

# Cruise report from the coordinated ecosystem survey with M/V "Libas" and M/V "Brennholm", M/V "Finnur Fridi" and R/V "Arni Fridriksson" in the Norwegian Sea and surrounding waters, 9 July- 20 August 2010

**By:** Norway (Nøttestad et al.), Faroes (Jacobsen et al.) and Iceland (Sveinbjørnsson et al.)

**Cruise report:** Survey number 2010 810 (Libas) and 2010 807 (Brennholm), 1051 Finnur Fridi and Arni Fridriksson

**Period:** 9 July – 20 August 2010

**Vessels:** M/V "Libas" (LMQI) (15 July-20 August), M/V "Brennholm" (LIWG) (15 July-6 August), M/V "Finnur Fridi" (XPXP) (9-23 July) and R/V "Arni Fridriksson" (TFNA) (20 July–12 August)

**Area:** Nordic Seas (60°00'-78°00'N, 32°00'E-20°00'W)

**Main purpose:** Study abundance, spatiotemporal distribution, aggregation and feeding ecology of Northeast Atlantic mackerel, Norwegian spring-spawning herring, blue whiting and other pelagic species in relation to oceanographic conditions, prey communities and marine mammals.

## Sub-goals:

- Map concentration and distribution of non-targeted species such as horse mackerel, Atlantic salmon and lump sucker.
- Systematic marine mammal sightings for species identification, group size and behaviour. Concurrent digital filming and photo for scientific purposes and validation.
- Quantify migration speed and direction of tracked herring and mackerel schools at different spatial scales on multibeam sonars (SH80 and SX 90) in the upper water masses (0-50m).
- Ecological studies on predator-prey interactions and avoidance behaviour of pelagic fish, krill and marine mammals using acoustics, visual observations and sampling.

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## 1) Summary

Two chartered Norwegian fishing vessels M/V "Libas" and M/V "Brennholm", one chartered Faroese vessel M/V "Finnur Fridi" and the research vessel R/V "Arni Fridriksson" performed an ecosystem survey from 9 July until 20 August 2010 in the Norwegian Sea and adjacent waters. The abundances of Northeast Atlantic mackerel (*Scomber scombrus* L.), Norwegian spring-spawning herring (*Clupea harengus* L.) and blue whiting (*Micromesistius poutassou* L.) were measured acoustically. The total acoustical estimate of biomass of mackerel was 12.1 million tons, while swept area estimate from trawl catches was 4.5 million tons. Mackerel was distributed over larger areas than previously documented for the Nordic Seas in July-August. Furthermore, a central and western distribution was pronounced in July 2010. Repeated offshore catches of two year's old individuals indicate that the Norwegian Sea is increasingly showing to be an important nursery and feeding ground for immature mackerel. The 2005- and 2006 year classes dominated with 24% and 31% of total catches, respectively. Large mackerel ate the squid *Gonatus fabricii* northeast of Iceland. Estimated biomass of herring was 10.7 million tons. Herring had rather periphery distribution in the Norwegian Sea and surrounding waters, and the majority of individuals were distributed feeding in the colder and frontal waters in the western, northwestern and northeastern parts of the Norwegian Sea. Herring also ate adult capelin, representing new scientific knowledge. The 2002 and 2004 year classes were most abundant representing 20% and 27% of the acoustical estimates, respectively. Estimated biomass of blue whiting was 3.46 million tons in the Norwegian Sea in July. The 2004 year class dominated with 36 % of the *acoustical estimates* followed by the 2003 year class with 23% of the acoustical estimates. No major young year classes less than four years of age were found during the survey. A total of nine salmon were caught in the epi-pelagic trawl hauls. Lumpsucker were caught in vast areas of the covered areas. Horse mackerel were caught in the southernmost area of the Norwegian Sea.

Surface waters in the eastern, central and northern Norwegian Sea were colder compared to the last year, but still warmer than average temperature the last two decades. Extremely warm temperatures were found in the southern and southwestern part off Iceland.

Zooplankton concentrations including *Calanus finmarchicus*, krill and amphipods were generally low, except a few locations in the southernmost areas.

Fewer marine mammals were generally present in the Norwegian Sea in July 2010, compared to previous years, based on dedicated whale observations on Libas and Brennholm. Both herring and mackerel swam predominantly in small and loose aggregations as recorded from sonars and echosounder, making it difficult for marine mammals to prey cost efficiently on schooling fish. Low concentrations of krill and amphipods also suggest why baleen whales such as humpback whale and minke whale were scarcely present in the Norwegian Sea in July.

**Key words:** Norwegian Sea, planktivorous fish, herring, mackerel, blue whiting, salmon, abundance, distribution, feeding ecology, schooling behavior, predator-prey interactions, genetics.

## 2) Introduction

### Ecosystem survey

We aim to use these coordinated cruises with chartered and scientific vessels as part of an integrated platform to perform quantitative and qualitative ecological studies on the interplay between ecologically and economically very important pelagic fish species in the Norwegian Sea and surrounding waters during summer. It is of great importance and interest for our understanding of the functioning of the Norwegian Sea ecosystem, how the 3-D and 4-D distribution, aggregation and diet of mackerel, herring, blue whiting and horse mackerel are and to what extent they overlap in space and time. We therefore collected a wide range of data including hydrographical measurements (CTD casts), current measurements from ADCP RDI instrument, plankton samples from WP 2 nets, and full biological analyses of pelagic fish species for each station applying epipelagic trawling at surface and deeper in the water column, both from pre-determined stations and trawling on registrations. Acoustic measurements and registrations were performed using multi-frequency acoustics from Simrad ER60 echosounder, as well as high-frequency medium range Simrad SH 80 (Libas and Brennholm), and low-frequency long-range Simrad SX 90 (Libas) and Simrad SP70 (Brennholm) multi-beam sonars. A new software developed by Ruben Patel at the Institute of Marine Research in Bergen, Norway were used to analyse fish schools on Simrad SH80 sonar and methodology tested on a large scale for the second time. The aim here in the medium term is to be able to automatically count number of fish schools along the cruise track and record relevant data on school size, swimming speed and direction.

The seven weeks coordinated cruises are part of a long-term project to collect updated and relevant data on abundance, distribution, aggregation, migration and ecology of major pelagic species. The Institute of Marine Research, Bergen, Norway chartered two commercial vessels, M/V "Libas" and M/V "Brennholm", both fulfilling the required scientific specifications set for this ecosystem study. Faroe Marine Research Institute in the Faroe Islands chartered the modern commercial fishing vessel M/V "Finni Fridur", whereas the Marine Institute in Iceland applied the research vessel, R/V "Arni Fridriksson" as their operating survey vessel. A scientific quota consisting of mackerel, capelin and blue whiting was provided to IMR from the Directorate of Fisheries and accepted by the Ministry of Fisheries and Coastal Affairs as an economical compensation for the chartered vessels operating as platforms for the scientific activities performed.

## 3) Material and Methods

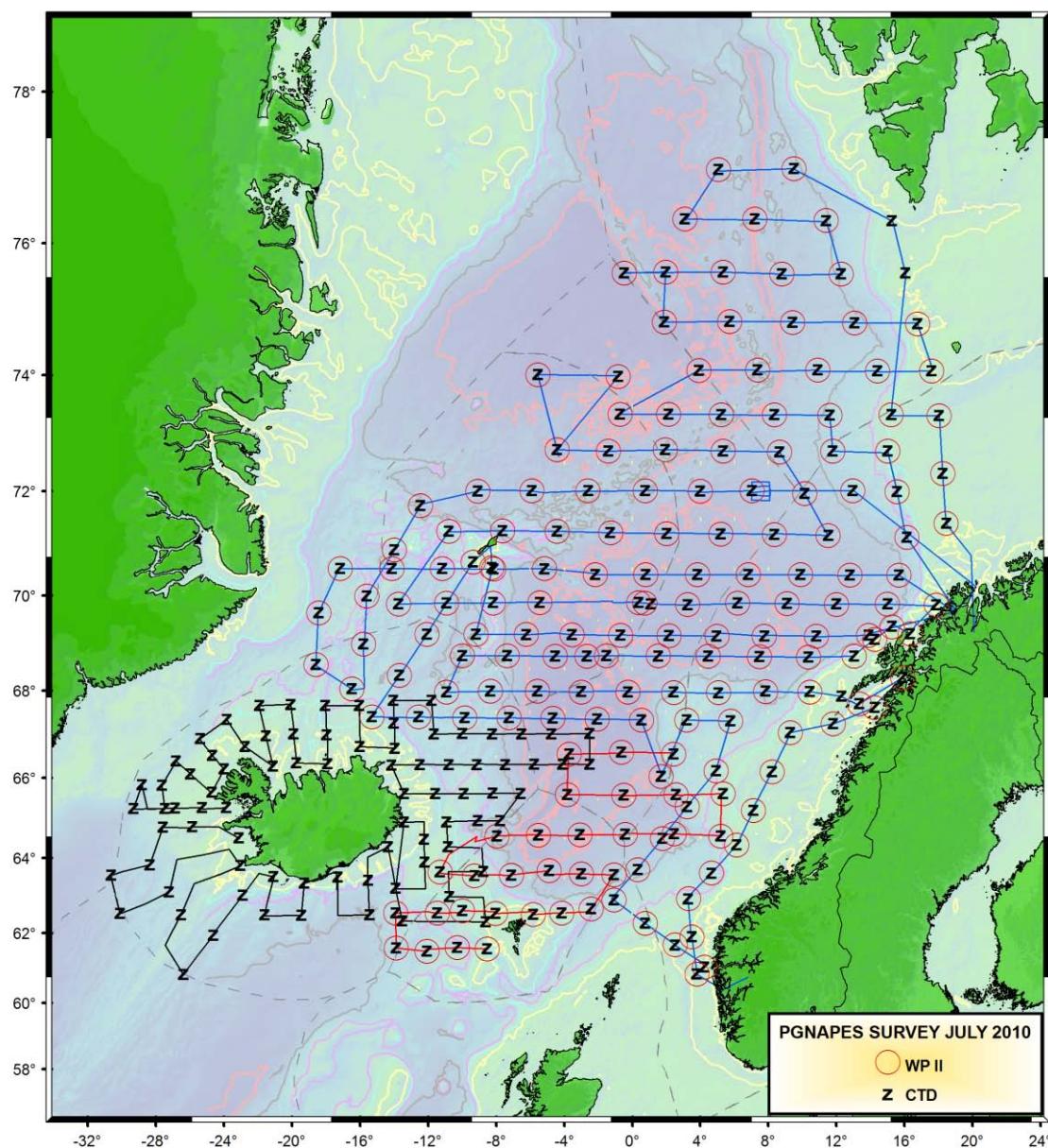
### *Calibration of echosounder transducers*

Libas and Brennholm were calibrated after standard hydro-acoustic calibration-procedure for each frequency prior to the cruise from 13-14 July 2010 (Foote, 1987). The transducers are placed in the drop keel onboard Libas, but not onboard Brennholm. The calibration on Libas and Brennholm took place inside a wind and wave protected area at Sandviksflaket, just outside the harbour of Bergen, Norway. The frequencies calibrated involved 18, 38, 70, 120 and 200 kHz on Libas and 38 and 200 kHz on Brennholm. We calibrated 38 kHz and 200 kHz transducers with 60 mm copper sphere (Cu 60). CTD measurements with a SAIW SD200W instrument were taken in order to get the correct sound velocity as input to the echosounder calibration settings.

Finni Fridur and Arni Fridriksson were also calibrated after standard hydro-acoustic procedure for each operating frequency (Foote, 1987).

## Cruise tracks

Libas, Brennholm, Finni Fridur and Arni Fridriksson followed predominantly predetermined survey lines with pre-selected pelagic trawl stations and occasionally performed pelagic trawl stations on registration from acoustics (Figure 1). An adaptive survey design was also adopted, due to uncertain geographical distribution of our main pelagic planktivorous schooling fish species. Some modifications in the southwestern regions, and central and western part in between Icelandic, Jan Mayen and Greenland waters were performed due to higher concentrations of herring and mackerel in these areas. The cruising speed was between 10-12.0 knots if the weather permitted it, otherwise 10.0 knots. CTD stations (0-500 m) using a SEABIRD and SAVI SD200 CTD sensor in combination with WP2 net samples (0-200 m) were taken systematically on every pelagic trawl station on all vessels, except onboard Arni Fridriksson, which did not perform any plankton sampling (Figure 1).



**Figure 1.** Survey lines along the cruise tracks with pre-defined CTD stations (0-500 m) and WP2 samples (0-200 m) for M/V "Libas", M/V "Brennholm", M/V "Finnur Fridur" and R/V "Arni Fridriksson"

9 July – 20 August 2010. This large ocean area included the following Economical Exclusive Zones (EEZ): Norwegian EEZ, United Kingdom EEZ, Faeroe Island EEZ, Iceland EEZ, Jan Mayen fishery protection zone, Spitzbergen protected area and International waters.

## ***Biological sampling***

### ***Pelagic planktivorous fish species***

Trawling was done with a rather large pelagic trawl from a blue whiting /capelin trawl with a trawl opening between 30-35 m, spread of 55-65 m using 160-200 m wire length on Brennholm and Libas. Most of the trawling was done in the surface area with floats attached to the wings and the headline. Towing speed at the surface was 4.2-5.3 knots and towing time was maximum 30 minutes. When large schools or aggregations of fish were detected on the trawl sonde, the towing duration was reduced accordingly in order to avoid too large catches. Targeted herring and blue whiting trawl hauls on registrations were performed with a capelin/herring trawl from 10-250 m depth. This trawl had an opening of 45 m and spread of 70 m using 200-600 m wire length. The tow duration was maximum 30 min. Towing speed at depths varied between 3.5-5.2 knots depending of the vessel performance, current, wind and wave conditions. The catch was sorted at each station and full biological sampling including otoliths of up to 25 mackerel, herring and blue whiting was taken in addition to length and weight measurements of 100 specimen and stomach samples of 10 individual per species (Alvsvåg et al. 2003, Mjanger et al 2007). We aimed to study possible interactions between species, and therefore decided when several pelagic species was caught in the same trawl haul that the sampling procedure should be adapted to enable to study ecological questions in more detail. Length and weight were measured for all other non-target species caught in the pelagic trawl hauls, as well as total weight for each species. Estimated biomasses for mackerel, herring and blue whiting were done in situations where not all the fish could be sampled and weighted from a pelagic trawl haul.

The salmon was photographed, measured and weighted. The specimen was labeled and stored immediately in the freezer to avoid contamination.

The biological sampling on Arni Fridriksson diveded from the above description in the way that the trawl used was smaller, or Wide Body 512, with vertical opening of 16.5m and horizontal of 23m. Furthermore, the full biological sampling included otoliths of up to 50 mackerels and blue whiting, and 100 herring in addition to length and weight measurements of at least 100 specimen and stomach samples of 10-15 individual per species.

The Faroese vessel used at Vólin 640m trawl with floats on the wingtips and a „floating sausage“ attached to the entire headline. The towing speed was on average 4.4 knots (3.8-4.6). The doors used were 5.5 m<sup>2</sup> and weighted 750 kg. In addition to length, weight, sex and maturation otolith and stomach samples were taken from 15 fish of each species during each haul, and further 100 fish were measured and weighted.

## ***Hydrography***

Libas, Brennholm and Finnur Fridi were equipped with SAIV SD200 CTD sensor recording temperature, salinity, pressure (depth) from the surface down to 500 m, or when applicable as linked to maximum bottom depth. The SAIV sensor was programmed to record data every 2 seconds and the speed of the wire during measurements was set to 0.5 m/s providing data approximately every 1 m in the water column. The sensor was positioned at about 1 m depth for 1 min at each

station in order to let the instrument sensors adapt to the seawater from being stored dry between stations on the vessel. CTD data from the downcast were used for further analyses. Sea surface temperature (6 m depth) was also recorded manually from a bottom-mounted temperature sensor with a display on the bridge systematically every hour during cruising between stations for both vessels. Libas and Arni Fridriksson had also a SEABIRD CTD sensor with a water rosette, that was applied during the entire cruise from 0-500 m depth. The SEABIRD in Libas was properly tested by IMR instrument people prior to the survey when the vessel was in the harbour at Nykirkekaien.

ADCP current speed and direction were measured continuously onboard Libas and Brennholm. These data are not yet analyzed for inclusion in this report.

## ***Plankton sampling***

Zooplankton sampling was performed at 90 stations on Libas, 62 stations on Brennholm and 30 stations on Finnur Fridi. A WP-2 net with 180  $\mu$  m mesh size was towed from 200 m depth to the surface at a speed of 0.5 m/s.

### ***Sample treatment***

#### *Macroplankton trawl*

Samples were sorted, species identified and length measured according to working standards. All subsamples were frozen to -30°C and the whole sample was frozen after length measurements in those cases where the total samples were small.

#### *WP2 net*

Plankton hauls were collected with a WP-2 plankton net, 56 cm in diameter and a mesh size of 180  $\mu$ m on M/V "Libas", M/V "Brennholm" and M/V "Finnur Fridi". One plankton haul was sampled on each predefined station from 200 m – 0 m depth. The choice of depth range was taken to link plankton concentrations directly within the depth ranges where the pelagic schooling species (mackerel and herring) are actively feeding during summer. The hauling speed should not exceed 0.5 m/s in order to avoid bucking effect. The vertical deviation on the wire should not exceed 30° and all plankton samples were repeated if this situation appeared. The plankton net is each time flushed with seawater to collect plankton from the net itself inside the cup, while the net is still hanging outside the railing. Furthermore, the area above the cup is flushed on deck to secure that the whole plankton sample is properly collected. The cup is detached from the net inside a bucket, to avoid losing part of the plankton sample. The plankton sample is divided into fractions; 1) taxonomic analyses (taxonomic species, size, and stadium composition, and 2) biomass estimates. The WP-2 samples were split into two equal parts, one for formaldehyde preservation, the second part for dry weighing. This part was separated into three size categories by filtering at 2000, 1000 and 180 mesh size sieves. The biomass in each size fraction was transferred into alumina trays for drying. The content of 2000 um fraction was identified, dependent upon species group the organisms were length measured and the various groups transferred to individual trays for drying. Weighing of trays took place at IMR laboratory after ended survey.

## ***Acoustics***

### Sonar data collection system configuration and data storage

The Simrad sonar available in Brennholm were SP90 and SH90, and onboard Libas were a SX90 and a SH80. The characteristics of the scientific output available for this sonar models are the following:

Frequency	Model	.dat file	.dat file	.raw file
		Screen data	Beam data	Beam data
Low (20-30 kHz)	SP90	✓		
	SX90		✓	✓
High (110-120 kHz)	SH80		✓	
	SH90		✓	✓

The synchronization between the sonar and echo sounder was not operational during the first leg of the survey. Due to the sonar interference in the echo sounder, sonar data was collected during selected trawl stations. A technician from Simrad determined that the COM port from the EK60 system was not working properly; therefore no output trig signal was sent to the sonars. The COM port was changed and the synchronization was re-established, allowing a continuous data collection of data from the SH80 sonar.

Onboard Brennholm, continuous scientific data was collected only from the SH90 during the whole survey, in a .dat file format. Onboard Libas was stored scientific data from the SH80 in the .dat file format during all the second leg and from the SX90 with a .raw format during selected periods during the first and second legs.

The SX90 data storage onboard Libas experienced problems due to increased periods losing contact with the NAS storage device where the .raw files were stored, resulting in a hang-up of the sonar PC. This was solved changing the storage place destination to the local hard disk and later transferred the files to the massive storage device NAS.

### Data processing

One of the objectives in this survey was to test the software module in LSSS "Processing system for fisheries omnidirectional sonar, PROFOS". This module is in development phase and already has the capabilities for semi-automatic school growing. First, the software reads the .dat files from the SH80 sonar, which are displayed together with the echo sounder data. Once a school is identified, manually it is selected in one of all the pings which are detected by the sonar. This selection is made in the center of the school, process we called "seed" the school, and later the software automatically will find the boundaries of the school in the present ping, and also in previous and later pings. The

number of pings used for the automatic growing can be set by the user and will depend in the noise level and the number of pings the school is detected along the ship track.

The manual seeding and automatic growing of the individual school is a very time demanding process, and this particular data, it took roughly two working days for scrutinizing one day sonar data. This time was determined by the noise level and the number of schools, which in this survey was characterized by a large number and in some cases quite noisy data.

Once scrutinized the school data can be exported in two text files, one with the information including all the data per ping for each school (Table 1), and the second with the aggregated information for each school (Table 2). The data per school also includes the swimming speed and direction of the schools, calculated primarily based in the geographical positions of the first and last detection.

Id	StartDate	Time	Box.Ion	Box.lat.	Depth	Sv.mean	Area	Ship lon.	Ship lat.	Ship speed	Ship heading	Tilt angle
5	26/07/2010	19:56:34	17.5452	69.7346	3.59	-40.69	61.3	17.548	69.74	5.56	322	-0.03
5	26/07/2010	19:56:39	17.5453	69.7347	3.35	-44.27	29.3	17.547	69.74	5.56	322	-0.03
5	26/07/2010	19:56:40	17.5454	69.7346	3.32	-41.58	55.4	17.547	69.74	5.56	322	-0.03
5	26/07/2010	19:56:41	17.5455	69.7346	3.35	-44.15	22.4	17.547	69.74	5.56	322	-0.03
5	26/07/2010	19:56:45	17.5455	69.7347	3.58	-44.14	26.9	17.546	69.74	5.61	322	-0.03
5	26/07/2010	19:56:46	17.5455	69.7346	3.68	-41.6	121.1	17.546	69.74	5.56	322	-0.03
5	26/07/2010	19:56:47	17.5457	69.7346	3.71	-42.69	94.5	17.546	69.74	5.50	322	-0.03
11	26/07/2010	19:59:31	17.5246	69.7418	8.08	-43.92	77.4	17.531	69.74	5.50	322	-0.03
11	26/07/2010	19:59:32	17.5245	69.7418	8.03	-43.96	130.5	17.53	69.74	5.50	322	-0.03
11	26/07/2010	19:59:33	17.5246	69.7418	7.77	-43.94	77.7	17.53	69.74	5.56	322	-0.03
11	26/07/2010	19:59:34	17.5246	69.7418	7.64	-44.45	51.0	17.53	69.74	5.56	322	-0.03

Table 1. Example of the file output with the school information for each ping, with some selected fields. Id, unique identifier of school; , Box.Ion and Box.lat., geographical position of square which contains each school detection; Depth, mean school depth (m); Sv mean, mean school s, ( $m^{-1}$ ); Area, mean school area ( $m^2$ ); Ship lon. and Ship lat., geographical position of the vessels; Ship heading, vessel heading (deg); Tilt angle, tilt angle of sonar (deg).

Id	StartDate	StartTime	StopDate	StopTime	Box.Ion	Box.lat.	Depth	Sv.mean	Area	Pings	Speed	Heading
1	26/07/2010	19:52:13	26/07/2010	19:52:35	17.570	69.726	3.3	-33.6	578	23	1.46	85
2	26/07/2010	19:53:24	26/07/2010	19:54:07	17.560	69.730	7.35	-38.0	1242	44	1.01	64.8
5	26/07/2010	19:56:14	26/07/2010	19:56:47	17.545	69.734	4.39	-41.0	123	23	0.85	90.5
11	26/07/2010	19:59:31	26/07/2010	19:59:45	17.524	69.742	7.12	-43.8	86	8	0.59	68.5
13	26/07/2010	20:02:10	26/07/2010	20:02:41	17.511	69.747	5.32	-40.0	450	29	0.95	83.9
16	26/07/2010	20:06:28	26/07/2010	20:06:30	17.487	69.758	6.72	-42.7	159	3	1.16	227.1

17	26/07/2010	20:07:24	26/07/2010	20:08:01	17.479	69.761	7.29	-38.0	625	38	1.22	60.4
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Table 2. Example of the file output with the school information for each ping, with some selected fields. Id, unique identifier of school; StartDate and StartTime, date and time of the first school detection, StopDate and StopTime, date and time of the last school detection, Box.Ion and Box.lat., geographical position of square which contains all school detections, Depth, mean school depth (m); Sv. mean, mean school  $s_v$  ( $m^{-1}$ ); Area, mean school area ( $m^2$ ); Pings, number of pings of detected school, Speed, school speed (knots); Heading, school heading (deg).

Selected period from the SH80 sonar data collected onboard Libas were scrutinized. First a transect between the Norwegian coast up to Greenland (26 to 30 July), and later a minisurvey designed specifically to study the school distribution beyond the transect sampling. The minisurvey included 5 transects of 20 nmi separated by 5 nmi, and started at 12:00 am on the 03 August ending on the 00:50 am of the 04 August.

In Figure 2 is showed a screen dump of the SH80 visualization window in which several small shallow schools were detected in 400 m range. Each red dot represents the central position of a detected school in each ping, and all detections in each school were delimited inside a red square assigned with a unique ID. The ship survey track is showed as a dotted grey line, and in this example the vessel was sailing from west to east. Also two buffers zones (white continuous lines); a circle around the vessel and two lines behind the vessel, to avoid the automatic school growing in these noisy regions.

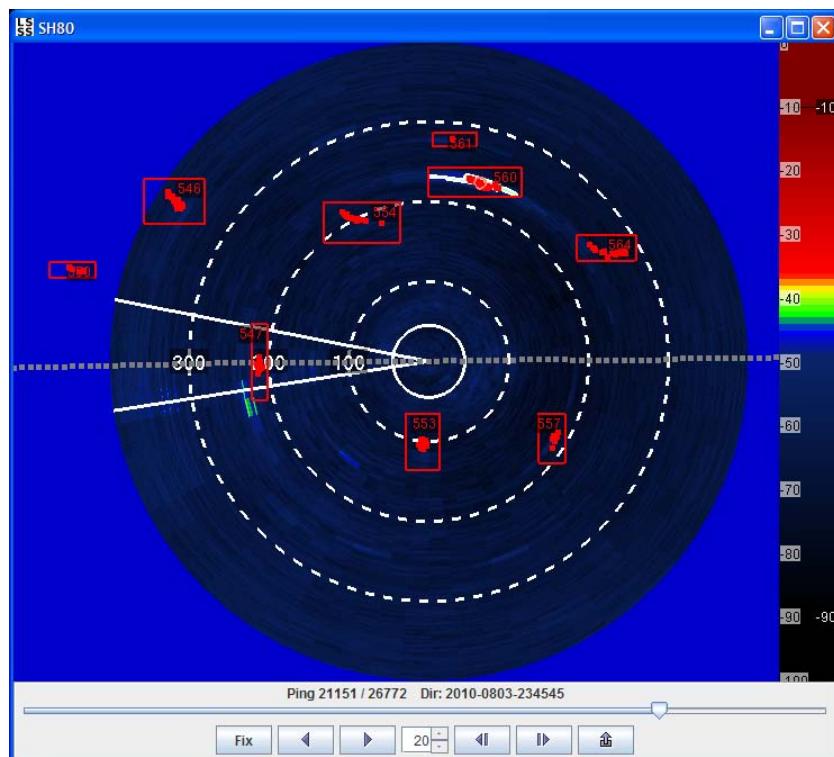


Figure 2. Example of the SH80 visualization window. School detections for each ping are noted with a red dot. Scale in the right is showing  $s_v$  values in dB. The lower panel is showing the tool bar for the replay of the sonar data. More details of the figure are explained in the text.

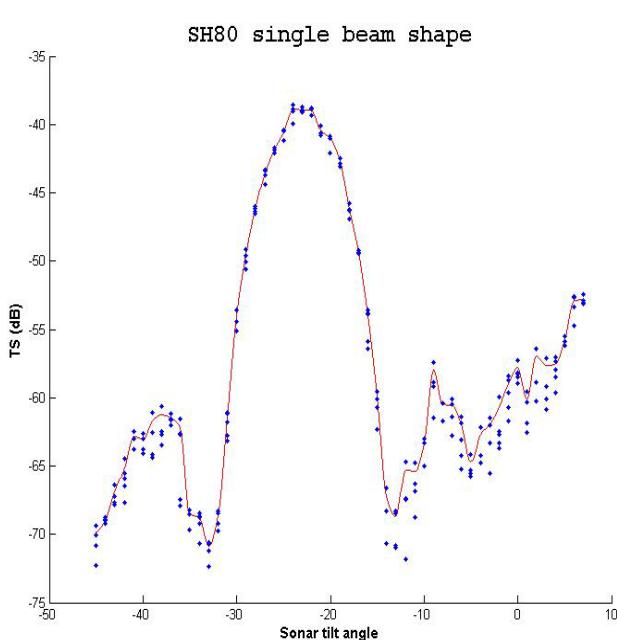
## Sonar detection and acoustic measurements of marine mammals

### Simrad SH80 omnidirectional sonar calibration

The need to increase the sampling volume in standard fishery surveys for better biomass estimation of major pelagic fish stocks brought the attention of the scientific community to apply omnidirectional sonars, previously used for fish school visualization during fishing activities.

Sonar cover considerable wider areas than traditional echosounder, and in large marine ecosystems such as the Norwegian Sea, there is clear advantages of also covering the water layers close to the surface, where a major part of the biomass of pelagic fish concentrate during summer due to the availability of suitable food, good light conditions and a strong thermocline.

With this in mind, it became clear the need of quantifying the output of this class of sonars. Since 2007 we have studied the Simrad SH80 high frequency omnidirectional sonar data output. Good results were achieved in the attempt of calibrating the unit. A fast *in situ* calibration protocol is a proposed prospect for the dedicated ICES SGCAL (Study Group on Calibration of Acoustic Instruments in Fisheries Science) which proposed a deadline in April 2012 for publication of new guidelines on this subject.



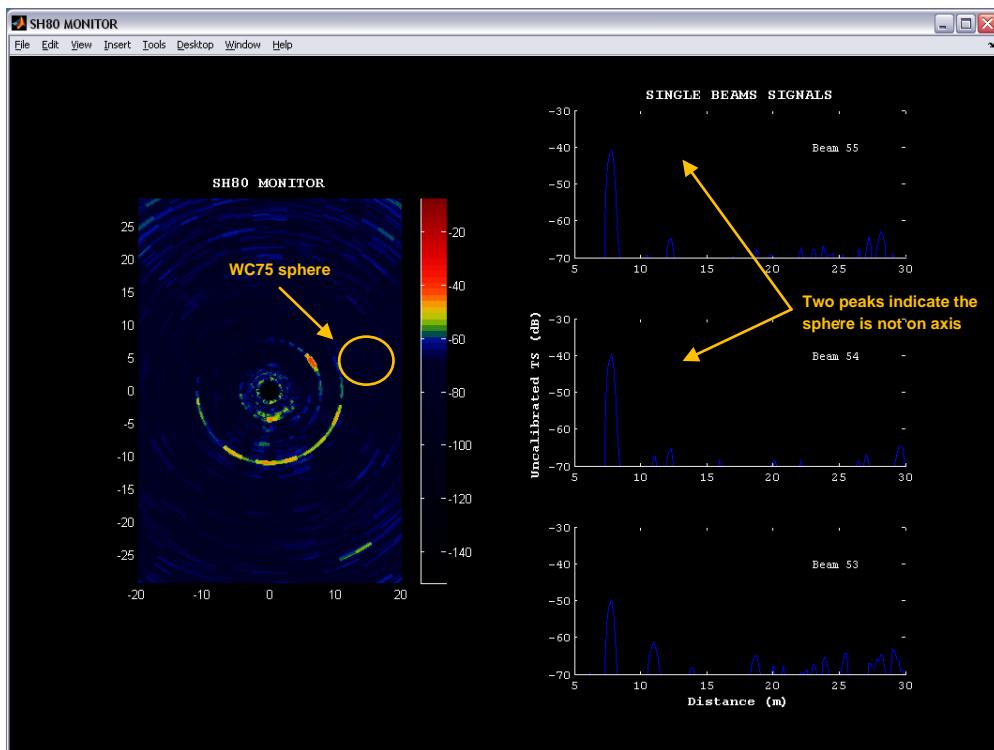
For the 2010 calibration we used a custom 75 mm tungsten carbide sphere as a reference target. This sphere was chosen for its ready availability and for the good results obtained in a similar experiment in 2008. The sphere was suspended from the side of the ship (Libas) in front of the sonar transducer (depth of 8.5 m) and moved through 8 different individual sonar beams using an electric controlled reel system.

**Figure 31:** Beam shaping obtained using the tilt angle control of the sonar unit during the 2008 calibration experiment.

connected to a pulley suspended to a crane at a horizontal distance of approximately 25 m from the transducer in the far field of the sonar. The sphere was moved in both the vertical plane, by the electric reel system, and in the horizontal plane, by operating the crane at the minimum speed. That procedure allowed us moving the target through the beam with centimeter steps for a better coverage of the acoustic beam, compared to the calibration obtained in 2008 (Figure 3).

In 2008 we limited our effort in placing the sphere in front of different beams at the axis center and scanning it electronically. The objective of the 2010 calibration was to verify the variance from the main axis of the acoustic beam and its peripheral areas in both horizontal and vertical plane and test how tilt angle settings could influence the shape of single beams. The reason for the particular attention given to the tilt angle setting stand in its constant adjustment need during the survey operation to obtain the optimal performance in terms of range.

Some electronic scan of the reference target were also performed as done previously in for a comparison of the 2008 material (see figure 1). From this calibration experiment we expected a better understanding of the sonar detection dynamicc. A dedicated Calibration SH80 Monitor, written in Java and Matlab languages, has been developed to read and extract fast and directly the single beam received dB level (Figure 4).

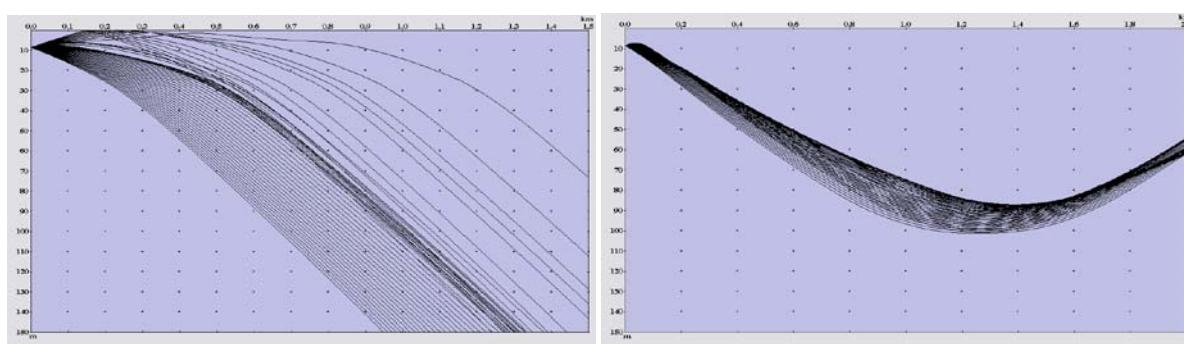


**Figure 4:** Screen shot of the Simrad SH80 Monitor developed in the last two years used to process, extract and analyze sonar signal directly from the raw data stored by the Simrad Winson software. From the energy plot in the left is possible

**to notice how the calibration sphere is not positioned exactly at the center of the beam 54, but is off axis between beam 54 and 55.**

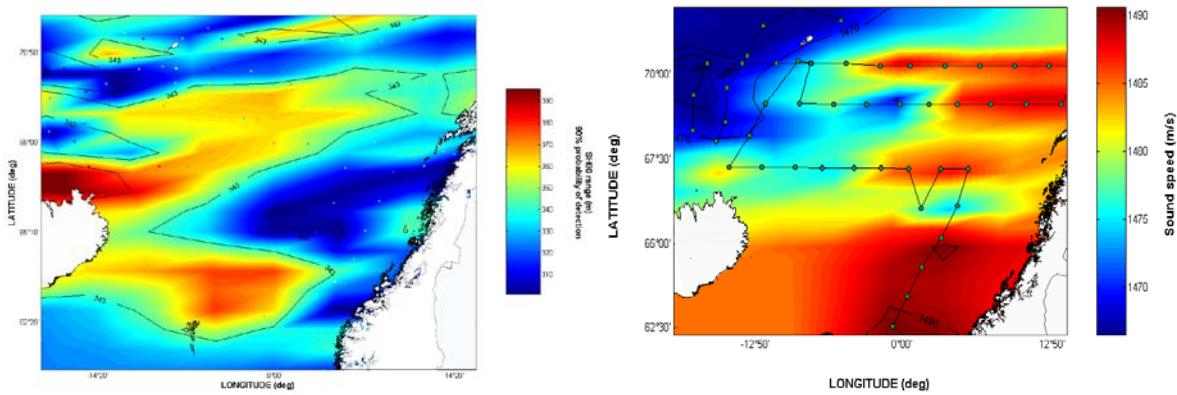
## SH80 performance evaluation using the Lybin ray trace model

During the survey the different physical conditions of the water encountered may strongly influence the performance of the acoustic instrumentations. When transducers are facing downwards these variations do not affect consistently the perception of the observed volume of the water column. A strong influence can instead be observed when sonars are directed horizontally. The travelling acoustic wave can suddenly bend and channeled, misleading the operator judgment about what is really on sight and its 3D position in the water column. What is visualized on the sonar screen as a school close to the surface in reality can be a school placed at hundred meters depth (Figure 5).



**Figure 5:** Ray trace simulations for two CTD stations for the Simrad SH80 unit operating at 110 kHz with a tilt angle setting of 0° and a pulse duration of 6 ms. In the two examples we can observe a typical bending that reduce the horizontal range of the sonar, and the most extreme situation encountered with the sound drastically channeled by fresh water masses close to Greenland.

The ray bending itself is not the only phenomenon to consider while navigating in different areas of the oceans. The constant consciousness of the maximum detection range is another important indication for the operator. Avoiding the over interpretation is at this stage of the instrument development our primary objective. We collected information about water masses with a SAIV SD204 CTD unit and use the data to run simulations through the acoustic ray trace model LYBIN. This model is a well established and frequently used sonar prediction model owned by the Norwegian Defence Logistic Organisation. The model is used onboard navy vessels as well as in training situations on shore. The choice of the SAIV SD204 unit for this purpose was made considering the capability of the SAIV Minisoft SD200W. This software generate directly, with an easy interface .xml files ready to be process with the Lybin 4.0 software that was use to update constantly the sonar setting during the survey.



**Figure 6:** plots of the SH80 detection range evaluated using the Lybin model with the sonar set to look target at the surface and map of the sound speed of the first 40 m of the water column.

The maps in Figure 6 show the average sound velocity of the first 40 m of the water column along the coordinated ecosystem survey of the Norwegian Sea and the Simrad SH80 performance using a tilt angle setting of 0° and a pulse duration of 6 ms in term of range based on over 100 CTD samples and 500 Lybin simulations. From a preliminary qualitative analysis is clear that will be very important in a near future to develop the use of such probability model to operate and collect sonar data for a concrete and reliable biomass estimation of fish stock and capitalize the potential of omnidirectional sonar units.

## Whale TS measurements and conservation issues

The effect that seismic survey could have on endangered whale species is a concern. Currently



**Figure 7.** *In situ* TS measurements of marine mammals were possible for the extreme tranquility showed by the animals once approached by the vessel. As we have experienced in the past years, it seems that the running acoustic equipments do not generate any notable reaction even if the operating frequencies overlap with the ones used by the whales to communicate as in the case of killer whale that we could observe during typical feeding activities at close range.

passive acoustic and visual observations are the common ways use to detect whales during seismic operations; however these methods clearly face strong limits due to the impossibility to detect silent animals and the effect generated by bad weather conditions. There are thus limitations to both presently used techniques, limitations that could fail to prevent conflict between human activities and cetaceans. For this reason with an opportunistic

approach, a unique project to develop a whale sonar detector has been carried on in the past three years as a subgoal in the development of omnidirectional sonar for fish abundance estimation. The particular aim of the project is to avoid breaking security ranges imposed as a stop to seismic operation in presence of cetaceans indicated by international guidelines and regulations. There are thus limitations to both presently used techniques, limitations that could fail to prevent conflict between human activities and cetaceans.

There is still a lot of concern appointing sonar as an eventual cause of stress and disturbance for the cetaceans, but our close encounters and the possibility of having good sonar recordings speeds lower than 4 knots seems to give us different indications than the one hypothesize by many popular science article that using the sonar word talk about military system that works at lower frequency with longer pulse and higher source level.

We want to take the advantage of active sonar for conservation purposes, giving to the operator in charge of detecting whales an instrument on which he has the choice of most parameters of the sonar equation (Eq. 1) except TS, the target strength (relative amount of sound reflected back to the receiver), define as:

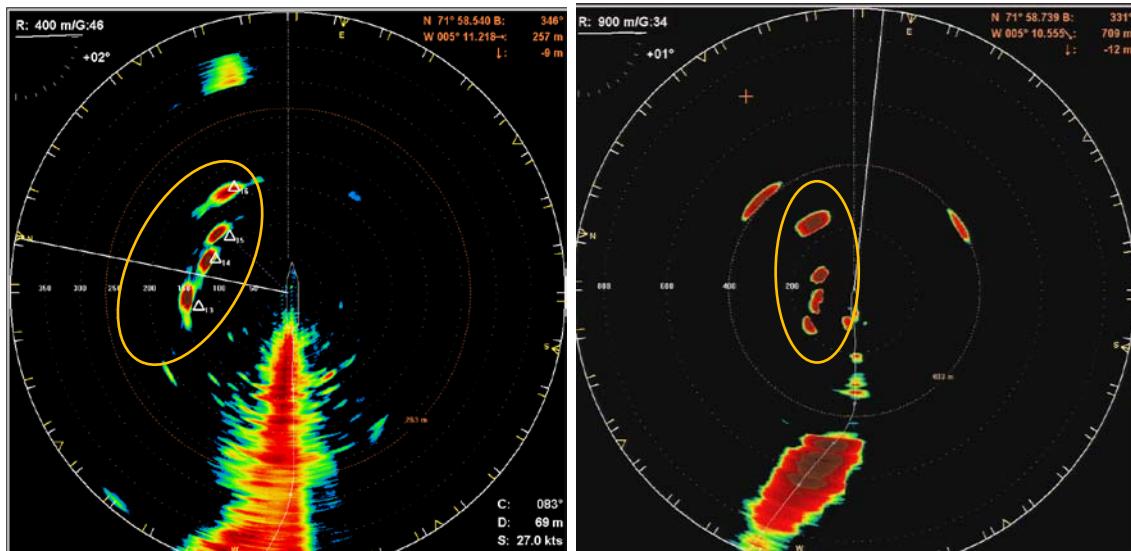
$$TS = dB_I - SL + TVG + Cal \quad (1)$$

where  $dB_I$  is the received dB level at the transducer;  $SL$  is the source level of the sonar;  $TVG$  is time varied gain corresponding to  $40\log_{10}R + 2\alpha R$  (with  $R$  the range and  $\alpha$  the absorption coefficient);  $Cal$  is a correction value obtained in a dedicated calibration experiment.

Active acoustic detection of whales, is still an unexplored field, and could offer an alternative approach to damage mitigation associated with seismic operations, providing real-time detection capabilities. The long-term goal of exploring the possibility of using fishery omnidirectional sonars to detect cetaceans during seismic operations and to use such detections as triggers to stop potentially harmful seismic shooting imply the need to gather consistent informations about different cetacean species TS as it has been done for years for many commercially important fish species.

We collected very good data about this parameter for different species. A detailed paper about fin whale (*Balaenoptera physalus*) TS has been recently submitted to the Journal of the Acoustical Society of America. In this manuscript we described TS for fin whale at all side from head to tail describing *in situ* what was observed before just *ex situ* for a dolphin by Au (1996). The recorded values had a span of 14 dB, not uncommon for such stochastic parameter with a maximum of - 4 dB and a minimum of - 14 dB. Our preliminary results also point in the direction

of the variation of such parameters due to recognizable behavioural swimming pattern that we could notice since our first attempt of whale sonar detection. In figure 6 is possible to observe how whales leave well marked print on the screen while surfacing to breath. In figure X the sequence of red mark are the print that the animal leave behind and that were quantified in 7 dB less than the actual whale represented by the first print in the sequence.



**Figure 8:** Within the circles we see typical marks left on the sonar screen by a fin whale swimming at the surface. We could quantify in term of 7 dB the difference between the actual whale (first mark of the series) and the prints left behind. The first screen capture is from the Simrad SH80 unit, the second from the new Simrad SX90, sonar we believe will be the optimal to adopt for marine mammals detections.

As a last note it has to be mention that in 2010 we could test the new low frequency sonar unit Simrad SX90. It seems it will be convenient in the future to adopt this sonar unit to detect marine mammals, not just for its longer detection range but for the better response that cetaceans body seems to have at frequencies between 20 and 30 kHz.

## Echosounder

Continuous data-logging and raw data recording from 18, 38, 70, 120 and 200 kHz Simrad ER60 echosounder were performed down to maximum 500 m depth on both Libas and Brennholm, 38 and 200 kHz on Finni Fridur and 18, 38, 120 and 200 kHz on Arni Fridriksson. The data collection was done using standard settings for later echo-integration calculations distance based reference using GPS data for position and vessel speed. The quantitative acoustic analyses and NASC species allocation were done with the software program Large Scale Survey System (LSSS) (<http://www.marec.no/>) onboard Libas and Brennholm, with Echoview software package (<http://www.echoview.com/>) onboard Finni Fridur and BI500 onboard of Arni Fridriksson. The analyses were based on the following species and groups of species:

**Main target species:** mackerel, herring, blue whiting

**Usable species:** capelin, mesopelagic fish, plankton

**Other species:** redfish, krill, amphipods.

## ***Marine mammal observations***

The two Norwegian vessels, Libas and Brennholm, conducted observations of marine mammals. Two dedicated marine mammal observers were present on board Libas and Brennholm, respectively. Observing was held from the roof or from the bridge when the weather conditions were bad (Beaufort scale > 7). Two observers were watching permanently. Among the equipment were: angle boards, binoculars 7x50 with reticles, portable two-way radio for communication with bridge, GPS device, microphones connected to personal computers with special software for the sound recording and simultaneous registration of the vessel's position. Each observer monitored a 90 degree sector, starboard and port side respectively, in the line of the course. They shifted the sides every hour and took short breaks every two hours. The main sector of observation was 45 degrees port and starboard of the course line. The priority periods of observing were during the transport stretches from one trawl station to another. When the weather conditions were nearly excellent, observing was also conducted during the trawl stations with the purpose of tracking marine mammals, which could possibly appear. Weather conditions were noted every hour of observation. Sightings were spoken into a microphone. Later, the recordings were transcribed to a special Sighting form. Fields in the sighting form included date, time, position, species, number, group size, behavior, angle from the vessel course and swimming direction. A diary summarizing each day's activities was kept by the observers. Data were summarized and presented in tables and a distribution map. Scientific personnel and crew members on board Libas and Brennholm also recorded incidental sightings of marine mammals more or less continuously on the bridge. Digital filming and photos were taken whenever possible for each registration from scientists onboard.

## ***Meteorology***

Wind conditions as derived from the Beaufort scale, air temperature, weather, cloud coverage and sea state were monitored and noted in the cruise logger program at each station for both vessels.

## **Digital photos and filming**

Digital photography with Nikon D70 digital filming with Sony TCR TRV50 were done throughout the cruise for documentation of trawl catches, various scientific activities and visual observations of marine mammals and seabirds along the cruise tracks on board Libas and Brennholm.

## ***Data management***

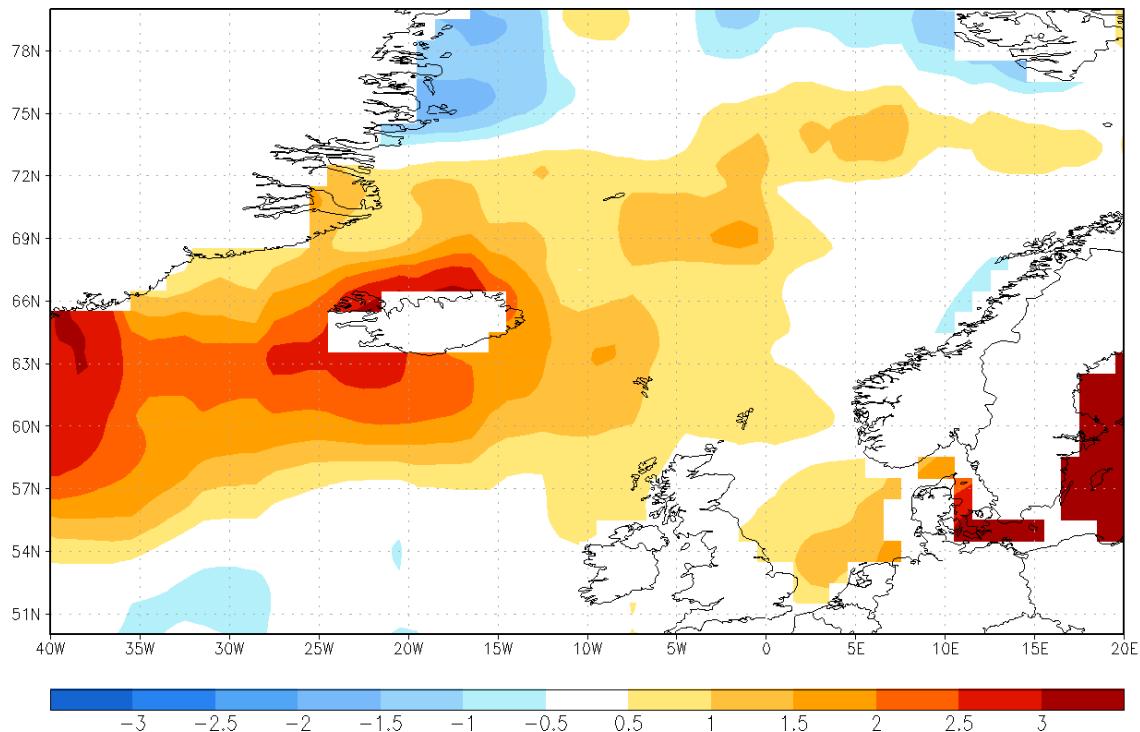
All collected data onboard Libas and Brennholm were stored on a server PC installed on each vessel under the area P:\\nas\\HI-Libas\\Tokt Name\\20108180 on Libas and P:\\nas\\HI-Brennholm\\Tokt Name\\2010807 on Brennholm. Collected data originating from echosounders, multibeam sonars, epi-pelagic and pelagic trawling, krill trawling, CTD stations, WP2 net sampling, sea surface temperatures, marine mammal observations, weather station, diary, cruise logger and digital photos were all stored on this server with advanced backup system. A timestamp synchronized the clock on all essential instrumentation and for all activities onboard each vessel and between the two vessels in order to ensure correct temporal comparison between different data sources collected during the cruise. All data were copied to two external hard drives for proper backup.

All collected data onboard Finnur Fridi and Arni Fridriksson were also stored on a server PC. After the surveys were finished the survey data were stored in the WGNAPES database located in the Faroes.

## 4) Results

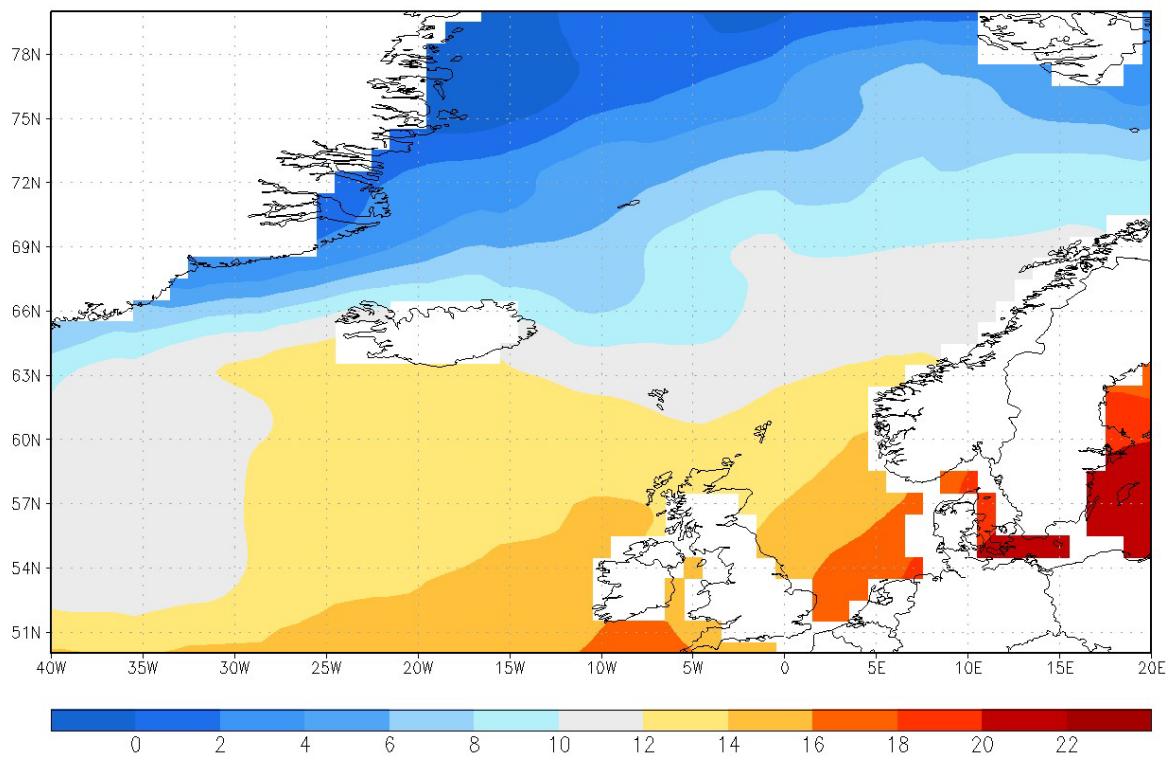
### *Hydrography*

There were considerable changes in the temperature regime in the Norwegian Sea and adjacent waters in July 2010 compared to previous periods (Figure 9). However, it must be mentioned that these NOAA sea surface measurements are sensitive to the weather condition (i.e. wind and cloudiness) prior to and during the observations and do therefore not necessarily reflect the oceanographic condition of the watermasses in the areas.



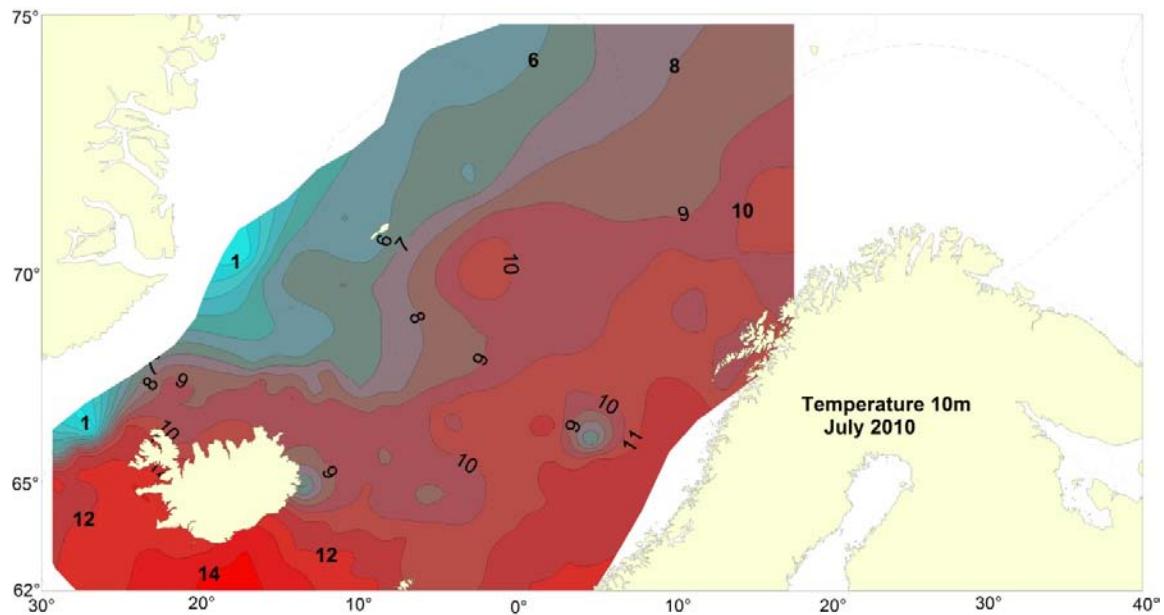
**Figure 9.** Sea surface anomalies (centered in week 21 July 2010) showing warm and cold conditions in comparison to a 20 year average.

Sea surface temperatures taken from the NOAA database in mid July 2010 (Figure 10).

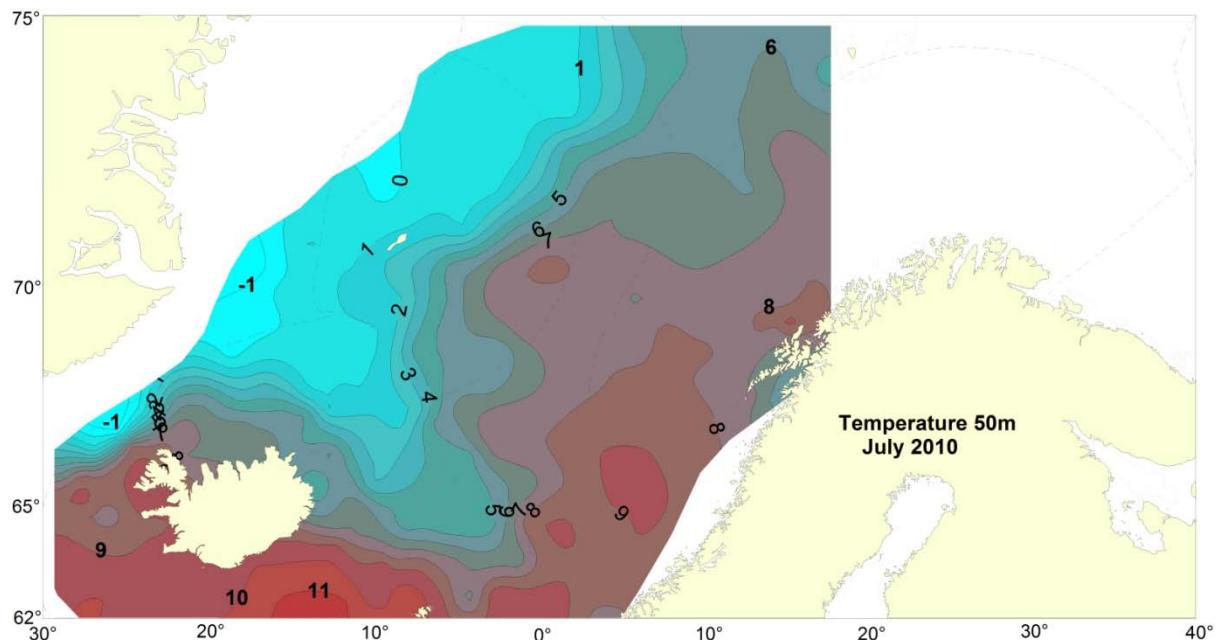


**Figure 10.** Sea surface temperature (SST) centred around 21 July 2010 in the Norwegian Sea and surrounding waters.

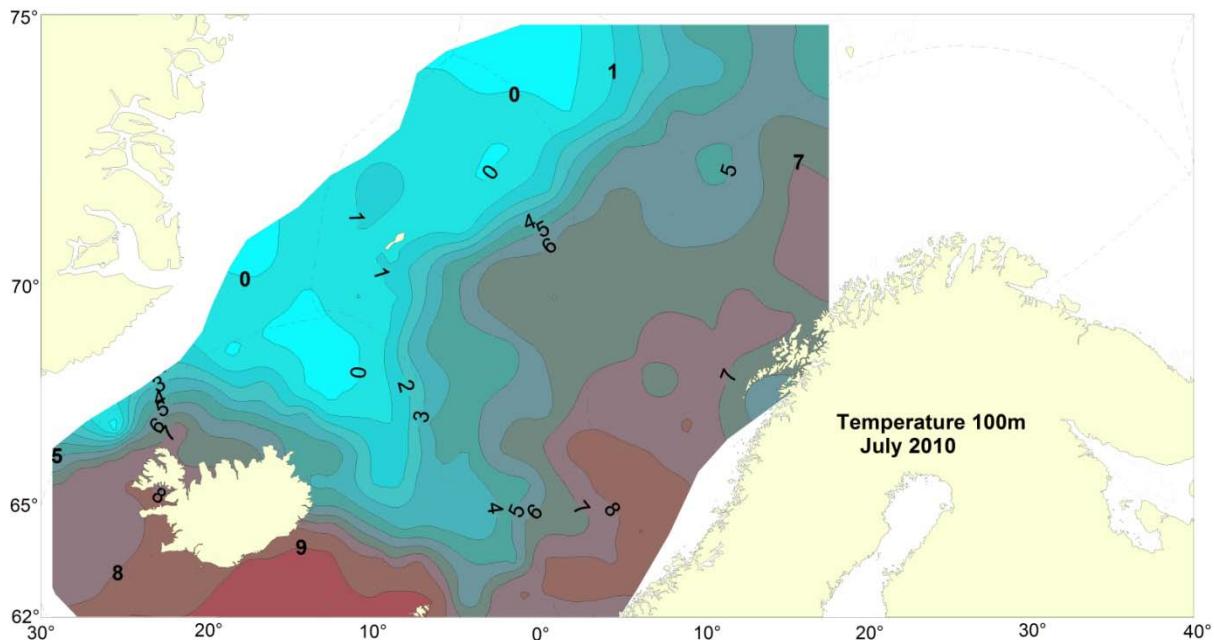
Temperature maps were produced in Surfer 9.0 and ArcGis 10.0 based on 278 CTD casts from Libas (90) and Brennholm (58) Finni Fridur (30) and Arni Fridriksson (100). Surface waters in the northwestern part of the Norwegian Sea in the Jan Mayen zone and in Icelandic waters were still warmer compared to the last two decades, and coincided with increased presence and concentrations of large herring and mackerel in the area. The eastern and northernmost areas were in contrast colder than previous years (Figure 13), although not limiting the extent of northern migration by herring and mackerel. We found a new record northerly distribution of large mackerel north up to 76.30°N. Coastal waters off Norway were also colder than recorded previous years (Figures 11, 12 and 13).



**Figure 11.** Temperature at 10 m depth in the Norwegian Sea and surrounding waters, 9 July - 20 August 2010.



**Figure 12.** Temperature at 50 m depth in the Norwegian Sea and surrounding waters, 9 July -20 August 2010.



**Figure 13.** Temperature at 100 m depth in the Norwegian Sea and surrounding waters, 9 July -20 August 2010.

## Acoustic doppler current profiler (ADCP)

The bottom mounted RDI ADCP was not working properly during the first leg and at the start of the 2<sup>nd</sup> leg of the survey. After the initial installation of the equipment back in 2004, the original PC has been replaced. Originally the gyro telegram was read from a RS422 serial line. The new PC only has RS232 serial ports. For the ADCP software to be able to read the gyro telegram the serial connection was reconfigured from RS422 to RS232 and the gyro telegram was successfully received.

Two of the PC COM-ports had connection problems and failed at times. This was due to the fact that the COM-port card does not fit properly into the card slot of the new PC. External USB-RS232 converters was used instead and worked without problems.

The ADCP received external trigger pulses from the ER60 echo sounder. An adjustable delay circuit was used to prevent interference from the ADCP on the echo sounder recordings. This worked very well.

It was discovered that the measured current direction was always ca. 45 deg to the side of the ship heading. Current magnitude was also far too high and correlated with the vessel speed. An example of this wrong data is showed in figure 6, where is clear how the current direction changes with the vessel heading. The reason for this problem was that the transducer misalignment was set to 0 deg .

A short calibration “survey” was performed to get the exact value for the misalignment. The analysis of the calibration survey provided with suitable data and a true misalignment of 40.98 deg. All the collected ADCP data have to be reprocessed before they can be included in any analysis. This has so far not been done, however technical expert from RDI have supervised all these works, and looked

at some of the data and verified that the data quality after reprocessing is good, and confirmed that the ADCP system now is working properly. A sample of data reprocessed is also showed in figure 14.

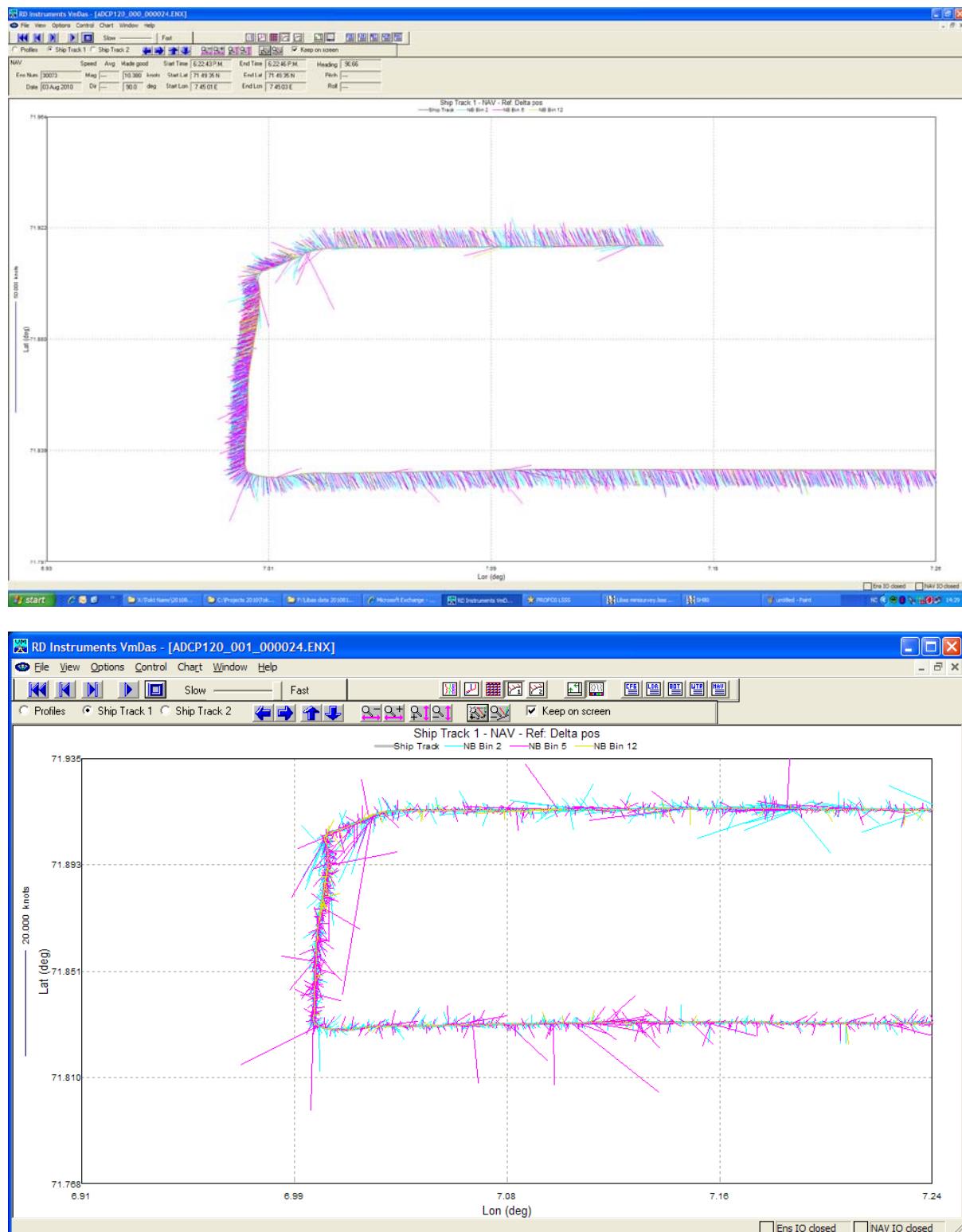


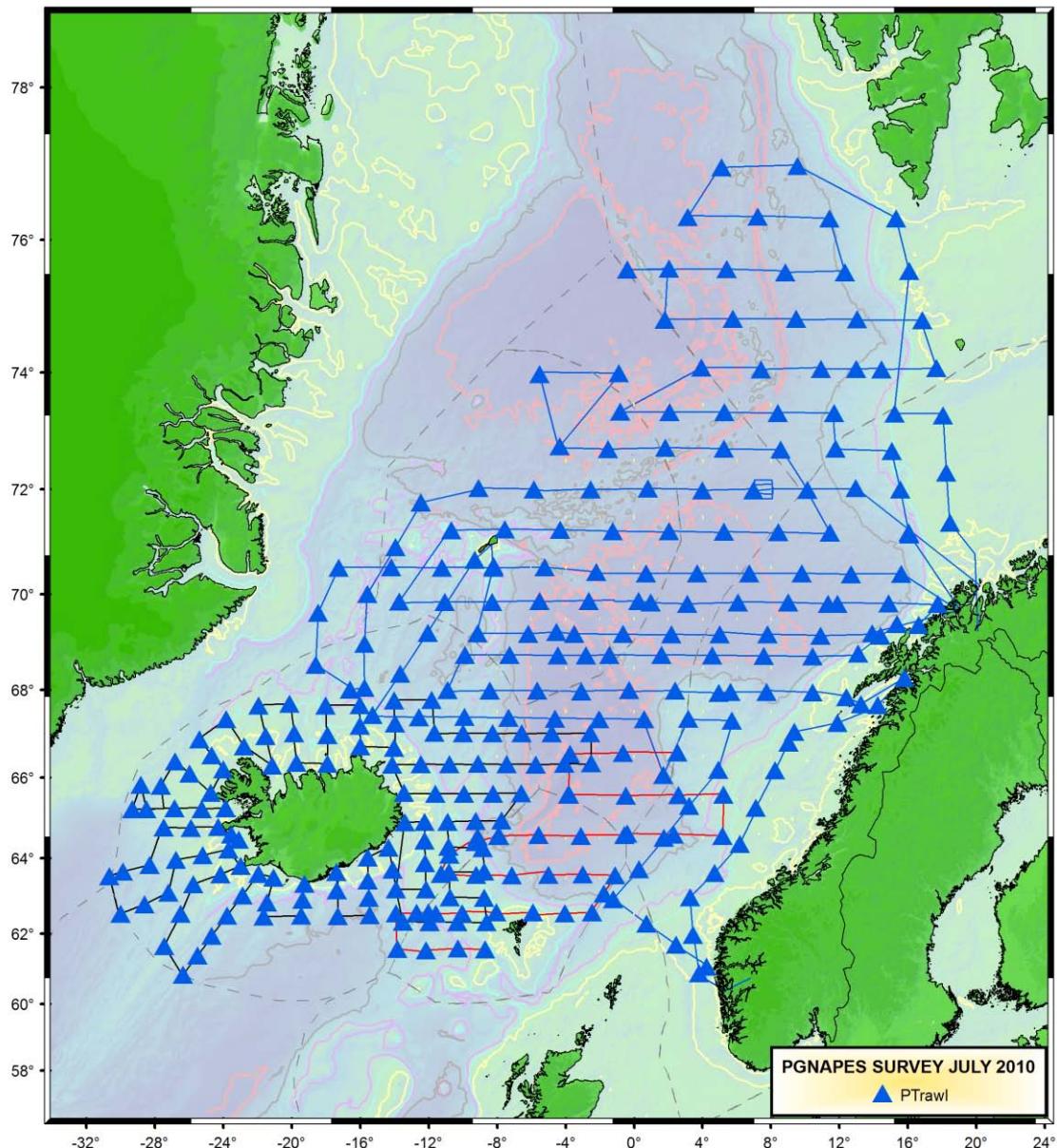
Figure 14. Example of ADCP data collected onboard Libas. Upper panel, data with wrong ADCP transducer alignment, where the current direction is influenced by the vessel heading. Lower panel, corrected data, reprocessed for misalignment correction.

## ***Weather conditions***

The weather conditions were mostly favourable for acoustic recordings and visual sightings with low wind speed (Baufort scale: 0-3). However, wind speed reached Baufort scale 8-10 some days within the survey tracks for Libas, Brennholm, Finni Fridur and Arni Fridriksson in the Norwegian Sea and surrounding water from 9 July to 20 August 2010. Low precipitation and limited rainfall provided good visibility throughout the cruise. Fog and fogbanks were mostly experienced in the westernmost area in the Greenland Sea, north and west of Iceland and around Jan Mayen.

## ***Biological samples***

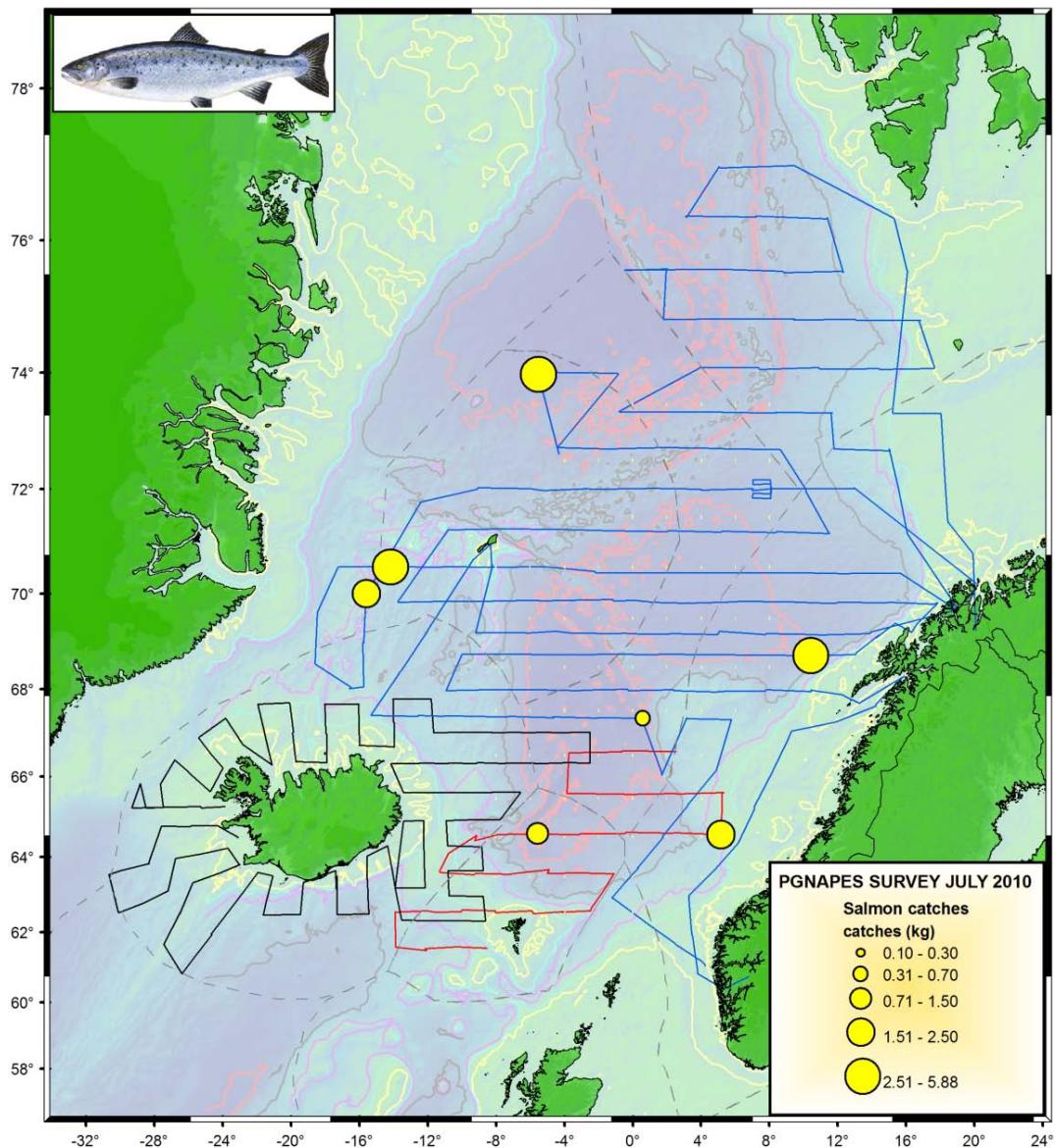
Libas performed 90 pelagic trawl stations, Brennholm performed 58 pelagic stations, Finnur Fridi performed 30 trawl samples, whereas Arni Fridriksson performed 100 pelagic trawl stations (Figure 15).



**Figure 15.** Map showing pelagic trawl hauls taken on Brennholm, Libas, Finni Fridur and Arni Fridriksson and survey tracks during the ecosystem survey 9 July to 20 August 2010.

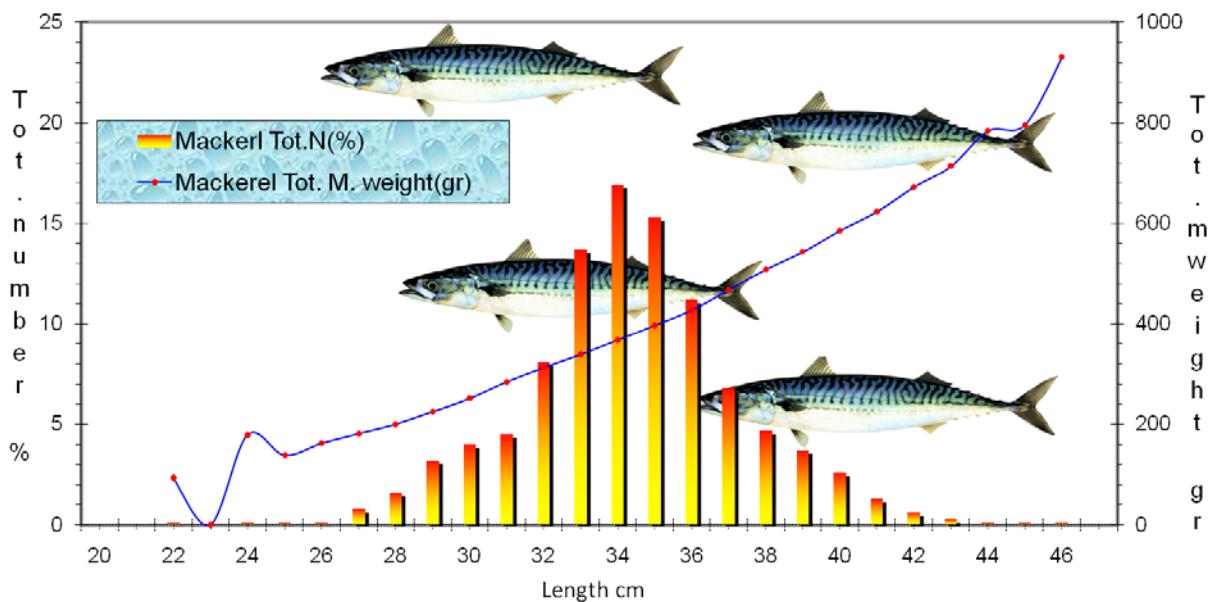
### Salmon

Totally 9 salmon were caught during the ecosystem survey in the Norwegian Sea. A total number of 1 salmon were caught on M/S Brennholm within the survey area. The largest salmon caught was 5.4 kg. In total, 6 salmon were caught in the survey areas covered by M/S Libas. Finni Fridur caught 2 small salmon. None of the salmon were classified as escaped farmed fish. The salmon were caught in different parts of the survey area (see figure 16). The northernmost catches of salmon were done at 74°N. The southernmost catch was a single individual caught at 64.5°N. This distribution of catches indicates that the survey area covered by M/S Libas probably only overlapped with postsmolt distribution during the most northerly transects. All salmon were measured. Lice were observed on all individuals originating from the Greenland Sea and northern waters.

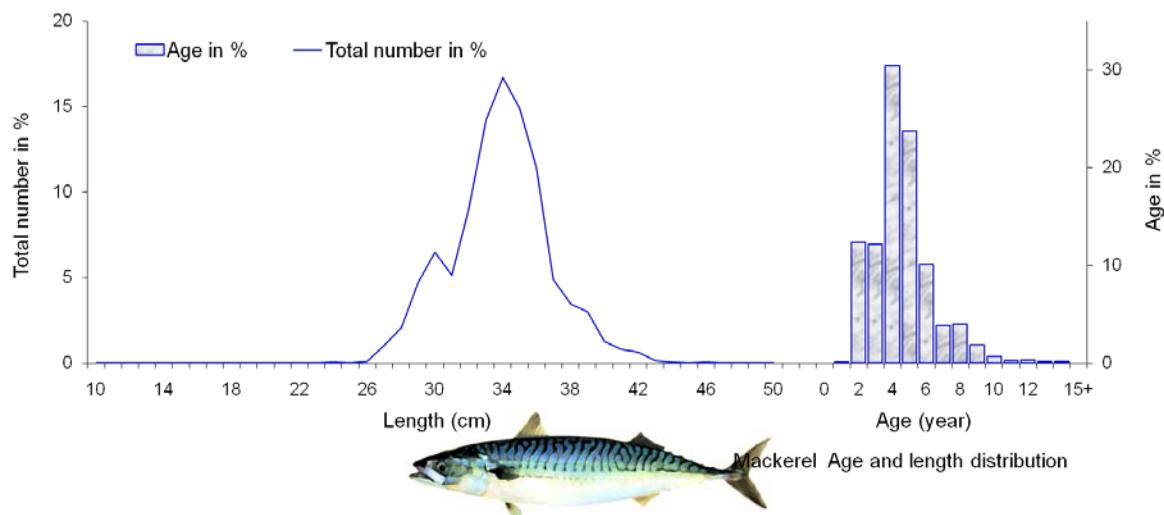


**Figure 16.** Salmon catches (kg) taken on epi-pelagic trawl hauls along the cruise tracks for Libas and Brennholm combined.

Mackerel caught in the pelagic trawl hauls on Libas, Brennholm, Finnur Fridi and Arni Fridriksson varied from 22 cm to 46 cm in length with the individuals between 33-35 cm dominating in the abundance. The mackerel weight (g) varied between 100 to 925 g (Figure 17). The 2005-year class of mackerel together with the 2006-year class dominated the mackerel population in the Norwegian Sea with more than 50% in number (Figure 18).

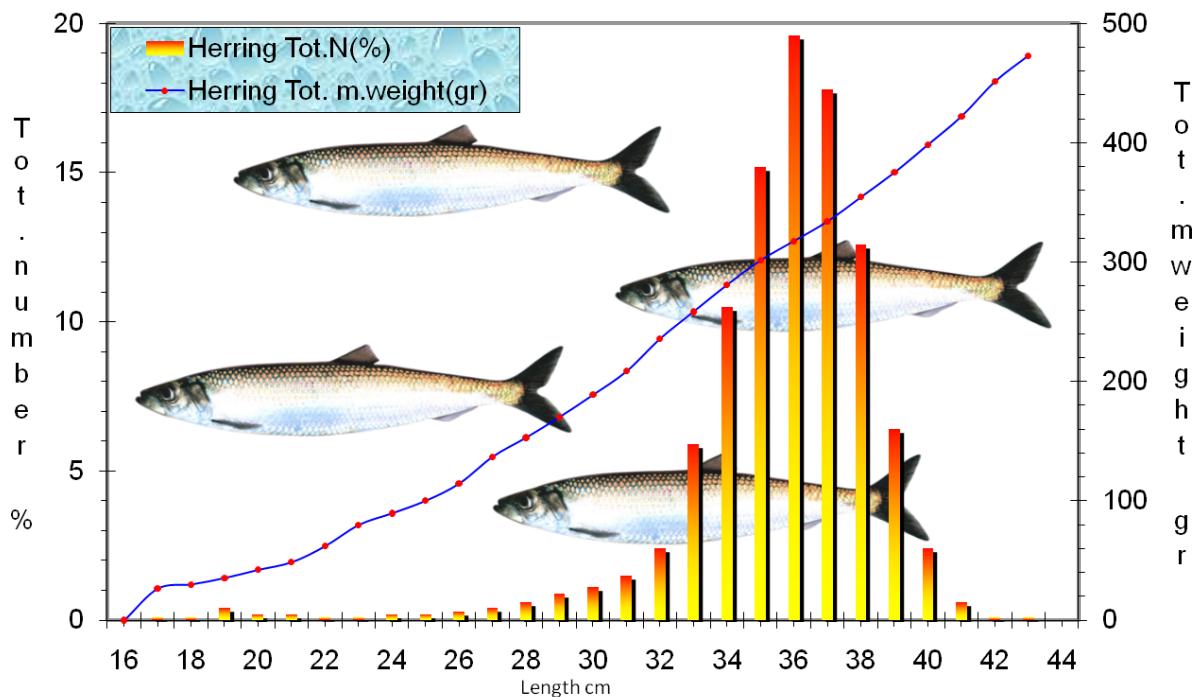


**Figure 17.** Total length (cm) and weight (g) distribution in percent (%) for mackerel in all catches.



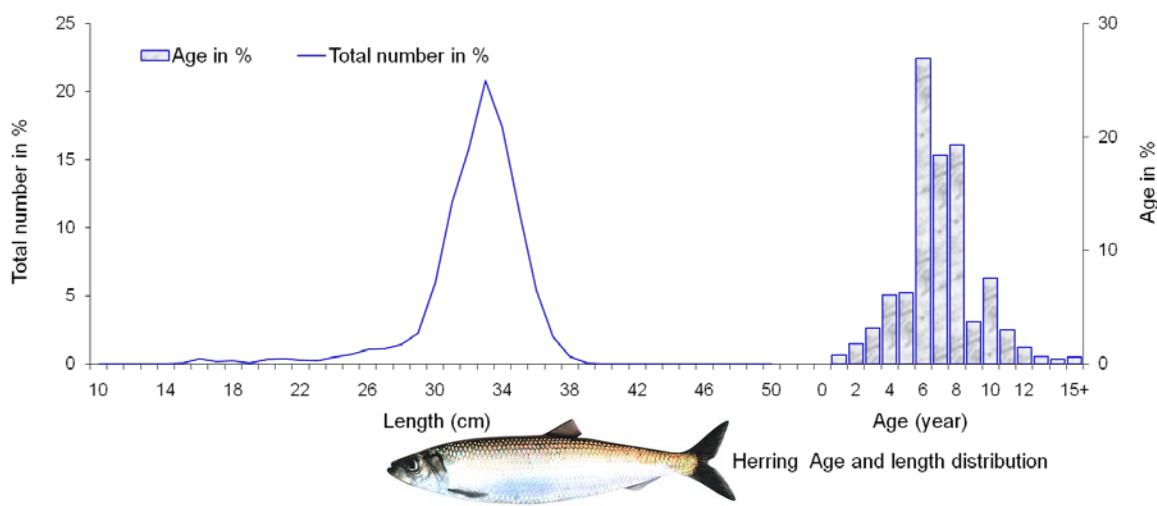
**Figure 18.** Age and length distribution in percent (%) of Atlantic mackerel in the Norwegian Sea.

Norwegian spring-spawning herring had a length distribution from 16-43 cm with a peak at 35-37 cm, and a weight ranging from 20-470 gram (Figure 19).



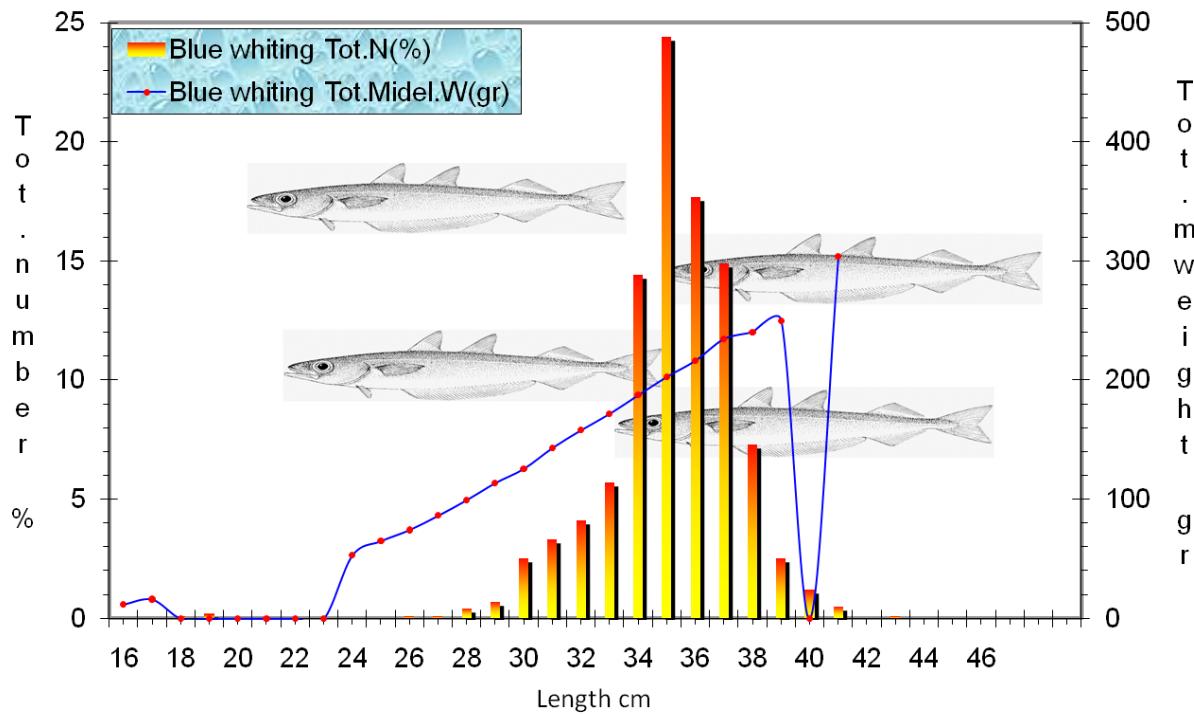
**Figure 19.** Length and weight distribution of herring in the pelagic trawl catches.

The age distribution in herring shows dominance of the 2002 year class. They constitute 27% of the total population in number. The 2004- (22%) and 2003 (15%) year classes are the second and third most numerous herring year classes, respectively. Younger herring than 3 years was practically absent in the trawl catches (Figure 20).



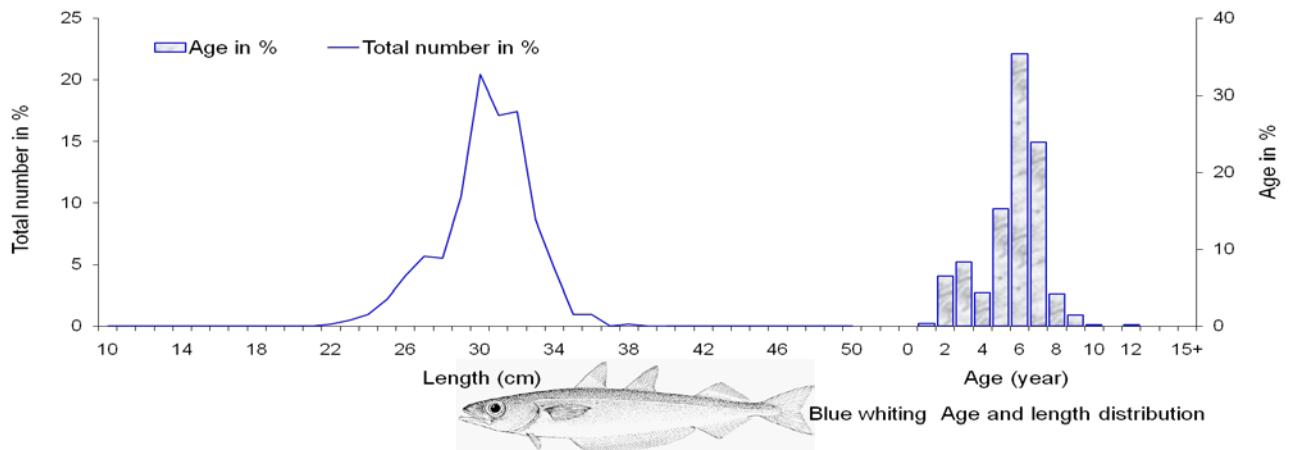
**Figure 20.** Herring age and length distribution in the pelagic trawl catches.

Blue whiting length distribution was from 27-36 cm and individual weight distribution was 100-240 gram. Blue whiting between 33-37 cm dominated the catches (Figure 21).



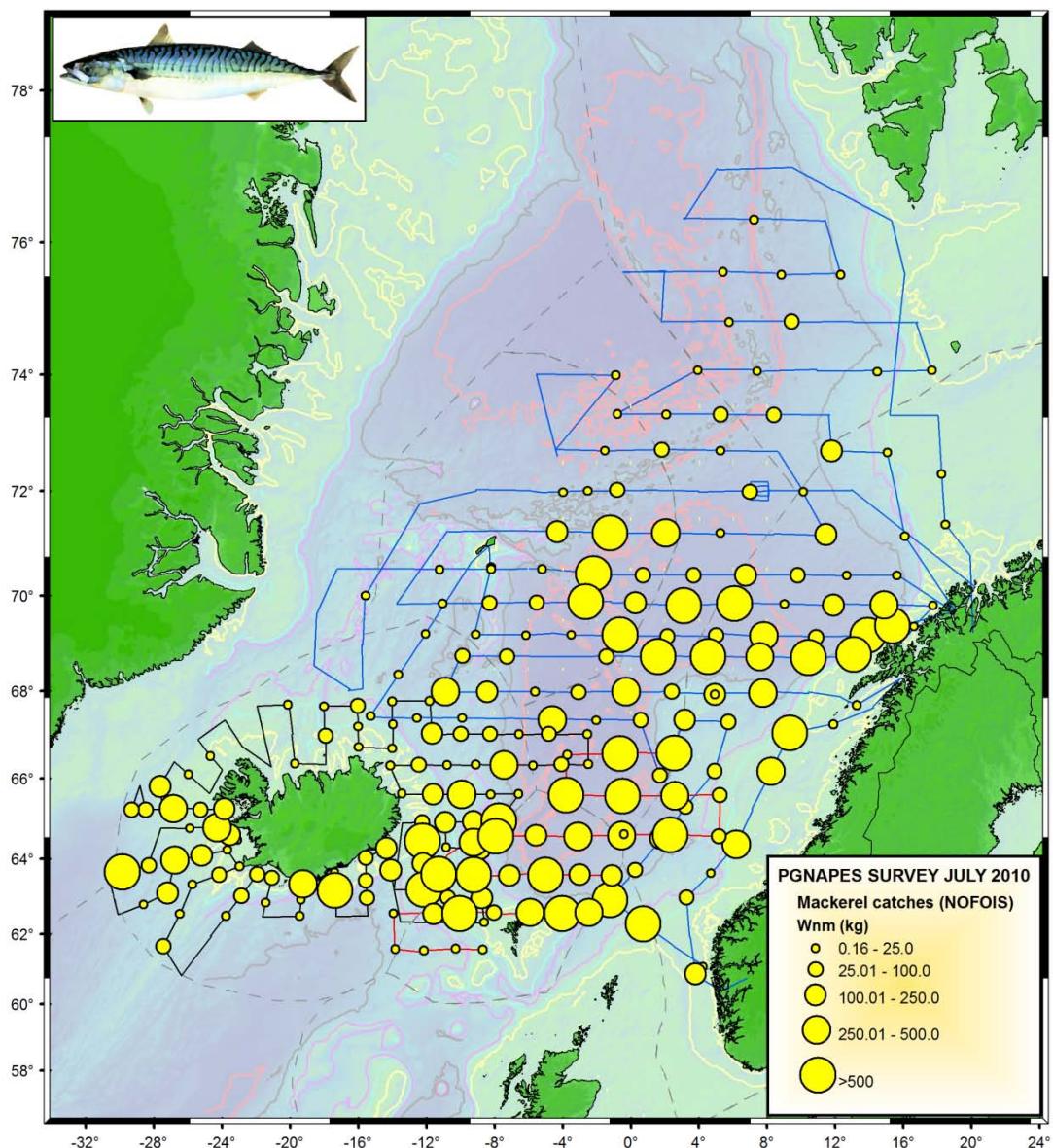
**Figure 21.** Length and weight distribution of blue whiting in the pelagic trawl catches.

The age distribution of blue whiting showed a dominance of 2004 year class (36%) followed by the 2003 year class (23%) and 2005 year class (17%). Blue whiting younger than 4 years of age was in low number in the trawl catches or less than 10% (Figure 22).



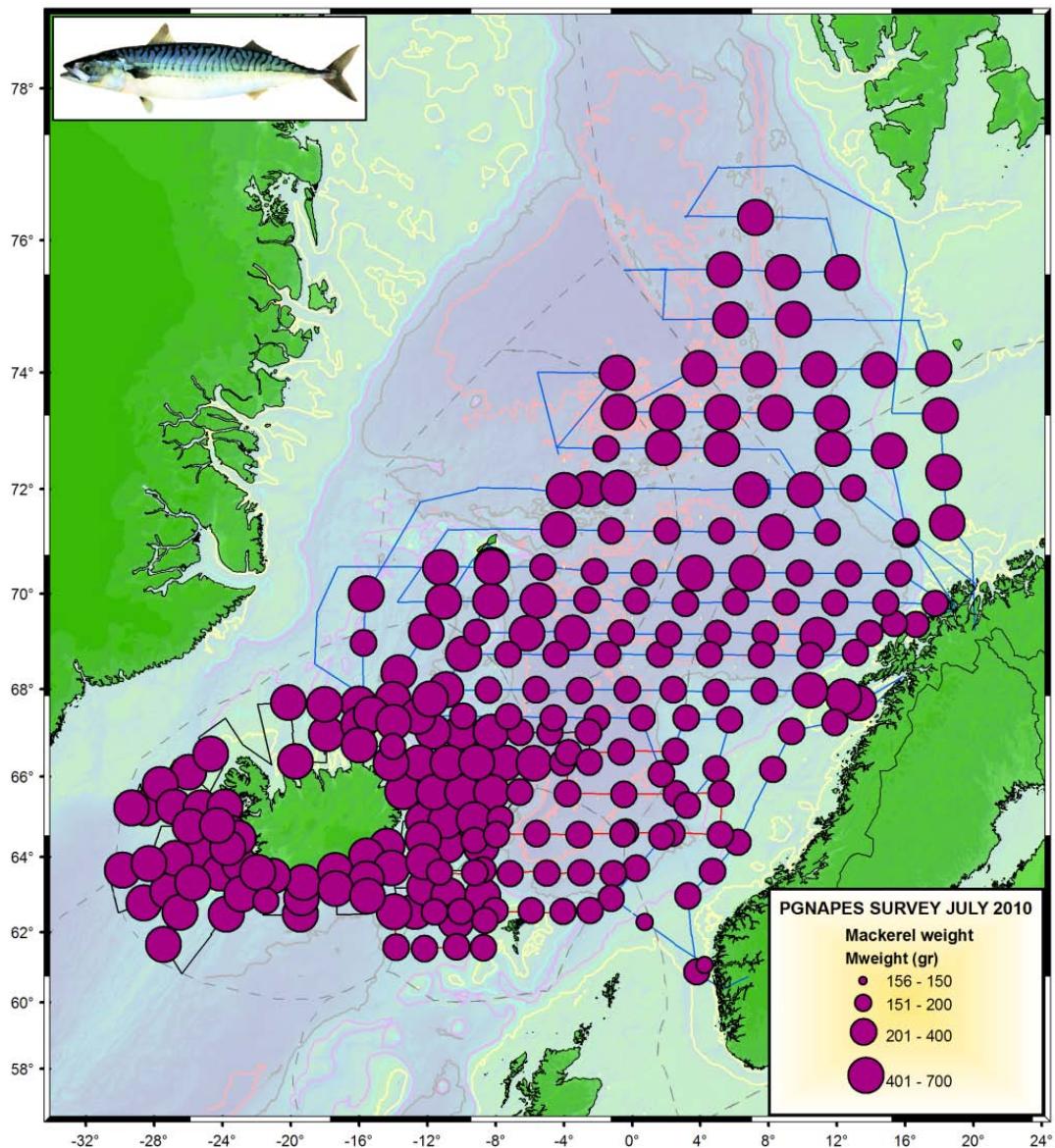
**Figure 22.** Blue whiting age and length distribution in the pelagic trawl catches.

Highest mackerel catches (kg/nmi) dominated in the western and central Norwegian Sea and adjacent areas from 62°N to 68°N in the northwestern and northern areas with Arctic water masses (Figure 23).



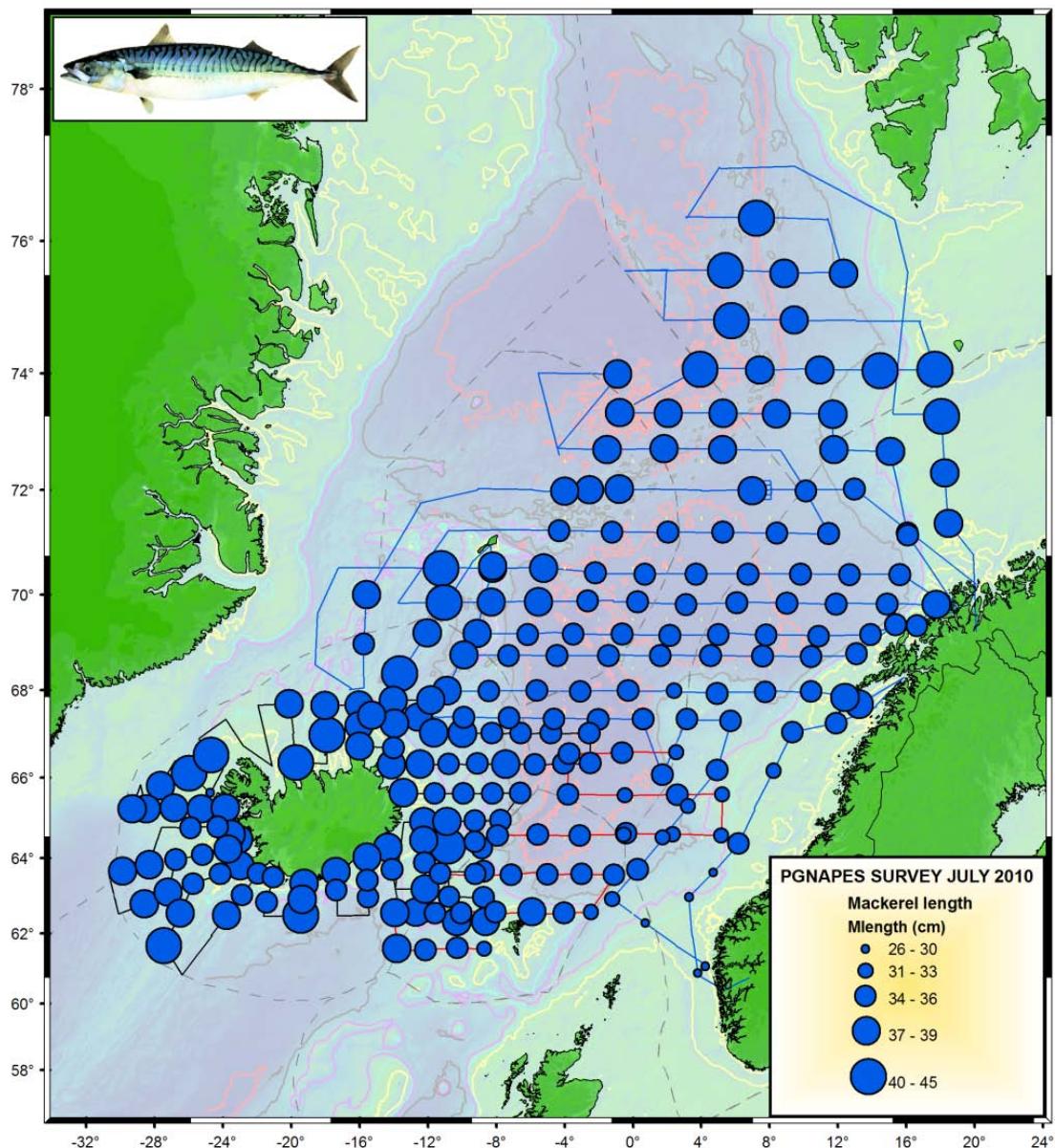
**Figure 23.** Mackerel catches (kg/nmi) from Libas and Eros combined in the Norwegian Sea and surrounding waters, 9 July- 20 August 2009.

Mean mackerel weight (g) within a category is shown for each biological station (Figure 24). A general trend is that the largest mackerel is found in the western and northwestern part of the Norwegian Sea.



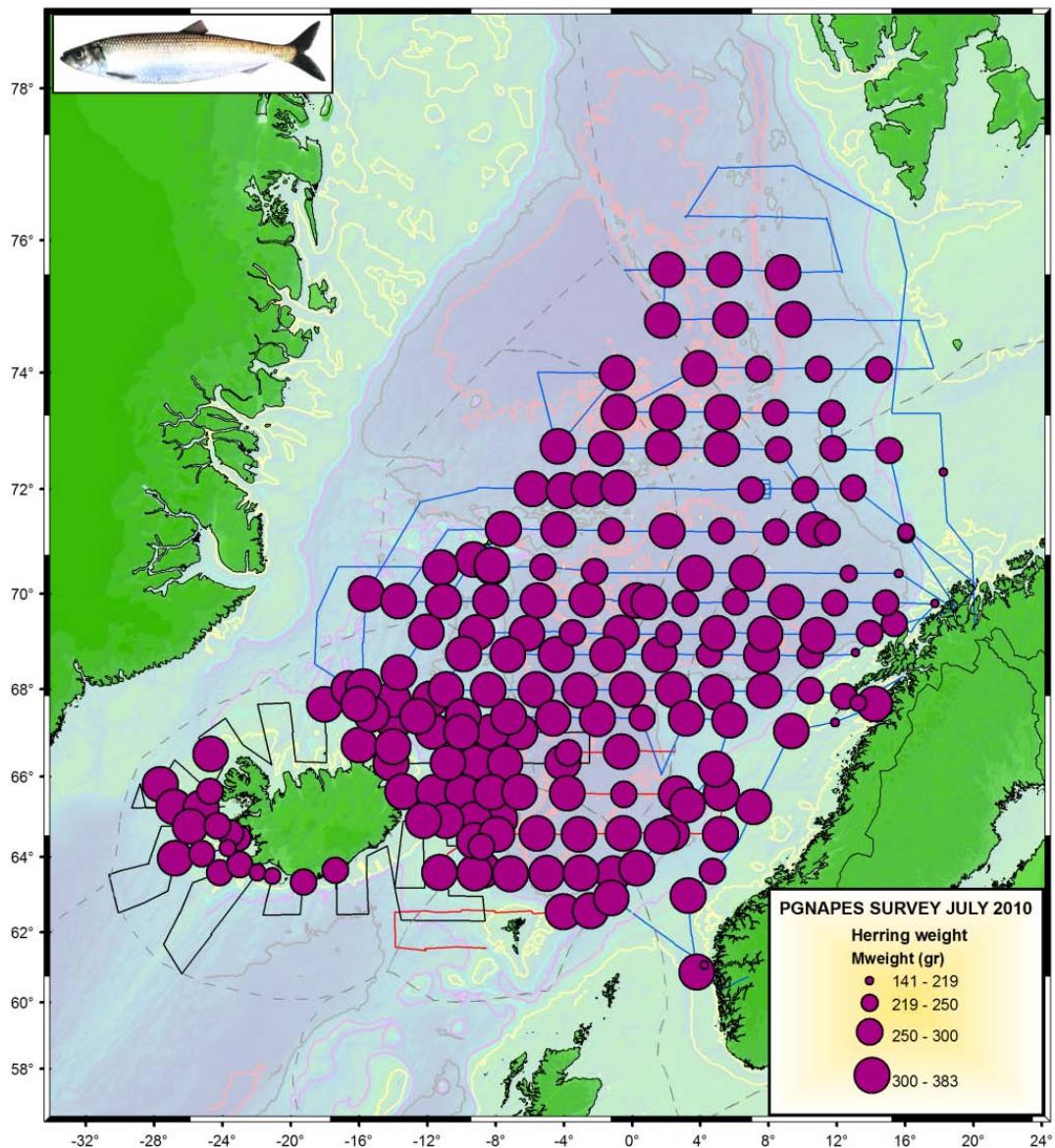
**Figure 24.** Mean mackerel weight (g) represented for each station within the categories shown. No catch of mackerel is indicated as a blank along the cruise track.

Mean mackerel length (cm) within each category is shown for each biological station (Figure 25). A general trend is that the longest mackerel is found in the western and northwestern part of the Norwegian Sea.



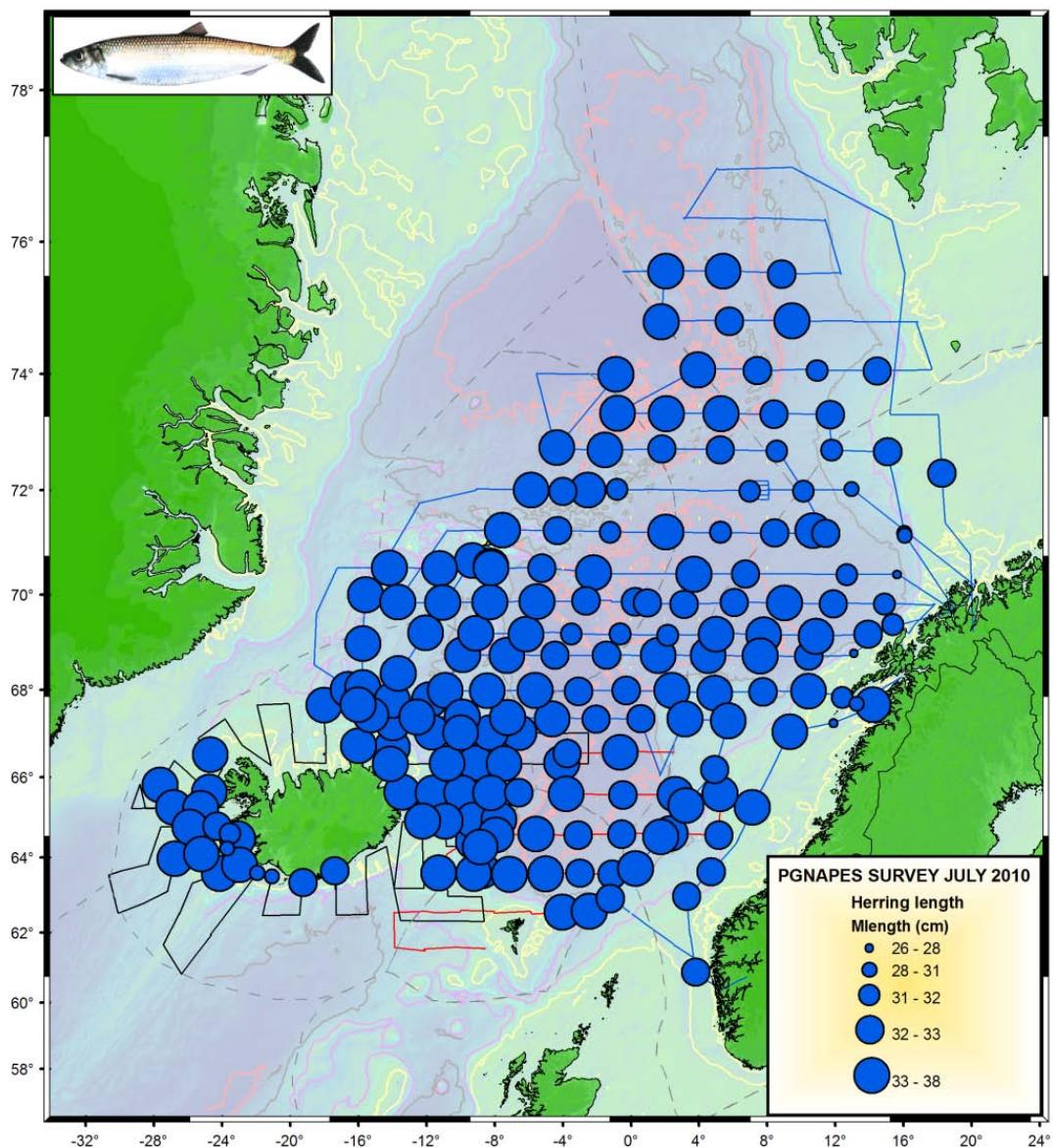
**Figure 25.** Mean mackerel length (cm) represented for each station within the categories shown. No catch of mackerel is indicated as a blank along the cruise track.

Mean herring weight (g) is shown in figure 26. We can see from the figure that herring is distributed over a substantial feeding area within the peripheral parts (donut shaped) of the entire study area. The largest herring were found in the northern and western areas, with a relatively clear weight dependent migration pattern was found.



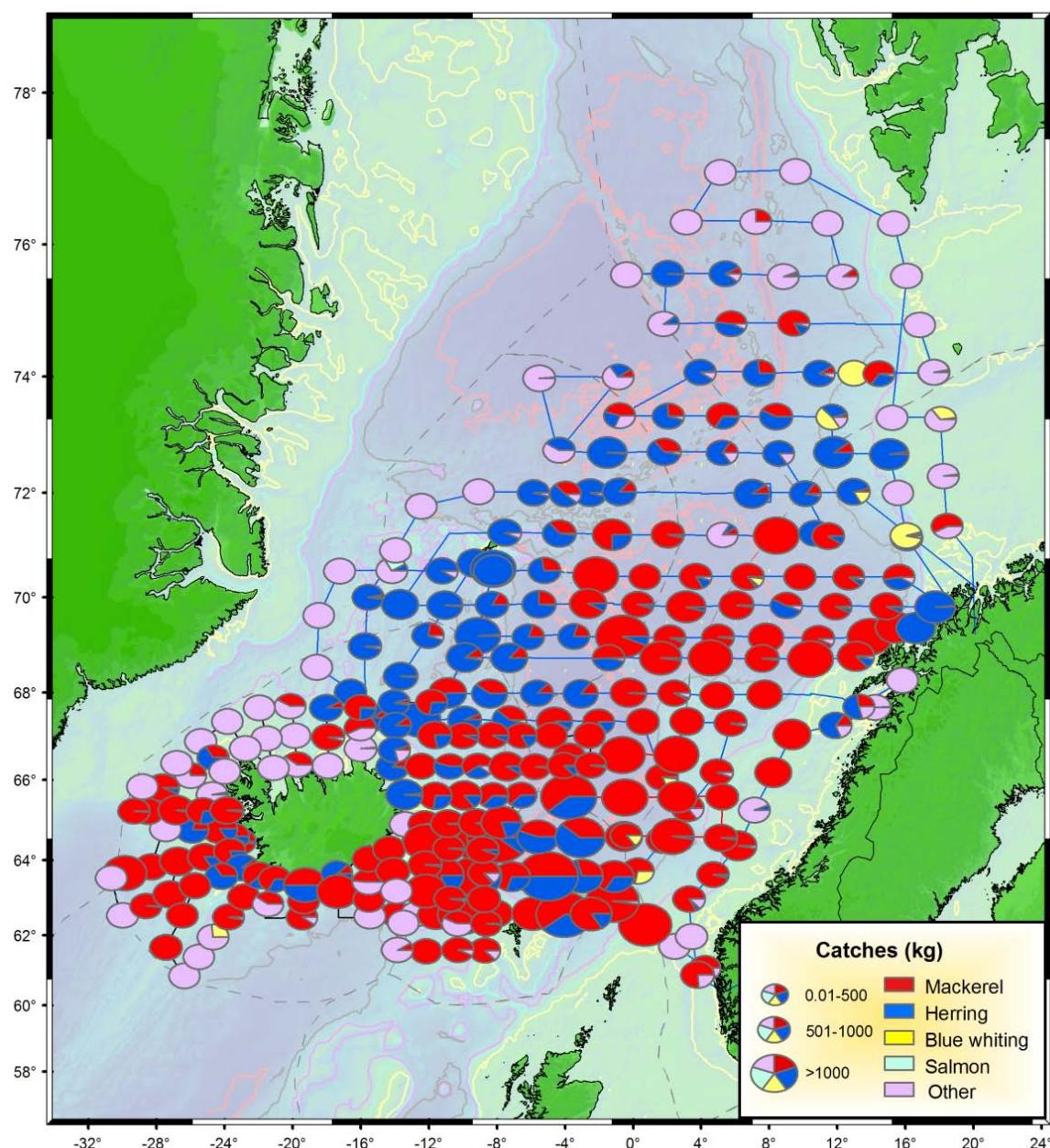
**Figure 26.** Mean herring weight (g) for herring represented for each station within the categories shown. No catch of mackerel is indicated as a blank along the cruise track.

We can see from Figure 27 that herring was distributed over a large feeding area within the study area. The largest herring were normally found in the western and northern part indicating a clear length-dependent herring migration pattern (Figure 27).



**Figure 27.** Mean herring length (cm) for each station within the different categories shown.

In order to illustrate and visualize the spatial and temporal overlap between mackerel, herring, blue whiting and other species such as salmon, horse mackerel and lumpsucker catches, we presented the catches for all species at each station to see where the abundant pelagic planktivorous species were present and compare their normalized catch rates (kg/nmi) from epi-pelagic trawling (Figure 28).



**Figure 28.** Distribution and spatial overlap between mackerel (red), herring (blue), blue whiting (yellow) and salmon (violet) from Libas and Brennholm in the Norwegian Sea between 15 July and 6 August 2010.

The spatial overlap between mackerel and herring were mostly found in the southern, southwestern and northern parts of the Norwegian Sea. Altogether 24 stations contained both mackerel and herring in the trawl samples. Herring were caught alone in the northeastern and northern part, whereas mackerel were caught alone in trawl catches in the coastal areas off Norway, central part of the Norwegian Sea and in several catches west, south and southeast off Iceland. Blue whiting was predominantly caught in western part of the Norwegian Sea in Arctic and frontal water masses. Blue whiting and herring had spatial overlap in frontal and Arctic waters, whereas blue whiting had overlap with mackerel in the western areas, whereas little spatial overlap with mackerel in the central part of the Norwegian Sea. The herring caught off west and south Iceland belonged entirely to the Icelandic summer-spawning stock.

## Acoustics

### Omnidirectional fisheries sonar

The results of the scrutinizing process of the sonar data showed that along all transects, either North or South of the central line (which correspond to the original survey line), a large number of schools were present. A North-South gradient in the number of school can be observed, with lower number of schools in the NE and SW corners of the sampled area. These results indicates that schools were distributed in this region more than 10 nmi from the central survey line. A comparative and integrated analysis with the data collected with the echo sounder and ADCP data will be done in a later stage.

From these preliminary results is also possible to observe the general swimming direction of the schools detected (Figure 29). In a selected region of the northernmost transect of the minisurvey the schools presented an east- south east direction, in the same direction of the vessel.

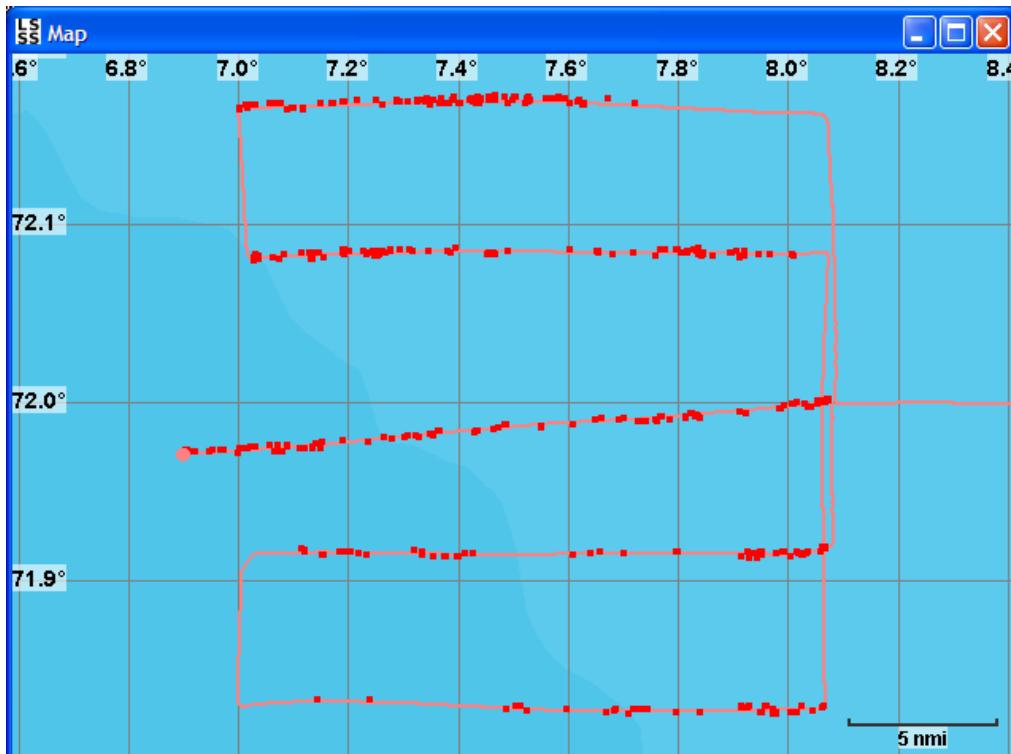


Figure 29. Schools detected by the SH80 sonar during the minisurvey. Each red dot represents the single detections for each school in every ping. The central line ( $ca. 72.0^{\circ}$  N) corresponds to the original survey track line.

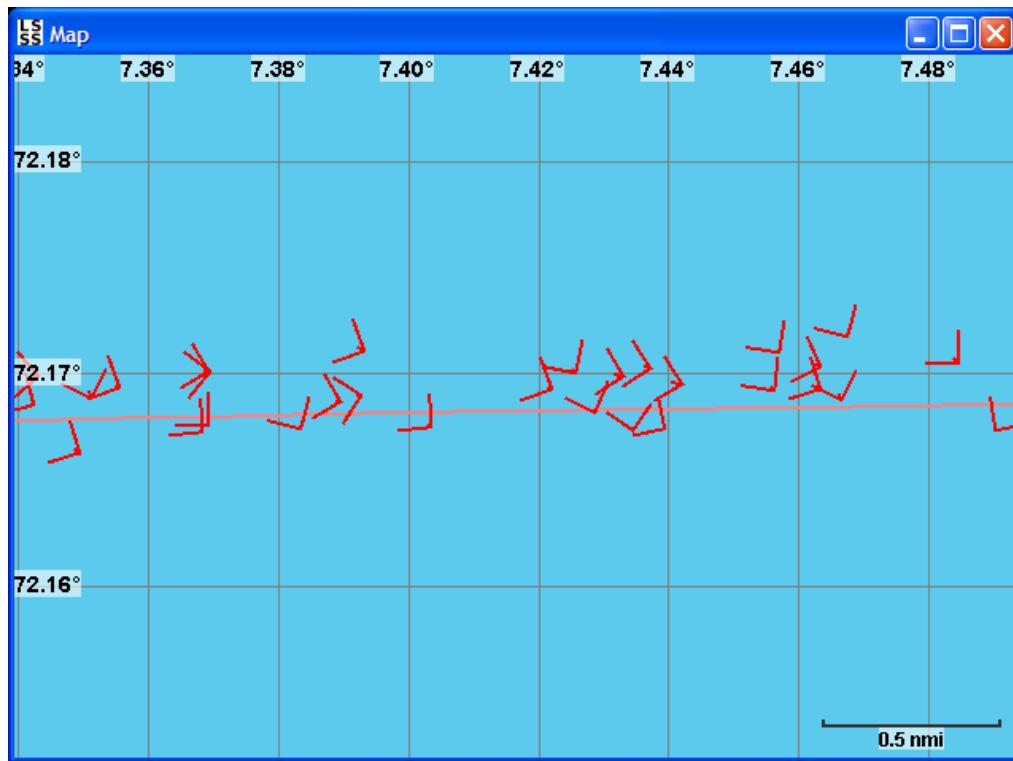


Figure 30. Detail of one of the survey lines in the minisurvey. Each arrow head is showing the mean school direction. In this particular transect the vessel was sailing from west to east, and the schools were swimming in a general east-southeast direction.

From the processing of the sonar data from one of the survey transects from the Norwegian coast to Greenland is possible to observe schools all along the transect, with relative more schools over the continental shelf off Tromsø. A detail of the first part of the transect showed that most of the schools have a swimming direction NE, similar to the prevailing currents in that area.

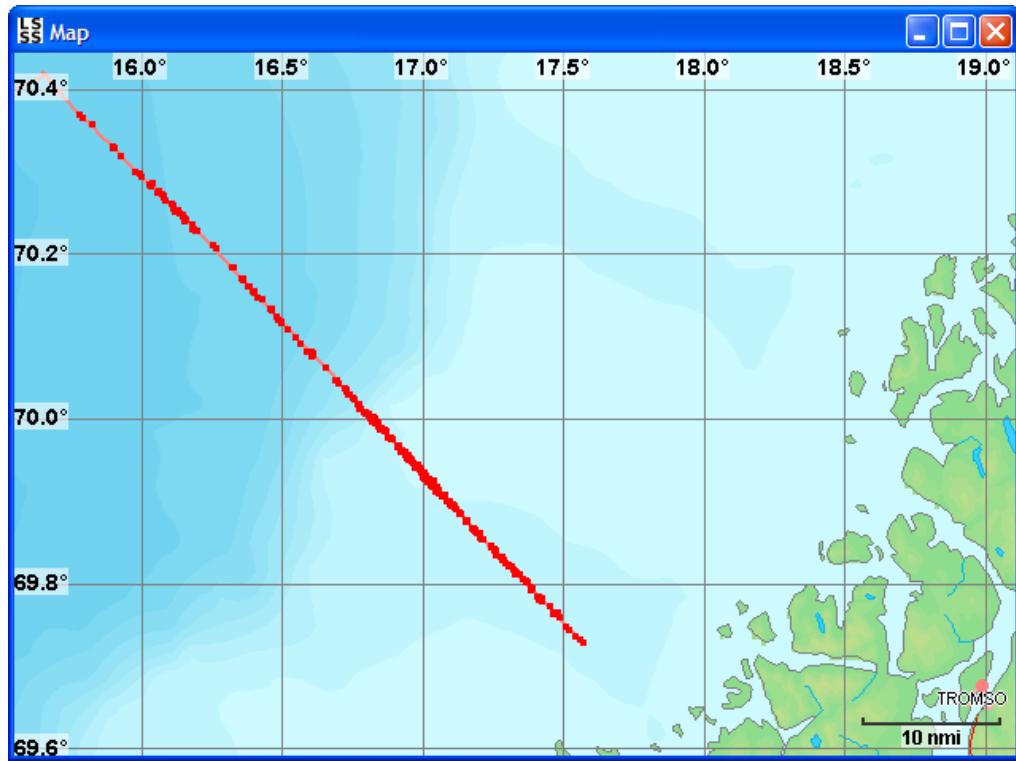


Figure 31. Schools detected by the SH80 sonar during the first survey transect during the second leg (26.07.2010). Each red dot represents the single detections for each school in every ping.

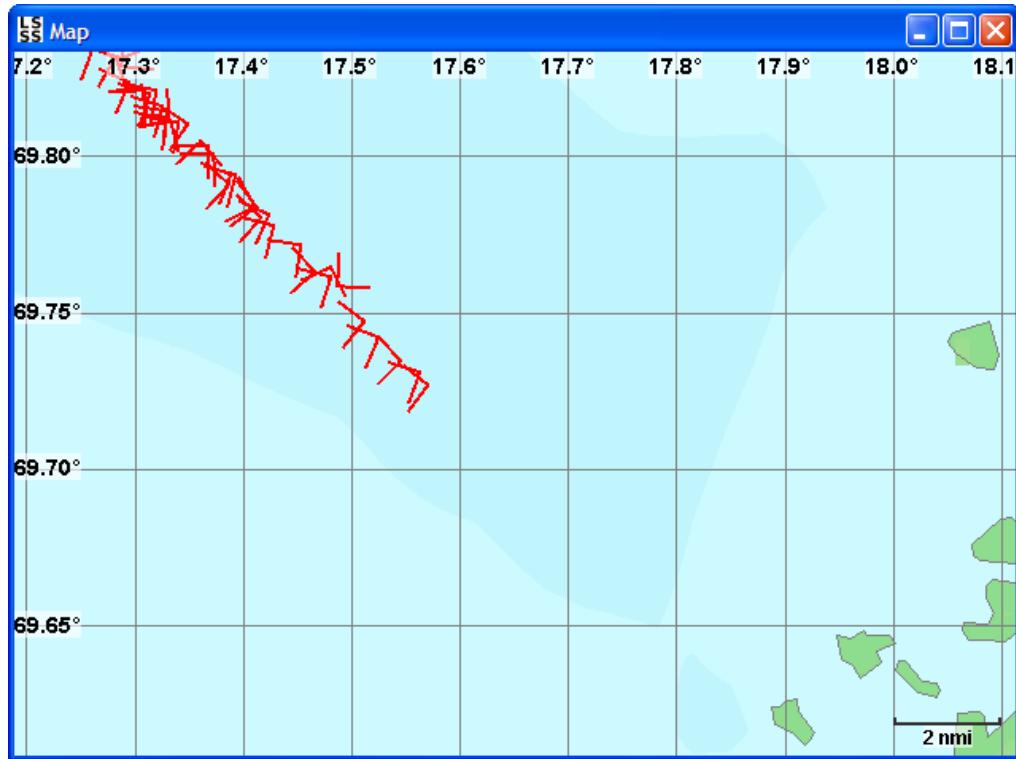


Figure 32. Detail of the first survey transect during the second leg (26.07.2010). Each arrow head is showing the mean school direction.

Also, was tried to process some of the files collected onboard Brennholm with the SH90 sonar. However, problems reading some .dat files was observed, and no explanation is yet found. Most likely, the .dat file format stored with the SH90 sonar is not exactly the same as the .dat format stored by the SH80 which was used to develop the PROFOS module. This problem is now investigated and already communicated to Simrad.

From the experience gained during the survey is clear that one of the main aspects that need to be solved is to improve the school growing process. For this, is crucial to perform the semi-automatic growing process in a more noise free and smoothed sonar image. Actually, the PROFOS module is working with the raw data files with no smoothing or noise filtering, making the automatic growing process inaccurate, and requiring manual corrections. The aim is to be able to filter the raw data to produce an image similar to the sonar screen, with the school very strong enhanced and low noise level. If this is accomplish, a full automatic school detection procedure will be tested, if successful with reduce significantly the scrutinizing time.

Another important problem is related with the data handling. Actually the .dat file format is structured in a way that the files corresponding to each sonar ping are stored inside a folder, every *ca.* 30 s. This procedure creates a large number of folders of small byte size, which in a large survey generates a problem for handling (storing, copying, etc) by the computer operating system and the PROFOS system. Has been communicated by Simrad that the new .raw format that will be available in the SH90 and SX90 sonars, will have a format similar to the EK60 data format. This format will allow an easier and faster handling of the sonar files.

#### Echosounders

Quantitative analyses of abundance, aggregation and distribution of mackerel, herring and blue whiting concentrations were also performed continuously based on Simrad ER60 raw data using 38 kHz as the primary frequency for fish species and nautical area scattering coefficient (NASC) allocation. Mackerel allocation was based on the formula:

$$TS_{\text{mackerel}} = 20 \log L - 84.9$$

where TS is the target strength of mackerel and L is the length of mackerel in cm. The S<sub>v</sub> thresholds applied in LSSS to allocate mackerel from other species were in the range from -69 to -75dB.

Herring allocation was based on the formula:

$$TS_{\text{herring}} = 20 \log L - 71.9$$

where TS is the target strength of herring and L is the length of herring in cm.

The S<sub>v</sub> thresholds applied in LSSS to discriminate and allocate herring from other species were in the range from -50 to -55dB.

Blue whiting allocation was based on the formula:

$$TS_{\text{blue whiting}} = 20 \log L - 64.2$$

The S<sub>v</sub> threshold applied in LSSS to discriminate and allocate blue whiting from other species was -68 dB.

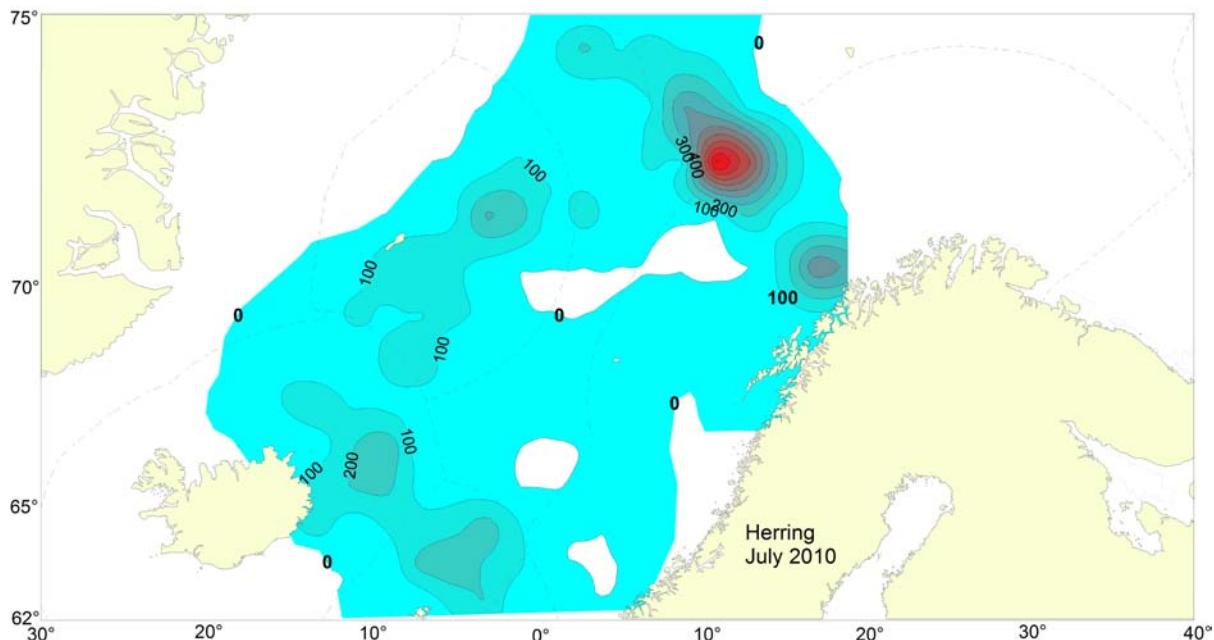
Multi-frequency patterns between 38 and 200 kHz (Brennholm and Finni Fridur) and 18, 38, 70 120 and 200 kHz (Libas and Arni Fridriksson), were also used actively to allocate acoustic

targets to species. Judging of the acoustic data was performed daily by two experienced scientists applying the post processing system Large Scale Survey System (LSSS) and <http://www.marec.no/>, Echoview (<http://www.echoview.com/>) and BI 500 (see above).

### Abundance estimation of pelagic fish

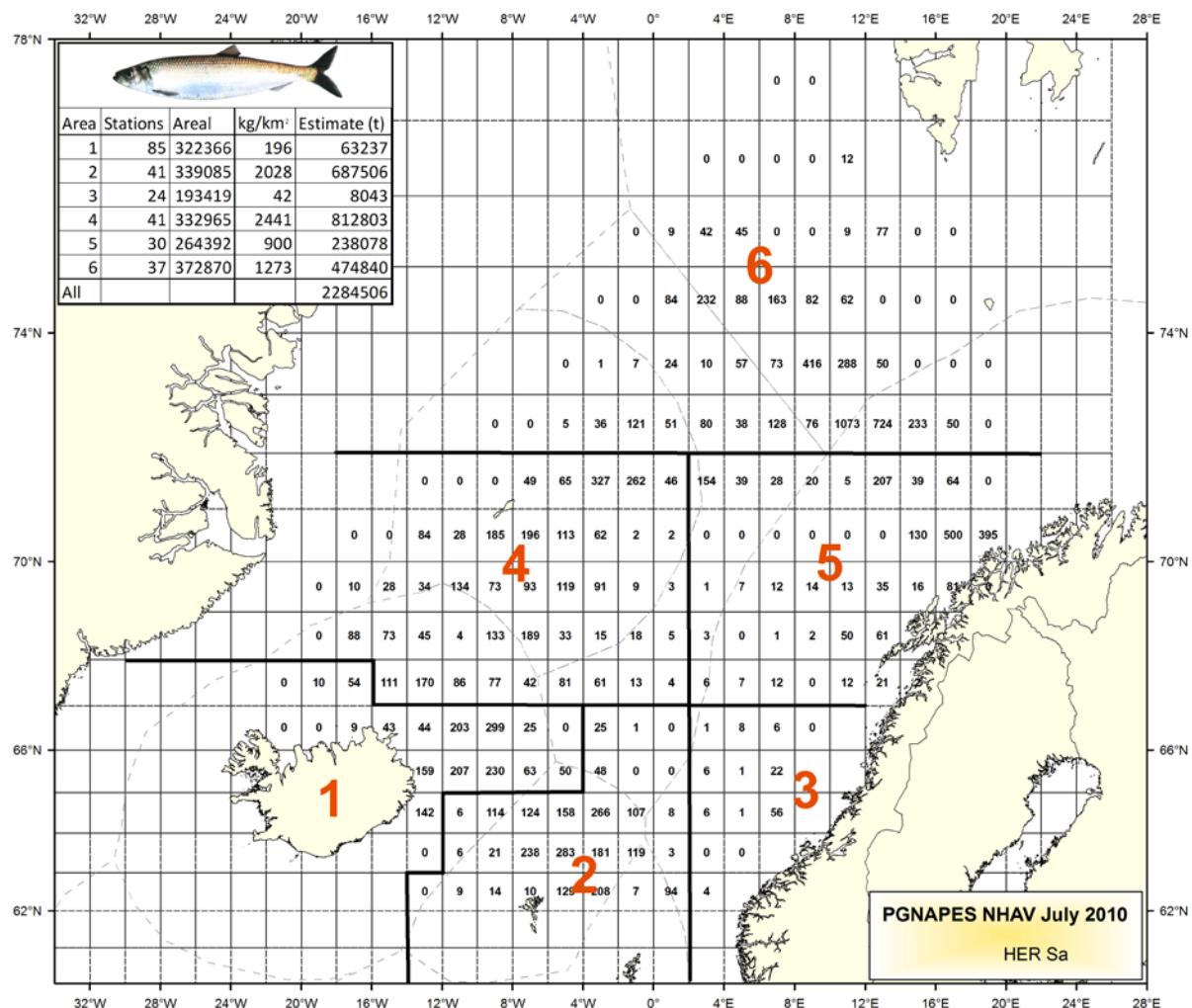
Acoustic abundance estimation using Large Scale Survey System (LSSS) was done for Norwegian spring-spawning herring, mackerel and blue whiting.

The herring population within the covered cruise tracks and areas was estimated to be 10.7 million tons consisting of 35.6 billion individuals. The average weight of herring was 300.7 gram and mean length was 32.6 cm. Altogether 15 different year classes were present in the catches, whereas only six year classes constituted to more than 5% of the catches.



**Figure 33.** Sa or Nautical Area Scattering Coefficient (NASC) values of herring along the cruise track.

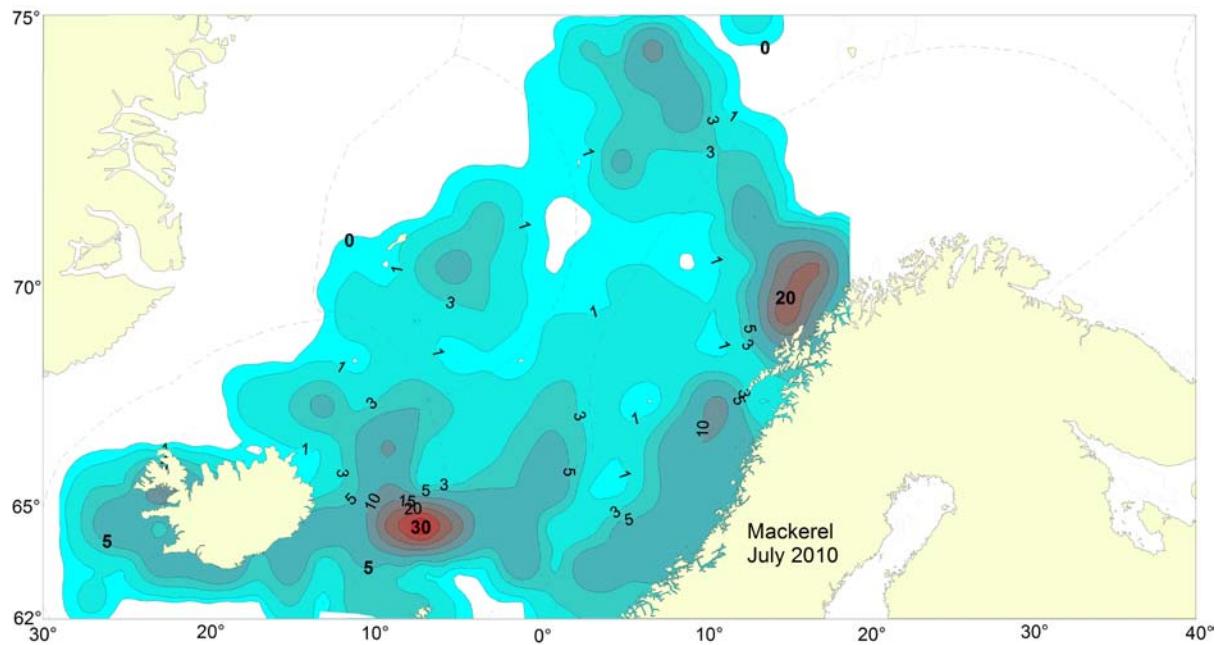
A swept area analyses was performed for Norwegian spring-spawning herring for Libas, Brennholm, Finni Fridur and Arni Fridriksson from 9 July to 20 August 2010. The input data for the calculation was as follows: a horizontal opening of 23 m was applied for Arni Fridriksson based on the trawl dimensions and performance geometry. A horizontal opening of 50 m was applied for the pelagic trawl onboard the chartered vessel Finni Fridur from Faroe Islands and Libas and Brennholm from Norway. Only surface trawl hauls were used in the analyses. The same six geographical areas were used for the swept area calculations as for the acoustic estimation. Based on these assumptions an overall biomass estimate for Norwegian spring-spawning herring from the swept area method came to 2.28 mill. tons (figure 34).



**Figure 34.** Swept area estimates for Norwegian spring-spawning herring based on pelagic trawl catches at the surface onboard Libas, Brennholm, Finni Fridur and Arni Fridriksson from 9 July to 20 August 2010.

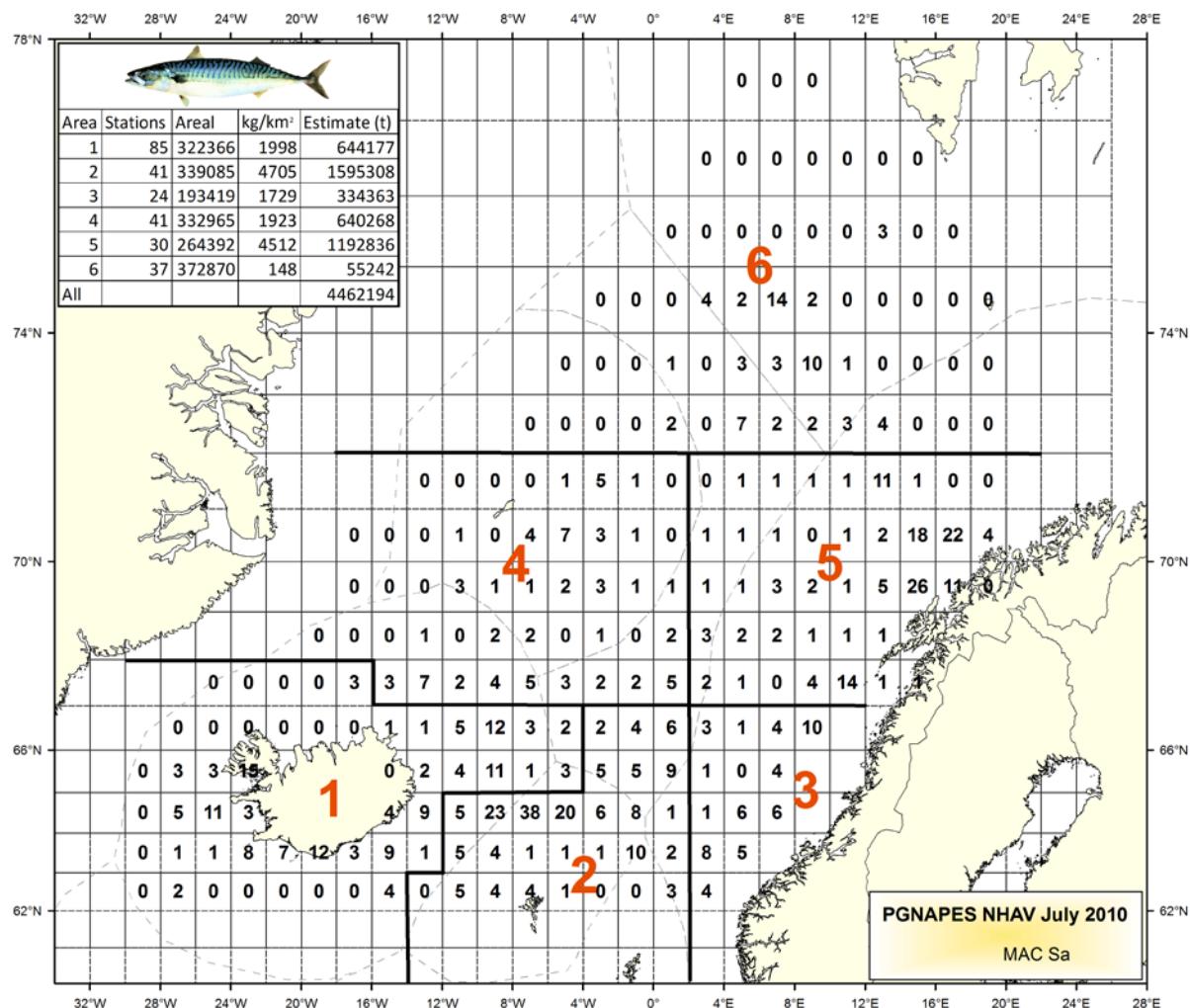
Acoustic detection of and NASC allocation to Atlantic mackerel were done based on the multi-frequency response of the acoustic echoes and especially the characteristic frequency response on 200 kHz. Biological samples taken at each station were used in tight combination with sonar and echosounder data to allocate NASC values to mackerel (figure 31). The allocation of NASC values to mackerel on Arni Fridriksson was however incomplete and were given a low priority during the survey because the methodology was considered to be too subjective and therefore unreliable by the scientists onboard, especially on the continental shelf. Consequently, the area covered by Arni Fridriksson should be considered with a caution with regards to the NASC values (Figure 35).

The mackerel population within the covered cruise tracks and areas was estimated to be 12.1 million tons consisting of 31.8 billion individuals. The average weight of mackerel was 382.1 gram and mean length was 34.7 cm. Altogether 13 different year classes were present in the catches, whereas five year classes constituted more than 5% of the catches.



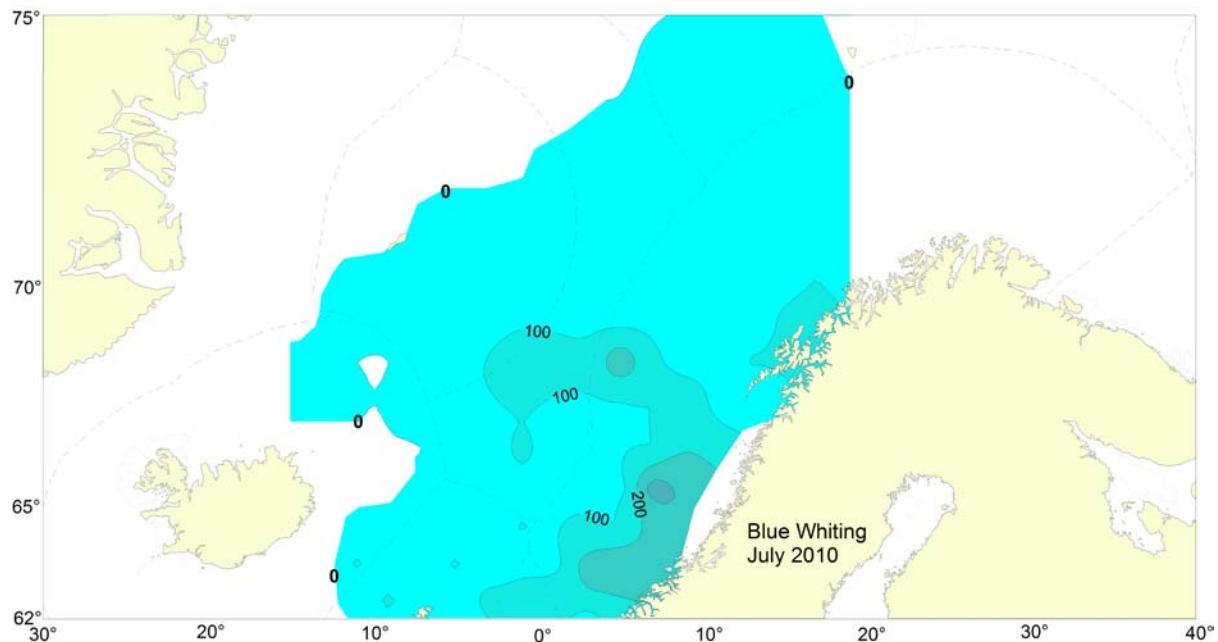
**Figure 35.** Sa or Nautical Area Scattering Coefficient (NASC) values of mackerel along the cruise track.

A swept area analyses was also performed for Northeast Atlantic mackerel for Libas, Brennholm, Finni Fridur and Arni Fridriksson from 9 July to 20 August 2010. The input data for the calculation was as follows: a horizontal opening of 23 m was applied for Arni Fridriksson based on the trawl dimensions and performance geometry. A horizontal opening of 50 m was applied for the pelagic trawl onboard the chartered vessel Finni Fridur from Faroe Islands and Libas and Brennholm from Norway. Only surface trawl hauls were used in the analyses. The same six geographical areas were used for the swept area calculations as for the acoustic estimation. Based on these assumptions an overall biomass estimate of 4.46 mill. tonnes was found for Northeast Atlantic mackerel from this swept area analysis(figure 36).



**Figure 36.** Swept area estimates for Northeast Atlantic mackerel based on pelagic trawl haul catches at the surface onboard Libas, Brennholm, Finni Fridur and Arni Fridriksson from 9 July to 20 August 2010.

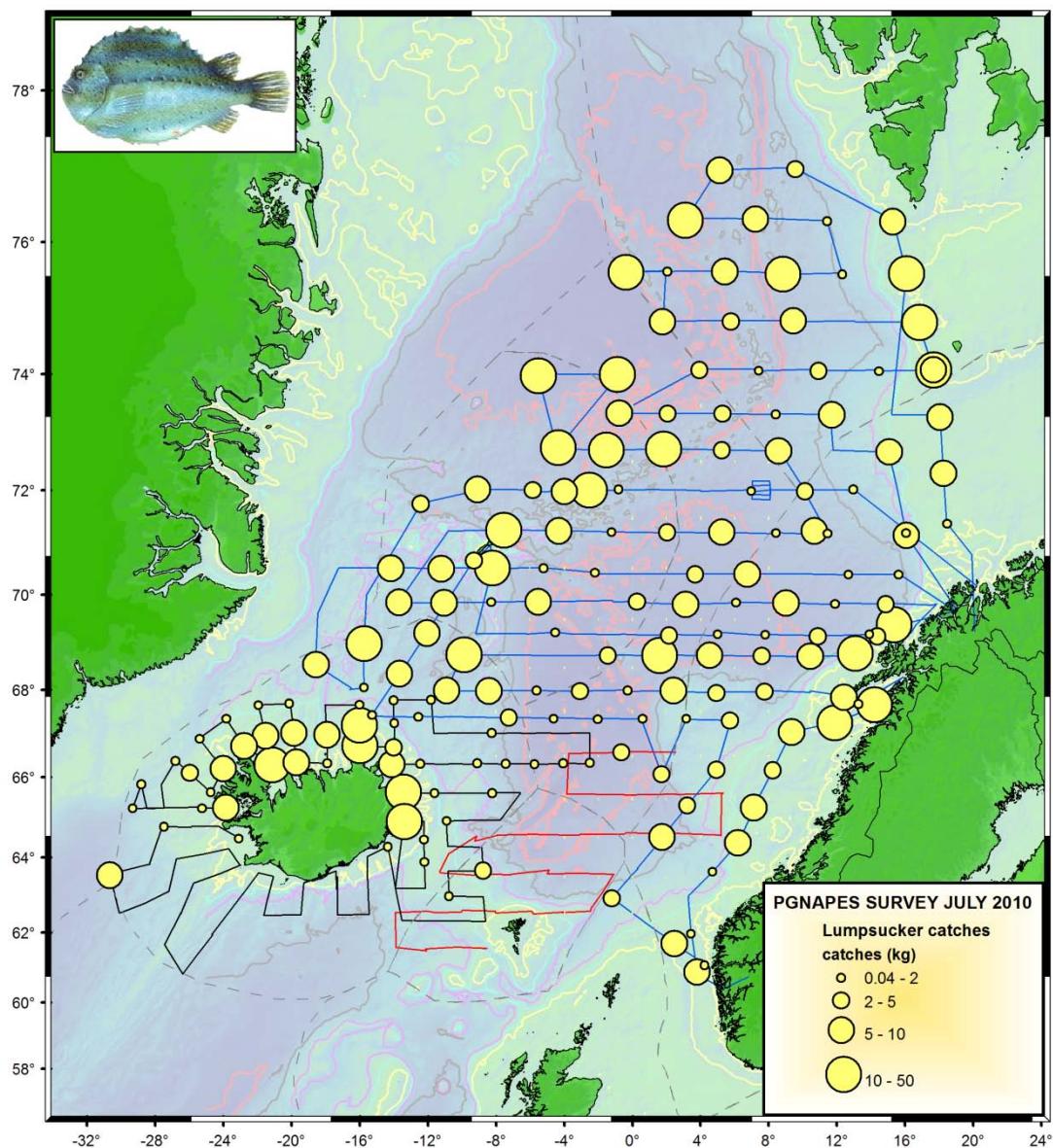
The blue whiting population within the covered cruise tracks and areas was estimated to be 3.46 million tons consisting of 21.1 billion individuals (figure 37). The average weight of blue whiting was 164 gram and mean length was 29.6 cm. Altogether 10 different year classes were present in the catches, although five year classes constituted more than 5% of the catches.



**Figure 37.** Map of blue whiting distribution and aggregation showing the *S<sub>a</sub>* or Nautical Area Scattering Coefficient (NASC) values estimated acoustically in the Norwegian Sea ecosystem.

## Lumpsucker

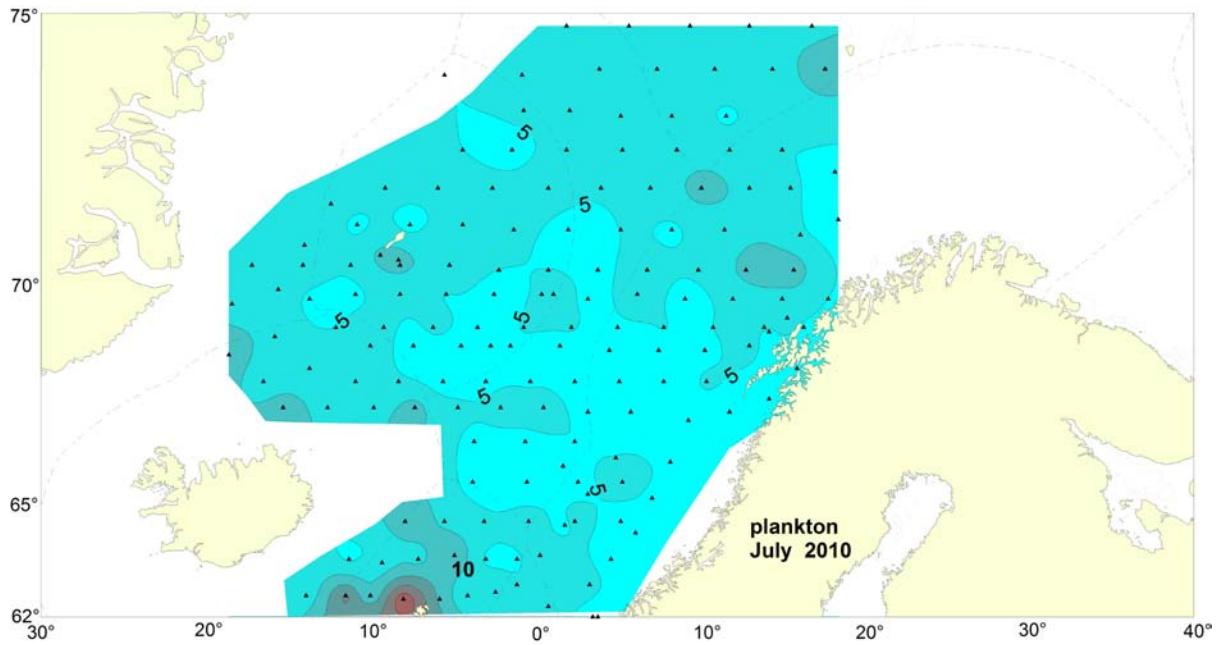
Lumpsucker was caught in most of the trawl hauls north of 64°N of the Norwegian Sea (Figure 38). The wide distribution and the range in size distribution from very small individuals to large adults could indicate that this species is in a healthy state in the Nordic Seas. Based on swept area calculations from epi-pelagic trawl hauls, an abundance of 53 000 tons of lumpsucker was calculated.



**Figure 38.** Distribution and catches of lumpsucker in the Norwegian Sea and surrounding waters, 9 July – 20 August 2009.

## **Plankton**

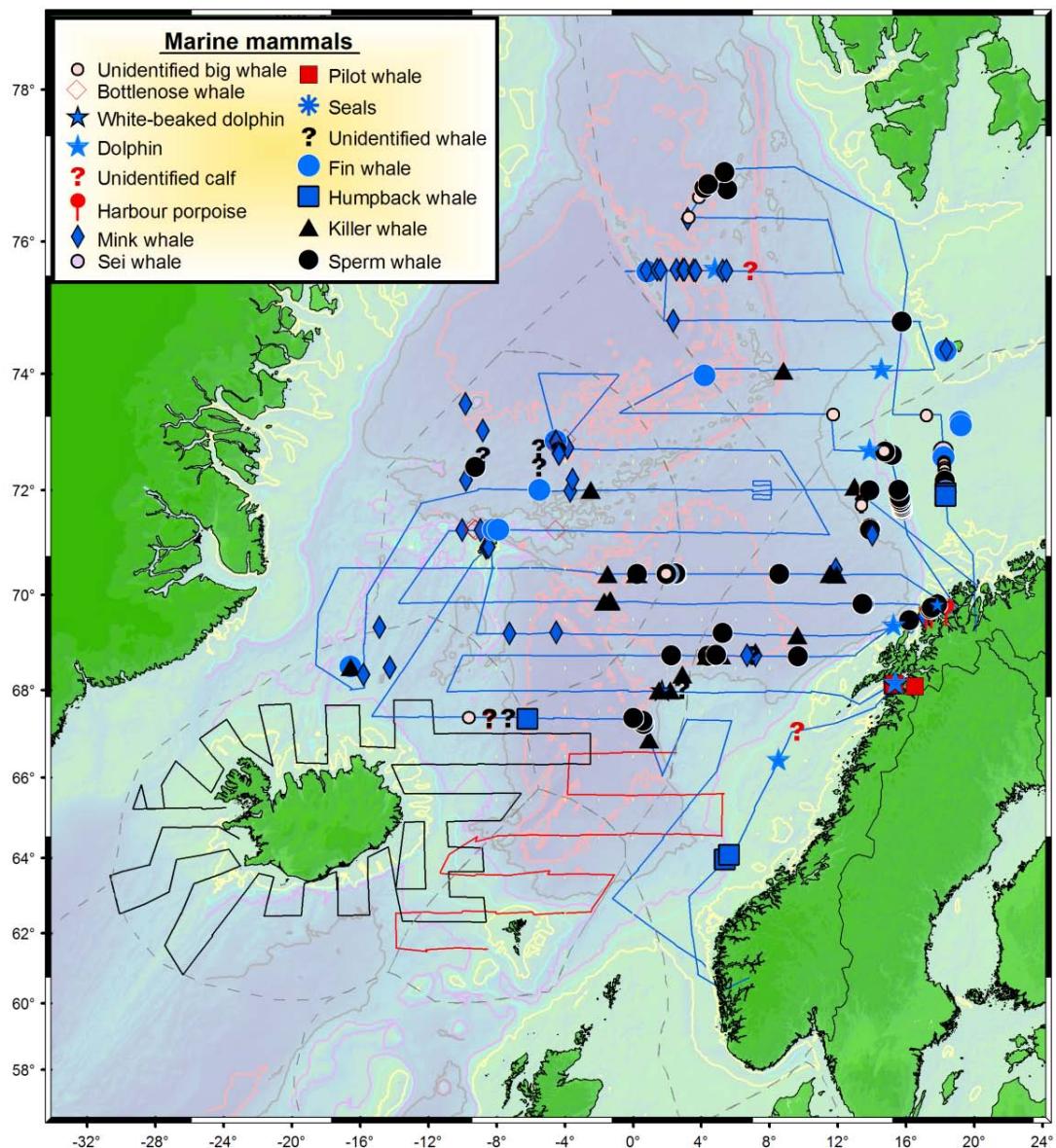
Plankton samples from the WP2 nets from Libas, Brennholm and Finni Fridur showed generally very low plankton concentrations (Figure 39). Summer 2010 showed the lowest plankton concentrations since we started these measurements.



**Figure 39.** Map of total zooplankton concentrations ( $\text{g}/\text{m}^2$ ) from WP2 net samples (0-200 m) at pre-selected stations.

## **Marine mammals**

The weather conditions were good and calm during the majority of the scientific cruise. However, dedicated observations were done from the bridge and not from the roof according to marine mammal sighting procedure. Result on marine mammal sightings are given in figure 40.



**Figure 40.** Marine mammals observed in the Norwegian Sea onboard “Libas” and “Brennholm” between stations in daylight hours, 15 July –20 August 2010.

## 5) Discussion

The ecosystem survey is considered to have covered the most central areas for the distribution and aggregation of mackerel, herring and blue whiting in the Norwegian Sea in summer. July-August is the feeding period for all the three major planktivorous species and during the time they have their maximum geographical distribution. One of the main aim of this study was to map the distribution of the entire populations of mackerel, herring and blue whiting in the Norwegian Sea and adjoining waters. Based on the continuous acoustic recordings from hydro-acoustics and extensive pelagic

trawling near the surface and midwater, we believe that we managed to cover the vast majority of these species and consequently their maximum spatial distribution. These ecosystem surveys in summer basically date back to 2004 and have been gradually expanded in geographical coverage and scientific complexity (Skaret et al. 2004; Nøttestad et al. 2005, 2006, 2007, 2009; Holm et al. 2008). Prior to 2004 the surveys were dedicated to northeast Atlantic mackerel alone.

Chartered commercial fishing vessels are suitable and well-equipped platforms for large-scale mapping of pelagic fish species such as mackerel, herring and blue whiting. Modern combined stern trawlers/purse seiners are also practical for more dedicated ecological studies. Since both Libas and Eros has drop keel the vessels can be used for abundance estimation using hydro-acoustic recordings with scientific echosounders and multibeam sonars. This combined methodology, in addition to the pre-defined surface trawling will ensure more reliable abundance estimation and distribution patterns of pelagic fish during the feeding period from May to August in the Norwegian Sea.

The shallow distribution and absence of dense schooling behaviour in both mackerel and herring within most of the study area in July-August, challenges the quantitative value and credibility of acoustic recordings from echosounder measurements. Substantial concentrations of pelagic species (mackerel, herring, and in some areas horse mackerel) were present above and close to the transducer depth. The upper acoustic blind zone is in the order of 10-15 m due to the drop keel on Eros and Libas. Furthermore, pronounced vessel avoidance during summer feeding may complicate these studies even more when applying standard echosounder technology. Nevertheless, a complementary approach with continues use of multibeam sonars and multi-frequency ensures a complete coverage of the water column along the cruise track.

Systematic stomach content analyses of our most important pelagic species mackerel, herring and blue whiting, combined with concurrent zooplankton analyses, mapping of marine mammals and measurements of the oceanographic conditions are paramount for a deeper understanding of the feeding ecology, potential inter-specific feeding competition, spatiotemporal overlap and migration patterns of mackerel, herring and blue whiting in the Norwegian Sea.

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