Influence of method of preservation on the elementary chemical composition of Pontella mediterranea (Copepoda: Pontellidae). *Marine Biology*.

COHEN, R. E. 1981. Length-Weight Relationships for Several Copepods Dominant in the Georges Bank-Gulf of Maine Area. *J. NORTHW. ATL. FISH. SCI.***,** 47-52.

DEMER, D. A. 1995. Zooplankton target strength: Volumetric or areal dependence? *The Journal of the Acoustical Society of America,* 98**,** 1111-1118.

ECONOMOU, A. N. 1991. Food and feeding ecology of five gadoid larvae in the northern North Sea. *Journal du Conseil - Conseil international pour l'exploration de la mer,* 47**,** 339-351.

EDWARDS, M. & RICHARDSON, A. J. 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature,* 430**,** 881-884.

ENGÅS, A. 1995. *Håndbok for vitenskapelig tråling,* Bergen, Institute of marine research,94.

FALKENHAUG, T. & OMLI, L. 2010. Sekundærproduksjon. *Havforskningsraporten.* Bergen: Institute of marine research.

FOOTE, K. G. 1980. Importance of the swimbladder in acoustic scattering by fish: a comparison of gadoid and mackerel target strengths. *The Journal of the Acoustical Society of America*.

FOOTE, K. G., KNUDSEN, H. P., ASDFASD & SDAF 1987. Calibration of acoustic instruments for fish density estimation: A practical guide. *In:* ANDERSON, E. (ed.) *ICES Cooperative Research Reports.* ICES.

FREDERIKSEN, M., EDWARDS, M., RICHARDSON, A. J., HALLIDAY, N. C. & WANLESS, S. 2006. From plankton to top predators: bottom-up control of a marine food web across four trophic levels. *Journal of Animal Ecology,* 75**,** 1259-1268.

FURNESS, R. W. 1990. A preliminary assessment of the quantities of Shetland sandeels taken by seabirds, seals, predatory fish and the industrial fishery in 1981-83. *Ibis,* 132**,** 205-217.

GJERTSEN, K. 06.07.2010 2010. *RE: Kart fra tokt-2010205.* Type to CIEKALS, E.

GREENLAW, C. F. 1977. Backscattering spectra of preserved zooplankton. *The Journal of the Acoustical Society of America,* 62**,** 44-52.

GREENLAW, C. F. 1979. Acoustical estimation of zooplankton populations. *Limnology and oceanography*.

HAY, S. 1995. Egg production and secondary production of common North Sea copepods: Field estimates with regional and seasonal comparisons. *Ices Journal of Marine Science,* 52**,** 315-327.

HEATH, M. R. 1999. Climate fluctuations and the spring invasion of the North Sea by Calanus finmarchicus. *Fisheries Oceanography,* 8**,** 163-176.

HELAOUEET, P. P. 2007. Macroecology of Calanus finmarchicus and C. helgolandicus in the North Atlantic Ocean and adjacent seas. *Marine ecology. Progress series,* 345**,** 147-165.

HISLOP, J. R. G. 1991. Variation in the calorific value and total energy content of the lesser sandeel (Ammodytes marinus) and other fish preyed on by seabirds. *Journal of zoology,* 224**,** 501-517.

HOWARTH, M. J. 2003. North Sea circulation. *In:* STEELE, J. H., THORPE, S. A. & TUREKIAN, K. K. (eds.) *Encyclopedia of Ocean Sciences.*3551.

ICES 2004. Report of the ICES Advisory Committee on Fishery Management and Advisory Committee on Ecosystems
Chopenhagen: International Council for the Exploration of the Sea

ICES 2006. Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems. Chopenhagen: ICES.

IMR. 2009. *CTD* [Online]. Bergen: Institute of marine research. Available: http://www.imr.no/temasider/redskap_og_teknologi/teknologi/ctd-sbe911/ctd/nb-no [Accessed 20.01 2011].

JENSEN, H. & CHRISTIANSEN, A. 2007. Chapter 18-Sandeel. Charlottenlund: Technichal uiniversity of Denmark, Danisk Institute for Fisheries Research,Department for Marine Fisheries.

JOBLING, M. 1981. The Influences of Feeding on the Metabolic Rate of Fishes: A Short Review. *Journal of fish biology,* 18**,** 385-400.

JOHANNESEN, T. & JOHNSEN, E. 2009. Tobistokt i Nordsjøen. Bergen: Institute of Marine Research.

JOHNSEN, E., PEDERSEN, R. & ONA, E. 2009. Size-dependent frequency response of sandeel schools. *ICES Journal of Marine Science: Journal du Conseil,* 66**,** 1100-1105.

JOHNSON, R. K. 1977. Sound scattering from a fluid sphere revisited. *The Journal of the Acoustical Society of America,* 61**,** 375-377.

JONASDOTTIR, S. H., TRUNG, N. H., HANSEN, F. & GARTNER, S. 2005. Egg production and hatching success in the calanoid copepods Calanus helgolandicus and Calanus finmarchicus in the North Sea from March to September 2001. *Journal of Plankton Research,* 27**,** 1239-1259.

KAPIRIS, K., MILIOU, H. & MORAITOU-APOSTOLOPOULOU, M. 1997. Effects of formaldehyde preservation on biometrical characters, biomass and biochemical composition of<i>Acartia clausi</i> (Copepoda, Calanoida). *Helgoland Marine Research,* 51**,** 95-106.

KNUTSEN, T. 2001. Determining the mass density of marine copepods and their eggs with a critical focus on some of the previously used methods. *Journal of Plankton Research,* 23**,** 859-873.

KORNELIUSSEN, R. & ONA, E. 2000. Applications of simple plankton acoustics: new technique separtes backscatter from zooplankton and fish.

KORNELIUSSEN, R. J. & ONA, E. 2002. An operational system for processing and visualizing multi-frequency acoustic data. *ICES Journal of Marine Science: Journal du Conseil,* 59**,** 293-313.

KORNELIUSSEN, R. J. & ONA, E. 2003. Synthetic echograms generated from the relative frequency response. *ICES Journal of Marine Science: Journal du Conseil,* 60**,** 636-640.

KORNELIUSSEN, R. J., ONA, E., ELIASSEN, I., HEGGELUND, Y., PATEL, R., GODØ, O. R., GIERTSEN, C., PATEL, D., NORNES, E., BEKKVIK, T., KNUDSEN, H. & LIEN, G. 2006. THE LARGE SCALE SURVEY SYSTEM - LSSS. 6.

KØGELER, J. W., FALK-PETERSEN, S., KRISTENSEN, Å., PETTERSEN, F. & DALEN, J. 1987. Density- and sound speed contrasts in sub-Arctic zooplankton. *Polar Biology,* 7**,** 231-235.

LEIKA. 2008. *Leica MZ7.5 Stereomicroscope* [Online]. Available: http://www.meyerinst.com/html/leica/mz75/default.htm [Accessed 21.01 2011].

LEVINTON, J. S. 1995. *Marine biology: Function, biodiversity, ecology,* 423

LØVÅS, G. 2004. *Statistikk for universiteter og høhskoler*, Universitetsforlaget,489

MAUCHLINE, J. 1998. Chemical composition. *In:* BLAXTER, J. H. S., SOUTHWARD, A. J. & TYLER, P. A. (eds.) *The Biology of Calanoid Copepods.* San Diego: Academic press.710.

MELLE, W. 2004. Zooplankton: The link to higher trophic levels. *In:* SKJOLDAL, H. R., MISUND, O. A., SAETRE, R., FAERNO, A. & ROTTINGEN, I. (eds.) *The Norwegian Sea Ecosystem.* Tapir forlag.137-202.

OLSEN, R. E., SUNDELL, K., MAYHEW, T. M., MYKLEBUST, R. & RINGØ, E. 2005. Acute stress alters intestinal function of rainbow trout, Oncorhynchus mykiss (Walbaum). *Aquaculture,* 250**,** 480-495.

OMORI, M. 1978. Some Factors Affecting on Dry Weight, Organic Weight and Concentrations of Carbon and Nitrogen in Freshly Prepared and in Preserved Zooplankton. *Internationale Revue der gesamten Hydrobiologie und Hydrographie,* 63**,** 261-269.

ONA, E. 1999. Methodology for target strength measurements (with special reference to in-situ techniques for fish and micro-nekton). *ICES Cooperative research report.* ICES.

ONA, E. 2004. Multiple targets lecture mar-332. *In:* ONA, E. (ed.) Lecture notes mar-332 ed. Bergen: Ona, E.

PANDIAN, T. J. 1985. Energetics of feeding and digestion. *In:* TYTLER, P. & CALOW, P. (eds.) *Fish energetics: new perspectives.*99-124.

PEDERSEN, G. & KORNELIUSSEN, R. J. 2009. The relative frequency response derived from individually separated targets of northeast Arctic cod (Gadus morhua), saithe (Pollachius virens), and Norway pout (Trisopterus esmarkii). *ICES Journal of Marine Science: Journal du Conseil,* 66**,** 1149-1154.

RADACH, G. & LENHART, H. J. 1995. Nutrient dynamics in the North Sea: Fluxes and budgets in the water column derived from ERSEM. *Netherlands Journal of Sea Research,* 33**,** 301-335.

REAY 1986. Fishes of the North-eastern Atlantic and the Mediterranean. Vol. 2. *In:* P.J.P. WHITEHEAD & M.-L. BAUCHOT, J.-C. H., J. NIELSEN & E. TORTONESE (eds.). Paris: UNESCO

SEA-BIRD. 2010. *CTD Profiling Instruments* [Online]. Available: http://www.seabird.com/products/profilers.htm [Accessed 20.01 2011].

SIMMONDS, J. & MACLENNAN, D. 2005. *Fisheries Acoustics, Theory and Practice*, Blackwell Publishing,437.

SIMRAD 2004. SIMRAD ek60 Scientific echo sounder instruction manual. 246.

SPARHOLT, H. 1990. AN ESTIMATE OF THE TOTAL BIOMASS OF FISH IN THE NORTH-SEA. *Journal Du Conseil,* 46**,** 200-210.

STANTON, T. K. 1994A. Acoustic characterization and discrimination of marine zooplankton and turbulence. *Ices Journal of Marine Science,* 51**,** 469-479.

STANTON, T. K. 1994B. On acoustic estimates of zooplankton biomass. *Ices Journal of Marine Science,* 51**,** 505-512.

STANTON, T. K. 2000. Review and recommendations for the modelling of acoustic scattering by fluid-like elongated zooplankton: euphausiids and copepods. *Ices Journal of Marine Science,* 57**,** 793-807.

TALBOT, C. 1985. *Laboratory methods in fish feeding and nutritional studies,* Baltimore, The Johns Hopkins university press,125-154

TEAM, R. D. C. 2008. R: A Language and Environment for Statistical Computing. Vienna: R Foundation for statistical computing.

TRAYKOVSKI, L. V. M., STANTON, T. K., WIEBE, P. H. & LYNCH, J. F. 1998. Model-based covariance mean variance classification techniques: Algorithm development and application to the acoustic classification of zooplankton. *Ieee Journal of Oceanic Engineering,* 23**,** 344-364.

UYE, S. 1988. Temperature-dependent development and growth of Calanus sinicus (Copepoda: Calanoida) in the laboratory. *Hydrobiologia,* 167-168**,** 285-293.

VAHL, O. 1979. An hypothesis on the control of food intake in fish. *Aquaculture,* 17**,** 221-229.

VAN DEURS, M. M. 2009. Recruitment of lesser sandeel Ammodytes marinus in relation to density dependence and zooplankton composition. *Marine ecology progress series,* 381**,** 249-258.

WARREN, J. D. 2001. In situ measurements of acoustic target strengths of gas-bearing siphonophores. *Ices Journal of Marine Science,* 58**,** 740-749.

WIEBE, P. H. 1990. Sound scattering by live zooplankton and micronekton: Empirical studies with a dual-beam acoustical system. *The Journal of the Acoustical Society of America,* 88**,** 2346-2360.

WILLIAMS, R. & CONWAY, D. V. P. 1980. Vertical distributions of <i>Calanus finmarchicus</i> and <i>C. helgolandicus</i> (Crustacea: Copepoda). *Marine Biology,* 60**,** 57-61.

WRIGHT, P. J. & BAILEY, M. C. 1996. Timing of hatching in Ammodytes marinus from Shetland waters and its significance to early growth and survivorship. *Marine Biology,* 126**,** 143-152.

WRIGHT, P. J., JENSEN, H. & TUCK, I. 2000. The influence of sediment type on the distribution of the lesser sandeel, Ammodytes marinus. *Journal of Sea Research,* 44**,** 243-256.

6. Appendixes

APPENDIX A- Tables from taxonomic analysis

APPENDIX B- Length distribution

APPENDIX C- CTD profiles

APPENDIX D- Echograms

APPENDIX E- Trawl drawings

APPENDIX F- Calibration

APPENDIX G- North Sea surface temperature

APPENDIX H- The most important sandeel grounds in the North Sea

APPENDIX A

Tables from taxonomic analysis

Results from the taxonomic analysis. Stations 194-206 (Table I) are from the 2009 survey and 308-335 (Table II) are from the 2010 survey. All animals are measured in volume density (ind/m^2).

Table I: Results from taxonomic analysis for the 2009 WP-2 samples. The animals were determined down to desired taxonomic level for this study. The calculations are in volume density (ind/m^2).

Stations 2009	Calanus sp.	Microcalanus	Psaudocalanus	Naupilii	Metridia sp.	Cyclopoid	Apendicularia
194	503808	4096	32768	14336	2048	331776	0
195	231424	10240	233472	4096	14336	473088	0
196	485376	6144	43008	6144	4096	212992	2048
197	146432	1024	12288	1024	0	122880	0
198	36352	0	3584	0	0	108544	0
199	104448	3072	10240	5120	2048	124928	1024
201	124928	1024	29696	31744	1024	712704	1024
202	34304	5632	37376	10240	1024	491520	0
203	38656	9216	11008	5376	512	145408	0
204	147456	32768	27648	7168	0	386048	0
205	266240	8192	59392	12288	4096	618496	0
206	125952	0	4096	0	0	96256	0

Stations 2009	Themisto sp.	Temora longicornis	Limacina retroversa	Polychaeta	Decapod larva	Chaetognata	Hydrozoa
194	4096	0	2688	0	0	2048	0
195	8192	0	128	0	0	0	0
196	8192	0	3328	0	0	12288	0
197	0	0	4224	0	0	6144	0
198	0	0	0	0	0	3072	0
199	1024	1024	0	0	0	4096	0
201	3072	0	2048	0	0	5120	0
202	0	0	0	0	0	1536	0
203	0	256	0	0	0	256	0
204	260	0	0	0	0	0	0
205	0	6144	0	0	0	0	4096
206	0	0	0	0	1024	1024	0

Table II: Results from taxonomic analysis for the 2010 WP-2 samples. The animals were determined to desired taxonomic level for this study. The calculations are in volume density (ind/m^2).The table continues on the next page.

Stations 2010	Calanus sp.	Microcalanus	Psaudocalanus	Naupilii	Metridia sp.	Cyclopoid	Apendicularia
308	38912	12288	19456	27136	28160	122880	17920
309	81408	13312	24576	25088	8704	143872	3584
310	34304	2048	5632	4096	5632	24576	512
311	141824	1536	41984	8192	40960	59392	26112
312	331264	4096	18944	28672	30208	71168	20992
313	299008	5120	19456	5120	22528	20480	46080
314	254976	7168	31744	14336	39936	107520	34816
315	62976	3584	13824	5120	8192	41472	5120
316	58368	3584	11264	10752	26624	53248	8192
317	102912	2048	3584	1024	19456	15360	0
318	95232	5120	11264	1024	30720	63488	3072
319	129024	9216	17408	0	79872	99328	8192
320	202752	21504	24576	6144	68608	45056	7168
321	63488	2560	7680	1536	17920	39936	1024
322	215040	9216	15360	3072	36864	55296	10240
323	44032	6144	25600	17408	6144	334848	3072
324	28672	5120	9216	15360	9216	316416	2048
325	11264	512	10240	2560	3584	95232	0
326	8192	0	6144	6656	3584	94208	1536
327	6656	2048	6144	4608	3584	28160	0
328	6400	1024	4096	1792	3072	30976	0
329	14336	512	12288	8192	7680	101888	512
330	6144	2048	6656	7168	3584	91136	0
331	15360	13824	17408	4096	10240	73728	512
332	4608	768	2816	4352	1280	39424	256
333	2560	1024	768	768	1280	32256	4096
334	28672	9216	15872	15360	3584	150528	0
335	291840	2048	23552	207872	22528	176128	34816

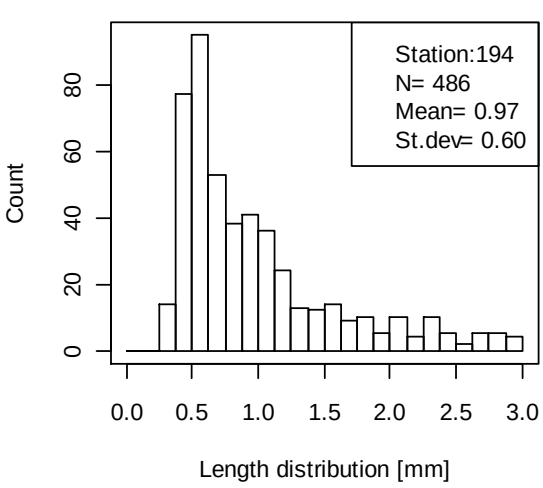
Stations 2010	Aglantha digitale	Temisto	Temora	Polychaet	Decapodlarve	Chaetognata	Hydrozoa	Teleost larva
308	7680	0	0	0	0	0	0	0
309	9216	0	1024	0	0	0	512	0
310	3072	0	1536	4608	0	0	1536	0
311	9728	512	4608	5632	512	0	0	0
312	10752	0	8192	4608	0	0	0	0
313	8192	0	0	3072	0	0	0	0
314	14336	0	3072	1024	0	0	0	0
315	7680	512	2048	2048	0	0	0	0
316	9216	0	1024	2560	0	0	1024	512
317	4608	0	0	512	0	4096	512	0
318	1024	2048	0	1024	14336	3072	0	0
319	1024	0	1024	0	6144	2048	0	0
320	5120	0	1024	2048	15360	2048	0	0
321	2048	1024	512	512	1024	512	512	0
322	5120	2048	0	0	1024	4096	0	0
323	0	0	3072	3072	0	0	0	0
324	2048	0	0	5120	0	0	0	0
325	1024	0	0	0	0	0	0	0
326	0	0	0	1536	512	0	0	0
327	1536	0	0	1024	0	0	0	0
328	1792	0	0	0	256	0	0	0
329	10752	512	1024	512	0	512	1536	0
330	5632	0	3584	0	512	0	0	512
331	0	0	512	1024	0	512	0	512
332	256	256	1792	0	0	0	0	0
333	0	0	512	0	0	0	0	0
334	0	0	2048	1536	512	0	0	0
335	3072	0	11264	2048	3072	0	0	0

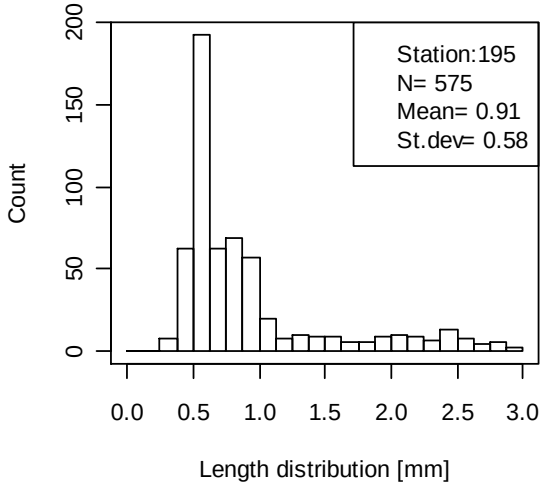
APPENDIX B

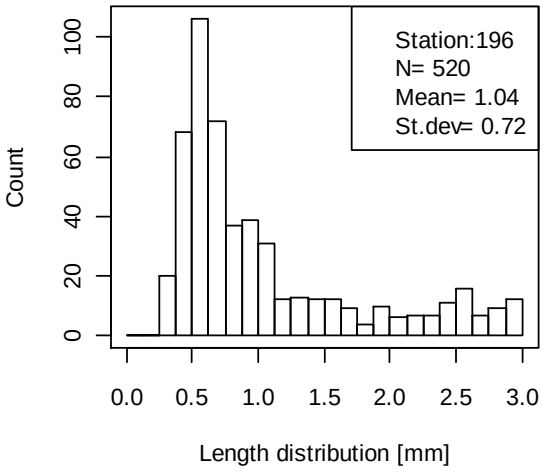
Length distribution

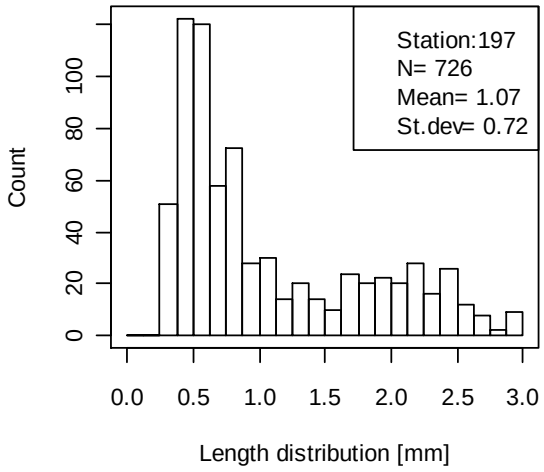
Histograms showing the length distribution obtained from the zooscan. Stations 194-205 are from the 2009 survey and 308-335 are from the 2010 survey. The box in the upper right corner of each histogram, show the station number, number of measured copepods, mean length and standard deviation.

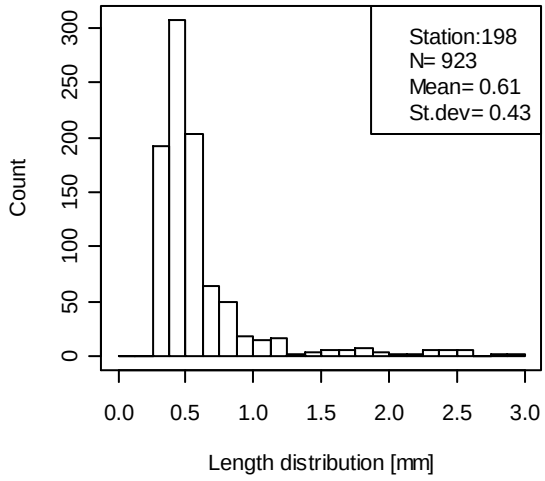
2009:

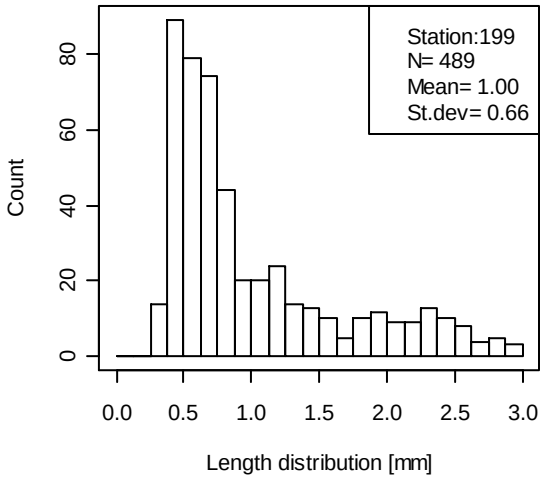









Station:198
N= 923
Mean= 0.61
St.dev= 0.43
Count
Length distribution [mm]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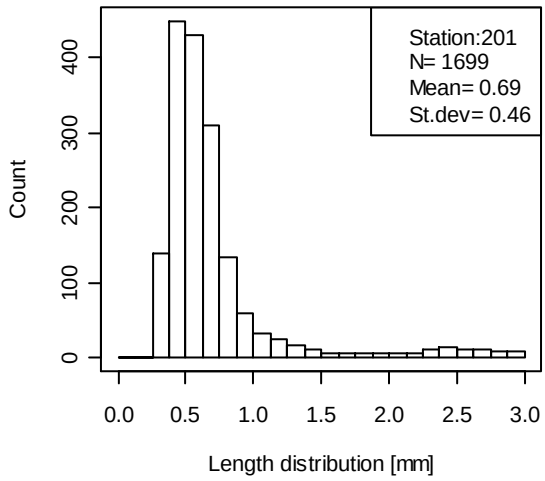
N= 489
Mean= 1.00
St.dev= 0.66
Count
Length distribution [mm]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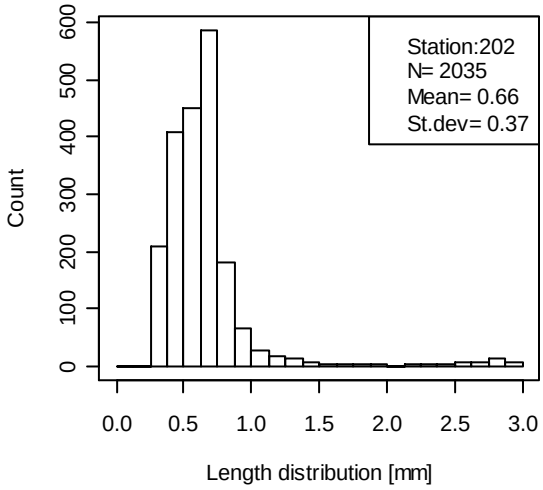
N= 1699
Mean= 0.69
St.dev= 0.46
Count
Length distribution [mm]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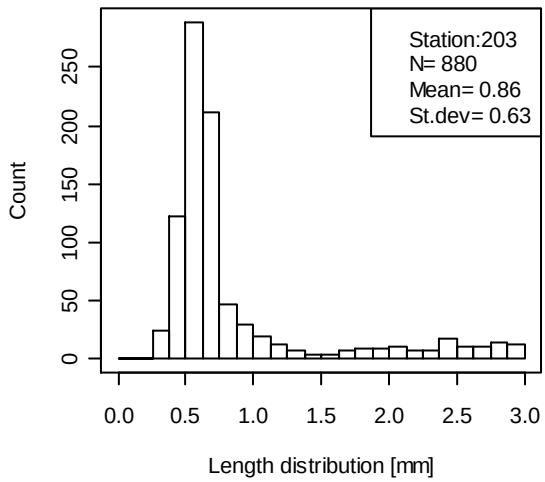
Mean= 0.66
St.dev= 0.37
Count
Length distribution [mm]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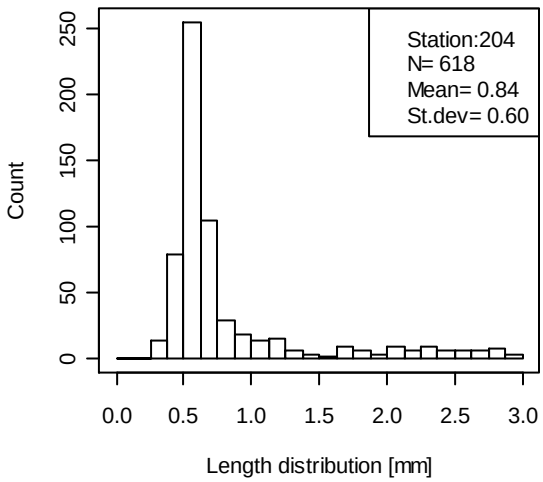
Length distribution [mm]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Mean= 0.84
St.dev= 0.60
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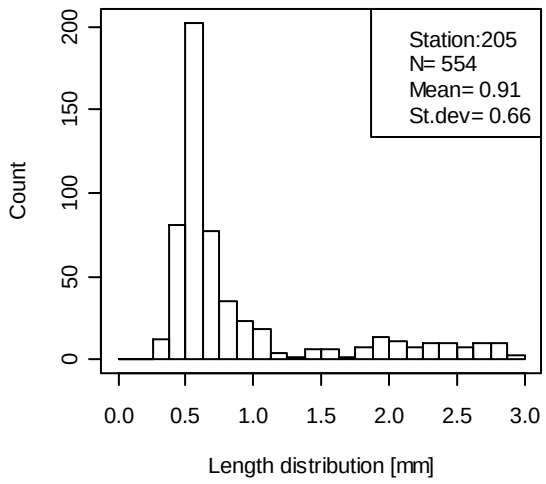
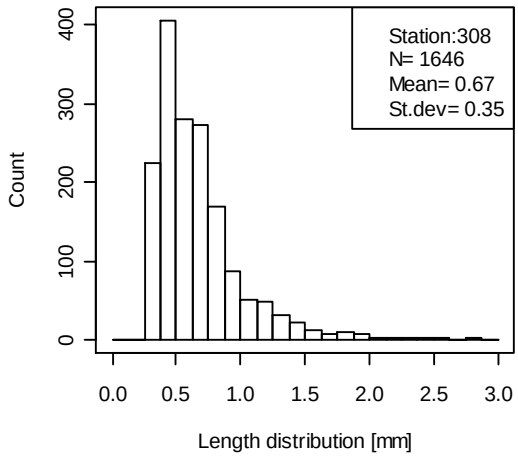
Length distribution [mm]


Station:205
N= 554
Mean= 0.91
St.dev= 0.66
Count
0
50
100
150
200
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Length distribution [mm]

2010: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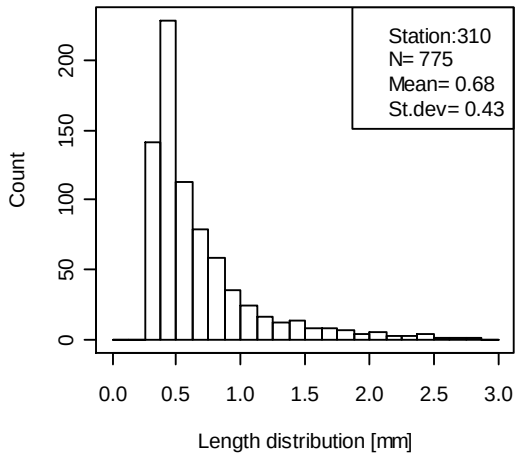
Count
Length distribution [mm]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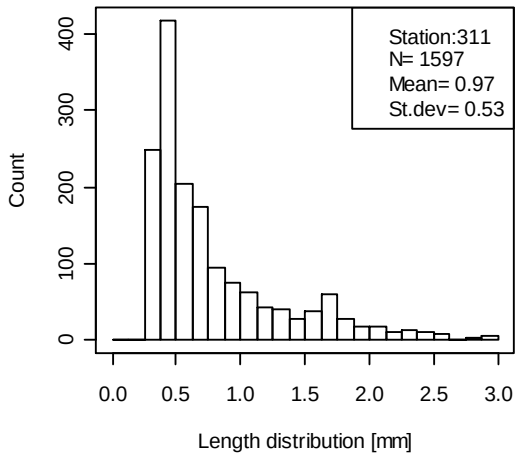
Length distribution [mm]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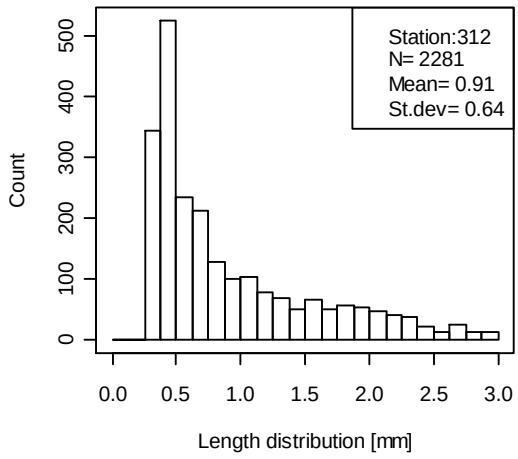
Mean= 0.97
St.dev= 0.53
Count
Length distribution [mm]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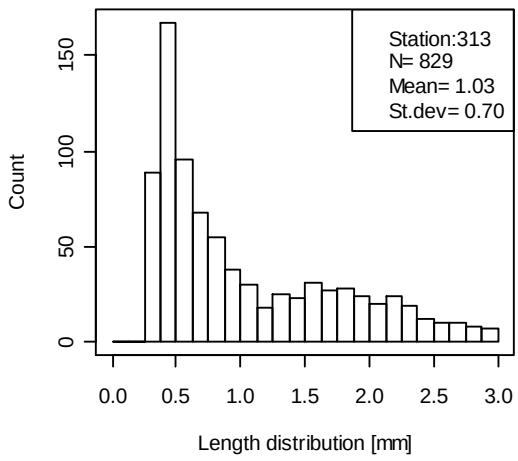
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Mean= 1.03
St.dev= 0.70
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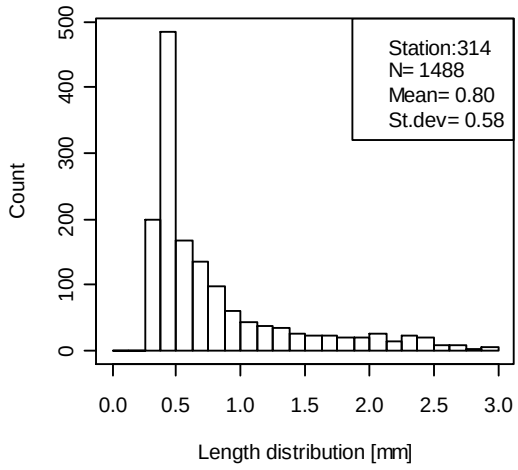
Length distribution [mm]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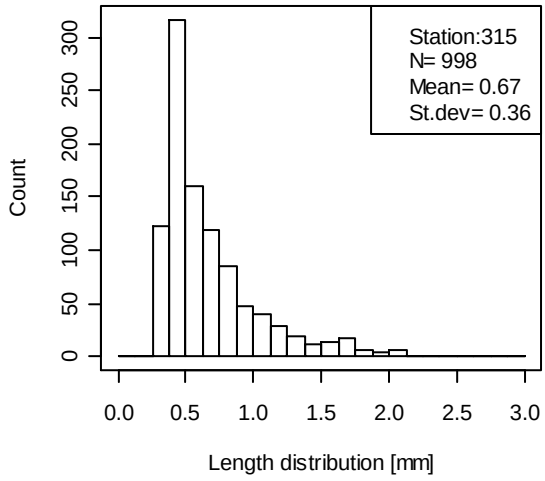
N= 1488
Mean= 0.80
St.dev= 0.58
Count
Length distribution [mm]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Mean= 0.67
St.dev= 0.36
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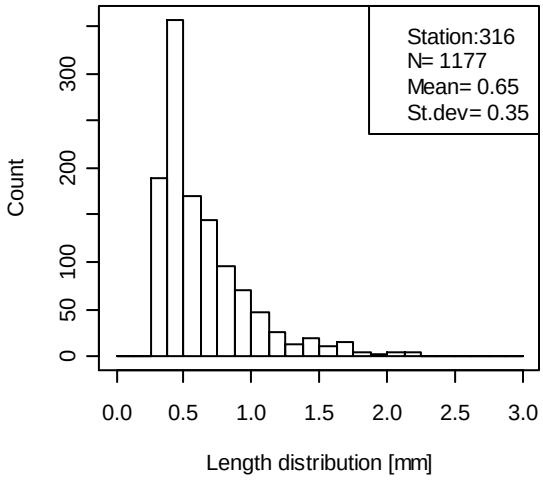
Length distribution [mm]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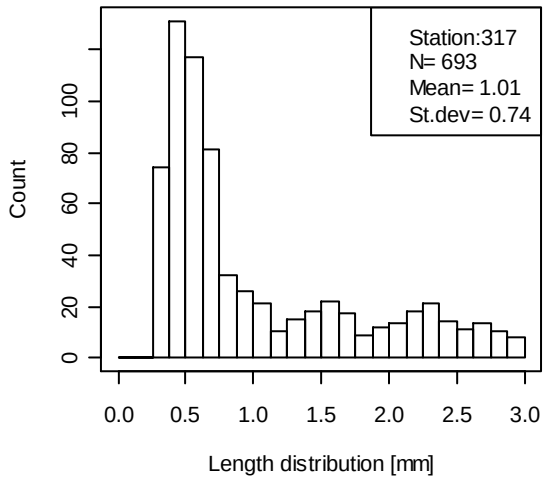
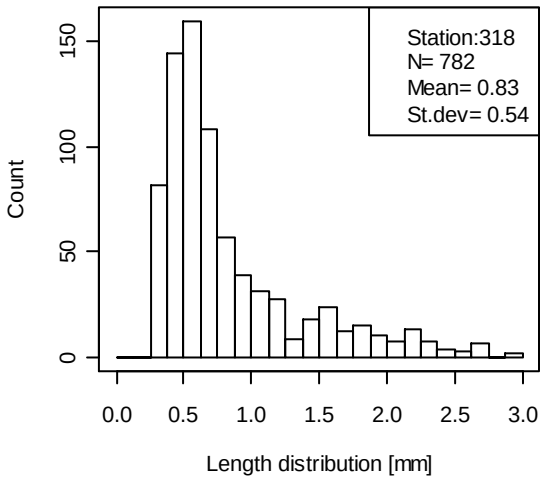
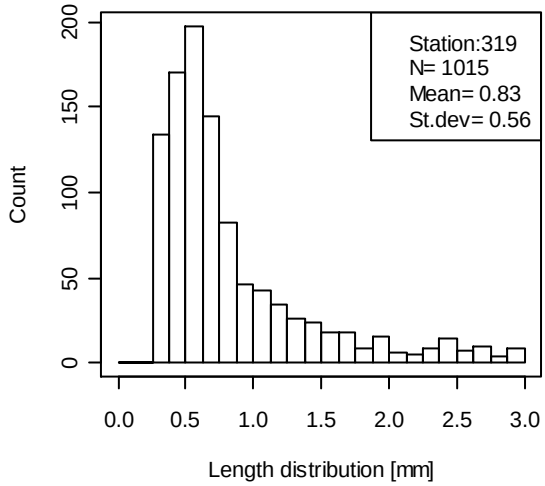
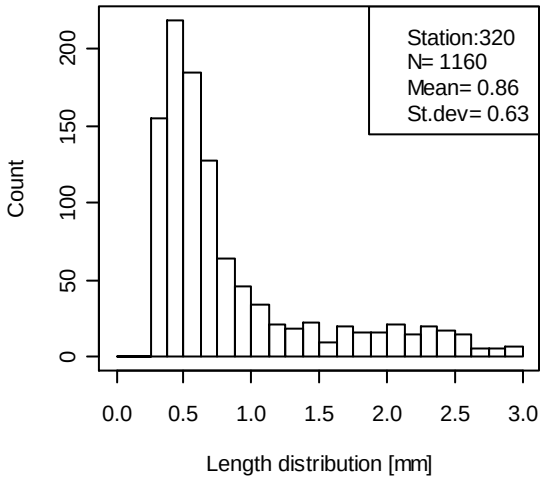
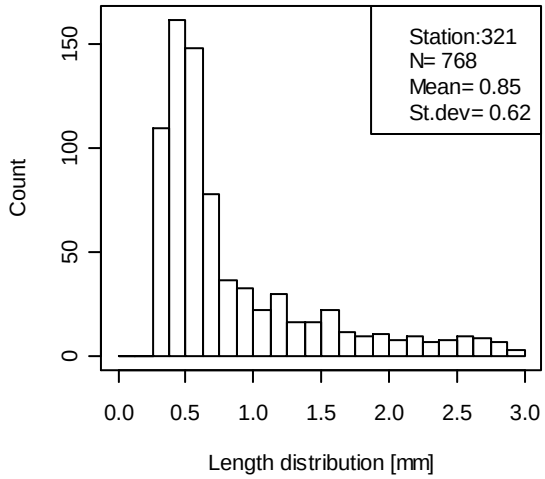
N= 1177
Mean= 0.65
St.dev= 0.35
Count
Length distribution [mm]

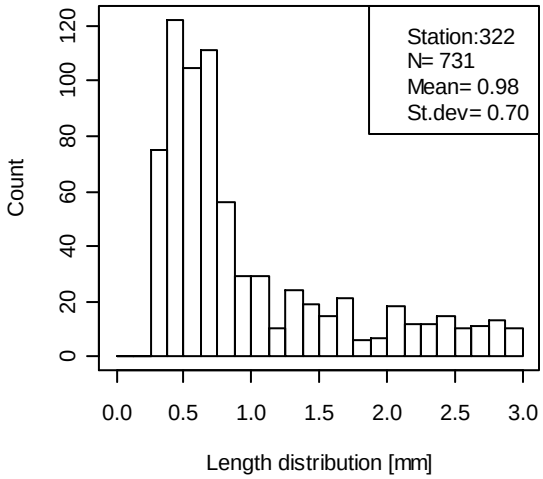

Station:317
N= 693
Mean= 1.01
St.dev= 0.74
Count
Length distribution [mm]

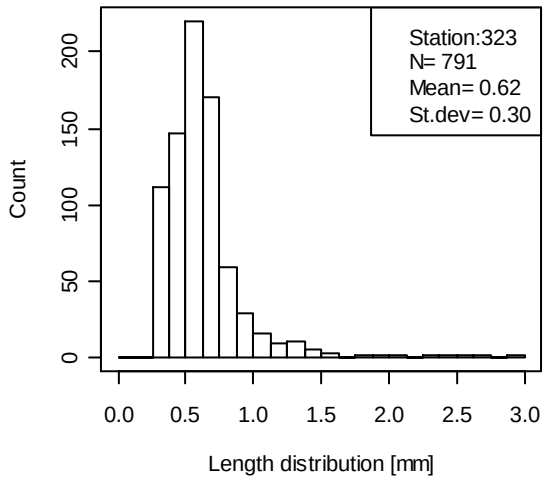

Station:318
N= 782
Mean= 0.83
St.dev= 0.54
Count
Length distribution [mm]

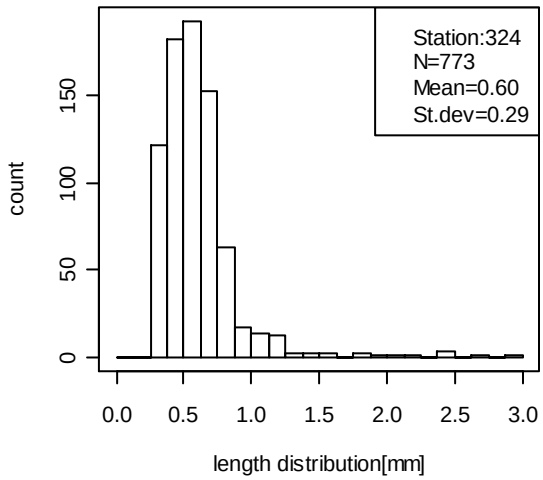

Station:319
N= 1015
Mean= 0.83
St.dev= 0.56
Count
Length distribution [mm]

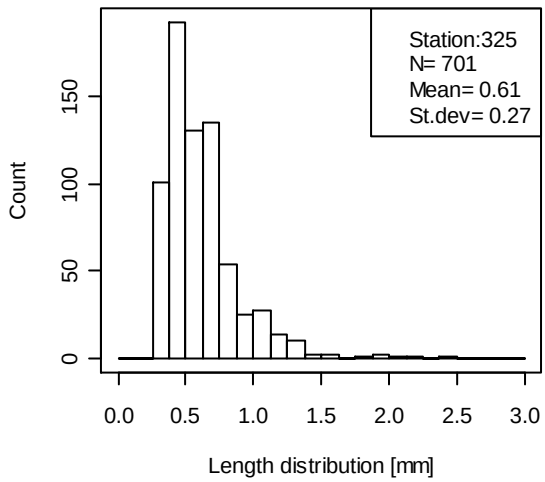

Station:320
N= 1160
Mean= 0.86
St.dev= 0.63
Count
Length distribution [mm]

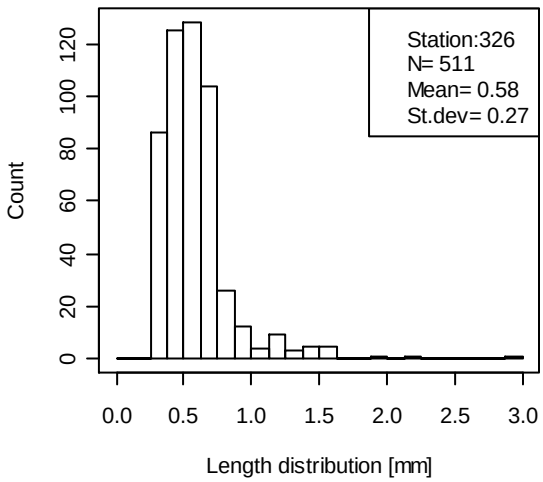

Station:321
N= 768
Mean= 0.85
St.dev= 0.62
Count
Length distribution [mm]

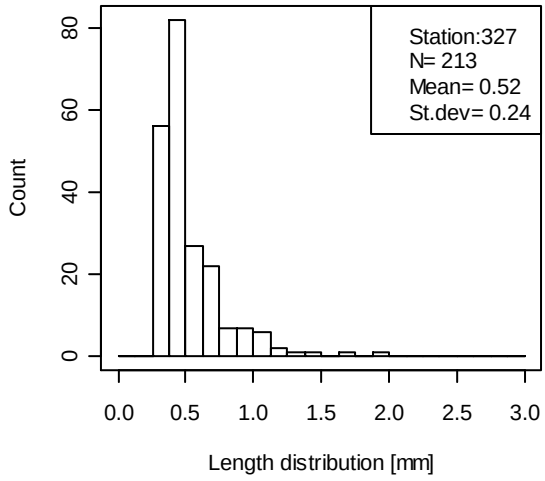

Station:322
N= 731
Mean= 0.98
St.dev= 0.70
Count
Length distribution [mm]

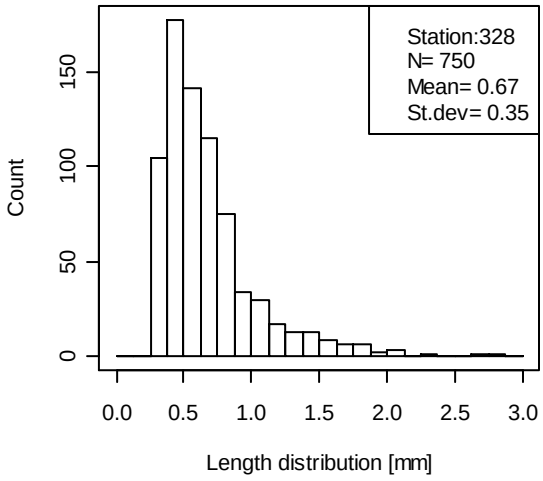

Station:323
N= 791
Mean= 0.62
St.dev= 0.30
Count
Length distribution [mm]

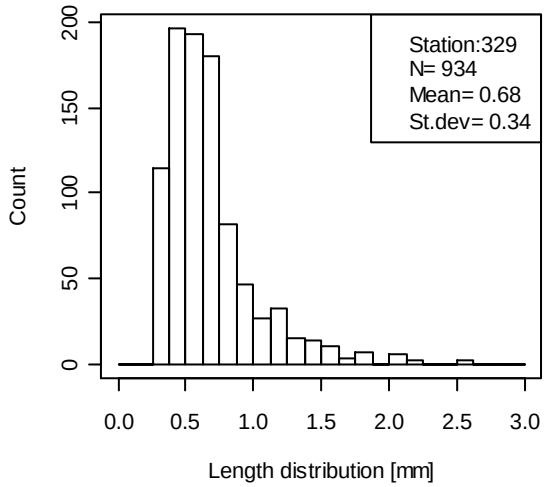

Station:324
N=773
Mean=0.60
St.dev=0.29
count
length distribution[mm]

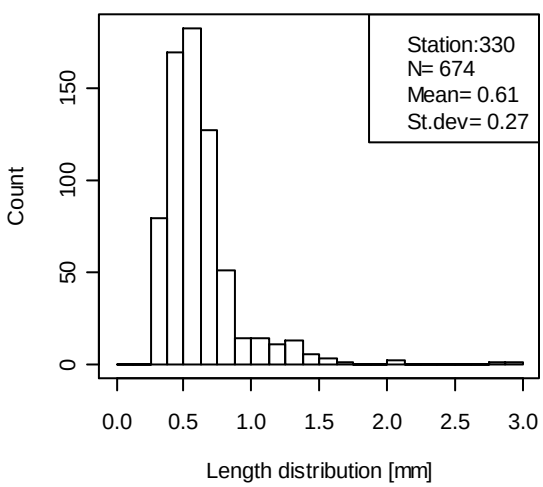

Station:325
N= 701
Mean= 0.61
St.dev= 0.27
Count
Length distribution [mm]

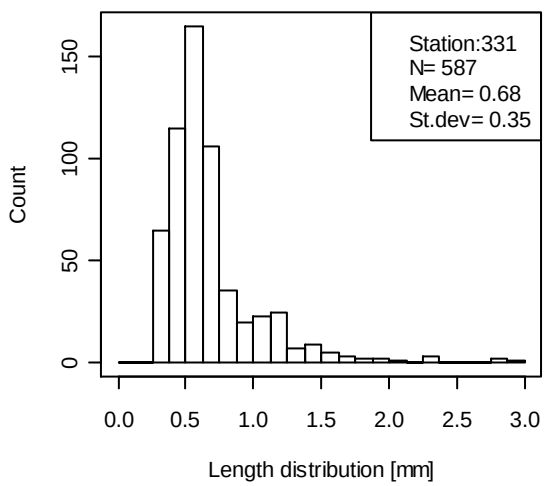

Station:326
N= 511
Mean= 0.58
St.dev= 0.27
Count
Length distribution [mm]

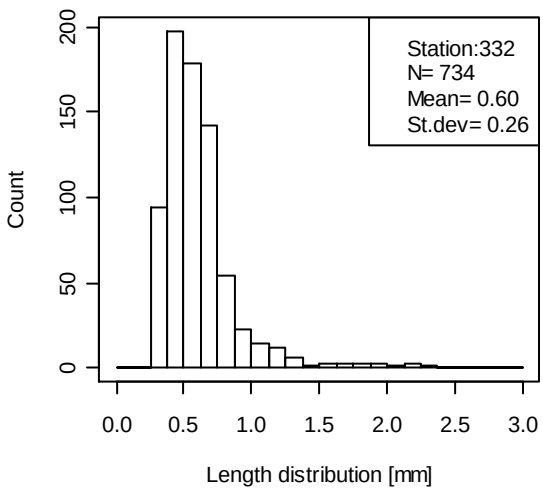

Station:327
N= 213
Mean= 0.52
St.dev= 0.24
Count
Length distribution [mm]

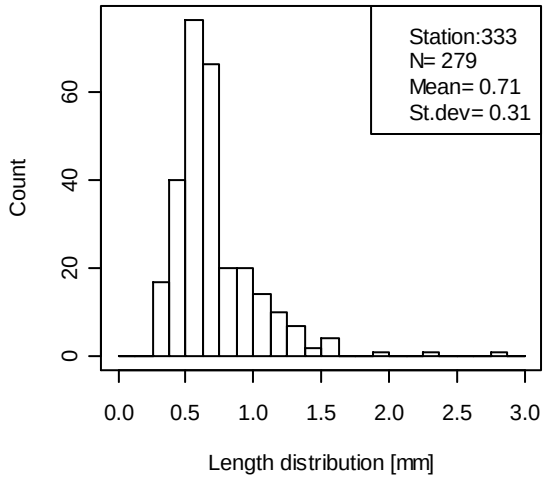

Station:328
N= 750
Mean= 0.67
St.dev= 0.35
Count
Length distribution [mm]

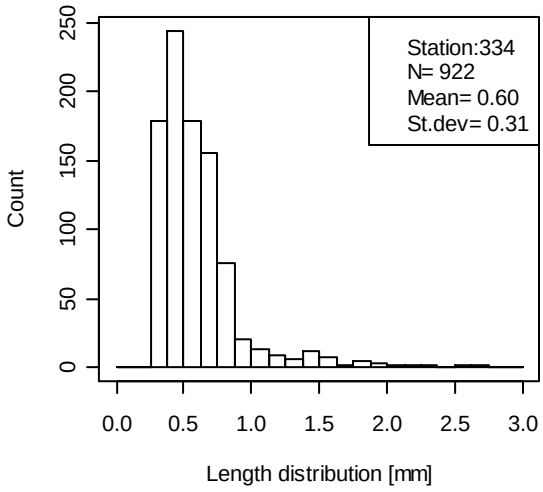

Station:329
N= 934
Mean= 0.68
St.dev= 0.34
Count
Length distribution [mm]

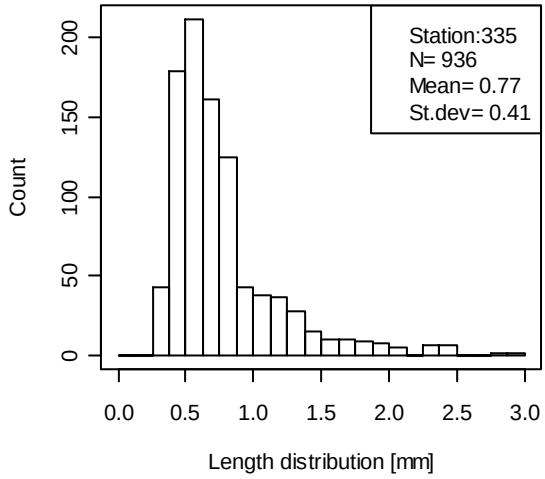

Station:330
N= 674
Mean= 0.61
St.dev= 0.27
Count
Length distribution [mm]


Station:331
N= 587
Mean= 0.68
St.dev= 0.35
Count
Length distribution [mm]


Station:332
N= 734
Mean= 0.60
St.dev= 0.26
Count
Length distribution [mm]


Station:333
N= 279
Mean= 0.71
St.dev= 0.31
Count
0
20
40
60
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Length distribution [mm]


Station:334
N= 922
Mean= 0.60
St.dev= 0.31
Count
0
50
100
150
200
250
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Length distribution [mm]

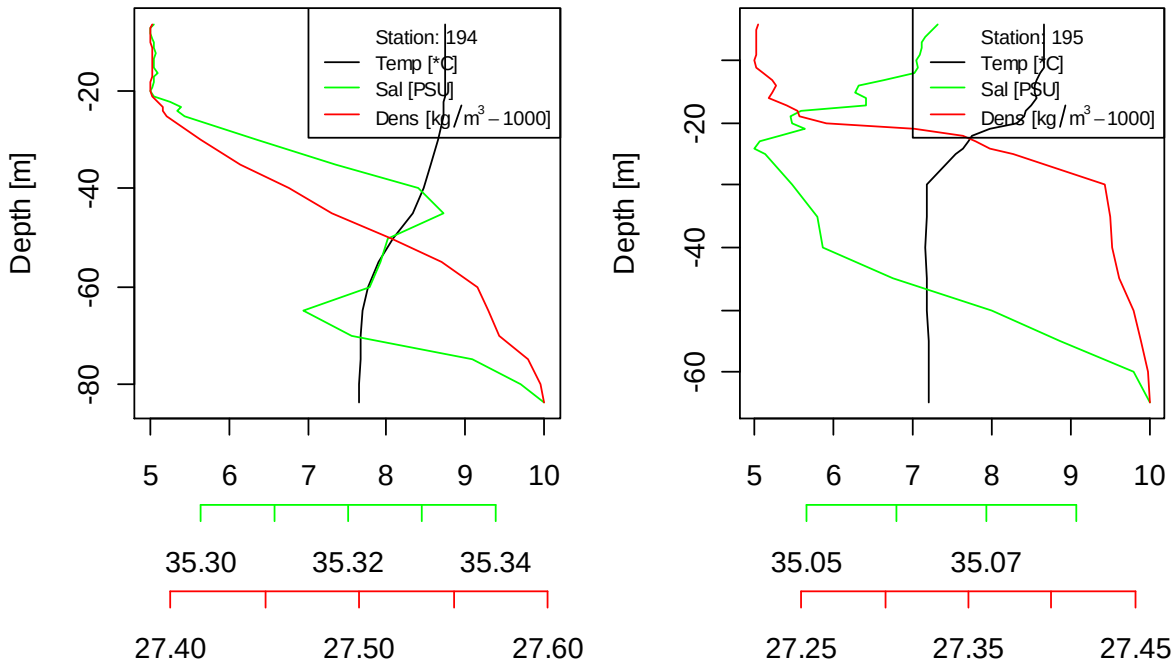

Station:335
N= 936
Mean= 0.77
St.dev= 0.41
Count
0
50
100
150
200
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Length distribution [mm]

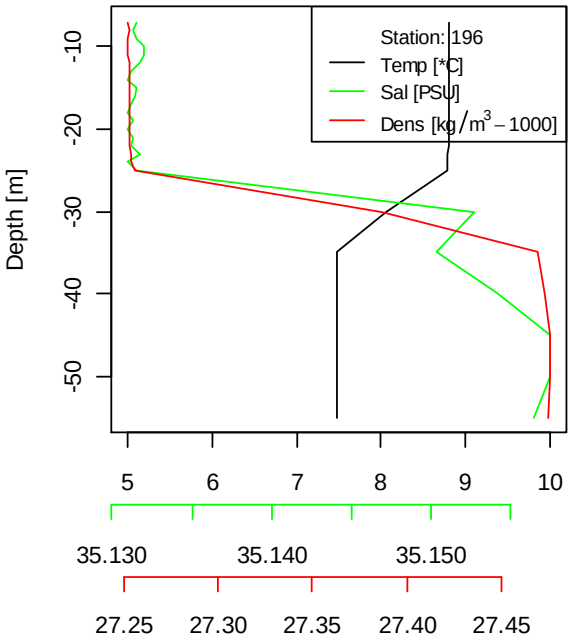
APPENDIX C

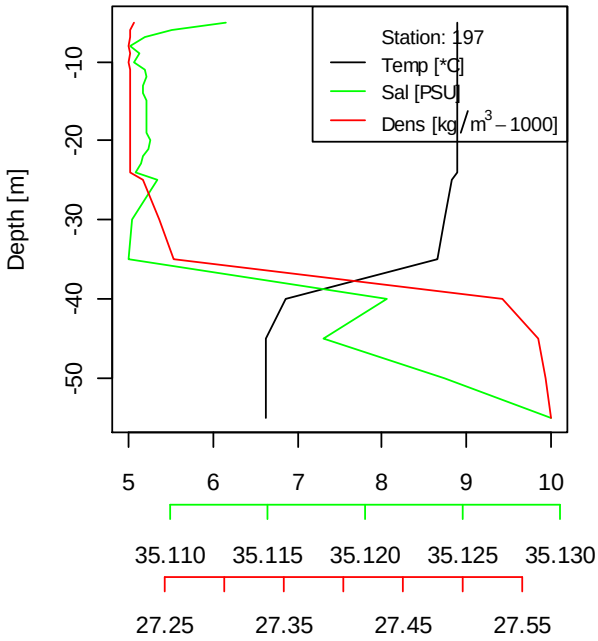
CTD profiles

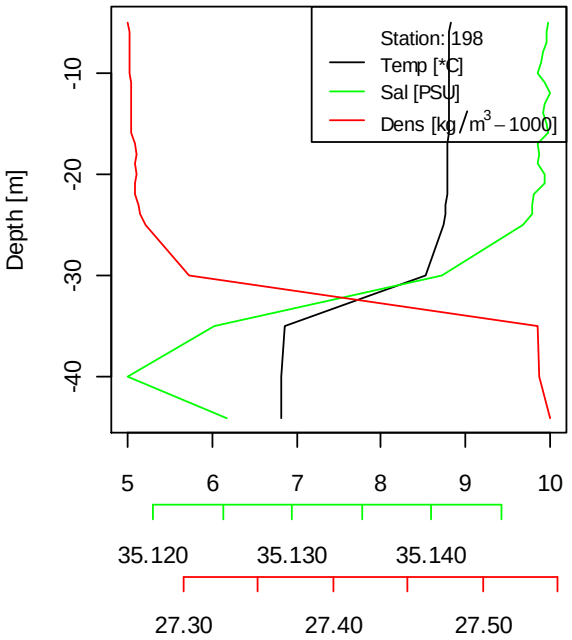
Stations 194-205 are from the 2009 survey and 308-335 are from the 2010 survey. The box in the upper right corner of each CTD profile, show the station number and the units for the different parameters. Temperature is measured in °C, salinity in practical salinity units (psu) and density in specific seawater density (kg/m^3-1000)

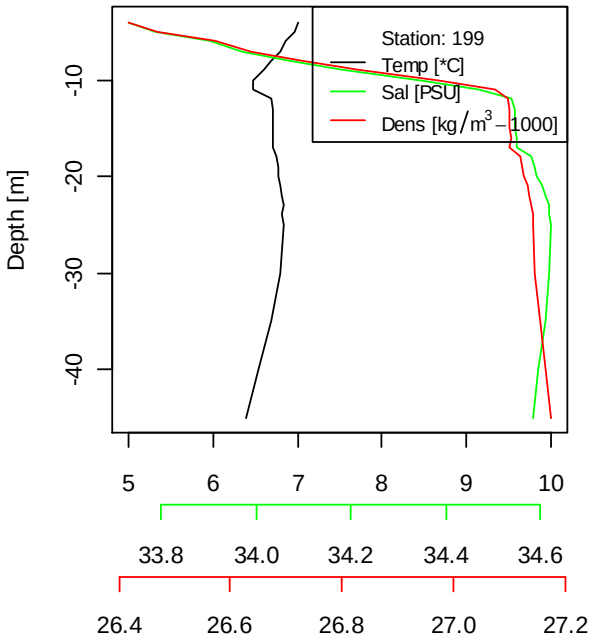
2009:

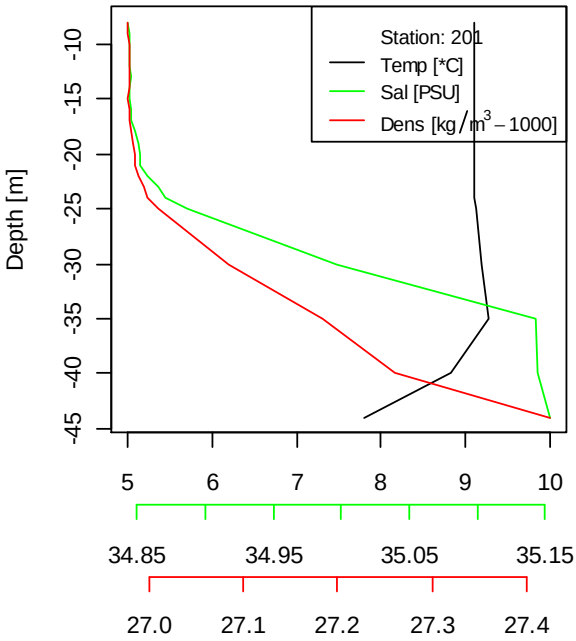


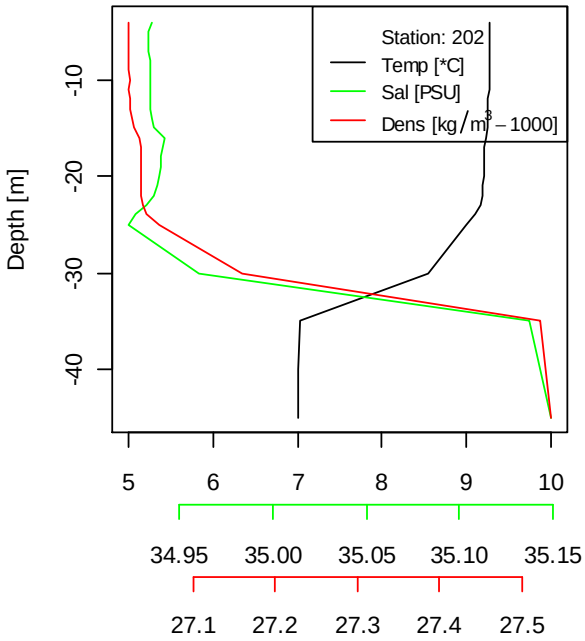

Station: 196
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
5
6
7
8
9
10
35.130
35.140
35.150
27.25
27.30
27.35
27.40
27.45

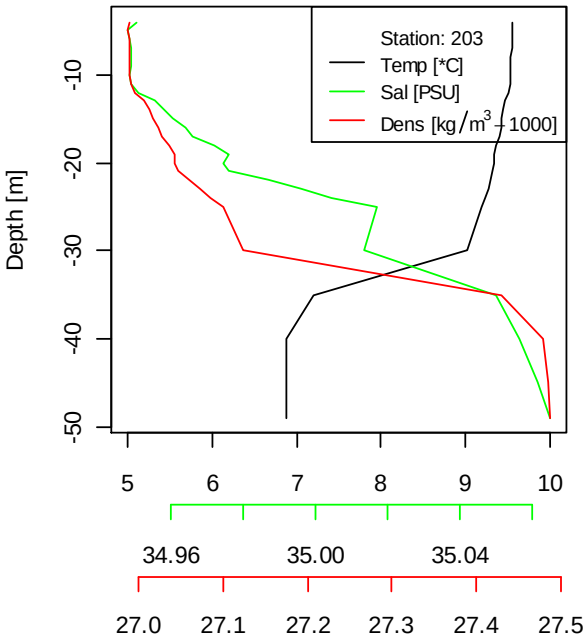

Station: 197
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
5
6
7
8
9
10
35.110
35.115
35.120
35.125
35.130
27.25
27.35
27.45
27.55

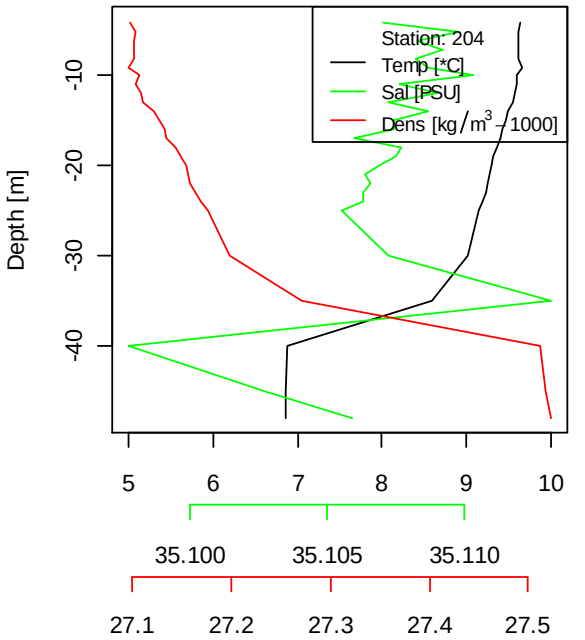

Station: 198
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
35.120
35.130
35.140
27.30
27.40
27.50

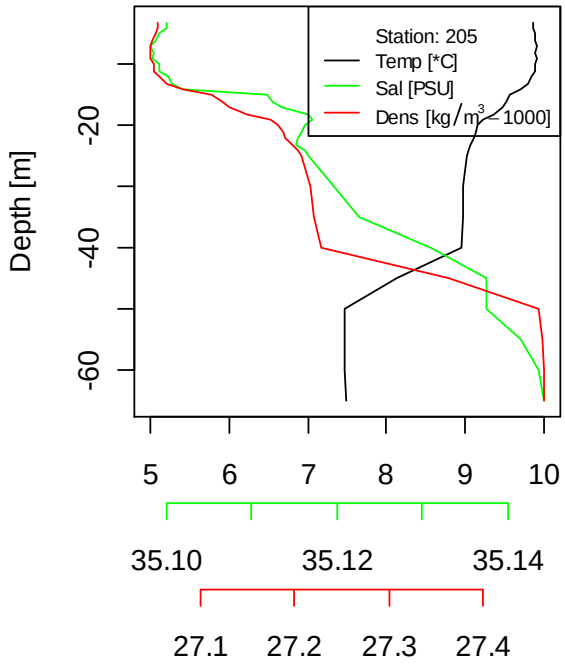

Station: 199
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
33.8
34.0
34.2
34.4
34.6
26.4
26.6
26.8
27.0
27.2

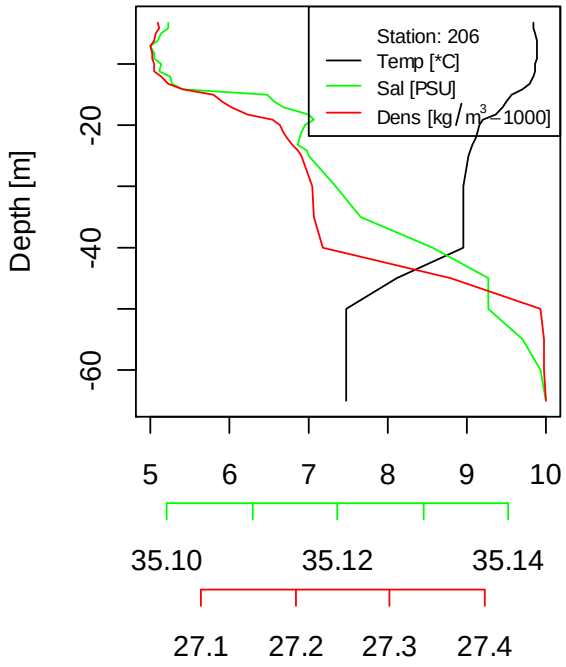

Station: 201
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-15
-20
-25
-30
-35
-40
-45
5
6
7
8
9
10
34.85
34.95
35.05
35.15
27.0
27.1
27.2
27.3
27.4


Station: 202
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
34.95
35.00
35.05
35.10
35.15
27.1
27.2
27.3
27.4
27.5

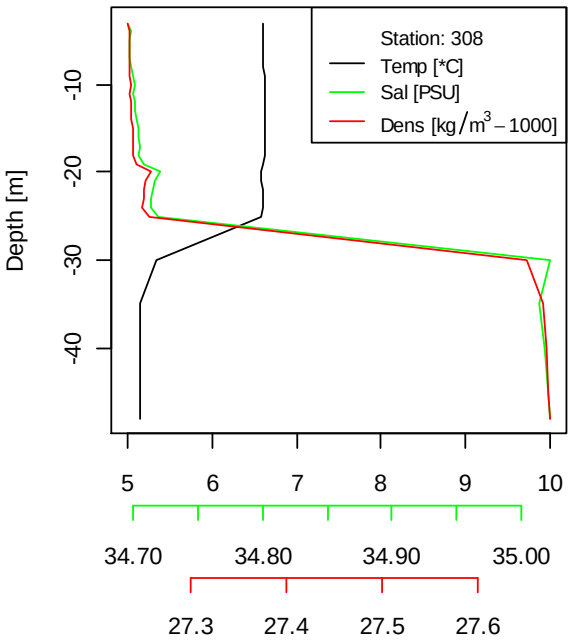

Station: 203
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
5
6
7
8
9
10
34.96
35.00
35.04
27.0
27.1
27.2
27.3
27.4
27.5

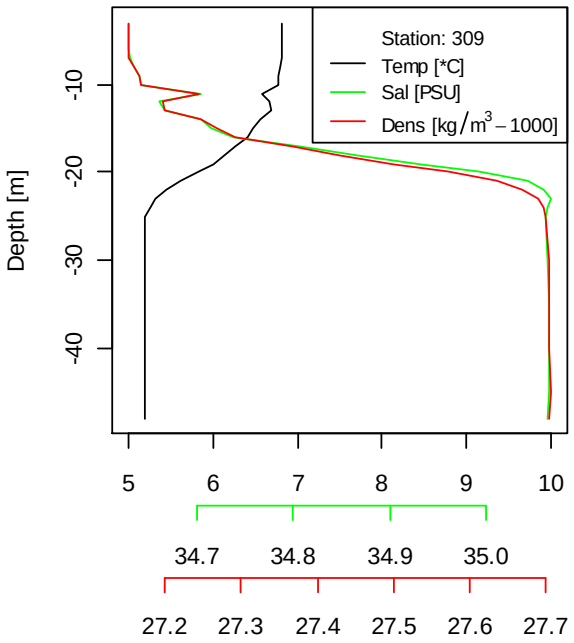

Station: 204
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
35.100
35.105
35.110
27.1
27.2
27.3
27.4
27.5

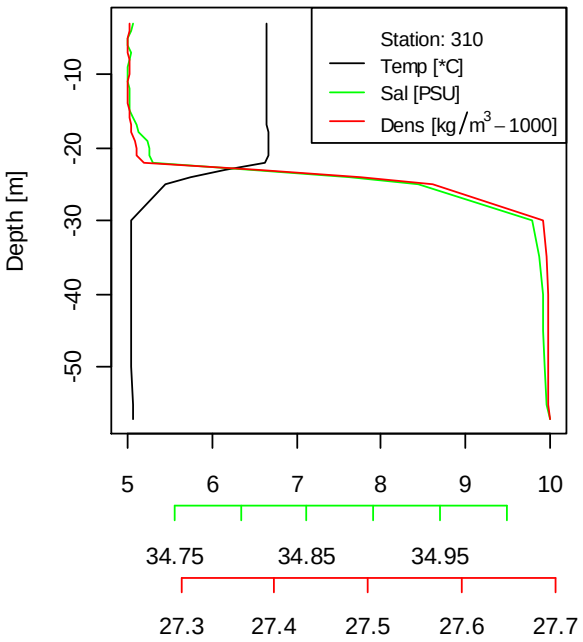

Station: 205
Temp [*C]
Sal [PSU]
Dens [kg/m3 − 1000]
Depth [m]
-20
-40
-60
5
6
7
8
9
10
35.10
35.12
35.14
27.1
27.2
27.3
27.4

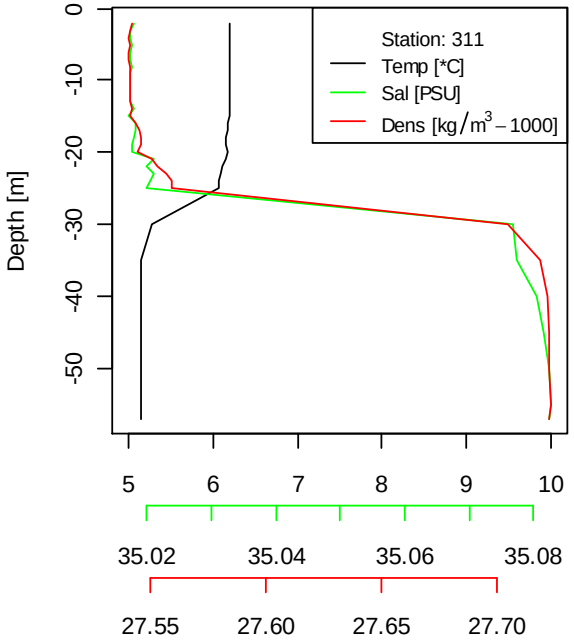

Station: 206
Temp [*C]
Sal [PSU]
Dens [kg/m3 − 1000]
Depth [m]
-20
-40
-60
5
6
7
8
9
10
35.10
35.12
35.14
27.1
27.2
27.3
27.4

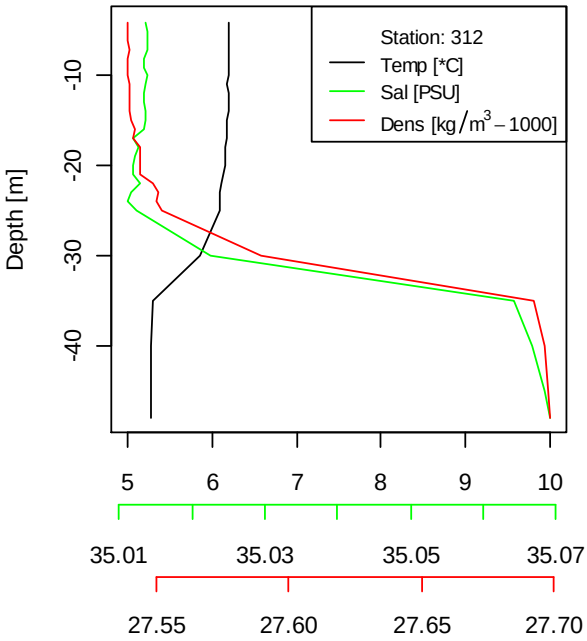
2010:

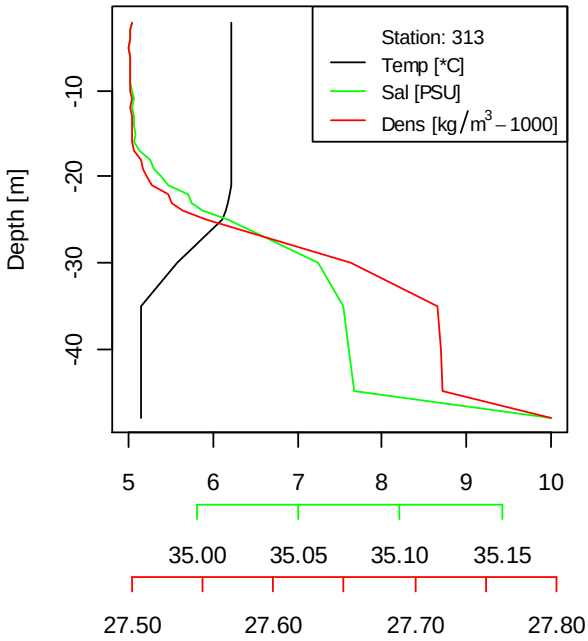

Station: 308
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
34.70
34.80
34.90
35.00
27.3
27.4
27.5
27.6

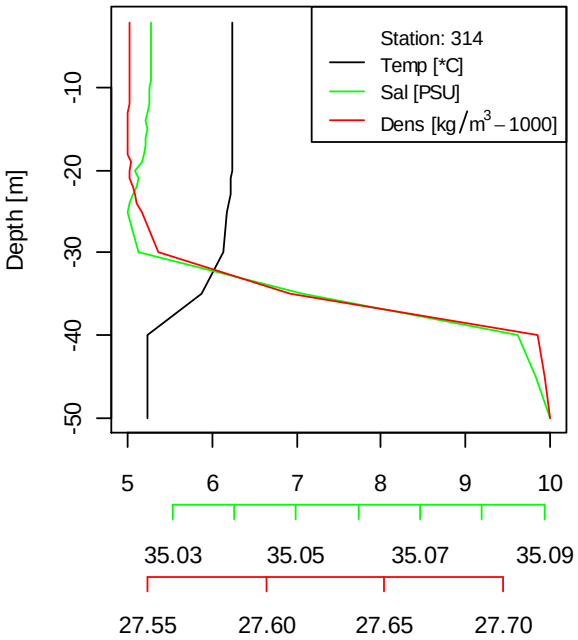

Station: 309
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
34.7
34.8
34.9
35.0
27.2
27.3
27.4
27.5
27.6
27.7

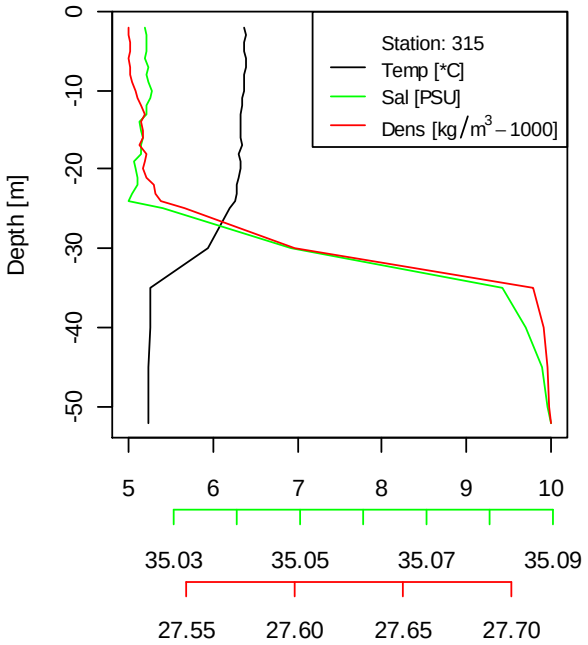

Station: 310
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
5
6
7
8
9
10
34.75
34.85
34.95
27.3
27.4
27.5
27.6
27.7

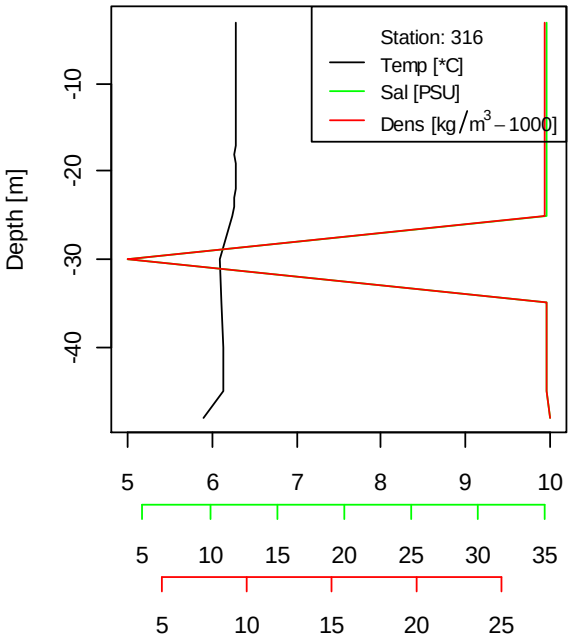

Station: 311
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
0
-10
-20
-30
-40
-50
5
6
7
8
9
10
35.02
35.04
35.06
35.08
27.55
27.60
27.65
27.70

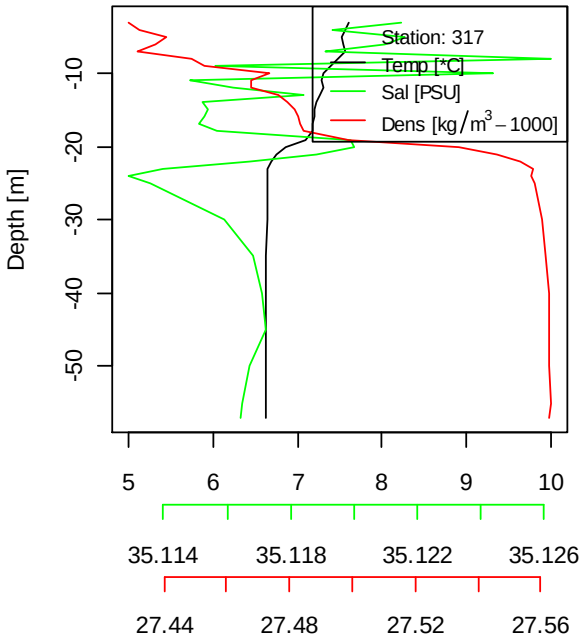

Station: 312
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
35.01
35.03
35.05
35.07
27.55
27.60
27.65
27.70

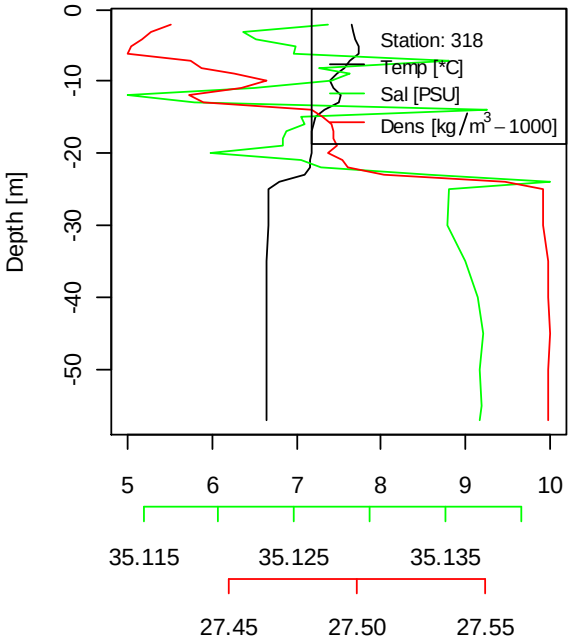

Station: 313
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
35.00
35.05
35.10
35.15
27.50
27.60
27.70
27.80

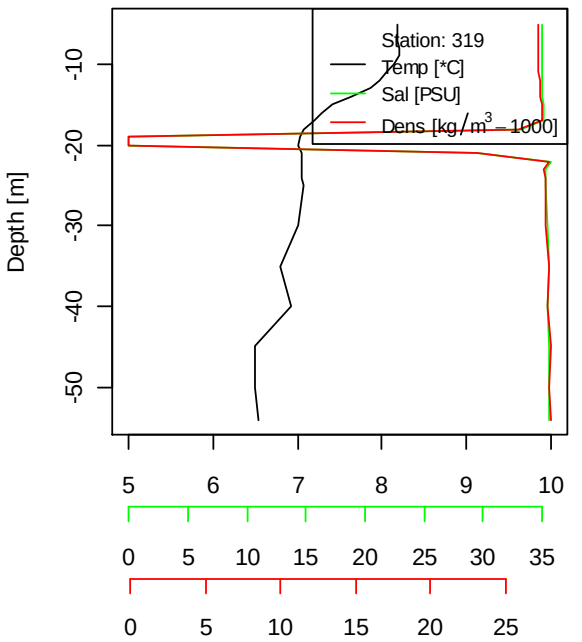

Station: 314
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
5
6
7
8
9
10
35.03
35.05
35.07
35.09
27.55
27.60
27.65
27.70

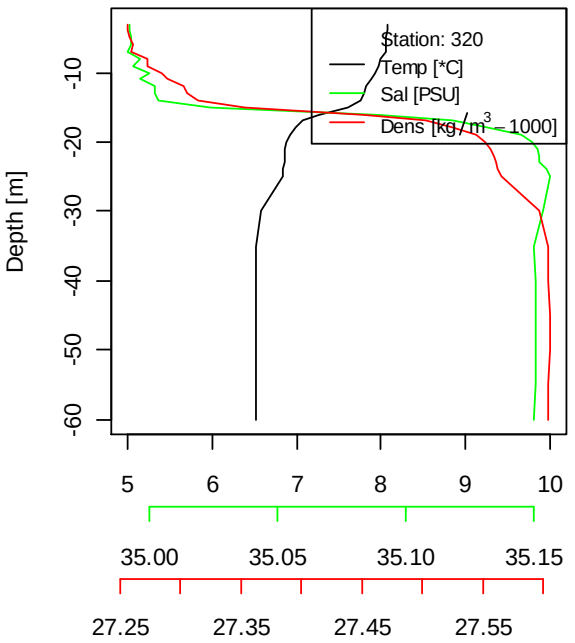

Station: 315
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
0
-10
-20
-30
-40
-50
5
6
7
8
9
10
35.03
35.05
35.07
35.09
27.55
27.60
27.65
27.70

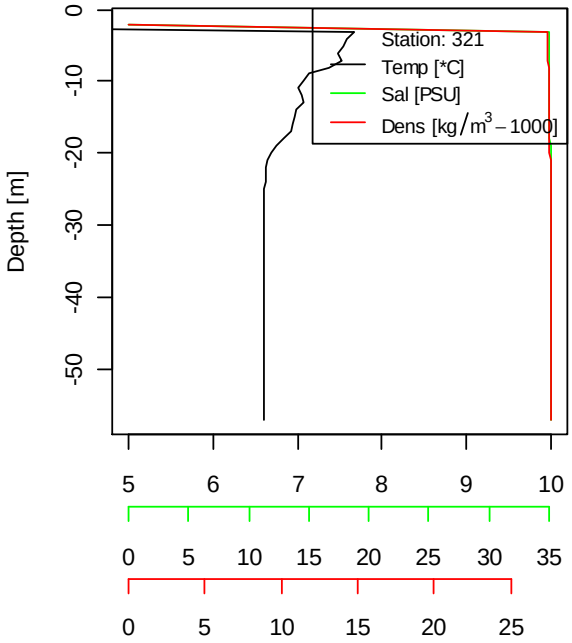

Station: 316
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5 6 7 8 9 10
5 10 15 20 25 30 35
5 10 15 20 25

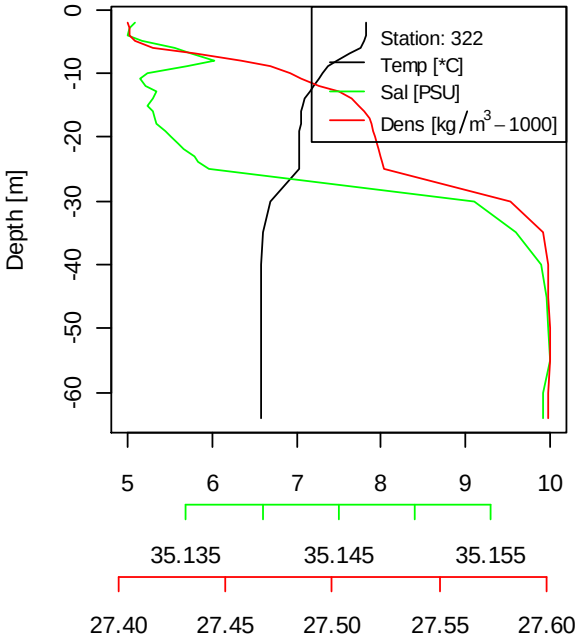

Station: 317
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
5 6 7 8 9 10
35.114 35.118 35.122 35.126
27.44 27.48 27.52 27.56

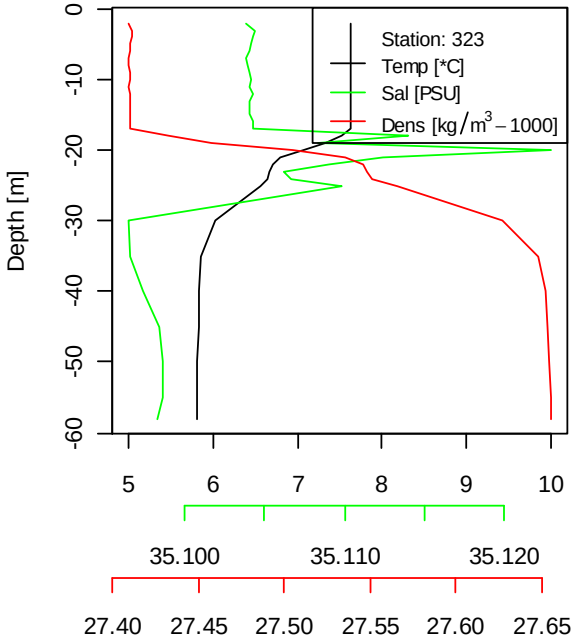

Station: 318
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
0
-10
-20
-30
-40
-50
5 6 7 8 9 10
35.115 35.125 35.135
27.45 27.50 27.55

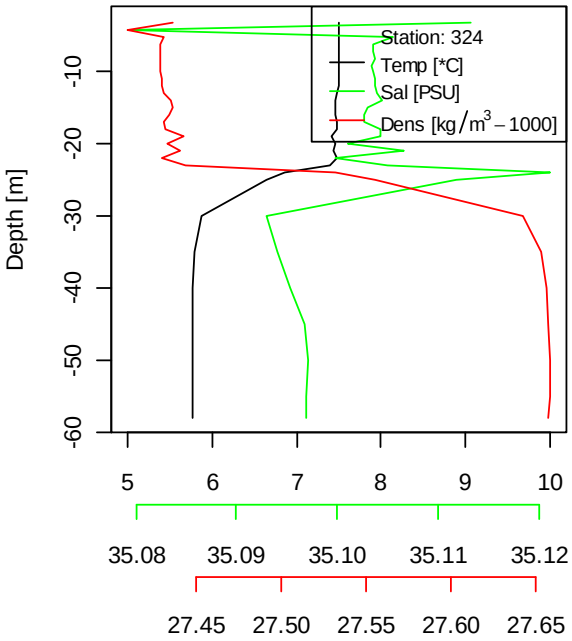

Station: 319
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
5 6 7 8 9 10
0 5 10 15 20 25 30 35
0 5 10 15 20 25

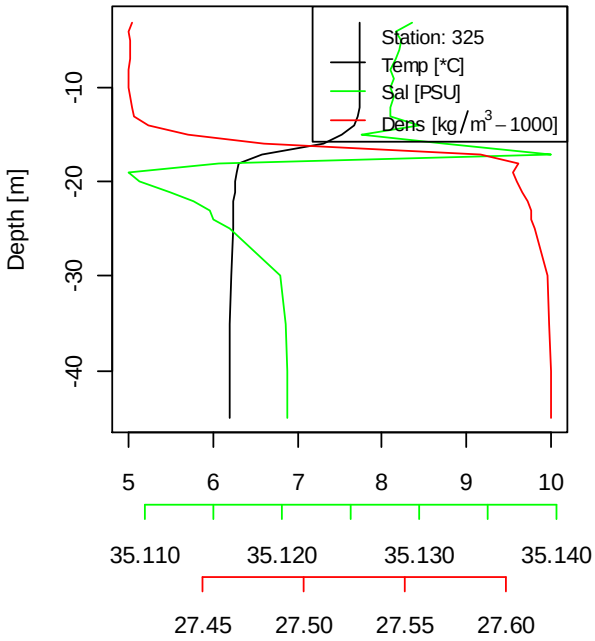

Station: 320
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
0
-10
-20
-30
-40
-50
-60
5
6
7
8
9
10
35.00
35.05
35.10
35.15
27.25
27.35
27.45
27.55

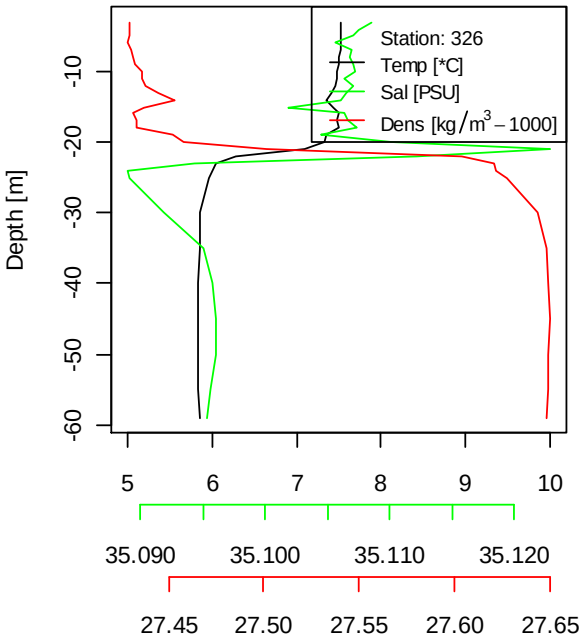

Station: 321
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
0
-10
-20
-30
-40
-50
5
6
7
8
9
10
0
5
10
15
20
25
30
35
0
5
10
15
20
25

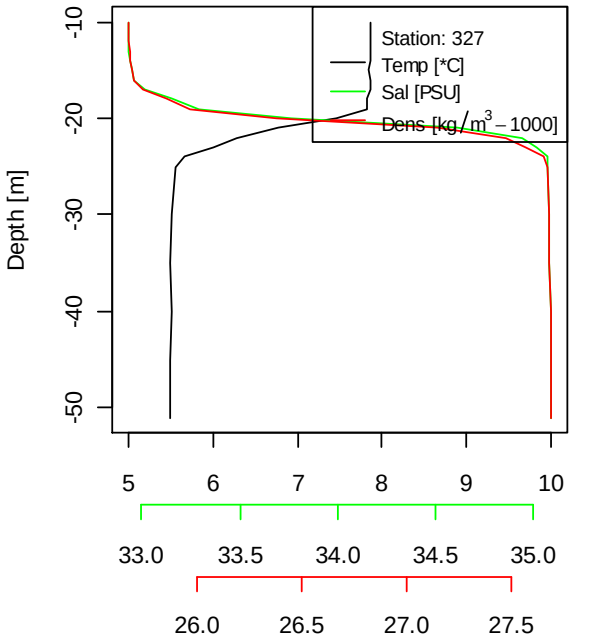

Station: 322
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
0
-10
-20
-30
-40
-50
-60
5
6
7
8
9
10
35.135
35.145
35.155
27.40
27.45
27.50
27.55
27.60

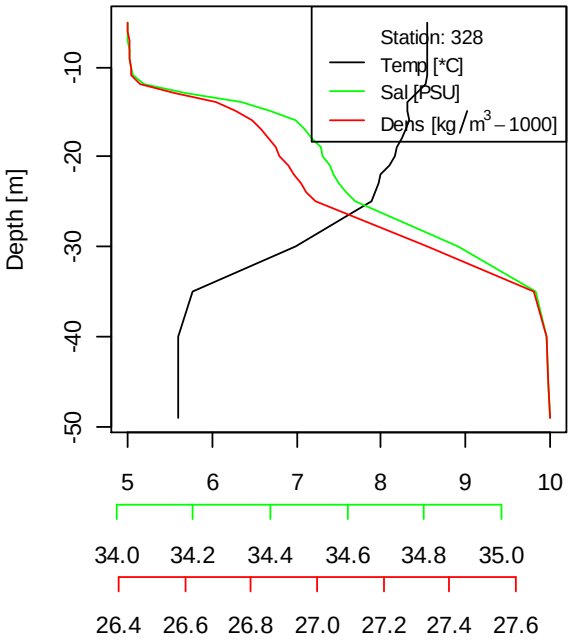

Station: 323
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
0
-10
-20
-30
-40
-50
-60
5
6
7
8
9
10
35.100
35.110
35.120
27.40
27.45
27.50
27.55
27.60
27.65

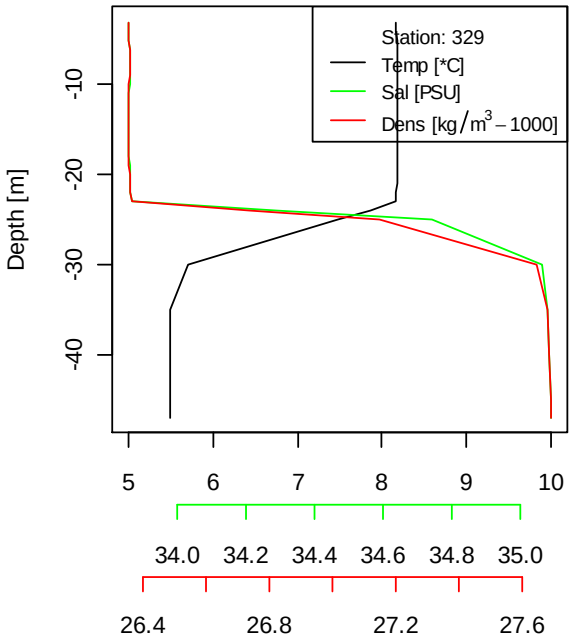

Station: 324
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
-60
5
6
7
8
9
10
35.08
35.09
35.10
35.11
35.12
27.45
27.50
27.55
27.60
27.65

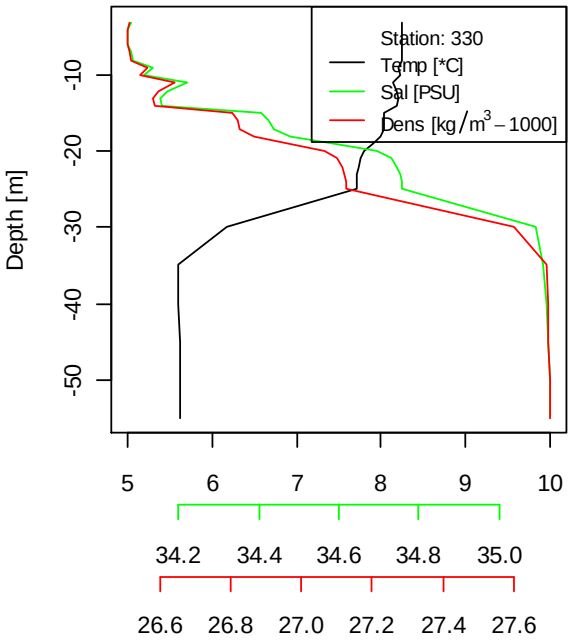

Station: 325
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
35.110
35.120
35.130
35.140
27.45
27.50
27.55
27.60

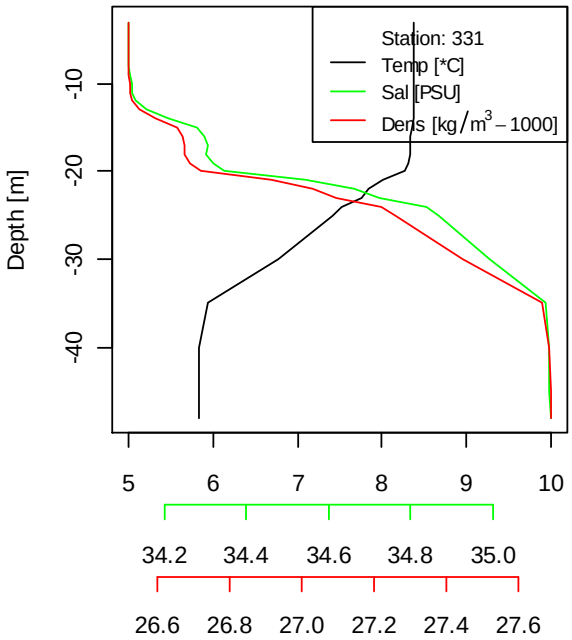

Station: 326
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
-60
5
6
7
8
9
10
35.090
35.100
35.110
35.120
27.45
27.50
27.55
27.60
27.65

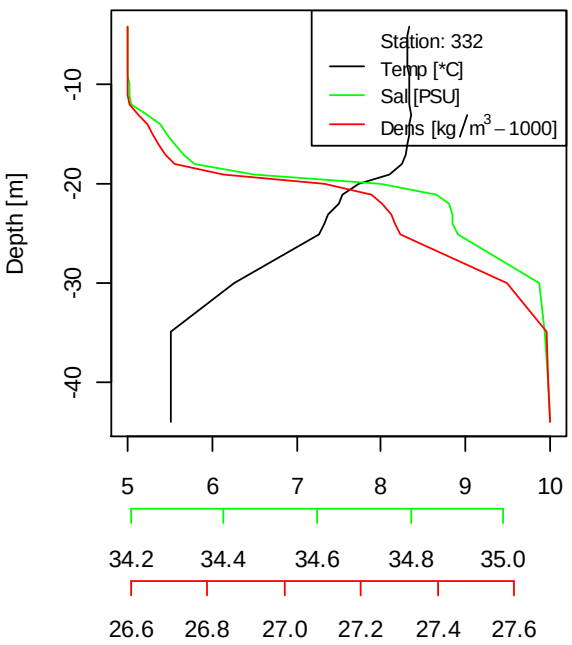

Station: 327
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
5
6
7
8
9
10
33.0
33.5
34.0
34.5
35.0
26.0
26.5
27.0
27.5

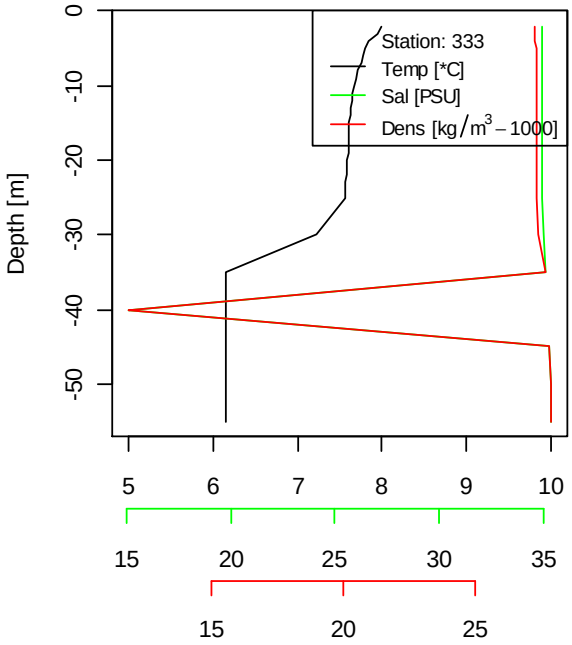

Station: 328
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
5
6
7
8
9
10
34.0
34.2
34.4
34.6
34.8
35.0
26.4
26.6
26.8
27.0
27.2
27.4
27.6

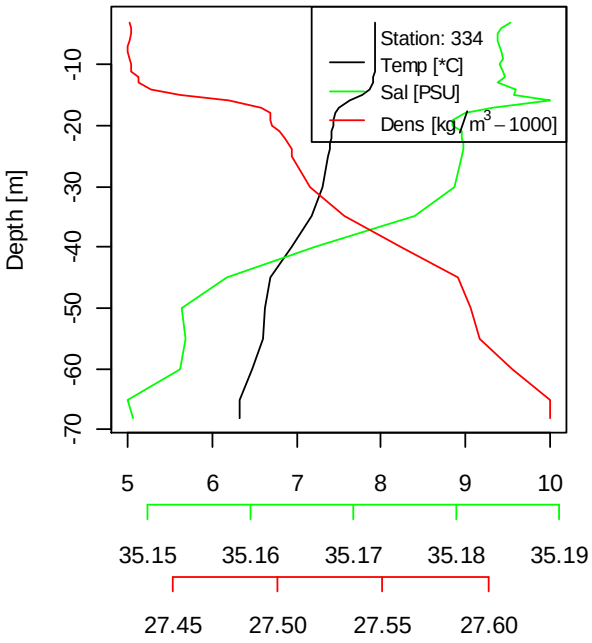

Station: 329
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
34.0
34.2
34.4
34.6
34.8
35.0
26.4
26.8
27.2
27.6

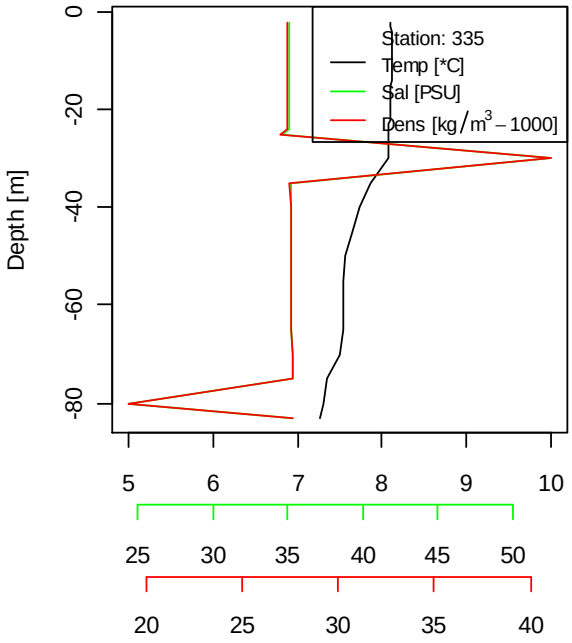

Station: 330
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
5
6
7
8
9
10
34.2
34.4
34.6
34.8
35.0
26.6
26.8
27.0
27.2
27.4
27.6


Station: 331
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
34.2
34.4
34.6
34.8
35.0
26.6
26.8
27.0
27.2
27.4
27.6


Station: 332
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
5
6
7
8
9
10
34.2
34.4
34.6
34.8
35.0
26.6
26.8
27.0
27.2
27.4
27.6


Station: 333
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
0
-10
-20
-30
-40
-50
5
6
7
8
9
10
15
20
25
30
35
15
20
25


Station: 334
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
-10
-20
-30
-40
-50
-60
-70
5
6
7
8
9
10
35.15
35.16
35.17
35.18
35.19
27.45
27.50
27.55
27.60

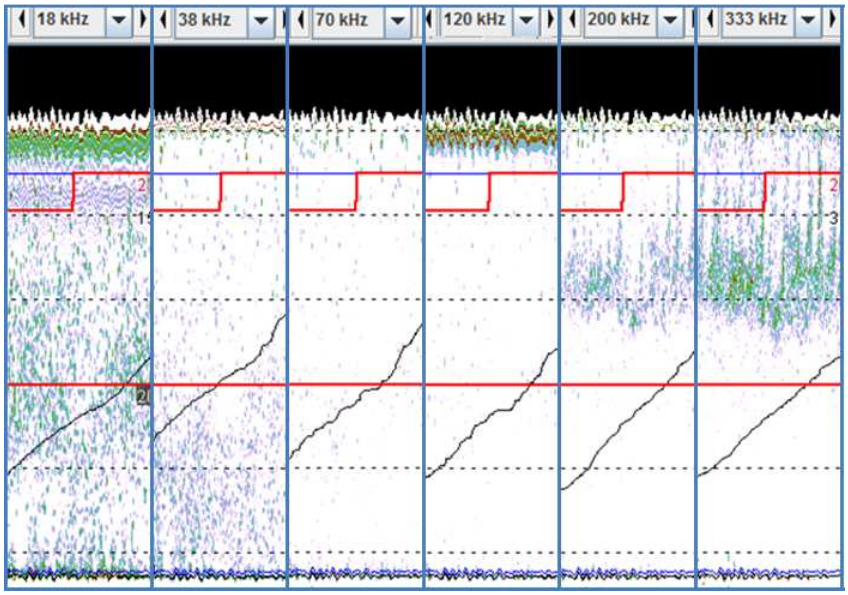

Station: 335
Temp [*C]
Sal [PSU]
Dens [kg/m3 – 1000]
Depth [m]
0
-20
-40
-60
-80
5
6
7
8
9
10
25
30
35
40
45
50
20
25
30
35
40

APPENDIX D

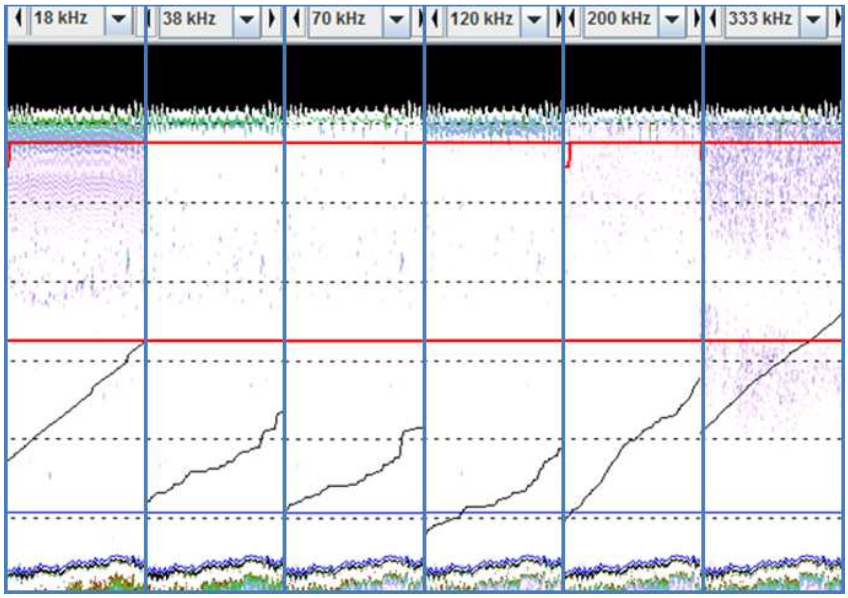
Echograms

Screen shots from LSSS. Stations 194-206 are from the 2009 survey showing fragments from each of the 6 frequencies 18, 38, 70, 120, 200, 200 and 333 kHz.

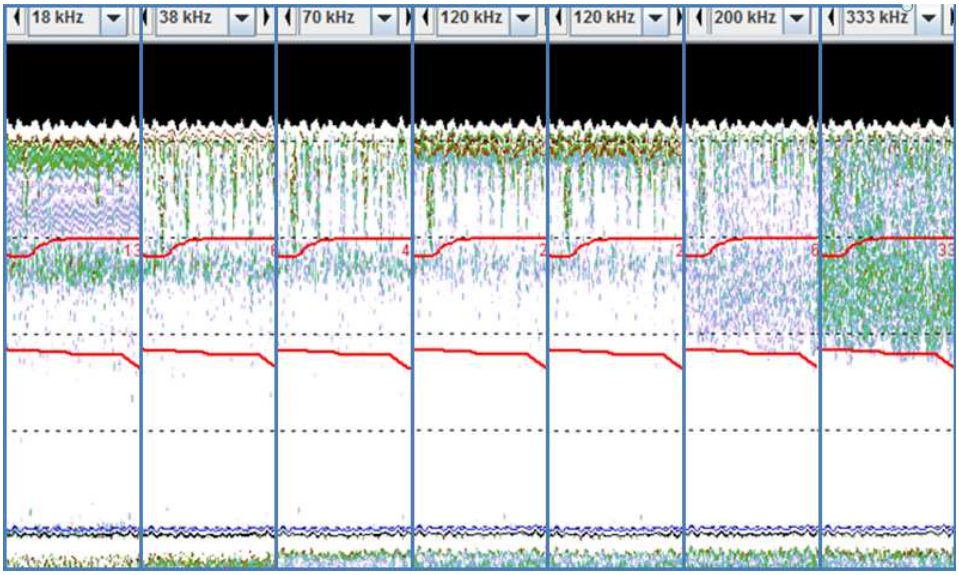
194



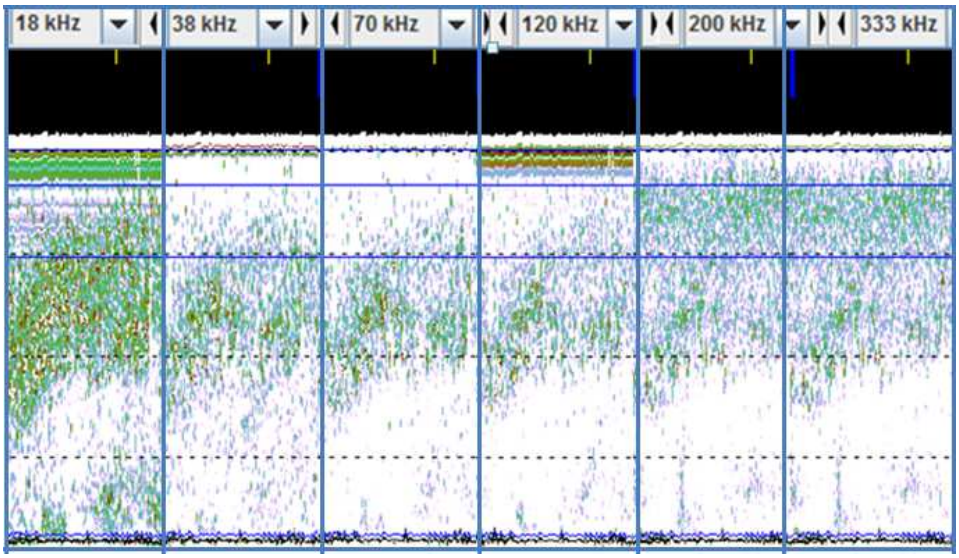
195



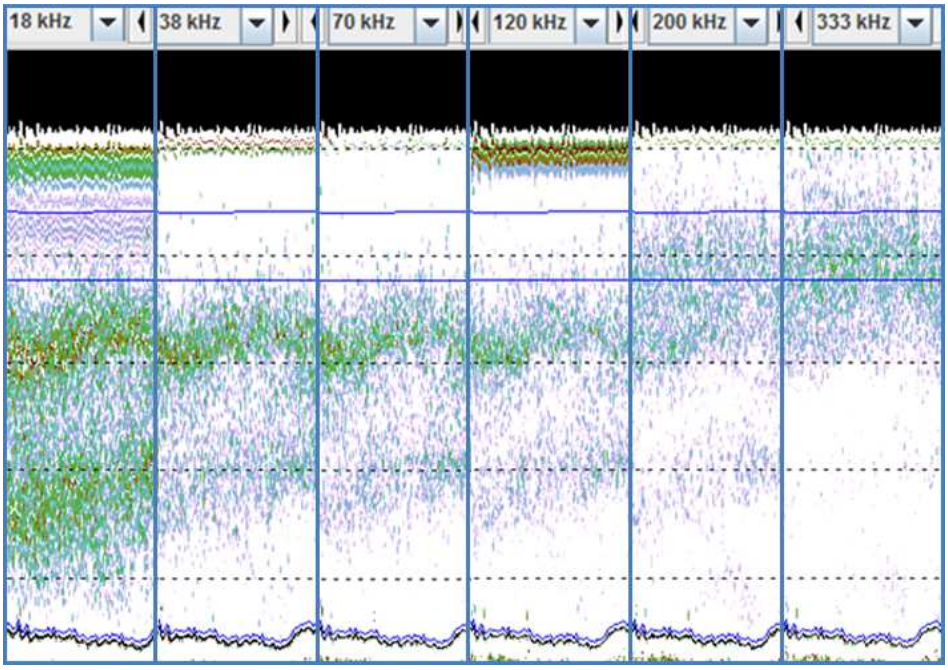
196


18 kHz
38 kHz
70 kHz
120 kHz
120 kHz
200 kHz
333 kHz

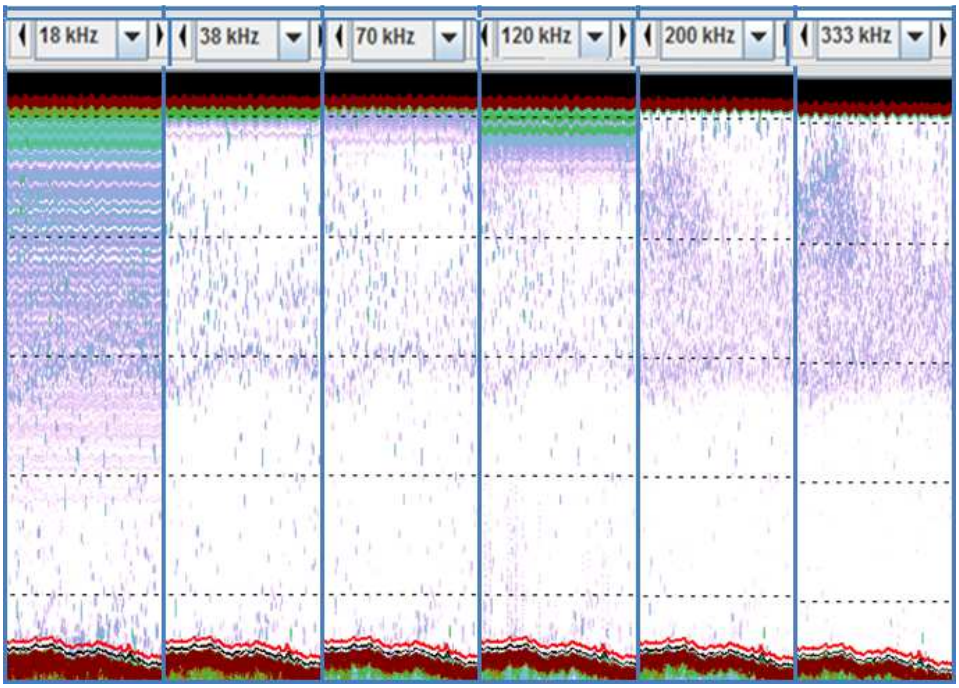
197


18 kHz
38 kHz
70 kHz
120 kHz
200 kHz
333 kHz

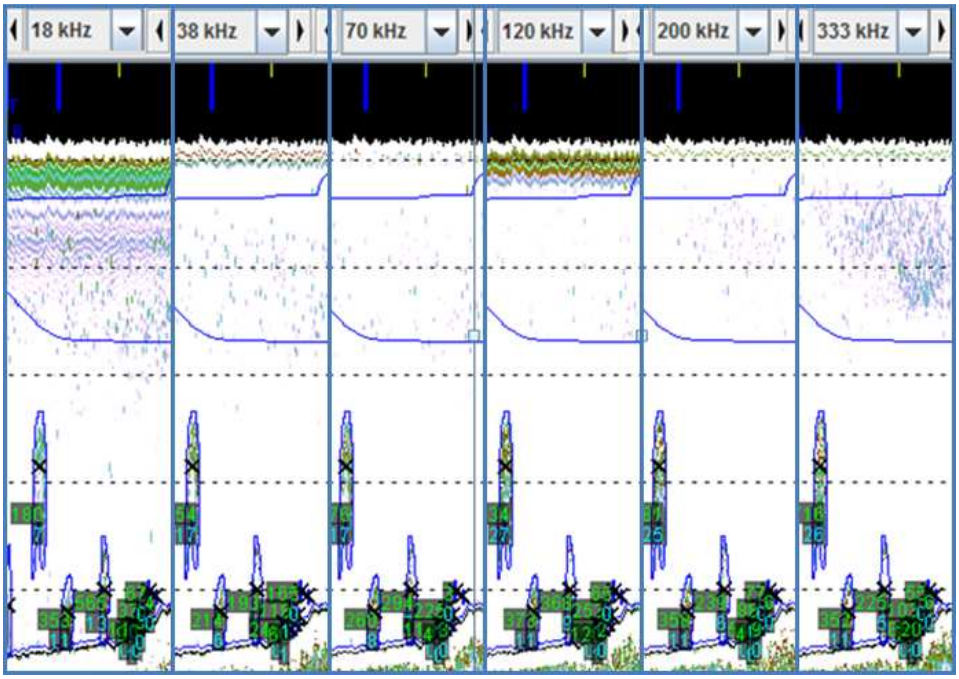
198


18 kHz
38 kHz
70 kHz
120 kHz
200 kHz
333 kHz

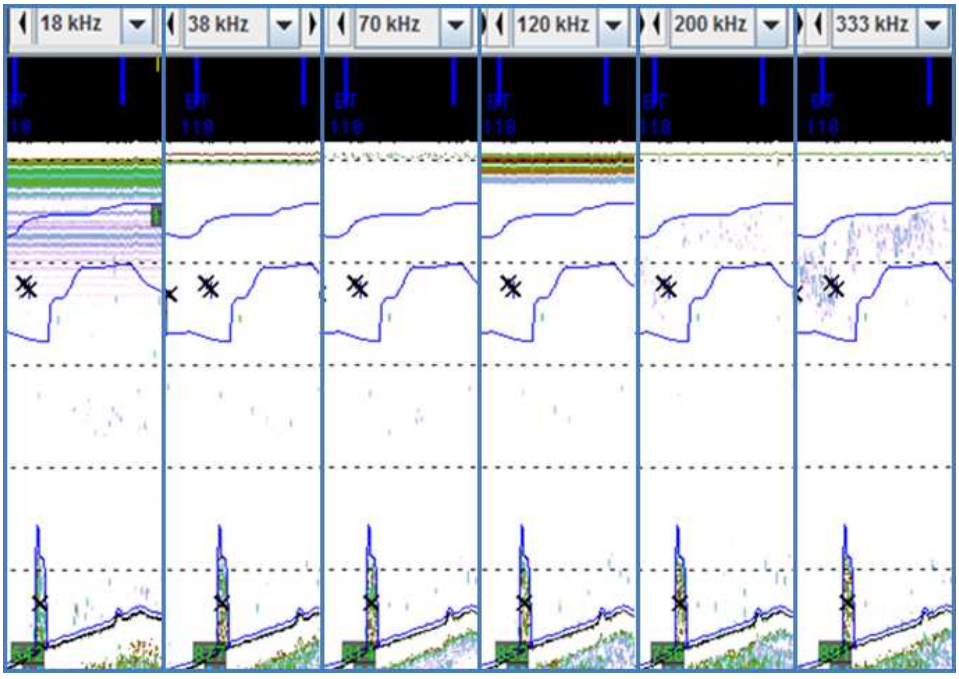
199


18 kHz
38 kHz
70 kHz
120 kHz
200 kHz
333 kHz

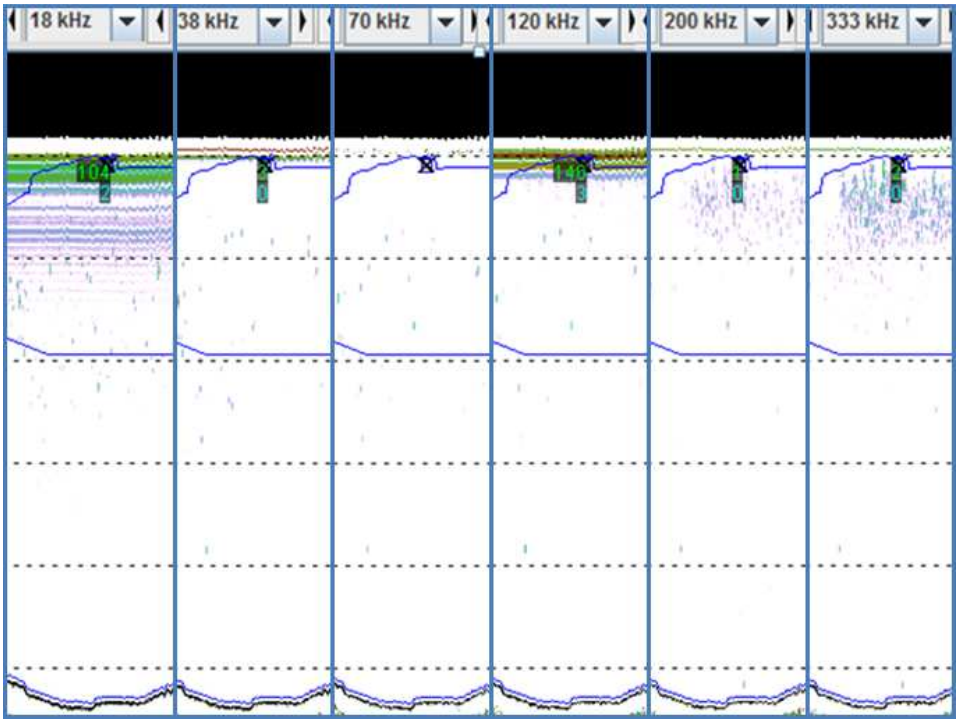
201


18 kHz
38 kHz
70 kHz
120 kHz
200 kHz
333 kHz

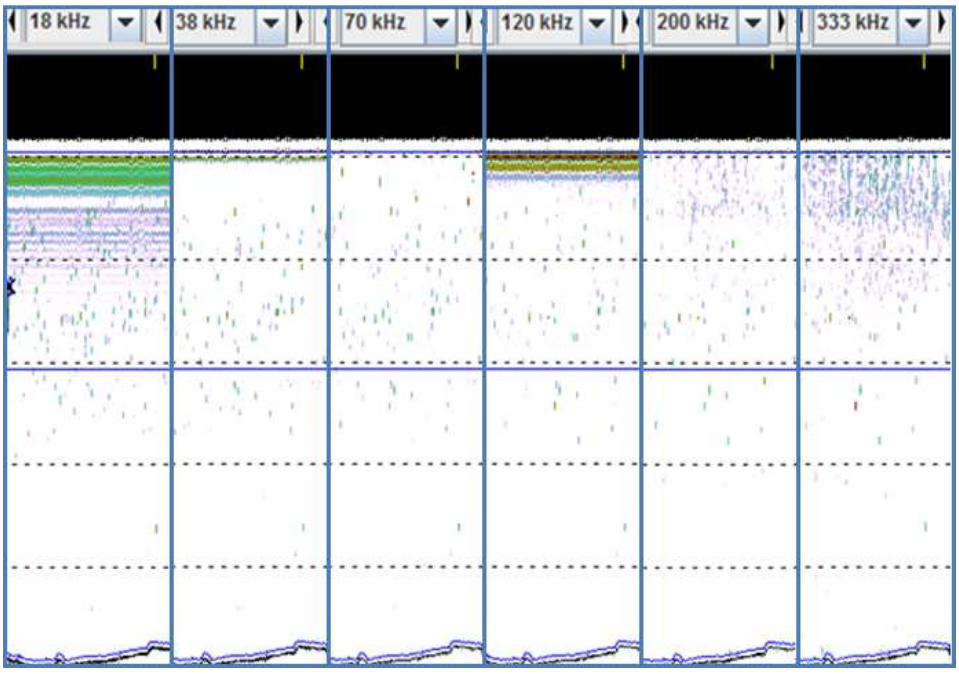
202


18 kHz
38 kHz
70 kHz
120 kHz
200 kHz
333 kHz

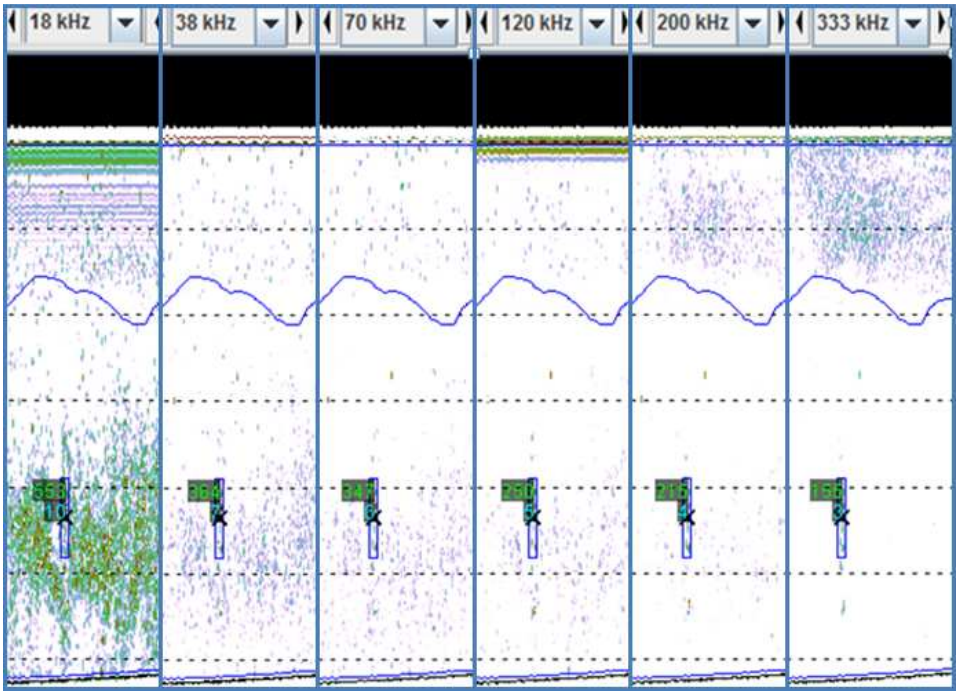
203


18 kHz
38 kHz
70 kHz
120 kHz
200 kHz
333 kHz

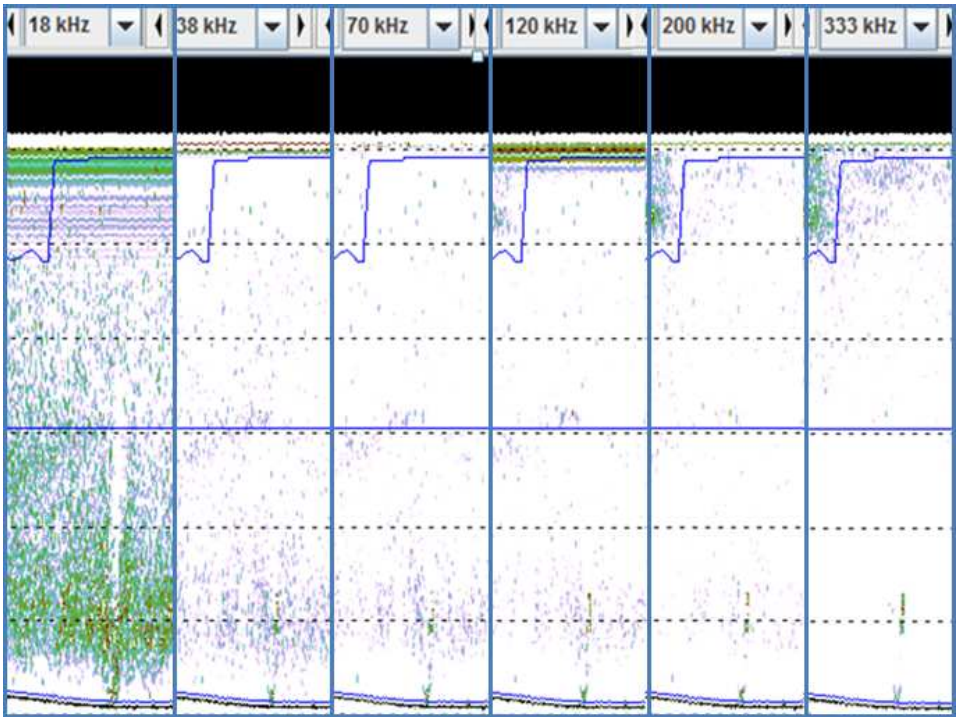
204


18 kHz
38 kHz
70 kHz
120 kHz
200 kHz
333 kHz

205

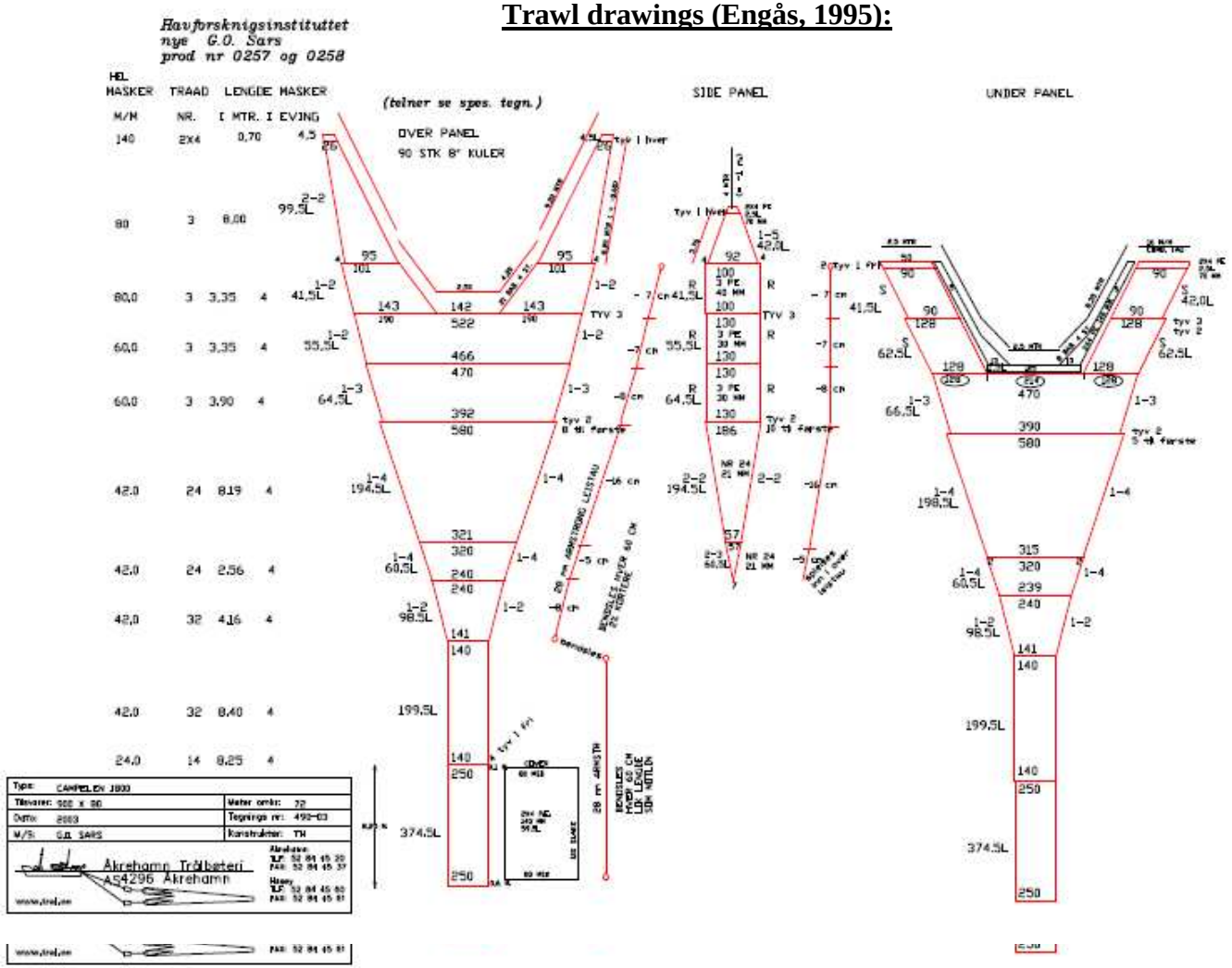

18 kHz
38 kHz
70 kHz
120 kHz
200 kHz
333 kHz

206

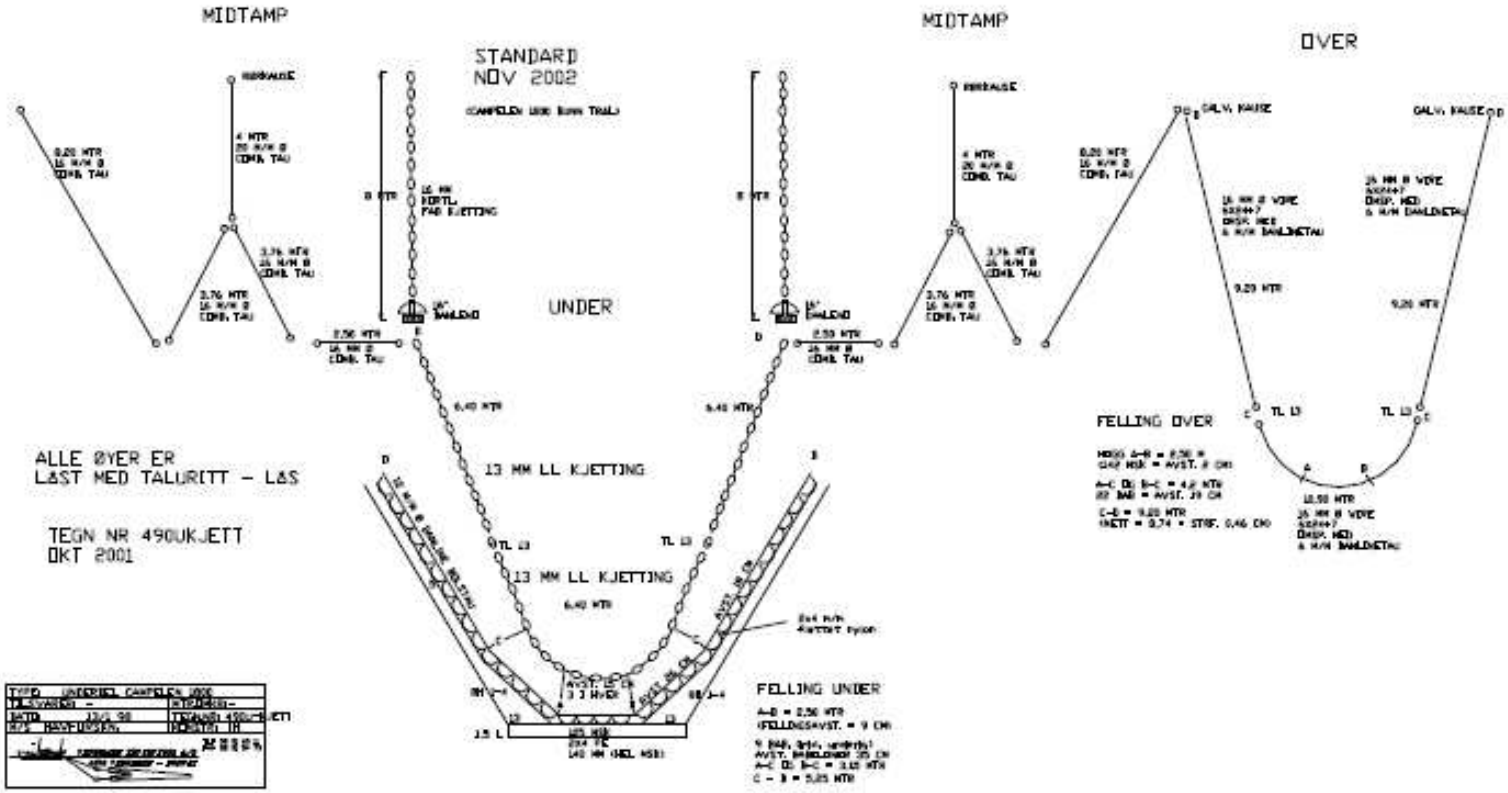

18 kHz
38 kHz
70 kHz
120 kHz
200 kHz
333 kHz

APPENDIX E

Trawl drawings (Engås, 1995):

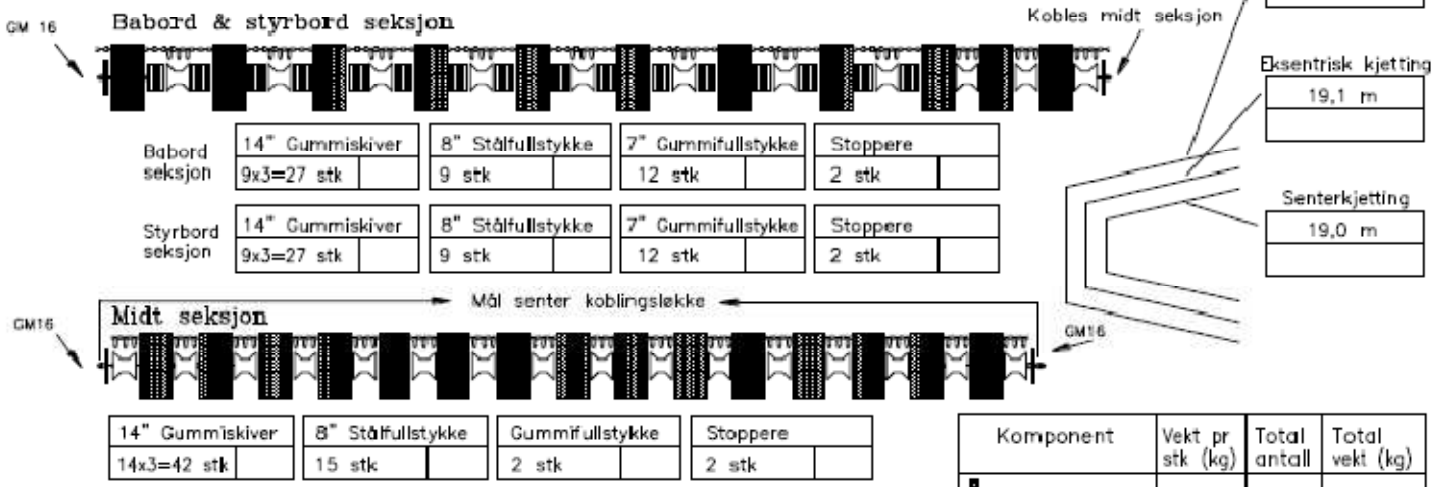


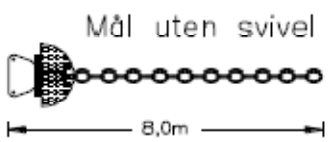
G.1.5.1 Campelen 1800 Rammeverk 490U



Rigging av rockhopper gear
Campelen 1800#

Gear nr./år	
Fartøy	
Dato	
Tokt	
Kontrollert av	





Stender 8,0m/16mm kjetting	

Babord/Styrbord

Kommentarer

Komponent	Vekt pr stk (kg)	Total antall	Total vekt (kg)
14" gummiskive	≈ 5,8	ca.102	610
8" stålfullstykke	6	33	198
Gummifullstykke	1,5	33	54
Stoppere	0,5	4	2,0
Senterkjetting 16mm	5,5kg/m	19,0m	104,5
Eksentrisk kjetting 7mm	1,1kg/m	19,1m	20,9
Festeringer (nr.5)		108	
SUM (≈)			ca.991

APPENDIX F

Calibration

2009: Calibration results for RV G.O. Sars for 18, 38, 70, 120, 200 and 333 kHz

HAVFORSKNINGSINSTITUTTET
REDERIAVDELINGEN
SEKSJON ELEKTRONISK INSTRUMENTERING

DRIFTSJOURNAL 1 **Kalibrering med referansekule** Rev 2006

Fartøy:	F/F G.O.Sars	Dato:	13.05.2009
Ekkolodd:	GOSER60nr2	Lokalitet:	Grönfjorden
Kule:	CU-64	TS_{kule}: (korrigert for lydhastighet eller t,S)	-34.30 dB
		Bunndyp:	45 m

Calibration Version 2.1.0.11

Comments:

Reference Target:

TS	-34.30 dB	Min. Distance	16.00 m
TS Deviation	6.0 dB	Max. Distance	21.50 m

Transducer: ES18-11 Serial No. 2039

Frequency	18000 Hz	Beamtype	Split
Gain	21.86 dB	Two Way Beam Angle	-17.3 dB
Athw. Angle Sens.	13.90	Along. Angle Sens.	13.90
Athw. Beam Angle	10.93 deg	Along. Beam Angle	10.83 deg
Athw. Offset Angle	-0.28 deg	Along. Offset Angl	0.08 deg
Sa Correction	-0.69 dB	Depth	0.00 m

Transceiver: GPT 18 kHz 009072033fb1 6 ES18-11

Pulse Duration	1.024 ms	Sample Interval	0.189 m
Power	2000 W	Receiver Bandwidth	1.57 kHz

Sounder Type:
EK60 Version 2.1.1

TS Detection:

Min. Value	-44.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %

Environment:

Absorption Coeff.	2.9 dB/km	Sound Velocity	1477.2 m/s

Beam Model results:

Transducer Gain =	22.01 dB	SaCorrection =	-0.56 dB
Athw. Beam Angle =	10.70 deg	Along. Beam Angle =	10.89 deg
Athw. Offset Angle =	-0.27 deg	Along. Offset Angle=	-0.08 deg

Data deviation from beam model:
RMS = 0.55 dB
Max = 2.54 dB No. = 89 Athw. = -4.6 deg Along = 3.6 deg
Min = -2.71 dB No. = 34 Athw. = 5.1 deg Along = -0.1 deg

Data deviation from polynomial model:
RMS = 0.52 dB
Max = 2.42 dB No. = 89 Athw. = -4.6 deg Along = 3.6 deg
Min = -2.71 dB No. = 34 Athw. = 5.1 deg Along = -0.1 deg

Bemerkninger :
Mye fisk
Vindstyrke : 4 kn. **Vindretning :** 44 grader
RådataFil:
Filnavn: \\fil-sars\ER60 Data\Calibration\Kalibrering 14050 9\18kHz\Kal_18kHz_1024

Kalibrering utført av: Terje Haugland, ,Bjarte Kvinge

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SEKSJON ELEKTRONISK INSTRUMENTERING

DRIFTSJOURNAL 1 — Kalibrering med referansekule

Rev:2006

Fartøy:	F/F G.O.Sars	Dato:	14.05.2009
Ekkolodd:	GOSER60nr2	Lokalitet:	Grönfjorden
Kule:	CU-60	TS_{korr}: -33.60 dB (korrigert for lydhastighet eller t,S)	Bunndyp: 45 m

Calibration Version 2.1.0.11

Comments:

Reference Target:

TS	-33.60 dB	Min. Distance	16.00 m
TS Deviation	6.0 dB	Max. Distance	22.00 m

Transducer: ES38B Serial No. 36310

Frequency	38000 Hz	Beamtype	Split
Gain	25.46 dB	Two Way Beam Angle	-20.8 dB
Athw. Angle Sens.	21.90	Along. Angle Sens.	21.90
Athw. Beam Angle	6.96 deg	Along. Beam Angle	6.96 deg
Athw. Offset Angle	-0.08 deg	Along. Offset Angl	0.14 deg
Sa Correction	-0.70 dB	Depth	0.00 m

Transceiver: GPT 38 kHz 009072034687 5 ES38B

Pulse Duration	1.024 ms	Sample Interval	0.189 m
Power	2000 W	Receiver Bandwidth	2.43 kHz

Sounder Type:
EK60 Version 2.1.1

TS Detection:

Min. Value	-44.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %

Environment:

Absorption Coeff.	10.1 dB/km	Sound Velocity	1477.2 m/s

Beam Model results:

Transducer Gain =	25.55 dB	SaCorrection =	-0.60 dB
Athw. Beam Angle =	7.14 deg	Along. Beam Angle =	6.98 deg
Athw. Offset Angle =	-0.10 deg	Along. Offset Angle=	-0.18 deg

Data deviation from beam model:
RMS = 0.52 dB
Max = 2.53 dB No. = 59 Athw. = -3.6 deg Along = 0.8 deg
Min = -2.45 dB No. = 87 Athw. = 3.0 deg Along = 2.3 deg

Data deviation from polynomial model:
RMS = 0.50 dB
Max = 2.44 dB No. = 25 Athw. = 2.1 deg Along = -0.5 deg
Min = -2.51 dB No. = 87 Athw. = 3.0 deg Along = 2.3 deg

Bemerkninger :
Mye fisk
Vindstyrke : 4 kn. **Vindretning :** 53 grader
RådataFil:
Filnavn: \\fil-sars\ER60 Data\Calibration\Kalibrering 140509\38kHz\Kal_38kHz_1024

Kalibrering utført av: Terje Haugland, ,Bjarte Kvinge

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DRIFTSJOURNAL 1 — Kalibrering med referansekule

Rev:2006

Fartøy:	F/F G.O.Sars	Dato:	14.05.2009
Ekkolodd:	GOSER60nr2	Lokalitet:	Grönfjorden
Kule:	WC-38,1	TS_{kule}: (korrigert for lydhastighet eller t,S)	-41.10 dB
		Bunndyp:	45 m

Calibration Version 2.1.0.11

Comments:

Reference Target:

TS	-41.10 dB	Min. Distance	16.00 m
TS Deviation	6.0 dB	Max. Distance	22.00 m

Transducer: ES70-7C Serial No. 105

Frequency	70000 Hz	Beamtype	Split
Gain	26.91 dB	Two Way Beam Angle	-20.6 dB
Athw. Angle Sens.	23.00	Along. Angle Sens.	23.00
Athw. Beam Angle	6.54 deg	Along. Beam Angle	6.55 deg
Athw. Offset Angle	-0.05 deg	Along. Offset Angl	0.04 deg
Sa Correction	-0.35 dB	Depth	0.00 m

Transceiver: GPT 70 kHz 009072033fb3 2 ES70-7C

Pulse Duration	1.024 ms	Sample Interval	0.189 m
Power	800 W	Receiver Bandwidth	2.86 kHz

Sounder Type:
EK60 Version 2.1.1

TS Detection:

Min. Value	-51.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %

Environment:

Absorption Coeff.	21.6 dB/km	Sound Velocity	1477.2 m/s

Beam Model results:

Transducer Gain =	26.93 dB	SaCorrection =	-0.34 dB
Athw. Beam Angle =	6.52 deg	Along. Beam Angle =	6.51 deg
Athw. Offset Angle =	-0.09 deg	Along. Offset Angle=	-0.06 deg

Data deviation from beam model:
RMS = 0.23 dB
Max = 0.68 dB No. = 101 Athw. = 0.8 deg Along = 3.0 deg
Min = -1.78 dB No. = 92 Athw. = 2.3 deg Along = 1.8 deg

Data deviation from polynomial model:
RMS = 0.21 dB
Max = 0.71 dB No. = 101 Athw. = 0.8 deg Along = 3.0 deg
Min = -1.70 dB No. = 92 Athw. = 2.3 deg Along = 1.8 deg

Bemerkninger :
Mye fisk
Vindstyrke : 7 kn. **Vindretning :** 53 grader
RådataFil: \\fil-sars\ER60 Data\Calibration\Kalibrering 14052009\70kHz\Kalibrering 14052009_70kHz_1ms-D20090514-T020038.r
Filnavn: \\fil-sars\ER60 Data\Calibration\Kalibrering 14052009\70kHz\Kal_70kHz_1024

Kalibrering utført av: Terje Haugland, ,Bjarte Kvinge

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SEKSJON ELEKTRONISK INSTRUMENTERING

DRIFTSJOURNAL 1 — Kalibrering med referansekule

Rev:2006

Fartøy:	F/F G.O.Sars	Dato:	14.05.2009
Ekkolodd:	GOSER60nr2	Lokalitet:	Grönfjorden
Kule:	WC-38,1	TS_{kule}: (korrigert for lydhastighet eller t,S)	-39.50 dB
		Bunndyp:	45 m

Calibration Version 2.1.0.11

Comments:

Reference Target:

TS	-39.50 dB	Min. Distance	16.00 m
TS Deviation	6.0 dB	Max. Distance	23.00 m

Transducer: ES120-7C Serial No. 124

Frequency	120000 Hz	Beamtype	Split
Gain	26.83 dB	Two Way Beam Angle	-21.0 dB
Athw. Angle Sens.	23.00	Along. Angle Sens.	23.00
Athw. Beam Angle	6.43 deg	Along. Beam Angle	6.49 deg
Athw. Offset Angle	0.02 deg	Along. Offset Angl	0.04 deg
Sa Correction	-0.31 dB	Depth	0.00 m

Transceiver: GPT 120 kHz 009072033fdc 3 ES120-7C

Pulse Duration	1.024 ms	Sample Interval	0.189 m
Power	250 W	Receiver Bandwidth	3.03 kHz

Sounder Type:
EK60 Version 2.1.1

TS Detection:

Min. Value	-50.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %

Environment:

Absorption Coeff.	33.2 dB/km	Sound Velocity	1477.2 m/s

Beam Model results:

Transducer Gain =	26.84 dB	SaCorrection =	-0.31 dB
Athw. Beam Angle =	6.53 deg	Along. Beam Angle =	6.47 deg
Athw. Offset Angle =	0.07 deg	Along. Offset Angle=	-0.18 deg

Data deviation from beam model:
RMS = 0.19 dB
Max = 0.41 dB No. = 256 Athw. = 4.3 deg Along = -0.5 deg
Min = -2.76 dB No. = 54 Athw. = 3.9 deg Along = 1.2 deg

Data deviation from polynomial model:
RMS = 0.17 dB
Max = 0.51 dB No. = 256 Athw. = 4.3 deg Along = -0.5 deg
Min = -2.68 dB No. = 54 Athw. = 3.9 deg Along = 1.2 deg

Bemerkninger :

Vindstyrke : 6 kn. **Vindretning :** 49 grader
RådataFil: \\fil-sars\ER60 Data\Calibration\Kalibrering 14052009\120kHz\Kalibrering 14052009_120kHz_1ms-D20090514-T024005
Filnavn: \\fil-sars\ER60 Data\Calibration\Kalibrering 14052009\120kHz\Kal_120kHz_1024

Kalibrering utført av: Terje Haugland, ,Bjarte Kvinge

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SEKSJON ELEKTRONISK INSTRUMENTERING

DRIFTSJOURNAL 1 — Kalibrering med referansekule

Rev:2006

Fartøy:	F/F G.O.Sars	Dato:	14.05.2009
Ekkolodd:	GOSER60nr2	Lokalitet:	Grönfjorden
Kule:	WC-38,1	TS_{kule}: -39.40 dB (korrigert for lydhastighet eller t,S)	Bunndyp: 45 m

Calibration Version 2.1.0.11

Comments:

Reference Target:

TS	-39.40 dB	Min. Distance	16.00 m
TS Deviation	6.0 dB	Max. Distance	23.00 m

Transducer: ES200-7C Serial No. 208

Frequency	200000 Hz	Beamtype	Split
Gain	26.72 dB	Two Way Beam Angle	-20.5 dB
Athw. Angle Sens.	23.00	Along. Angle Sens.	23.00
Athw. Beam Angle	6.66 deg	Along. Beam Angle	6.70 deg
Athw. Offset Angle	-0.09 deg	Along. Offset Angl	0.06 deg
Sa Correction	-0.27 dB	Depth	0.00 m

Transceiver: GPT 200 kHz 00907203465b4 ES200-7C

Pulse Duration	1.024 ms	Sample Interval	0.189 m
Power	150 W	Receiver Bandwidth	3.09 kHz

Sounder Type:
EK60 Version 2.1.1

TS Detection:

Min. Value	-50.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %

Environment:

Absorption Coeff.	46.7 dB/km	Sound Velocity	1477.2 m/s

Beam Model results:

Transducer Gain =	26.62 dB	SaCorrection =	-0.29 dB
Athw. Beam Angle =	6.67 deg	Along. Beam Angle =	6.47 deg
Athw. Offset Angle =	-0.05 deg	Along. Offset Angle=	-0.09 deg

Data deviation from beam model:
RMS = 0.25 dB
Max = 0.76 dB No. = 78 Athw. = 2.7 deg Along = 2.3 deg
Min = -1.00 dB No. = 227 Athw. = 4.6 deg Along = -0.7 deg

Data deviation from polynomial model:
RMS = 0.16 dB
Max = 0.44 dB No. = 258 Athw. = 3.5 deg Along = -2.0 deg
Min = -0.58 dB No. = 227 Athw. = 4.6 deg Along = -0.7 deg

Bemerkninger :

Vindstyrke : 7 kn. **Vindretning :** 61 grader
RådataFil: \\fil-sars\ER60 Data\Calibration\Kalibrering 14052009\200kHz\Kalibrering 14052009_200kHz_1ms-D20090514-T032300.raw
Filnavn: \\fil-sars\ER60 Data\Calibration\Kalibrering 14052009\200kHz\Kal_200kHz_1024

Kalibrering utført av: Terje Haugland, ,Bjarte Kvinge

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DRIFTSJOURNAL 1 — Kalibrering med referansekule

Rev:2006

Fartøy:	F/F G.O.Sars	Dato:	14.05.2009
Ekkolodd:	GOSER60nr2	Lokalitet:	Groenfjorden
Kule:	WC-22	TS_{kule}: -43.90 dB (korrigert for lydhastighet eller t,S)	Bunndyp: 45 m

Calibration Version 2.1.0.11

Comments:

Reference Target:

TS	-43.90 dB	Min. Distance	17.50 m
TS Deviation	6.0 dB	Max. Distance	21.50 m

Transducer: ES333-7C Serial No. 102

Frequency	333333 Hz	Beamtype	Split
Gain	26.07 dB	Two Way Beam Angle	-21.0 dB
Athw. Angle Sens.	23.00	Along. Angle Sens.	23.00
Athw. Beam Angle	6.87 deg	Along. Beam Angle	6.19 deg
Athw. Offset Angle	-0.07 deg	Along. Offset Angl	0.13 deg
SaCorrection	-0.33 dB	Depth	0.00 m

Transceiver: GPT 333 kHz 00907205a6bd 1 ES333-7C

Pulse Duration	1.024 ms	Sample Interval	0.190 m
Power	60 W	Receiver Bandwidth	3.11 kHz

Sounder Type:
EK60 Version 2.1.1

TS Detection:

Min. Value	-54.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %

Environment:

Absorption Coeff.	73.7 dB/km	Sound Velocity	1481.4 m/s

Beam Model results:

Transducer Gain =	26.90 dB	SaCorrection =	-0.29 dB
Athw. Beam Angle =	6.52 deg	Along. Beam Angle =	6.44 deg
Athw. Offset Angle =	-0.06 deg	Along. Offset Angle=	-0.07 deg

Data deviation from beam model:
RMS = 0.64 dB
Max = 1.67 dB No. = 19 Athw. = 2.7 deg Along = 0.4 deg
Min = -2.09 dB No. = 58 Athw. = 4.3 deg Along = -1.2 deg

Data deviation from polynomial model:
RMS = 0.60 dB
Max = 1.40 dB No. = 19 Athw. = 2.7 deg Along = 0.4 deg
Min = -1.97 dB No. = 162 Athw. = -0.8 deg Along = 0.4 deg

Bemerkninger:

Vindstyrke: 16 kn. **Vindretning:** 20 grader
RådataFil: \\fil-sars\ER60 Data\Calibration\Kalibrering 140509\333kHz\Kalibrering 14052009_333kHz_1ms-D20090514-T065545
Filnavn: \\fil-sars\ER60 Data\Calibration\Kalibrering 140509\333kHz\Kalibrering 14052009_333kHz_1ms slste

Kalibrering utført av: Terje Haugland, ,Bjarte Kvinge

Survey settings and calibration results for the six echo sounders used in the 2009 sandeel survey

Parameter	Frequency					
	18	38	70	120	200	333
Absorption coefficient [dB/km]	2.90	10.1	21.6	33.2	46.7	73.7
Pulse Duration [ms]	1.024	1.024	1.024	1.024	1.024	1.024
Bandwidth [kHz]	1.57	2.43	2.86	3.03	3.09	3.11
Power [W]	2000	2000	800	250	150	60
2 Way Beam Angle [dB]	-17.3	-20.8	-20.6	-21.0	-20.5	-21.0
TS Transducer Gain [dB]	22.01	25.55	26.93	26.84	26.62	26.90
Sa Correction [dB]	-0.69	-0.70	-0.35	-0.31	-0.27	-0.33
Angle Sensitivity - Along ship	13.90	21.90	23.00	23.00	23.00	23.00
Angle Sensitivity - Athwart ship	13.90	21.90	23.00	23.00	23.00	23.00
3 dB Beam Width - Along ship [deg]	10.83	6.96	6.55	6.49	6.70	6.19
3 dB Beam Width - Athwart ship [deg]	10.93	6.98	6.54	6.43	6.66	6.87
Angle Offset - Along ship [deg]	0.08	0.14	0.04	0.04	0.06	0.13
Angle Offset - Athwart ship [deg]	-0.28	-0.08	-0.05	0.02	-0.09	-0.07

2010: Calibration results for RV Johan Hjort for 18, 38, 120 and 200 kHz

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DRIFTSJOURNAL 1 **Kalibrering med referansekule** Rev 2006

Fartøy:	F/F Johan Hjort	Dato:	11.05.2010
Ekkolodd:	jher60nr1	Lokalitet:	Sandviksflaket
Kule:	CU-64	TS_{kule}: -34.25 dB (korrigert for lydhastighet eller t,S)	Bunndyp: 66 m

Calibration Version 2.1.0.12

Comments:
sandviksflaket 11.5.2019

Reference Target:

TS	-34.25 dB	Min. Distance	19.00 m
TS Deviation	4.0 dB	Max. Distance	25.00 m

Transducer: ES18-11 Serial No.

Frequency	18000 Hz	Beamtype	Split
Gain	22.89 dB	Two Way Beam Angle	-17.0 dB
Athw. Angle Sens.	13.90	Along. Angle Sens.	13.90
Athw. Beam Angle	11.08 deg	Along. Beam Angle	11.04 deg
Athw. Offset Angle	-0.01 deg	Along. Offset Angl	0.12 deg
Sa Correction	-0.60 dB	Depth	6.00 m

Transceiver: GPT 18 kHz 009072057371 1-1 ES18-11

Pulse Duration	1.024 ms	Sample Interval	0.189 m
Power	2000 W	Receiver Bandwidth	1.57 kHz

Sounder Type:
EK60 Version 2.2.1

TS Detection:

Min. Value	-45.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %

Environment:

Absorption Coeff.	2.7 dB/km	Sound Velocity	1478.0 m/s

Beam Model results:

Transducer Gain =	22.91 dB	SaCorrection =	-0.70 dB
Athw. Beam Angle =	11.01 deg	Along. Beam Angle =	10.81 deg
Athw. Offset Angle =	0.03 deg	Along. Offset Angle=	-0.06 deg

Data deviation from beam model:
RMS = 0.12 dB
Max = 0.43 dB No. = 103 Athw. = -6.0 deg Along = 5.4 deg
Min = -0.38 dB No. = 125 Athw. = -1.2 deg Along = 7.3 deg

Data deviation from polynomial model:
RMS = 0.10 dB
Max = 0.27 dB No. = 103 Athw. = -6.0 deg Along = 5.4 deg
Min = -0.24 dB No. = 201 Athw. = 2.1 deg Along = -3.0 deg

Bemerkninge Meget gode kal.forhold

Vindstyrke : 1.5 kn. **Vindretning :** 09 grader
RådataFil: W:\ER60\Kalibrering\2010\Rådata\20100205-D20100511-T162843.raw
Filnavn: W:\ER60\Kalibrering\2010\18 på sandviksfl

Kalibrering utført av: Egil Ona, Terje Svoren, Jan Erik Nygaard

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DRIFTSJOURNAL 1 Kalibrering med referansekule Rev 2006

Fartøy:	F/F Johan Hjort	Dato:	11.05.2010
Ekkolodd:	jher60nr1	Lokalitet:	Sandviksflaket
Kule:	CU-60	TS_{kule}: (korrigert for lydhastighet eller t,S)	-33.60 dB
		Bunndyp:	66 m

Calibration Version 2.1.0.12

Comments:
38 sandviksflaket 11.5.2010

Reference Target:

TS	-33.60 dB	Min. Distance	19.00 m
TS Deviation	4.0 dB	Max. Distance	25.00 m

Transducer: ES38B Serial No.

Frequency	38000 Hz	Beamtype	Split
Gain	26.64 dB	Two Way Beam Angle	-20.6 dB
Athw. Angle Sens.	21.90	Along. Angle Sens.	21.90
Athw. Beam Angle	7.17 deg	Along. Beam Angle	7.25 deg
Athw. Offset Angle	0.10 deg	Along. Offset Angl	0.05 deg
Sa Correction	-0.58 dB	Depth	6.00 m

Transceiver: GPT 38 kHz 009072057380 2-1 ES38B

Pulse Duration	1.024 ms	Sample Interval	0.189 m
Power	2000 W	Receiver Bandwidth	2.43 kHz

Sounder Type:
EK60 Version 2.2.1

TS Detection:

Min. Value	-45.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %

Environment:

Absorption Coeff.	9.9 dB/km	Sound Velocity	1478.0 m/s

Beam Model results:

Transducer Gain =	26.89 dB	Sa Correction =	-0.61 dB
Athw. Beam Angle =	6.84 deg	Along. Beam Angle =	6.88 deg
Athw. Offset Angle =	0.10 deg	Along. Offset Angle =	-0.06 deg

Data deviation from beam model:
RMS = 0.13 dB
Max = 0.33 dB No. = 102 Athw. = 2.2 deg Along = 3.6 deg
Min = -0.31 dB No. = 86 Athw. = -3.4 deg Along = 2.6 deg

Data deviation from polynomial model:
RMS = 0.10 dB
Max = 0.30 dB No. = 124 Athw. = -1.5 deg Along = 4.7 deg
Min = -0.30 dB No. = 111 Athw. = 0.3 deg Along = 4.2 deg

Bemerkninge Meget gode kal.forhold

Vindstyrke: kn. **Vindretning:** grader
RådataFil: W:\ER60\Kalibrering\2010\Rådata\20100205-D20100511-T162843.raw
Filnavn: W:\ER60\Kalibrering\2010\38 på sandviksfl

Kalibrering utført av: Egil Ona, Terje Svoren, Jan Erik Nygaard

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SEKSJON ELEKTRONISK INSTRUMENTERING

DRIFTSJOURNAL 1 — Kalibrering med referansekule

Rev:2006

Fartøy:	F/F Johan Hjort	Dato:	11.05.2010
Ekkolodd:	jher60nr1	Lokalitet:	Sandviksflaket
Kule:	WC-38,1	TS_{kule}: (korrigert for lydhastighet eller t,S)	-39.50 dB
		Bunndyp:	66 m

Calibration Version 2.1.0.12

Comments:
120 Sandviksflaket

Reference Target:

TS	-39.50 dB	Min. Distance	19.00 m
TS Deviation	4.0 dB	Max. Distance	25.00 m

Transducer: ES120-7 Serial No.

Frequency	120000 Hz	Beamtype	Split
Gain	23.93 dB	Two Way Beam Angle	-20.8 dB
Athw. Angle Sens.	21.00	Along. Angle Sens.	21.00
Athw. Beam Angle	7.23 deg	Along. Beam Angle	7.07 deg
Athw. Offset Angle	0.15 deg	Along. Offset Angl	0.08 deg
SaCorrection	-0.34 dB	Depth	6.00 m

Transceiver: GPT 120 kHz 009072057387 4-1 ES120-7

Pulse Duration	1.024 ms	Sample Interval	0.189 m
Power	250 W	Receiver Bandwidth	3.03 kHz

Sounder Type:
EK60 Version 2.2.1

TS Detection:

Min. Value	-50.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	4.8	Max. Echolength	180 %

Environment:

Absorption Coeff.	7.8 dB/km	Sound Velocity	1478.0 m/s

Beam Model results:

Transducer Gain =	24.23 dB	SaCorrection =	-0.36 dB
Athw. Beam Angle =	7.13 deg	Along. Beam Angle =	6.94 deg
Athw. Offset Angle =	-0.02 deg	Along. Offset Angle=	0.04 deg

Data deviation from beam model:
RMS = 0.15 dB
Max = 0.37 dB No. = 80 Athw. = 3.3 deg Along = 3.3 deg
Min = -0.86 dB No. = 271 Athw. = -1.5 deg Along = -4.5 deg

Data deviation from polynomial model:
RMS = 0.12 dB
Max = 0.37 dB No. = 141 Athw. = 0.1 deg Along = 4.9 deg
Min = -0.73 dB No. = 271 Athw. = -1.5 deg Along = -4.5 deg

Bemerkninge Meget gode kal.forhold

Vindstyrke: 1.5 kn. **Vindretning:** 09 grader
RådataFil: W:\ER60\Kalibrering\2010\Rådata\20100205-D20100511-T162843.raw
Filnavn: W:\ER60\Kalibrering\2010\120 på sandviksfl

Kalibrering utført av: Egil Ona, Terje Svoren, Jan Erik Nygaard

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SEKSJON ELEKTRONISK INSTRUMENTERING

DRIFTSJOURNAL 1 Kalibrering med referansekule Rev:2006

Fartøy:	F/F Johan Hjort	Dato:	11.05.2010
Ekkolodd:	jher60nr1	Lokalitet:	Sandviksflaket
Kule:	WC-38,1	TS_{kule}: -39.40 dB (korrigert for lydhastighet eller t,S)	Bunndyp: 66 m

Calibration Version 2.1.0.12

Comments:
200 kHz Sandviksf. cal no:2

Reference Target:

TS	-39.40 dB	Min. Distance	19.00 m
TS Deviation	4.0 dB	Max. Distance	25.00 m

Transducer: ES200-7C Serial No.

Frequency	200000 Hz	Beamtype	Split
Gain	26.33 dB	Two Way Beam Angle	-20.7 dB
Athw. Angle Sens.	23.00	Along. Angle Sens.	23.00
Athw. Beam Angle	6.27 deg	Along. Beam Angle	6.46 deg
Athw. Offset Angle	0.19 deg	Along. Offset Angl	0.28 deg
Sa Correction	-0.23 dB	Depth	6.00 m

Transceiver: GPT 200 kHz 00907205738a 3-1 ES200-7C

Pulse Duration	1.024 ms	Sample Interval	0.189 m
Power	120 W	Receiver Bandwidth	3.09 kHz

Sounder Type:
EK60 Version 2.2.1

TS Detection:

Min. Value	-45.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %

Environment:

Absorption Coeff.	3.1 dB/km	Sound Velocity	1478.0 m/s

Beam Model results:

Transducer Gain =	26.81 dB	SaCorrection =	-0.28 dB
Athw. Beam Angle =	6.17 deg	Along. Beam Angle =	6.61 deg
Athw. Offset Angle =	-0.02 deg	Along. Offset Angle=	0.20 deg

Data deviation from beam model:
RMS = 0.20 dB
Max = 0.44 dB No. = 184 Athw. = -3.9 deg Along = -1.7 deg
Min = -0.80 dB No. = 213 Athw. = 3.7 deg Along = -2.3 deg

Data deviation from polynomial model:
RMS = 0.16 dB
Max = 0.49 dB No. = 157 Athw. = 4.0 deg Along = -0.5 deg
Min = -0.61 dB No. = 256 Athw. = 2.0 deg Along = -3.8 deg

Bemerkninge Meget gode kal.forhold

Vindstyrke : 1.5 kn. **Vindretning :** 09 grader
RådataFil: W:\ER60\Kalibrering\2010\Rådata\20100205-D20100511-T162843.raw
Filnavn: W:\ER60\Kalibrering\2010\200 på sandviksf\cal 2

Kalibrering utført av: Egil Ona, Terje Svoren, Jan Erik Nygaard

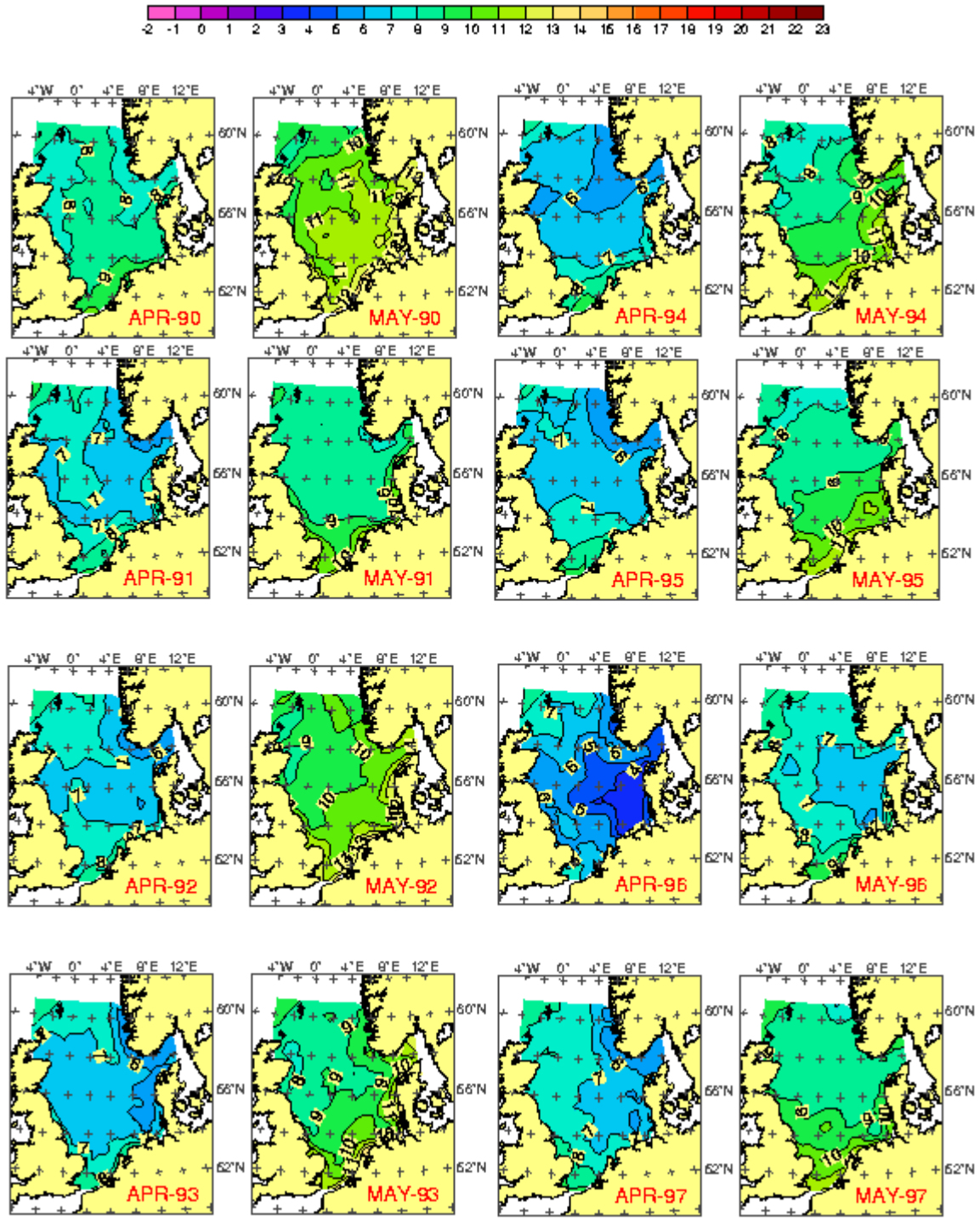
Survey settings and calibration results for the six echo sounders used in the 2009 sandeel survey

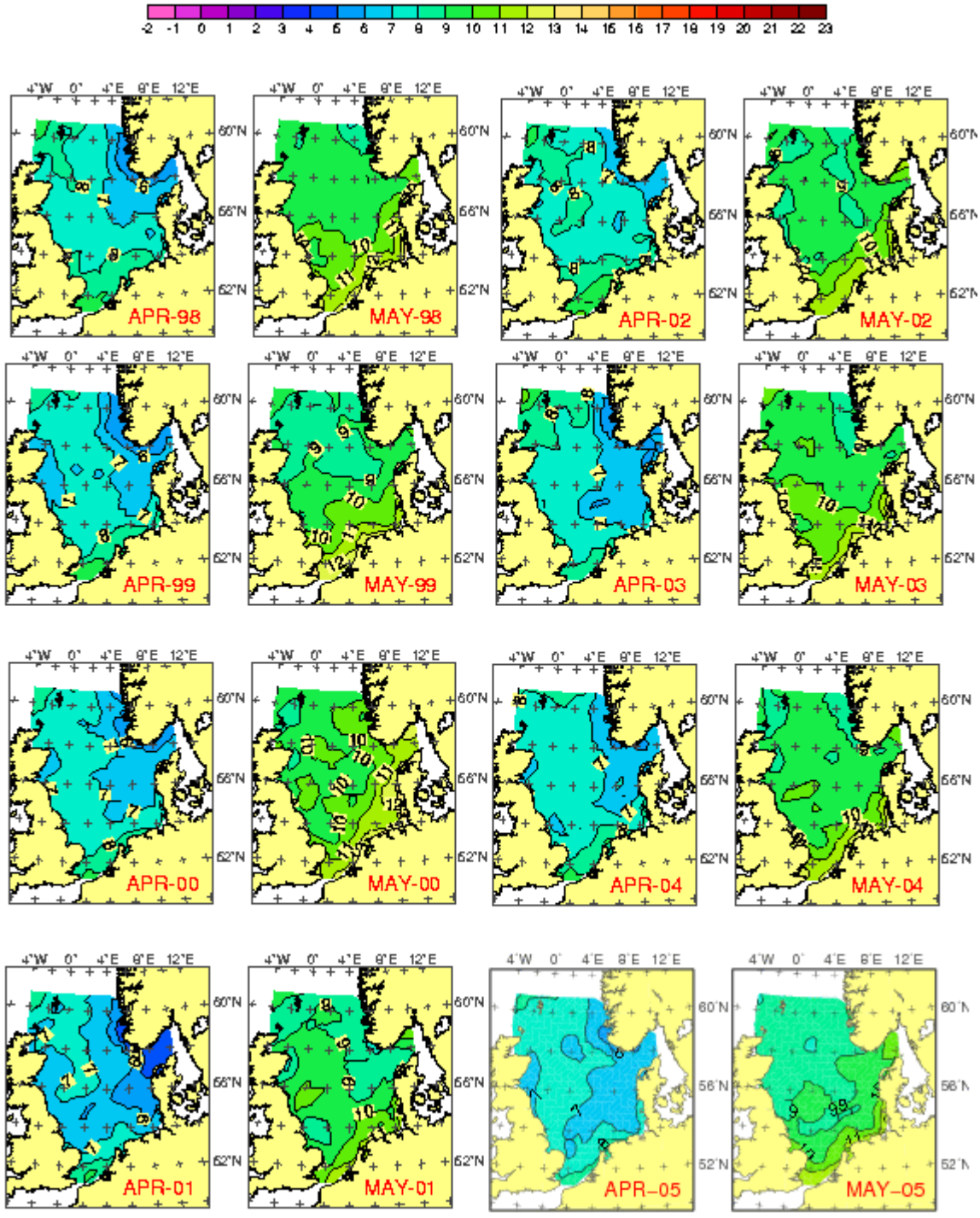
Parameter	Frequency			
	18	38	120	200
Absorption coefficient [dB/km]	2.70	9.9	7.8	3.1
Pulse Duration [ms]	1.024	1.024	1.024	1.024
Bandwidth [kHz]	1.57	2.43	3.03	3.09
Power [W]	2000	2000	250	120
2 Way Beam Angle [dB]	-17.00	21.90	-20.8	-20.7
TS Transducer Gain [dB]	22.91	26.98	24.23	26.81
Sa Correction [dB]	-0.60	-0.58	-0.34	-0.23
Angle Sensitivity - Along ship	13.90	21.90	21.00	23.00
Angle Sensitivity - Athwart ship	13.90	21.90	21.00	23.00
3 dB Beam Width - Along ship [deg]	11.04	7.25	7.07	6.46
3 dB Beam Width - Athwart ship [deg]	11.08	7.17	7.23	6.27
Angle Offset - Along ship [deg]	0.12	0.05	0.08	0.28
Angle Offset - Athwart ship [deg]	-0.01	0.10	0.15	0.19

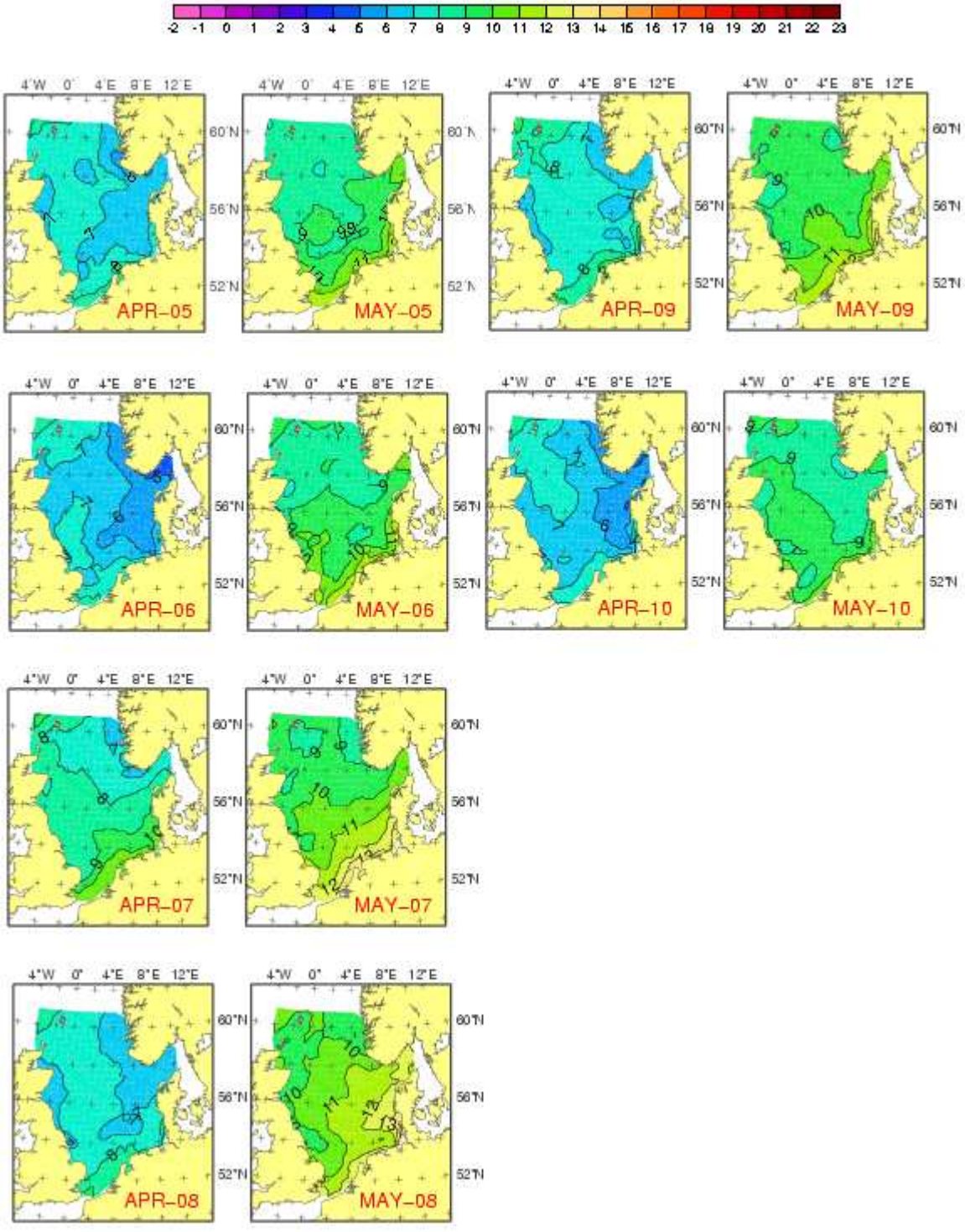
APPENDIX G

North Sea surface temperature

North Sea surface temperature in April and May from 1990-2010 (BSH, 2011)




-2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
4°W 0° 4°E 8°E 12°E
60°N
56°N
52°N
APR-98
MAY-98
APR-02
MAY-02
APR-99
MAY-99
APR-03
MAY-03
APR-00
MAY-00
APR-04
MAY-04
APR-01
MAY-01
APR-05
MAY-05


-2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
4°W 0° 4°E 8°E 12°E
60°N
56°N
52°N
APR–05
MAY–05
APR–09
MAY–09
APR–06
MAY–06
APR–10
MAY–10
APR–07
MAY–07
APR–08
MAY–08

APPENDIX H

The most important sandeel grounds in the North Sea