Cruise report on coordinated ecosystem survey with M/V "Libas" and M/V "Eros" in the Norwegian Sea, 15 July - 6 August 2007

Cruise report: Survey number 2007 831

Period: 15 July – 6 August 2007
Vessels: M/V "Libas" (LMQI), M/V "Eros" (LIVA)
Area: Norwegian Sea (62º30-75º00N, 22º00E-18º00W)
Main purpose: Study abundance, spatiotemporal distribution, aggregation and feeding ecology of Atlantic mackerel, Norwegian spring-spawning herring and blue whiting in relation to oceanographical conditions, prey communities and marine mammal predators.

Sub-goals:

Quantify migration speed and direction of tracked herring and mackerel schools at different spatial scales on multibeam sonars in the upper water masses (0-50m).

Continuous counting of total number of detectable herring and mackerel schools on the multibeam sonars, with corresponding estimated school size every 15 min along the cruise track.

Map concentration and distribution of non-targeted species such as horse mackerel, salmon, lumpsucker, snake pipefish, polar cod, capelin, O-group cod, haddock and herring, gonatus, krill and amphipods.

Systematic marine mammal sightings for species identification, group size and behaviour. Concurrent digital filming and photo for scientific purposes and validation.

Ecological studies on predator-prey interactions and avoidance behaviour of pelagic fish, krill and marine mammals using acoustics, visual observations and sampling.

Sonar recordings of marine mammal detections, group size and underwater swimming behaviour up to 1200 m distance.

Continuous recordings of surface light conditions for studies of vertical fish migration and behaviour.

Underwater and surface filming of marine life and predator-prey interactions in the Norwegian Sea by BBC Natural History Unit (NHU) for the new documentary program series LIFE.

Personnel:

"***Libas***": Leif Nøttestad (cruise leader, project leader, (IMR)), Ruben Patel (IMR), Valantine Anthonypillai (IMR), Herdis Langøy (IMR), Gro Nilsson (IMR), Lise Langård (IMR), Julie Andersen (IMR), Alexander Lisovsky (Giprorybflot, Russia) and Nikolay Lukin (PINRO, Russia), Doug Andersen (BBC NHU, UK), Jonathan Smith (BBC NHU, UK), Nick Guy (BBC NHU, UK).
"***Eros***": Mikko Heino (cruise leader part I, IMR), Øyvind Tangen (cruise leader part II, IMR), Terje Torkelsen (IMR), Helga Gill (IMR), Jostein Røttingen (IMR), Kjell Rong Utne (IMR), Johanna Myrseth (UoB), Matteo Bernasconi (Univ. St. Andrews, Scotland), Ole Bernt Gammelsæter (Simrad, Norway).

Institute of Marine Research, Bergen, Norway

Cruise report: 15 July- 6 August 2007

Content

1) Summary

The major aim of this coordinated cruise was to map the large-scale oceanic distribution and quantify the abundance, aggregation and feeding ecology of Northeast Atlantic mackerel (*Scomber scombrus*), Norwegian spring-spawning herring (*Clupea harengus* L.) and blue whiting (*Micromesistius poutassou*) in relation to their experienced physical and biological environment during summer in the Norwegian Sea and surrounding waters. The fleet included two chartered commercial fishing vessels: M/V *Libas* and M/V *Eros*. These two vessels have adjustable drop keel and highly advanced acoustic instrumentation, making them excellent for large-scale scientific surveys. The vessels covered substantial areas (7395 nmi.) in the Norwegian Sea and surrounding waters between 62 30-75.00ºN and 18 W-22 E. The Atlantic mackerel was distributed over substantial areas in Coastal, Atlantic and Arctic water masses as well as frontal coastal and Arctic regions within shallow waters less than 50 meters depth. The dominant catches were taken in the southern and eastern part of the Norwegian Sea. The largest and oldest mackerel were typically caught in the western and northern part of the Norwegian Sea in the Jan Mayen area and 5 years old individuals dominated the catches (21%), together with 2 years old (20%). Atlantic mackerel was caught as far north as 73 30 N. The mackerel was occasionally difficult to detect both on sonars and echosounder recordings due to shallow distribution, low-density aggregations/shoals/schools, and reduced acoustic reflectivity of mackerel This may strongly influence the quantitative echosounder recordings. Mackerel and herring schools and looser shoals were mostly recorded near the surface on the different sonars in most areas within the Norwegian Sea. Most of the schools were quite small in size with shallow distribution 0-50 m and the school biomass typically ranged from about 100 kg – 20 tons. Libas and Eros counted > 30 000 individual schools

along the cruise tracks. Herring were distributed over immense areas including Coastal, Atlantic, Arctic and frontal regions from 62 30-74.00 N and 22 00 E-12 00 W. The largest concentrations of herring were acoustically detected and caught by pelagic trawling along the periphery in the southwestern, western and northern part of the Norwegian Sea. Herring also performed a pronounced length dependent feeding migration. Blue whiting were distributed in the central and northwestern part of the Norwegian Sea in Atlantic and Arctic waters. Temperatures in the upper water column were from 14ºC along the Norwegian coast down to 0.2ºC in Arctic waters along the ice-edge in the Greenland Sea. Atlantic water masses penetrated far into the northern and western part of the Norwegian Sea, contributing to the extended distribution of both herring and mackerel into these waters compared to previous years. Higher surface temperatures should affect the migration and distribution pattern of mackerel in the Norwegian Sea through a direct physiological influence on the mackerel itself and an indirect influence on their main prey species. The largest zooplankton concentrations from preliminary qualitative measurements were found in the western and northwestern part of the Norwegian Sea, probably linked to the Arctic front between warmer Atlantic water masses and colder Arctic water masses from the Northeast Icelandic current. Low plankton biomasses were generally found in coastal and central areas of the Norwegian Sea coinciding with moderate mackerel and herring catches. Systematic visual observations of marine mammals were also performed and approximately 12 different species were sighted. A strong ecological perspective has been put into these cruises involving concurrent measurements at each station on the physical environment, plankton communities, pelagic fish species (mackerel, horse mackerel, herring, blue whiting, salmon, snakefish, lumpsucker etc) including systematic stomach sampling of mackerel, herring and blue whiting. This approach enables us to study ecological questions across spatial and temporal scales, which is important to reveal new knowledge about the functioning and food web dynamics of the Norwegian Sea.

3) Introduction

We wish to use these cruises 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 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), plankton samples (WP 2 nets) and full biological analyses of pelagic fish species for each station applying epi-pelagic trawling close the surface. 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 Eros) and low-frequency long-range Simrad SP 90 (Libas) and Simrad SP70 (Eros) multi-beam sonars.

The three weeks cruise 15 July- 6 August 2007 is 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 “Eros”, both fulfilling the required scientific specifications set for this ecosystem study. Both vessels have a drop keel installed and in operation when performing acoustic survey, in order to avoid bubble and surface generated noise during acoustic operation in open ocean under different sea state conditions. A scientific quota of 650 ton mackerel and x ton herring was provided to IMR from the Directorate of Fisheries and accepted by the Ministry of Fisheries as an economical compensation for the chartered vessels for the scientific activities performed.

4) Material and Methods

Calibration of echosounder transducers

Libas and Eros were calibrated after standard hydro-acoustic calibration-procedure for each frequency prior to the cruise (Foote, 1987). The transducers are placed in the drop keel onboard Libas and Eros. The calibration took place inside a wind and wave protected area at Tysnes, south of Bergen, Norway. We attached a rope to a pole on land from the aft of the vessel and dropped an anchor in the bow about 400 m from land for maximum stability of the vessel during the calibration procedure. The frequencies calibrated involved 18, 38, 70, 120 and 200 kHz. We calibrated 38 kHz and 200 kHz transducers with 60 mm copper sphere (Cu 60). CTD measurements with a SAIV SD200W instrument were taken in order to get the correct sound velocity as input to the echosounder calibration settings.

Cruise tracks

Libas and Eros followed predominantly predetermined survey lines with pre-selected pelagic trawl stations and occasionally performed pelagic trawl stations on registration from acoustics (Fig. 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 northwestern part were performed due to attempts to film blue whale and other baleen whales along their annual feeding migration between Iceland, Jan Mayen and eastern Greenland along the ice edge with high concentrations of krill. Eros covered approximately 3670 nautical miles distance in total during the 21 days ecosystem cruise. Libas covered approximately 3725 nautical miles distance in total for the cruise track, providing a total of 7395 nmi = 13695 km distance for both vessels. The cruising speed was 12.0 knots if the weather permitted it. CTD stations (0-500 m) using a SAIV SD200 CTD sensor in

combination with WP2 net samples (0-200 m) were taken systematically on every pelagic trawl station (Figure 1).

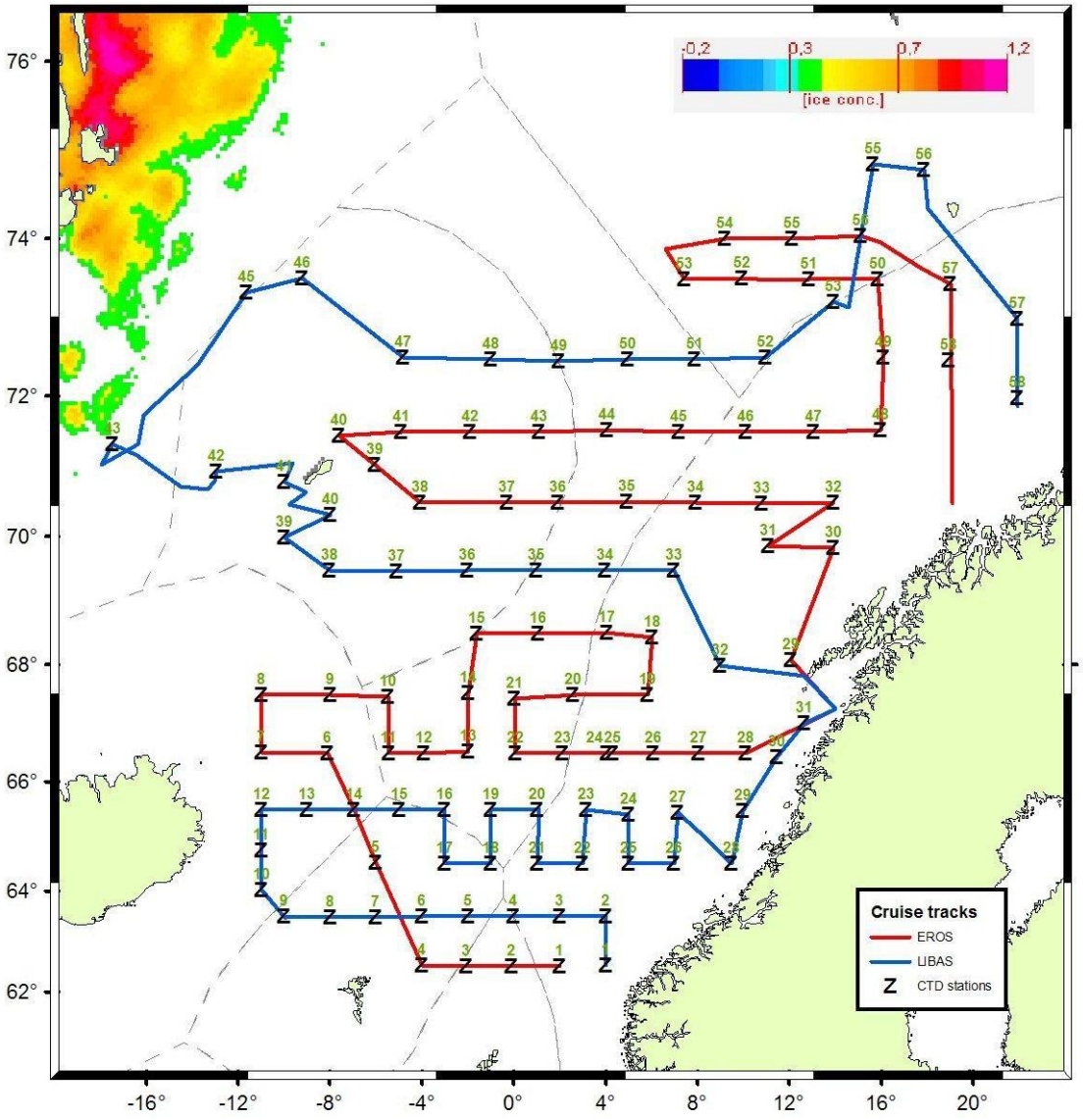


Figure 1. Survey lines along the cruise tracks with pre-defined CTD stations (0-500 m) and WP2 samples (0-200 m) for M/V"Libas" and M/V"Eros", 15 July – 6 August 2007. This large ocean area include the following Economical Exclusive Zones (EEZ): Norwegian EEZ, United Kingdom EEZ, Faeroe Island EEZ, Iceland EEZ, Greenland EEZ, Jan Mayen fishery protection zone, Spitzbergen protected area and International waters. The two vessels took 129 pelagic trawl stations, 116 CTD and WP2 stations and covered about 7400 nmil.

Biological sampling

Trawling was done with a large commercial blue whiting pelagic trawl (Egersund trawl) with a trawl opening between 52-65 m applying 200 m wire length. Most of the trawling was done from 5-10 m depth down to 40-50 m depth. Targeted blue whiting trawl hauls on registrations were performed from 120-250 m depth. The tow duration was maximum 30 min and minimum about 10 min in order to avoid large trawl catches of mackerel and herring. Towing speed varied between 4.0-5.3 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. Salmon was measured for length and weight. Individual salmon were put in a plastic bag and labeled with location (position), date and time before putting the fish into the freezer to preserve the salmon for further analyses. Pictures where taken for each individual fish caught.

Hydrography

Libas and Eros were both 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. Intercalibration between the CTD sensors applied onboard Libas and Eros were done in order to compare the measurements for pressure (depth), temperature and salinity values.

Plankton sampling

Plankton hauls were collected with a WP-2 plankton net, 56 cm in diameter and a mesh size of 180 m on M/V "Libas" and M/V "Eros". 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 were 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 30º 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 loosing part of the plankton sample. The plankton sample is divided in to fractions; 1) taxonomic analyses (taxonomic species, size, and stadium composition, and 2) biomass estimates.

Acoustics

Sonar

Two sonars were used simultaneously and continuously as a high priority activity during the survey, in order to identify and sample mackerel and herring schools along the entire cruise track. The high frequency sonar, Simrad SH80 (from 110 to 122 kHz), was used as primary sonar onboard Eros and secondary sonar on Libas, which software includes the option to save the sonar raw data using a "Scientific Output" through an Ethernet connection. The processing of these data is time-consuming task that will be done in a later stage and is not included in the present cruise report. Continuous school counting each 15 min period along the cruise track was done manually. School counting was also done based on ping-to-ping data analyses along the cruise track. Raw data from areas with school detections were stored for both Simrad SH80 and SP90. Extraction and visualisation of number, position, size, density and shape of schools as well as swimming direction and speed on automatically detected individual schools were performed.

An overview of the operational sonar settings for the different multibeam sonars is given in Table 1. The range used for this sonar was between 400 to 750 m, depending on the aggregations of the shoals/schools found during the survey and detection probability curve for acoustic registrations of schools with increased range (Figure X). Together with digital storing of the data, a visual observation of the schools on the screen was done using ad-hoc forms; noting time and position of the observation, sonar range and tilt angle, depth, number and relative size of the schools. To get a better estimate of the *in situ* observations on the relative size of the schools, an expert opinion of the skipper and trawl bas was provided and noted on the sonar sheet accordingly.

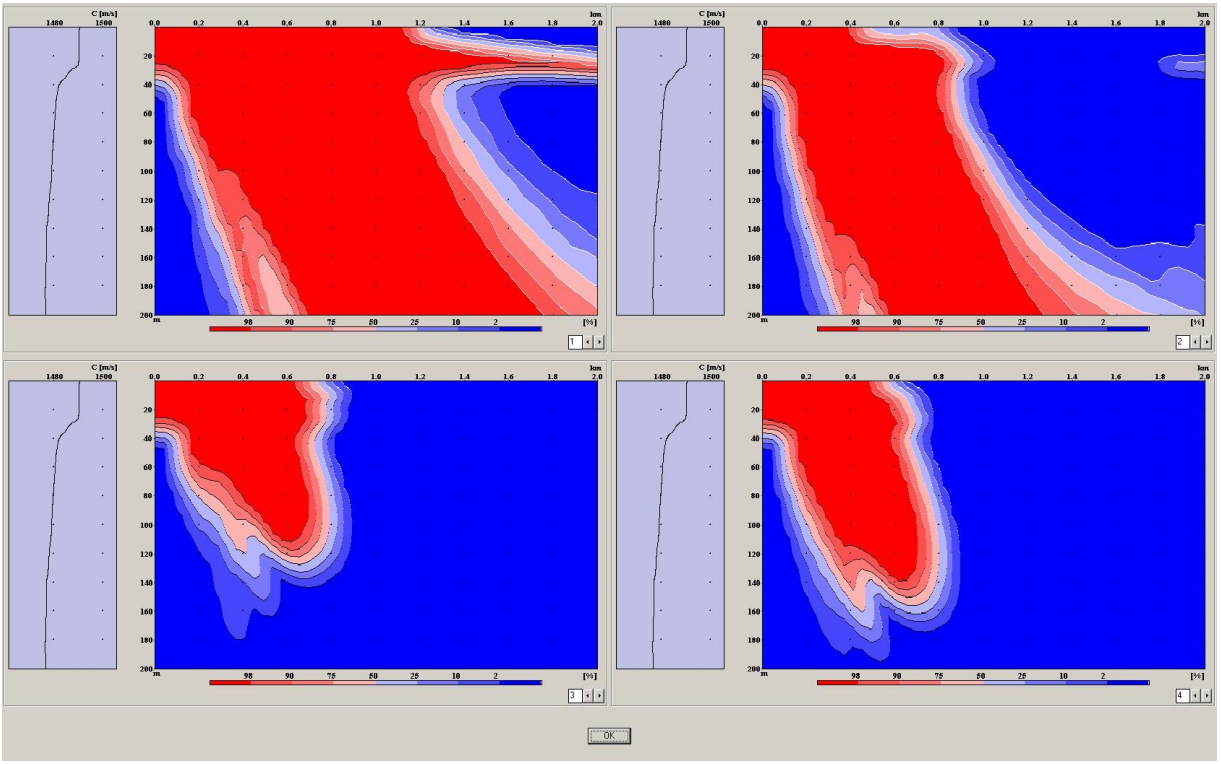


Figure 2. Acoustic detection probability curve using vertical CTD cast with a pronounced thermocline as input for sound propagation properties at increased distance and water depth for Simrad SP90 sonar with: A) 8 degrees tilt angle B) 12 degrees tilt angle C) Simrad SH80 sonar with C) 3 degrees tilt angle D) 6 degrees tilt angle. Note the downward bending of the sonar beams with range, due to changing physical properties and density of the water masses.

The primary sonar used onboard Libas was a low frequency Simrad SP90 (from 20 to 30 KHz) with horizontal selected range from 750 m to 1200 m. The secondary sonar used onboard Eros, was a low frequency Simrad SP70. The long-range sonar was used mainly in a range between 500 to 1200 m. Selected screen dumps were obtained and stored from all the Simrad sonars.

Each sonar registration was obtained at time intervals according the speed of the vessel and the range of the sonar, ensuring that the schools registered in each event were outside the screen before the next registration, avoiding a double counting the schools.

For this report a relative biomass of the schools was calculated for each event, as a product between the number of schools and the estimated size of each school.

Herring and mackerel schools and aggregations were tracked with Simrad SH80 and SP70 multi-beam sonars onboard Libas. Parameters such as position, size, swimming-speed and -direction were logged continuously while tracking on both vessels with the NMEA-datalogger.

Table 1. Standard operational settings for Simrad SP70/90 long-range sonar and SH80 medium range sonar onboard Libas and Eros.

Horisontal	Simrad SP 70/90	Simrad SH80
Range	600-1200	400-750
Tilt	6 -15	4-10
Gain	40	45
Pulsform	FM4/Auto	Auto
TX Power	Full	ON
Beam	Normal	Narrow
Freq:	27 kHz	114 kHz
TVG	25 Log R	25 Log R
AGC	Weak	N.A.
Noise filter	N.A.	Medium
RCG:	Medium	Strong
PP Filter	Medium	Medium
Display:		
Display gain	5	N.A
Colout tresh.	2	3
Colours	Strong	Strong

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 Eros. 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/). The analyses were based on the following species and groups of species:

Main target species: mackerel, herring, blue whiting

Usable species: bottom fish including cod and haddock, horse mackerel, capelin, mesopelagic fish, plankton
Other species: other bottom fish species, 0-group mixed, redfish, krill, amphipods and polar cod.

Marine mammal observations

Two dedicated marine mammal observers were present onboard each of the vessels Libas and Eros. They operated applying a TNASS observation regime and sighting procedure including date, time, position, species, number, group size and behaviour were noted from the 1) the roof when whether conditions were Baufort scale < 4 in with no or moderate rain, and 2) on the bridge when weather conditions (Baufort scale > 4) did not allow observations from the roof. Scientific personnel and crewmembers onboard Libas and Eros also did 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.

Weather

Wind conditions as derived from the Baufort scale, weather, cloud coverage, sea state and wave height were monitored and noted on the trawl diary at each station for both vessels.

Light conditions

Surface light conditions throughout the cruise were recorded every 5 min interval on a LI-COR data logger onboard M/V Eros.

Digital photos and filming

Digital photography with Nikon D70, D200 and digital filming with Sony TCR TRV50 were done throughout the cruise for documentation of various scientific activities and visual

observations along the cruise track. BBC NHU team had professional equipment for both underwater filming and topside filming and still photos.

Data management

All collected data onboard Libas and Eros were stored on a server PC installed on each vessel under the area P:\Økosystemtokt juli 2007. Collected data originating from echosounders, sonars, pelagic 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.

5) Results

Hydrography

Temperature maps were produced in Surfer 9.0 and ArcGis 10.0 based on 123 CTD casts from Libas (59) and Eros (64). Sub-surface temperatures recorded at 6 m water depth every hour are shown in Figure 4. Surface temperatures ranged from 15-16ºC along the coast of Norway to cold Arctic water masses in the northwest with surface temperatures of 2-4ºC around Jan Mayen and –0.2-2.0ºC in the Greenland Sea close to the ice edge. The temperature in the central Atlantic water masses ranged from about 10-14ºC (Figure 3).

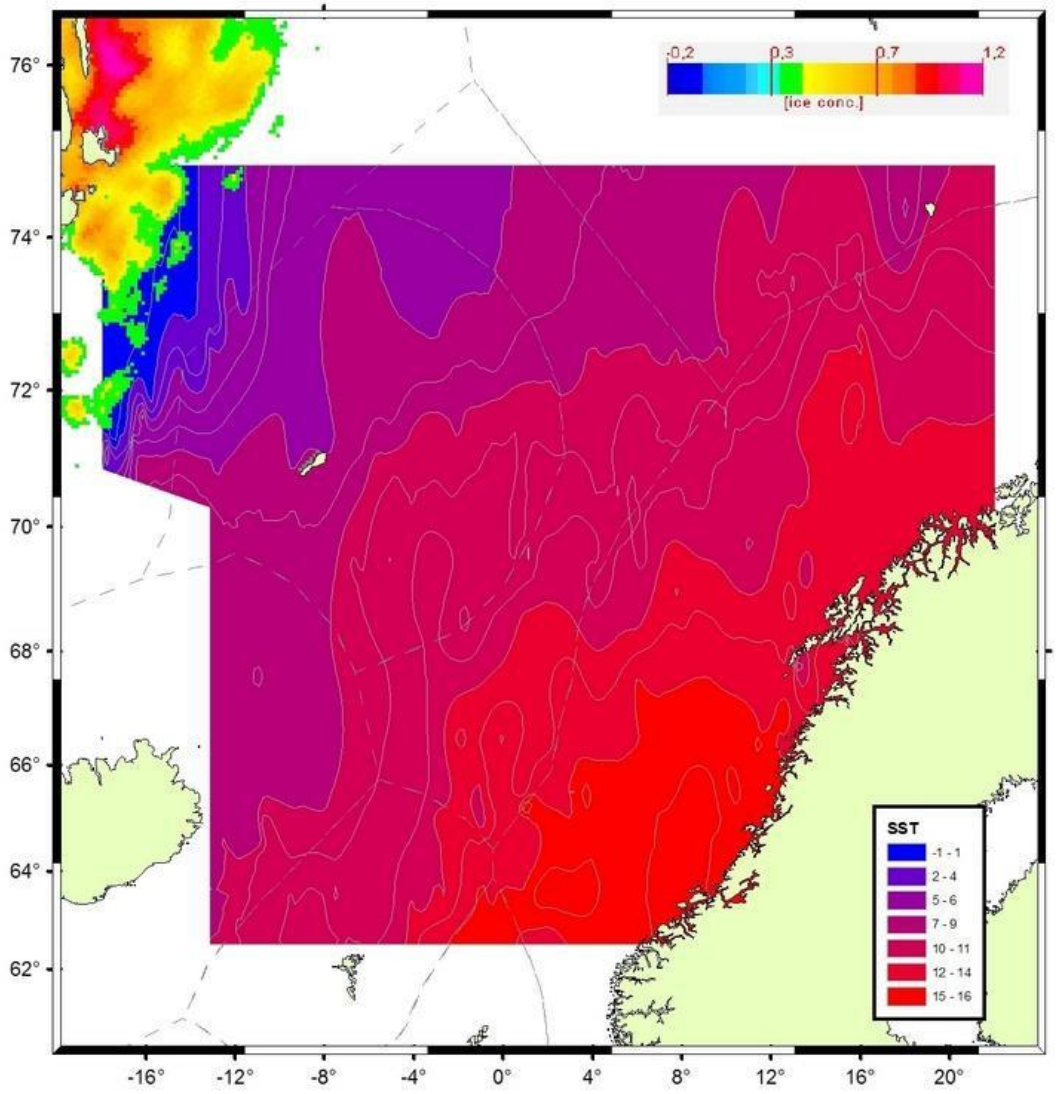


Figure 3. Sea surface temperature (SST) in the Norwegian Sea, 15 July - 5 August 2007.

Salinity varied from 28.5 – 35.0 within the Norwegian Sea (Figure 4). Atlantic water masses spread deep into the western and northern part of the Norwegian Sea.

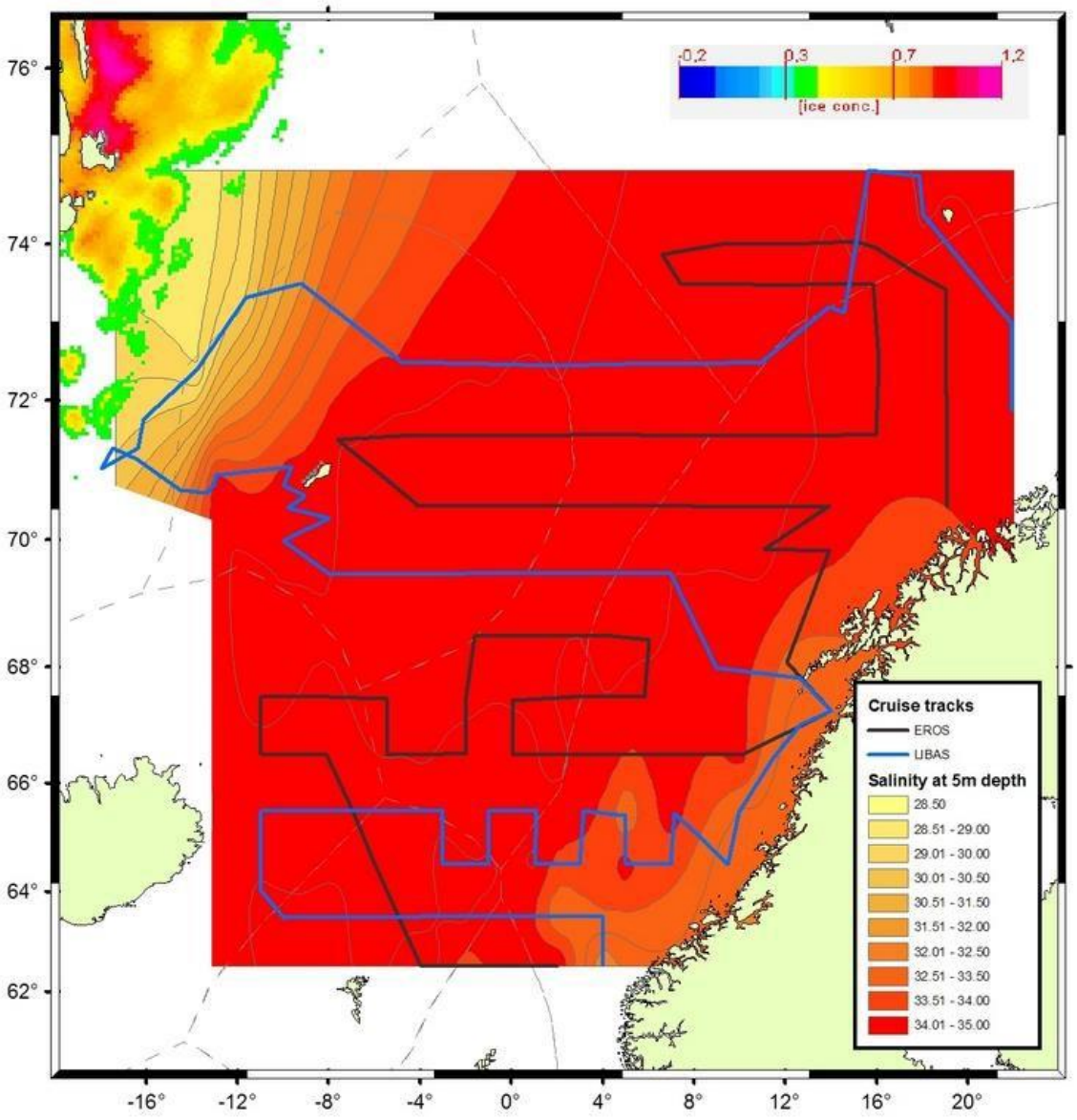


Figure 4. Salinity distribution at 5 m depth and cruise tracks by Eros and Libas in the Norwegian Sea, 15 July-5 August 2007.

Biological samples

Libas performed in total 61 pelagic trawl stations, while Eros performed in total 68 pelagic trawl stations. Length and weight measurements on the most important pelagic schooling species included 5451 mackerel, 5688 Norwegian spring-spawning herring, 2666 blue whiting and 6 horse mackerel. Age determination was determined for 1377 mackerel, 1391 herring and 631 blue whiting. Stomach samples were taken from 900 mackerel (92 stations), 912

herring (91 stations) and 390 blue whiting (39 stations). Furthermore, a substantial amount of herring stomachs from 60 stations were taken in samples where both herring and mackerel were present in the same trawl catch. Similarly, blue whiting stomach samples were taken from 10 stations where mackerel or herring were present in the same trawl catch. Other species caught in the epi-pelagic trawling included salmon, lumpsucker, snake pipefish, Greenland halibut, halibut, anglerfish, sea lamprey, daggertooth, grey gurnard, whiting, haddock, mesopelagic fish, redfish, cod and spotted catfish.

Mackerel caught in the pelagic trawl hauls on Libas and Eros varied from 22 cm to 45 cm in length distribution with the concentration of individuals between 30-39 cm. Mackerel weight (g) distribution varied between 100 to 900 g (Figure 5).

The 2002-year class of mackerel together with the 2005-year class dominates the mackerel population in the Norwegian Sea with more than 40% (Figure 6).

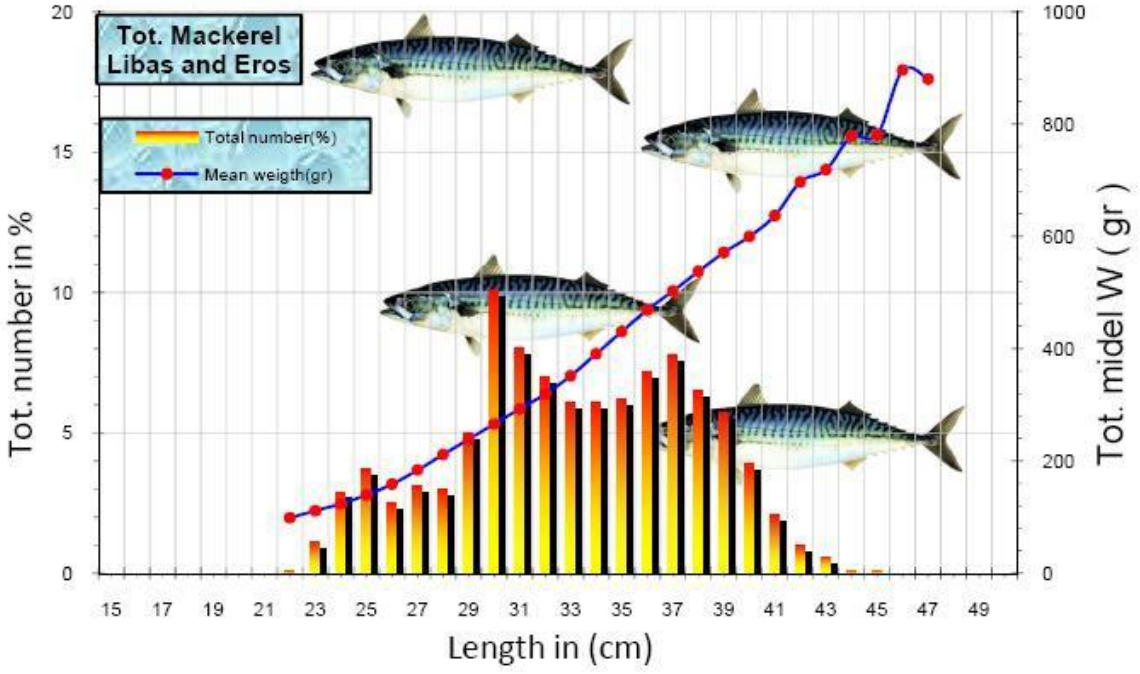


Figure 5. Total length (cm) and weight (g) distribution in percent (%) for mackerel in all catches.

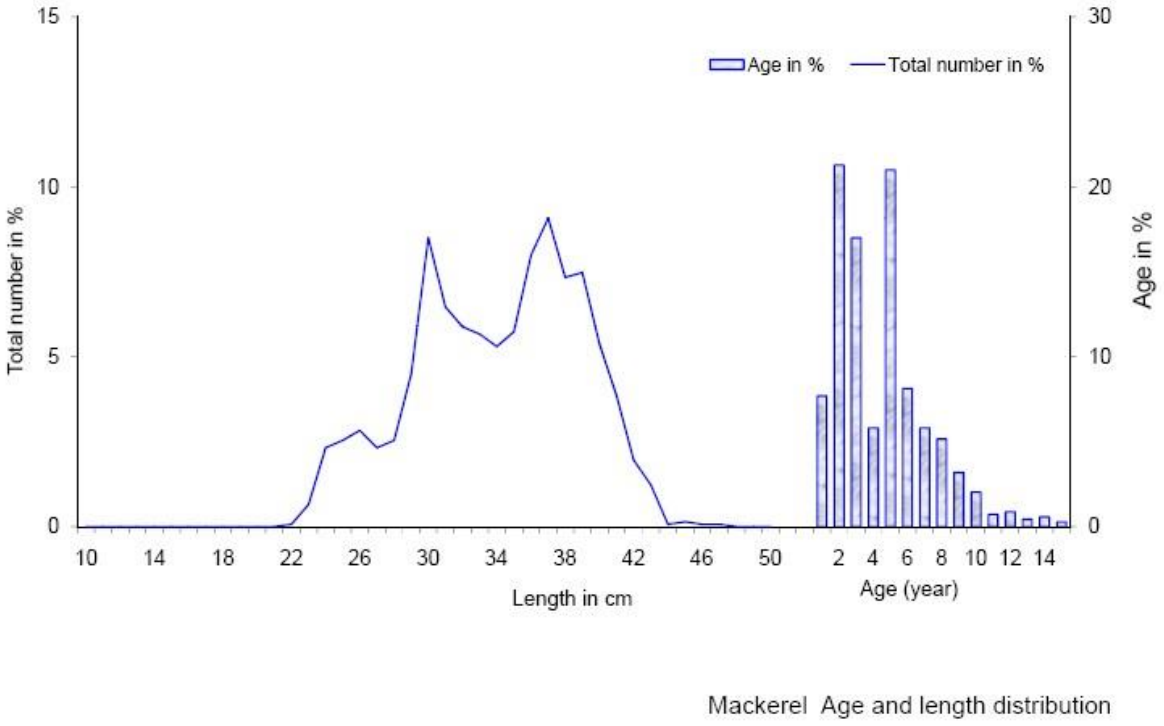


Figure 6. Age and length distribution in percent (%)of Atlantic mackerel in the Norwegian Sea

Norwegian spring-spawning herring had a length distribution from 21-38 cm with a peak at 31-33 cm in length, and a weight distribution from 20-430 gram (Figure 7).

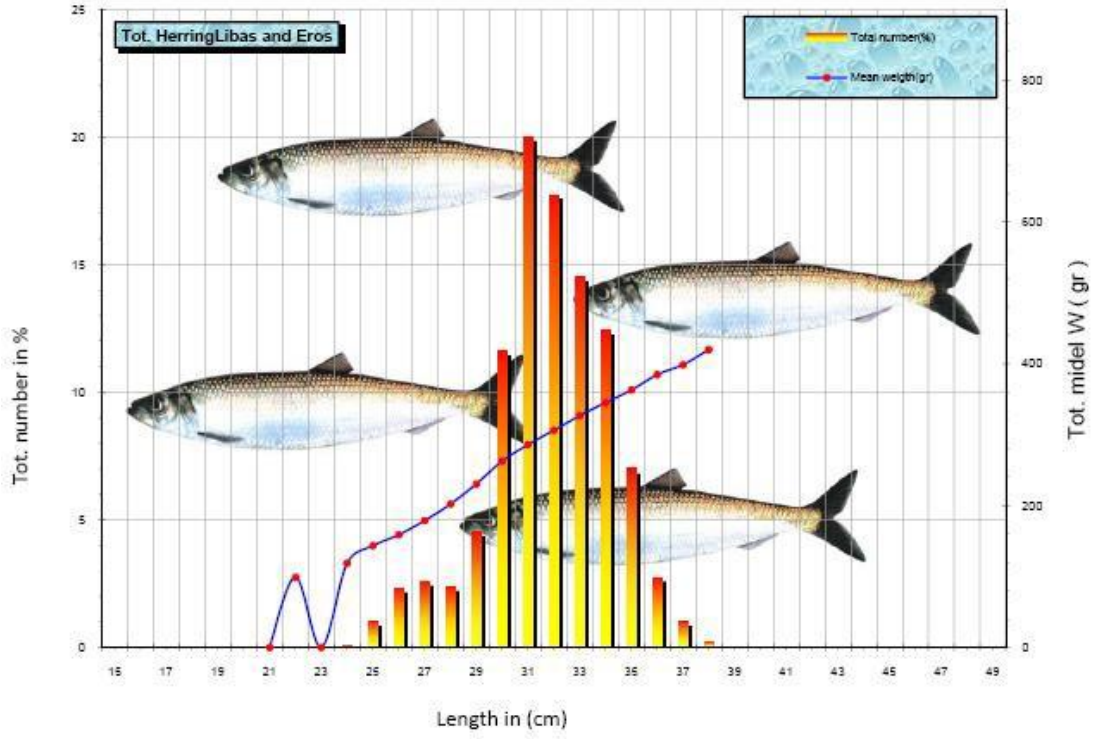


Figure 7. Length and weight distribution of herring in the pelagic trawl catches.

Age distribution in herring show a pronounced dominance of the 2002 years with 5 years old herring. They constitute 42% of the total population. The 1998-year class (17%) and 1999 year class (12%) are the second and third most dominant herring year classes, respectively.

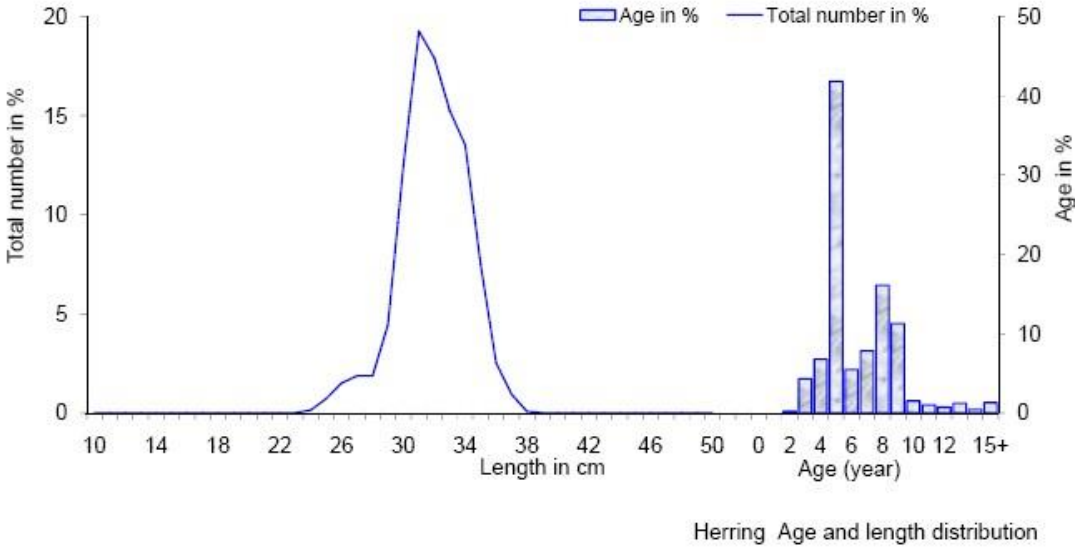


Figure 8. Herring age and length distribution in the pelagic trawl catches.

Blue whiting length distribution was from 21-35 cm and individual weight distribution was 50-250 gram Blue whiting between 27-30 cm dominated the catches (Figure 9).

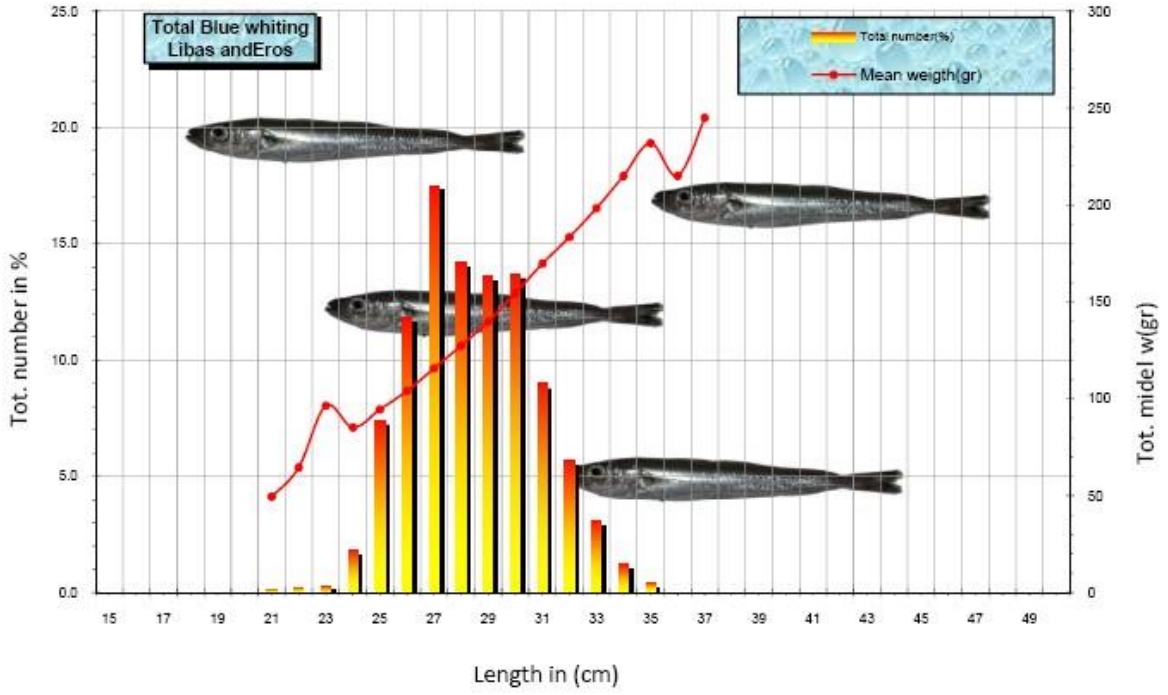


Figure 9. Length and weight distribution of blue whiting in the pelagic trawl catches.

The age distribution of blue whiting showed a dominance of 2003 year class (37%) followed by the 2004 year class (25%) and 2002 year class (22%).

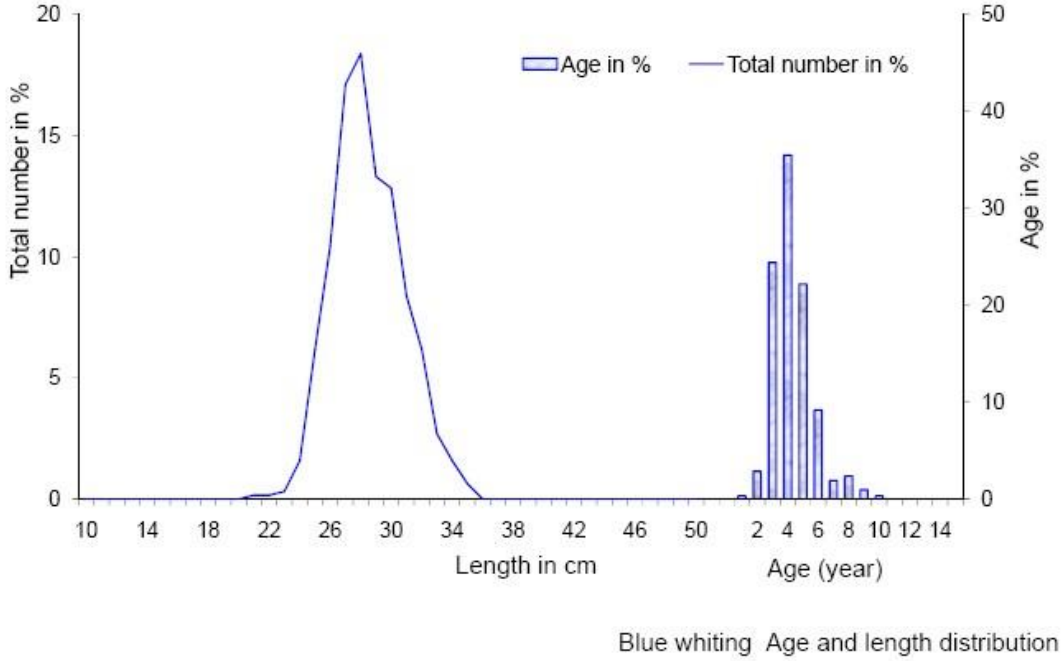


Figure 10. Blue whiting age and length distribution in the pelagic trawl catches.

High mackerel catches (kg/nmi) dominated in the central Norwegian Sea from 63ºN to 70ºN in warmer and more saline water compared to along the Norwegian coast and in the western areas with Arctic water masses (Figure 6).

Figure 6. Mackerel catches (kg/nmi) from Libas and Eros combined in the Norwegian Sea, 15 July- 6 August 2007.

Mean mackerel weight (g) within a category is shown for each biological station (Figure 7). A general trend is that the largest mackerel is found in the western and northwestern part of the Norwegian Sea.

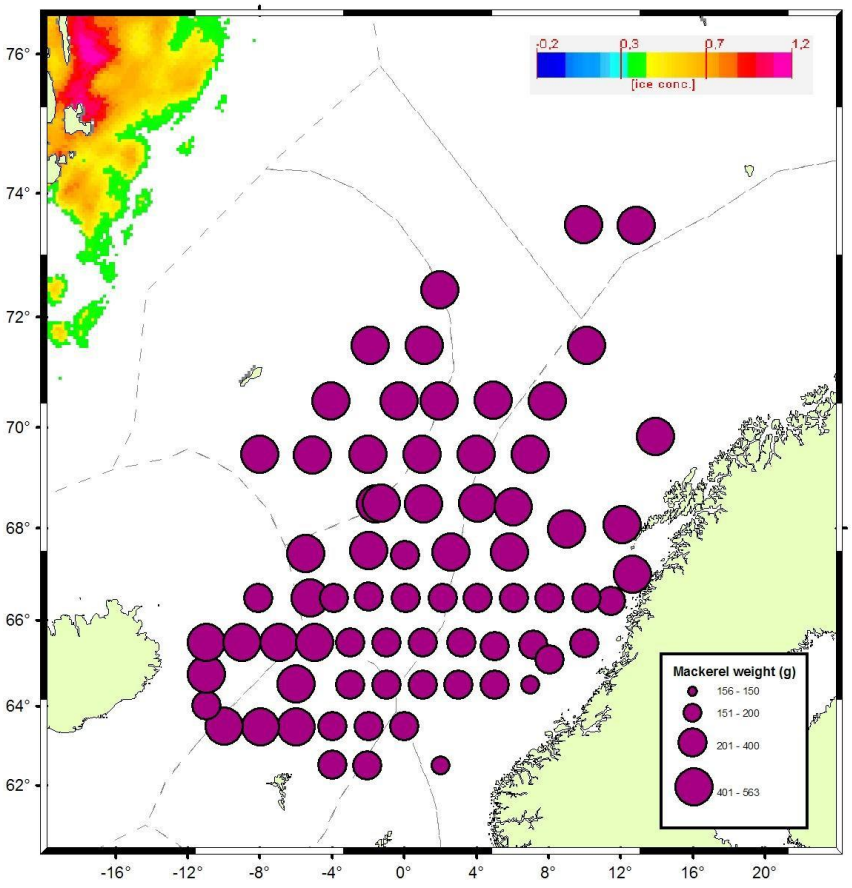


Figure 7. Mean mackerel weight (g) represented for each station within the categories shown. No catch of mackerel is indicated as a blank along the cruise track.

Mean mackerel length (cm) within each category is shown for each biological station (Figure 8). A general trend is that the longest mackerel is found in the western and northwestern part of the Norwegian Sea.

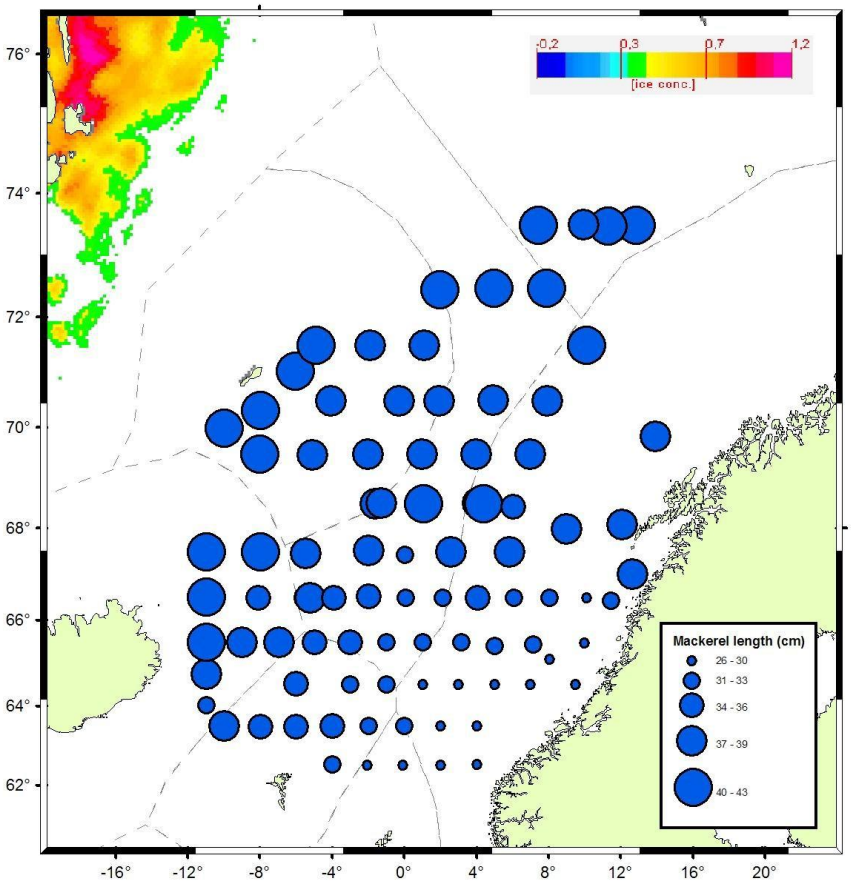
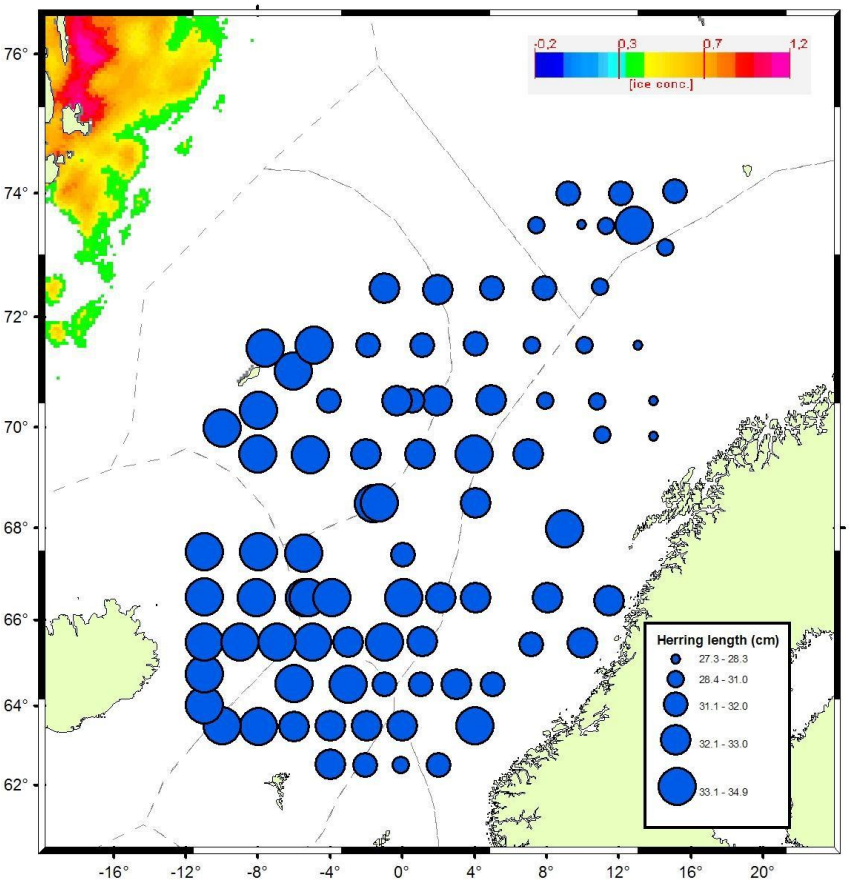


Figure 8. Mean mackerel length (cm) represented for each station within the categories shown. No catch of mackerel is indicated as a blank along the cruise track.

Herring catches (kg/nmi) are shown in Figure 9. Largest catches of herring were found in a few biological stations in the north-eastern and north-western part of the Norwegian Sea, while small herring catches were found in in numerous stations within the the study area.

Figure 9. Herring catches (kg/nmi) at each station for M/V Libas and M/V Eros combined.

Mean herring wight (g) is shown in figure 10. We can see from the figure that herring is distributed over a substantial feeding area within the study area. The largest herring are found in the northern and western areas, with a relatively clear weight dependent migration pattern was found.



Mean herring length (cm) is shown in figure 11. We can see from the figure that herring is distributed over a large feeding area within the study area. The longest herring are found in several areas with predominance in the southwestern and western part with a fairly clear picture of length-dependent herring migration was found.

Figure 11. 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 and blue whiting catches we presented the catches for all species at each station to see where the abundant pelagic planktivorous species were present and compare their catch rates (kg/nmi) from epi-pelagic trawling (Figure 12).

The spatial overlap between mackerel and herring were mostly found in the southwestern part of the Norwegian Sea. Altogether XX stations contained both mackerel and herring in the trawl samples. Herring were caught alone in the northeastern, northern and northwestern part, whereas mackerel were caught alone in trawl catches in the coastal areas off Norway and central part of the Norwegian Sea. 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 little spatial overlap with mackerel in the central part of the Norwegian Sea.

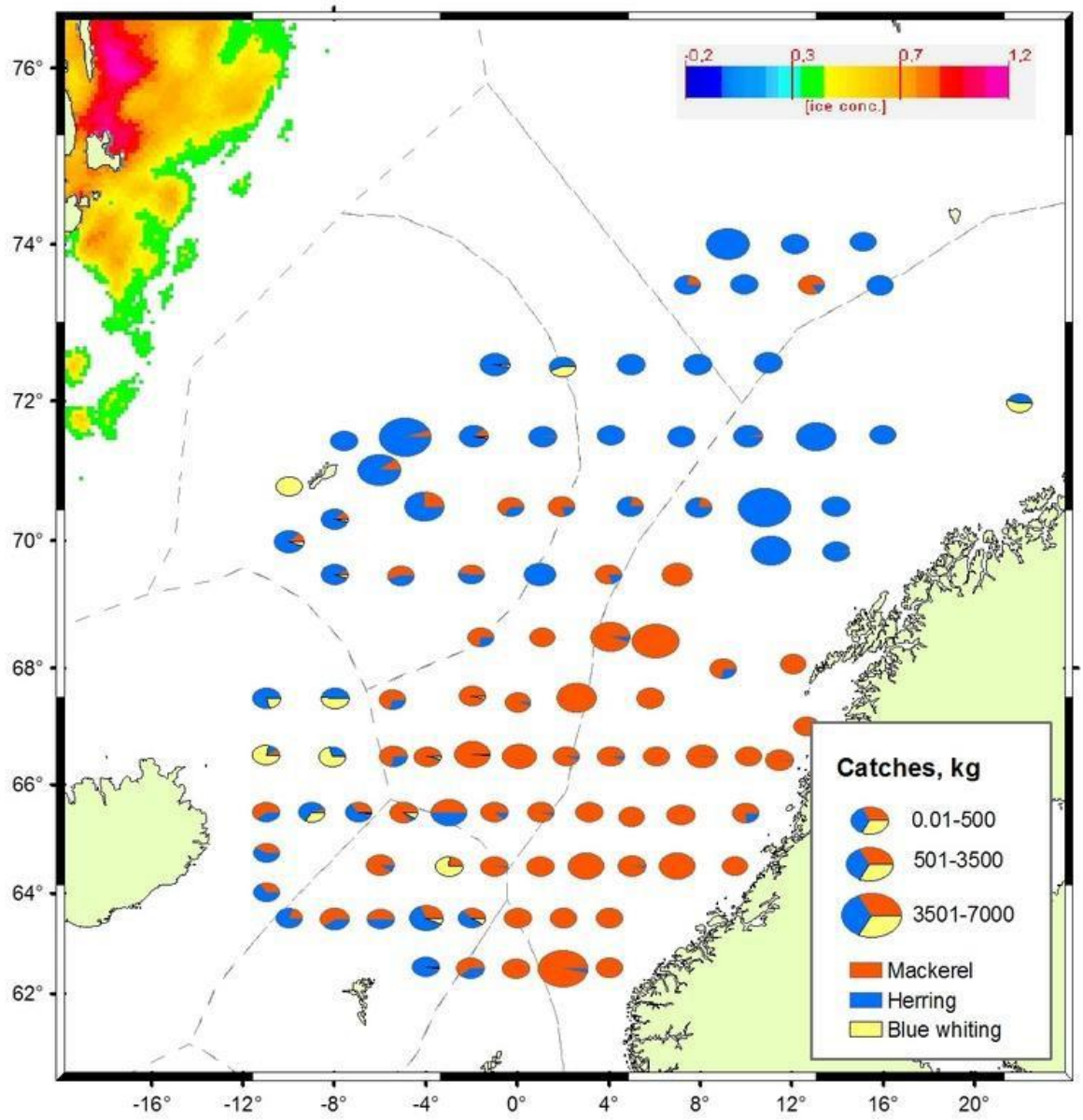


Figure 12. Map of the spatially overlapping catches of mackerel, herring and blue whiting found in pelagic trawling from surface down to 350 m.

Acoustics

Sonars

Most of the mackerel schools detected on the sonars during the survey were located in the central Norwegian Sea. Nevertheless, sonar registrations were also detected in the

southwestern and northwestern part of the ocean in Faeroe Island, Icelandic and Jan Mayen area. This is a new situation compared to previous years and clearly shows a wider distribution pattern of mackerel as well as more westerly and northerly migration pattern than observed previously. Approximately 100 distinct pelagic schools from herring and mackerel were tracked with Simrad SP90 sonar during a period of more than 10 seconds. Interschool distances between neighboring schools were quite consistent varying between 20-80 m in densely aggregated areas.

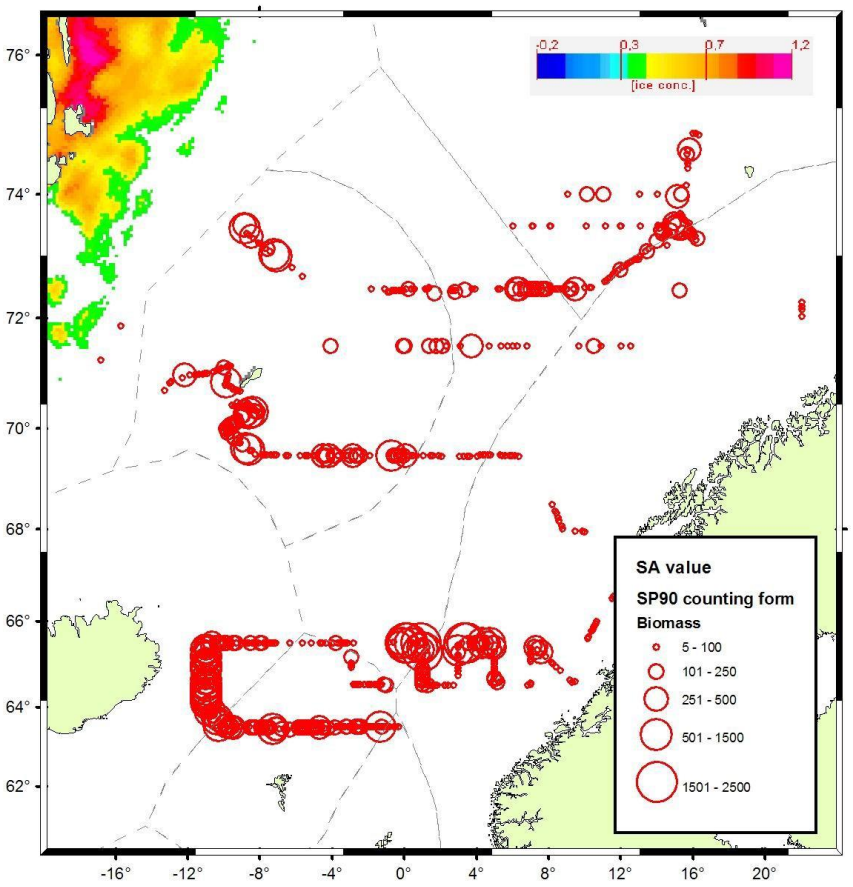


Figure 10. Sonar biomass estimated along the cruise track from Simrad SP72 and SH80 sonar

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. Judging of the acoustic data was performed daily by two scientists applying the post processing system Large Scale Survey System (LSSS) http://www.marec.no/ .

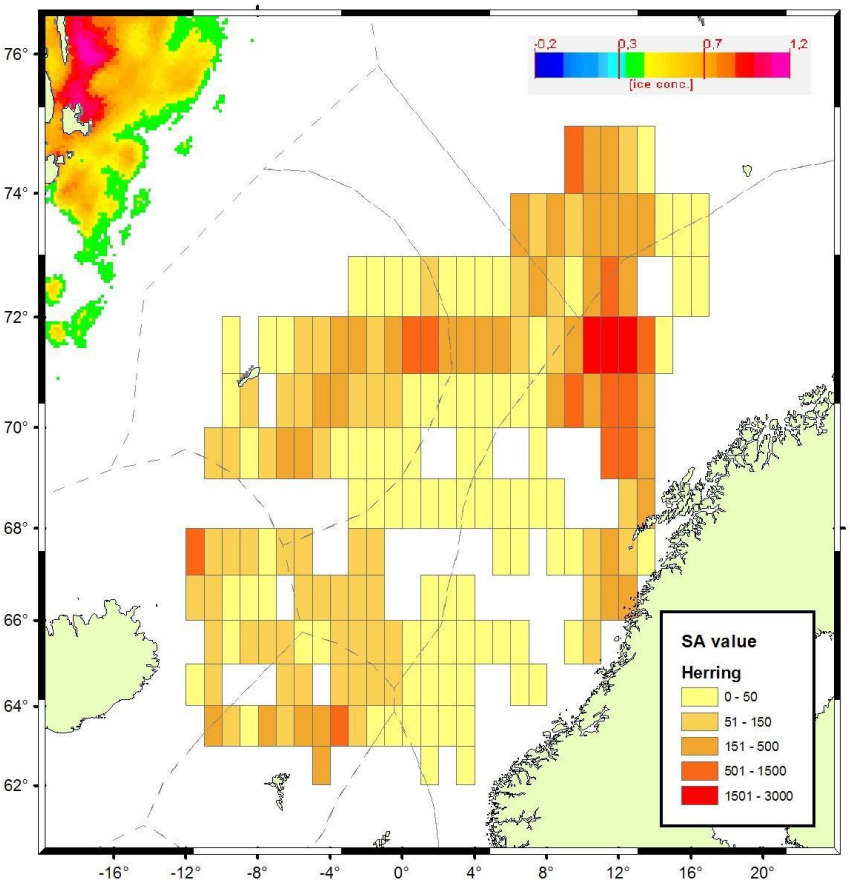


Figure X. Sa or Nautical Area Scattering Coefficient (NASC) values of herring along the cruise track.

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

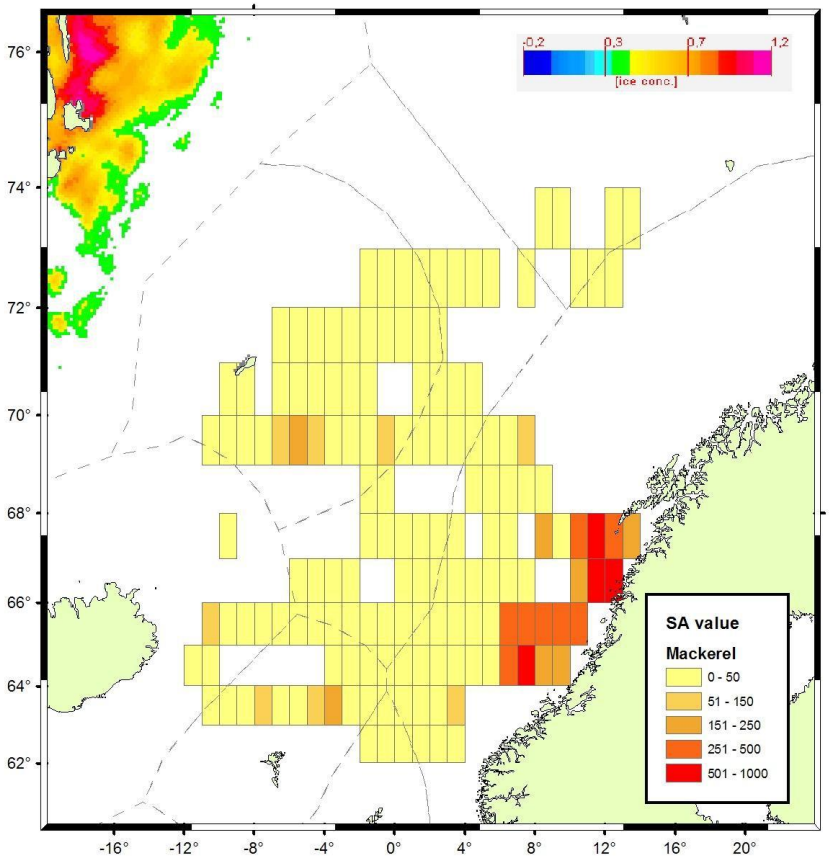


Figure X. Sa or Nautical Area Scattering Coefficient (NASC) values of mackerel along the cruise track.

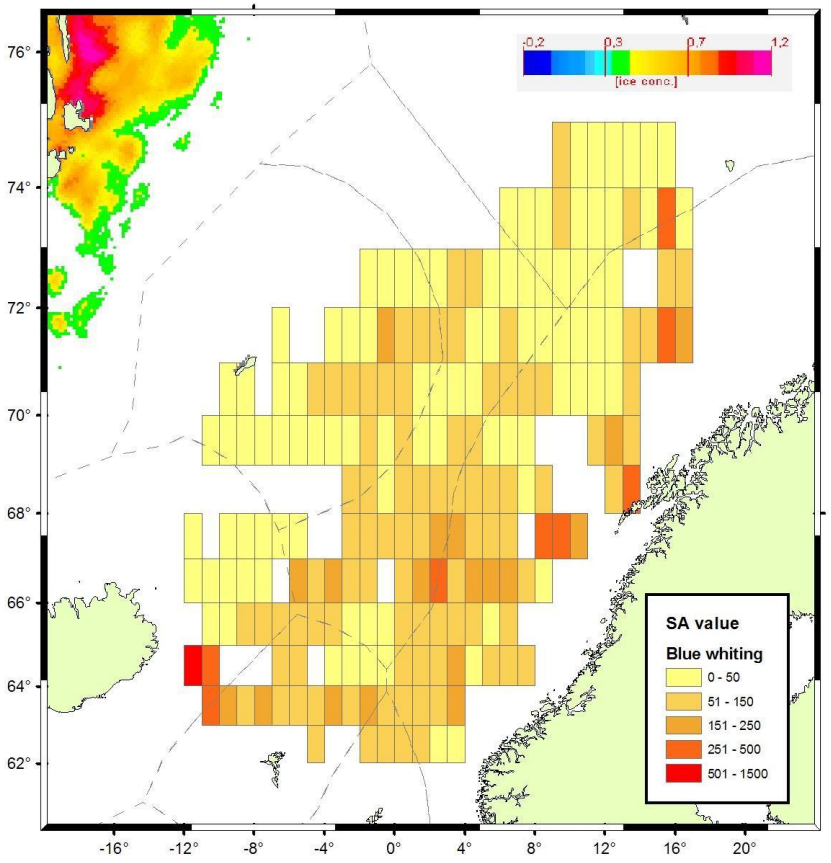


Figure X. Sa or Nautical Area Scattering Coefficient (NASC) values of blue whiting along the cruise track.

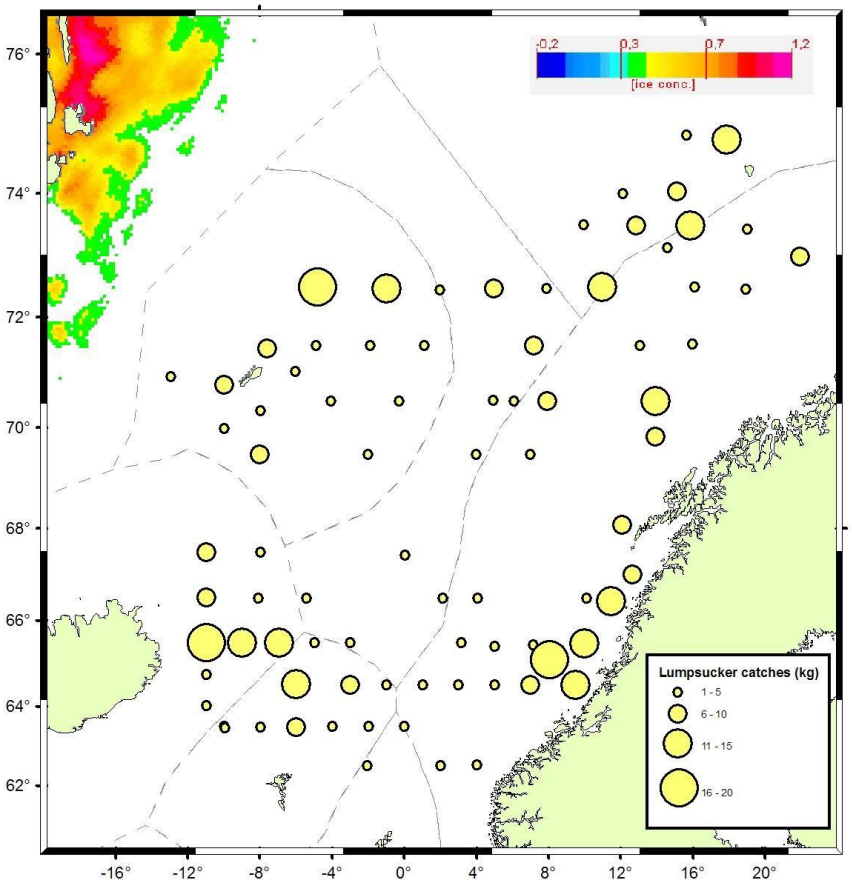


Figure. Distribution and catches of lumpsucker in the Norwegian Sea, 15 July – 6 August 2007.

Plankton

The plankton concentrations appeared to be highest along the coast of central Norway, and in the north-eastern part of the Norwegian Sea (Figure). The plankton concentrations from 0 – 200 meters depth were divided into biomass categories 1) low 2) medium 3) high and preliminary qualitative results are shown in figure x. The highest zooplankton concentrations mostly consisting of *Calanus finmarchicus* developmental stages IV-VI, coincided with medium and high trawl catches and corresponding acoustic registrations of Atlantic mackerel,

whereas high zooplankton production were not linked to the spatiotemporal distribution and aggregation of herring and blue whiting in the Norwegian Sea in July.

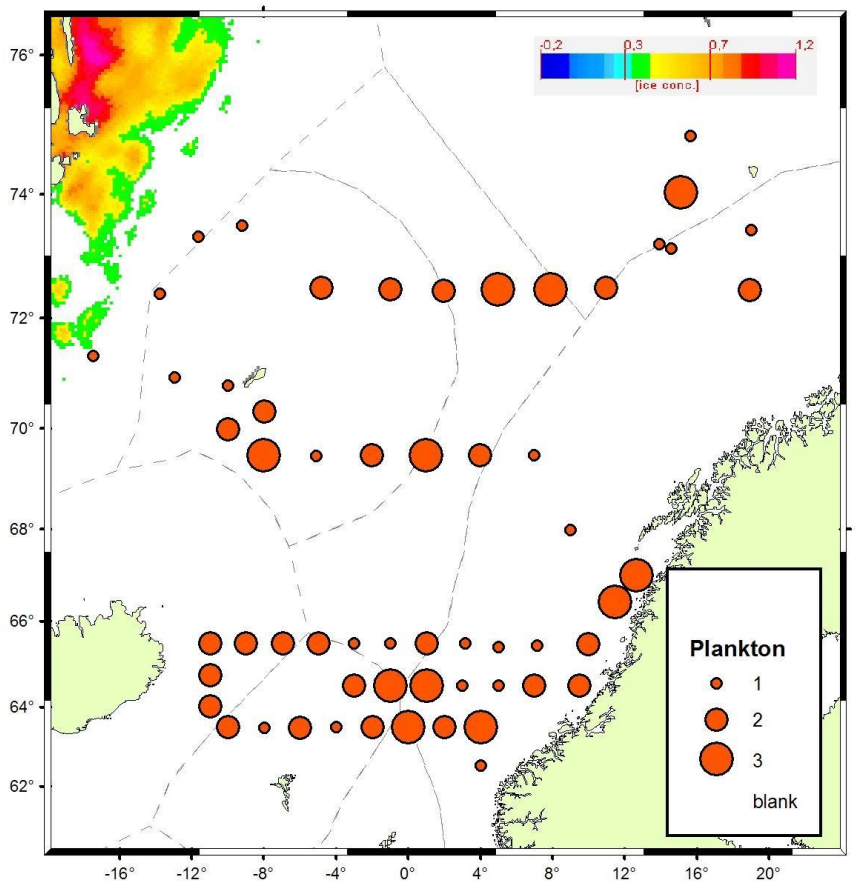
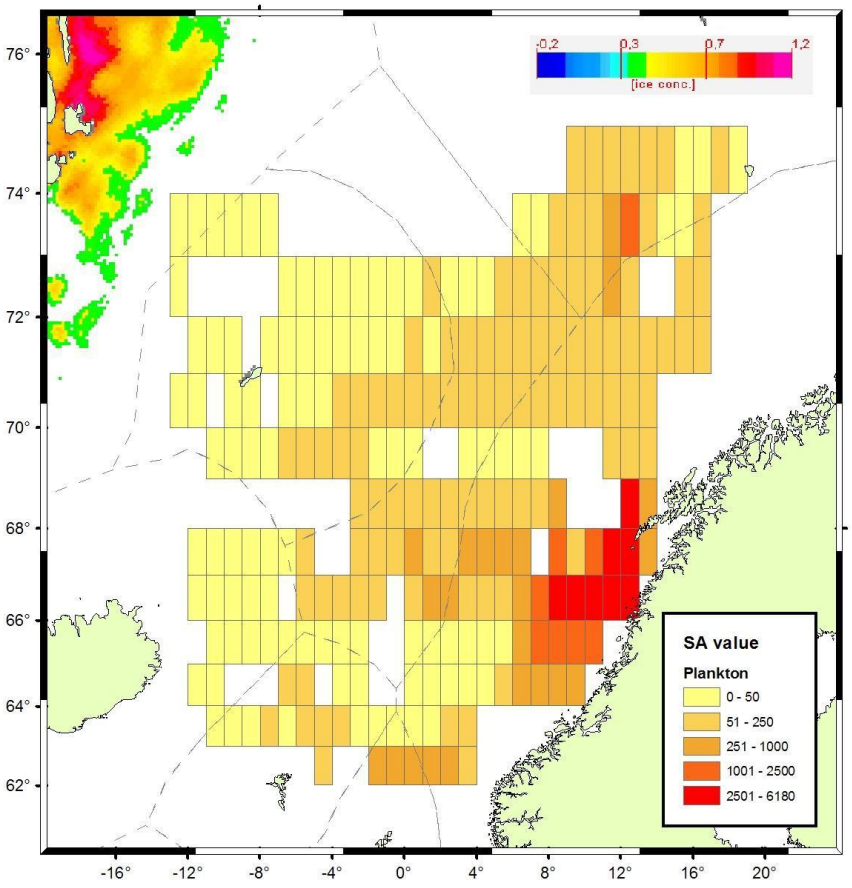


Figure. Qualitative evaluation of plankton concentrations from WP2 net samples. 1) Low 2) Medium 3) High concentration.



Sa or Nautical Area Scattering Coefficient (NASC) values of plankton along the cruise track.

Marine mammals

Marine mammals and basking sharks were observed systematically during the cruise on Libas and Eros and sightings are shown in figure 17. The sightings also include incidental observations of marine mammals from other scientists and crewmembers onboard Libas and Eros. Our observations show sperm whales along the deep continental slopes off Norway, Faeroe Island and Iceland and deep-water trenches and basin within the central part of the Norwegian Sea. Minke whales were detected in several areas, with the highest number of sightings north off Faeroe Island and south of Jan Mayen. Fin whales were observed in the western and northern part with the highest concentrations north of Bear Island and west of Jan

Mayen. They were mainly feeding on krill and herring near the surface and down to 150 m depth. Humpback whales were observed in the southern and northern part, while mostly feeding on krill swarms and herring in relatively shallow water. Killer whales were seen in close proximity to Atlantic mackerel and several feeding events where they attacked mackerel schools were documented. Pods of killer whales were also seen along the drift ice edge off eastern Greenland, and we speculate whether they are hunting for seals in these Arctic waters. White-sided dolphins were associated with dense aggregations of herring in the southwestern part of the ocean, whereas white beaked dolphins were observed predominantly along the shelf break off Bear Island in frontal water and in the northeastern part of the Norwegian Sea. Basking sharks were observed off the Norwegian continental shelf and sighted as far north as 71º30 N. A newly dead northern bottlenose whale was identified and biopsy samples for genetic and fatty acid analyses were taken from the animal.

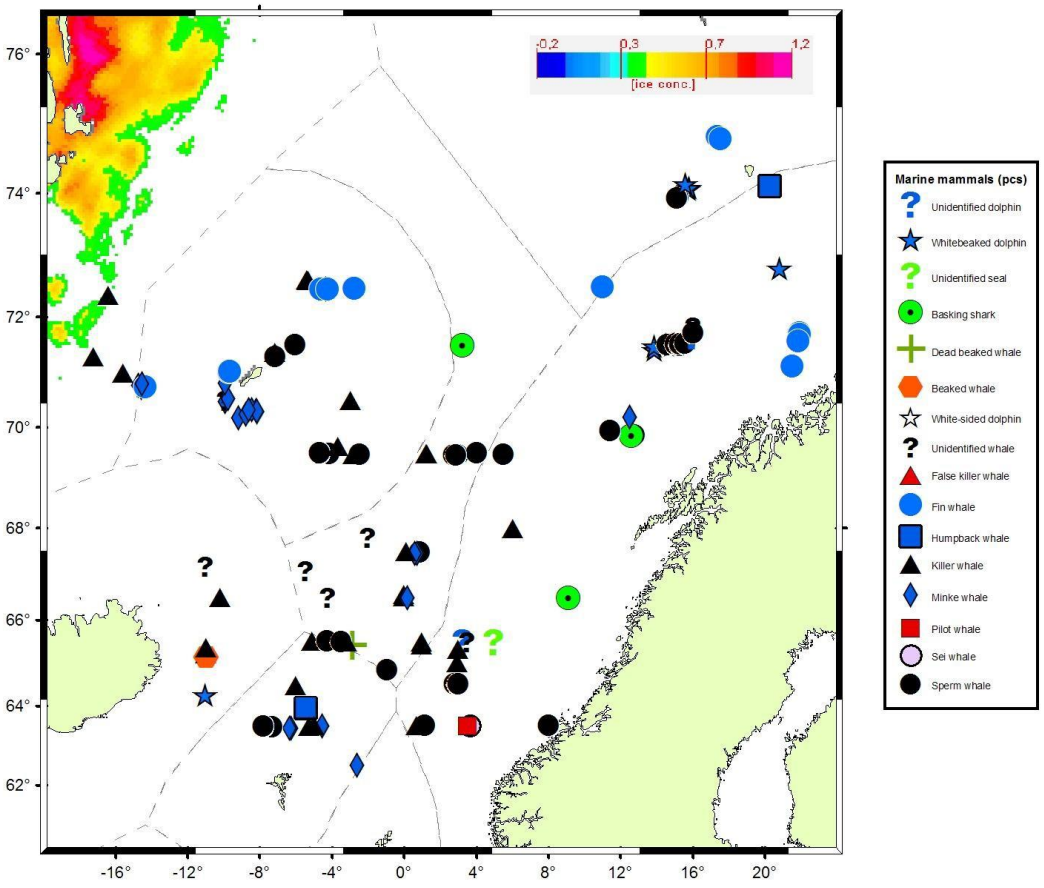


Figure 17. Marine mammals and sharks observed in the Norwegian Sea onboard "Libas" and "Eros" between stations in daylight hours, 15 July –6 August 2007.

Weather conditions

The weather conditions were mostly very favourable for acoustic recordings and visual sightings with low wind speed (Baufort scale: 0-3) and only occasional (< 24 h) did the wind speed reach Baufort scale 4 within the survey tracks in the Norwegian Sea in July. The dominant wind direction was northeasterly followed by southwesterly. Low precipitation and limited rainfall provided good visibility throughout the cruise. Fog and fogbanks were mostly experienced in the westernmost area into the Greenland Sea, south of Jan Mayen and around Bear Island. Wave height was mostly < 1 m and limited swells were experienced along the shelf breaks.

Surface light measurements

Average surface light measurements were recorded every 5 min onboard M/S Eros during the entire ecosystem survey. Diel pattern of surface light (lux) is given in figure 15.

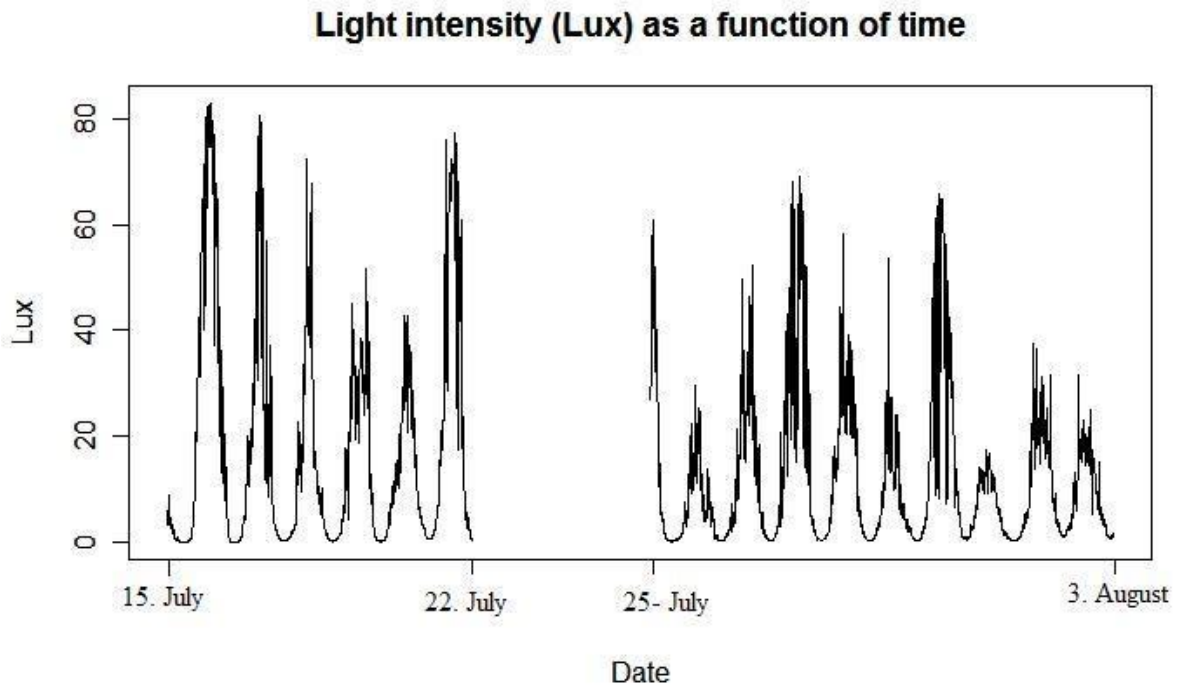


Figure 15. Surface light intensity (Lux) varied between 0 Lux (night time) and 80 Lux (day time) during the diel cyle in the Norwegian Sea from 15 July – 6 August 2007.

Discussion

The ecosystem survey managed to cover both substantial and 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 where all the three major planktivorous species have their maximum geographical distribution. A major aim of this study was to map almost the entire populations of mackerel, herring and blue whiting in the Norwegian Sea. Based on the continuous acoustic recordings from hydro-acoustics and extensive pelagic trawling near the surface and midwater, we managed to cover the vast majority of these species and consequently their maximum spatial distribution.

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 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, 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 and physical oceanography mapping 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.

Acknowledgement

We thank skippers and crew members onboard Libas and Eros for outstanding collaboration and practical assistance on the ecosystem cruise in the Norwegian Sea.

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