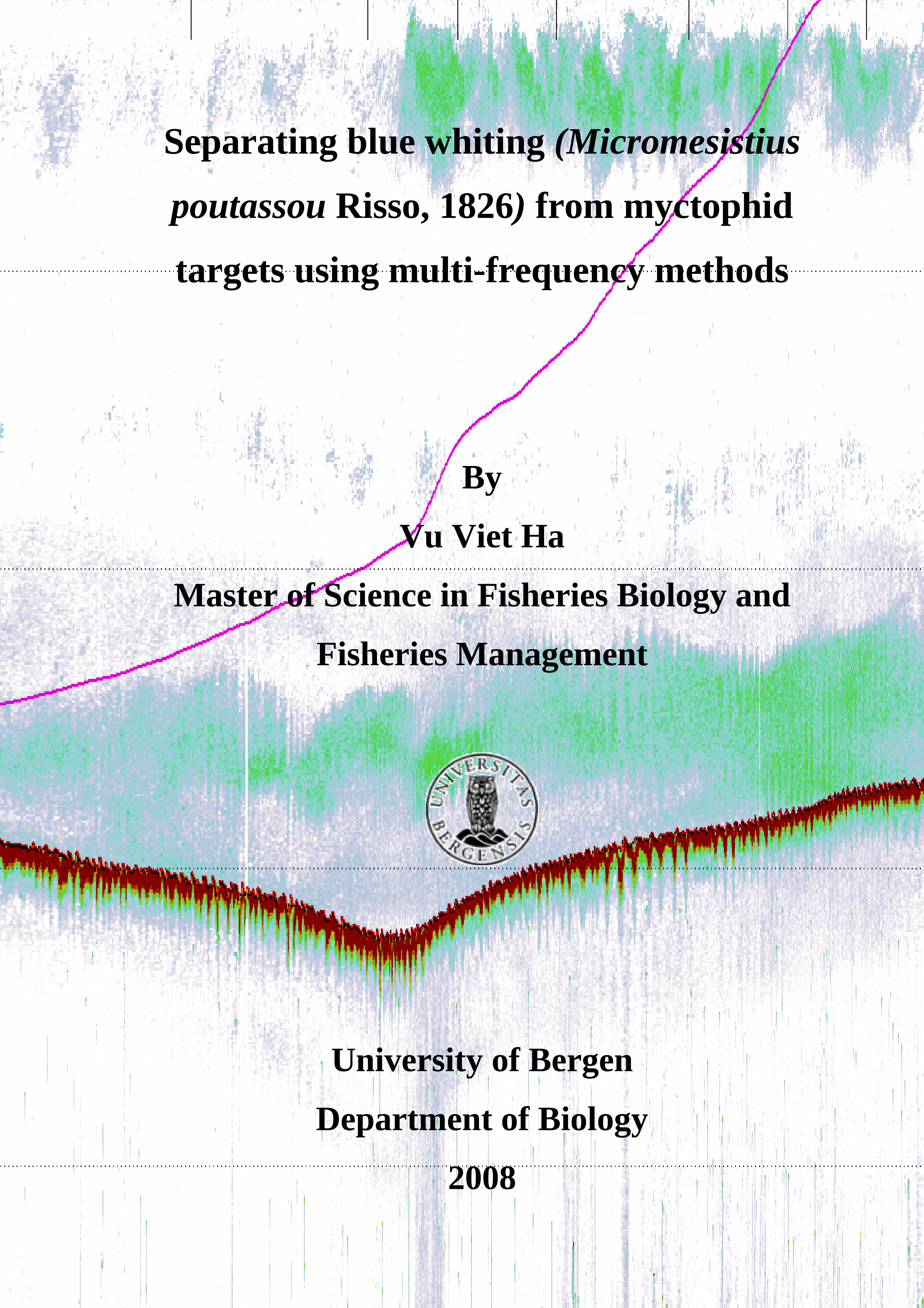

Separating blue whiting *(Micromesistius poutassou* Risso, 1826*)* from myctophid targets using multi-frequency methods

By

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ABSTRACT

Blue whiting (*Micromesistius poutassou* Risso, 1826) is a physoclists species, widely distributed in the Barents Sea, Norwegian Sea and Mediterranean Sea. They appear on the continental slope and shelf, in high concentration at 300-400 m depth. They play an important role in these ecosystems not only in term of abundance but also in the food chain. The abundance of the blue whiting stock is now estimated annually by acoustic methods. Traditionally, blue whiting was separated from other targets using catch information. Therefore, it often becomes problematic when only a few net samples are to be conducted. Multi-frequency method with an approach of measuring frequency response, r(f), is a reliable method for distinguishing between species recorded in echograms.

Acoustic data collected during blue whiting surveys in 2005 and 2006 were used to calculate r(f) of blue whiting and myctophids. The r(f) of blue whiting and myctophids were estimated for each “trawl-polygon” and for schools recorded along the survey tracks. The results showed significantly differences in r(f) for blue whiting and myctophid groups. It is evidently believed that r(f) are reliable variables used to discriminate between these species. Two approaches were deployed to separate blue whiting and myctophids; the discriminant function analysis and the classification tree. The r(f) at 18, 38 and 70 kHz, the echo strength at 38 kHz, $s_A(38)$, and the depth of fish schools (school depth) were used as independent variables. Both discriminant function analysis and classification tree were successfully used to separate between species with a relatively high accuracy. r(18), r(70) and $s_A(38)$ were the most important variables in the discriminant function analysis while r(18) and r(38) were the most powerful variables in the classification tree method.

During the survey in 2006, target strength, TS, of blue whiting was measured *in situ* using the TS probe method. The TS were estimated to be from -37 dB to -34 dB for 38 kHz and from -39 dB to -38 dB for 120 kHz. The relationship between target strength and length of fish was $TS=20\log(L)-64.2$; $L=26.0$ cm. No significant relationship between TS and depth was found.

The change in densities (tonnes/nmi^2) of blue whiting in 2005 and 2006 were about +11.8%. Total biomass estimated for the 2005 survey was about 1.8 million tonnes within an area of 75,899 nmi^2. In the 2006 survey, it was estimated around 1.0 million tonnes for an area of 38,131 nmi^2.

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ABBREVIATIONS

	Unit
LSSS: Large Scale System Survey	
BEI: Bergen Echo Integration	
"trawl-polygon": a polygon in echogram that is sampled by trawling, delimited vertically by trawl height and horizontally by trawled distance also called as "trawlpol"	
BW: Blue whiting	
R_MYC: resonant myctophids	
D_MYC: deep myctophids	
s_A: Nautical Area Scattering Coefficient	m^2/nmi^2
s_{Ai}: Nautical Area Scattering Coefficient of stratum i^{th}	m^2/nmi^2
$s_A(38)$: Nautical Area Scattering Coefficient at 38 kHz	
S_V: Volume back scattering strength	dB/m
A_i: Area of region i^{th} being surveyed	m^2/nmi^2
TS: Target Strength	dB
f: Frequency	Hz
r(f): Frequency response	
log: Logarithm	
logr(f): logarithmic transformed of frequency response	
r(18): frequency response at 18 kHz	
r(38): frequency response at 38 kHz	
r(70): frequency response at 70 kHz	
logcshdepth: logarithmic transformed of school depth	
$\overline{s_A}(f)$: Mean area-backscattering coefficient of frequency f	m^2/nmi^2
$\overline{s_A}(fN)$: Mean area-backscattering coefficient of all used frequencies	m^2/nmi^2
SE: Standard error	
SD: Standard deviation	
σ_{bs}: Backscattering cross section	m^2
σ_j: Backscattering cross section of length group j^{th}	m^2
(β): Along-ships angle	degree
(α): Athwart-ships angle	degree
(θ): Spherical angle	degree
TS_u: Uncompensated Target Strength	dB
TS_c: Compensated Target Strength	dB
SNR: Signal to noise ratio	

Ω_D: Solid angle of sampled volume	steradian
ΔZ: Depth interval	m
c: Sound speed	m/s
r: Range from transducer	m
τ: Pulse duration	m/s
N: Number of detection in the pulse volume	detection/m^3
p_{ij}: Acoustic contribution of the length group j^{th} to the total energy of stratum i^{th}	
W: Weight of fish	g
L: Length of fish	cm
a: catabolism coefficient	
b: anabolism coefficient	
L_j: Length of fish in group j^{th}	cm
TL_{ijk}: Length group j^{th} of species (i) at station k^{th}	cm
$\overline{TL}_{ik}$: The mean total length of species (i) at station k^{th}	cm
RMSL: Root Mean Square Length	cm
w_i: catch percentage of species (i) contributed to total catch	%
N_{ij}: Number of individual in length group j^{th} at stratum i^{th}	individual
n_j: number of individual in length group j^{th}	individual
n_{ik}: number of individual of species i^{th} at station k^{th}	individual
n_{ijk}: number of individual in length group j^{th} of species i^{th} at station k^{th}	individual
t_k: Time spent fishing at haul k^{th} (or station k^{th})	minute
q_{ik}: Total catch of species i^{th} at haul k^{th} (or station k^{th})	kg
q_k: Total catch of the haul k^{th} (or station k^{th})	kg
P_i: Frequency of the length group i^{th}	

1. INTRODUCTION

Acoustic methods are now widely used to locate and qualitatively visualize distributions, abundances and behaviours of fish (Simmonds and MacLennan 2005). It has become increasingly sophisticated and useful tools for fisheries research over the years (Jennings *et al.* 2001) and provide quick results and up-to-date information about the distributions and abundances of target species in the surveyed areas. The fundamental assumption of this method is based on the linear relationship between the integrated echo intensity and density of fish in the water column (Foote 1983; Gunderson 1993). However, the potential problem of the acoustic method is not showing information for categorizing the species as well as size composition of targets reflected as signals (Simmonds and MacLennan 2005). Therefore, there is a need for conducting trawl samples in order to determine the species composition registered in echograms. When classification and identification of acoustic targets are investigated, information about distributions and behavioural patterns of target species are also required (Horne 2000).

During acoustic data processing, in many cases it may be impossible to allocate acoustic energy to species based only on the interpretation of a few net samples. The acoustic information obtained from mixed aggregations is often dismissed because of our inability to properly identify or discriminate species (Gauthier and Horne 2004). Moreover, the use of catch composition from trawl samplings to interpret acoustic samples have several limitations, including the selectivity, catch-efficiency of the fishing gear among species and the resolution of net samples (Gunderson 1993; Simmonds and MacLennan 2005). In multi species situations, a huge number of trawl hauls is necessary to appropriately identify the species composition of the aggregations in a given stratum and the allocation of the echo data to different species become problematic when the catches contain more than a single species (Gunderson 1993).

Acoustic data processing has become more complicated but much more powerful with the synthetic echograms method, that is the combination of several echograms constructed using arithmetic and logical operators (Simmonds and MacLennan 2005). The use of multi frequencies in an acoustic survey can therefore improve the accuracy of the scrutinizing process, especially if the acoustic properties of individual species vary with the frequencies in use.

There were a number of researchers using multi frequency methods to discriminate reflected echograms into target species groups. Such techniques have been applied to discriminate fish and zooplankton (McKelvey and Christopher 2006), between groups of fish (Jech and Michaels 2006) and between various targets such as mackerel, swim-bladdered fish and zooplankton (Korneliussen and Ona 2002), myctophids, morids and macrourids and orange roughy (Kloser *et al.* 2002). Fernandes and Stewards (2004) used the multi frequency method to distinguish sandeel (*Ammodytes spp.*) and North Sea Mackerel (*Scomber scombrus*). Kang *et al.* (2002) separated fish and plankton targets using different mean volume backscattering strength among frequencies. This technique was also used by Elizabeth and Christopher (2004) to discriminate between juvenile pollock *(Theragra chalcogramma)* and capelin *(Mallotus villosus)* in the Gulf of Alaska. The multi frequency method was, moreover, applied to estimate abundance and distribution of zooplankton biomass by size class (Pieper *et al.* 1990). The benefits and limitations of this method for survey of fisheries were also discussed (Jech and Michaels 2006)

Blue whiting (*Micromesistius poutassou* Risso, 1826) is a small fish species belonging to the Gadidae family, characterised as an oceanic, semi-pelagic species (Cohen *et al.* 1990). They play an important role in terms of abundance in the North Atlantic (Carrera *et al.* 2001) and in the food chains as well. Blue whiting is widely distributed in the Barents Sea, Norwegian Sea and in the Mediterranean Sea as well. They appear on the continental slope and shelf from 150 to more than 1000 m depth, however, more common at 300-400 m (Cohen *et al.* 1990). Carrera *et al.* (2001) has studied distribution and population structure of blue whiting in the bay of Biscay using acoustic methods. The results showed that there were significant variations in blue whiting abundance in spring and they were strongly associated with the continental shelf-break and the continental shelf in the depth layer 200-300m.

The total blue whiting population consists of overlapping populations that are mainly referred to as a southern and a northern population. In the winter season, the northern population is mostly distributed in the Norwegian Sea, with high concentrations north and east of the Faeroe Islands. Before spawning, the mature part of the population starts migrating southwards along the continental ridge west of the British Isles. The most important spawning areas stretch from southwest of Ireland, over the Porcupine Bank and further northwards to the Hebrides. Spawning also takes place in the Bay of Biscay as well as off the coast of Spain and Portugal. When the spawning season is over, blue whiting are found in the Norwegian Sea in the summer season *(*Standal 2006*)*.

Blue Whiting feeds on crustaceans, copepods, euphausids, larvae of decapods, large individuals also prey on cephalopods (Cabral and Murta 2002) and myctophids (Miller 1966). Inger *et al.* (2006) study on diet of Blue Whiting in the Barents Sea, the results indicated that krill was also the main prey, they were accounted for approximately 87% and 47% of stomach content during the winter and summer season, respectively.

Blue whiting is considered as a fast growing and long life span species with maximum age about 20 years, and total body length reaches to 50cm. They first spawn at the age of 3 years. In the landings, the fish length dominated in the range 15-30cm (Cohen *et al.* 1990*)*. Blue whiting can be caught by various fishing gear but mainly by trawls.

Myctophids are small species belonging to the Myctophidae family. There were more than 200 different species recorded all over the world (www.fishbase.org; Stiassny 1997). They are found in the deep seas, more common distributed from 300 to 500m (Anon 1997) and often characterized by a specific diurnal migration pattern. At night, myctophids are moving from deep layers to the surface and feed on the layer around 100 m depth (Rissik and Suthers 2000). During the day, they are distributed deeper, even reported occurrences at 1000m depth (Anon 1997; Brodeur and Yamamura 2005). The main prey of myctophids are crustacean and zooplankton, such as copepods, euphausiids, amphipods, and ostracods (Hopkins and Gartner 1992).

The abundance of the blue whiting stock has been estimated since 1982 by acoustic surveys (Anon 1982) with the purpose of monitoring changes in abundance, age composition and other population characteristics of the spawning stock, spawning areas, distribution and migration patterns as well (Heino *et al.* 2003; 2004; 2005; 2006).

In blue whiting surveys, several frequency transducers have been employed, but only data collected by 38 kHz frequency was used for estimation of fish abundance. Data was categorized by plankton, meso-pelagic species, blue whiting and bottom fish. Traditionally, blue whiting was separated from other recordings using catch information confirmed by trawl sampling. Problem concerned to scrutinize the echograms were the use of catch data. It is a pivotal indicative used to allocate the area backscattering to species. If there were no myctophids at all, the rest would probably be blue whiting. But when there were catches from myctophids, we have to rely on the echogram or the catch to calculate the mixing in order to portion the correct area backscattering to blue whiting. However, the catch efficiency is not equal for myctophids and blue whiting. Their vertical distribution may also be different. Pulling the trawl through a layer of myctophids before hitting the blue whiting layer can also happen. If no multi-sampler is used, closing the codend, then care should be taken when examining the recorded trawl data for scrutinizing. Measuring frequency response - r(f) can be helpful if the r(f) for blue whiting and myctophids are different. The relative frequency response r(f) is defined as the volume backscattering coefficient and the response at the acoustic frequency f is normalized to that at 38 kHz, r(f) is determined for each pixel of the echogram, representing the elementary sampling volume or volume segment in the stored data (Korneliussen and Ona 2003).

The aims of this study are therefore to develop acoustic methods for separating blue whiting target from myctophid targets using the multi frequency method. The specific objectives are as follows:

- Develop acoustic methods for separating blue whiting target from myctophids targets using the deep-reaching frequencies 18, 38 and 70 kHz.
- Collect and process the target strength measurements for blue whiting using a new instrument - TS probe method.
- Conduct the conventional biomass estimation of blue whiting for the area covered the surveys.

2. MATERIALS AND METHODS

2.1. Data collection

2.1.1. Acoustic data sampling

Echo sounder sampling

The data used in this study were collected by the Norwegian Research Vessel R/V "G. O. Sars" in 2005 and 2006 under the International Blue Whiting Spawning Stock Survey in collaboration with the Faeroe Islands, Ireland, the Netherlands and Russia. Acoustic data were conducted using the SIMRAD EK60 scientific echo sounder with five frequencies: 18, 38, 70, 120 and 200 kHz split beam transducers mounted on a drop keel (Figure 1). The keel was able to extend to its maximum range of 3 m outside the hull of the vessel with the aim to prevent air bubbles created when cruising in bad weather condition. The raw echo data was transmitted from the transceiver mounted close to the transducers to the computer via local area network and stored there in EK60 format, which is containing the data from all frequencies. The echo sounders were calibrated using standard reference target as described by Foote *et al. (1987)*, details in section 2.2.2.

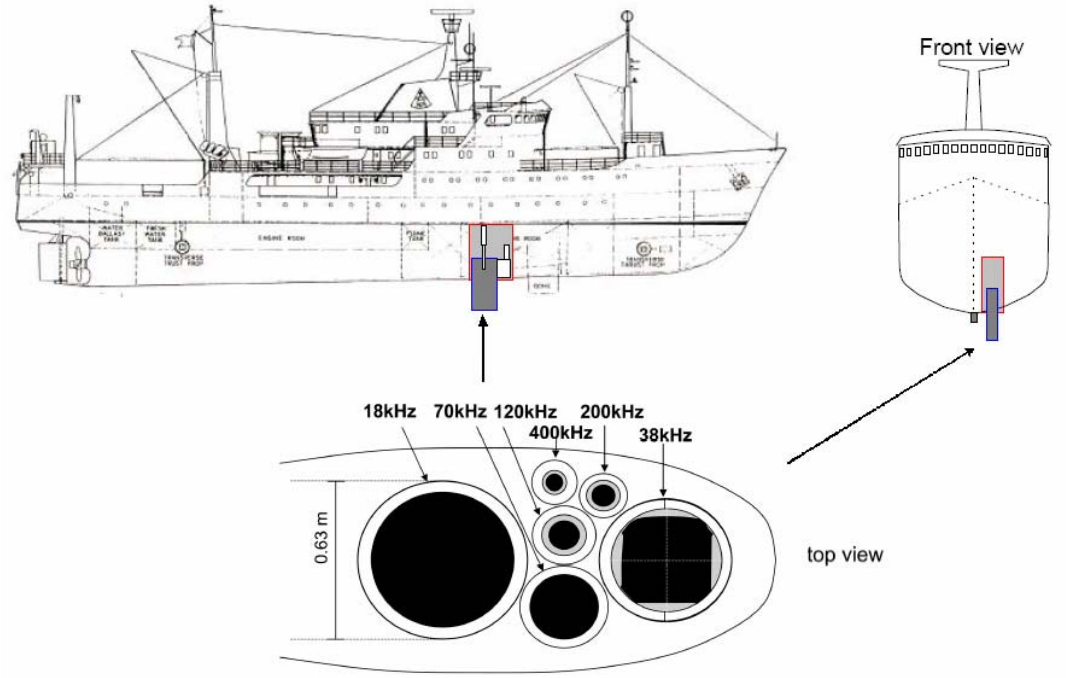

Figure 1. Transducer mounting on the drop keel of research vessel G.O.Sars.

The survey area covered the spawning ground of blue whiting to the west of the British Isles (Figure 2). The survey design was mainly systematic parallel grid pattern and the distance between transects was about 30 nautical miles. Vessel speed was approximately 10 knots during the survey.

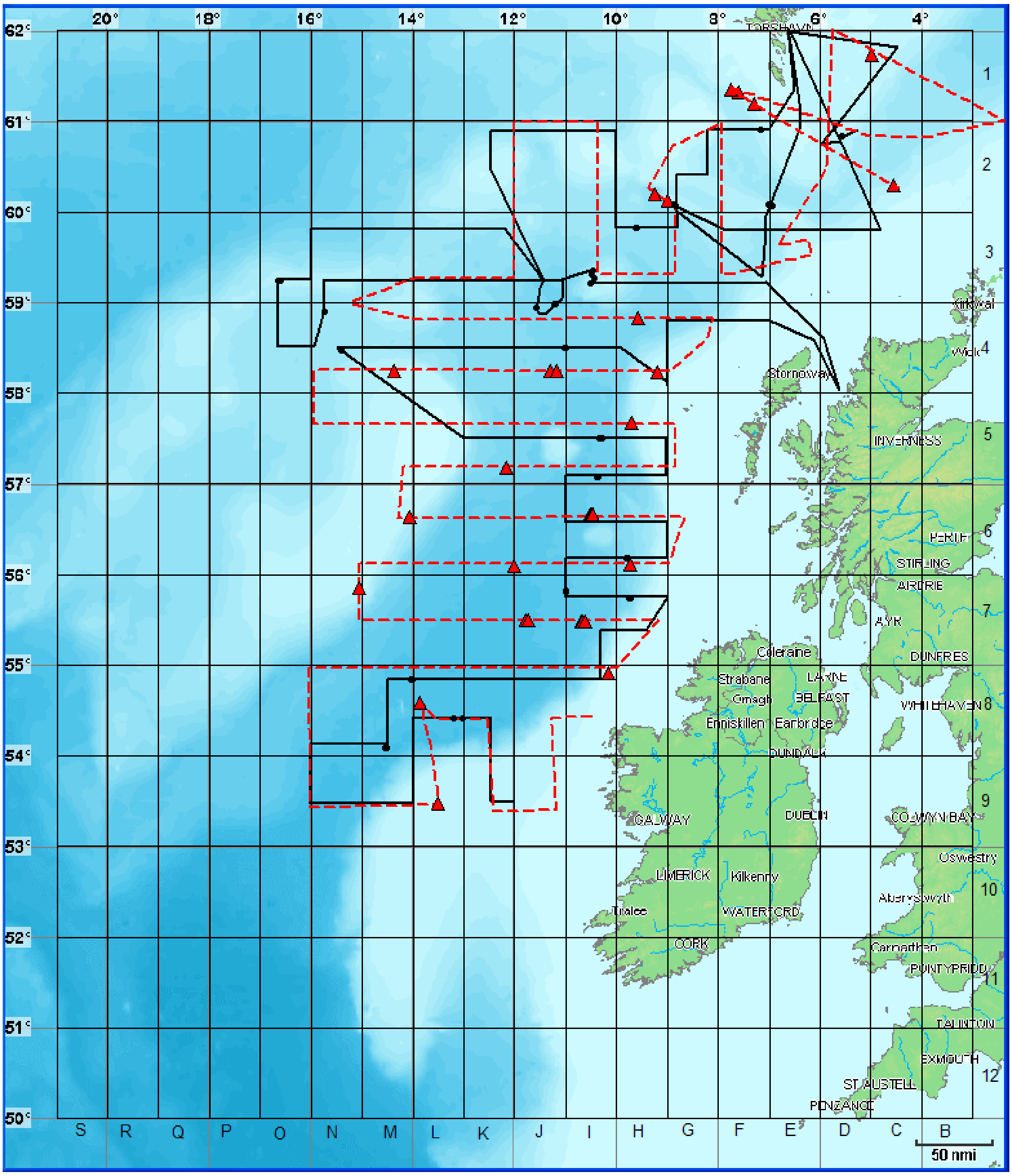

Figure 2. The map showing transects and trawl-sampling stations of the spring spawning blue whiting surveys. Black solid line with dots indicates the survey in 2005 and red dashed with triangles presents the survey in 2006.

The primary purpose of the surveys was to obtain estimates of the blue whiting stock abundance in the main spawning grounds and to collect hydrographic information as well (Heino *et al.* 2005; 2006).

The target strength probe sampling

During the survey in 2006, target strength of blue whiting was measured by *in situ* method using deep reaching probe transducers – a TS probe (Figure 3). The probe was equipped with the scientific echo sounders operating at 38 kHz and 120 kHz. These are the oil filled transducers, stably working at the high pressure in deep waters (Ona and Svellingen 1999; Ona and Svellingen 2001). Blue whiting is deep distributed (Cohen *et al. 1990),* therefore, it is difficult to detect the single target because of the large pulse volume for the hull mounted vessel transducer. In order to resolve a single target at short range, the TS probe has been developed (Ona and Svellingen 2001; Ona *et al.* 2006) which is an advanced technique for *in situ* target strength measurements of fish and zooplankton in dense layers (Ona *et al*. 2006).

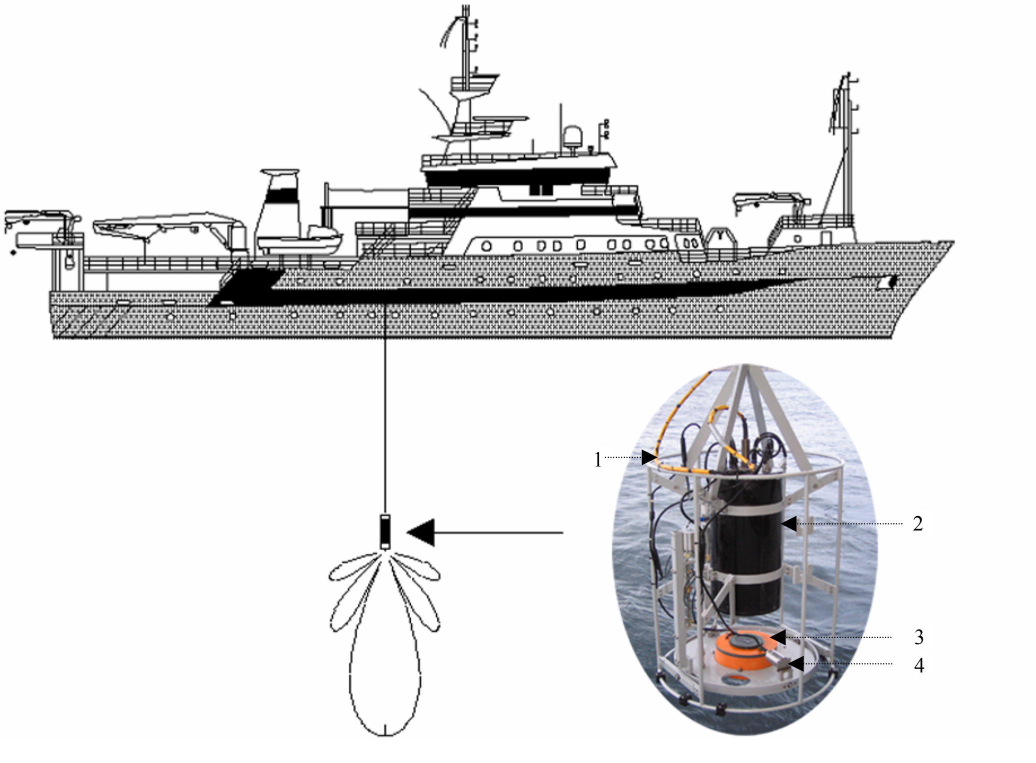

Figure 3. Target strength probe used for TS measurements during blue whiting survey in 2006. The probe was equipped transducers ES38 and ES120 operating at 38 kHz and 120 kHz connected to the computer onboard vessel via optical cable (1: optical cable; 2: pressure housing where the transceiver is mounted; 3: transducers; 4: tilt, roll, compass-sensor).

The target strength measurements of blue whiting were performed at selected stations on the survey tracks. On site, during data collection, the transducer gains were 26.81 dB for the transducer 38 kHz and 27.00 dB for 120 kHz (Table 1). These settings were relatively high compared to that of calibration results. The differences in gain were then adjusted by computing the total gain used during data collection subtracted for the total calibrated gain.

Table 1. Transducer settings used for the target strength measurement of blue whiting during the survey in 2006.

Frequency	38 kHz	120 kHz
Transducer	ES38D	ES120-7C
Power (W)	2000	500
Pulse duration (m/s)	1.024	1.024
Two way beam angle (dB)	-22.60	-21.00
Alongship angle sensitivity	21.90	23.00
Athwardship angle sensitivity	21.90	23.00
Alongship 3dB beamwidth (degree)	7.19	7.00
Athwardship 3dB beamwidth (degree)	7.10	7.00
Gain (dB)	26.81	27.00
Sa correction	-0.64	0.00
Sound velocity (m/s)	1494.00	1494.00

When conducting the target strength measurements, the probe was directly lowered from the research vessel to the dense layers of species of interest. If single targets were resolved, the ping repetition frequency is increased to maximum for the selected range. The EK60 was running without bottom detector. Data were collected and transmitted via an optical cable which connects the transducers on the probe to the computer on board vessel. During the TS sampling of fish, a calibration sphere was permanently mounted just in front of the transducers. This was done not only to pick up and adjust for small deviation in transducer sensitivity with depth especially between the fixed calibration depths, but also as a robust quality assurance of the target strength data. The copper sphere (Cu60) was used on the stations 196, 199, 204 and the tungsten carbide sphere (WC38.1) on stations 208, 218 and 219. The spheres were suspended about 7 to 8 meters beneath the probe by three nylon lines. The TS of the calibration spheres collected during the experiments were then computed and compared to its nominal target strength. These data was used to adjust the target strength of measured fish.

Trawl sampling was further conducted to verify the length distribution of fish registrations in echograms, details in section 2.1.3.

2.1.2. Calibration of equipment

Calibration of vessel echo sounder

Echo sounders were calibrated on October 27, 2005 using the standard reference targets as described by Foote et al *(1987)*. The used calibration spheres were the copper Cu64 and copper Cu60 for the frequencies 18 kHz and 38 kHz, respectively. The frequencies 70, 120 and 200 kHz were calibrated by tungsten carbide sphere (WC38.1).

The standard calibration spheres were soaked into the soap-water solution to remove any air bubbles and other surfactants and then suspended about 20-21 meters beneath the transducer. The calibration spheres were moved across the beam pattern and covered all four quadrants and acoustic axis. The pulse duration was 1.024 m/s and the sound velocity from transducer to the depth of sphere was 1498.8 m/s. The echo sounder calibration data are shown in Appendix 2.

Calibration of the target strength probe

The TS probe was not calibrated during the blue whiting survey on March-April 2006, but parameter settings in both transducers from previous calibrations were used as reference gains.

The transducer ES38 was calibrated on January 27, 2006 using a Cu60 sphere having the standard TS of -33.6 dB at the sound velocity of 1490 m/s. The equipment was calibrated at 10m, 200m, 480m and 485m depth. In order to have target strength of the sphere close to the standard value during the measurement, the transducer gain was adjusted from 24.5 to 21.9 or 25.12 dB. The transmit power applied during calibration was 2000W.

The transducer ES120 was calibrated on June 04, 2006 at 100m, 200m, 300m, 400m and 465m depth. A tungsten carbide sphere with standard target strength of -39.50 dB was used. The gain was set at 27.00 dB. During the calibration, the transmit power of 500W was applied. The sound velocity during the calibration was 1478.7 m/s.

Before calibration practice, the spheres were dipped into a solution of soap-water to remove any air bubbles. The spheres were located at 7-10 m and 25-30 m beneath the transducers ES38 and ES120, respectively. The pulse duration 1.024 m/s was applied for both transducers. All parameters and results obtained in the calibration process are given in the Appendix 3.

2.1.3. Biological data sampling

Acoustic abundance estimation requires samples of the species composition and size or age frequency of the fish registrations in echograms (Toresen *et al.* 1998). This information is normally provided by regular trawl sampling.

In the spring spawning blue whiting survey, a pelagic trawl Åkra with vertical opening from 25 to 35 m and stretched mesh at cod-end of 24 mm was mainly used to sample biological data. In addition, a bottom trawl Camplene 1800 with 4x18m opening and 24 mm stretched mesh at cod-end was employed on shallower areas (Heino *et al.* 2005; 2006). The exact trawl designs are shown in the Appendix 1. Normally, trawl sampling was conducted whenever fish aggregations were recorded in echograms. The towing speed was from 3 to 4 knot, distance trawled from 1 to 2 nautical miles. Fish entrance was monitored by the scanmar trawl eye and the trawling seized when an appropriate catch was assumedly obtained.

When the trawl was hauled on board, the catches were sorted by species or species groups and then counted and weighed separately (Mjanger *et al.* 2000). If large catches were taken, a sub-sample was drawn and the procedure above was applied. Finally, raising factor that is the ratio between total catch and sub-sample catch were applied to estimate the composition of the whole catch. Biological data of targeted species was also sampled. Normally, 50-200 fish was selected for the length measurement. Individual length was measured to nearest centimeter below with length interval of 0.5 cm (Mjanger *et al.* 2000). Additionally, 50 blue whiting were sexed, aged, and measured for length and weight, maturity status and stomach content were also recorded.

2.2. Data analysis

2.2.1. Echograms analysis

The echogram data were analyzed using the Large Scale Survey System post processing program - LSSS (Korneliussen *et al.* 2006). This study only used data collected by the frequency of 18, 38 and 70 kHz. Originally, acoustic data were collected and stored in EK60 format, then it was directly loaded to LSSS for scrutinizing. Due to the failure in retrieving the EK60 data of the 2005 survey from stored tapes, the data in BEI format were used instead of EK60. During post processing, a S_V threshold of -80 dB was equivalently applied to all echograms. Schools of fish were manually drawn at the clearest frequency, 70 kHz, and then inherited to the other frequencies. Species composition, trawl positions and the distance trawled were used as references for the scrutinizing process. A flow diagram of the data analysis is shown in Appendix 4.

2.2.2. Biological data analysis

Biological data consist of species composition, length frequency, mean length and length-weight relationship were analysed for each sampled station using the descriptive statistic methods as described by Simmonds and MacLennan (2005) for the analysis of fishing sample. Suppose there are M trawl hauls in the surveyed region, the percentage of catch (w_i) of species *(i)* contributed to the total catches of the haul k (q_k) was estimated by the formula:

$$w_i = \sum_{k=1}^{M} \frac{q_{ik}}{t_k} / \sum_{k=1}^{M} \frac{q_k}{t_k} \qquad (1)$$

q_{ik} is total catch of species (i) at haul k.

The frequency of a given length group (P_i) was computed by the equation

$$P_i = \sum_{k=1}^{M} \frac{n_{ijk}}{t_k} / \sum_{k=1}^{M} \frac{n_{ik}}{t_k} \qquad (2)$$

n_{ijk} is number of individuals in length group j^{th} of species i at station k and n_{ik} is total number of individuals of species i at station k. t_k is time spent fishing at station k.

The mean total length in centimetre of species i at station k ($\overline{TL_{ik}}$) was estimated as follows

$$\overline{TL_{ik}} = \frac{\sum n_{ijk} TL_{ijk}}{\sum n_{ik}} \qquad (3)$$

TL_{ijk} is length group jth of species i at station k.

The length-weight relationship is expressed as

$$W = aL^{b} \qquad (4)$$

where W is weight of fish in gram, L is total length measured in centimetre, a and b are catabolism and anabolism coefficients, respectively.

In this study, species composition was pooled into three main groups namely blue whiting, myctophids and others. This information was used as reference for the scrutinizing process.

2.2.3. Target strength analysis

The target echograms were analysed using the LSSS post processing system. The parameters used for the single-target detection algorithm included in the LSSS software were shown in Table 2. The layers having a clean echogram registration of targeted species were manually drawn, isolated and generated for basic parameters that are used to calculate the mean target strength value.

Table 2. Parameter settings used during TS analysis using the LSSS post processing software

TS detection menu	**38 kHz**	**120 kHz**	**Unit**
Minimum TS value	-60.0	-60.0	dB
Minimum echo length	0.8	0.8	
Maximum echo length	1.8	1.8	
Maximum gain compensation	6.0	6.0	dB
Maximum phase deviation	0.6	0.6	degree

Target strength of calibration spheres used during the experiments were also stored, calculated and then compared to its nominal value at the given depth. The difference in target strength of the sphere during the measurements and its nominal value was employed to adjust for the measured target strength of the fish at each station.

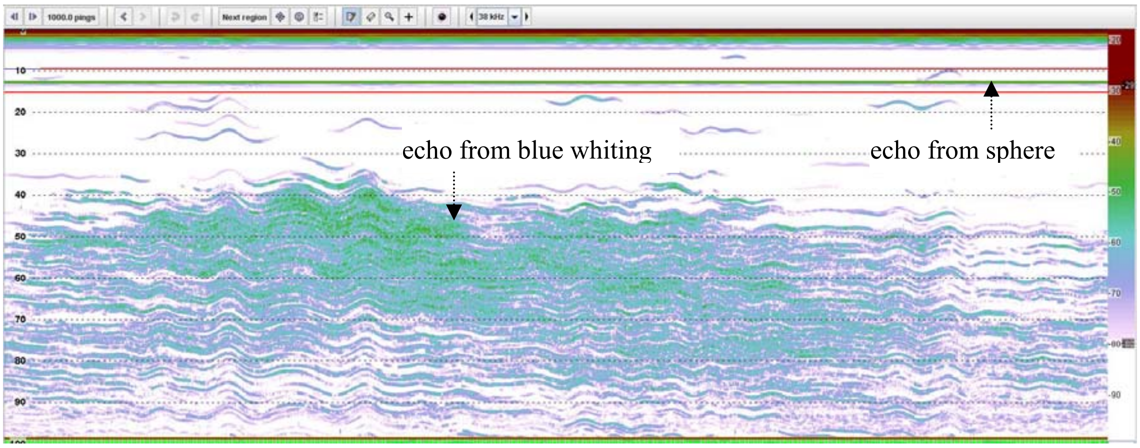

Figure 4. Echogram showing the layer of blue whiting generated for target strength analysis. The upper panel is the echo from the calibration sphere and the lower panel indicates the layer where the target strength of blue whiting was scrutinized. An echogram of 38 kHz with resolution of 1000 pings is shown. The probe was lowered about 300m from the surface, just above the BW layer.

As described by Ona (1999), the signal processing of the split beam system consist of five different filter steps that can be adjusted by operator. The generated information from LSSS are the TS-compensated (TS_c), TS-uncompensated (TS_u), athward-ships angle (α) and along-ships angle (β) as well as the time and depth of detected targets. Data were then rearranged into the standard case-by-variable format and imported into SYSTAT (SYSTAT Software Inc. 2007) for final analysis.

First, the spherical angle (θ) and back scattering cross section (σ_{bs}) of each case were calculated as recommended in Ona (1999)

$$\theta = \sqrt{\alpha^2 + \beta^2} \qquad (5)$$

and

$$\sigma_{bs} = 4\pi 10^{(TSc/10)} \qquad (6)$$

Then a scatter plot of the spherical angle against the backscattering cross section and a histogram plot of observed and expected detections by spherical angle can be used to determine the outliers and a proper cut-off of spherical angle. Theoretically, the larger the spherical angle, the more targets detected (Ona and Svellingen 2004). However, since the beam loss, $b^2(\Phi)$, is acting on the detected targets, the signal to noise ratio (SNR) is best at acoustic axis and worst in the out-skirting of the beam. In order to investigate how the SNR is working on the recorded data, the distribution of measured

TS can be plotted as a function of off-acoustic axis angle. In addition, the detection probability can be plotted and analyzed. Based on that, the noises threshold data can be removed.

Mean TS values were calculated from mean backscattering cross section ($\overline{\sigma}_{bs}$) by the formula (Ona 1999)

$$\text{TS} = 10\log(\frac{\overline{\sigma}_{bs}}{4\pi}) \qquad (7)$$

where

$$\overline{\sigma}_{bs} = \frac{1}{n}\sum_{i=1}^{n}\sigma_i \qquad (8)$$

The TS of fish is size dependent and expressed using the equation *(*Simmonds and MacLennan *2005)*

$$TS = mLog(L) + b \qquad (9)$$

in which: m and b are specific constants for species and L is the mean total length of the fish. For fish with swimbladder and normal body shape, m is close to 20 and b is written as b_{20}. The Root Mean Square Length (RMSL) was used instead of the mean length (Ona *et al.* 2001), RMSL is calculated by the equation

$$RMSL = \sqrt{\frac{\sum n_j L_j^2}{\sum_{i=1}^{n} n_j}} \qquad (9)$$

The specific formula use for estimated b_{20} value is

$$b_{20} = TS - 20Log(RMSL + 0.5) \qquad (11)$$

The addition of 0.5 cm to the RMSL is due to the fact that the length of fish was measured to the nearest centimeter below its total length.

Number of detection (N) for pulse volume was calculated by the equation as reviewed by Ona (1999)

$$N = \frac{s_A (c\tau/2) r^2 \Omega_D}{4\pi 10^{TS/10} \Delta Z (1852)^2} \qquad (12)$$

Where Ω_D is the solid angle of sampled volume, c is the sound speed, τ is the pulse duration, r is range from transducer and ΔZ =z2-z1 is depth interval. Typically, for the 38kHz transducer, θ_{3dB} =7.1°, but the angle detector for TS measurements work over 10° in total or 5° to each side of acoustic axis in alongship and athwardship directions. Ω_D =0.02391 steradians were therefore used for the half-spherical angle of 5°. Normally, for safe target strength measurements with respect to the bias in accepting multiple targets as one, the recommended probability of having more than one target in the pulse volume should be low. Assuming random (Poison) distribution of the targets within the pulse volume, the probability can be computed when the mean density is known, from equation 12.

2.2.4. Frequency response analysis

Frequency response of blue whiting (BW) and myctophids were analysed for the echograms which showed a clean concentration of the species of interest, which was also verified by trawl sampling. For BW, the echograms were considered as clean concentration if the trawl sampling showed that the catch of this species contributed more than 90% of the total catches. Unfortunately, very few catch data of myctophids was available. Only 6 trawl hauls caught myctophids with very low contribution to the total catches (Appendix 7). Actually, there were several species of myctophids in the trawl samples. However, they were not separately identified. All species of myctophids were pooled together and named as myctophid group.

The position of the trawl hauls, the trawling depth and the distance trawled were used to construct polygons that delimit the area in the echograms sampled by the trawl, these were namely designed as "trawl-polygon". The horizontal dimension of the trawl-polygon was defined as the depth when the trawl first reached the target and the vertical dimension was identified as the height of the net opening. In case when the trawl-polygon is less than 1 nautical mile horizontally, it will be extended to 1 nautical mile long. An example of constructed trawl-polygons and the concentration layer of blue whiting are indicated in Figure 5. After constructed, the trawl-polygons were scrutinised with a resolution of 0.1 nautical miles.

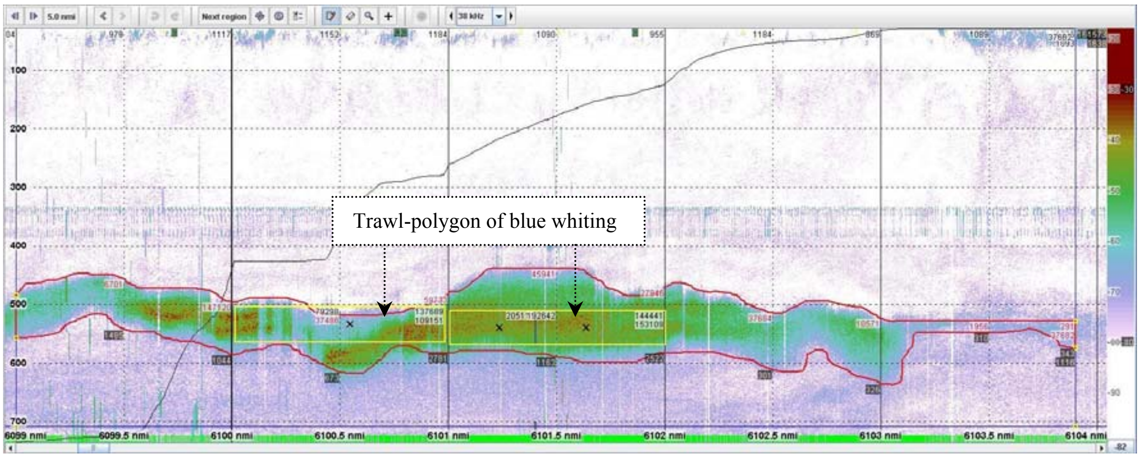

Figure 5. The echogram presents a five nautical mile transect line moving from left to right over the blue whiting school. Numbers on the left side indicate the depth in meter and threshold in dB shows on the right side. The two yellow rectangles indicate the positions of trawl sampling, referred to as “trawl-polygon” number 23019 and 23020 and the red layer is school of blue whiting that refers to as outside of the trawl-polygon. The echogram at 38 kHz is shown.

The frequency response of BW was estimated for each trawl-polygon. The clean concentration layers of BW outside the trawl-polygons were also scrutinised and calculated frequency response and then compared to that of inside the trawl-polygons.

The trawl-polygon of myctophid groups was constructed for stations which showed a high fraction of myctophids in the catches. Actually, there were no clean echograms of myctophids available. Myctophids were mixed with BW targets so that the trawl-polygon of myctophids was an area inside the constructed trawl-polygon after having isolated all the registration of BW. During scrutinizing process, the myctophid targets were found having different acoustic reflection properties depending on the depth of the myctophid registrations. They could be pooled into two separate groups called “resonant myctophids” (R_MYC) and “deep myctophids” (D_MYC).

After having ideas about r(f) of BW and myctophids using the trawl-polygon method, we started looking at all concentration layers of BW and myctophids along the survey transects. Only good quality echograms were selected for further analysis. We isolated schools of BW, R_MYC and D_MYC and scrutinized for area backscattering coefficient (sA), and the depth of schools were also recorded.

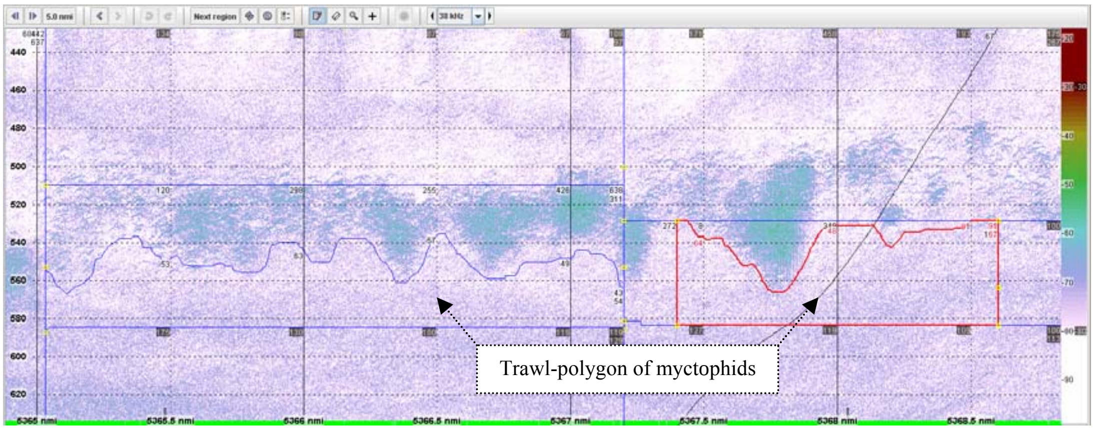

Figure 6. An example of constructed trawl-polygon for myctophids group, green rectangles indicate the swept area of the trawls (trawl number 200-23008 on the left and 200-23009 on the right), myctophids were delimited by polygons below the dense layer of blue whiting. The echogram at 38 kHz is shown.

The relative frequency response r(f) was defined by Korneliussen and Ona (2002) as the volume backscattering coefficient (Sv) at the acoustic frequency f normalizes to that at 38 kHz. Mohammed (2006) used area backscattering coefficient instead of volume backscattering coefficient, as suggested by Ona to define the frequency response, the formula is:

$$r(f) = \frac{\bar{s}_A(f)}{\bar{s}_A(f_N)} \qquad (13)$$

where $\bar{s}_A(f)$ is mean area backscattering coefficient of frequency f and $\bar{s}_A(f_N)$ is mean area backscattering coefficient of all used frequencies.

Theoretically, the properties of multi frequency acoustics can be examined by the difference in backscattering properties at different frequencies. In order to analyse the r(f) of BW and myctophid targets, the differences in mean r(f) of 18 kHz, r(18), and 70 kHz, r(70), to that of 38 kHz, r(38), were examined. The difference in mean r(f) is expressed by the formula:

$$\Delta r(f)_i = r(f)_i - r(38) \qquad (14)$$

The mean r(18), r(38), r(70), $s_A(38)$ and the depth of fish schools were logarithmically transformed and then used for discriminant function analysis and classification tree (see section 2.2.5).

2.2.5. Discriminant function analysis and classification tree

Discriminant function analysis

Discriminant function analysis is used to determine which variables discriminate between two or more naturally occurring groups (Klecka 1980) which is multivariate analysis of variance reversed. In discriminant function analysis, the dependent variables are the groups and independent variables are predictors.

Discriminant function analysis assumes that the data follow a normal distribution. The function, also called a canonical root, is a latent variable which is indicated as a linear combination of the independent variables, such that $L = b_1x_1 + b_2x_2 + ... + b_nx_n + c$, where the L is latent variable, b's are discriminant coefficients, the x's are discriminating variables, and c is a constant. In statistics, there is only one discriminant function for two dependent variable groups. If there are more than two dependent variable groups, the number of discriminant functions is (g-1) where g refers to number of dependent variable groups.

Discriminant analysis consists of two steps that are testing significance of a set of discriminant function and classification of the groups (Klecka 1980). The first step is an F test (Wilks' lambda). This is used to test if the discriminant model as a whole is significant. Lambda varies from 0 to 1, the smaller the variable Wilk's lambda, the greater is the unique discriminatory power of respective variable. The second step is performed when the F test showed significance, then the individual dependent variables are analysed to see which differ significantly mean by group and these are then used to classify the dependent variable. This performance is done based on Mahalanobis distance, which is the distance between each case and the center of the group. The smaller the Mahalanobis distance, the more confidence is the case belonging to that group. Each discriminant function is a dimension which differentiates a case into categories of the dependent variable based on its values on the independent variables. The first function will be the most powerful differentiating dimension, but later functions may also represent additional significant dimensions of differentiation.

In this study, discriminant function was used to analyse the difference in echograms between blue whiting and myctophids, if they behave as separate concentrations, or overlaps. Species was set as dependent variable and frequency response at three frequencies, area backscattering coefficient at 38 kHz, $s_A(38)$, and the school depth were independent variables. All data were logarithmically transformed before putting them in the model.

Classification tree

Classification tree (Wilkinson 2007) is used to search for independent variables which are optimal for classification between species. This is an alternative method to discriminant analysis. Classification trees are directed graphs starting with one node and branching into many. The tree is binary, each node is split into two sub-samples by searching a candidate set of predictor variables for a way to split the cluster into two clusters. It is expressed as cutting point which is based on the difference of particular independent variable between dependent variables. In this study, BW, R_MYC and D_MYC are dependent variables and r(18), r(38), r(70), $s_A(38)$ and the school depth are independent variables. All independent variables were logarithmically transformed before running the model. Hence, the performance of this method is compared with discriminant function analysis method on the data sets of BW and two myctophid groups.

2.2.6. Biomass estimation

The echo integrator measures the mean echo intensity of returned echoes. For estimation of fish abundance, it is therefore required to apply appropriate target strength function to convert acoustic energy into fish density. Target strength of fish depends on its length. Thus, there is a need to know the length frequency distribution of fish in the population.

The abundance of fish is estimated for each stratum of 1^0 longitude and 1^0 latitude by length group as shown in equations 15 (Toresen *et al.* 1998). Total abundance in the surveyed area is the sum of abundance of all strata. MapInfo computer program (MapInfo Corperation 2000) was used to calculate the area of stratum and also to map the distribution of blue whiting within the surveyed area.

$$N_{ij} = \frac{s_{Ai}}{\sigma_j} p_{ij} A_i \qquad (15)$$

where N_{ij} is the number of fish in length group jth of stratum ith, s_{Ai} is nautical area scattering coefficient (NASC) of the stratum ith. A_i is area (nmi^2) of stratum ith, σ_j is the backscattering cross section of fish in the length group jth and p_{ij} is the acoustic contribution of the length group jth to the total energy of stratum ith, which is estimated as equation 2 (section 2.2.2). The abundance of fish was further converted to biomass using the length – weight relationship as expressed in equation 4 (section 2.2.2).

3. RESULTS

3.1. Summary of biological data

During the blue whiting survey, a total of 75 trawl hauls were conducted, of which 43 trawl hauls were taken in 2005 and 32 hauls were sampled in 2006 (Appendix 5). Most trawl hauls caught blue whiting at a relatively high catch rates. Descriptive statistic of species composition indicated that there were 22 and 14 trawl hauls having a clean concentration of blue whiting with more than 90% of the catches in 2005 and 2006, respectively (Appendix 6).

During the survey in 2005, 3800 individuals of blue whiting were measured. The length of fish was in the range from 14.5 to 39.0 cm with the overall mean length of 26.3 cm. In the 2006 survey, 2519 individuals were measured and the overall mean length of fish was 26.1 cm, ranging from 15.0 to 42.0 cm. The length frequency distributions of blue whiting corresponding to the echogram recordings are shown in Appendix 27. Statistics of the fish length for each haul are indicated in Appendix 9.

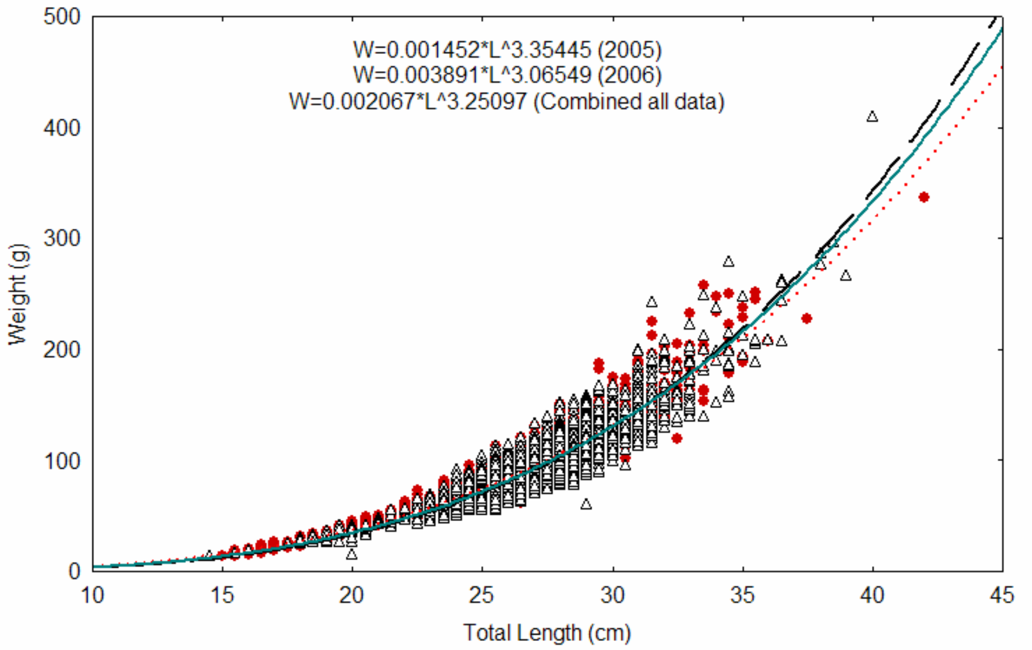

Figure 7. Plots of length weight relationship for blue whiting. Triangles are observed data in 2005 and dashed curve is fitted, dots are observed data in 2006 and dotted line shows the fitted curve. Solid line indicates the fitted curve for all data combined.

The length – weight relationship for blue whiting is graphically presented in Figure 7. Totally, 6523 fish individuals were individually measured for length and weight during two surveys, of which, number of fish measured in 2005 and 2006 were 4156 and 2367, respectively. Combined all data of 2005 and 2006 gave a length-weight relationship of $W=0.0026L^{3.2509}$ (R=0.92).

3.2. Target strength

TS measurements were conducted at 10 randomly selected stations along the survey transects. Species composition registered in echograms was sampled by trawl (see section 2.1.3). Summaries of biological data of fish associated with target strength measurement for each station are shown in Appendix 6 and Appendix 8. Six stations had a relatively high proportion of blue whiting (80-100%) in the catches. Echograms collected at these stations were chosen for the TS analysis. Four stations were excluded due to low quality of data in terms of species appearance in the catches as well as registrations of the target species in the echograms.

A total of 61560 single targets were detected for 38 kHz and 28889 targets for 120 kHz. After post processing removal of unwanted targets, the accepted targets were 48307 and 23904 for 38 kHz and 120 kHz, respectively. The TS distribution is highly variable from station to station and generally bimodal. The total spread distribution is about 30 dB at all stations, ranged from -60 dB to -30 dB. The TS of 38 kHz dominated in the range from -44 dB to -42 dB and from -56 dB to -54 dB. For 120 kHz, the TS were mostly skewed and dominated at the range from -56dB to -53dB. The mean TS of fish measured at each station for each of the two frequencies are shown in Appendix 12. For blue whiting with the mean length from 23 to 27 cm, the mean target strength was estimated at -47 to -44 dB for the frequency 38 kHz. At 120 kHz, the estimated mean target strength value was from -45 to -44 dB.

Actually, the mean target strength values are higher. During the target strength measurements, the gain was set at 26.81 dB for 38 kHz and 27.00 dB for 120 kHz while the calibrated gains were 21.89 and 24.07 dB (Appendix 3) for 38 kHz and 120 kHz frequencies, respectively. Since the gain was set very far from its expected value, the calibrated gains were necessary to use for correcting target strength. The TS values of 38 kHz and 120 kHz were increasing by 9.42 and 6.72 dB, respectively (Appendix 11). The exact mean target strength values for 38 kHz were therefore adjusted to be from -37 dB to -34 dB and -39 dB to -38 dB for 120 kHz frequency. During the TS measurement of fish, the TS of a calibration sphere with known TS were also measured to observe proper calibration settings and quality assurance. However, unfortunately, there was only three stations successfully collected (station 196, 199 and 204) applying the standard copper sphere (Cu60). The WC38.1 tungsten carbide was deployed at other stations but the data could not be used due to poorer quality. The estimated TS of calibration sphere showed that the mean TS value was slightly lower compared to its known value in normal condition. It was in the range -34.3 to -33.9 dB and overall mean was -34.1 dB (Appendix 13). Length frequency distributions of blue whiting at six stations of target strength measurements are graphically shown in Appendix 19. The length of fish ranged widely, from 15 to 35 cm, but varied among stations. The predominating length was in the range from 25 to 27 cm.

The TS distributions of combined data from six different stations for 38 kHz and three different stations for 120 kHz are indicated in Figure 8. The global mean TS at 38 and 120 kHz were -35.7 and -38.5 dB, respectively.

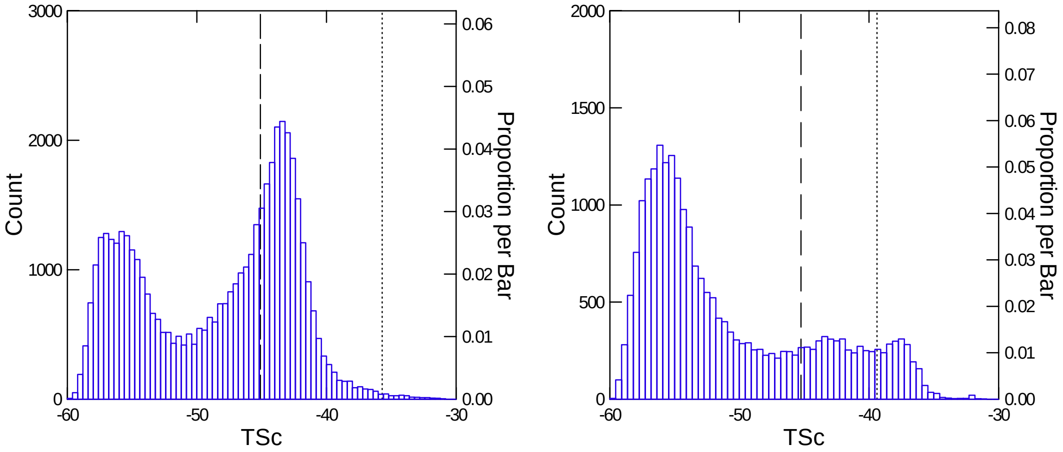

Figure 8. Histograms of all TS measurements of blue whiting conducted in 2006, 38 kHz frequency are shown in the left (mean TS=-45.1 dB, corrected mean TS=-35.7 dB, n=48307) and in the right is 120 kHz (mean TS=-45.2dB, corrected mean TS=-38.5 dB, n=23904). Dash indicates mean TS and dotted line indicates adjusted mean TS by gain.

3.3. Frequency response analysis

3.3.1. Frequency response of blue whiting and myctophids groups at the trawl sampling areas

Clean echograms of BW determined by trawl sampling were delimited as trawl-polygons and the area outside the trawl-polygons were analysed separately. An example of the constructed trawl-polygon and the area outside the trawl-polygon is shown in Figure 5. The mean r(f) of each sample are indicated in Appendix 20 and global mean values for the trawl-polygon and outside are shown in Table 3. Thirty two trawl-polygons and 15 layers outside the trawl-polygon were constructed for two surveys in 2005 and 2006.

Table 3. Mean frequency response of blue whiting inside and outside the trawl-polygon at different frequencies

Layer	Frequency	Mean	95.0% Lower Confidence Limit	95.0% Upper Confidence Limit	N	SE
Inside	18kHz	0.414	0.406	0.422	32	0.004
Inside	38kHz	0.285	0.280	0.290	32	0.003
Inside	70kHz	0.302	0.293	0.308	32	0.004
Outside	18kHz	0.414	0.405	0.423	15	0.004
Outside	38kHz	0.291	0.285	0.294	15	0.002
Outside	70kHz	0.296	0.288	0.304	15	0.003

Frequency response measurements of different BW schools showed that it was highest at 18 kHz, sharply drops at 38 kHz and 70 kHz (Figure 10). The global mean r(f) values inside the trawl-polygon were 0.414±0.004; 0.285±0.003 and 0.302±0.004 for the frequency 18, 38 and 70 kHz, respectively. For the layers outside the trawl-polygons, these values were not very much different compared to that of the trawl-polygon. It was 0.414±0.004 for 18 kHz; 0.291±0.002 for 38 kHz and 0.296±0.004 at 70 kHz. Mann-Whitney U test of r(f) between the trawl-polygon and outside the trawl-polygon among frequencies (Appendix 22) showed that there was no significant difference (p value >0.05).

The relationship between the mean length of fish and r(f) are graphically presented in Figure 9. For 38 and 70 kHz, r(f) and the mean length of fish seemed to be negatively related, whereas it had a positive relation at 18 kHz. However, the regression analysis of r(f) versus the length of fish showed no significant correlation ($p > 0.05$, see Appendix 26).

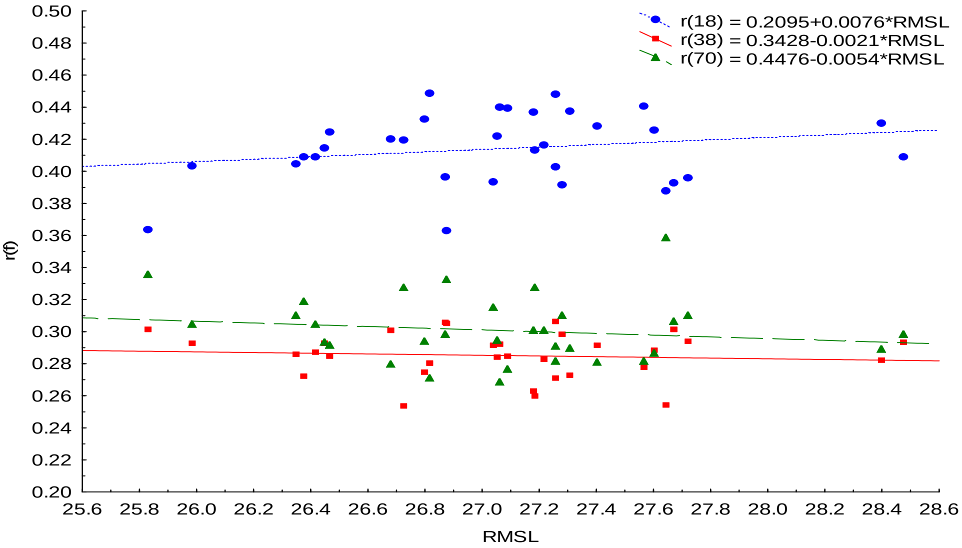

Figure 9. Relationships between mean length of fish and r(f). Points indicated r(f) at 18 kHz (r(18)), squares are r(f) at 38 kHz (r(38)), triangles are r(f) at 70 kHz (r(70)). Dotted line, solid line and dashed denote a linear relation to the length of fish (Root Mean Square Length, RMSL) of r(18), r(38) and r(70), respectively.

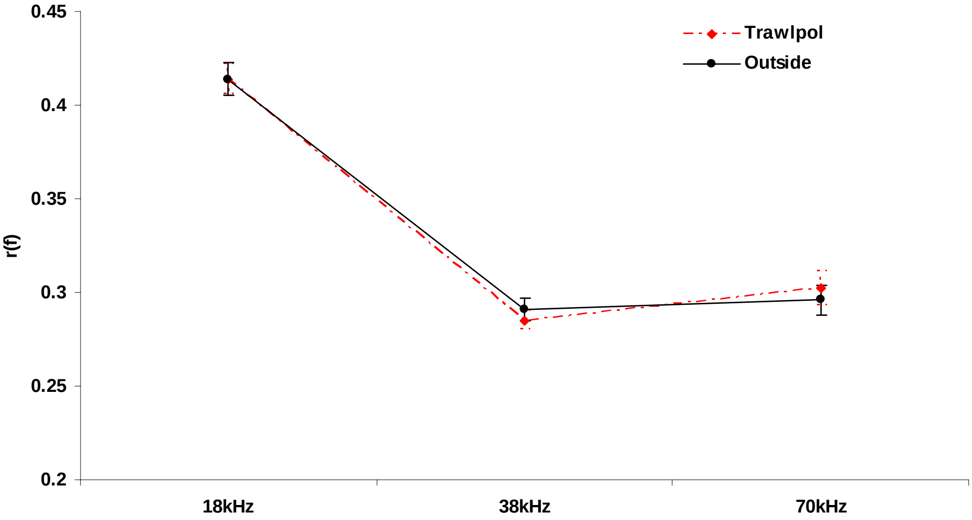

Figure 10. Plots of mean r(f) versus frequency of blue whiting, red dash indicates the r(f) of the area sampled by trawl and black solid line is the area outside the trawl, vertical bars denote 95% confidence intervals of mean values

Analysing the differences in frequency responses relative to the r(f) of 38 kHz for blue whiting in the trawl-polygon and outside the trawl-polygon showed that for 18 kHz delta r(f) - Δr(f) - had positive values for every school while it was alternatively positive and negative for 70 kHz (Appendix 20).

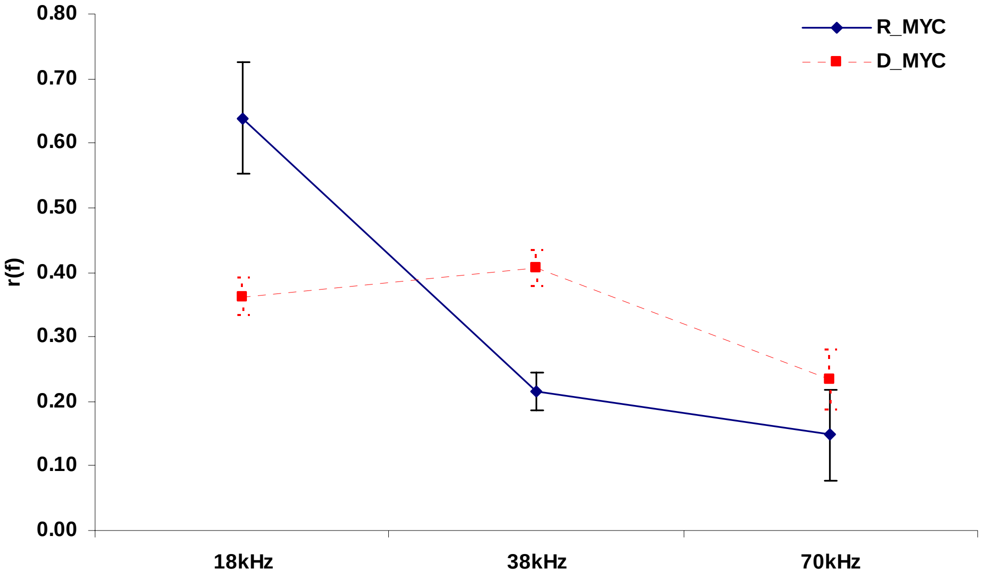

Figure 11. Plots of mean frequency response of myctophids groups versus frequency. Red dash indicates r(f) of deep myctophids and black solid line is resonant myctophids, vertical bars denote 95% confidence intervals of mean values

The frequency responses of myctophid groups are graphically shown in Figure 11, details for each trawl-polygon are indicated in Appendix 21. Only 5 trawl-polygons of R_MYC and 6 trawl-polygons of D_MYC were constructed corresponding to the trawl samplings. Both r(f) of D_MYC and R_MYC among frequencies varied from trawl-polygon to trawl-polygon. The mean r(f) of R_MYC was highest at 18 kHz, sharply decreasing and got lowest value at 70 kHz. The global mean frequency responses were 0.638±0.031; 0.214±0.010; and 0.147±0.025 at 18, 38 and 70 kHz, respectively (Table 4). For D_MYC, r(f) was highest at 38 kHz, lower at 18 kHz and lowest at 70 kHz. The global mean values were 0.361±0.011; 0.405±0.011 and 0.233±0.018 at 18, 38 and 70 kHz, respectively.

Table 4. Mean frequency response for the trawl-polygon of resonant myctophids (R_MYC) and deep myctophids (D_MYC).

Species group	Frequency	Mean	95.0% Lower Confidence Limit	95.0% Upper Confidence Limit	N	SE
R_MYC	18kHz	0.638	0.552	0.725	5	0.031
R_MYC	38kHz	0.214	0.185	0.243	5	0.012
R_MYC	70kHz	0.147	0.077	0.218	5	0.025
D_MYC	18kHz	0.361	0.332	0.390	6	0.011
D_MYC	38kHz	0.405	0.377	0.434	6	0.011
D_MYC	70kHz	0.233	0.187	0.279	6	0.018

3.3.2. Frequency responses of blue whiting and myctophids groups for the selected areas along the survey transects

Mean r(f) of BW and myctophid groups scrutinized at selected areas along the survey transects are shown in Table 5. Fifty-seven schools of BW, 42 and 33 layers of R_MYC and D_MYC were interpreted, respectively. The mean r(f) for each school at frequencies are indicated in Appendix 24 and global mean value for each species among frequencies are shown in Table 5.

The mean r(f) of different blue whiting schools were high at 18 kHz, decreased at 38 and 70 kHz. The global mean values of r(f) were 0.411±0.003; 0.290±0.002 and 0.298±0.002 for 18, 38 and 70 kHz, respectively.

Table 5. Mean frequency response of blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC) for the "blue whiting" cruise in 2005 and 2006

Species	**Frequency**	**Number of school**	**Mean**	**SE**	**95.0% Lower Confidence Limit**	**95.0% Upper Confidence Limit**
BW	18kHz	57	0.411	0.003	0.405	0.418
	38kHz	57	0.290	0.002	0.287	0.294
	70kHz	57	0.298	0.002	0.294	0.303
R_MYC	18kHz	42	0.683	0.006	0.670	0.695
	38kHz	42	0.204	0.004	0.196	0.211
	70kHz	42	0.114	0.003	0.107	0.120
D_MYC	18kHz	33	0.352	0.004	0.344	0.360
	38kHz	33	0.396	0.003	0.389	0.403
	70kHz	33	0.252	0.004	0.244	0.260

The r(f) of R_MYC group had a decreasing trend from low frequency to high frequency. It was relatively high at 18 kHz (0.683±0.006), sharply dropped at 38 kHz (0.204±0.004) and got lowest value at 70 kHz (0.114±0.003).

On the contrary, the r(f) of D_MYC group were observed highest at 38 kHz compared to that at 18 and 70 kHz. The lowest value was estimated at 0.252±0.004 for 70 kHz.

Mann-Whitney U test for the mean r(f) at a given frequency (Appendix 25) showed significant difference between species (p value <0.05). Plots of r(f) versus frequencies for BW and myctophid groups are presented in Figure 12.

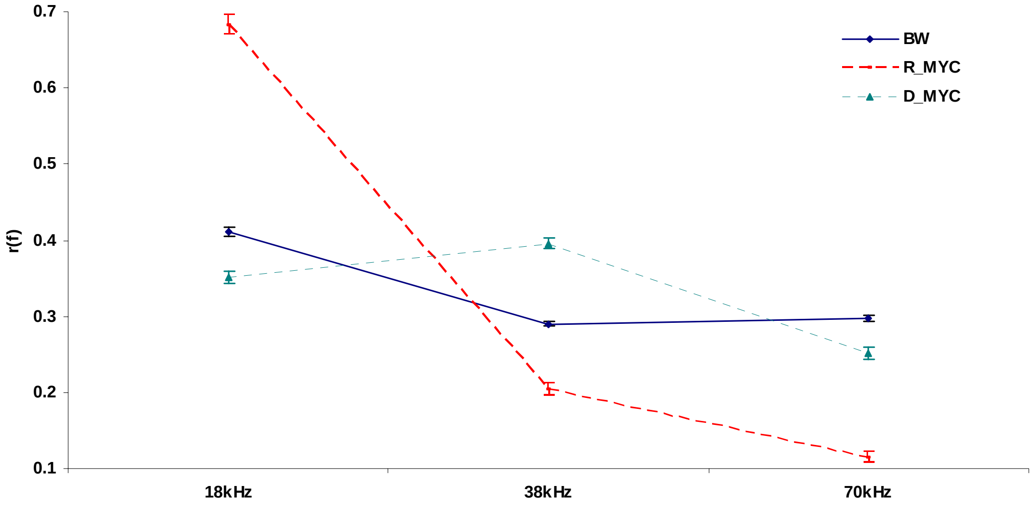

Figure 12. Plots of frequency response versus frequency of blue whiting, BW, (black solid line), resonant myctophids, R_MYC, (dashed line) and deep myctophids, D_MYC, (dotted line) for the survey in 2005 and 2006. Vertical bars denote the 95% confident limit of the mean value.

The difference of r(f) at a given frequency relatively to r(38) showed the different trends between each species. Blue whiting had positive values at both 18 and 70 kHz while R_MYC group was positively at 18 kHz and negatively at 70 kHz. In contrast, D_MYC group had negative values at both 18 and 70 kHz (Table 6). The difference between mean value at 18 kHz and 38 kHz for BW, R_MYC group and D_MYC group were 0.121; 0.479 and -0.044, respectively. The difference between that value of 70 kHz and 38 kHz were 0.008 for blue whiting, -0.090 for R_MYC group and -0.144 for D_MYC.

Table 6. Difference of frequency response of certain frequency to the frequency response of 38 kHz of blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC).

Species	r(18)-r(38)	r(70)-r(38)
BW	0.121	0.008
R_MYC	0.479	-0.090
D_MYC	-0.044	-0.144

3.4. Discriminant function analysis and classification tree

3.4.1. Discriminant function analysis

The r(f) of 18, 38 and 70 kHz, school depth and $s_A(38)$ of 57 BW schools, 42 R_MYC schools and 33 D_MYC schools were logarithmically transformed and deployed for discriminant analysis. The classical discriminant function analysis employing forward stepwise selection of variables was used to determine the best subset of variable discriminated between species. The discriminant analysis was able to distinguish completely between BW, R_MYC and D_MYC (Appendix 33). The F-test for the overall discriminant model showed a significant discriminant (Wilks' lambda = 0.005; F=328.16; p value <0.001). The F test for the equality of group mean for each pair of groups is indicated in Appendix 31. It showed that the centroids for BW and D_MYC are closest (F=194.9) compared to those of BW and R_MYC (F=460.84) and of R_MYC and D_MYC (F=476.39).

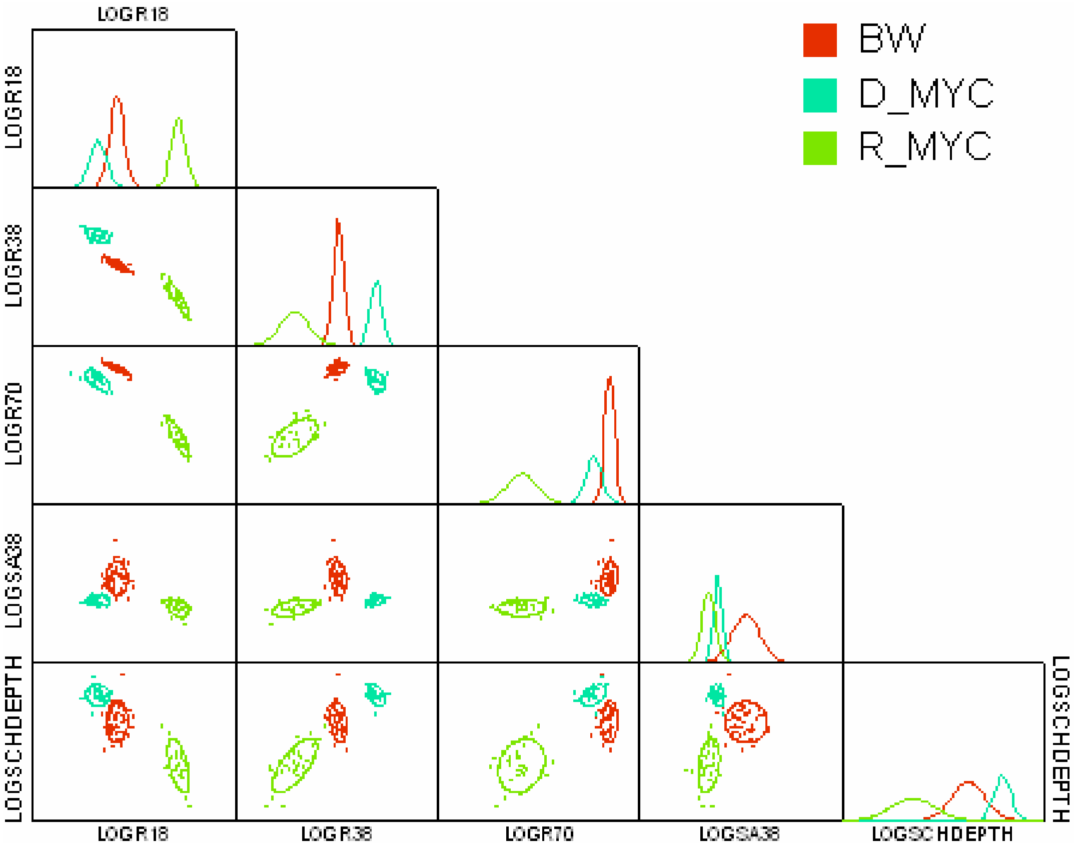

Figure 13. Plots of independent variables with within-group bivariate confidence elipses and normal curves.

Analysing the contribution of independent variables to the discriminant model showed that the r(18) and r(70) were most importance variables included. At step 1, logr(18) was entered into the model based on its contribution to discriminatory power of the model (Wilks' lambda=0.006; F=23.82; p<0.001). At step 2, logr(70) was entered into the model since it contributed most to the discriminatory power (Wilks' lambda=0.008; F=48.09; p<0.001). The last variable entered into the model was logs_schooldepth. It was least helpful variable for distinguishing among species (Appendix 30). The first canonical variable is linear combination of variables, which illustrated the best discrimination among the groups. The first eigenvalue was relatively high (22.46) compared to the second (7.50) indicating that the first canonical variable contributed most to the difference among groups. The canonical correlations were 0.98 and 0.94 for the first function and second function, respectively. Chi square test showed a significant statistic with p-level <0.001 (Appendix 34).

Two discriminant functions were obtained from three species groups taken into account. The coefficients of canonical discriminant function are listed in Appendix 35. The canonical score plot is graphically presented in Figure 14. It can be seen from the figure that the score clouds of BW, R_MYC and D_MYC are separately distributed. The centroid for BW, D_MYC and R_MYC are (-2.57; -2.73), (6.79 0.55) and (-4.21; 4.00), respectively.

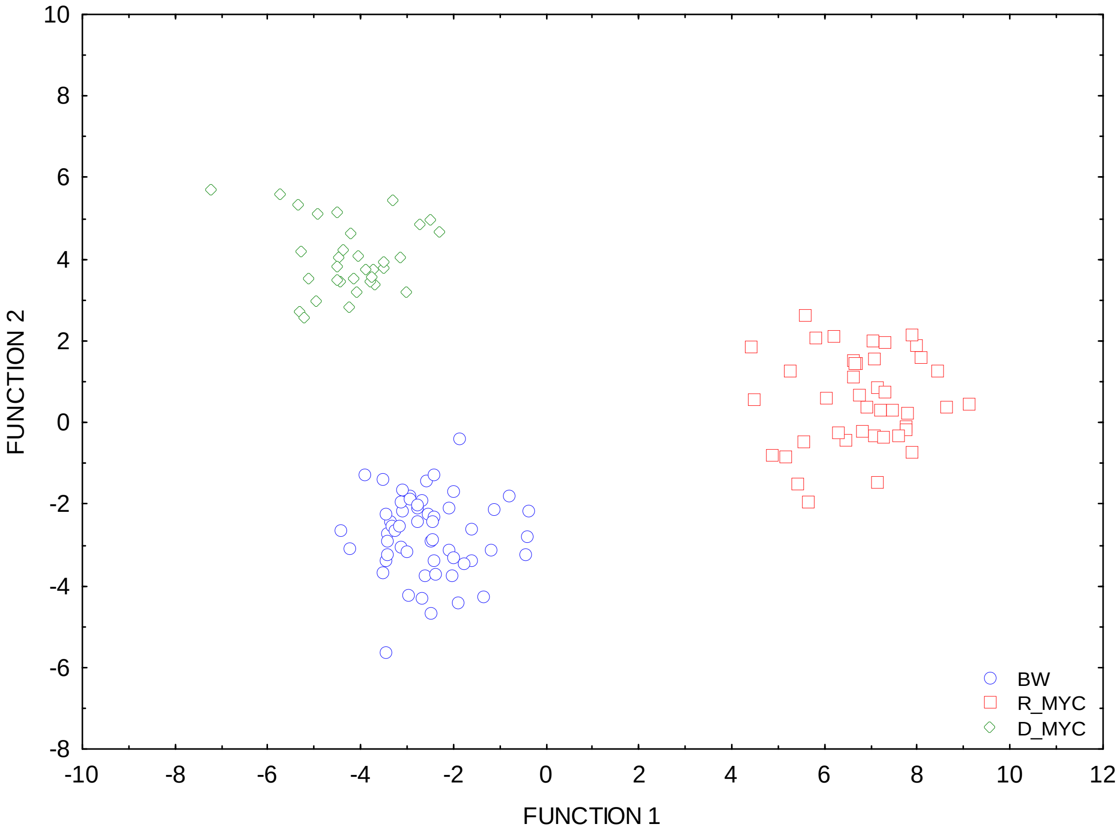

Figure 14. Plotted canonical scores for blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC). Logr(18), logr(38), logr(70), logsA(38) and logschooldepth were independent variables.

When the less important variables are excluded from the model and then only use r(18) and r(70) and sA38, the model still worked well. The F-test for the overall discriminant model showed a significant statistic probability (Wilks's lamda = 0.006; F = 493.72 and p<0.001). BW, R_MYC and D_MYC were completely separated with 100% classification success (Appendix 39). The first eigenvalue was 21.27 and the second was 6.19 with Wilks' lamba is 0.01 and 0.14, respectively, indicating the differences between species came from the first canonical variable. Chi square test with success roots removed from the model is shown in Appendix 41. The canonical correlation were 0.98 and 0.93 for the first and second variable, respectively. Plot of canonical score is shown in Figure 15. The centroid for BW is (2.61; -2.44), for D_MYC is (-6.63; 0.41) and for R_MYC is (3.92; 3.7). The canonical function components are illustrated in Appendix 39.

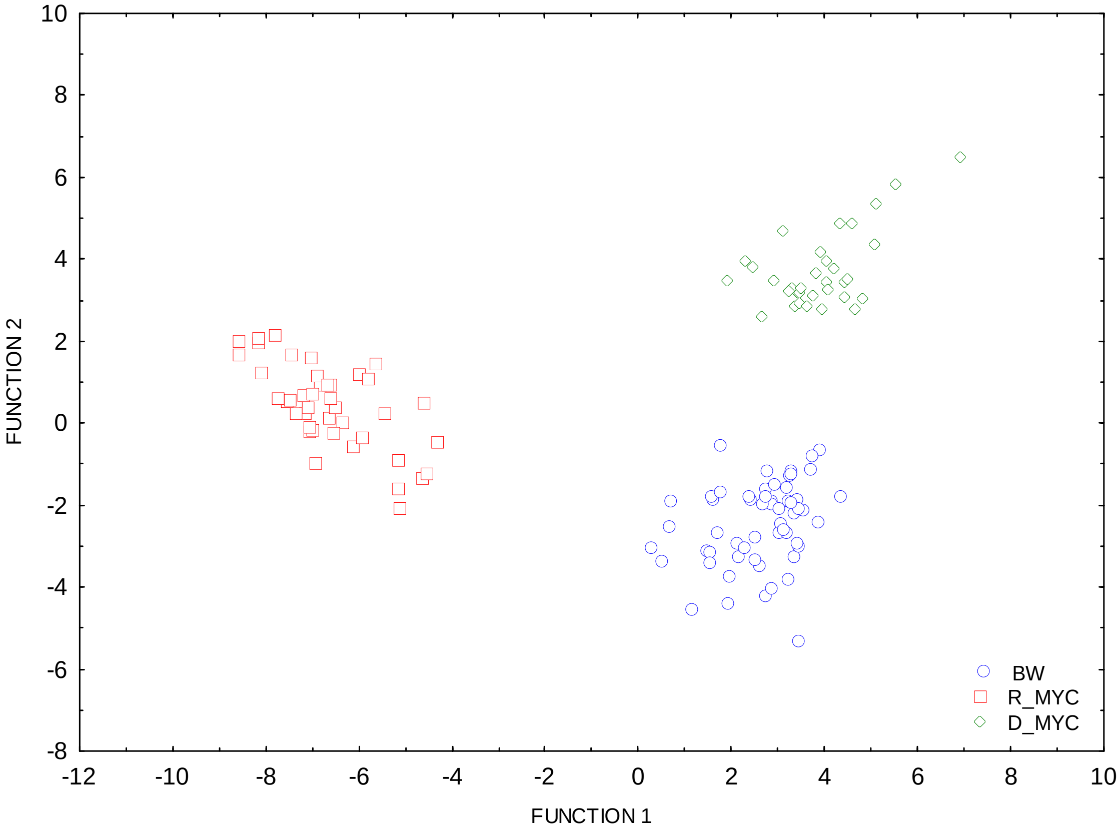

Figure 15. Plotted canonical scores for blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC). Only logarithm of r(18), r(70) and sA(38) were used in discriminant model.

3.4.2. Classification tree

An alternative approach tried for separating BW, R_MYC and D_MYC was the classification tree analysis. The logarithm of r(18), r(38), r(70), school depth and s_A38 were used as independent variables. The results showed that only r(18) and r(38) were needed in the model. BW could be separated from R_MYC using r(18). The r(38) was used to distinguish between BW and D_MYC. The model showed that if logarithm of r(18) is greater than -0.59, species is R_MYC. If logarithm of r(18) is less than -0.59 and logarithm of r(38) is greater than -1.09, it is D_MYC, otherwise, it is BW. The classification tree for identification of echo trace of BW, R_MYC and D_MYC is shown in Figure 16.

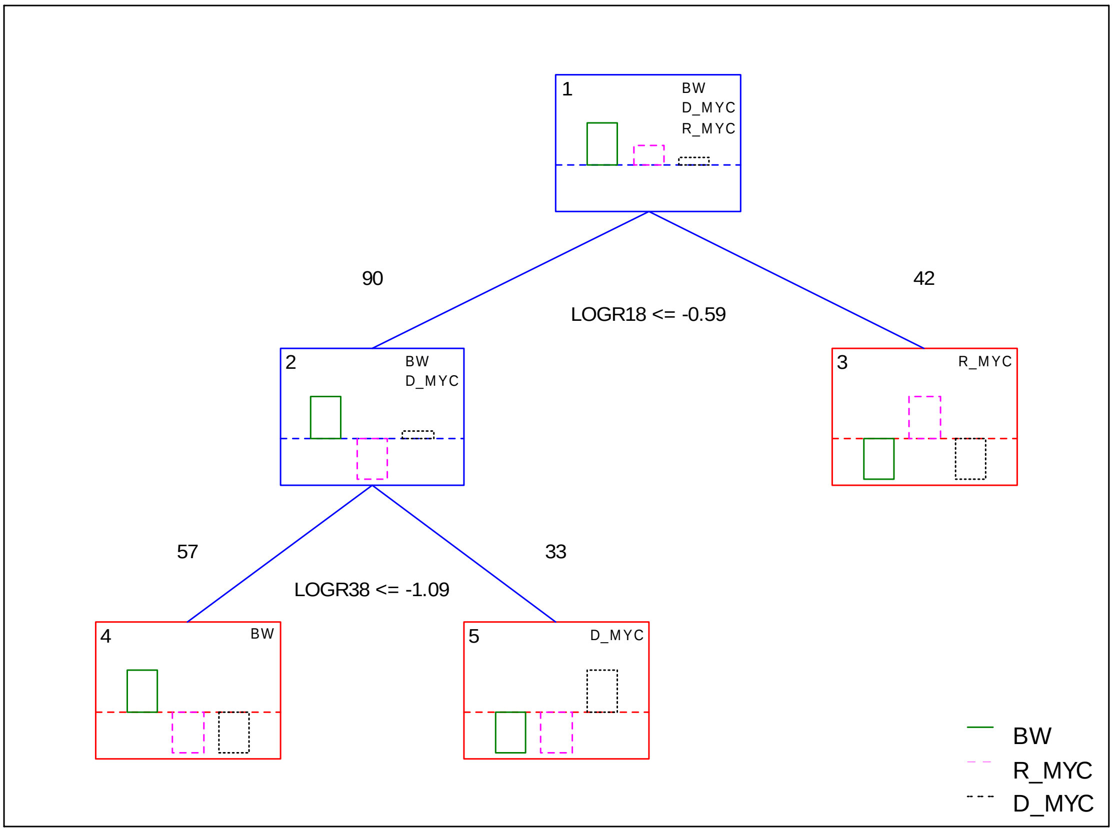

Figure 16. Classification tree for separating blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC). LOGR18 denote the logarithm of frequency response at 18 kHz and LOGR38 is logarithm of frequency response at 38 kHz.

3.5. Biomass estimation for blue whiting

Blue whiting were recorded in most of the surveyed area during the survey in 2005. However, the densities were different among strata (Appendix 44). Globally, density of blue whiting was estimated to be 23.6 tonnes/nmi^2 in 2005 and 26.4 tonnes/nmi^2 in 2006. The change in blue whiting density between 2005 and 2006 was 11.8%. Total area was taken into account to be 75,899 square nautical miles and the estimated total biomass was about 1.8 million tonnes, representing an abundance of approximately 20 thousand million individuals. The stock was dominated by the fish in the length group 20-30 cm (88.5% of total biomass), whereas the older fish (length ≥ 30 cm) contributed about 11.2 % to the total stock biomass and younger fish (length < 20 cm) contributed only 0.3 % (Table 7).

In 2006, due to the failure in retrieving some data from stored tapes thus we only estimated biomass for the areas where the data were available. Total area used in biomass estimates was 38,131 square nautical miles, limited from latitude 53°00 north to 58°00 north (Appendix 43). The estimated biomass was about 1.0 million tonnes with an abundance of 11 thousand million individuals. Blue whiting in the length range 20-30 cm contributing 84.0% to the total stock biomass. The proportions of both younger and older fish in the stock were higher compared to that in 2005 (Table 7). Biomass and abundance of blue whiting for each length class are graphically plotted in Appendix 42.

Table 7. Estimated abundance (10^6 individuals) and biomass (10^3 tonnes) for blue whiting in 2005 and 2006.

	Length group (cm)	2005	2006
Biomass (thousand tonnes)	<20	6 (0.3)[*]	4 (0.4)
	≥20 and < 30	1,587 (88.5)	844 (84.0)
	≥30	200 (11.2)	157 (15.6)
	Total	1,794	1,005
Numbers (10^6 individuals)	<20	252 (1.2)	213 (1.9)
	≥20 and <30	18,893 (92.2)	9,740 (88.7)
	≥30	1,337 (6.5)	1,029 (9.4)
	Total	20,482	10,982
Survey area (nmi^2)		75,899	38,131

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[*] Numbers in the bracket indicate percentage of total

4. DISCUSSION

4.1. Target strength

Target strength is defined as the backscattering cross section, which is the amount of energy reflected backward the sound source when having hit a single target (Gunderson 1993; Simmonds and MacLennan 2005). It is a key parameter for converting the echo energy to fish quantity (Foote 1987). Target strength can be measured by several methods such as: immobile fish, live fish in cages, wild fish and modelling (Simmonds and MacLennan 2005).

The spring spawning stock of blue whiting is monitored annually, the relationship between target strength and fish length at 38 kHz frequency applied in the acoustic survey as reported by Monstad (1992) cited in Simmond and MacLennan (2005) has a form of

$$TS = 21.8 \log L - 72.8 \text{ dB}$$

Robinson (1982) conducted *in situ* target strength experiment for blue whiting using 29.4 kHz frequency, but the transducer was mounted on the hull. The b_{20} was estimated to be -71.9 dB for the fish length from 21 to 37cm with a mean length of 31.1cm. Simmonds and MacLennan (2005) summarized the target strength of several species measured by various techniques. It was shown that the target strength of blue whiting is quite low compared to that of other species in the cod family. However, in this study, target strength of blue whiting measured by the TS probe technique during the spring spawning season 2006 was high. For the fish with mean lengths in the range from 23 to 27 cm, the b_{20} value was estimated to be from -65 to -63 dB at 38 kHz. The pooled data for all measurements at 38 kHz gave a b_{20}-value of -64.2 dB for fish with a mean length of 26 cm.

The target strength of fish depends on many factors. Calibration of the equipment was known as stochastic variable and greatest source of error. It directly influences the accuracy of measurements. Since the recent development of techniques, the errors from the calibration can be better controlled (Foote *et al.* 1987; Simmonds and MacLennan 2005). A proper calibration deployed with the standard reference target technique (Foote *et al.* 1987) practically removes this source of error (Aglen 1994).

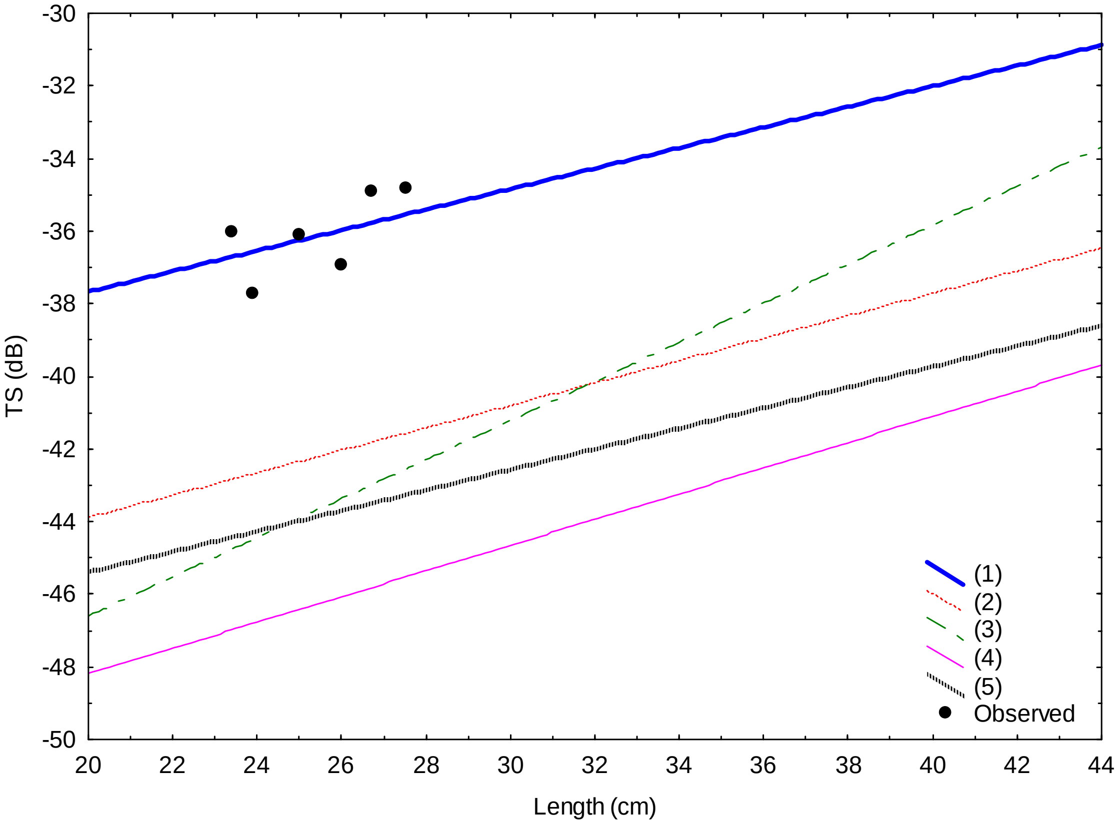

Figure 17. Variation of target strength with fish length. Dots are the mean target strength of blue whiting at measured stations, (1) TS = 20logL-64.2 (this study). Collected results from other experiments: (2) TS-Length relationship as use regularly in biomass estimation for blue whiting (TS=21.8logL-72.8; Anon 1982), (3) TS=38logL-97; modeled by Dunford and Macaulay (2006) using swimbladder modeling; (4) TS=25.05logL-81.35; estimated by McClatchie *et al* (1998) and (5) TS=20logL-71.9; measured in situ by Robinson (1982). (3) and (4) are of southern blue whiting. (5) is at 29.4 kHz and others are at 38 kHz.

Published research articles show that the target strength of some physostome fish species are dependent on depth (Francis and Foote 2003; Ona 2003; Gorska and Ona 2003a; Gorska and Ona 2003b; Simmonds and MacLennan 2005), because swimbladder volume of fish is decreasing with increasing of depth (Francis and Foote 2003). The swim bladder accounts for 90-95% of total reflected energy from a fish (Foote 1980), illustrating that the bigger the swim bladder volume the higher is the target strength of fish. However, blue whiting is a physoclist species, possess a closed swimbladder thus the swimbladder volume may not be changed very much with depth. The relationship between target strength and depth was not clearly seen. As addressed in Figure 18, TS fluctuated, it showed both increasing and decreasing trends at depth. The swim bladder volume is also dependent on fat contents (Jacobsen *et al.* 2002) and size of the gonads (Ona *et al.* 2001). Jacobsen *et al.* (2002) conducted experiments on the effect of seasonal variation in fat content of blue whiting versus the acoustic conversion factor. He concluded that fat content of fish affects its target strength. Fat content of blue whiting varies significantly during the year, being at a minimum in April/May and at a maximum in August. The in situ target strength measurements of blue whiting were conducted during March/April. During this time, the fat content is low thus it may result in higher estimates of target strength.

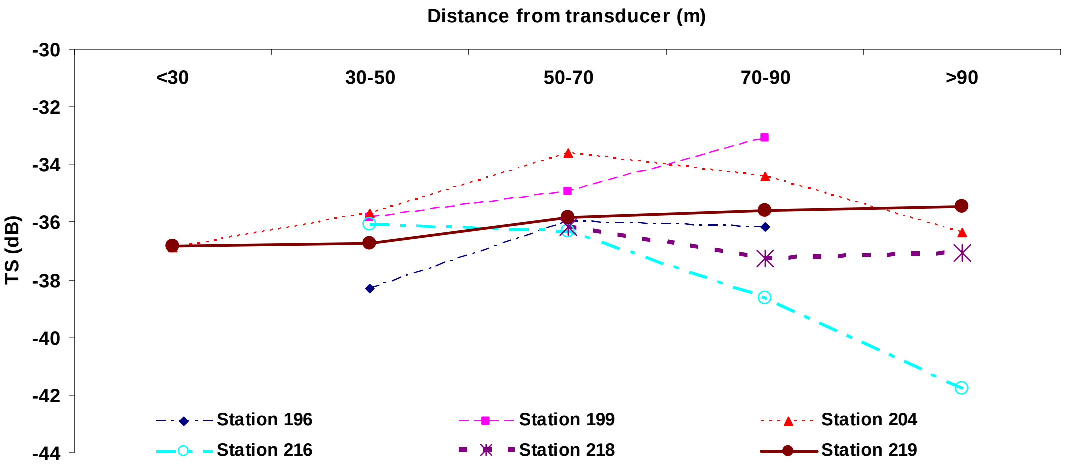

Figure 18. Plots target strength (dB) of blue whiting at stations against the distance from transducer (m).

Behavioural patterns of fish are important factors when performing target strength measurements. During the daytime, fish is normally aggregated at higher densities while they are sparsely distributed in the evening (Hjellvik *et al.* 2004). Johnsen and Godø (2007) analysed the diel variations in acoustic registrations of blue whiting and they found that there was a significant variation in distribution of fish. Blue whiting distributes in the deeper water column during the daytime but in the shallower at night. The tilt angle expresses the orientation of fish related to observing transducer. It is variable with swimming directions of fish and is considered as a potential factor affecting the mean TS. Both the mean value and spread of the tilt angle distribution are important. If the standard deviation of the tilt angle distribution is small during daytime, the mean TS will be high. A representative mean TS for the survey showed contain data from both day and night since the survey is conducted continuously. When observing the dorsal aspect target strength, the tilt angle needs to be carefully measured. Love

(1971) analysed dorsal aspect target strength of an individual fish of eight different species at various frequencies and he found that the TS of fish is variation with the L/λ ratio. Huse and Ona (1996) conducted experiments on the tilt angle distribution and swimming speed of overwintering Norwegian spring spawning herring, the results showed that the swimming angle is closed to horizontal during the day while in the evening, it is positive with tilt angles up to 40^o. It is known that the TS of fish is highest when the tilt angle closes to 0^o horizontally and lower when the tilt angle increase either positively or negatively (Nakken and Olsen 1977). The mean TS of blue whiting was estimated to be - 35.7 dB and the b_{20} was - 64.2 dB. This is relatively high compared with others reported (Robinson 1982; Monstad 1992 cited in Simmonds and MacLennan 2005) and also higher than that of other species with similar morphology and behaviour as the southern blue whiting (McClatchie *et al.* 1998; Dunford and Macaulay 2006). The high TS may likely be explained by the time of experiments. All the TS measurements of blue whiting were conducted daytime, no experiment was conducted at night, thus the estimated results probably do not reflect adequately the overall TS. It is evidently believed that the TS of fish measured during the day is 2-3 dB higher than that if conducted at night (Foote 1987).

Analysis of echograms collected during the target strength measurements showed that the distributions of blue whiting were dense at station 204, 199 and scattered at other stations. Average number of fish per sampled volume is shown in Table 8. It is known that if the fish is densely aggregated, the single detection may fail and multi targets can be accepted as single detections (Ona 1999; Simmonds and MacLennan 2005). The highest density was observed at station 204 with 846 individuals/10^6m^3 corresponding to 0.05 fish per pulse volume. This corresponds to probability of multi target detections of 5%. At station 199, fish was also densely distributed, approximately 343 individuals/10^6m^3. The mean backscattering cross section of 38 kHz was highest at station 204 (4.80±0.05 cm^2) and 199 (4.70 ±0.03 cm^2) (Appendix 12), probably because of multi targets were eroded as one. The sizes of fish in these stations were also larger than at other stations. The lowest mean backscattering was observed at station 216, 2.47±0.03cm^2 at 38 kHz for a mean fish length of 23.9 cm. On the contrary, for 120 kHz, the mean backscattering cross section was highest at station 216 and slightly lower at other stations.

Table 8. Mean area backscattering coefficient (s_A, m^2/nmi^2), average number of fish per m^3 and per sampled volume at different stations conducted during the blue whiting survey in 2006 using TS probe.

Station	s_A (m^2/nm^2)	Density (fish/$10^6 m^3$)	Pulse volume (m^3)	Density (fish/pulse volume)	p*
196	44	98.6	61.7	0.006	<0.01
199	173	342.7	64.3	0.022	<0.02
204	724	864.5	64.2	0.055	<0.05
216	35	92.2	64.0	0.006	<0.01
218	7	17.9	70.0	0.001	<0.01
219	53	80.9	57.8	0.005	<0.01

Biological sampling can introduce possible errors of in situ target strength measurements. It is difficult to sample exactly the fish registration in the echogram when trawling because of fish movement, avoidance of fish to the sound sources (Aglen 1994; McClatchie *et al.* 2000) as well as gear selectivity and catching efficiency (Engas and Godo 1989; Gunderson 1993; Fraser *et al.* 2007). Actually, the research vessel like G.O. Sars is not quite silent as it was supposed to be (Ona *et al.* 2007). The size of fish reflects different escapement ability themselves. Small fish can escape via the mesh of the net while big sized fish can escape by swimming toward the net mouth (Gunderson 1993). Length frequency distribution of blue whiting sampled at TS measurement stations showed that most of fish observed had lengths in the range 17-31 cm, however, some variability were observed among stations. The length frequency distribution of fish corresponded to the target strength measurements are presented in Appendix 19 with the fairly narrow length distribution seen, the error from samples are assumed to be low.

4.2. Frequency response

Echograms express acoustic data that are arranged as vertical and horizontal reflections of the water column. Fish schools are acoustically detected as echo-traces which provide a variety of descriptive features such as height, length, position and shape (Reid

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* Probability of more than one target in the pulse volume of the mean density, random distribution is assumed, as summarized in Ona (1999).

2000). Generally, reflective ability of targets is different between species and frequency used. Fish that posses a gar filled swim bladder have higher acoustic reflection properties compared to that of fish without swim bladder and other biological objects such as plankton and fluid-like objects (Simmonds and MacLennan 2005). When the transducers operate, not only echoes of fish are recorded but also scattering from other targets than fish. Thus, it is difficult to discriminate exactly among species especially for species with swimbladder mixing registrations. The use of multi frequencies in acoustic surveys can therefore improve the accuracy of the scrutinizing process, especially if the acoustic properties of a certain species vary with the frequency in use (Madureira et al. 1993). The multi frequencies method has been used since early 1970's to describe the low frequency resonant structure in echoes from schooled pelagic fish (Holliday 1972). The author also concluded that the method could be used for the remote identification of fish by providing a tool for establishing the presence of a swim bladder. Recently, multi frequencies method has been widely used to estimate biomass and abundance of zooplankton (Pieper *et al.* 1990), discriminate fish and plankton (Kang *et al.* 2002; McKelvey and Christopher 2006), distinguish between fish groups (Kloser *et al.* 2002; Korneliussen and Ona 2002; Fernandes and Stewart 2004; Logerwell and Wilson 2004; Jech and Michaels 2006).

It is known that the reflective ability of fish to the sound of different frequencies can be expressed by frequency response. Korneliussen and Ona *(*2003*)* developed an approach for multi frequency based analysis of the relative frequency response. The categorisation process was also simplified and made the results more reliable and efficient.

In this study, frequency response, r(f), of blue whiting (BW) and myctophid groups were analysed using the mean area backscattering coefficient of 18, 38 and 70 kHz. The other operating frequencies were not used because of limitation on their detectable depth. The r(f) of BW were analysed in three steps. First, the r(f) was estimated for the trawl-polygon. Then, we estimated r(f) for the pure concentration layers of BW outside the trawl-polygons. At last, r(f) of all BW schools found along the survey transects having good quality echograms were isolated, scrutinised and analysed.

There was no significant difference between r(f) of BW in the trawl-polygon and those outside the trawl-polygon (Man-Whiney, $p>0.05$, Appendix 22). However, it seemed like that the r(f) at 70 kHz of the area outside the trawl-polygon is slightly lower compared to that of the trawl-polygon. Whereas, at 38 kHz, the r(f) outside the trawl-polygon is slightly higher than that of the trawl-polygon. This may be explained by the species registration in the echograms where the trawl-polygons were constructed. Practically, only clean echograms of BW were used to construct the trawl-polygons. However, there still some other species within the trawl-polygon (Appendix 7) which could introduce errors to the interpretations. Therefore, r(f) could be lower or higher depending on which species were mixed with BW within the trawl-polygons. Moreover, myctophid schools are distributed close to the BW school so that when a trawl sampling was taken without myctophids in the catches that does not mean that myctophids were absent. Myctophids are small sized fish compared to BW and may easily escape via the mesh during trawling because of gear selectivity. For the area outside the trawl-polygon, only the pure layers of BW were scrutinised and taken into account. Thus, the r(f) may be more accurate compared to that of the trawl-polygon.

During the surveys, myctophids were not identified separately by trawl. This created some problems for the interpretations. Myctophids were pooled into two groups namely resonant myctophids (R_MYC) and deep myctophids (D_MYC) during scrutinizing. Mann-Whitney U test for the mean r(f) of the trawl-polygons at frequencies between R_MYC and D_MYC showed differences at 18 kHz ($p=0.04$) and at 38 kHz ($p=0.04$), but at 70 kHz, there was no significant difference ($p>0.05$). The problems concerned with the comparison of r(f) between R_MYC and D_MYC were the sample size. Only 5 trawl-polygons of R_MYC and 6 trawl-polygons of D_MYC were constructed so that the estimated mean values were very much variable (Appendix 21).

Graphically, the r(f) of BW, R_MYC and D_MYC were totally different (Figure 12). The r(f) of R_MYC were relatively high at 18 kHz and dropped sharply at higher frequencies. Whereas, the r(f) of D_MYC had a peak at 38 kHz and lower at 18 and 70 kHz. While the r(f) of BW was high at 18 kHz, it dropped at 38 kHz and then slightly increased at 70 kHz. It is believed that r(f) could be used for separating BW from myctophid targets.

The data collection for r(f) analysis strictly requires the arrangement of equipment. For collection of multi frequency acoustic data, it is suggested that the percentage vertical overlap *(pvo)* between the frequencies using similar pulse lengths should be greater than

85% (Korneliussen *et al.* 2008) and the percentage horizontal overlap *(pho)* requirement for combining acoustic multi frequency is over 90%. Thus, since 2003 position of the transducers mounted on drop keel of R/V G. O. Sars has been closely rearranged to minimize the horizontal offset due to the distance between the transducers and ensure the reflected echograms are the same in the sampled water volume.

During the spring spawning blue whiting surveys, the length of BW was in the range from 14 to 39 cm in 2005 and 15 to 42 cm in 2006. However, at stations which were taken into analysis of r(f), the length of fish was not very much variable. The mean lengths of fish at stations were almost from 26 to 28 cm (Appendix 9). The length frequencies of fish corresponding to the trawl-polygon are shown in Appendix 27. A regression analysis of r(f) and length of fish was performed, the results showed no correlations. The r(f) varied very much with lengths of fish and also within a certain length group. Gorska *et al.* (2007) studied on acoustic backscattering of adult Atlantic mackerel. They found that the relative frequency response of fishes with the length from 28-42 cm was highly variable. Less variability is expected for fish with swimbladder.

The differences of r(f) at a given frequency between BW, R_MYC and D_MYC could be explained by the swimbladder morphology and size of fish. Myctophids have various types of swimbladder. Some species are characterized by inflated swimbladder having a strong backscatter strength while other species with atrophied or fat-filled swimbladder and weak backscatter strength (Brodeur and Yamamura 2005). The target strength measurements of BW showed that their TS were high, range from -38 to - 35 dB for the fish length from 24 to 28 cm (this study). Myctophids are small sized fishes, most species have total length around 10 cm or less. Yasuma *et al.* (2003) measured target strength of some myctophid species based on swimbladder morphology. The results showed that the TS were below -60 dB. This is very low compared to that of BW.

Myctophidae is the most abundant family in terms of number and biomass (Brodeur and Yamamura 2005). There were more than two-hundred species reported (Stiassny 1997). The swimbladder morphology is different between species, affecting differences in reflected echo strength. It is recommended that species composition should be separately identified to confirm species allocation when scrutinizing echograms.

4.3. Discriminant analysis and classification tree

Discriminating species registered in echograms is a difficult task due to the influence by many factors. Traditionally, identification and interpretation of acoustic targets needed to combine knowledge on distribution and behavior patterns of targeted species with a confirmation by trawl sampling. In the blue whiting surveys, trawl sampling was regularly carried out to identify echograms registration of blue whiting and for biological sampling of the fish. Myctophids were not targeted species, hence, biological data of myctophids were not sampled.

Two approaches were employed in this study to differentiate between BW, R_MYC and D_MYC. Both discriminant function analysis and classification tree were successfully used to separate between species with 100% classification success. All 57 BW schools were completely distinguished from 33 R_MYC schools and 42 D_MYC schools (Appendix 33). The r(18) and r(70) were the important variables contributing to the discriminant model. In contrast, the classification tree only uses r(18) and r(38) to separate between species. Backscattering coefficient at 38 kHz (s_A38) was an essential variable as well in discriminant function model. When excluding two less important variables r(38) and school-depth and using r(18), r(70) and $s_A(38)$ as independent variables for discriminant analysis, the classification success were also high (Appendix 39).

In the classification tree approach, by accepting or rejecting the amplitude of r(f), the tree for BW, R_MYC and D_MYC were created with a relatively high accuracy. It is believed that success in classification between species depends very much on chosen independent variables to be taken into account. Lawson *et al.* (2001) used acoustic descriptors and ancillary information for discriminant analysis of anchovy, sardine and round herring in South African continental shelf. They concluded that 88.3% of known species composition schools could be categorized correctly to species, school-depth and acoustic energy were the most contributed variables. Haralabous and Georgakarakos (1996) used the main school descriptors interpreted from acoustic data of 120 kHz frequency as independent variables to distinguish between anchovy, horse mackerel and sardine, the results showed that classification success was from 75% to 96%. Horne (2000) reviewed acoustic approaches to identify species and he stated that the discriminant function analysis success was from 41% to 96%.

In this study, the school depth is not important variable in both discriminant function analysis and classification tree. Since the frequency response of BW and myctohphids are absolutely different, therefore by using only the frequency response as independent variables, we can successfully separate between species.

As mentioned in previous sections, BW, R_MYC and D_MYC are different in size, shapes and morphological characteristics that produce differences in backscattering level. It is known that small fish with swim bladder has a stronger backscatter at 18 kHz relative to 38 kHz compared to that of bigger fish (Anon 2006). BW is bigger than myctophids in size, however, the mean r(18) of R_MYC was very much higher compared to that of BW (Table 5). Myctophids consist of different species, some species bear an inflated swimbladder while others are characterized with an atrophied swimbladder or even absent swimbladder (Brodeur and Yamamura 2005). Therefore, backscattering amplitude of myctophids is highly variable between species. In this study, two myctophid groups appeared with different trends in r(f) and also different to that of BW. In addition, vertical distribution is different between species. By analyzing echograms, we found that BW was distributed deeper than R_MYC, D_MYC appeared below the BW layer. Summarizing the min depth and max depth of each species group are indicated in Appendix 24. It was evident from echogram analyzed that myctophid species were scatteredly distributed whereas BW was observed in dense schools. Visually, this information could support the scrutinizing process, especially for identification echograms that had not been confirmed by trawl samples.

Discriminating between species recorded in echograms using r(f) has been applied in recent years. However, it become more reliable and efficiency method. We claim that the use of r(f) as independent variable in the discriminant function analysis or the classification tree successfully performed when distinguishing between BW, R_MYC and D_MYC.

4.4. Biomass estimation

Acoustic method has long been used to investigate the distribution and abundance of fish populations. Accompanied with trawl sampling, this method provides accurate results with high resolution for species of interest within the surveyed area. The spring spawning blue whiting has been acoustically investigated annually with aim to monitor trends in stock abundance. The survey design covered completely the known spawning ground of the species with systematic parallel transects. It is evidently believed that this design diminishes the bias from spatial distribution giving the most precise estimates (Simmonds and Fryer 1996).

The potential errors in acoustic estimation of fish abundance were reviewed by Foote and Stefansson (1993), Aglen (1994) and Toresen et al (1998) and can be classified into two main categories. The first source of errors with regarding to the estimate include spatial sampling, species allocation of acoustic data, fish behaviours and the second source of errors is from technical aspects such as equipment, transmission of the sound and the target strength.

In this study, biomass of blue whiting was estimated for each stratum of 1^o longitude and 1^o latitude applying the elementary distance sampling unit of 1.0 nautical mile. Problems concerned with the estimation were the biological data. Practically, trawl sampling was conducted regularly. However, it was impossible to cover all strata of interest. In case the stratum was not biologically sampled, data from the adjacent strata were used instead. Furthermore, the size of fish may be different for each region. As discussed by Simmonds and MacLennan (2005) on the selection of homogeneous regions in acoustical spatial analysis, population structure is an important variable to consider. Small fish tend to inhabit shallow water and close to the shore while the bigger fish is distributed deeper. Thus, applying the size distribution sampled from a particular stratum to others is not favourable and will probably be biased. Ground-truth using trawl is a potential source of errors in acoustic estimation of fish abundance. Since scrutinizing echograms depend on species composition and allocation of acoustic energy to species by size class, it can be biased. Samples from trawl do not usually reflect adequately the populations in the sea. Fish in different size classes may reflect differences in vulnerability and selectivity to the gear (Gunderson 1993). Small fish can escape via the mesh while bigger fish can escape by swimming in front of the net mouth. Therefore the sampled size or age distribution of fish may deviate from the actual size distribution of the population.

Schooling behaviours of fish influences the accuracy of acoustic biomass estimation. Theoretically, there is a linear relation between the acoustic energy and density of fish. However, when the fish aggregation are very dense, the acoustic backscattering coefficient is no longer proportional to fish density but rather too low (Toresen 1991; Furusawa *et al.* 1992; Zhao and Ona 2003) due to acoustic extinction. The biomass is probably underestimated. On the other hand, only a few elementary distance sampling unit (NASC) for the blue whiting survey are very dense. In this case, correction for extinction is necessary performed.

Target strength is a stochastic variable (Foote 1987; Simmonds and MacLennan 2005). It may directly influence the biomass estimate. In this study, target strength of blue whiting obtained from TS probe measurements in 2006 was used to convert acoustic energy to fish density. It is evidently believed that the target strength employed was very high compared to the one used regularly in blue whiting surveys. The catabolism and anabolism coefficients in the length – weight relationship equation applied to convert the fish abundance to biomass were estimated by combining all the length-weight data from 2005 and 2006. Results showed that the estimated stock size was lower compared to that reported by Heino *et al* (2006). However, it could be explained by applying different target strength and also the differences in area estimates. As reported by Heino e*t al* (2006), blue whiting surveys were cooperatively investigated by several countries sharing the stock. The investigated area was widely covered compared to that of this study using only data conducted by G.O.Sars research vessel. Heino *et al.* (2005; 2006) estimated biomass for 2005 and 2006 to be 8.0 and 10.4 million tonnes for an area of 172000 and 170000 square nautical miles, respectively (Table 9). The change in total biomass of blue whiting between 2005 and 2006 was +30% of which the change in mature stock was +36%. The difference in the investigated area between the two years was -1%. It is said that the blue whiting stock was increased and population was maintained in an acceptable situation

Table 9. Estimated stock size of blue whiting during spring spawning blue whiting survey in 2004, 2005 and 2006 as reported by Heino et al 2006.

		2004	2005	2006	Change from 2005 (%)
Biomass (mill.tonnes)	Total	11.4	8.0	10.4	+30
	Mature	10.9	7.6	10.3	+36
Number (10^9)	Total	137	90	108	+20
	Mature	128	83	105	+27
Survey area (nmi^2)		149,000	172,000	170,000	-1

It is believed that biomass estimates from acoustic surveys provide relative indices of the spawning stock. The absolute values may be higher or lower depending on many factors, especially the target strength of fish used in the estimation and the experience of person who participate in the scrutinizing work. However, from relative indices of investigated fish stock, we can monitor the changes of its population size and therefore give an appropriate strategy on how to secure the stock to remain at a sustainable level.

5. CONCLUSION REMARKS

Mean target strengths of blue whiting were estimated to be from -37 to -34 dB for 38 kHz and from -39 to -38 dB for 120 kHz. The global mean target strengths were -35.7 dB and -38.5 dB for 38 kHz and 120 kHz, respectively. The relationship between target strength and length of fish had a form: $TS=20\log(L)-64.2$; $L=26.0$cm. A relationship between target strength and depth was not clearly seen.

There was no difference between the frequency responses of blue whiting in the trawl-polygon and in the area outside the trawl-polygon ($p>>0.05$).

There were significant differences between frequency responses of blue whiting, deep myctophids and resonant myctophids ($p<0.05$). Frequency response of blue whiting was highest at 18 kHz, dropped down at 38 kHz and slightly increased to 70 kHz. For resonant myctophids, frequency response was highest at 18 kHz, dramatically decreased at higher frequencies and had its minimum value at 70 kHz. Frequency response of deep myctophids was low at 18 kHz, increased a peak at 38 kHz and dropped at 70 kHz.

Frequency responses at 18 kHz, 38 kHz, 70 kHz with the addition variables of $s_A(38)$ and school depth were successfully used in both discriminant function analysis and classification tree to distinguish blue whiting from myctophid targets. r(18), (70) and $s_A(38)$ were the most important variables in the discriminant function analysis while r(18) and r(38) were the most powerful variables in the classification tree.

Biomass of blue whiting was estimated approximately 1.8 million tonnes in 2005, for an area of 75899 square nautical miles, representing an abundance of about 20 thousand million individuals. In 2006, the biomass was about 1.0 million tonnes with an abundance of 11 thousand million individuals for an area of 38131 square nautical miles. Both estimates were done with the new TS obtained here.

Globally, the density of blue whiting was estimated to be 23.6 tonnes/nmi^2 during the survey in 2005. In the 2006 survey, the density increased about 11.8%, to be 26.4 tonnes/nmi^2. It is said in the survey reports and in this assessment that the blue whiting stock was in an acceptable situation.

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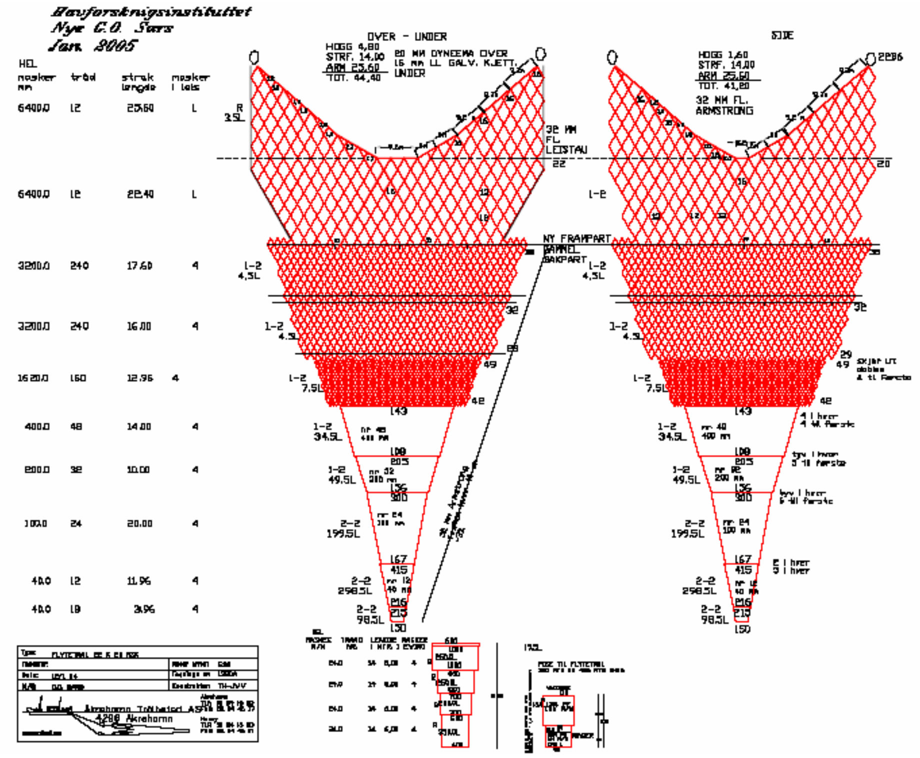
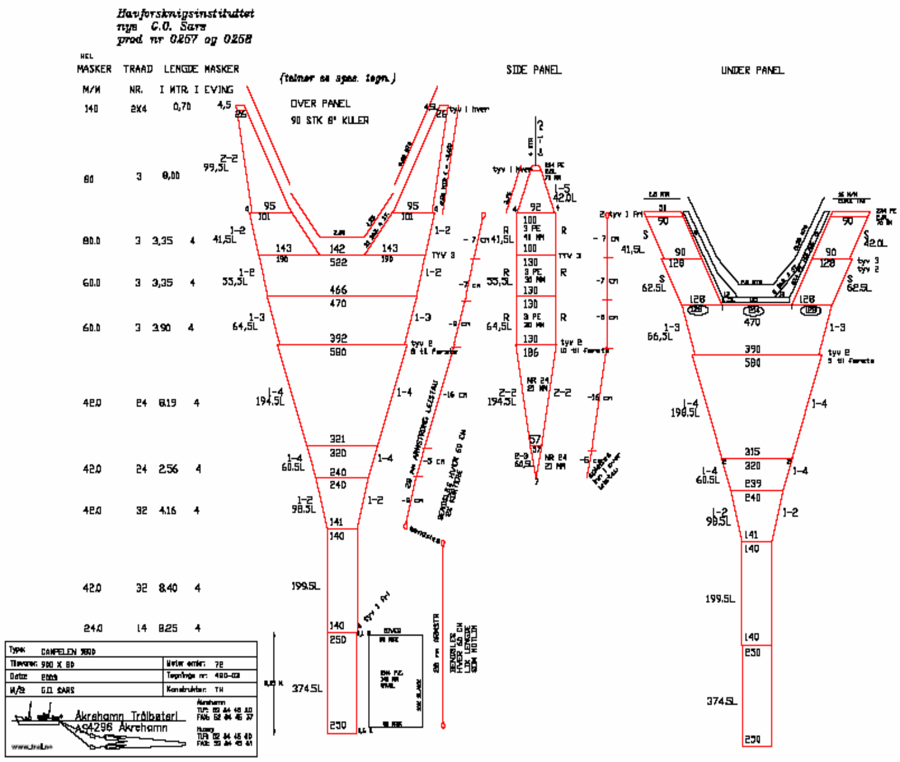
APPENDICES

Appendix 1. The designs of trawl used during the surveys of blue whiting. (A) pelagic trawl – Åkra trawl and (B) bottom trawl – Camplene 1800

(A)



(B)



Appendix 2. Instrument technical specification, parameter settings and calibration results used during blue whiting survey in 2005 and 2006. The calibration was done on October 27, 2007.

SIMRAD EK 60	18 kHz	38 kHz	70 kHz	120 kHz	200 kHz
Transceiver menu: Permanent settings					
Transducer type	ES18-11	ES38	ES70-7C	ES120-7C	ES200-7C
Absorption coefficient (dB/km)	2.20	8.32	20.70	36.46	53.0
Pulse duration (m/s)	1.024	1.024	1.024	1.024	1.024
Bandwidth (kHz)	1.574	2.43	2.86	3.03	3.09
Transducer gain (dB)	22.43	25.68	26.69	26.63	26.87
sA correction (dB)	-0.61	-0.65	-0.32	-0.33	-0.28
Maximum transmitting power (W)	2000	2000	800	250	150
Sound velocity (m/s)	1498.8	1498.8	1498.8	1498.8	1498.8
Two way beam angle (dB)	-17.30	-20.8	-20.6	-21.0	-20.5
Alongship angle sensitivity	13.90	21.9	23.0	23.0	23.00
Athwardship angle sensitivity	13.90	21.9	23.0	23.0	23.00
Alongship 3 dB beamwidth (degree)	10.67	6.96	6.49	6.49	6.35
Athwardship 3 dB beamwidth (degree)	10.50	7.02	6.56	6.42	6.39
Alongship offset angle (degree)	-0.09	-0.14	-0.03	-0.14	-0.27
Athwardship offset angle (degree)	-0.17	-0.11	-0.08	0.00	-0.08
Transceiver menu: Entered after calibration					
Transducer gain (dB)	22.28	25.54	26.77	26.81	26.84
sA correction (dB)	-0.65	-0.66	-0.39	-0.32	-0.29
Alongship 3 dB beamwidth (degree)	10.66	7.01	6.47	6.39	6.41
Athwardship 3 dB beamwidth (degree)	10.58	7.01	6.55	6.40	6.58
Alongship offset angle (degree)	-0.13	-0.15	-0.02	-0.13	-0.16
Athwardship offset angle (degree)	-0.21	-0.07	-0.01	0.01	-0.09

Appendix 3. Parameter settings and calibration results used during TS Probe measurement for blue whiting in 2006. (A): 38 kHz and (B): 120 kHz.

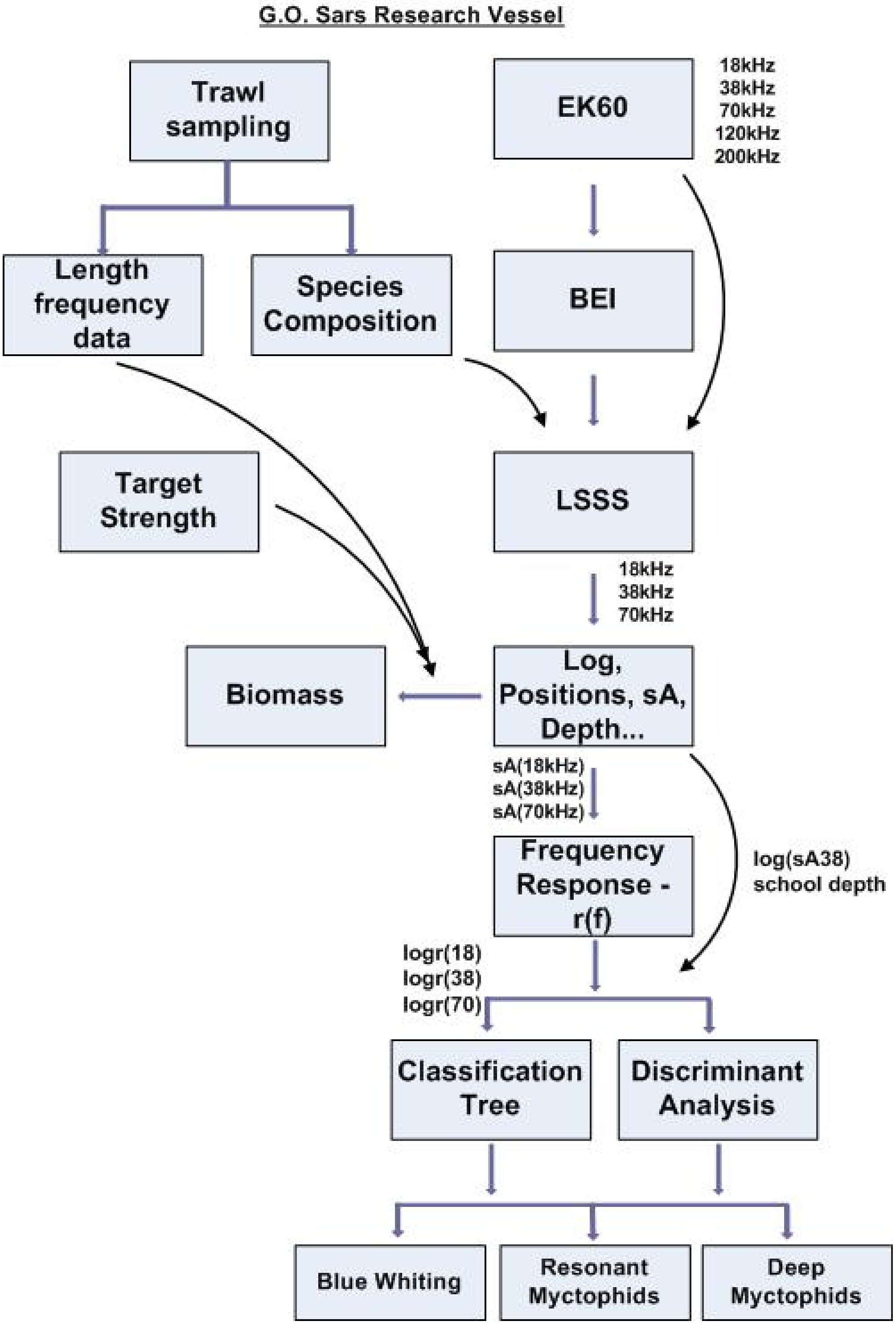
(A)

	Depth of calibration			
SIMRAD EK 60, 38 kHz	10 m	200 m	480 m	485 m
Transceiver menu: Permanent settings				
Transducer type: ES38D				
Absorption coefficient (dB/km)	10.1	10.0	10.1	10.1
Pulse duration (m/s)	1.024	1.024	1.024	1.024
Bandwidth (kHz)	2.43	2.43	2.43	2.43
Transducer gain (dB)	24.50	25.12	21.90	21.90
sA correction (dB)	0.00	-0.59	-0.45	-0.45
Maximum transmitting power (W)	2000	2000	2000	2000
Two way beam angle (dB)	-20.60	-20.60	-20.60	-20.60
Alongship angle sensitivity	21.9	21.90	21.90	21.90
Athwardship angle sensitivity	21.9	21.90	21.90	21.90
Alongship 3 dB beamwidth (degree)	7.10	6.92	7.12	7.12
Athwardship 3 dB beamwidth (degree)	7.10	7.16	7.20	7.20
Alongship offset angle (degree)	0.00	-0.08	-0.02	-0.02
Athwardship offset angle (degree)	0.00	-0.06	-0.07	-0.07
Transceiver menu: Entered after calibration				
Transducer gain (dB)	25.12	21.90	21.72	21.89
sA correction (dB)	-0.59	-0.45	-0.46	-0.43
Alongship 3 dB beamwidth (degree)	6.92	7.12	7.27	7.09
Athwardship 3 dB beamwidth (degree)	7.16	7.20	7.18	7.06
Alongship offset angle (degree)	-0.08	-0.02	0.00	-0.06
Athwardship offset angle (degree)	-0.06	-0.07	-0.05	-0.01

(B)

SIMRAD EK 60, 120 kHz	Depth of calibration 100 m	200 m	300 m	400 m	465 m
Transceiver menu: Permanent settings					
Transducer type: ES120-7C					
Absorption coefficient (dB/km)	32.5	32.5	32.5	32.5	32.5
Pulse duration (m/s)	1.024	1.024	1.024	1.024	1.024
Bandwidth (kHz)	3.03	3.03	3.03	3.03	3.03
Transducer gain (dB)	27.00	27.00	27.00	27.00	27.00
sA correction (dB)	0.00	0.00	0.00	0.00	0.00
Maximum transmitting power (W)	500	500	500	500	500
Two way beam angle (dB)	-21.00	-21.00	-21.00	-21.00	-21.00
Alongship angle sensitivity	23.00	23.00	23.00	23.00	23.00
Athwardship angle sensitivity	23.00	23.00	23.00	23.00	23.00
Alongship 3 dB beamwidth (degree)	7.00	7.00	7.00	7.00	7.00
Athwardship 3 dB beamwidth (degree)	7.00	7.00	7.00	7.00	7.00
Alongship offset angle (degree)	0.00	0.00	0.00	0.00	0.00
Athwardship offset angle (degree)	0.00	0.00	0.00	0.00	0.00
Transceiver menu: Entered after calibration					
Transducer gain (dB)	25.18	24.90	24.52	24.14	24.07
sA correction (dB)	-0.33	-0.29	-0.29	-0.36	-0.43
Alongship 3 dB beamwidth (degree)	6.14	6.19	6.21	6.50	6.71
Athwardship 3 dB beamwidth (degree)	5.93	6.11	6.16	6.42	6.46
Alongship offset angle (degree)	-0.01	0.00	-0.23	0.07	0.04
Athwardship offset angle (degree)	0.13	0.20	0.27	0.18	0.26

Appendix 4. Flow diagram of data analysis.



Appendix 5. Parameters of trawl settings of the blue whiting survey in 2005 and 2006.

Date	Station	Series number	Latitude (degree)	Longitude (degree)	Start time	Start log	Stop time	Distance (nmi)	Opening (m)	Spread (m)	Fishing depth max (m)	Fishing depth min (m)
18/3/2005	165	23001	54.42	-13.20	13.07	28.4	13.45	1.2	23	(-)	550	500
	165	23002	54.42	-13.02	13.45	29.6	13.62	0.6	23	(-)	550	500
20/3/2005	166	23003	54.09	-14.52	3.55	285.6	3.80	0.7	26.5	(-)	560	530
	166	23004	54.09	-14.54	3.82	286.3	4.07	0.7	27	(-)	530	500
	167	23005	54.84	-14.00	14.72	362.4	14.97	0.8	23	(-)	507	505
	167	23006	54.84	-14.03	14.98	363.3	15.25	0.9	25	70	530	500
21/3/2005	168	23007	55.74	-9.75	20.90	599.9	21.07	0.7	(-)	(-)	(-)	(-)
	168	23008	55.74	-9.73	21.08	600.6	21.30	0.8	(-)	(-)	(-)	(-)
22/3/2005	169	23009	55.83	-11.00	5.38	656	5.62	0.7	26	(-)	500	470
	169	23010	55.82	-10.99	5.62	656.7	5.90	0.7	26	(-)	480	430
	170	23011	56.18	-9.80	13.22	722.3	13.40	0.6	26	(-)	490	475
	170	23012	56.18	-9.79	13.42	723	13.58	0.6	26	100	475	450
23/3/2005	171	23013	57.08	-10.36	16.00	900.1	16.20	0.5	26	(-)	500	480
	171	23014	57.08	-10.38	16.20	900.7	16.40	0.6	24	(-)	510	490
	171	23015	57.08	-10.40	16.42	901.3	16.62	0.5	26	(-)	520	490
24/3/2005	172	23016	57.50	-10.34	8.85	9.7	9.02	0.6	22	120	520	(-)
	172	23017	57.50	-10.32	9.02	10.4	9.22	0.7	22	(-)	500	(-)
	172	23018	57.51	-10.30	9.23	11.2	9.40	0.7	22	120	480	(-)
25/3/2005	174	23020	58.47	-15.41	9.87	208.2	10.38	2.1	21	100	550	500
26/3/2005	175	23021	58.50	-10.99	7.50	362.1	7.63	0.4	22	(-)	520	500
	175	23022	58.50	-11.01	7.65	362.6	7.80	0.5	22	(-)	520	500
	175	23023	58.50	-11.03	7.85	363.2	7.98	0.4	22	120	520	500
30/3/2005	176	23024	59.32	-10.50	7.85	857.4	8.07	0.8	25	138	520	485
	176	23025	59.33	-10.49	8.08	858.3	8.30	0.9	26	137	500	(-)
	176	23026	59.35	-10.46	8.48	860	8.67	0.7	27	142	455	445
	177	23027	59.27	-10.44	13.05	872.7	14.00	3	34	145	530	250
	178	23028	59.21	-10.51	16.87	883.3	17.63	2.6	55	235	510	490
31/3/2005	179	23029	58.91	-15.75	20.02	75.7	20.93	2.8	35	140	520	490

1/4/2005	180	23030	59.25	-16.60	15.63	200.8	15.90	0.9	24	140	610	580
	180	23031	59.25	-16.63	15.90	201.7	16.17	0.8	25	140	560	550
	180	23032	59.25	-16.66	16.17	202.7	16.65	1.6	24	140	550	540
3/4/2005	181	23033	58.99	-11.21	2.13	473.8	2.40	1	28	130	450	440
	181	23034	58.98	-11.23	2.42	474.8	2.73	1	26.5	139	530	496
	182	23035	58.94	-11.57	12.08	515.1	12.60	1.7	33	150	500	460
5/4/2005	183	23036	59.83	-9.61	1.97	805	2.23	0.9	25	138	520	480
	183	23037	59.83	-9.64	2.25	806	2.52	0.8	25.2	144	470	460
6/4/2005	184	23038	60.91	-7.18	0.15	960.7	0.72	1.9	(-)	141	410	385
8/4/2005	185	23039	60.08	-7.03	15.03	178.3	15.38	1.2	25	141	400	380
	185	23040	60.08	-6.98	15.38	179.6	15.72	1.1	25	140	400	370
	185	23041	60.07	-6.95	15.73	180.8	16.07	1.1	25	140	400	370
10/4/2005	187	23044	60.08	-8.86	2.42	381.4	2.68	0.9	24.3	140	470	440
	188	23046	60.07	-8.84	4.80	388.8	7.18	8.1	35	150	480	400
11/4/2005	189	23047	60.84	-5.57	10.32	583.4	11.40	3.7	32	141	420	400
19/3/2006	196	23001	54.58	-13.86	12.03	734.2	12.37	1	40	145	550	520
20/3/2006	197	23003	53.48	-13.50	(-)	818.1	1.12	2.1	3.8	52	180	175
22/3/2006	198	23004	54.92	-10.15	2.65	194.5	3.18	2	3.8	52	125	120
	199	23005	55.49	-10.69	13.90	299.8	14.25	1.1	35	145	560	540
	199	23006	55.49	-10.66	14.25	301	14.58	1.1	35	145	540	520
	199	23007	55.49	-10.62	14.60	302.2	14.95	1.2	35	145	560	540
23/3/2006	200	23008	55.50	-11.78	1.63	365.3	2.13	2	38	145	530	510
	200	23009	55.50	-11.72	2.15	367.4	2.68	2.1	38	145	540	520
	201	23010	55.86	-15.05	20.12	519.3	20.78	1.8	3.6	54	439	429
24/3/2006	202	23011	56.10	-12.02	12.78	645.2	12.95	0.5	38	145	550	520
	202	23012	56.10	-12.00	13.02	645.9	13.32	1	38	145	560	540
25/3/2006	203	23013	56.11	-9.72	2.82	735.5	3.00	0.6	38	145	500	490
	203	23014	56.11	-9.74	3.00	736.2	3.33	1.1	(-)	(-)	(-)	(-)
	204	23015	56.67	-10.52	19.42	863.1	19.65	0.8	43	140	515	503
	204	23016	56.66	-10.50	19.67	864	19.90	0.8	43	144	503	500
	204	23017	56.66	-10.47	19.92	864.9	20.18	0.9	43	144	495	477

26/3/2006	205	23018	56.64	-14.06	9.95	991.1	10.47	1.6	5.4	35	380	370
27/3/2006	206	23019	57.18	-12.15	2.18	100.6	2.27	0.2	38	145	520	510
	206	23020	57.18	-12.16	2.30	101	2.33	0.1	38	145	520	510
1/4/2006	207	23021	57.67	-9.69	7.63	587.2	8.15	1.7	27	144	515	460
3/4/2006	208	23022	58.24	-14.37	(-)	886.1	(-)	1.7	28	140	440	390
	209	23023	58.25	-11.29	14.60	996.3	15.33	2.4	32	125	600	500
	210	23024	58.24	-11.17	17.27	10.3	17.87	1.7	30	150	600	540
4/4/2006	211	23025	58.23	-9.19	3.25	83.8	4.10	2.8	30	125	200	150
	212	23026	58.83	-9.57	16.68	202.5	18.02	4	29.3	152	550	485
9/4/2006	213	23027	60.12	-9.00	4.48	861.5	5.93	4.8	30.6	148	550	475
	214	23028	60.19	-9.24	16.73	925.7	17.78	3.6	32	145	550	500
12/4/2006	215	23029	61.73	-4.98	3.03	365.1	3.33	1	3.9	57	235	230
14/4/2006	216	23030	61.32	-7.59	1.00	689.3	1.57	1.8	26	150	450	410
	217	23031	61.19	-7.30	3.98	705.1	4.55	1.8	3.7	55	480	470
	218	23032	61.35	-7.75	13.55	745.2	14.20	2.6	32	155	510	470
15/4/2006	219	23033	60.30	-4.54	7.95	899.4	8.45	1.9	27	140	460	430

(-): not available

Appendix 6. Total catch (kg) and species composition (%) of the blue whiting survey in 2005 and 2006, grouped by station. TS probing measurement was performed in 2006 at stations 196, 199, 204, 205, 208, 213, 215, 216, 218 and 219.

Year	Station	% Catch			Total Catch (kg)
		BW	MYC	Others	
2005	165	95.7	2.3	2.0	29.6
2005	166	65.8	6.8	27.3	7.7
2005	167	61.3	7.8	30.9	4.0
2005	168	99.9	0.0	0.0	270.2
2005	169	82.2	2.3	15.4	11.2
2005	170	99.8	0.0	0.1	150.2
2005	171	99.9	0.1	0.0	360.7
2005	172	96.6	0.4	3.0	52.0
2005	174	44.3	0.9	54.8	4.9
2005	175	99.8	0.0	0.2	230.6
2005	176	99.2	0.6	0.3	126.1
2005	177	97.7	1.8	0.6	133.2
2005	178	99.7		0.3	1002.8
2005	179	79.1	3.2	17.7	50.6
2005	180	6.0	28.7	65.3	19.9
2005	181	58.0	17.3	24.7	11.8
2005	182	97.4	0.8	1.8	339.3
2005	183	98.6	0.3	1.1	334.6
2005	184	66.8	15.3	17.9	41.9
2005	185	98.4	0.2	1.4	157.5
2005	187	99.8	0.1	0.2	18.9
2005	188	99.9	0.1	0.0	1000.4
2005	189	56.9	0.3	42.7	87.8
2006	196	83.3		16.7	35.3
2006	197	0.1		99.9	66.9
2006	198			100.0	321.0
2006	199	92.7	0.5	6.8	193.3
2006	200	71.1	4.4	24.5	39.0
2006	201	12.5		87.5	214.9
2006	202	99.7	0.2	0.1	410.4
2006	203	99.6	0.2	0.2	164.1
2006	204	94.3	0.9	4.7	132.5
2006	205	41.3		58.7	1066.2
2006	206	100.0			480.0
2006	207	98.9	0.0	1.1	202.2
2006	208	37.4	0.4	62.2	4.7
2006	209		12.4	87.6	3.7
2006	210	94.0	0.6	5.4	191.6
2006	211	11.0		89.0	24.7
2006	212	2.6	18.5	78.9	19.5
2006	213	26.5	7.2	66.3	43.0
2006	214	53.5	6.1	40.4	53.5
2006	215			100.0	183.8
2006	216	80.5	6.8	12.7	11.0
2006	217	2.4		97.6	161.3
2006	218	96.6	0.1	3.3	105.6
2006	219	96.0		4.0	93.8

Appendix 7. Total catch and species composition (%) of the blue whiting survey in 2005 and 2006, grouped by trawl haul.

Year	Station	Series number	% Catch			Total Catch (kg)
			BW	MYC	Others	
2005	165	23001	96.6	1.6	1.8	28.8
2005	166	23004	62.3	6.6	31.1	4.4
2005	167	23005	47.3	10.2	42.6	1.3
2005	167	23006	68.5	6.6	24.9	2.6
2005	168	23007	100.0	0.0	0.0	150.1
2005	168	23008	99.9	0.0	0.1	120.1
2005	169	23009	77.2	2.1	20.7	6.0
2005	169	23010	88.1	2.6	9.3	5.1
2005	170	23011	99.8	0.0	0.2	70.2
2005	170	23012	99.9	0.1	0.0	80.1
2005	171	23013	99.7	0.3	0.0	30.1
2005	171	23014	99.5	0.3	0.2	30.2
2005	171	23015	100.0			300.4
2005	172	23016	98.3	0.7	1.0	17.3
2005	172	23017	76.5	2.1	21.4	4.1
2005	172	23018	98.3	0.1	1.6	30.5
2005	174	23020	44.3	0.9	54.8	4.9
2005	175	23021	99.9	0.1	0.0	50.1
2005	175	23022	98.4		1.6	30.5
2005	175	23023	100.0		0.0	150.0
2005	176	23024	99.9	0.1	0.1	75.1
2005	176	23025	98.4	1.0	0.6	30.5
2005	176	23026	97.7	1.7	0.6	20.5
2005	177	23027	97.7	1.8	0.6	133.2
2005	178	23028	99.7		0.3	1002.8
2005	179	23029	79.1	3.2	17.7	50.6
2005	181	23033	59.3	22.0	18.7	4.0
2005	181	23034	57.3	14.9	27.8	7.8
2005	182	23035	97.4	0.8	1.8	339.3
2005	183	23036	97.0	0.7	2.3	134.0
2005	183	23037	99.7	0.1	0.3	200.7
2005	184	23038	66.8	15.3	17.9	41.9
2005	185	23039	99.7	0.1	0.2	70.2
2005	185	23040	99.7	0.2	0.1	50.2
2005	185	23041	94.3	0.1	5.6	37.1
2005	187	23044	99.8	0.1	0.2	18.9
2005	188	23046	99.9	0.1	0.0	1000.4
2005	189	23047	56.9	0.3	42.7	87.8
2006	196	23001	83.3		16.7	35.3
2006	199	23005	46.4	3.1	50.5	18.7
2006	199	23006	97.0	1.2	1.8	21.1
2006	199	23007	97.7	0.1	2.2	153.5
2006	200	23008	68.8	3.6	27.6	19.3
2006	200	23009	73.4	5.1	21.5	19.7
2006	201	23010	12.5		87.5	214.9
2006	202	23011	99.9		0.1	378.1
2006	202	23012	97.6	2.2	0.2	32.3
2006	203	23013	99.7	0.2	0.1	150.5

2006	203	23014	98.8	0.5	0.7	13.6
2006	204	23015	87.6	1.7	10.8	40.0
2006	204	23016	96.3	1.0	2.7	46.7
2006	205	23017	98.2	0.2	1.5	45.8
2006	205	23018	41.3		58.7	1066.2
2006	206	23019	100.0			280.0
2006	206	23020	100.0			200.0
2006	207	23021	98.9	0.0	1.1	202.2
2006	208	23022	37.4	0.4	62.2	4.7
2006	210	23024	94.0	0.6	5.4	191.6
2006	211	23025	11.0		89.0	24.7
2006	212	23026	2.6	18.5	78.9	19.5
2006	213	23027	26.5	7.2	66.3	43.0
2006	214	23028	53.5	6.1	40.4	53.5
2006	216	23030	80.5	6.8	12.7	11.0
2006	217	23031	2.4		97.6	161.3
2006	218	23032	96.6	0.1	3.3	105.6
2006	219	23033	96.0		4.0	93.8

Appendix 8. Descriptive statistic of length measurement (total length in centimeter) of blue whiting during the survey in 2005, 2006 by station. RMSL is Root Mean Square Length

Year	Station	Min	Max	Mean	SD	RMSL	N
2005	165	23.0	30.5	26.3	1.8	26.4	100
2005	166	19.0	28.5	24.0	2.6	24.1	35
2005	167	19.5	34.5	26.8	3.1	27.0	28
2005	168	20.5	39.0	27.0	2.2	27.1	200
2005	169	20.0	36.5	26.8	2.4	26.9	103
2005	170	22.5	33.5	26.5	2.1	26.6	200
2005	171	20.5	38.0	26.6	2.5	26.7	300
2005	172	14.5	34.0	26.8	2.6	26.9	238
2005	174	20.0	31.5	26.9	2.6	27.1	23
2005	175	19.0	34.5	26.5	2.1	26.6	300
2005	176	20.5	35.0	27.1	2.2	27.2	296
2005	177	22.5	34.5	27.5	2.2	27.6	200
2005	178	22.5	33.5	27.0	2.0	27.1	200
2005	179	20.0	36.0	27.0	2.3	27.1	199
2005	181	23.0	36.5	27.1	2.2	27.2	78
2005	182	20.0	32.0	25.9	2.0	26.0	200
2005	183	22.0	36.5	26.7	2.2	26.8	200
2005	184	15.5	31.0	24.8	3.4	25.0	100
2005	185	17.5	35.5	26.8	2.7	26.9	300
2005	187	23.0	35.5	27.2	2.5	27.3	100
2005	188	23.0	33.5	26.7	2.0	26.8	200
2005	189	19.0	33.0	26.4	2.2	26.5	200
2006	196	20.0	33.0	25.9	1.9	26.0	100
2006	199	22.5	33.0	26.6	1.8	26.7	305
2006	200	23.0	35.0	27.0	2.1	27.1	300
2006	201	20.5	32.0	24.9	2.3	25.0	100
2006	202	21.5	34.0	26.6	2.4	26.7	200
2006	203	23.0	33.0	27.4	1.7	27.5	150
2006	204	15.5	36.0	27.3	2.8	27.5	200
2006	205	18.0	35.0	22.5	2.5	22.7	100

2006	206	23.0	35.5	28.4	2.3	28.5	150
2006	207	15.5	32.0	25.4	3.7	25.7	100
2006	208	24.5	31.5	26.2	1.8	26.2	21
2006	210	22.5	32.5	26.6	1.9	26.6	100
2006	211	15.0	21.0	17.3	1.2	17.3	50
2006	212	16.5	28.0	24.7	3.6	25.0	7
2006	213	17.5	31.5	25.7	2.9	25.9	100
2006	214	21.5	42.0	27.4	2.2	27.5	200
2006	216	17.5	35.5	23.6	3.3	23.9	100
2006	217	15.5	37.5	26.9	4.7	27.3	36
2006	218	18.0	31.0	25.9	2.4	26.0	100
2006	219	17.0	30.0	23.2	3.4	23.4	100

Appendix 9. Descriptive statistic of length measurement of blue whiting (total length in centimeter) during the survey in 2005 and 2006 by trawl sample. RMSL is Root Mean Square Length.

Year	Station	Trawl	Min	Max	Mean	SD	RMSL	N
2005	165	23001	23.0	30.5	26.3	1.8	26.4	100
2005	166	23004	19.0	28.5	24.0	2.6	24.1	35
2005	167	23005	24.5	31.0	27.1	2.1	27.2	7
2005	167	23006	19.5	34.5	26.7	3.4	26.9	21
2005	168	23007	23.5	39.0	27.2	2.2	27.3	100
2005	168	23008	20.5	35.0	26.8	2.2	26.9	100
2005	169	23009	20.0	33.0	27.2	2.4	27.3	50
2005	169	23010	20.0	36.5	26.5	2.4	26.6	53
2005	170	23011	22.5	33.5	26.6	2.1	26.7	100
2005	170	23012	23.0	32.0	26.4	2.1	26.5	100
2005	171	23013	23.5	38.0	26.9	2.5	27.1	100
2005	171	23014	20.5	35.5	27.1	2.7	27.2	100
2005	171	23015	20.5	32.5	25.7	2.2	25.8	100
2005	172	23016	14.5	32.0	26.9	2.6	27.1	99
2005	172	23017	15.5	33.0	25.5	3.5	25.7	39
2005	172	23018	23.5	34.0	27.2	2.0	27.3	100
2005	174	23020	20.0	31.5	26.9	2.6	27.1	23
2005	175	23021	23.0	32.0	26.4	1.8	26.4	100
2005	175	23022	19.0	30.5	26.1	2.1	26.1	100
2005	175	23023	23.0	34.5	27.2	2.2	27.2	100
2005	176	23024	23.0	35.0	27.1	2.1	27.2	100
2005	176	23025	20.5	34.5	27.5	2.6	27.6	96
2005	176	23026	23.0	33.0	26.7	1.9	26.8	100
2005	177	23027	22.5	34.5	27.5	2.2	27.6	200
2005	178	23028	22.5	33.5	27.0	2.0	27.1	200
2005	179	23029	20.0	36.0	27.0	2.3	27.1	199
2005	181	23033	24.0	34.5	26.9	2.1	27.0	26
2005	181	23034	23.0	36.5	27.2	2.2	27.3	52
2005	182	23035	20.0	32.0	25.9	2.0	26.0	200
2005	183	23036	22.0	33.0	26.3	2.0	26.4	100
2005	183	23037	23.0	36.5	27.2	2.4	27.3	100
2005	184	23038	15.5	31.0	24.8	3.4	25.0	100
2005	185	23039	19.0	34.0	27.1	2.4	27.2	100
2005	185	23040	18.5	35.5	26.6	3.0	26.7	100
2005	185	23041	17.5	32.0	26.7	2.7	26.9	100

2005	187	23044	23.0	35.5	27.2	2.5	27.3	100
2005	188	23046	23.0	33.5	26.7	2.0	26.8	200
2005	189	23047	19.0	33.0	26.4	2.2	26.5	200
2006	196	23001	20.0	33.0	25.9	1.9	26.0	100
2006	199	23005	22.5	33.0	26.4	1.9	26.5	105
2006	199	23006	23.0	32.5	26.4	1.6	26.4	100
2006	199	23007	23.5	32.5	27.0	1.9	27.0	100
2006	200	23008	23.0	35.0	27.4	2.3	27.5	100
2006	200	23009	23.0	35.0	26.9	1.9	27.0	200
2006	201	23010	20.5	32.0	24.9	2.3	25.0	100
2006	202	23011	21.5	34.0	27.0	2.4	27.1	100
2006	202	23012	23.5	33.5	26.3	2.3	26.4	100
2006	203	23013	23.0	33.0	27.3	1.8	27.4	100
2006	203	23014	24.5	31.5	27.6	1.6	27.7	50
2006	204	23015	15.5	33.5	26.7	3.3	26.9	50
2006	204	23016	16.5	34.5	27.5	2.5	27.6	100
2006	204	23017	17.5	36.0	27.6	2.6	27.7	50
2006	205	23018	18.0	35.0	22.5	2.5	22.7	100
2006	206	23019	23.5	35.5	28.4	2.3	28.5	100
2006	206	23020	23.0	34.5	28.3	2.4	28.4	50
2006	207	23021	15.5	32.0	25.4	3.7	25.7	100
2006	208	23022	24.5	31.5	26.2	1.8	26.2	21
2006	210	23024	22.5	32.5	26.6	1.9	26.6	100
2006	211	23025	15.0	21.0	17.3	1.2	17.3	50
2006	212	23026	16.5	28.0	24.7	3.6	25.0	7
2006	213	23027	17.5	31.5	25.7	2.9	25.9	100
2006	214	23028	21.5	42.0	27.4	2.2	27.5	200
2006	216	23030	17.5	35.5	23.6	3.3	23.9	100
2006	217	23031	15.5	37.5	26.9	4.7	27.3	36
2006	218	23032	18.0	31.0	25.9	2.4	26.0	100
2006	219	23033	17.0	30.0	23.2	3.4	23.4	100

Appendix 10. Target strength probe sampling stations for blue whiting survey in 2006

Date	Time	Ship	Cruise	Raw Data Filename	Trawl Station	Bottom Depth	Measure Depth	Reference Target	Trlist.ini Filename	GPT-1 Freq.	GPT-2 Freq.	Comments
19.03.06	14:30	GOS	2006104	TS-PROBE-D20060319-T142501.raw	196	2500	480	Cu60	1	38	-	Mellomstor kolmule, kl. 15:13, satt Temp=10 Salt=35
22.03.06	17:30	GOS	2006104	TS-PROBE-D20060322-T173029.raw	199		470	Cu60	1	38	-	Heave Comp. på
22.03.06	18:53	GOS	2006104		199		500	Cu60	1	38	-	Svinger nermere fisk(Bedre oppløsning)
22.03.06	19:30	GOS	2006104		199			Cu60	1	38	-	Stopp Logging
25.03.06	16:20	GOS	2006104	TS-PROBE-D20060325-T161850.raw	204		485	Cu60	1	38	-	Heave Comp. av
25.03.06	16:50	GOS	2006104		204			Cu60	1	38	-	Stopp Logging
25.03.06	16:50	GOS	2006104	TS-PROBE-D20060325-T165042.raw	204		465	Cu60	1	38	-	Heave Comp. av
25.03.06	17:17	GOS	2006104		204		495	Cu60	1	38	-	Heave Comp. på
25.03.06	17:28	GOS	2006104		204		495	Cu60	1	38	-	Stopp Logging.
26.03.06	11:21	GOS	2006104	TS-PROBE-D20060326-T112101.raw	205	300	275	Cu60	1	38	-	Heave Comp. På, Små kolmule, uer, få registr.
26.03.06	12:28	GOS	2006104		205					38		Stopp Logging.
03.04.06	1:44	GOS	2006104	TS-PROBE-D20060403-T014439.raw	208	520	420	Wc38.1	1	38	120	Små kolmule nær bunn
09.04.06	7:24	GOS	2006104	Ts-Probe-D2006409-T072412-	213	1500	460	-	1	38	-	Pitch og Roll måling stoppet klokken 07:00 Stop Logging 08:25
12.04.06	4:01	GOS	2006104	TS-PROBE-D20060412-T040133.raw	215	233	190	-	1	38	120	Med heavekomp.
12.04.06	4:16	GOS	2006104				170	-		38		Stop Logging 05:02
14.04.06	7:00	GOS	2006104		216	684	410	-	1	38	120	Hive Comp.
14.04.06	7:15	GOS	2006104	TS-PROBE-D20060414-T070018.raw			430					Stopp Logging 10:35
14.04.06	16:02	GOS	2006104	TS-PROBE-D20060414-T160215.raw	218	712	430	WC38.1	1	38	120	Med Heave Comp.
14.04.06	16:15	GOS	2006104		218	712	430	WC38.1	1	38	120	Heave Comp. AV
14.04.06	16:26	GOS	2006104		218	712	430	WC38.1	1	38	120	Heave Comp. PÅ
14.04.06	17:02	GOS	2006104		218	712	430	WC38.1	1	38	120	Stop Logging
15.04.06	10:02	GOS	2006104	TS-PROBE-D20060415-T100138.raw	219	644	400	-	1	38	120	Heave Comp. AV
15.04.06	11:14	GOS	2006104	TS-PROBE-D20060415-T111435.raw	219	644	400	-	1	38	120	Heave Comp. PÅ

Appendix 11. The adjusted for gains used during the TS probe experiment during blue whiting survey in 2006

	Settings during data collection			Calibration			
	Gain (dB)	Sa correction	Total gain (dB)	Gain (dB)	Sa correction	Total gain (dB)	Adjusted * (dB)
38kHz	26.81	-0.64	26.17	21.89	-0.43	21.46	9.42
120kHz	27.00	0.00	27.00	24.07	-0.43	23.64	6.72

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[*] Adjusted gain = 2x(Total gain used during data collection – Total calibrated gain)

Appendix 12. The estimated mean backscattering cross section (sigma), mean target strength and b_{20} values of blue whiting for stations using TS probe during blue whiting survey in 2006.

		Sigma (cm^2)					TSc (dB)			TS	Fish length (cm)			
	Station	Mean	-95%	95%	SE	N	Mean	-95%	95%	corrected	RMSL	n	SD	b20
38kHz	196	0.352	0.345	0.358	0.003	8096	-45.5	-45.6	-45.5	-36.1	26.0	100	1.9	-64.6
38kHz	199	0.470	0.461	0.479	0.005	7418	-44.3	-44.4	-44.2	-34.9	26.7	260	1.8	-63.6
38kHz	204	0.480	0.466	0.494	0.007	12508	-44.2	-44.3	-44.1	-34.8	27.5	185	2.8	-63.7
38kHz	216	0.247	0.241	0.253	0.003	8313	-47.1	-47.2	-47.0	-37.7	23.9	100	3.3	-65.4
38kHz	218	0.293	0.270	0.316	0.012	1242	-46.3	-46.7	-46.0	-36.9	26.0	100	2.4	-65.4
38kHz	219	0.359	0.350	0.367	0.004	10730	-45.4	-45.6	-45.4	-36.0	23.4	100	3.4	-63.6
38kHz	All data	0.385	0.380	0.390	0.002	48307	-45.1	-45.2	-45.1	-35.7	26.0	845	2.9	-64.2
120kHz	216	0.389	0.373	0.405	0.010	9197	-45.1	-45.3	-44.9	-38.4	23.9	100	3.3	-66.1
120kHz	218	0.333	0.298	0.367	0.020	2013	-45.8	-46.3	-45.3	-39.1	26.0	100	2.4	-67.5
120kHz	219	0.374	0.362	0.386	0.010	12694	-45.3	-45.4	-45.1	-38.6	23.4	100	3.4	-66.1
120kHz	All data	0.376	0.367	0.385	0.000	23904	-45.2	-45.4	-45.1	-38.5	24.4	300	3.3	-66.4

Appendix 13. The estimated mean backscattering cross section and mean target strength of reference sphere during measurement of TS probe. The "cupper sphere 64 mm" was used.

	Sigma (cm^2)				TS (dB)			TS corrected	Standard	Difference
Station	Mean	-95%	95%	N	Mean	-95%	95%	by gain (dB)	TS (dB)	(dB)
196	0.590	0.589	0.591	7537	-43.28	-43.29	-43.28	-33.88	-33.60	-0.28
199	0.544	0.543	0.544	4130	-43.64	-43.64	-43.64	-34.18	-33.60	-0.58
204	0.540	0.539	0.540	9349	-43.67	-43.67	-43.67	-34.28	-33.60	-0.68
All data	0.559	0.558	0.559	21016	-43.52	-43.52	-43.52	-34.08	-33.60	-0.48

Appendix 14. Estimated mean back scattering cross section (sigma, cm^2), mean target strength (dB) and mean adjusted target strength of blue whiting for each station at depth. Data collected by 38 kHz frequency transducer.

		Sigma (cm^2)				Mean TS	Mean Adjusted
Station	Depth[*] (m)	Mean	-95%	95%	N	(dB)	TS (dB)
196	30-50	0.21	0.19	0.23	464	-47.72	-38.30
196	50-70	0.36	0.35	0.37	6281	-45.40	-35.98
196	70-90	0.35	0.33	0.36	1332	-45.59	-36.17
199	30-50	0.38	0.37	0.39	2976	-45.24	-35.82
199	50-70	0.46	0.45	0.48	2968	-44.36	-34.94
199	70-90	0.71	0.68	0.74	1270	-42.5	-33.08
204	<30	0.30	0.27	0.32	891	-46.28	-36.86
204	30-50	0.39	0.37	0.41	3098	-45.1	-35.68
204	50-70	0.62	0.59	0.66	3401	-43.04	-33.62
204	70-90	0.52	0.49	0.54	3827	-43.85	-34.43
204	>90	0.33	0.29	0.38	1291	-45.76	-36.34
216	30-50	0.35	0.34	0.37	1350	-45.51	-36.09
216	50-70	0.33	0.32	0.35	2449	-45.75	-36.33
216	70-90	0.20	0.19	0.21	2996	-48.05	-38.63
216	>90	0.10	0.09	0.1	1443	-51.19	-41.77
218	50-70	0.35	0.31	0.38	329	-45.58	-36.16
218	70-90	0.27	0.24	0.3	643	-46.68	-37.26
218	>90	0.28	0.2	0.36	245	-46.49	-37.07
219	<30	0.30	0.27	0.33	360	-46.27	-36.85
219	>90	0.41	0.38	0.44	711	-44.86	-35.44
219	30-50	0.31	0.29	0.33	3221	-46.14	-36.72
219	50-70	0.37	0.36	0.39	3619	-45.26	-35.84
219	70-90	0.39	0.38	0.41	2819	-45.03	-35.61

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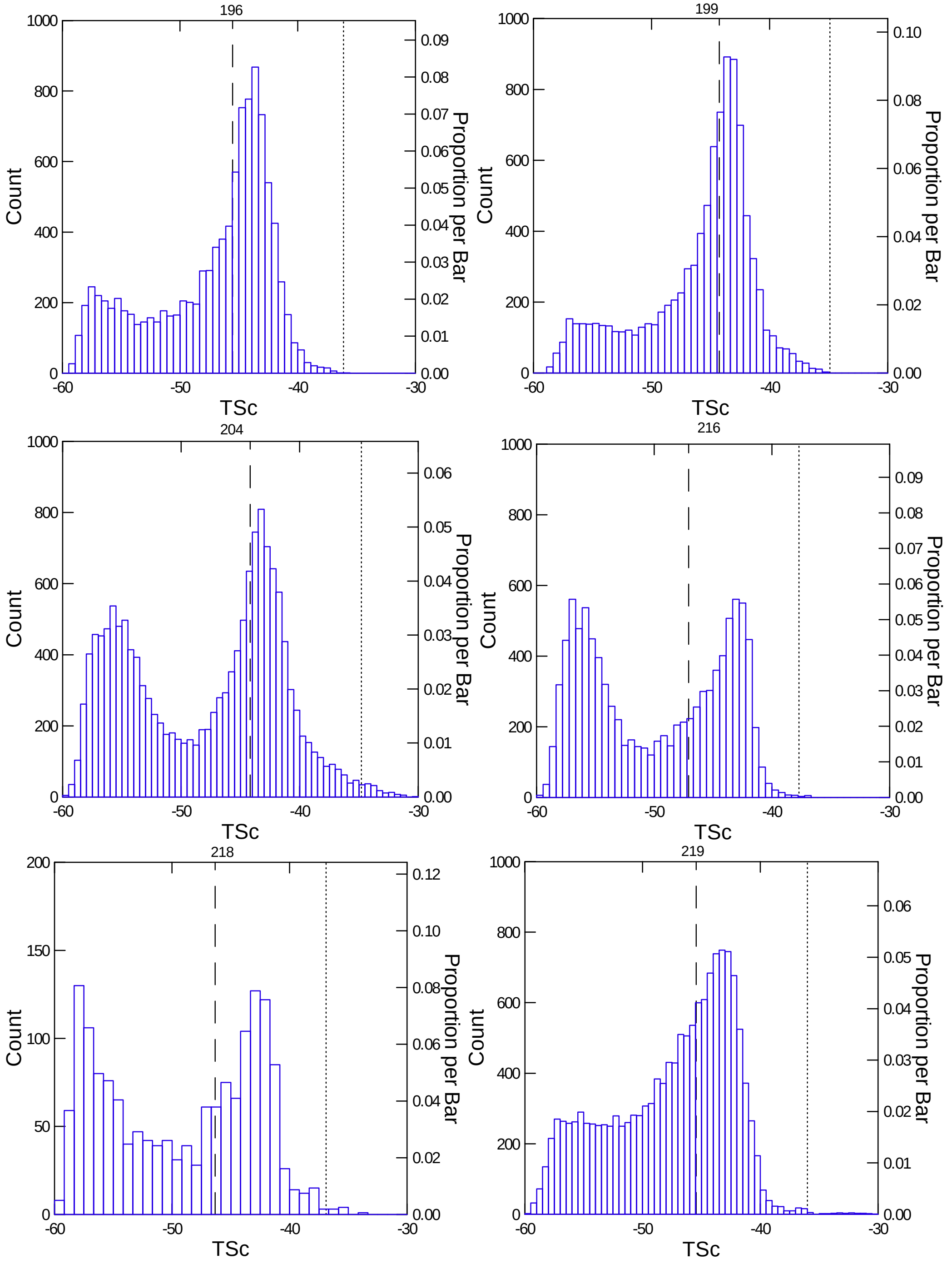
[*] Distance from the transducer (m)

Appendix 15. TS distributions of blue whiting conducted by TS probe of 38kHz frequency transducer during blue whiting survey in 2006. The mean TS corresponding to the mean cross section by station are: 196: TS=-45.5 (-36.1)*, n=8096; 199: TS=-44.3 (-34.9), n=7418; 204: TS=-44.2 (-34.8), n=12508; 216: TS=-47.1 (-37.7), n=8312; 218: TS=-46.3 (-39.9), n=1242; 219: TS=-45.4 (-36.0), n=10730. Dashes indicate the mean TS and dotted lines are the TS corrected by gain.



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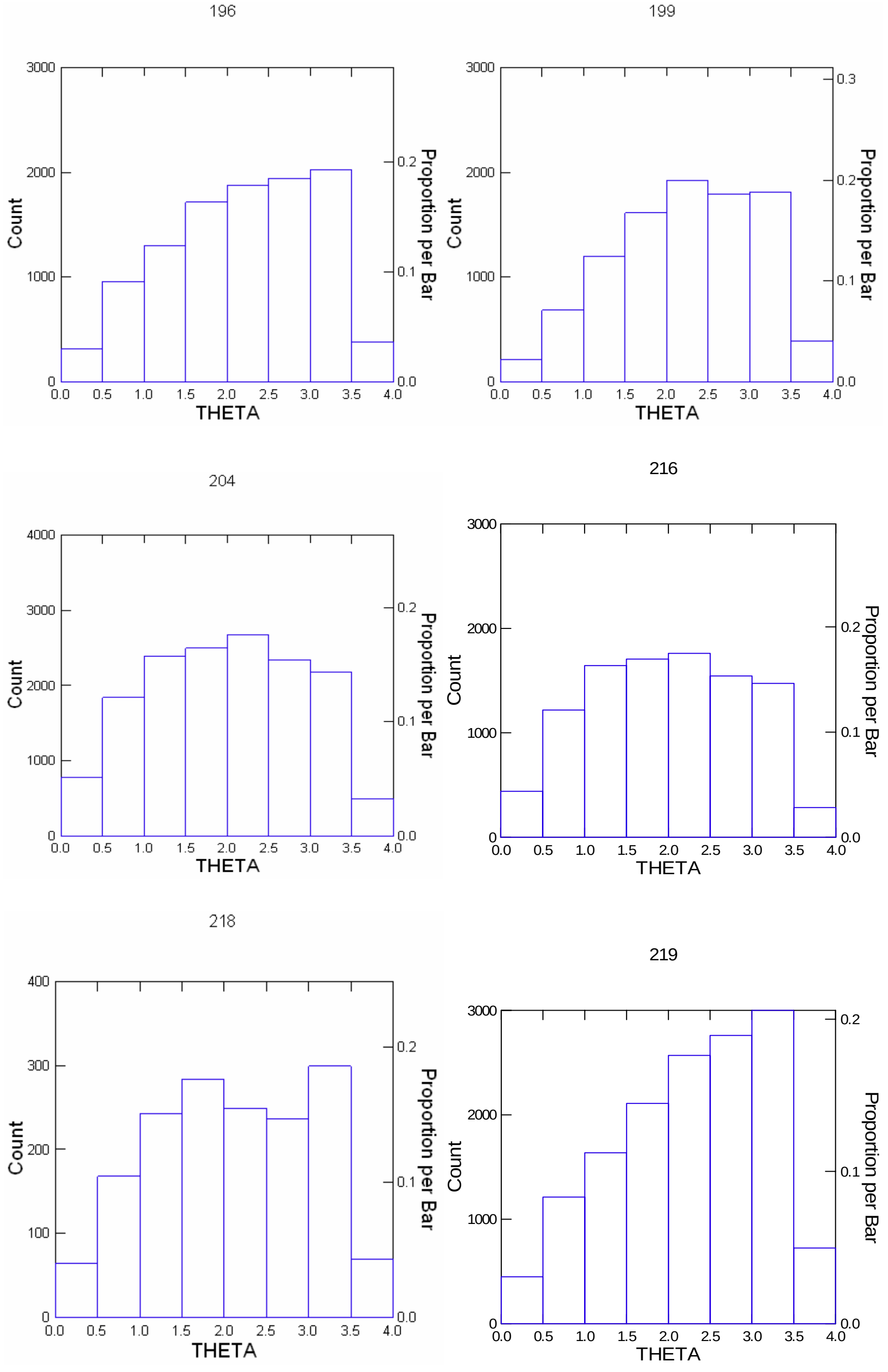
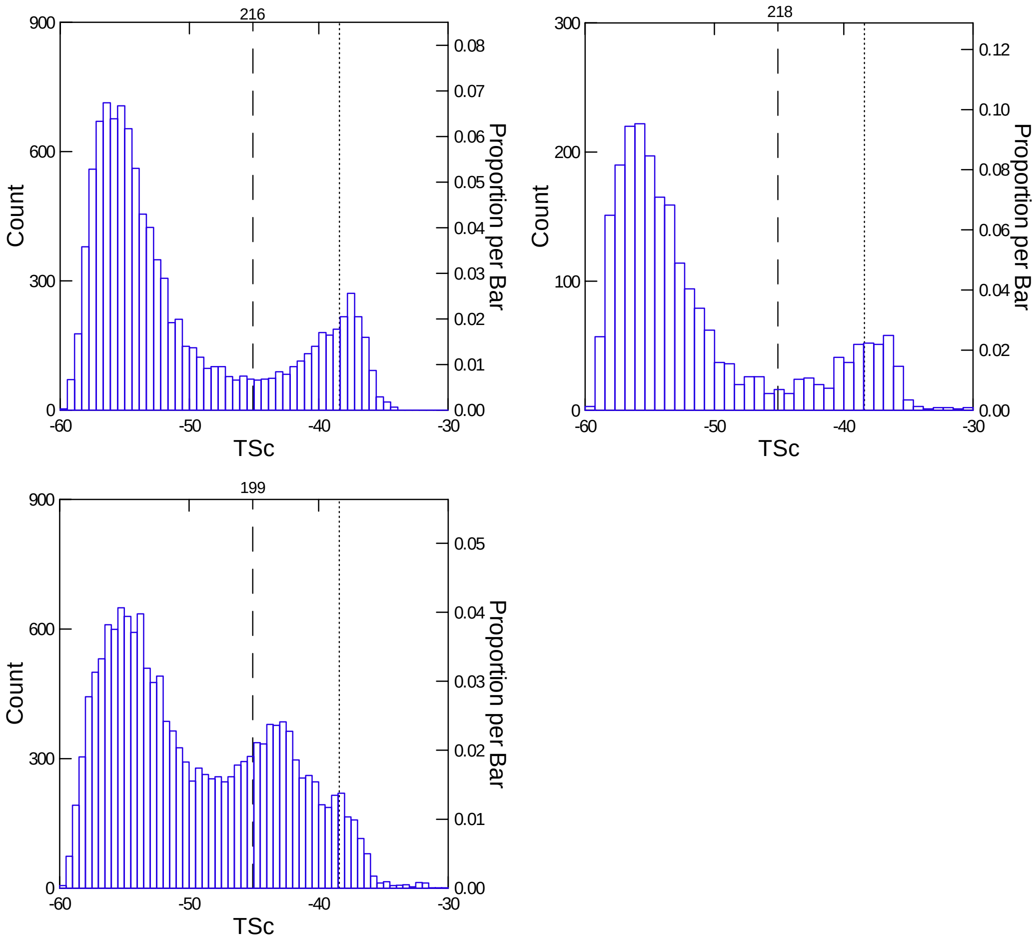
* Number in bracket indicates the TS corrected by gain

Appendix 16. Histogram plots of number target detected against spherical beam angle (θ) of 38 kHz TS probe measurements for blue whiting in 2006. Raw data were plotted.



Appendix 17. TS distributions of blue whiting conducted by TS probe of 120kHz frequency transducer during blue whiting survey in 2006. The mean TS corresponding to the mean cross section by station are: 216: TS=-45.1 (-38.4)*, n=9197; 218: TS=-45.8 (-39.1), n=2013; 219: TS=-45.2 (-38.6), n=12694. Dashes indicate the mean TS and dotted lines are the TS corrected by gain



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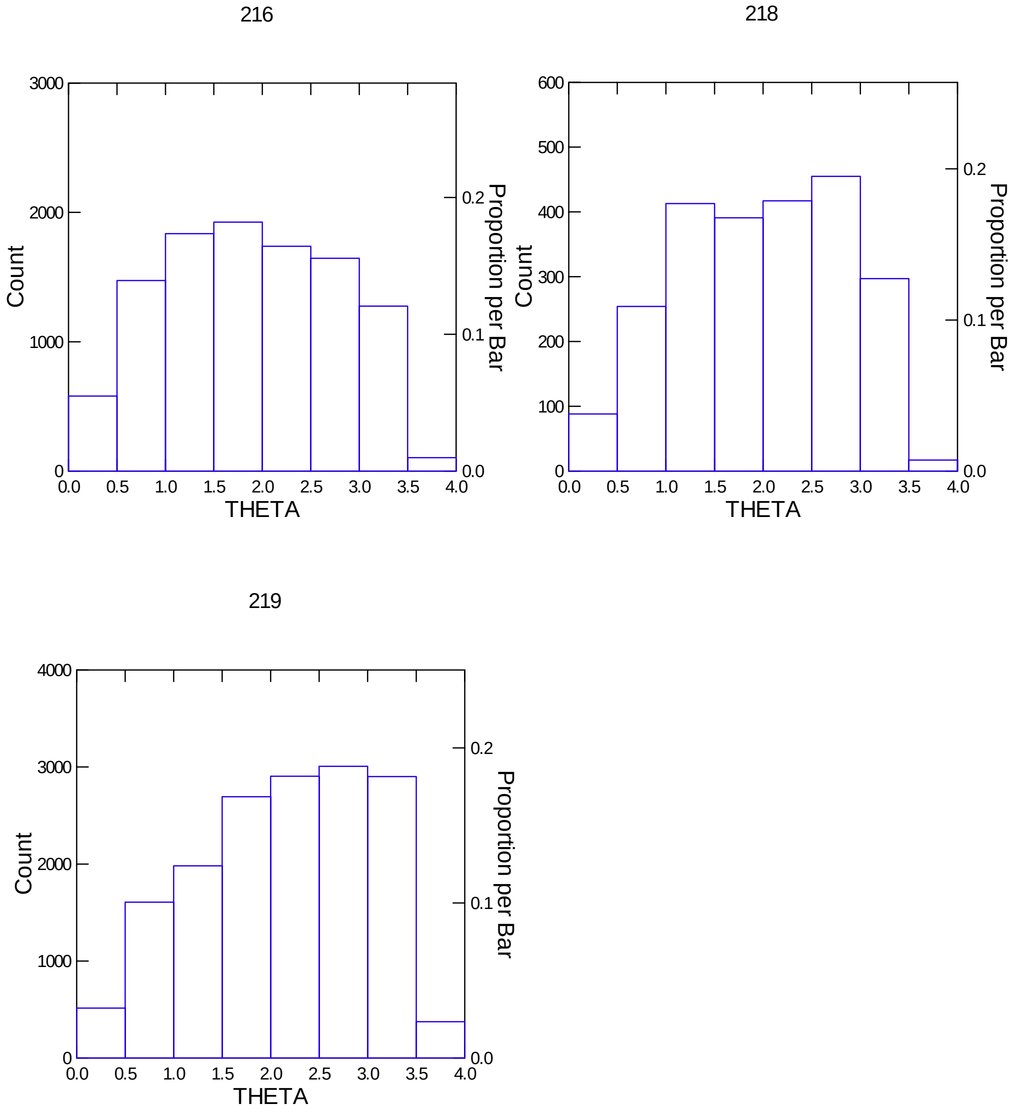
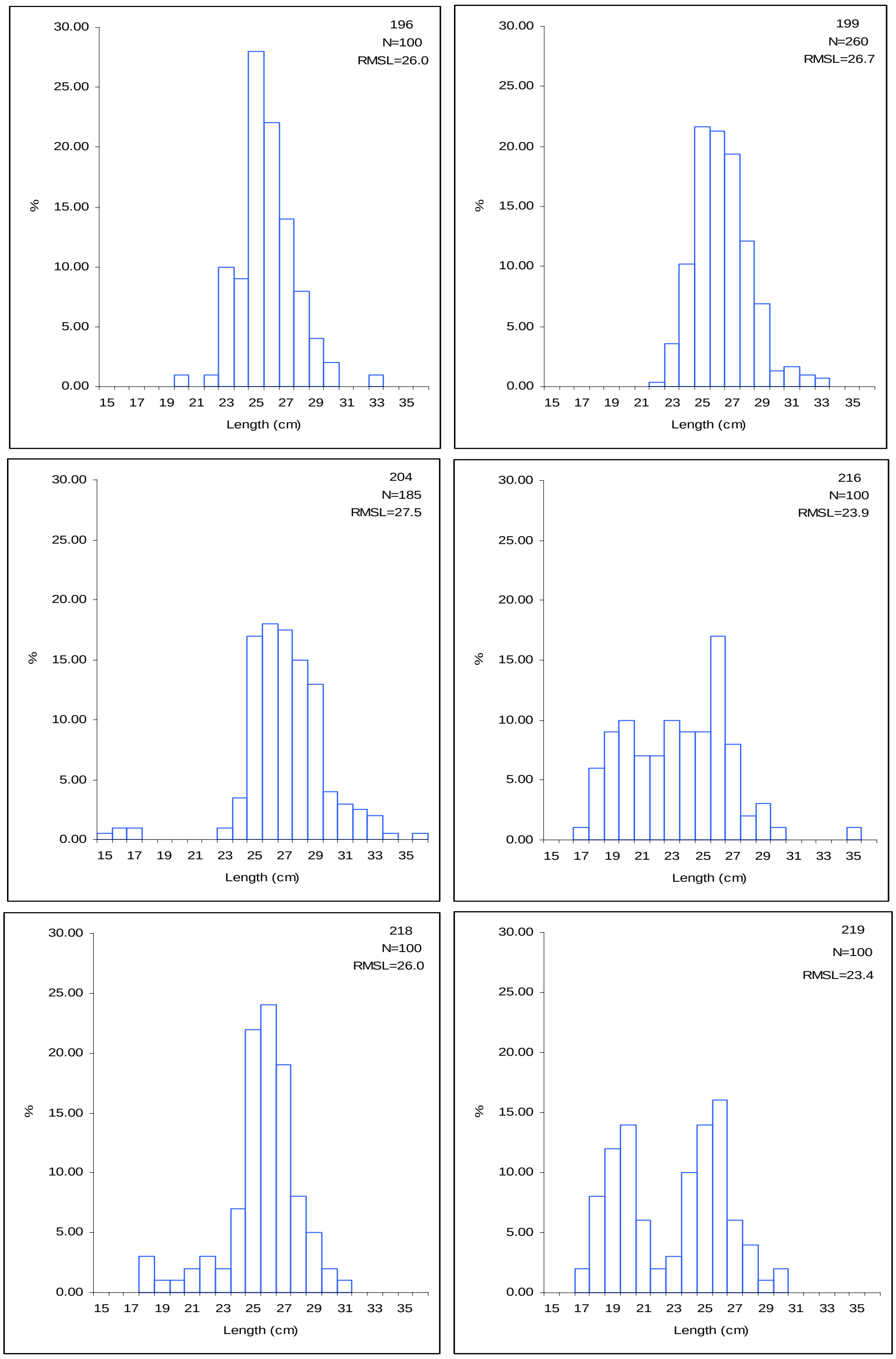
* Number in bracket indicates the TS corrected using gain

Appendix 18. Histogram plots of number target detected against spherical beam angle (θ) of 120 kHz TS probe measurements for blue whiting in 2006. Raw data were plotted



Appendix 19. Length frequency distributions of blue whiting at the stations where the target strength were conducted during the blue whiting survey in 2006.



Appendix 20. Descriptive statistics of the mean frequency response, r(f), values for the trawl-polygons and layers outside the trawl-polygons of blue whiting for the surveys in 2005 and 2006

		18kHz			38kHz			70kHz			Delta r(f)	
Survey	Layer	Mean	SE	N	Mean	SE	N	Mean	SE	N	18-38	70-38
2005	Trawl-polygon165-23001	0.43	0.02	7	0.26	0.01	7	0.31	0.01	7	0.16	0.04
2005	Trawl-polygon168-23007	0.38	0.01	9	0.30	0.00	9	0.32	0.01	9	0.08	0.02
2005	Trawl-polygon168-23008	0.44	0.01	11	0.27	0.00	11	0.29	0.01	11	0.17	0.02
2005	Trawl-polygon170-23011	0.40	0.01	10	0.31	0.00	10	0.30	0.00	10	0.09	-0.01
2005	Trawl-polygon170-23012	0.43	0.01	11	0.30	0.01	11	0.27	0.01	11	0.13	-0.02
2005	Trawl-polygon171-23013	0.49	0.04	11	0.26	0.02	11	0.25	0.02	11	0.24	-0.01
2005	Trawl-polygon171-23014	0.41	0.01	10	0.29	0.01	10	0.31	0.01	10	0.12	0.02
2005	Trawl-polygon171-23015	0.38	0.02	9	0.29	0.01	9	0.32	0.01	9	0.09	0.03
2005	Trawl-polygon172-23016	0.45	0.02	6	0.29	0.01	6	0.26	0.01	6	0.16	-0.03
2005	Trawl-polygon172-23018	0.43	0.03	6	0.29	0.02	6	0.28	0.01	6	0.15	-0.01
2005	Trawl-polygon176-23024	0.42	0.01	10	0.27	0.01	10	0.31	0.02	10	0.15	0.04
2005	Trawl-polygon176-23025	0.40	0.02	10	0.27	0.02	10	0.33	0.04	10	0.14	0.07
2005	Trawl-polygon176-23026	0.46	0.02	10	0.26	0.01	10	0.28	0.02	10	0.20	0.02
2005	Trawl-polygon177-23027	0.48	0.01	31	0.27	0.00	31	0.25	0.01	31	0.21	-0.02
2005	Trawl-polygon178-23028	0.44	0.02	13	0.28	0.01	13	0.28	0.01	13	0.16	0.00
2005	Trawl-polygon182-23035	0.43	0.02	19	0.28	0.01	19	0.29	0.01	19	0.15	0.00
2005	Trawl-polygon183-23036	0.41	0.01	10	0.29	0.00	10	0.30	0.01	10	0.12	0.02
2005	Trawl-polygon183-23037	0.45	0.01	11	0.27	0.00	11	0.28	0.01	11	0.18	0.01
2005	Trawl-polygon185-23039	0.44	0.01	11	0.26	0.00	11	0.30	0.01	11	0.17	0.04
2005	Trawl-polygon185-23040	0.41	0.01	10	0.26	0.01	10	0.33	0.02	10	0.15	0.08
2005	Trawl-polygon187-23044	0.39	0.01	11	0.30	0.00	11	0.31	0.01	11	0.09	0.01
2005	Trawl-polygon188-23046	0.45	0.00	80	0.28	0.00	80	0.27	0.00	80	0.17	-0.01
2005	Outside165-23001	0.40	0.03	8	0.29	0.01	8	0.31	0.01	8	0.11	0.02
2005	Outside168-23007-23008	0.43	0.01	19	0.28	0.01	19	0.29	0.01	19	0.15	0.00
2005	Outside170-23011-23012	0.43	0.01	24	0.29	0.01	24	0.28	0.00	24	0.14	-0.01
2005	Outside171-23013-23014-23015	0.43	0.01	30	0.28	0.01	30	0.29	0.01	30	0.15	0.01

2005	Outside172-23016-23018	0.47	0.02	16	0.27	0.01	16	0.26	0.01	16	0.20	-0.01
2005	Outside177-23027	0.45	0.01	35	0.28	0.01	35	0.27	0.01	35	0.17	0.00
2005	Outside178-23028	0.46	0.01	27	0.27	0.01	27	0.27	0.01	27	0.19	0.00
2005	Outside182-23035	0.45	0.01	63	0.27	0.00	63	0.28	0.01	63	0.18	0.01
2005	Outside187-23044	0.43	0.01	31	0.28	0.00	31	0.29	0.00	31	0.15	0.01
2005	Outside188-23046	0.45	0.00	113	0.28	0.00	113	0.28	0.00	113	0.17	0.00
2006	Trawl-polygon23006	0.45	0.03	10	0.28	0.01	10	0.27	0.01	10	0.18	0.00
2006	Trawl-polygon23007	0.41	0.01	12	0.29	0.00	12	0.30	0.01	12	0.12	0.00
2006	Trawl-polygon23011	0.44	0.01	9	0.28	0.01	9	0.28	0.01	9	0.16	-0.01
2006	Trawl-polygon23012	0.42	0.01	7	0.27	0.01	7	0.30	0.00	7	0.15	0.03
2006	Trawl-polygon23013	0.46	0.01	10	0.28	0.01	10	0.26	0.01	10	0.18	-0.02
2006	Trawl-polygon23014	0.41	0.01	11	0.30	0.00	11	0.29	0.01	11	0.11	-0.01
2006	Trawl-polygon23016	0.44	0.01	10	0.29	0.00	10	0.27	0.01	10	0.15	-0.02
2006	Trawl-polygon23017	0.40	0.01	10	0.29	0.00	10	0.31	0.00	10	0.10	0.01
2006	Trawl-polygon23019	0.46	0.02	9	0.27	0.01	9	0.27	0.01	9	0.19	0.01
2006	Trawl-polygon23020	0.43	0.01	11	0.28	0.00	11	0.29	0.00	11	0.15	0.01
2006	Outside23006-23007	0.44	0.01	38	0.30	0.01	38	0.27	0.01	38	0.14	-0.03
2006	Outside23011-23012	0.43	0.01	42	0.28	0.01	42	0.29	0.01	42	0.15	0.01
2006	Outside23013-23014	0.43	0.01	35	0.29	0.00	35	0.28	0.00	35	0.14	-0.02
2006	Outside23016-23017	0.44	0.01	49	0.29	0.00	49	0.27	0.00	49	0.15	-0.02
2006	Outside23019-23020	0.45	0.01	49	0.28	0.01	49	0.27	0.00	49	0.17	-0.01

Appendix 21. Descriptive statistic of the mean frequency response, r(f), values for the trawl-polygons of the resonant myctophids (R_MYC) and deep myctophids (D_MYC) for the “blue whiting surveys” in 2005 and 2006 .

		18kHz			38kHz			70kHz			Delta r(f)	
Species Group	Trawl-polygon	Mean	SE	N	Mean	SE	N	Mean	SE	N	18-38	70-38
R_MYC	Trawl-polygon167-23005	0.67	0.01	8	0.21	0.01	8	0.12	0.01	8	0.46	-0.09
R_MYC	Trawl-polygon167-23006	0.66	0.02	11	0.22	0.01	11	0.11	0.02	11	0.44	-0.11
R_MYC	Trawl-polygon181-23033	0.69	0.03	12	0.17	0.02	12	0.13	0.01	12	0.52	-0.04
R_MYC	Trawl-polygon181-23034	0.52	0.01	8	0.23	0.01	8	0.25	0.01	8	0.28	0.01
R_MYC	Trawl-polygon199-23005	0.65	0.01	12	0.23	0.00	12	0.12	0.01	12	0.42	-0.10
	Overall mean	*0.64*	*0.09*		*0.21*	*0.03*		*0.15*	*0.07*		*0.42*	*-0.06*
D_MYC	Trawl-polygon166-23003	0.40	0.03	8	0.39	0.03	8	0.21	0.00	8	0.00	-0.19
D_MYC	Trawl-polygon166-23004	0.36	0.02	8	0.42	0.02	8	0.23	0.01	8	-0.06	-0.19
D_MYC	Trawl-polygon180-23031	0.34	0.01	7	0.43	0.02	7	0.23	0.02	7	-0.09	-0.21
D_MYC	Trawl-polygon199-23006	0.32	0.01	9	0.36	0.01	9	0.32	0.01	9	-0.04	-0.04
D_MYC	Trawl-polygon200-23008	0.38	0.01	21	0.41	0.01	21	0.21	0.00	21	-0.03	-0.20
D_MYC	Trawl-polygon200-23009	0.37	0.01	12	0.42	0.01	12	0.21	0.00	12	-0.05	-0.21
	Overall mean	*0.36*	*0.03*		*0.41*	*0.03*		*0.23*	*0.05*		*-0.04*	*-0.17*

Appendix 22. Summaries of Mann-Whitney U test of frequency response between trawl-polygon and outside the trawl-polygon among frequencies for blue whiting

Frequency	Rank Sum inside	Rank Sum outside	U	Z	p level	Z adjusted	p level	Valid N inside	Valid N outside	2*1 sided exact p
18kHz	772	356	236	0.091	0.927	0.091	0.927	32	15	0.937
38kHz	723	405	195	-1.027	0.304	-1.027	0.304	32	15	0.314
70kHz	798	330	210	0.685	0.494	0.685	0.494	32	15	0.505

Appendix 23. Summaries of Mann-Whitney U test of frequency response between R_MYC and D_MYC among frequencies

Frequency	Rank Sum R_MYC	Rank Sum D_MYC	U	Z	p level	Z adjusted	p level	Valid N R_MYC	Valid N D_MYC	2*1 sided exact p
18kHz	45	21	0.00	2.74	0.006	2.74	0.006	5	6	0.004
38kHz	15	51	0.00	-2.74	0.006	-2.73	0.006	5	6	0.004
70kHz	20	46	5.00	-1.83	0.067	-1.83	0.067	5	6	0.082

Appendix 24. s_A (m^2/nmi^2), r(f) and depth (m) of blue whiting schools (A), resonant myctophids (B) and deep myctophids (C) selected along the survey transects during the survey in 2005 and 2006

(A)

School	$s_A(18)$	$s_A(38)$	$s_A(70)$	r(18)	r(38)	r(70)	Min depth (m)	Max depth (m)	School depth (m)	r(18)-r(38)	r(70-r(38)	Log(s_A38)
1	4849	3942	4392	0.37	0.30	0.33	513	597	555	0.07	0.03	3.60
2	1570	1236	1243	0.39	0.31	0.31	483	541	512	0.08	0.00	3.09
3	1191	802	765	0.43	0.29	0.28	842	583	713	0.14	-0.01	2.90
4	510	307	307	0.45	0.27	0.27	500	585	543	0.18	0.00	2.49
5	404	294	266	0.42	0.30	0.28	492	625	559	0.12	-0.02	2.47
6	1733	1280	1287	0.40	0.30	0.30	500	562	531	0.10	0.00	3.11
7	1666	1384	1377	0.38	0.31	0.31	483	537	510	0.07	0.00	3.14
8	2347	1809	1831	0.39	0.30	0.31	500	570	535	0.09	0.01	3.26
9	2515	1890	2068	0.39	0.29	0.32	479	574	527	0.10	0.03	3.28
10	1179	814	877	0.41	0.28	0.31	490	572	531	0.13	0.03	2.91
11	1627	1160	1160	0.41	0.29	0.29	437	542	490	0.12	0.00	3.06
12	1266	966	936	0.40	0.30	0.30	456	562	509	0.10	0.00	2.98
13	2957	1844	1612	0.46	0.29	0.25	411	555	483	0.17	-0.04	3.27
14	2116	1515	1574	0.41	0.29	0.30	404	600	502	0.12	0.01	3.18
15	1272	942	990	0.40	0.29	0.31	468	554	511	0.11	0.02	2.97
16	3569	2686	2615	0.40	0.30	0.29	454	528	491	0.10	-0.01	3.43
17	4881	3254	3332	0.43	0.28	0.29	500	700	600	0.15	0.01	3.51
18	22555	13121	13178	0.46	0.27	0.27	452	679	566	0.19	0.00	4.12
19	27538	18153	19951	0.42	0.28	0.30	442	545	494	0.14	0.02	4.26
20	12384	8400	8905	0.42	0.28	0.30	454	620	537	0.14	0.02	3.92
21	2725	1649	1804	0.44	0.27	0.29	474	600	537	0.17	0.02	3.22
22	4348	2645	2844	0.44	0.27	0.29	496	641	569	0.17	0.02	3.42
23	3482	1974	1952	0.47	0.27	0.26	370	650	510	0.20	-0.01	3.30
24	3680	2731	2973	0.39	0.29	0.32	465	644	555	0.10	0.03	3.44
25	2256	1668	1817	0.39	0.29	0.32	500	630	565	0.10	0.03	3.22
26	13994	10103	11036	0.40	0.29	0.31	510	630	570	0.11	0.02	4.00
27	1947	1423	1456	0.40	0.29	0.30	480	610	545	0.11	0.01	3.15
28	3031	2521	2436	0.38	0.32	0.30	391	492	442	0.06	-0.02	3.40
29	1505	1170	1199	0.39	0.30	0.31	425	539	482	0.09	0.01	3.07
30	34395	23659	24675	0.42	0.29	0.30	430	590	510	0.13	0.01	4.37
31	32498	23192	24430	0.41	0.29	0.30	412	595	504	0.12	0.01	4.37
32	13807	10263	10824	0.40	0.29	0.31	469	634	552	0.11	0.02	4.01
33	26222	16321	16991	0.44	0.27	0.29	435	633	534	0.17	0.02	4.21
34	205148	140497	154593	0.41	0.28	0.31	469	631	550	0.13	0.03	5.15
35	1001	663	658	0.43	0.29	0.28	410	500	455	0.14	-0.01	2.82
36	6727	4535	4644	0.42	0.29	0.29	403	581	492	0.13	0.00	3.66
37	7555	5033	5486	0.42	0.28	0.30	462	566	514	0.14	0.02	3.70
38	5081	3216	3161	0.44	0.28	0.28	312	665	489	0.16	0.00	3.51
39	792	531	537	0.43	0.29	0.29	540	615	578	0.14	0.00	2.73
40	3915	2999	3062	0.39	0.30	0.31	530	624	577	0.09	0.01	3.48
41	2742	2018	2061	0.40	0.30	0.30	544	626	585	0.10	0.00	3.30
42	3877	2568	2476	0.43	0.29	0.28	431	617	524	0.14	-0.01	3.41
43	4969	3768	3703	0.40	0.30	0.30	420	582	501	0.10	0.00	3.58
44	6869	5398	5344	0.39	0.31	0.30	438	561	500	0.08	-0.01	3.73
45	6982	5096	5411	0.40	0.29	0.31	457	570	514	0.11	0.02	3.71
46	1796	1405	1412	0.39	0.30	0.31	435	549	492	0.09	0.01	3.15
47	5340	3450	3731	0.43	0.28	0.30	490	676	583	0.15	0.02	3.54

48	1279	1067	1094	0.37	0.31	0.32	497	609	553	0.06	0.01	3.03
49	5547	4174	4803	0.38	0.29	0.33	556	669	613	0.09	0.04	3.62
50	7198	5388	5356	0.40	0.30	0.30	371	530	451	0.10	0.00	3.73
51	2015	1131	1109	0.47	0.27	0.26	503	584	544	0.20	-0.01	3.05
52	16113	12156	12387	0.40	0.30	0.30	477	623	550	0.10	0.00	4.08
53	5840	4186	4482	0.40	0.29	0.31	476	650	563	0.11	0.02	3.62
54	5498	3971	4268	0.40	0.29	0.31	552	655	604	0.11	0.02	3.60
55	11190	7127	7396	0.44	0.28	0.29	481	622	552	0.16	0.01	3.85
56	6419	4480	4525	0.42	0.29	0.29	402	544	473	0.13	0.00	3.65
57	6880	5398	5436	0.39	0.30	0.31	433	562	498	0.09	0.01	3.73
			Overall mean	*0.411*	*0.29*	*0.298*	*469*	*595*	*532*	*0.12*	*0.01*	
			SE	*0.003*	*0.002*	*0.002*						

(B)

School	$s_A(18)$	$s_A(38)$	$s_A(70)$	r(18)	r(38)	r(70)	Min depth (m)	Max depth (m)	School depth (m)	r(18)-r(38)	r(70-r(38)	Log(s_A38)
1	498	157	78	0.68	0.21	0.11	323	544	434	0.47	-0.10	2.20
2	758	239	119	0.68	0.21	0.11	345	513	429	0.47	-0.10	2.38
3	602	221	100	0.65	0.24	0.11	303	540	422	0.41	-0.13	2.34
4	596	150	68	0.73	0.18	0.08	293	544	419	0.55	-0.10	2.18
5	422	134	67	0.68	0.22	0.11	328	513	421	0.46	-0.11	2.13
6	401	110	49	0.72	0.20	0.09	300	490	395	0.52	-0.11	2.04
7	794	246	114	0.69	0.21	0.10	300	505	403	0.48	-0.11	2.39
8	946	284	150	0.69	0.21	0.11	268	510	389	0.48	-0.10	2.45
9	602	134	65	0.75	0.17	0.08	263	528	396	0.58	-0.09	2.13
10	304	93	44	0.69	0.21	0.10	340	509	425	0.48	-0.11	1.97
11	347	94	54	0.70	0.19	0.11	350	450	400	0.51	-0.08	1.97
12	304	75	37	0.73	0.18	0.09	345	458	402	0.55	-0.09	1.88
13	613	157	86	0.72	0.18	0.10	264	468	366	0.54	-0.08	2.20
14	127	40	27	0.66	0.20	0.14	326	445	386	0.46	-0.06	1.60
15	627	168	99	0.70	0.19	0.11	200	600	400	0.51	-0.08	2.23
16	272	87	67	0.64	0.21	0.16	323	495	409	0.43	-0.05	1.94
17	425	91	48	0.75	0.16	0.09	250	370	310	0.59	-0.07	1.96
18	775	205	120	0.70	0.19	0.11	120	500	310	0.51	-0.08	2.31
19	883	247	124	0.70	0.20	0.10	328	518	423	0.50	-0.10	2.39
20	93	22	14	0.72	0.17	0.11	306	472	389	0.55	-0.06	1.34
21	1129	366	260	0.64	0.21	0.15	300	450	375	0.43	-0.06	2.56
22	800	200	133	0.71	0.18	0.12	290	469	380	0.53	-0.06	2.30
23	429	112	69	0.70	0.18	0.11	300	470	385	0.52	-0.07	2.05
24	147	37	24	0.71	0.18	0.12	320	420	370	0.53	-0.06	1.57
25	463	200	103	0.60	0.26	0.13	383	640	512	0.34	-0.13	2.30
26	568	238	139	0.60	0.25	0.15	387	518	453	0.35	-0.10	2.38
27	449	166	89	0.64	0.24	0.13	414	565	490	0.40	-0.11	2.22
28	393	138	90	0.63	0.22	0.14	244	551	398	0.41	-0.08	2.14
29	266	98	70	0.61	0.23	0.16	300	524	412	0.38	-0.07	1.99
30	314	90	49	0.69	0.20	0.11	266	487	377	0.49	-0.09	1.95
31	304	94	52	0.68	0.21	0.12	295	498	397	0.47	-0.09	1.97
32	739	275	180	0.62	0.23	0.15	268	517	393	0.39	-0.08	2.44
33	390	119	75	0.67	0.20	0.13	275	500	388	0.47	-0.07	2.08
34	412	154	74	0.64	0.24	0.12	348	562	455	0.40	-0.12	2.19
35	529	165	93	0.67	0.21	0.12	359	600	480	0.46	-0.09	2.22
36	312	72	40	0.74	0.17	0.09	226	425	326	0.57	-0.08	1.86
37	391	154	70	0.64	0.25	0.11	356	588	472	0.39	-0.14	2.19

38	586	168	76	0.71	0.20	0.09	327	543	435	0.51	-0.11	2.23
39	676	208	101	0.69	0.21	0.10	345	577	461	0.48	-0.11	2.32
40	882	224	120	0.72	0.18	0.10	300	521	411	0.54	-0.08	2.35
41	359	95	56	0.70	0.19	0.11	220	446	333	0.51	-0.08	1.98
42	393	114	69	0.68	0.20	0.12	280	500	390	0.48	-0.08	2.06
			Overall mean	*0.682*	*0.204*	*0.114*	*302*	*508*	*405*	*0.48*	*-0.09*	
			SE	*0.006*	*0.004*	*0.003*						

(C)

School	s_A(18)	s_A(38)	s_A(70)	r(18)	r(38)	r(70)	Min depth (m)	Max depth (m)	Scholl depth (m)	r(18)-r(38)	r(70-r(38)	Log(s_A38)
1	227	352	219	0.28	0.44	0.27	511	750	631	-0.16	-0.17	2.55
2	154	148	101	0.38	0.37	0.25	549	700	625	0.01	-0.12	2.17
3	349	371	191	0.38	0.41	0.21	537	700	619	-0.03	-0.20	2.57
4	157	218	130	0.31	0.43	0.26	523	700	612	-0.12	-0.17	2.34
5	184	211	110	0.36	0.42	0.22	512	700	606	-0.06	-0.20	2.32
6	205	272	160	0.32	0.43	0.25	540	700	620	-0.11	-0.18	2.43
7	181	191	128	0.36	0.38	0.26	520	722	621	-0.02	-0.12	2.28
8	126	130	82	0.37	0.38	0.24	514	700	607	-0.01	-0.14	2.11
9	254	271	169	0.37	0.39	0.24	508	700	604	-0.02	-0.15	2.43
10	480	518	303	0.37	0.40	0.23	520	720	620	-0.03	-0.17	2.71
11	336	366	238	0.36	0.39	0.25	564	720	642	-0.03	-0.14	2.56
12	222	232	172	0.35	0.37	0.27	537	700	619	-0.02	-0.10	2.37
13	325	379	238	0.34	0.40	0.25	528	700	614	-0.06	-0.15	2.58
14	250	277	190	0.35	0.39	0.26	550	750	650	-0.04	-0.13	2.44
15	410	479	315	0.34	0.40	0.26	410	700	555	-0.06	-0.14	2.68
16	228	285	162	0.34	0.42	0.24	528	673	601	-0.08	-0.18	2.45
17	244	305	202	0.33	0.41	0.27	500	720	610	-0.08	-0.14	2.48
18	193	206	136	0.36	0.39	0.25	574	700	637	-0.03	-0.14	2.31
19	237	256	206	0.34	0.37	0.29	587	750	669	-0.03	-0.08	2.41
20	163	176	137	0.34	0.37	0.29	588	750	669	-0.03	-0.08	2.25
21	184	202	164	0.34	0.37	0.30	563	750	657	-0.03	-0.07	2.31
22	204	212	150	0.36	0.37	0.26	560	750	655	-0.01	-0.11	2.33
23	209	240	152	0.35	0.40	0.25	519	750	635	-0.05	-0.15	2.38
24	246	311	180	0.33	0.42	0.24	522	750	636	-0.09	-0.18	2.49
25	312	367	213	0.35	0.41	0.24	500	750	625	-0.06	-0.17	2.56
26	445	475	300	0.36	0.39	0.25	500	750	625	-0.03	-0.14	2.68
27	404	427	272	0.37	0.39	0.25	500	750	625	-0.02	-0.14	2.63
28	272	271	143	0.40	0.40	0.21	522	750	636	0.00	-0.19	2.43
29	355	402	257	0.35	0.40	0.25	572	750	661	-0.05	-0.15	2.60
30	338	384	233	0.35	0.40	0.24	526	700	613	-0.05	-0.16	2.58
31	161	180	132	0.34	0.38	0.28	653	750	702	-0.04	-0.10	2.26
32	255	268	138	0.39	0.41	0.21	505	700	603	-0.02	-0.20	2.43
33	359	387	239	0.36	0.39	0.24	505	750	628	-0.03	-0.15	2.59
			Overall mean	*0.352*	*0.396*	*0.252*	*532*	*728*	*630*	*-0.04*	*-0.14*	
			SE	*0.004*	*0.003*	*0.004*						

Appendix 25. Mann-Whitney U test for the mean frequency response, r(f) at given frequency between species. (A): blue whiting and resonant myctophids; (B): blue whiting and deep myctophids and (C): deep myctophids and resonant myctphids

(A)

Frequency	Rank Sum BW	Rank Sum R_MYC	U	Z	p level	Z adjusted	p level	Valid N BW	Valid N R_MYC	2*1 sided exact p
18kHz	1653.00	3297.00	0.00	-8.48	0.00	-8.49	0.00	57	42	0.00
38kHz	4047.00	903.000	0.00	8.47	0.00	8.55	0.00	57	42	0.00
70kHz	4047.00	903.000	0.00	8.47	0.00	8.52	0.00	57	42	0.00

(B)

Frequency	Rank Sum BW	Rank Sum D_MYC	U	Z	p level	Z adjusted	p level	Valid N BW	Valid N D_MYC	2*1 sided exact p
18kHz	3491.00	604.00	43.00	7.51	0.00	7.55	0.00	57	33	0.00
38kHz	1653.00	2442.00	0.00	-7.87	0.00	-7.96	0.00	57	33	0.00
70kHz	3442.00	653.00	92.00	7.10	0.00	7.16	0.00	57	33	0.00

(C)

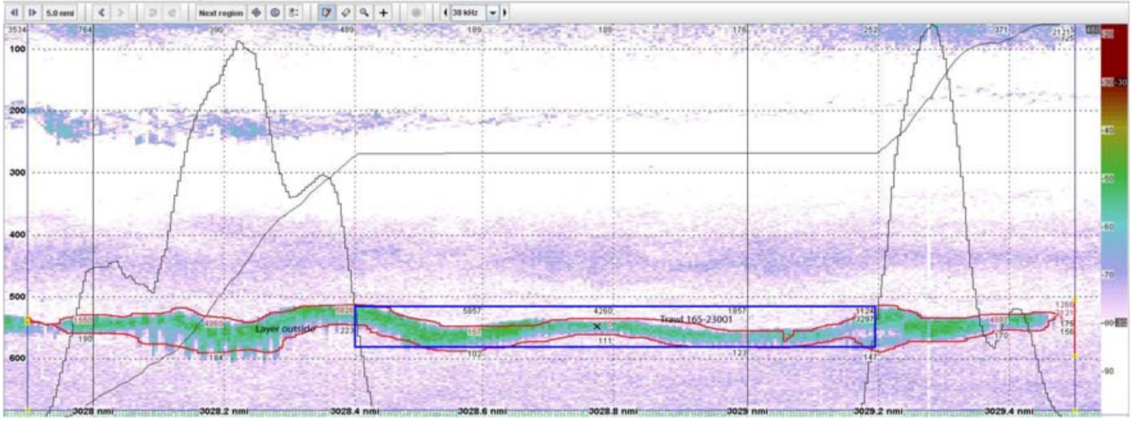
Frequency	Rank Sum R_MYC	Rank Sum D_MYC	U	Z	p level	Z adjusted	p level	Valid N R_MYC	Valid N D_MYC	2*1 sided exact p
18kHz	2289.00	561.00	0.00	7.39	0.00	7.41	0.00	42	33	0.00
38kHz	903.00	1947.00	0.00	-7.39	0.00	-7.42	0.00	42	33	0.00
70kHz	903.00	1947.00	0.00	-7.39	0.00	-7.43	0.00	42	33	0.00

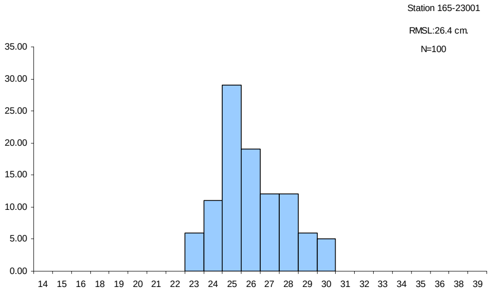
Appendix 26. Summaries of regression analysis between frequency responses r(18), r(38), r(70) and length of fish.

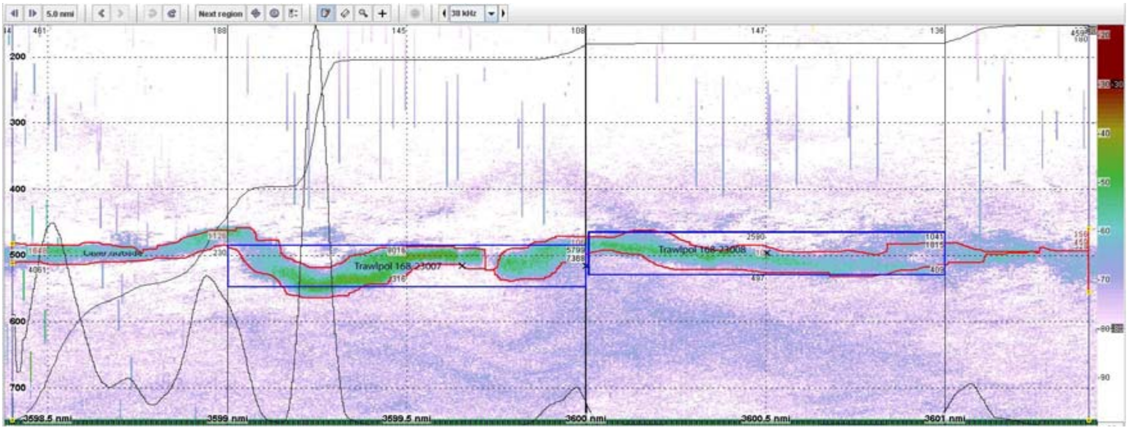
	r(18)	r(38)	r(70)
R	0.21	0.09	0.16
R^2	0.04	0.01	0.03
F(1,30)	1.34	0.24	0.79
p-value	0.26	0.63	0.38
SD of estimate	0.02	0.02	0.02

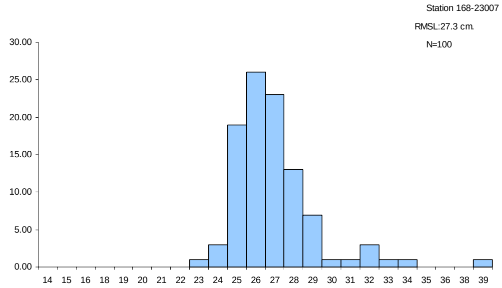
Appendix 27. Echograms show the constructed trawl-polygon (trawlpol) and the layer outside the trawl-polygon that used to calculate the frequency response of blue whiting. The length frequency distributions of blue whiting corresponding to the trawl-polygon showed below the echogram. X-axis is length of fish in centimeter and Y-axis indicates relative frequency (%).

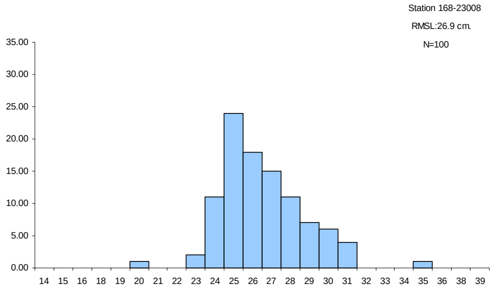
A: Blue whiting survey 2005

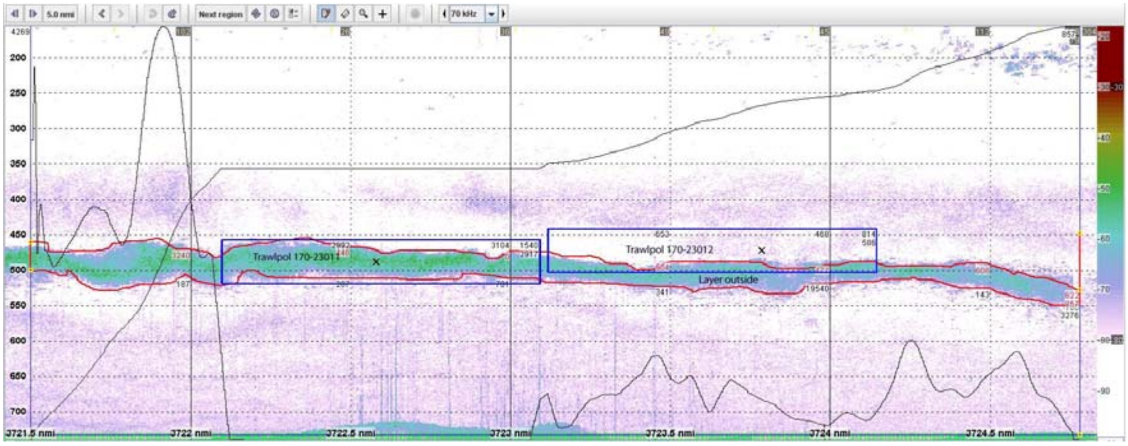


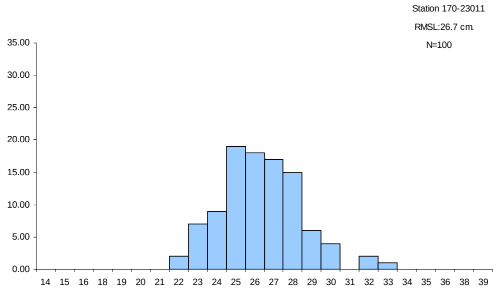


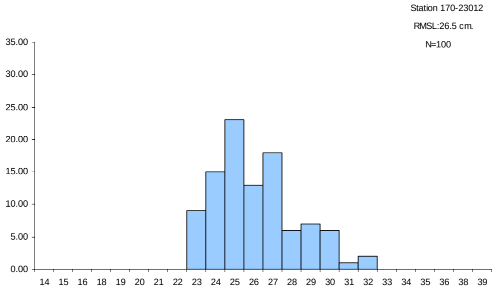







5.0 nmi
Next region
70 kHz
200
250
300
350
400
450
500
550
600
650
700
Trawlpol 170-23011
Trawlpol 170-23012
Layer outside
3721.5 nmi
3722 nmi
3722.5 nmi
3723 nmi
3723.5 nmi
3724 nmi
3724.5 nmi
-30
-40
-50
-60
-70
-80
-90


Station 170-23011
RMSL:26.7 cm.
N=100
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
14 15 16 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 38 39


Station 170-23012
RMSL:26.5 cm.
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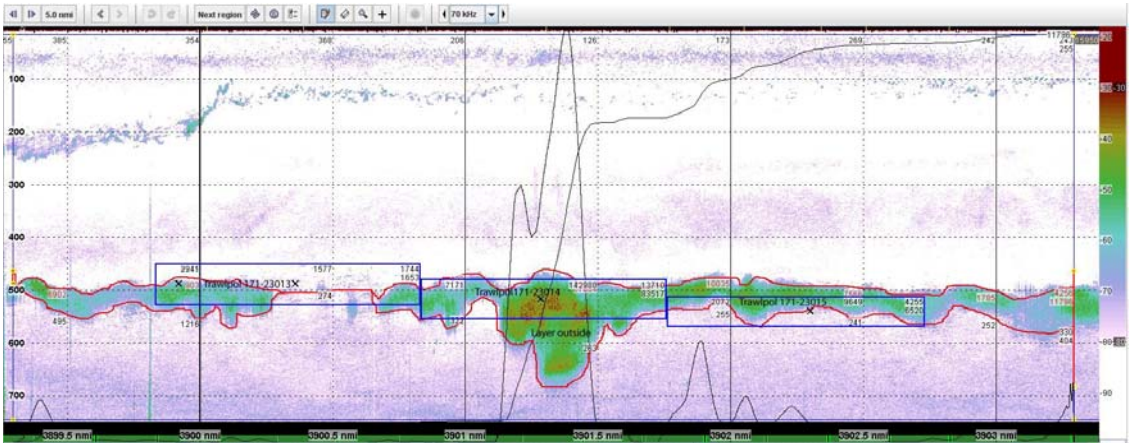
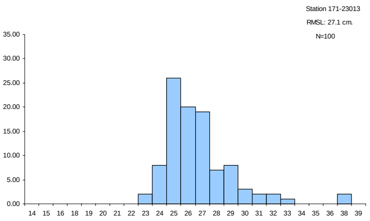
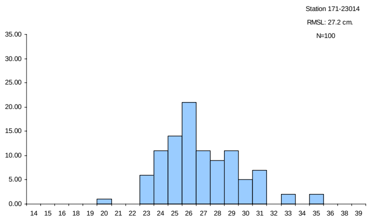
25.00
20.00
15.00
10.00
5.00
0.00
14 15 16 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 38 39


5.0 nmi
Next region
70 kHz
100
200
300
400
500
600
700
Trawlpol 171-23013
Trawlpol 171-23014
Trawlpol 171-23015
Layer outside
3899.5 nmi
3900 nmi
3900.5 nmi
3901 nmi
3901.5 nmi
3902 nmi
3902.5 nmi
3903 nmi
-30
-40
-50
-60
-70
-80
-90


Station 171-23013
RMSL: 27.1 cm.
N=100
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
14 15 16 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 38 39


Station 171-23014
RMSL: 27.2 cm.
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20.00
15.00
10.00
5.00
0.00
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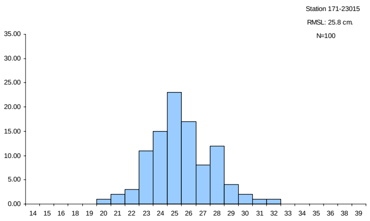
Station 171-23015
RMSL: 25.8 cm.
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35.00
30.00
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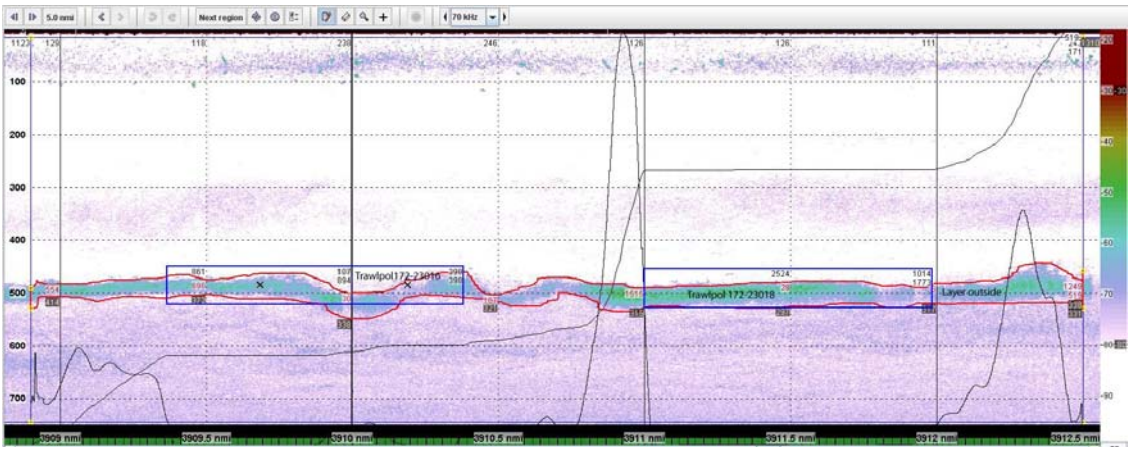
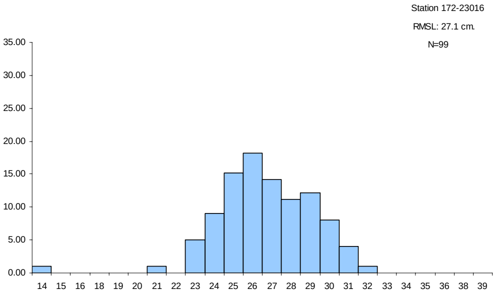
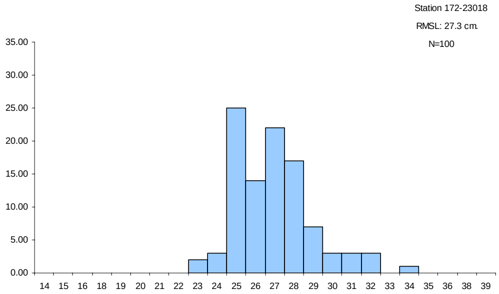
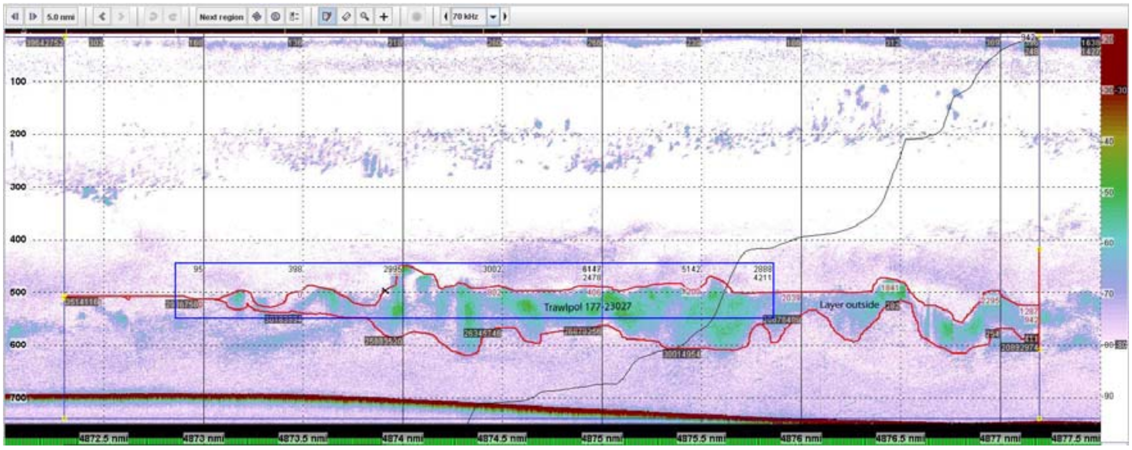
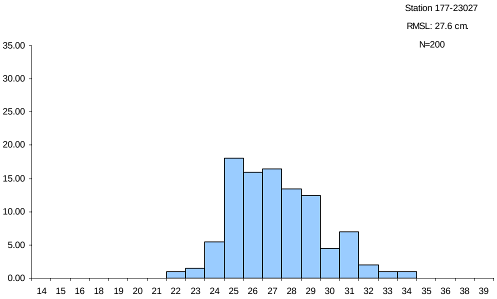
20.00
15.00
10.00
5.00
0.00
14 15 16 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 38 39

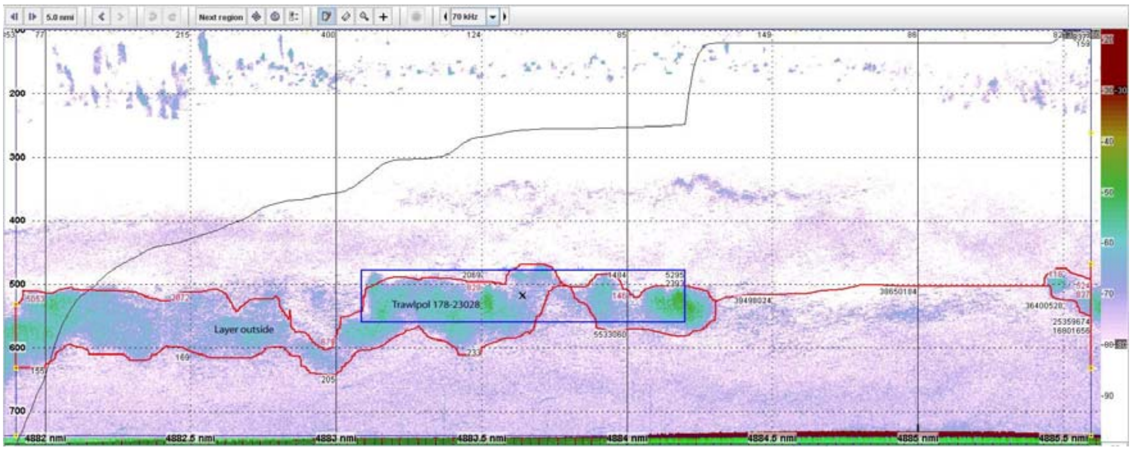


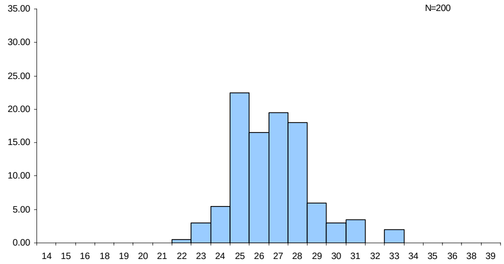

Station 172-23016
RMSL: 27.1 cm.
N=99

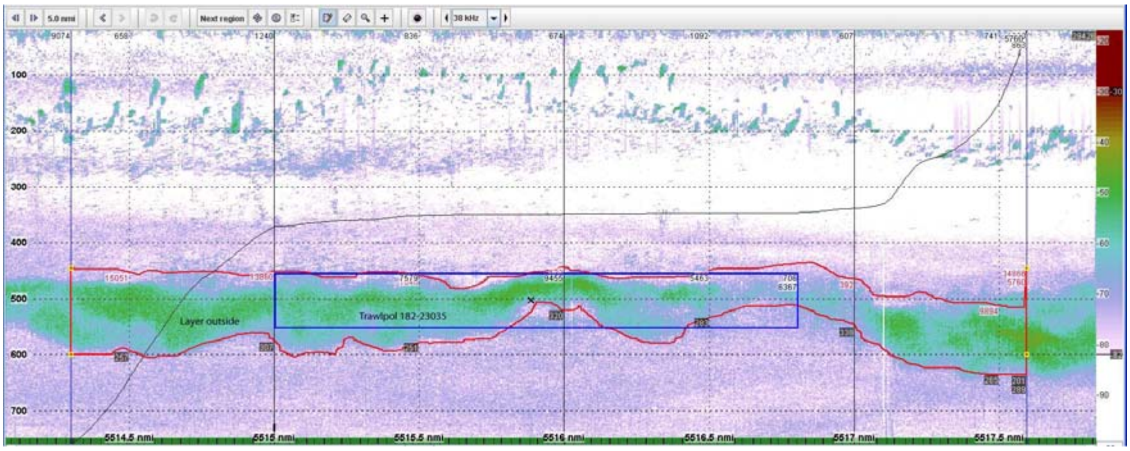

Station 172-23018
RMSL: 27.3 cm.
N=100

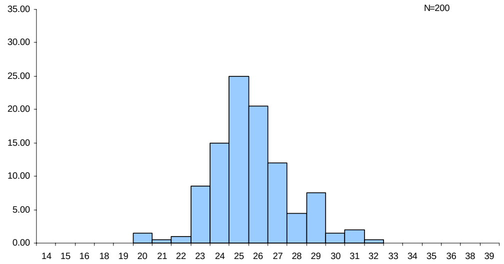


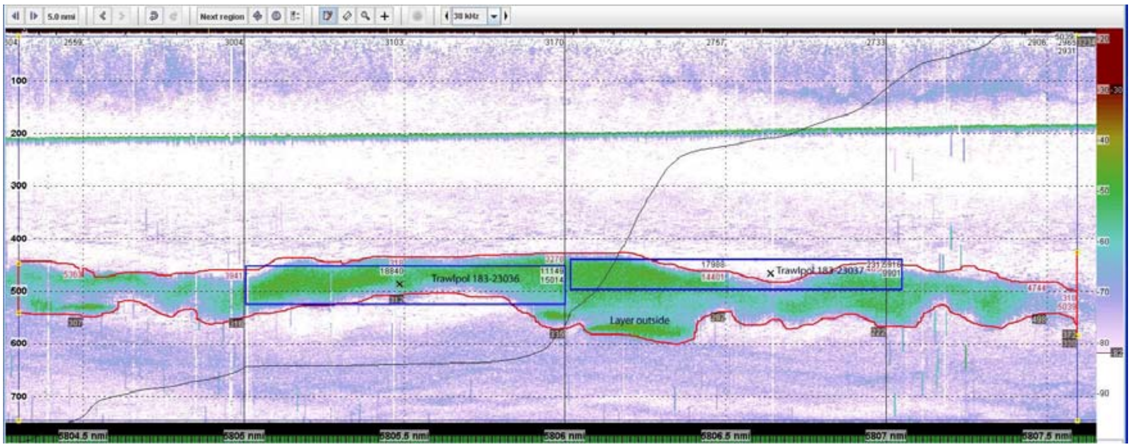

Station 177-23027
RMSL: 27.6 cm.
N=200



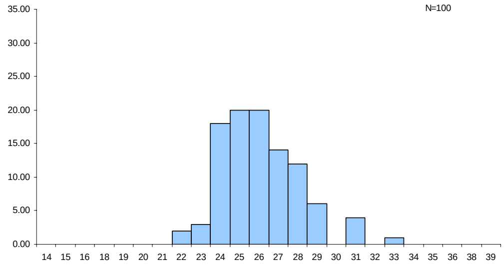

Station 178-23028
RMSL: 27.1 cm.
N=200



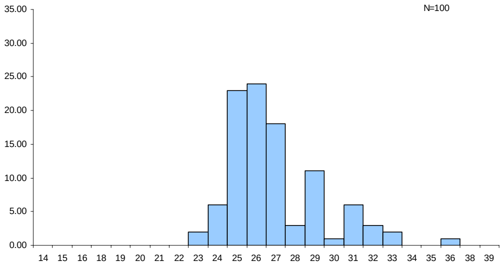

Station 182-23035
RMSL: 26.0 cm.
N=200

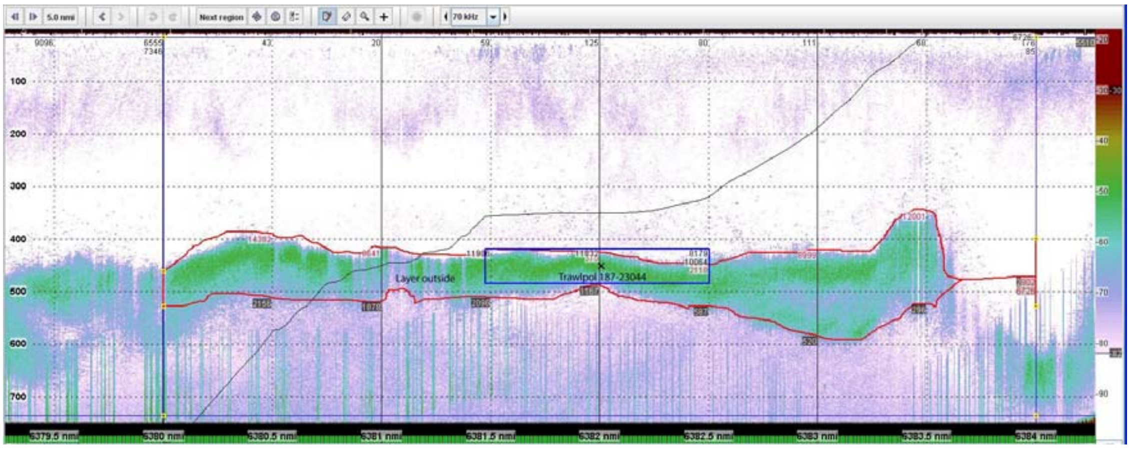


Station 183-23036
RMSL: 26.4 cm.
N=100

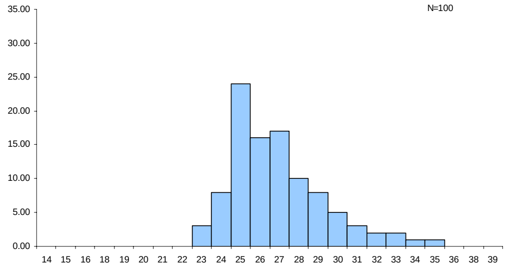


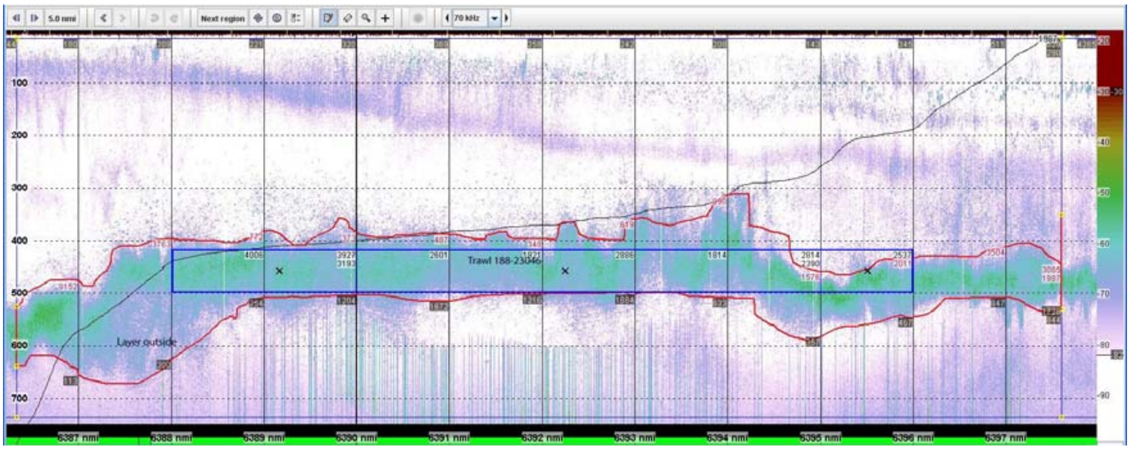
Station 183-23037
RMSL: 27.3 cm.
N=100

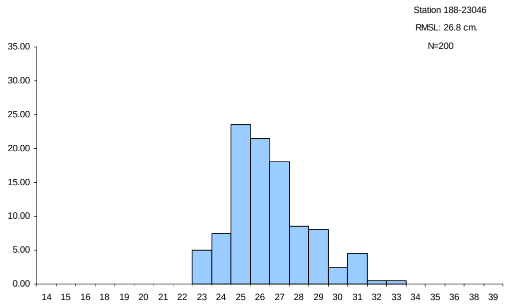




Station 187-23044
RMSL: 27.3 cm.
N=100



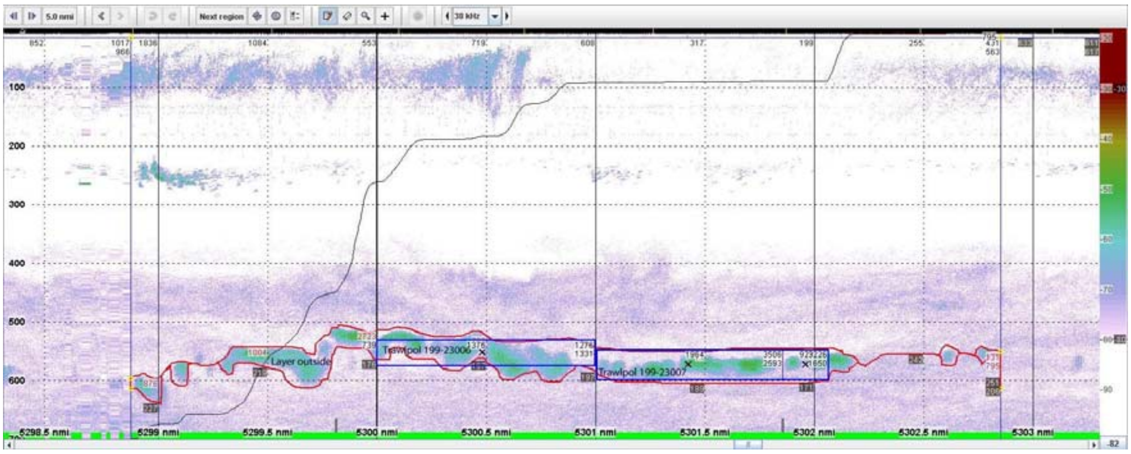


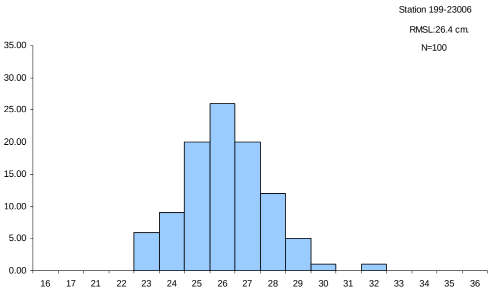

Station 188-23046

RMSL: 26.8 cm.

N=200

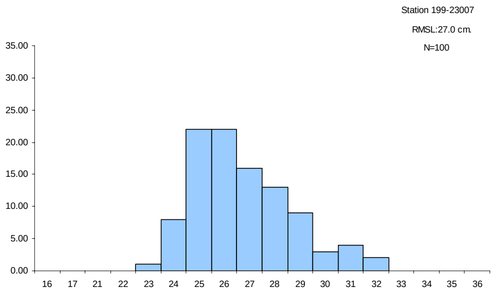
B: Blue whiting survey 2006




Station 199-23006

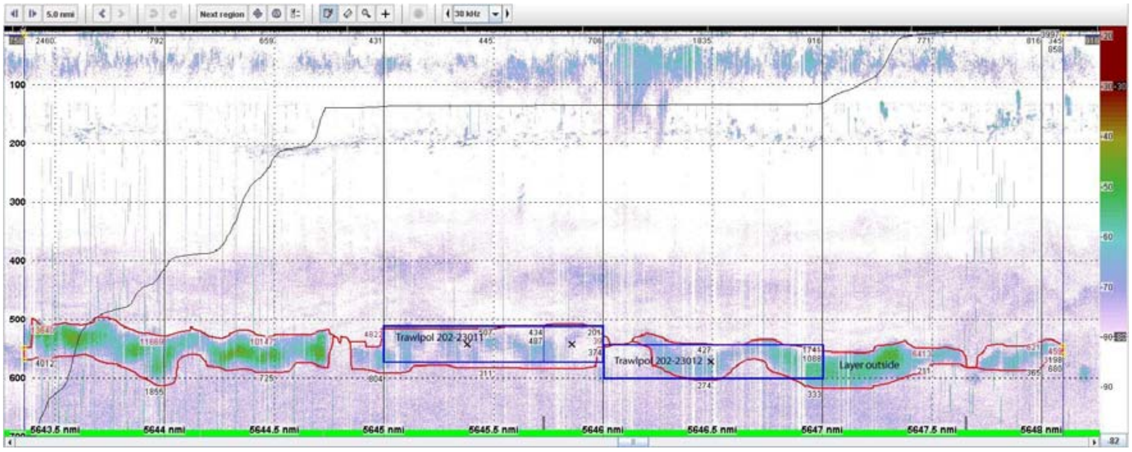
RMSL:26.4 cm.

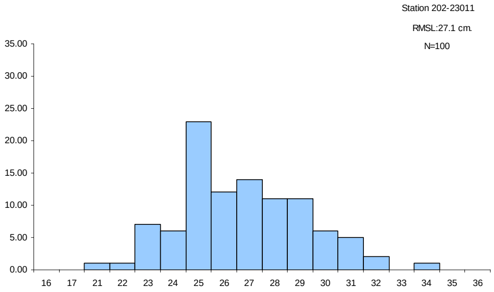
N=100

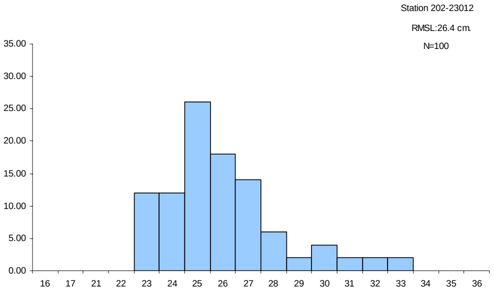

Station 199-23007

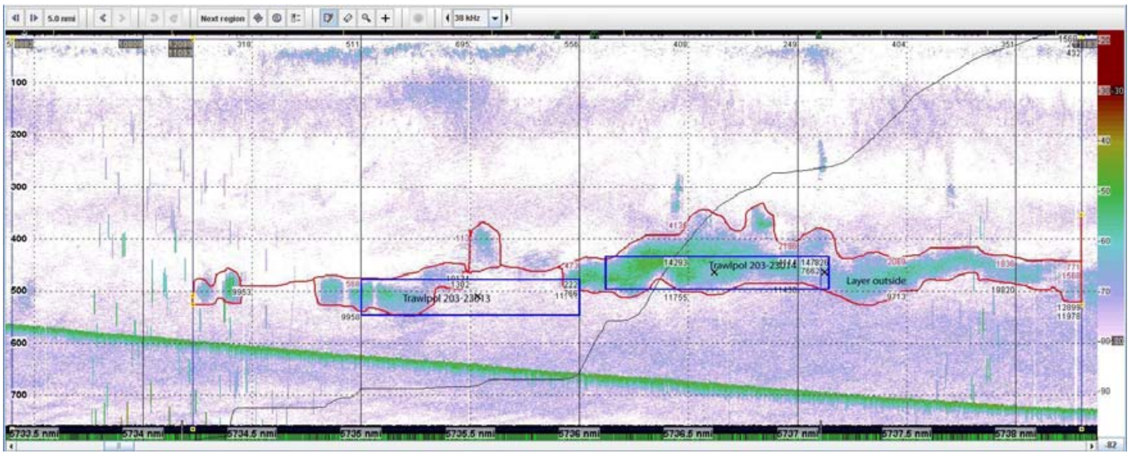
RMSL:27.0 cm.

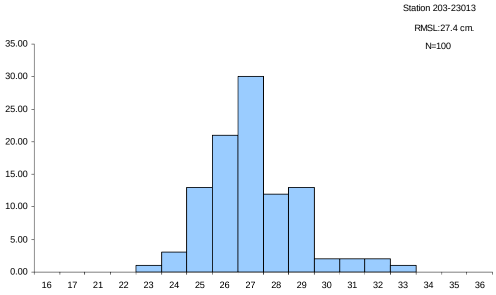
N=100

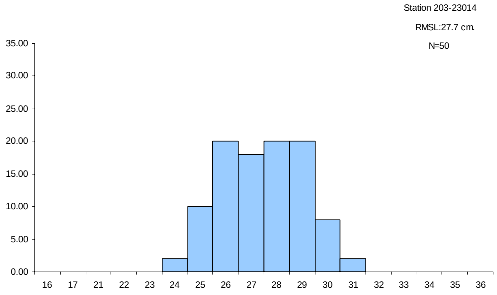


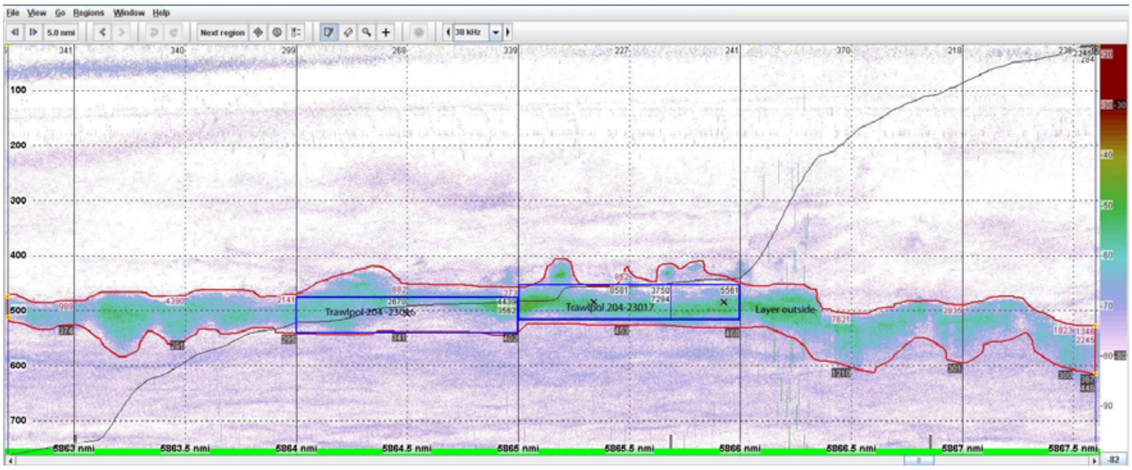

Station 202-23011
RMSL:27.1 cm.
N=100

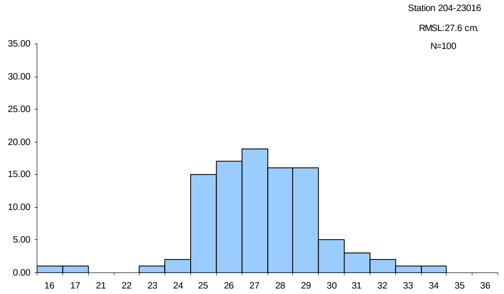

Station 202-23012
RMSL:26.4 cm.
N=100

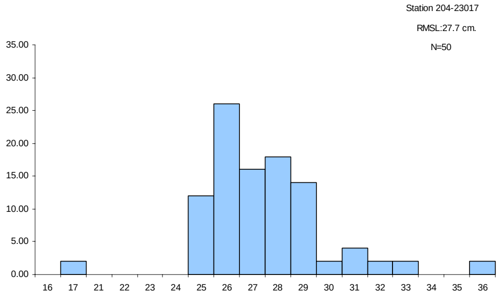



Station 203-23013
RMSL:27.4 cm.
N=100


Station 203-23014
RMSL:27.7 cm.
N=50


File View Go Regions Window Help
5.0 nmi
Next region
38 kHz
100
200
300
400
500
600
700
Trawlpol 204-23016
Trawlpol 204-23017
Layer outside
5863 nmi
5863.5 nmi
5864 nmi
5864.5 nmi
5865 nmi
5865.5 nmi
5866 nmi
5866.5 nmi
5867 nmi
5867.5 nmi


Station 204-23016
RMSL:27.6 cm.
N=100
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
16 17 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36


Station 204-23017
RMSL:27.7 cm.
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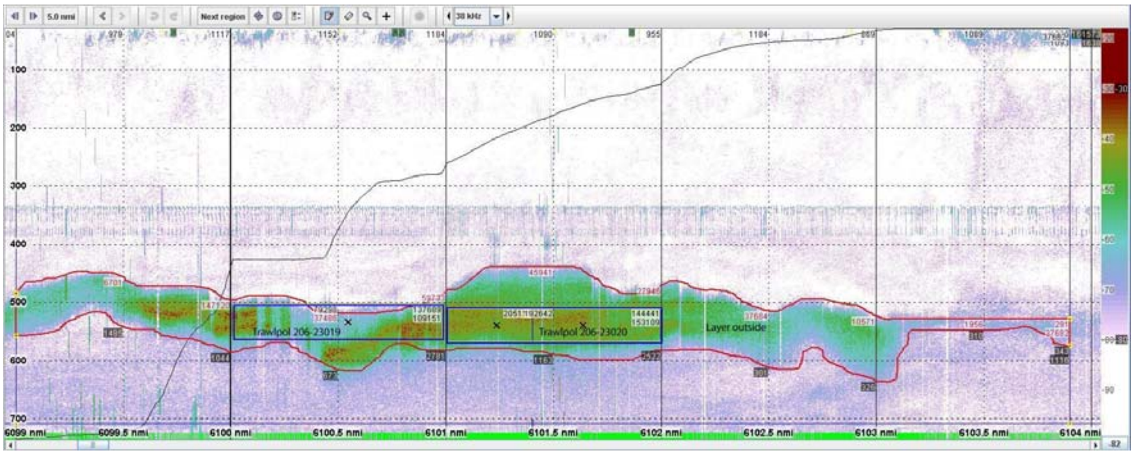
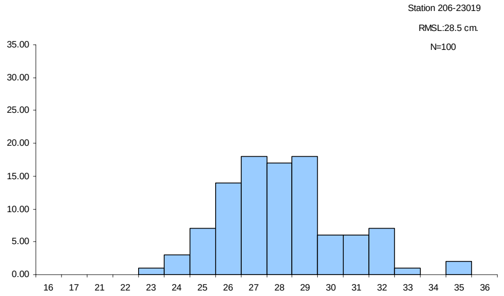
30.00
25.00
20.00
15.00
10.00
5.00
0.00
16 17 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36


5.0 nmi
Next region
38 kHz
100
200
300
400
500
600
700
Trawlpol 206-23019
Trawlpol 206-23020
Layer outside
6099 nmi
6099.5 nmi
6100 nmi
6100.5 nmi
6101 nmi
6101.5 nmi
6102 nmi
6102.5 nmi
6103 nmi
6103.5 nmi
6104 nmi


Station 206-23019
RMSL:28.5 cm.
N=100
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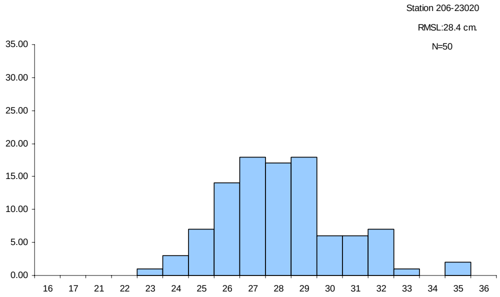
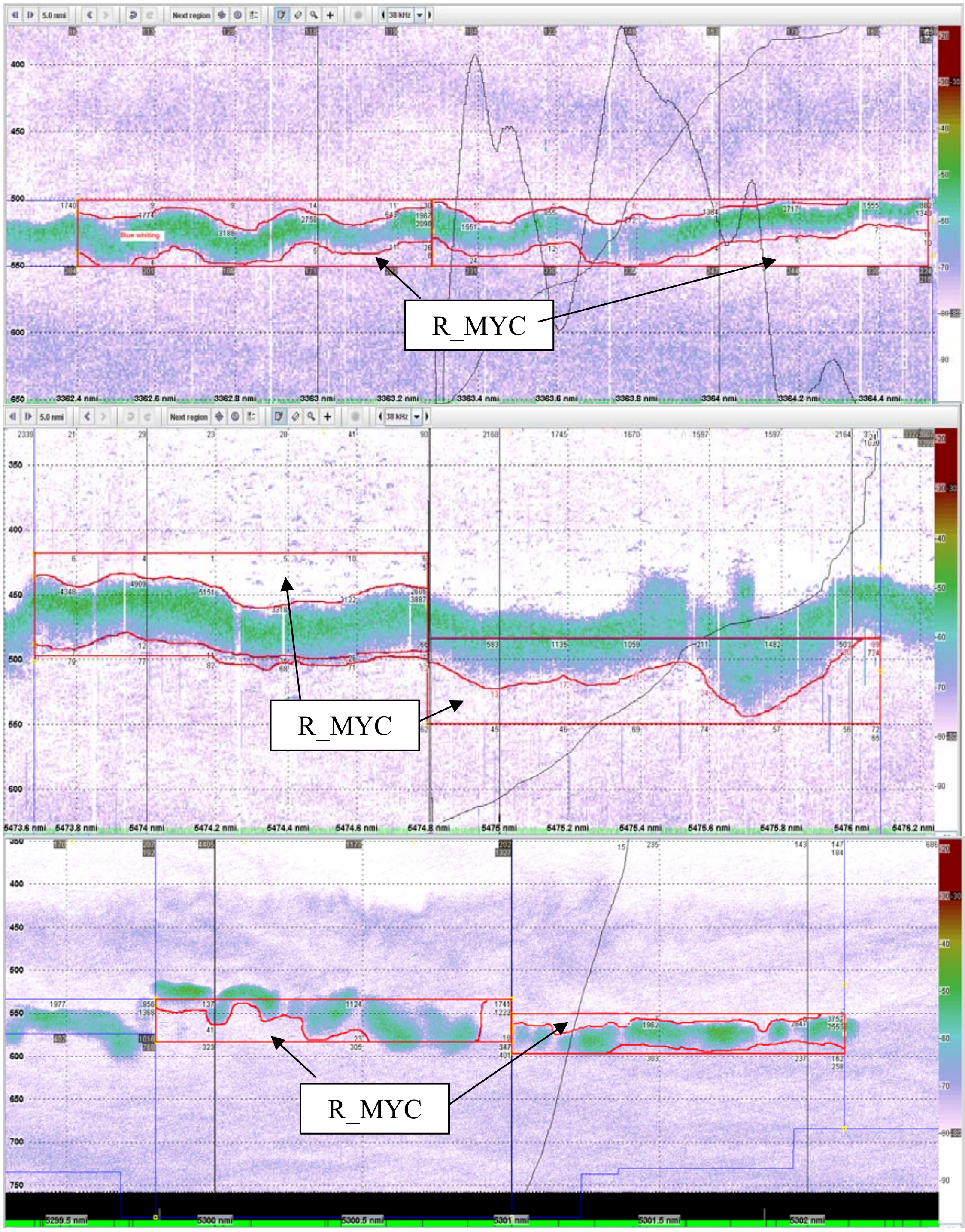
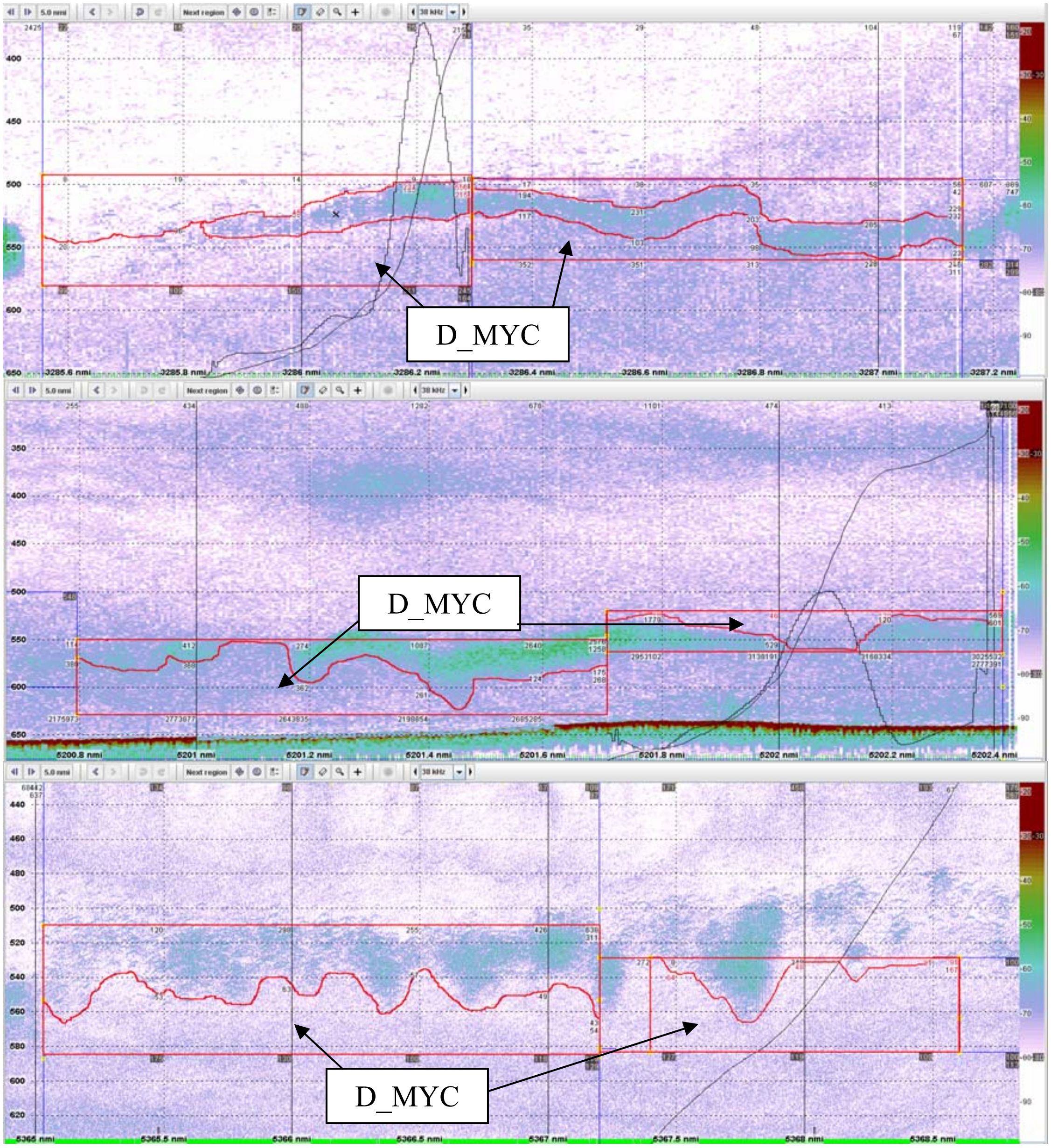
25.00
20.00
15.00
10.00
5.00
0.00
16 17 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36


Station 206-23020
RMSL:28.4 cm.
N=50
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
16 17 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

Appendix 28. Constructed trawl-polygons of resonant myctophid group (R_MYC). Echograms of 38 kHz are shown, from top to the bottom is trawl number 167, 181 and 199. Rectangles indicate the trawl-polygon, blue whiting is isolated by polygons inside the rectangle.



Appendix 29. Constructed trawl-polygons of deep myctophid group (D_MYC). Echograms of 38 kHz are shown, from top to the bottom is trawl number 166, 180 and 200. Rectangles indicate the trawl-polygon, blue whiting is isolated by polygons inside the rectangle.



Appendix 30. Statistic summaries of discriminant function analysis

	Wilks' Lambda	Partial Lambda	F-remove	p-value	Tolerance	R^2
LOGR(18)	0.007	0.724	23.827	0.000	0.293	0.707
LOGR(70)	0.009	0.565	48.092	0.000	0.470	0.530
LOGS$_A$(38)	0.007	0.744	21.539	0.000	0.988	0.012
LOGR(38)	0.006	0.893	7.493	0.001	0.447	0.553
LOGSCHOOLDEPTH	0.005	0.938	4.135	0.018	0.855	0.145

Appendix 31. Summary of F test for the equality of group means for each pair of groups using Mahalanobis distance. Blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC) using logarithm of r(18), r(38), r(70), school depth and sA38 as independent variables.

Between Groups F-matrix (df : 5 125)

	BW	D_MYC	R_MYC
BW	-	460.84	194.92
D_MYC	460.85	-	476.39
R_MYC	194.93	476.39	-

Appendix 32. The estimated classification functions for blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC) using logarithm of r(18), r(38), r(70), school depth and sA38 as independent variables.

	BW	D_MYC	R_MYC
LOGR(18)	-1960.25	-1858.58	-2044.03
LOGR(38)	-1402.91	-1368.75	-1359.48
LOGR(70)	-609.94	-652.53	-667.77
LOGS$_A$(38)	11.36	7.71	7.41
LOGSCHOOLDEPTH	1192.00	1169.14	1206.45
Constant	-5894.48	-5690.28	-6069.06

Appendix 33. Classification matrix of blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC). Cases in row categories classified into columns. Model used using logarithm of r(18), r(38), r(70), school depth and sA38 as independent variables.

	BW	D_MYC	R_MYC	% correct
BW	57	0	0	100
D_MYC	0	33	0	100
R_MYC	0	0	42	100
Total	57	33	42	100

Appendix 34. Chi square test with success roots removed

	Eigen-value	Canonical R	Wilk's lambda	Chi Square	df	p-level
0	22.46	0.98	0.005	672.60	10	0.00
1	7.50	0.94	0.117	271.85	4	0.00

Appendix 35. The estimated canonical discriminant functions using logarithm of r(18), r(38), r(70), school depth and s_A(38) as independent variables. Standardized by within variances are shown in brackets.

	Function 1	Function 2
LOGR(18)	0.952 (0.844)	-0.152 (-0.542)
LOGR(38)	-0.664 (0.097)	0.445 (0.511)
LOGR(70)	-0.778 (-0.160)	-0.414 (-1.010)
LOGsA(38)	-0.229 (-0.141)	-0.475 (-0.522)
LOGSCHOOLDEPTH	-0.414 (-0.250)	0.194 (0.121)
Constant	0.952	-0.152

Appendix 36. Statistic summaries discriminant analysis using logarithm of r(18), r(70) and s_A(38) as independent variable

	Wilks' Lambda	Partial Lambda	F-remove	p-value	Tolerance	R square
LOGR(18)	0.032	0.193	265.922	0.000	0.485	0.515
LOGR(70)	0.016	0.400	95.196	0.000	0.487	0.513
LOGsA(38)	0.009	0.730	23.446	0.000	0.992	0.008

Appendix 37. Summary of F-matrix testing for the equality of group means for each pair of groups using Mahalanobis distance. Blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC) using logarithm of r(18), r(70), and s_A38 as independent variables.

Between Groups F-matrix (df : 5 125)

	BW	D_MYC	R_MYC
BW		743.27	270.68
D_MYC	743.27		740.98
R_MYC	270.68	740.98	

Appendix 38. Classification functions for blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC) using logarithm of r(18), r(70) and s_A(38) as independent variables

	BW	D_MYC	R_MYC
LOGR(18)	-752.82	-681.61	-882.81
LOGR(70)	-385.91	-433.53	-447.07
LOGsA(38)	9.94	6.34	6.22
Constant	-609.15	-621.91	-789.48

Appendix 39. Classification matrix of blue whiting (BW), resonant myctophids (R_MYC) and deep myctophids (D_MYC). Cases in row categories classified into columns. Model used logarithm of r(18), r(70) and s_A(38) as independent variables

	BW	D_MYC	R_MYC	%c orrect
BW	57	0	0	100
D_MYC	0	33	0	100
R_MYC	0	0	42	100
Total	57	33	42	100

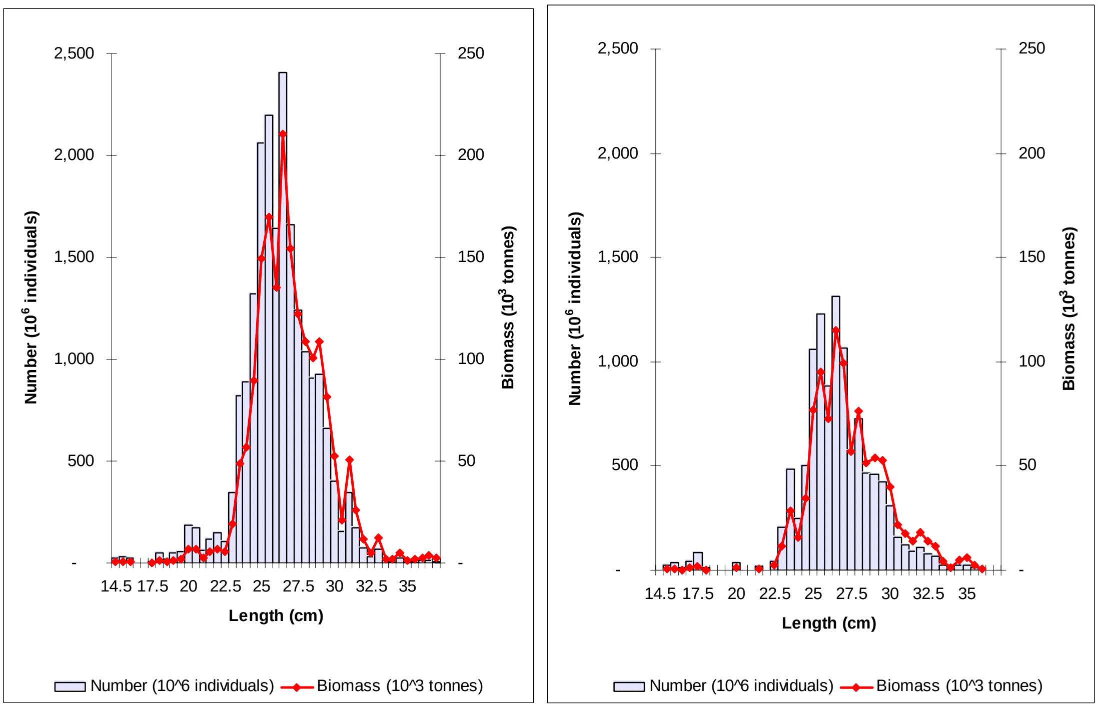
Appendix 40. Estimated canonical functions using logarithm of r(18), r(70) and $s_A(38)$ as independent variables. Standardized by within variances are shown in brackets.

	Function 1	Function 2
LOGR(18)	-13.356 (-0.80)	-18.316 (-1.10)
LOGR(70)	1.948 (0.22)	-10.367 (-1.17)
LOGsA(38)	0.189 (0.16)	-0.646 (-0.53)
Constant	-8.419	-26.147

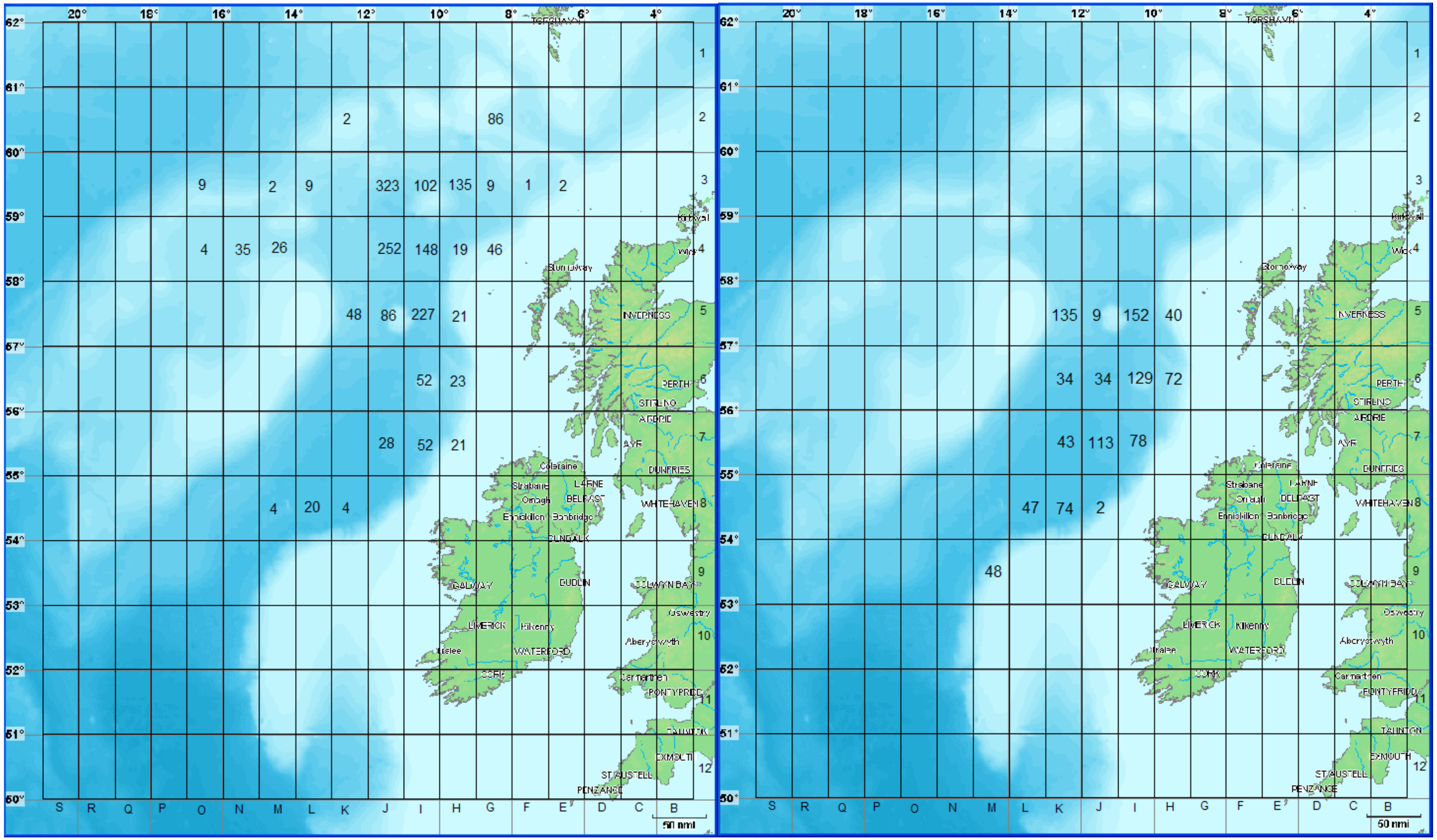
Appendix 41. Chi square test with success roots removed

	Eigen-value	Canonical R	Wilk's lambda	Chi square	df	p-level
0	21.27	0.98	0.01	649.89	6.00	0.00
1	6.20	0.93	0.14	252.65	2.00	0.00

Appendix 42. Plots of biomass (x10^3 tonnes) and abundance (x10^6 individuals) against length (cm) of blue whiting in 2005 (on the left) and 2006 (on the right)



Appendix 43. Estimated blue whiting biomass (in thousand tonnes) for each stratum of 1^0 latitude and 1^0 longitude. The survey in 2005 on the left and in 2006 on the right.



Appendix 44. Estimated biomass (thousand tonnes) and density (tonnes/nmi^2) of blue whiting for each stratum in 2005 and 2006. Stratum is limited of 1^0 longitute and 1^0 latitude, as shown in Figure 2.

Stratum	Area	2005		2006	
	(nmi^2)	Biomass (x10^3 tonnes)	Density (tonnes/nmi^2)	Biomass (x10^3 tonnes)	Density (tonnes/nmi^2)
E3	2423	2	0.9		
F3	2423	1	0.3		
G2	2351	86	36.6		
G3	2423	9	3.8		
G4	2494	46	18.4		
H3	2423	135	55.8		
H4	2494	19	7.7		
H5	2556	21	8.1	40	15.6
H6	2635	23	8.7	72	27.2
H7	2704	21	7.6		
I3	2423	102	42.1		
I4	2494	148	59.2		
I5	2556	227	88.8	152	59.5
I6	2635	52	19.6	129	48.8
I7	2704	52	19.2	78	28.7
J4	2494	252	100.9		
J5	2556	86	33.5	9	3.4
J7	2704	28	10.2	113	41.6
K2	2351	2	1.0		
K5	2556	48	18.8	135	52.8
K8	2772	4	1.6	74	26.5
L3	2423	9	3.7		
L8	2772	20	7.1	47	16.8
M3	2423	2	0.9		
M4	2494	26	10.3		
M8	2772	4	1.5		
N4	2494	35	13.8		
O3	2423	9	3.8		
O4	2494	4	1.5		
J3	2423	323	133.3		
J8	1998			2	0.9
M9	1713			46	27.0
K7	2704			43	16.0
J6	2635			34	13.0
K6	2635			34	12.8
Grand Total		1,794	23.6	1,005	26.4
Area (nmi^2)		75,889		38,131	