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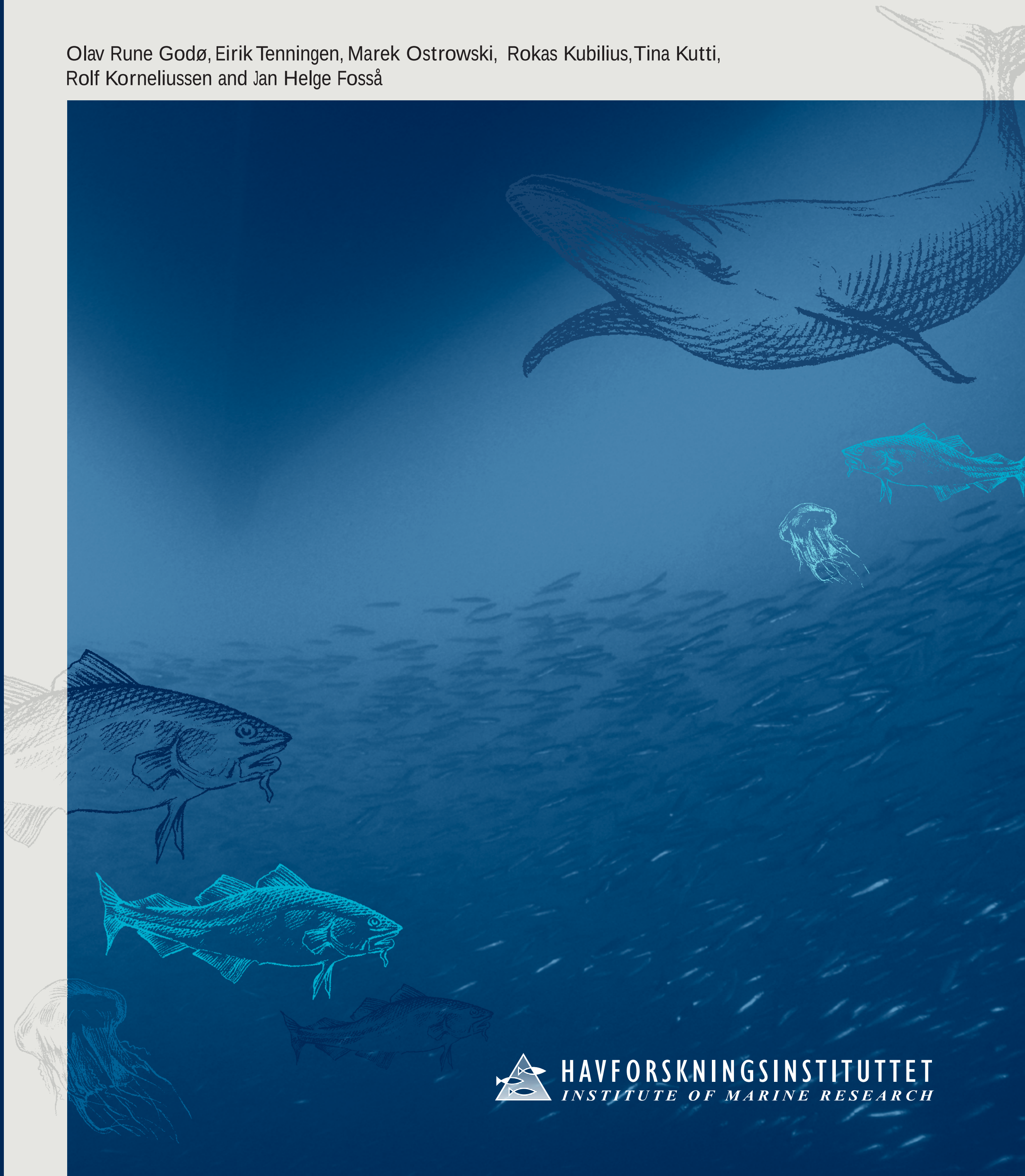
The Hermes Lander project – the technology, the data, and the evaluation of concept and results

Olav Rune Godø, Eirik Tenningen, Marek Ostrowski, Rokas Kubilius, Tina Kutti, Rolf Korneliussen and Jan Helge Fosså



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PROSJEKTRAPPORT

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Sammendrag (norsk):
Rapporten oppsummerer teknologi, operasjoner, erfaringer og vitenskapelig resultat fra prosjektet Hermes Lander. Prosjektet etablerte en autonom, batteridrevet, multisensor undervanns plattform. Plattformen ble plassert på et korallfelt i Hola utfor Vesterålen og samlet inn data gjennom syv måneder i 2010 (mars-september). Oseanografiske og ekkolodd data ble analysert og sammenlignet med tilsvarende data sporadisk innsamlet med forskningsfartøy og data produsert av modeller. Resultatene viser at området har en til dels kaotisk oseanografi, og akustisk tilbakespredning viser interessante årstidsvariasjoner og uvanlig lite døgnvariasjon. Prosjektet verken bekreftet eller avkreftet noen spesiell sammenheng mellom biomasse og korallrev. Dataene og erfaring fra arbeidet er avgjørende for effektiv planlegging, utvikling og operasjon av det planlagte Statoilfinansierte kabelobservatoriet i samme området.

Summary (English):
This report summarizes technology, operations, experience, and scientific results from the Hermes Lander project. The Project established an autonomous, multi-sensor, sub-sea sensor platform powered by batteries. The platform was launched at a coral reef location in Hola off Vesterålen and collected data during seven months in 2010 (March – September). Oceanographic and echo-sounder data were analyzed and compared with similar data from sporadically collected data from research vessels as well as model-produced data. The results demonstrate a partly chaotic variation. The project neither confirmed nor excluded a connection between coral reef and biomass density. The data and experience are crucial for efficient planning, development, and operation of the planned Statoil-financed cable observatory in the same area.

Emneord (norsk):
Undervannsteknologi, akustikk, miljø, Økosystemovervåking

Subject heading (English):
Sub-sea technology, acoustics, environment, ecosystem monitoring

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Content

1 Summary

This report covers the experience and results obtained during the Hermes Lander project. The project was technology-driven, and represents a significant step forward in methodology for habitat studies using multiple sensors over an extended period of time. The project originated from the European Union-funded project Hermes (Hotspot Ecosystem Research on the Margins of European Seas, http://www.eu-hermes.net/about.html), while this extension of the project was jointly funded and carried out by Statoil and Institute of Marine Research. The project has been technologically challenging, and the original ambitions were not fully achieved due to technical obstacles encountered underway. The outcome of the project consists of technology experience combined with a dataset of multiple sensor recordings over three of the four seasons of the year. The technology experience will be furthered into the Statoil planned cabled observatory (LoVe observatory) at the same location and is also summarised in this report. We here offer an overview of the data collected and the most important results.

The observatory approach demanded extremely robust subsea technology capable of long-term operation as well as withstanding launch and retrieval operations. As vessel time is expensive and operations are sometimes complex and risky, it is essential to realise that technology that has not been scrupulously tested prior to launching should not be taken to sea for operation. The results demonstrated that the coral reef location at Hola stands out from its surroundings. The oceanographic situation is quite chaotic in the sense that temperature and salinity vary widely over short periods of time. On the other hand, the current runs steadily to the northwest and by topographic steering may form a closed circulation over the Nordgrunnen. Biomass density in the area appears to be generally low, except for periods when schools of mackerel or herring patrol the area. We were surprised by the lack of a consistent vertical migration pattern, which is normally present in these areas. This may be a result of the variability of the physical environment, but is definitely an issue for further studies. There are seasonal changes in the distribution and abundance of organisms that also need to be paid further attention in the future. The data are rather inconclusive, but offer no support for the idea that biomass concentrates around coral reefs. More flexible operations of the acoustic beams are needed to improve the possibility of performing studies of this sort. Although substantial information is available about the dominant species composition in the area through catches from research and commercial vessels, few samples were taken directly over the Lander, thus making comparison difficult. In the future, dedicated efforts should be made to sample the observation volumes of the acoustic beams.

2 Introduction

2.1 Background of the project

The Hermes (Hotspot Ecosystem Research on the Margins of European Seas) project (http://www.eu-hermes.net/about.html) started in April 2005 and finished in March 2009. The project involved 41 scientific partners and nine SMEs, and focused on technology-driven research for enhancing the scientific basis of our understanding and management of marine ecosystems (Grehan et al. 2009). The Institute of Marine Research (IMR) participated, with particular emphasis on WP2: Cold-water corals and carbonate mound systems.

In an interaction between Hermes, ESONET (European Seas Observatory NETwork, http://www.esonet-noe.org/) and Statoil ASA, it was decided to initiate an add-on project called Hermes-Lander, which would be financially supported by Statoil. This initiative arose from a successful cabled acoustic observatory in the Ofotfjord (Godø et al. 2005, Doksæter et al. 2009a) and autonomous acoustic systems used at the Mid-Atlantic Ridge (Doksæter et al. 2009b) and in the Barents Sea (Johansen et al. 2009) for ecological studies. Based on the outcome from earlier studies, it was decided to establish the observatory in Hola, a coral reef area outside Vesterålen (Figure 1). This area is of particular interest because of its rich pelagic and benthic communities, which include a cold-water coral reef field. The choice of location was based on the need for more detailed temporarily resolved information about coral reefs and the associated marine life, especially fish, and their variability in relation to the physical environment. In particular, there was a request for photographic documentation with time laps camera, which unfortunately could not be satisfied in this project. This has been demonstrated in another Statoil funded project[1]. This particular area is also interesting as shelf related physical and biological processes are intensified when the various water masses flow through this narrow bottleneck of the North Norway shelf.

In place of the above-mentioned technical solution, we decided to develop a more complex multisensor system that would be capable of collecting an integrated set of information, physical as well as biological, for evaluation of marine life in the area, with specific emphasis on factors of importance to life around coral reefs.

2.2 Information about the area

The continental shelf off the coast of Norway consists of numerous banks separated by glacially over-deepened cross-shelf troughs. The shelf becomes progressively narrower towards the north, and is at its narrowest off Lofoten-Vesterålen. The study area, the Hola Trough, lays off Vesterålen, between the Nordgrunnen and Eggakanten banks, about 20 km from land and 25 km from the shelf break (Figure 1). The water depth at the bottom of the trough reaches 270 m, with the northeastern flank sloping at 4^o and the southwestern flank sloping at less than 2^o. The Hola trough is characterized by several remarkable geomorphological features, including two moraine ridges, four major sand wave fields, and the presence

[1] Tenningen, E. (eds). 2011. Morvin environmental monitoring report 2009-2010 (Statoil). Havforskningsinstituttet, Bergen.

of cold-water coral mounds (Boe et al. 2009). Gas seeps producing carbonate crusts and bacterial mats are also widespread (www.mareano.no). The coral reef field is located near the southeastern part of the trough. Here, 330 elongated coral mounds, each 100-200 m long and on average 20 m high, have been interpreted from multi-beam bathymetric maps (Figure 1, www.mareano.no). During a MAREANO cruise with RV *G.O. Sars* (October 2007), 20 reefs were ground-truthed using a towed video platform (Campod), and all were found to contain live *Lophelia pertusa* (Figure 2). Individual reefs resemble those found in the Trændjupet Trough (Mortensen and Lepland 2007) and are aligned parallel to the main current direction with a head-end, with the live *L. pertusa*, facing the current.

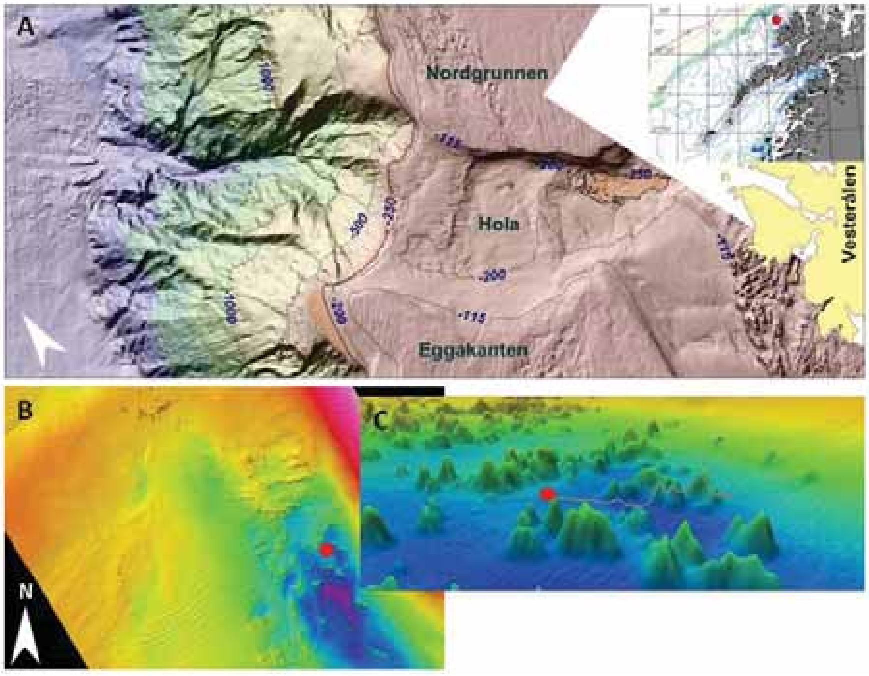

Figure 1. (A) Map showing the bathymetry of the Hola Trough and surrounding banks. The insert shows the Vesterålen area. (B) Multibeam bathymetry of the Hola Trough, showing coral reefs field in the southeastern part of the trough and the research site indicated by a red dot. (C) Three-dimensional map of the research area, showing detailed topography of the elongated coral reef clusters. The position of the Lander is indicated by a red dot and the line showing a stretch from the Lander 600 m straight to the east.

Figure 2. Image taken during the Mareano cruise in 2007 with RV *G.O. Sars*, showing parts of a typical cold water coral reef from Hola with the reef-building coral *Lophelia pertusa* and the associated coral *Paragorgea arborea*.

The water masses of the area are dominated by coastal water close to the coast and Atlantic water offshore. Both water masses are transported northwards and mixed with the Norwegian Coastal Current (NCC) and the North Atlantic Drift. Due to the narrowing of the shelf and the complex topography, the area is dominated by a strong, variable, and complicated current system, including turbulence and mixing at various scales (see Chapter 4.4.3). Bottom current modelling and the presence of large erosional scours and gravelly sand waves in the vicinity of the coral reef field indicate high current speeds (i.e. up to 100 cm s^{-1}) in a predominantly northerly or north-westerly direction in this part of the trough (Boe et al. 2009).

Hola is located in a region of the greatest importance for reproduction of commercial fish stocks. The main gadoid species, cod (*Gadus morhua*) and haddock (*Melannogrammus aeglefinus*), spawn in the Lofoten area, either on the shelf or along the shelf break (Bergstad et al. 1987). Furthermore, herring (*Clupea harengus*) are numerous along or off the shelf during wintering, and pass through the area during spawning migration, sometimes also spawning in the Vesterålen area (http://www.imr.no/temasider/fisk/sild/norsk_vargytende_sild/en). The larvae of these three dominant commercial species all drift through the Vesterålen area and over Hola, our study location.

The topography and current system have created a particularly interesting and vulnerable habitat, the Hola cold-water coral reefs. The Hola reef area is believed to host a rich community of marine species, in line with that found in other cold-water coral (CWC) ecosystems on the shelf (Mortensen and Fosså 2006), and is therefore regarded as a biodiversity hotspot.

2.3 Cold-water corals and ecological function

The global distribution of framework-building, cold-water corals (CWC) is limited to oceanic waters and temperatures between 4 and 12 ^{o}C. In general, these conditions are found in shallow waters (50-1000 m) at high latitudes and in deeper waters (up to 4000 m) at low latitudes. Although cold-water corals can be found in most oceans, the framework-building cold-water corals seem to be especially common on the continental slopes and shelves of the NE Atlantic (Roberts et al. 2006). On the slopes and shelves off Ireland, Iceland and Norway, large coral mounds and reefs have been built by the scleractinians *L. pertusa* and *Madrepora occulata*. Within the region providing suitable oceanographic conditions (temperature and salinity) for coral growth, the distribution seems to be further limited by the presence of locally elevated hard substrata and the occurrence of permanently or episodically elevated bottom current speeds (Freiwald et al. 2002). Food supply (vertical or lateral flux) is a further important limiting factor.

Cold-water coral reef systems or mounds are reported from slopes and topographical highs in sites with enhanced bottom currents (Freiwald et al. 2002, Davies et al. 2009, Mienis et al. 2009) at sites where internal waves enhance particle availability (Davies et al. 2009, Mienis et al. 2009) and at sites with high surface productivity (White et al. 2005, Duineveld et al. 2007). High-velocity currents associated with topographic relief are important because they help to prevent live corals from being buried by sediment (Mienis et al. 2009). Elevated current speeds and breaking internal waves that redistribute suspended particles near the sea bed also increase the rate of encounter of particles and increase the food supply to the corals (Thiem et al. 2006). Breaking internal waves may also promote surface productivity by increasing the vertical nutrient flux and thereby further increase food availability for the corals (Frederiksen et al. 1992). Resuspended particles are often of low nutritional value, and so far there has been no evidence to support the idea that corals do feed on resuspended material. On the contrary, the few studies that have been performed suggest that corals feed primarily on relatively fresh phytodetritus (Duineveld et al. 2007), zooplankton faecal pellets (Duineveld et al. 2004, Duineveld et al. 2007), and zooplankton (Kiriakoulakis et al. 2005). Wide seasonal differences in the quantity and quality of the input of organic carbon to the sea-bed have been observed at several coral sites (Mienis et al. 2009), with fresh phytodetritus and zooplankton faecal pellets mostly arriving after the spring phytoplankton bloom (Duineveld et al. 2004, Mienis et al. 2009). The arrival of high-quality organic matter is thought to be an important factor, limiting both coral growth (Gass and Roberts 2006, Thiem et al. 2006) and reproduction (Waller and Tyler 2005). So far, no studies appear to have investigated CWC hydrodynamics and food supply or the food consumption of corals on the Norwegian shelf. A recent survey at the Træna coral reef field, however, measured respiration rates that were 30 times as high as those of the normal background community across the coral reefs, emphasising the role of these sites as hotspots for carbon processing on the shelf (C. Cathalot, NIOZ-Yerseke, Royal Netherlands Institute for Sea Research, pers. Comm.).

Several studies have emphasised that CWC ecosystems are biodiversity hotspots (reviewed in Buhl-Mortensen et al. 2010). The living zone of *L. pertusa* reefs is mainly inhabited by the polychaete *Eunice norvegica*, the sponge *Mycale lingua*, the bivalve *Acesta lingua*, and other coral species such as *P. arborea*, *Paramuricea placomus*, and *Primnoa reseadeformis* (www.mareano.no). Dead coral branches form a substrate for organisms that attach themselves to the dead coral skeleton (including bacteria, foraminifera, sponges, hydroids and anemones) (Freiwald et al. 2004, van Soest et al. 2007), while polychaetes and meiofauna are often found living on or in between dead coral branches (Raes and Vanreusel 2005). In total, 361 invertebrate taxa were found living in the Sula reef complex and near-by coastal reefs (Mortensen and Fosså 2006), while over 1300 species have been found living in association with *L. pertusa* in the NE Atlantic (Roberts et al. 2006). Costello et al. (2005) reported more fish and a higher species diversity in *Lophelia* habitats than in surrounding areas at sites in Norway, north Scotland, and west of Ireland, and (Husebø et al. 2002) report higher long-line catches of redfish (*Sebastes viviparous*) in coral habitats than in non-coral habitats on the continental shelf break off southwestern Norway. Whether CWCs are important or essential habitats for any fish species has not been established. This is one of the objectives of the ongoing EU project CoralFISH, in which IMR is a partner.

2.4 History of the technology

The project had very ambitious plans to develop technology for data collection and communication of results. The basic idea was to establish a bottom-mounted platform for all sensors and a surface-floating system for data communication and generation of electricity to run the sensors and communication system. All parts of the technology were developed and tested. The tests demonstrated the feasibility of the concept in terms of technical functionality, but made it clear that lack of technical and operational robustness prevented full-scale implementation in the very rough environment of Vesterålen. Moreover, the original plans were for two platforms; one at a coral reef and one outside the coral reef habitat. The second of these was abandoned, also due to technical difficulties.

Several tests and investigations in the area were performed:

Cruise	Date	Objective	Comment
Hermes Jun 2008	15-25.6 2008	Deploy two Landers for one week in a coral area to validate methodology	Successful monitoring of coral reefs
Hermes Dec 2008	4-11.12 2008	ROV survey of the Hola area to find suitable Lander deployment locations close to a live coral reef	Found suitable location for Lander in Hola. Deployed one Lander. Failed to retrieve
Hermes Mar 2009	12-17.3 2009	Retrieval of missing Lander	Lander retrieved, but no data due to water leakage
Hermes Aug 2009	13-18.8 2009	Lander, surface boy, and reference Lander	Failed to deploy main Lander system. Reference Lander deployed
Hermes Nov 2009	11-19.11 2009	Recovery of reference Lander	Lander retrieved, but no data due to water leakage in battery container

Several tests and studies were performed as part of the technology development and training in operational skills (see above text table).The first test deployment was performed in June 2008, when two autonomous Landers were deployed for one week. Successful monitoring of a coral reef and its surroundings was followed up by a ROV survey later in the same year to identify a suitable location for a coral observatory. An autonomous Lander was deployed to collect data during the cruise. Recovery of the Lander failed and a new cruise was set up in March 2009. The Lander was entangled in fishing gear and difficult to retrieve. When retrieved, there was no data due to a water leakage in the instrument container. In August 2009, the Coral Observatory was to be deployed. This was a complex multisensor Lander system, including a camera satellite for detailed studies of live corals and a surface buoy with a wind generator and Internet link to shore. The system also included an autonomous Lander closer to the continental shelf to act as a reference site. Unfortunately, due to the complexity of the system and insufficient vessel and ROV resources, the deployment failed, and only the autonomous system was deployed. The autonomous system was retrieved in November 2009, but without any data due to water leakage in the battery container. On the basis of this experience and a number of technical difficulties accompanied by high financial costs, the level of ambition of the original plans was reduced, and we ended up with a simpler autonomous multisensory platform that is the main subject of this report.

2.5 The interest of Statoil and IMR

Statoil is developing a strategy for real-time integrated environmental monitoring. This ambitious and forward-looking strategy requires input from the technology side as well as from expertise in marine science. The Hermes Lander was part of the approach, and the content of this report forms part of the scientific foundation for further development of Statoil's real-time integrated environmental monitoring strategy.

Studied of bottom and pelagic habitats, and in particular vulnerable habitats is important for IMR as a basis for management. Spatial coverage is focused through the Mareano program (www.mareano.no) and other routine monitoring, but temporarily resolved data are scarce. Further, the Vesterålen area is a hot spot for ecosystem processes of importance to the high north ecosystems and thus of interests for both partners. The present project was considered a test for the observatory approach and, if successful, there is a genuine interest from both parties to further develop the approach through a cabled system. These plans are now under implementation by Statoil and IMR is developing plans for receiving the continuous stream of data for analysis and distribution to users. Also, IMR is no establishing a consortium with the aim of preparing a proposal for extending the cabled system with several nodes to reach deep water off the shelf break.

2.6 Objectives and aim of report

The overarching goal of the project is to establish a technology solution that permit the collection of information that will enhance our understanding of marine life in the Vesterålen area. More specifically, our sub-objectives are:

- To develop an autonomous, multisensory platform with an emphasis on acoustic technology, that will permit simultaneous data collection of zooplankton and fish as well as some of the major physical drivers that regulate their distribution.
- To collect information throughout a full year in order to capture variability and trends in physical and biological variables, with particular emphasis on the distribution of biomass in the coral reef neighbourhood, as well as factors of importance for the establishment and further development of cold-water coral reefs (i.e. production and hydrodynamics).
- To evaluate the information gathered and suggest further development and improvement of the approach that will support Statoil's plans for a cabled observatory in the same area.

The aim of this report is to describe the technology and the challenges and difficulties associated with developing the observatory system.We put this effort into an ecosystem context and demonstrate application of observatory techniques in relation to studies of a specific location. We also bring in associated vessel observations, in order to put observatory solutions into a larger context. The report provides examples of the results, but is far from reflecting the full content. One important aim has been to summarise our experience and results so as to prepare ourselves to efficiently exploit the flow of information from the cabled system that Statoil plans to deploy later this year (2012).

3 Data-acquisition systems

The basic data in this project were acquired by a Lander system deployed in the Hola area off Vesterålen (Figure 1; see also 2.4). This system collected stationary information from several sensors, with high temporal resolution. Auxiliary information collected from other platforms was used to; a) support categorisation to species or group of the acoustics recordings, b) put the Lander data into a spatial context, and c) evaluate the strengths and weaknesses of stationary observation systems. The auxiliary information was collected by research vessels, from commercial catch information, and data from a Statoil-financed egg and larvae study in the same area. Oceanographic modelling outputs were also available for comparison with Lander data as well as for better spatial and temporal coverage of oceanographic information.

3.1 The Lander system

Various bottom-mounted platforms and Landers have become important in marine research in recent years. Photographic Landers have provided unique new information about marine life and processes (Priede and Bagley 2000), and cabled multiple sensor observatory systems are being developed all over the world (Favali and Beranzoli 2006). The operational, technological, and scientific bases for the choice of technology have emerged from the general development of observatories, and have been refined by specific competence and experience in this technology at IMR. In this section, we report the development activities performed in the course of the project, and describe in more detail the final system used during the 2010 period of operations.

3.1.1 The observation system and its history

IMR’s history of acoustics research goes back to the 1930s (Sund 1935). The development of vessel-independent platforms started in the 1990s, with a self-sustained acoustic buoy (Godø and Totland 1996), mainly for detecting and quantifying vessel-induced avoidance behaviour by fish. The next step was to establish a cabled system in the Ofotfjord (Godø et al. 2005) to study the dynamics of overwintering herring. During the international Mid-Atlantic Ridge expedition in 2004, an autonomous self-sustained platform for long-term deployment was developed, to collect data for a complete annual cycle at this remote location. For all products the conclusions were the same; marine data from stationary acoustics resolve detailed temporal dynamics, and are a cost-efficient way to collect fine-scale ecosystem information, as well as information about the human impact on ecosystem components (Ona et al. 2007, Doksæter et al. 2009a). Experience from these developments provided a basis for the developments in the Hermes-Lander project.

3.1.2 The platform

Our observatory platform was designed to collect long-term data. The Lander holds a large battery container to permit this to be done, and minimisation of power consumption is a key design criterion for such systems. The data are acquired by an industry-type PC housed inside a separate container. The computer also runs the software required by some of the sensors. The same container also houses an electronics unit that controls the battery capacity and manages the sampling scheme. The need for directional stability to ensure that the acoustic data were properly oriented, and the potential for using sensors on satellite platforms, demanded a bottom-mounted heavy and robust construction. The Lander was deployed in position: N68°55.35, E14°24.07 on 23 March 2010 by R/V “Johan Hjort”, and retrieved on 2 July 2011. Figure 3 shows the Lander being retrieved by “Acergy Viking”.

Figure 3. Instrument platform retrieval.

3.1.3 The sensors

The sensors installed on the platform included a Simrad EK60 38 kHz, a RDI ADCP 70 kHz Workhorse, an AADI RDCP600 with various oceanographic sensors (temperature, pressure, salinity, turbidity, chlorophyll), and a Naxys hydrophone.

The Simrad EK60 echosounder was attached to two 7^{o} transducers. One pointed vertically upwards and was mounted in gimbals, thus ensuring a straight upward-pointing beam under all conditions. The other transducer was hung with a slight upward angle of about 7^{o} to the horizontal plane. Here we collected information from the bottom zone in a straight eastward direction slightly touching two bottom elevations, possibly coral reefs. More specified information about the sounder system is shown in Table 1. The setup was designed to study biological density structures in relation to the coral reefs. In order to ensure long-term operation with limited battery capacity, we operated the EK60 in accordance with a mission plan. The system was active for one hour and then paused for four hours. During the active period, multiplexing provided alternative pinging with a ping rate of one ping every two seconds. The system started recording on 23 March, and closed down by 5 September due to lack of power.

Table 1. The position and basic properties of vertical and horizontal pointing echo sounders, as used for beam pattern modelling.

Property/Parameter	Vertical	Horizontal
Lander position	68 55.223N 14 23.880E	68 55.223N 14 23.880E
Seabed depth, m	264	264
Transducer depth, m	262	262
Tilt-up from horizontal to acoustic axis, deg	90	7
Transducer bearing	-	East (+/- 5°)
Frequency, kHz	38	38
Bandwidth, kHz	2.43	2.43
Half-power beam width, deg	7.0	7.0
Sidelobe, Transmitter, dB	-18	-18
Sidelobe, Receiver, dB	-18	-18
Source level, dB	218	218
Directivity index, dB	27	27
Pulse length, ms	1.024	1.024
Recording range, m	262	750

Current measurements were collected using two acoustic profiling systems, an RDI ADCP 75 kHz for measurements over the entire water column, and an Aadi RDCP 600 kHz for short-range high-resolution measurements close to the bottom. The two systems were stand-alone units, operating on internal batteries, independent of the echosounder system.

Other oceanographic data were collected by temperature, salinity, chlorophyll and turbidity sensors on the AADI RDCP from 23 March - 8 May.

Passive acoustics provide valuable information on the overall background noise level in the area, as well as the possibility of collecting biological sounds from fish and whales. The Lander was fitted with a Naxys Ethernet hydrophone, specified to record sound in the frequency range 10 - 300 kHz. The hydrophone produces large amounts of data, so continuous recording was not realistic. The hydrophone was therefore set to record at the same intervals as the active acoustic system; one hour of operation and four hours off.

3.2 Vessel data

3.2.1 Research vessel catch data

The region of our study site is a key area for fish stock recruitment, as many commercially exploited species either spawn or drift through the area during the pelagic phase of their first year of life. From 16 - 18 April 2010, an IMR herring larvae survey passed the area, and horizontal high-speed bongo samples or vertical net samples were taken (Figure 4) (Stenevik et al. 2010). As part of the Statoil-financed activity off Vesterålen, a chartered vessel took similar vertical samples on April 8-9 and 28 and on May 11 in the proximity of the Lander (Figure 5, 6). The larvae found in these field studies were all at the yolk-sac stage and lacked a swim-bladder. This makes them far less detectable by acoustic means, but careful studies of the upper 50 m during all these periods were carried out in order to determine whether they could be identified on the echograms. Similarly, five research pelagic trawl hauls were made in July – August, sampling both at the surface in the deep waters, and three shrimp trawl hauls in March (Figure 7, Table 5).

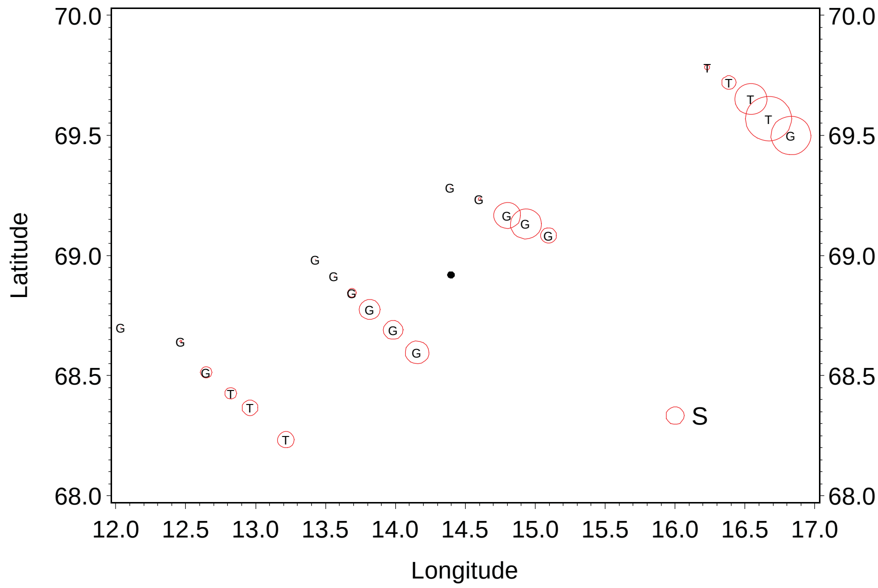

Figure 4. Sampling location of the IMR larvae survey in April 2010 with high-speed Gulf (G) and vertical net (T). Bubble scaling given by S (100 ind/m^2), see (Stenevik et al. 2010). Black dot indicates Lander position.

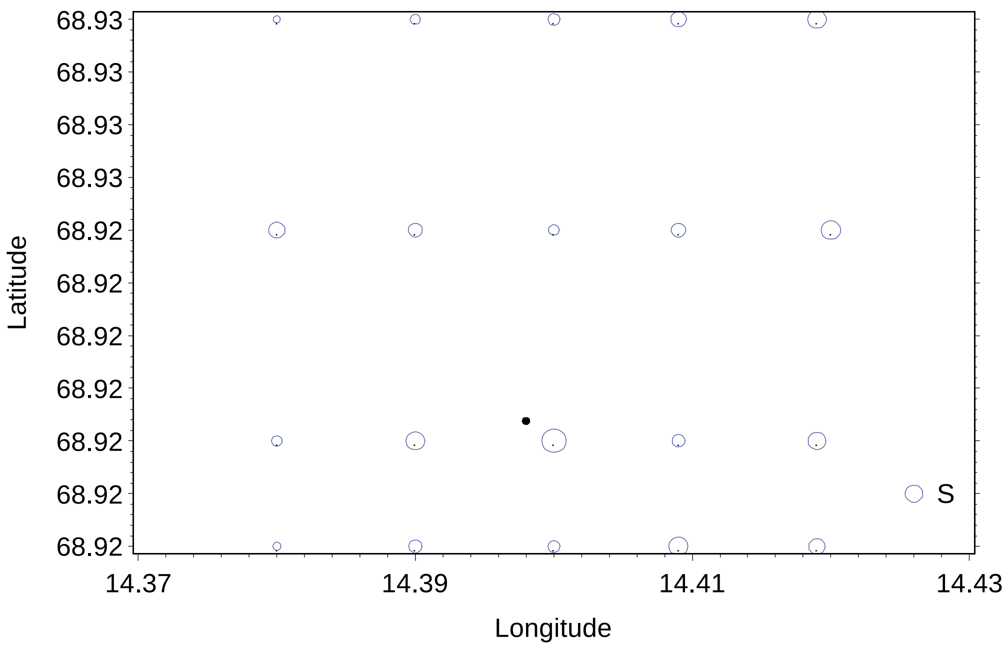

Figure 5. Sampling locations and relative variation in catch of fish larvae (bubbles) in a standard haul during the May 2010 survey (University of Bodø). Black dot indicates Lander position. Bubble size related to catch in numbers (bubble marked S is 100 larvae).

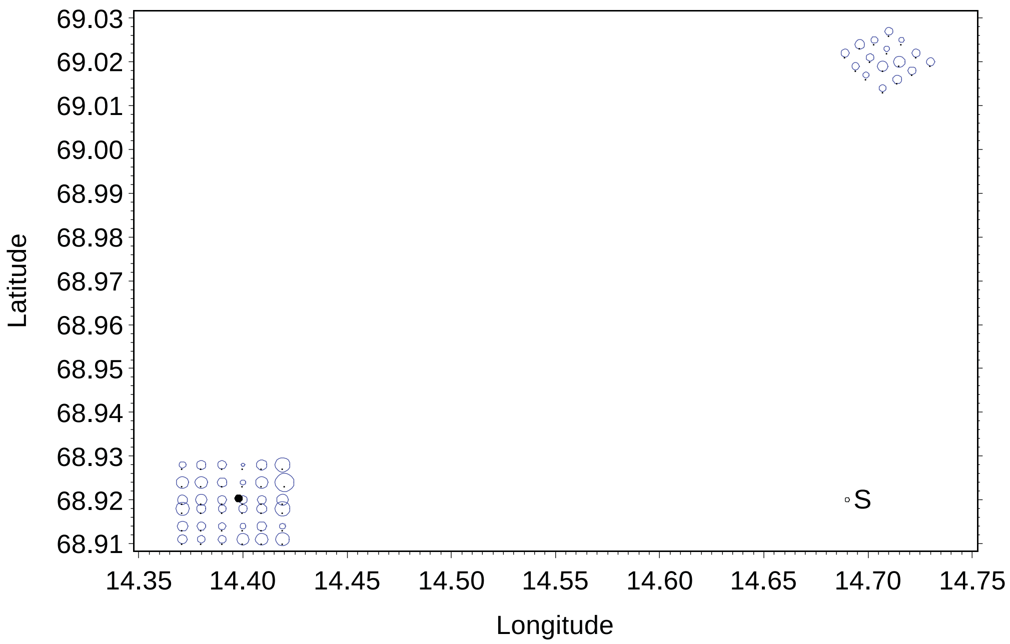

Figure 6. Sampling around Lander location and at a reference area in early April (University of Bodø). Black dot indicates Lander position. Bubble size related to catch in numbers(bubble marked S is 100 larvae).

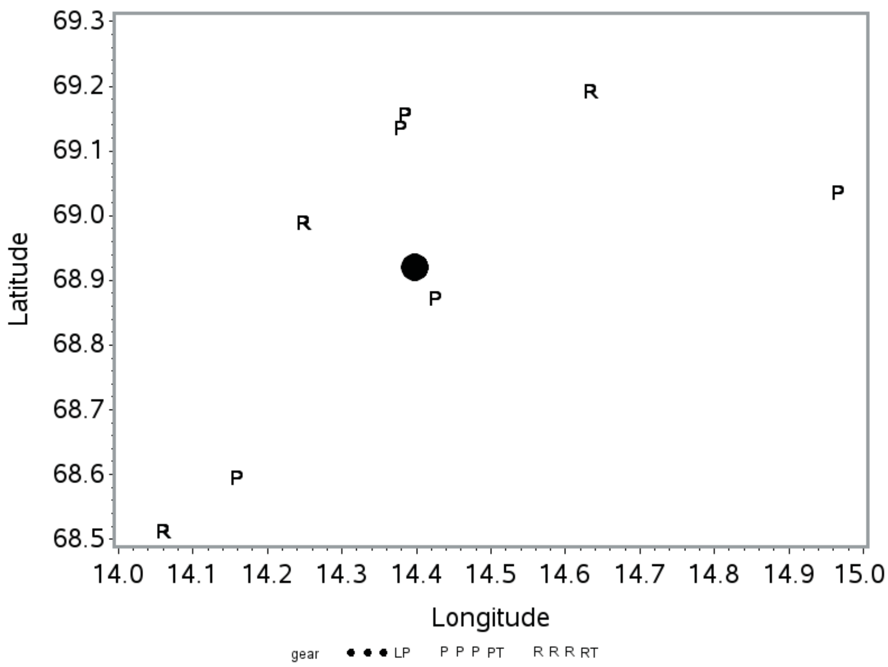

Figure 7. Catches taken by research vessels with shrimp trawl (R) and pelagic trawl (P). Black dot indicates Lander position.

3.2.2 Commercial fishing data

The database at IMR was searched for information from commercial catches taken in the neighbourhood of the Lander (68.5-69.5 ^{o}N and 14–15 ^{o}E). The fishing gears used in the sampling were gillnets, longlines, Danish seines, and bottom trawls (Figure 8), and are of interest in relation to backscattering from the bottom zone.

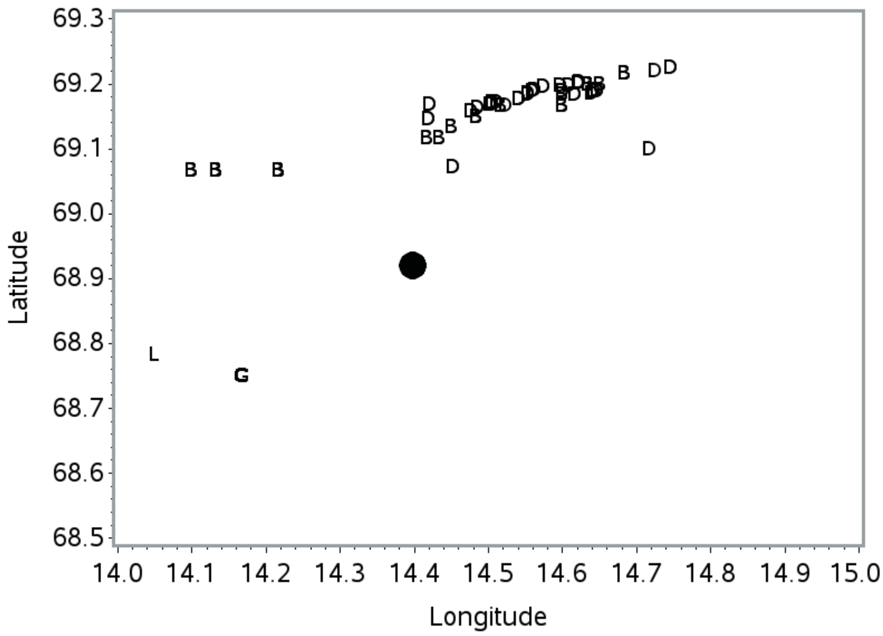

Figure 8. Distribution of sampled commercial catches during the observation period with bottom trawl (B), Danish seine (D) and longlines (L). Lander position indicated by black dot.

3.2.3 Research vessel acoustic data

IMR research vessels passed through the area several times during 2010 as shown in the following text table. Some of them passed very close to the Lander location ("Location" in the table) while others operated in the area but never passed over the location ("Area" in the table).

Vessel	Date	Coverage
G.O. Sars	17-19 April	Location
Johan Hjort	18-24 March	Location
Haakon Mosby	10-11 July	Area
Johan Hjort	14-16 August	Location
Johan Hjort	10 October	Area

The data are compared to Lander acoustics from the vertical pointing transducer.

3.3 Data from oceanographic models

Understanding the dynamics ecosystem requires basic information about the physical environment. Such information is available only for the Lander position on the bottom and some scattered observations in the vicinity of the rig during the observation period (see 4.4). The observed current velocities at the Lander site were compared to predictions from the Norwegian Coast 800-m model (NorKyst-800; Albretsen et al. 2011). The predicted current velocities were extracted from the model output at the grid node that corresponded to the Lander location, and organized in the form of a synthetic current time-series. The simulated datasets covered the period from 1 January to 1 October 2010, with a time step of one hour between consecutive profiles. Although the simulated and observed data at the Lander site turned to diverge somewhat, their comparison helped us to understand the role of the abrupt topography of the Nordgrunnen in the vicinity of the Lander site in the shaping of the local currents.

3.4 Data analysis

This is a data report, and detailed analysis is not yet complete. Both oceanographic and acoustic data have been subjected to some general analysis to extract the information required. The method is explained together with the analysis. General guidelines and definitions regarding the data processing have been used. Acoustic nomenclature follows (MacLennan et al. 2002), where s_V and s_A are defined as volume and area backscattering coefficients and represent measures of biomass within a certain volume or over a certain area.

- Times are expressed as UTC.
- We used civil day (sun elevation>0 degree), twilight (-6<sun elevation<0) degree and night (sun elevation<-6 degree) definitions.
- Sun elevation was calculated by date, UTC and position of instrument platform according to standard procedures (see e.g. http://en.wikipedia.org/wiki/Solar_elevation_angle).
- Summer is defined as the period when sun never went down below the horizon (May 23 – July 19). Spring and autumn are the periods before and after summer.
- The echosounder data are treated in bins of 50 m, where 25 represents 0-50m, 75 represents 51-100m and so on.
- Vessel and Lander acoustic data are not quantitatively comparable as vessel data are integrated over distances while Lander data are integrated over time. In this comparison, Lander data are mostly multiplied by 1000, in order to make them comparable in size to vessel information.

4 Results

The results are organised according to sensors and platforms, and are presented and discussed here as independent sources of information. A synthesis of the information and discussion of results in relation to objectives and future perspectives is provided in Chapter 5.

4.1 Lander echosounder biomass data

Vertically-pointing beam

The vertically-pointing transducer collected data from the whole water column (from 5 m above the bottom), and represents a time series of information about short- and long-term variability in the biomass densities above the Lander. The data show a clear seasonal trend (Figure 9). Densities gradually increased and peaked on day 50-60 (end of May-beginning of June). The density was generally low during summer, but displayed an increasing trend towards the end of the time series. The trends were smooth except for some peaking days during summer and autumn. The echograms from these days were studied in particular, and the strongest peaks represent schools of fish passing the Lander, while the smallest were generally higher concentrations during shorter periods (Figure 9).

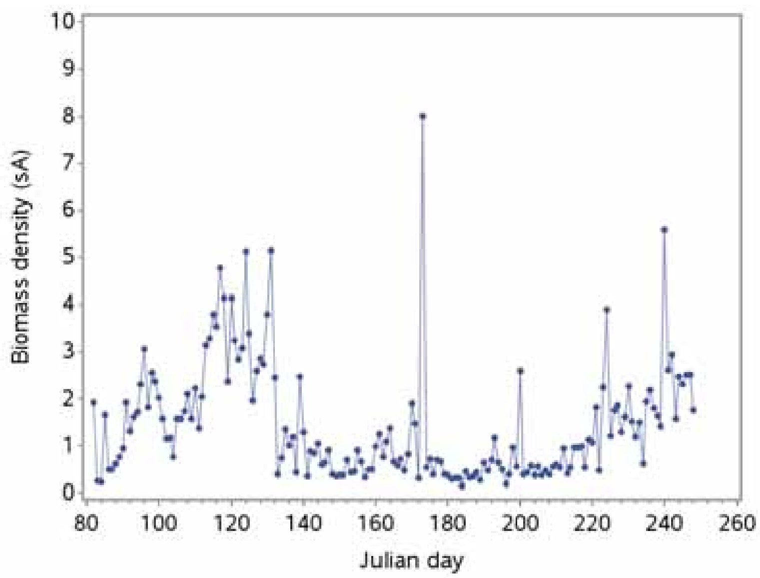

Figure 9. Time series of acoustic biomass density data, averaged by day during the observation period.

Figure 10 also demonstrates that the bulk of the acoustically recorded biomass is found in the upper layers (depths 25 and 75). The vertical distribution changed through spring, summer and autumn. In the upper layers, densities were clearly highest during spring, while at the bottom, they were highest during autumn.

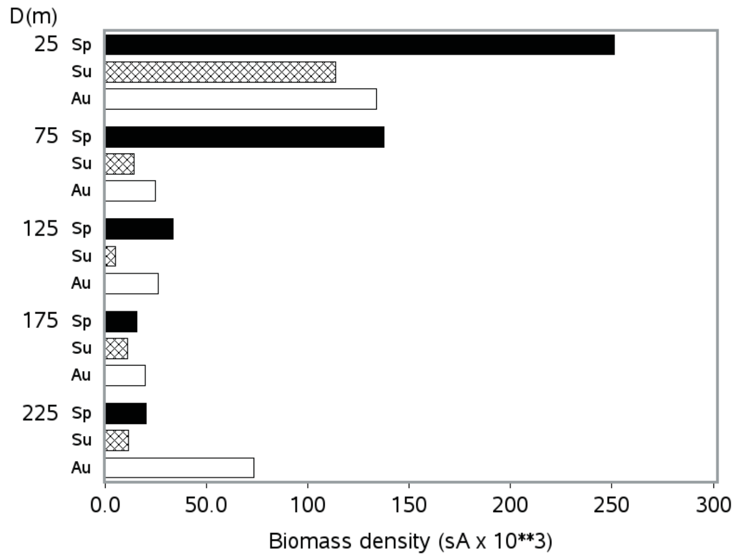

Figure 10. Vertical distribution over spring (Sp), summer (Su) and autumn (Au). D is water depth.

Marine organisms often perform substantial diel vertical migrations, depending on species and the time of year. In our analysis, we have used civil day and night definitions, where the twilight zone is when the sun is between the horizon and 6^{o} below the horizon. Considering the impact of height of sun independent of season, it indicates that light is a weak stimulus for the distribution of biomass densities (s_A) in any of the 50-m layers from the bottom (225) to the surface (25) (Figure 11). The surface layers (upper panel) are at a maximum when the sun is below the horizon, indicating biomass transportation to the surface layers during night. If this is the case, we would expect to observe minima at the same time in the deeper layers. This is clearly not the case, as can be seen in lower panel. The layer closest to bottom has maximum at about the same sun elevation. An alternative to vertical migration is that light conditions affect fish orientation, which is an important factor in determing backscattering strength (Foote 1979).We need to revisit this issue too in the context of seasonal effects.

Figure 12 display accumulated values over the seasons. Studies of vertical distribution by day, twilight, and night for the three seasons support the impression of limited vertical migration. Biomass densities were highest in the two upper layers of the water column during all the seasons. Only in autumn did the nighttime and twilight densities reach comparable levels. This is the season of highest bottom densities (see also Figure 10). The higher night densities are probably bottom-associated animals that stay below transducer depth during the day and move into the water column at night. The higher nighttime densities during the summer may have been due to an accumulation of vertically migrating animals in the upper part of the water column. However, there were no associated reductions of biomass in deeper layers. It thus seems difficult to pinpoint specific general diel vertical migration patterns in this dataset. This is supported by a General Linear Model (GLM) using month, time (day, night, twilight), and range as explanatory factors for variations in s_A. Month and range are significant factors, while time is not. A more plausible explanation of variation in density patterns is horizontal movements. The upper part of the water column is affected by pelagic fish moving into and out of the area. We know that especially during the summer mackerel schools patrol surface waters, and herring schools may also visit the area. Further, our location was situated close to the wall bordering the Nordgrunnen (Figure 1). Fish and plankton from these very different biotopes might even have been brought in and out of the upper water column biomass by passive transportation of currents. In conclusion, we think that the possible vertical migration by the animals above the observatory is confounded by a substantial horizontal and diel-independent process of immigration and emigration.

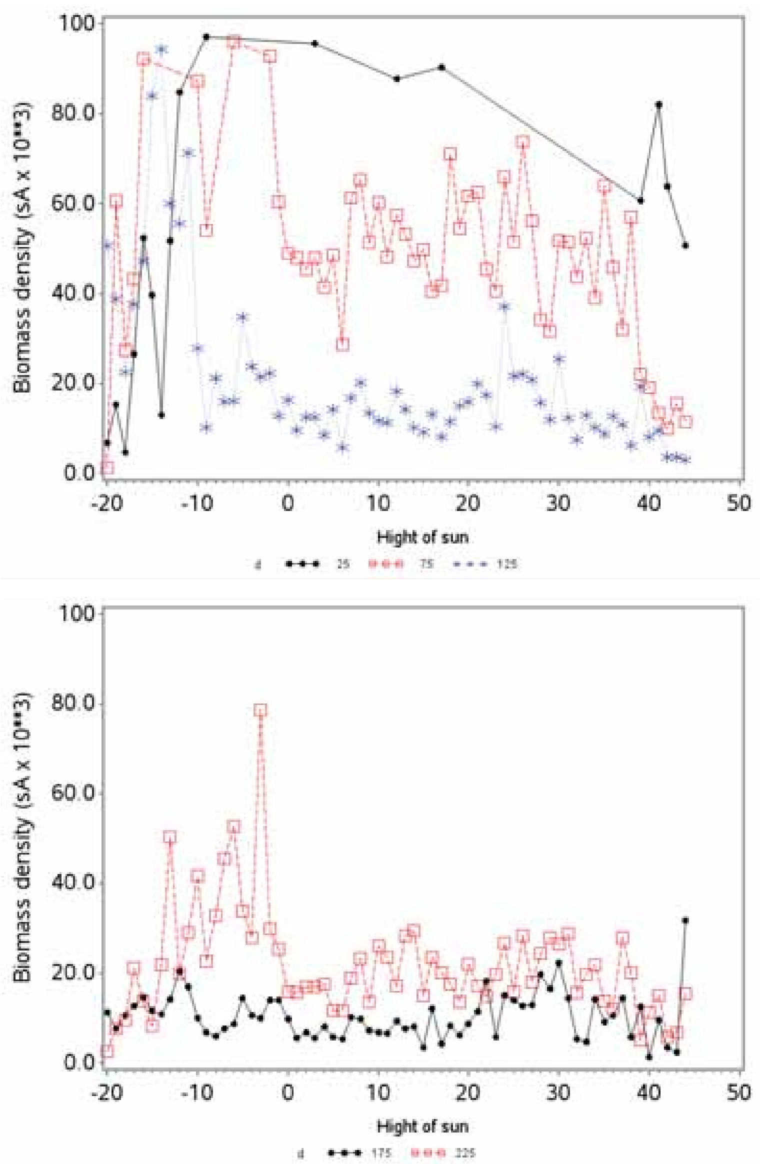

Figure 11. Biomass density (sA) in relation to sun height (degrees below or above horizon). Top panel shows the three layers closest to surface while lower panel shows the two layers close to bottom.

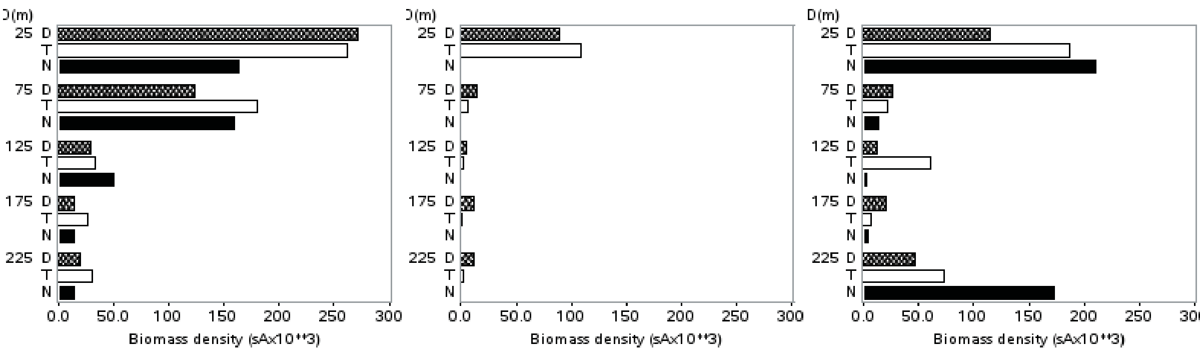

Figure 12. Vertical distribution by day (D), night (N) and twilight (T) at five depth layers at different distances from bottom (R=25) to surface (R=225) during spring (left panel), summer (middle), and autumn (right).

The horizontally-pointing beam
The horizontal beam covers an increasing height above bottom with distance from about 2 m at the platform to 50 m at range 270 m (Figure 13). The acoustic beam shape can be deformed substantially from its theoretical, roughly conical shape in water mass, as it is structured by changes in sound speed. The sound speed varies according to the water's differing physical properties (e.g. salinity, temperature). The effect of changing sound velocities on the acoustic beam pattern is usually minor for vertically (up/down)-oriented echo sounders. However, it can be substantial for sideways-oriented echo sounders, due to reflection or acoustic beam bending in water layers with different sound speeds.

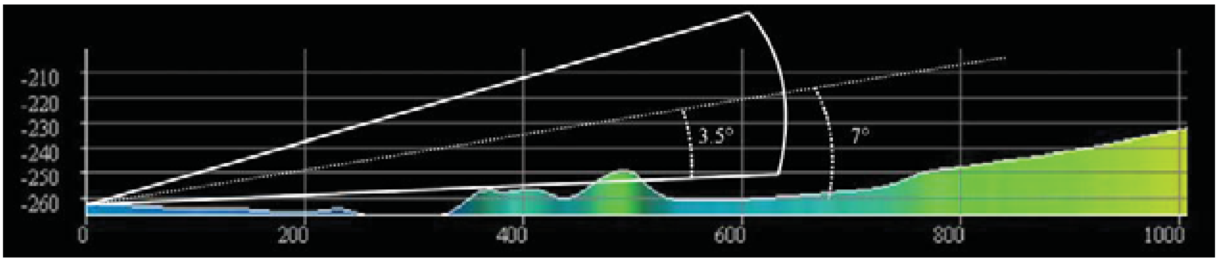

Figure 13. Horizontal beam coverage over the seabed profile. Vertical axis – depth (m); horizontal axis – range (m).

Ray-tracing exercises (acoustic beam pattern modelling) were performed using Lybin 4.0 ray-tracing software and CTD data from the region about 200 km radius from the Lander site and over the time period of the Lander operation. The basic properties of the sideways-looking echo sounder, as used for beam pattern modelling, are shown in Table 1 and model results are illustrated in Figure 14.

The ray-tracing model results regarding the acoustic beam pattern of the horizontally-orientated echo sounder are shown in Figure 14. The two distinct features that can be seen on the sideways-orientated echo sounder recording (Figure 15) are believed to be detections of two bottom elevations marked with white dots in Figure 14 (upper panel).

The analysis of vertical sound-speed profile, as calculated from data from several CTD measurement stations, indicated substantial dynamics over time in the water mass down to about 100-120 m depth, but also showed a relatively stable change in the speed of sound below this depth. Subsequently, the acoustic beam modelling exercises suggested that the horizontally sideways-oriented echo sounder beam pattern over the entire period of operation of the Lander was stable.

The recorded biomass along the horizontal transect is low and relatively stable throughout the measurement period (Figure 16). There was no indication of biomass patchiness that could be explained by coral reefs or other bottom features. Peaking densities during some days were paid specific attention, and careful studies of the echograms during identified them as fish aggregations, probably blue whiting (*Micromesistius poutassou*) or Norway pout (*Trisopterus esmarkii*) according to their character and based on research vessel shrimp trawl catches (Table 5).

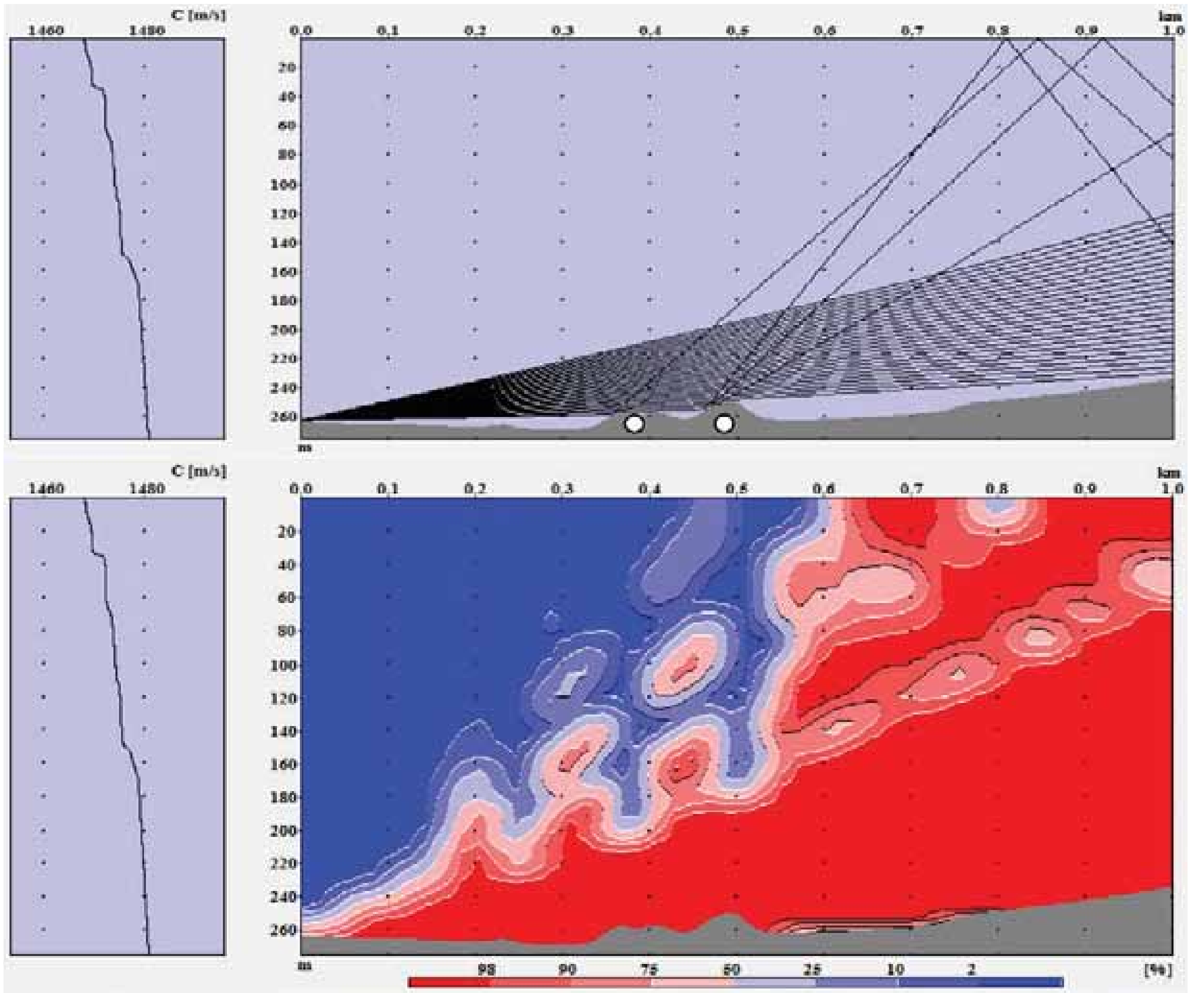

Figure 14. Acoustic beam pattern modelling results using the data of CTD profile next to the Lander site on the day of unit deployment (23.3.2010).

Top:Ray tracing model illustrating the general shape of the acoustic beam.

Bottom: Probability of target detection map (target strength -50dB, lower threshold -100dB). Vertical axis – depth (m), horizontal axis – range from the Lander (km). Left - the sound speed profile is indicated (C [m/s]).

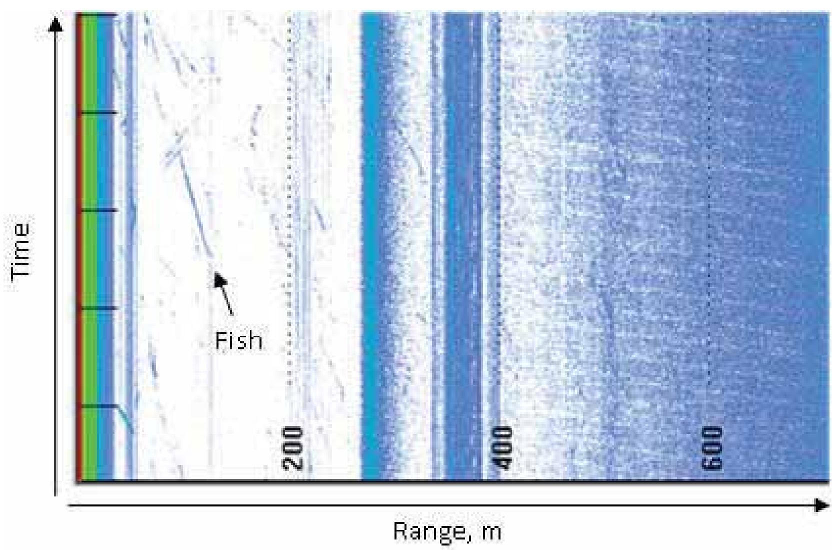

Figure 15. Echogram from the horizontal pointing transducer. Note features at 250 and 400 m. Blue stripes transversing the echogram are single fish detections.

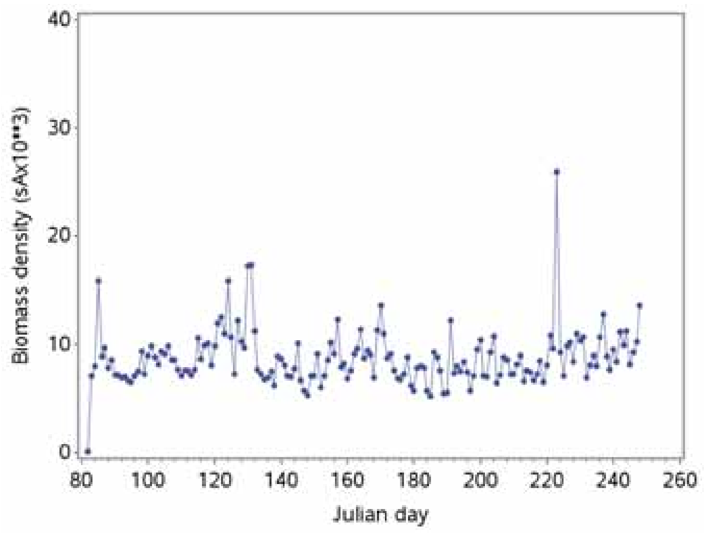

Figure 16. Overall acoustic biomass densities over time as observed by the horizontal transducer.

When biomass measures were averaged by season and distance from platform, we found that there are wide variations in time and space (Figure 17). Recorded biomass in the first 50 m (range 25 m) was extremely low throughout the whole period. This may have been due to the low sampling volume close to the transducer, combined with a paucity of organisms located in a depth zone ~4-8 m above bottom. Outside 50 m, there seemed to be a minimum in the middle and maxima at 75 m and 275 m. At all ranges the biomass densities were highest in the autumn.

Sun height did not appear to strongly affect recorded biomass densities (Figure 18). The exceptions are the peaks observed when the sun is below the horizon during the spring and autumn (Figure 18). There is probably a link between this peak and the increased density observed close to the bottom in the vertical distribution (Figure 12) during night and twilight. If bottom-dwelling organisms rise in the water column only when the sun is below the horizon, the two observations seem to consistently reflect the same phenomenon.

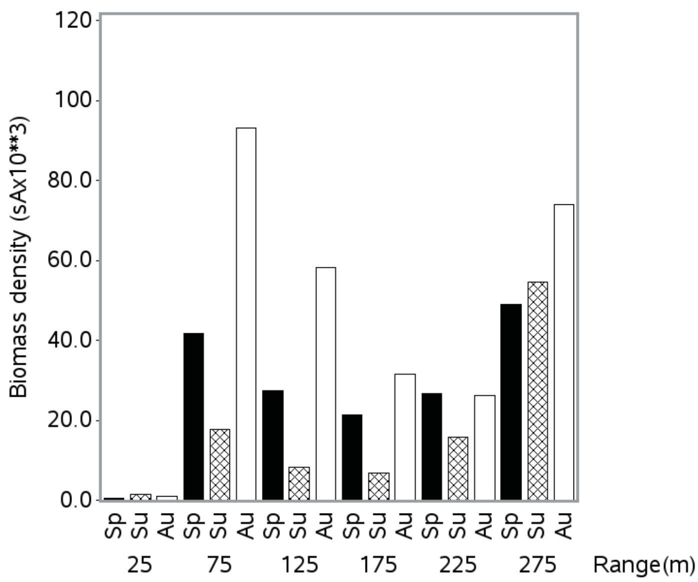

Figure 17. Biomass density during spring (Sp), summer (Su) and autumn (Au) at 50-m intervals from the transducer.

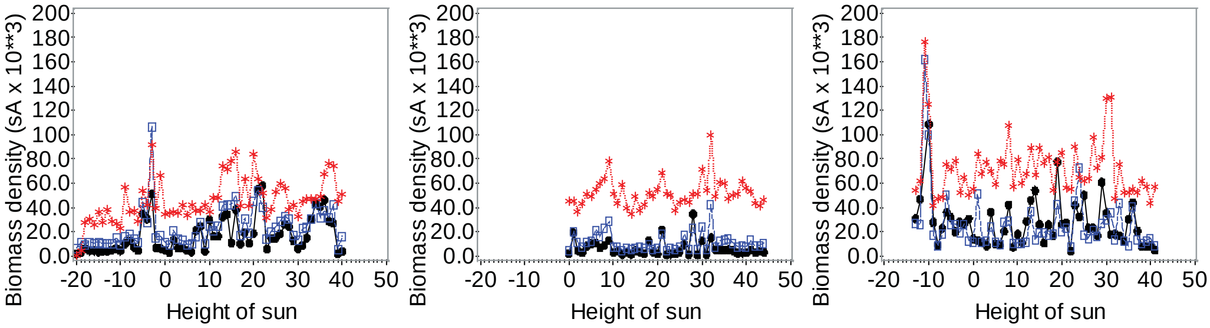

Figure 18. Biomass density in relation to height of sun during spring (left), summer (middle) and autumn (right) for various ranges (r) from the transducer, r=175 (black, dot), r=225 (blue, square) and r=272 (red, star).

Analysis of changes over day and night as a function of distance from the transducer (range) revealed two striking features (Figure 19). First, we see that density measures were generally highest in the autumn, as is also indicated in Figure 17. During autumn, values are significantly higher at night at 75 m, but this difference is gradually reduced to nothing with increasing range. Similarly, although not significantly, higher twilight values during spring at 75 m gradually fell to zero difference with increasing range. During the summer, no such trends were apparent. We believe that such diel differences are associated with the increasing vertical coverage of the beam as the range increases. During the summer, the activity of bottom-associated organisms seems very limited, probably because the sun is always above the horizon. During the spring, organisms migrate into the narrow beam at short range (R) during twilight, while the wider beam volumes dilute this density at larger ranges. Few targets seem to be left in the beam volume during spring nights, while this was the period of highest densities during the autumn.

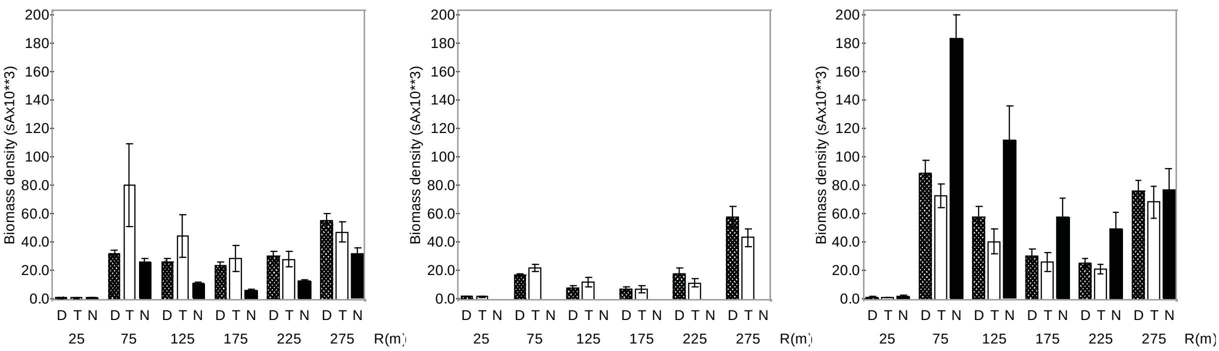

Figure 19. Variations in acoustically recorded biomass by day (D), twilight (T) and night (N) with range (R) during spring (left), summer (middle) and autumn (right). Error bars indicate confidence limits.

4.2 Lander echosounder acoustic target strength data

Acoustic target strength (TS) is a measure of echo strength originating from well-resolved single targets in the water column (e.g. fish). Although the TS is stochastic in its nature, it can be used as a proxy for average fish sizes when the species of fish has been identified and its TS has been described via experimental measurements. As rough examples, large saithe or cod are likely to have TS of about -30 to -40dB, while small pelagic fish with a swim bladder probably have TS of about -50 to -60dB. Bladderless fish such as the lesser sandeel (abundant in parts of the North Sea) would have even lower average TS within the range of about -65 to -75dB while larger bladderless fish like mackerel might fall within the same TS range as small bladdered fish.

The acoustic target strength measurements were extracted from a TS range of -30dB to -80dB from both vertically and horizontally oriented echo sounder data. In general, the "window" or range between the upper and lower thresholds for accepted TS measurements have to be kept relatively narrow for good-quality measurements (≤30-40dB range). If the "window" for accepted TS measurements is too wide, there is a higher probability of excluding strong echoes, as these may not pass generally strict TS detector filters. Subsequently, both acoustic data sets (vertically and horizontally oriented observations) were analysed for TS measurements twice, using two overlapping "windows" of upper and lower thresholds for accepted acoustic targets: -30 to -60dB and -50 to -80dB. The rest of the single-echo detector settings were kept unchanged (Table 2). TS were analysed using LSSS acoustic data post-processing software (Korneliussen et al. 2006).

The acoustic target strength measurements are summarised in Figure 20 and 21. There appeared to be a general decrease in the number of targets detected during the summer months (Figure 20 left and 21 left). There was also a suggestion of more abundant and generally stronger acoustic targets detected in the water column in spring and closer to the bottom during the autumn (Figure 20, 21 top left). The characteristic vertical distribution of weaker acoustic targets (Figure 20, bottom right) is expected as an intrinsic property of the TS measurement method: the diameter of the beam increases with distance from the echo sounder; therefore the probability of two weak acoustic targets (e.g. two small fish) occurring within the same acoustic sampling volume increases, and increases more rapidly than for relatively strong targets (Figure 20, top right). However, there is one peculiar observation in the pattern of vertical distribution of TS detections. Apparently, there were fewer strong TS detections (-40 to -55 dB) just above the acoustic Lander (15-100 m) than higher up in the water column (Figure 20, top right), indicating that strong acoustic targets tended to be more abundant higher up in the water column.

Table 2. The LSSS acoustic target strength detector settings, as used analysing data collected with vertically-up and horizontally-sideways oriented echo sounders. The same acoustic data were analyzed using two detector setups: "Setup 1" for extracting stronger TS measurements and "Setup 2" for extracting the weaker fraction of the TS distribution.

Parameter	Settings	
	Setup 1	Setup 2
Minimum TS [dB]	-60	-80
Maximum TS [dB]	-30	-50
Min/max echo length (relative to pulse length τ)	0.8τ, 1.8τ	
Maximum phase deviation [deg.]	8.0	
Maximum gain compensation [dB]	6	
Min echo spacing [samples]	1	

The horizontally oriented echo sounder TS measurements were accepted within a range of 56 m to 260 m. The relatively distant starting range was needed because of multiple bottom detections up to about 56 m range. These were often detected and accepted as valid TS measurements. The first substantial bottom elevation was detected at about 270 m (Figure 15), which was the reason for setting the upper range limit to 260 m. Weak TS detections are better resolved as single targets when close to the echo sounder, so fewer TS detections in the range -50 to -80 dB were to be expected (Figure 21 bottom left). More TS detections from the stronger fraction of the distribution were observed close to the acoustic Lander (Figure 21, topright). This is to be expected, as single targets tend to be better resolved closer to the echo sounder. It should be noted that the number of TS detections within -30 to -60 dB close to the sea bottom were nearly twice as many as were observed by the vertically oriented echo sounder during the same period of time. The target strength measurements of the ventral and side aspects of the same fish should be compared with caution. On the other hand, vertically oriented observations indicated few strong acoustic targets in the range about 17-100 m from the sea bottom, while the horizontally oriented echo sounder detected many targets close to the sea bottom (Figure 21 top right; below 30 m above the bottom, which corresponds to the recording range up to 150 m here).

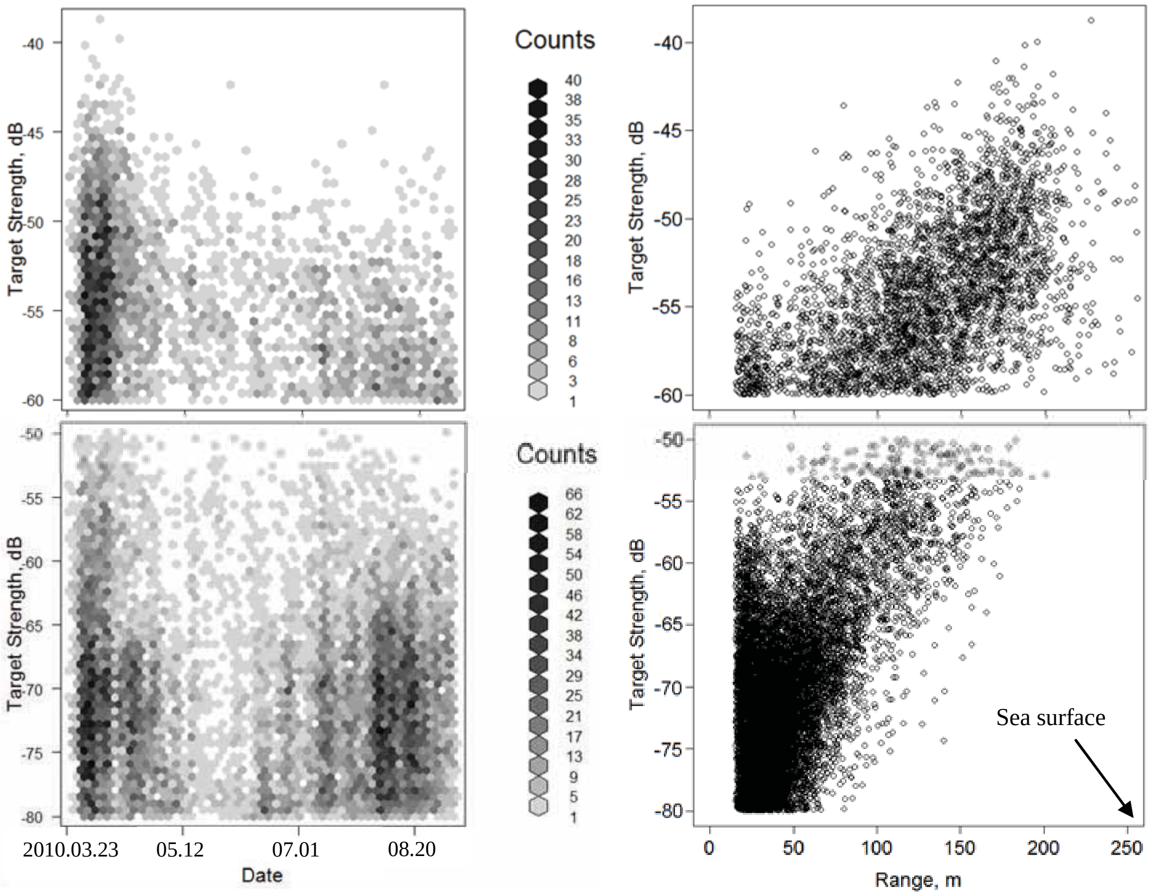

Figure 20. Vertically oriented transducer acoustic target strength measurements over time (left) and their distribution in the water column (right). Top – stronger acoustic targets (upper and lower thresholds -30 dB and -60dB, respectively). Bottom – weaker acoustic targets (upper and lower thresholds -50 dB and -80 dB). TS were measured within the 15-262 m range interval from the echo sounder. “Range” marks the height above the sea bottom.

4.3 Passive acoustics

The Naxys Ethernet hydrophone recorded at time intervals identical to the echosounders, 1 hour active and 4 hours off. Naxys Ethernet Hydrophone Manager software was used to record the sound and control the hydrophone, intending to sample with 16 bit resolution. Unfortunately, it turned out that the hydrophone had been set up for 24 bit resolution, which meant that that extensive data conversion was required. To do this we need the exact file format of the two different systems, which was not available at the time of this report. We are in contact with Naxys regarding this problem, but due to limited capacity at Naxys, the process cannot be completed within the time-frame of this reporting. We will therefore perform the conversion, scrutiny, analysis and reporting of the hydrophone data as part of the LoVe cabled observatory project.

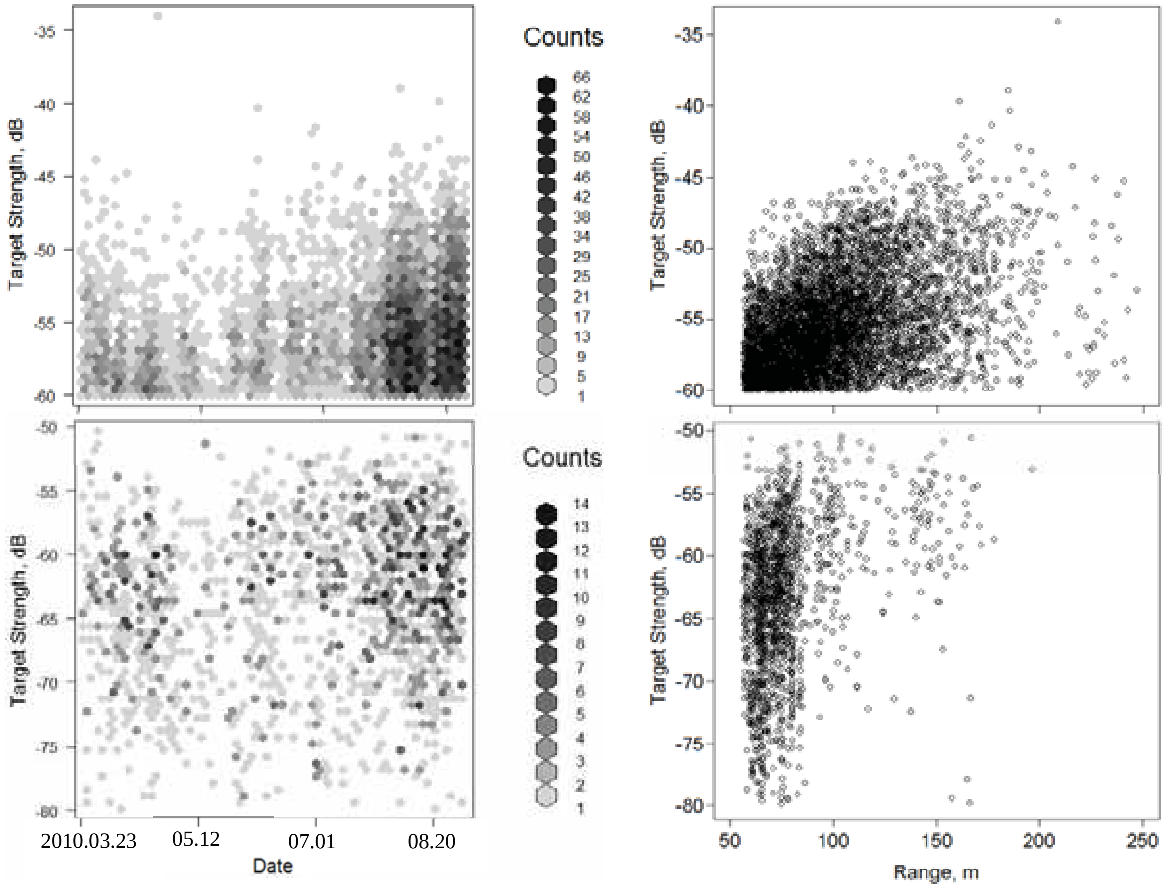

Figure 21. Horizontally oriented transducer acoustic target strength measurements over time (left) and their distribution in the water column (right). Top – stronger acoustic targets (upper and lower thresholds -30 dB and -60 dB respectively). Bottom – weaker acoustic targets (upper and lower thresholds -50dB and -80dB). TS were measured within 56-260 m range interval from the echo sounder. "Range" marks the distance from the bottom mounted echo sounder (eastwards).

4.4 Lander oceanographic data and results

4.4.1 The data

The two inverted ADCP systems installed on the Lander independently recorded continuous current profiles through the water column. While the use of two parallel current systems may be regarded as redundant, it was justified by the fact that each instrument covered a different region of the water column. Operating at a relatively low frequency of 76.6 kHz, the LR ADCP covered the vertical range of the water column to some few hundred metres above its deployment depth, but using relatively large-sized vertical bins and long time-averaging lags. The 600 kHz RDCP, on the other hand, recorded currents at much finer depth and time resolutions, but its total vertical depth range was limited to about 50 m above the deployment depth. In view of the different vertical ranges of the two instruments, this report refers to the 76.5 kHz LR ADCP observations at the Lander site as water column currents, and those obtained with the 600 kHz RDCP as currents in the bottom boundary layer (BBL).

Between 2009 and 2011, two deployments took place, each providing both BBL and water column observations. The sampling characteristics and observational periods of these two deployments, referred to as Deployment I and Deployment II, are summarised in Table 3 (see also text table on page 10).

Table 3. Sampling characteristics and deployment periods of the Lander-mounted ADCP systems between 2009 and 2011.

	Instrument	Sampling rate and ping averaging interval	Vertical resolution	Period of good data	Remarks
Deployment I	LR ADCP	15 min/15 min	1 m	17.08-12.11 2009	Quality poor. Averaging to larger time-depth bins necessary *)
	RDCP	10 min/4min	2 m	17.08-10.09 2009	
Deployment II	LR ADCP	Planned: 1 hour/20 min Recovered: 9 day/(20 min?)	5 m	21.03.2010-13.06.2011	The sampling rate in the recovered dataset was very low and not consistent with that set prior to the deployment.
	RDCP	1 hour /4 min,	2 m	22.03-28.05.2010	Good data limited to10 m nearest bottom . *)

*) See details in text

In the case of the water column measurements (Deployment I, using the LR ADCP), which started in August 2009 and lasted for the three months until November, a relatively short sampling rate was used with the vertical bins and ensemble averaging times set to 1 metre and 15 minutes, respectively. Scrutiny of the data after the instrument recovery revealed that these settings produced gaps in the record, as almost 80 percent of the data bins did not meet the quality criteria (error velocity < 3 cm s^{-1} and percent of good data >= 60). The continuous record was obtained during post processing by averaging the valid data into the larger bins of 10 m x 1 hour.

During Deployment II, which started in late March 2010, 5 m depth bins and 1 hour time lag settings were used. This deployment lasted for more than one year. Unfortunately, the data sampled at the original 1-hour time step could not be recovered due to instrument failure. The only dataset that was recovered consisted of 52 separate profiles, recorded at a rate of approximately one profile per 9 days. Although the resulting current flow patterns were consistent, the 9-day sampling rate was not deliberately set prior to the deployment. This implies that data were recorded according to an unspecified timing sequence triggered by the instrument's own electronics, which raises some concerns about the quality assurance of these data.

The bottom boundary current observations (with the use of the RDCP) started parallel to the water column observations, but the deployments lasted for much shorter periods: 20 days and 2 months for Deployments I and II, respectively. The vertical bin size was kept constant at 1 m, while the time step had changed from 10 minutes to 1 hour between these deployments.

Both the ADCP units were fitted with additional oceanographic sensors. The LR ADCP was fitted with a temperature sensor only while the RDCP also included bottom pressure, conductivity and turbidity sensors. The RADCP unit used in Deployment II also included a fluorescence (chlorophyll a) sensor.

4.4.2 Comparison with oceanographic models

Data from the Norwegian Coast 800-m model (NorKyst-800; Albretsen et al. 2011) will be used to enhance undetanding of the point data from the lander and also to show how point data can shed light on model performance.

4.4.3 Oceanographic results

Hydrographical variability near bottom

During the periods when both ADCP units were being operated simultaneously, their temperature sensors recorded virtually identical conditions, as Figure 22**,** which is based on data from Deployment I, shows. It is clear that the temperature fluctuations exhibited highly nonstationary behaviour. For instance, on August 19, at midday, the temperature rose from 7.7 to 8 °C. This was followed by three minor fluctuations within two- to three-hour periods terminated by a rise to above 8.1 °C on August 20 at midnight. Six hours later, the temperature dropped sharply below 7.5 °C. This type of temperature cycling was on virtually all examined records. The observed fluctuations occurred on a wide range of time scales and were typically characterized by longer and more stable periods of warm-water crests than cold-water troughs. Local bathymetry and stratification conditions at shelf margins often lead to highly dynamic localized physical forcing (Huthnance 1995, Kunze and Smith 2004, Thiem et al. 2006). The non-stationary temperature fluctuations observed during our observations indicated the existence of such an enhanced localized mixing at the Lander site.

The annual cycle of the nine-day near-bottom temperature at the Lander site is shown in Figure 23. The minimum temperature occurred between the end of March and the beginning of April in both 2010 and 2011, while the warmest conditions were observed in early November 2010. The observed timing of the annual cycle is consistent with the seasonal fluctuations of the thermocline that separates the Atlantic Water (AW) from the Norwegian Sea Arctic Intermediate Water (NSAIW) off Northern Norway (Mork and Skagseth 2010).

Figure 23 gives the impression that the changes in the seasonal hydrographic conditions at the Lander site occur slowly, but this is due to the fact that the nine-day subsampled data-set effectively filters out the rapid non-stationary variations as observed in Figure 22. The true pace of the seasonal change may be identified from the RDCP data gathered during Deployment II, since this data-set was collected at a high sampling rate and during the transition period from winter to spring conditions (22.03 - 28.05.2010). Figure 24 depicts the respective salinity and temperature plots. Note the threshold values indicating the transition from NSAIW to AW conditions, which are marked by the horizontal lines. This figure makes it clear that the emergence of AW at the Lander site took place rather suddenly on April 19. Thereafter, both the near-bottom temperature and salinity fields were dominated by non-stationary fluctuations of the same type as observed in summer 2009 (Figure 24).

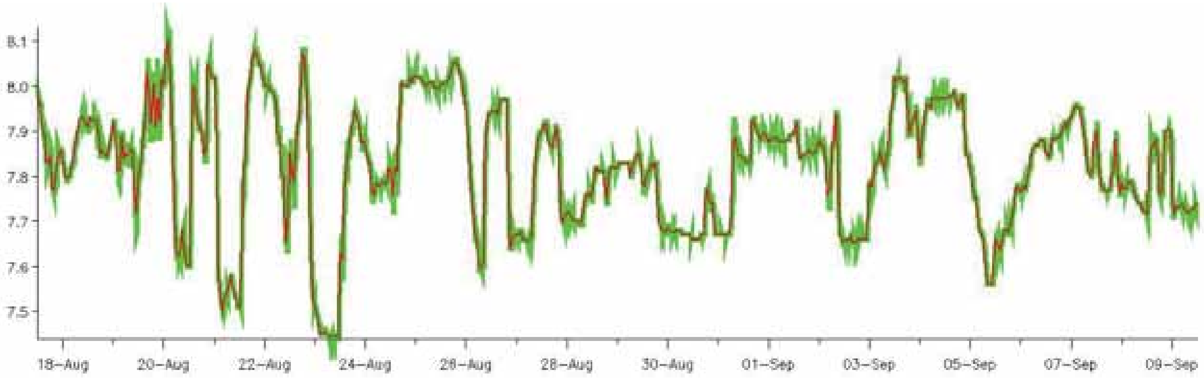

Figure 22. Comparison of near-bottom temperature recorded during 18.08-09.09.2009, with LR ADCP (red) and RDCP temperature sensors (green). The sampling rates are 1 hour and 10 minutes for the LR ADCP and RDCP, respectively.

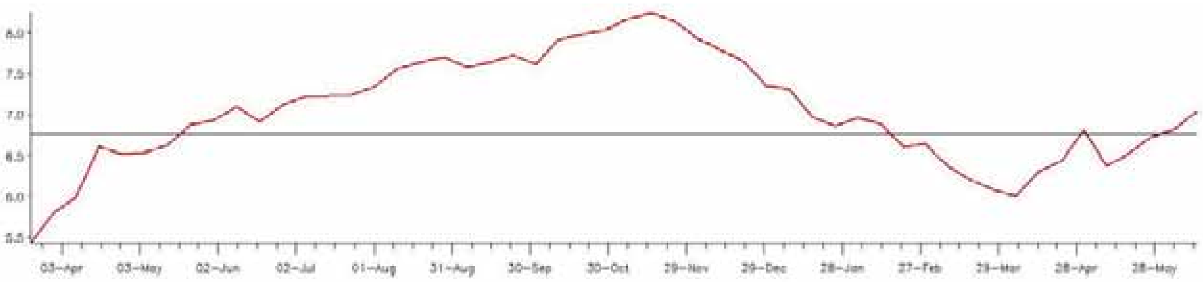

Figure 23. Evolution of the nine-day near-bottom temperature at the Lander site, between 21.03.2010 and 13.06.2011. The horizontal line denotes T=6.75 °C.

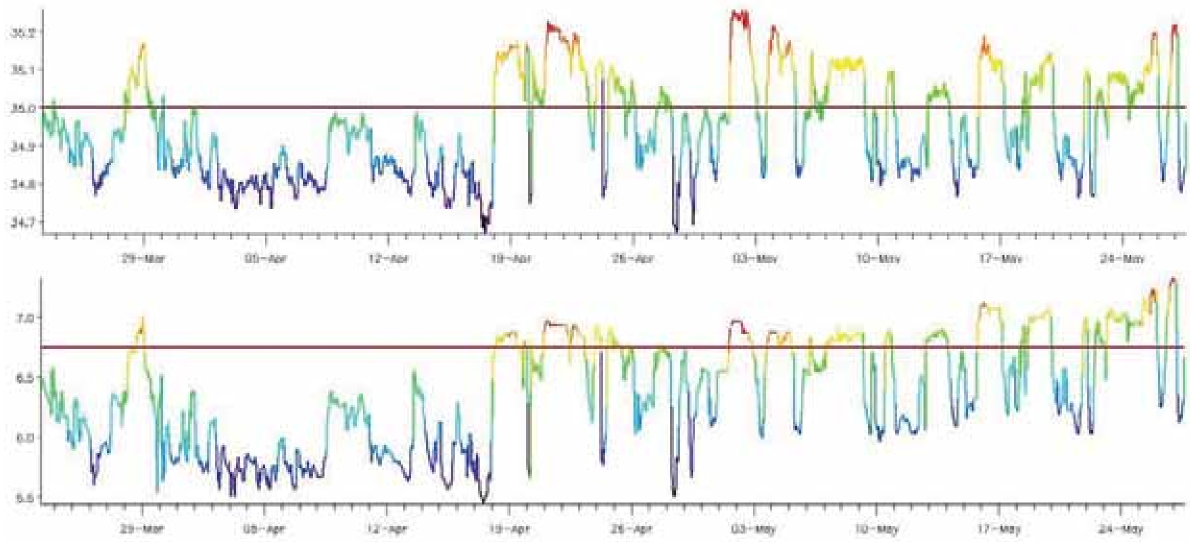

Figure 24. Evolution of salinity (top) and temperature (bottom) 23.03-27.05 2010. Both curves are colour-coded according to the salinity scale shown on the left axis in the top figure. The horizontal lines denote S=35 and T=6.75°C, in the upper and lower panels, respectively.

Evolution and seasonality of the current

Table 4 and Figure 25 summarise the seasonal characteristics of the current, based on the water-column observations during Deployment II. The strongest surface currents characterized the autumn period (OND (October, November, December)), the weakest were during the spring (AMJ (April, May, June)). Note that the vertical structure of the flow changed strongly with the seasons: during OND the surface and deep currents differed greatly in their respective magnitudes and directions. On the other hand, in AMJ the current profile matched the barotropic model quite closely (a unidirectional current and constant velocity at all depth levels). Overall, the flow was strongly westwards throughout the year, in particular in the depth range below 100 metres.

Table 4. Annual and seasonal mean current from selected depth levels, based on the nine-day LR ADCP from Deployment II.

Depth	Mean		JFM		AMJ		JAS		OND	
	V(cm s^{-1})	Dir(°)	V(cm s^{-1})	Dir(°)	V(cm s^{-1})	Dir(°)	V(cm s^{-1})	Dir(°)	V(cm s^{-1})	Dir(°)
Surface	31.6	323	33.8	335	27.6	303	30.9	339	34.7	341
50m	25.8	322	27.5	28	25.6	318	23.4	315	25.8	330
100m	23.2	311	24.7	25	25.1	312	22.0	299	21.5	311
150m	21.8	308	22.6	23	20.6	308	22.6	301	23.4	302
200m	17.3	304	17.3	17	21.0	303	18.2	301	17.0	297

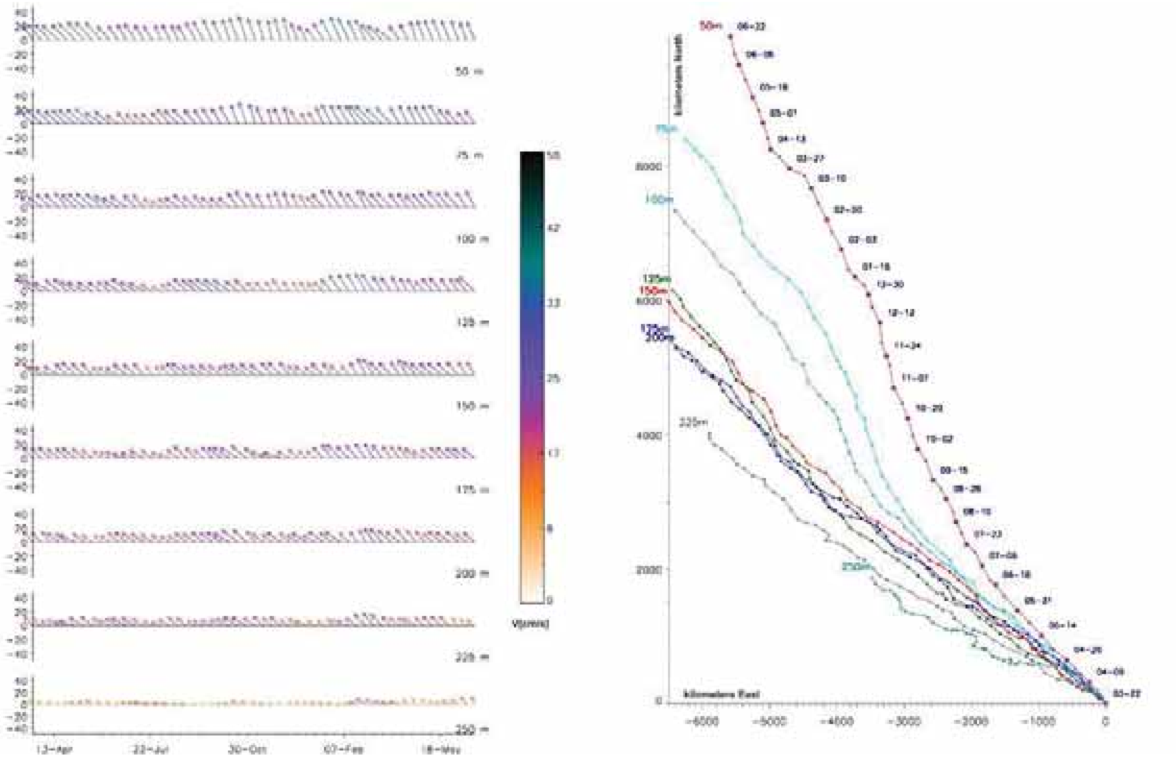

Figure 25. Stick plot and progressive vector diagram for the nine-day water-column observations during Deployment II. Both plots display current at the same depth levels between 50 and 250 m. In the left panel, the plots for each depth are stacked one on top of the other. The vertical axis denotes the northward velocity component. The vectors were smoothed with a three-point moving average and plotted for each nine-day measured current value. The colour of the arrows denotes speed of the current in cm s^{-1} according to the colour scale shown. In the right panel, the day and month are marked along the first progressive vector plot (50 m). The axes describe distance in kilometres; the negative-only distance along the horizontal axis is due to the absence of eastward (positive) current.

Topographic steering of the flow

The depth-increasing deflection of the current towards the west, observed in Figure 25, indicates that the flow is affected by topographic steering by nearby bathymetry. To the extent that the flows can be treated as barotropic, they should be steered along the contours of constant *f/H*, where *f* is the Coriolis parameter and *H* denotes the ocean depth. Topographic steering is a general feature of the circulation in the Vesterålen-Troms area (Sundby 1984), and the flow patterns observed at the Lander location would not be an exception. The degree to which the current is subjected to topographic control varies seasonally according to seasonal changes in stratification. Figure 26 demonstrates this by means of hodogram plots of the mean current during two seasons February-April (FMA) and August-October (ASO), which are characterized by very different stratification conditions. Both seasons exhibit the clear pattern of the topography-inducted anticlockwise (depth contour-following) deflection with depth. However, the directional spread of the current along the vertical profile during the unstratified season (FMA) is relatively weak. This case corresponds to the nearly barotropic profile data from Table 4. In contrast, during the stratified season (ASO), the current direction veers broadly with depth from an almost northwards flow at the surface to northwestwards at 180 m. Below this depth, the flow is maintained in the northwestward direction at all depth levels. Note that the top plateau of the southern Nordgrunnen wall is located within the same depth range. As the Lander site is located close to this wall (Figure 28, top), the nearly fixed direction of the current observed in Figure 27 below 180 m is probably indicative of the westward current attached to the abrupt topography in a manner similar to Taylor Cone flow patterns, typical of seamounts (Chapman and Haidvogel 1993). The observed stronger decoupling of the current in the upper layers from the topography-guided current below during the autumn is consistent with other observations made off Northern Norway (Skarðhamar and Svendsen 2005).

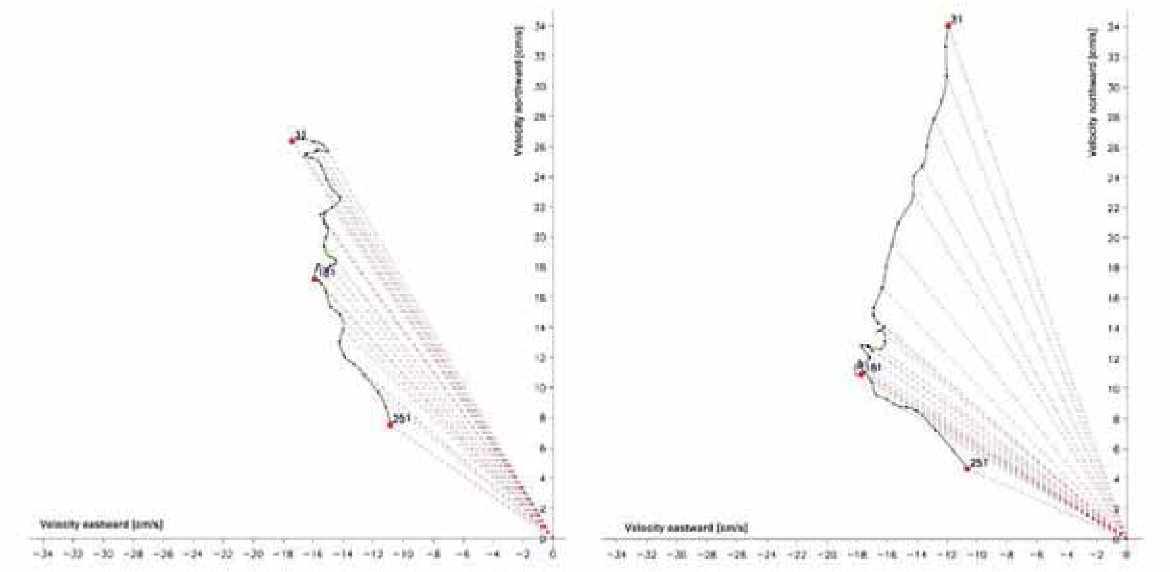

Figure 26. Hodograms (curves drawn by tips of current vectors at consecutive depth levels) of the mean seasonal flows during FMA (left) and ASO (right). The hodograms are marked by the green lines. Selected depth levels: 31, 181 and 251 metres are marked with the red dots. The broken lines denote the current vectors for each ADCP bin measured; all originating at the same velocity coordinate origin (0, 0). The horizontal and vertical axes denote the eastward and northward velocity components in cm s^{-1}. Only the negative (westward) and positive (northward) branches are shown for the horizontal and vertical coordinates, respectively.

Model predicted currents at the Lander site

Figure 27 shows an evolution plot and progressive vector diagram that depicts the results of current predictions obtained with the NordKyst-800m model (Albretsen et al. 2011). The deflection of the simulated flow to the west, which increases with depth, (Figure 27, right) manifests the strong topographic control of the flow by the elevation of Nordgrunnen, which is a similar feature to that revealed by the observations (Figure 25, right). In other respects, the simulation result clearly differs from the observed currents. The simulated flow veers clockwise by some 40 degrees from the observed current. The speed distribution of the simulated flow is more uniform with depth, resulting in noticeably stronger currents near the bottom. A comparison between the topography used in the model and the high-resolution multi-beam bathymetry of the Lander site area (Figure 28) suggests a reason for these contrasts. The Lander site is located close to the steep promontory of the southern Nordgrunnen edge (Figure 28, top). The flow conditions in such a location would be dominated by highly localized effects of physical forcing and abrupt topography on metre scales (Lavelle and Mohn 2010). For this reason, the precise conditions at the Lander spot could not be reproduced using the model forced the topography with the grid node size of 800 m. Nevertheless, on larger spatial scales, the simulation produced a realistic representation of the bottom-layer circulation within the Hola Trough. For instance, the orientation of the direction of the model current to the north of the Lander position (Figure 28, bottom) appears to match the observational data better. The overall expectation is that this simulation produces realistic results except in regions with abrupt topographies, such as the vicinity of the Nordgrunnen wall examined here.

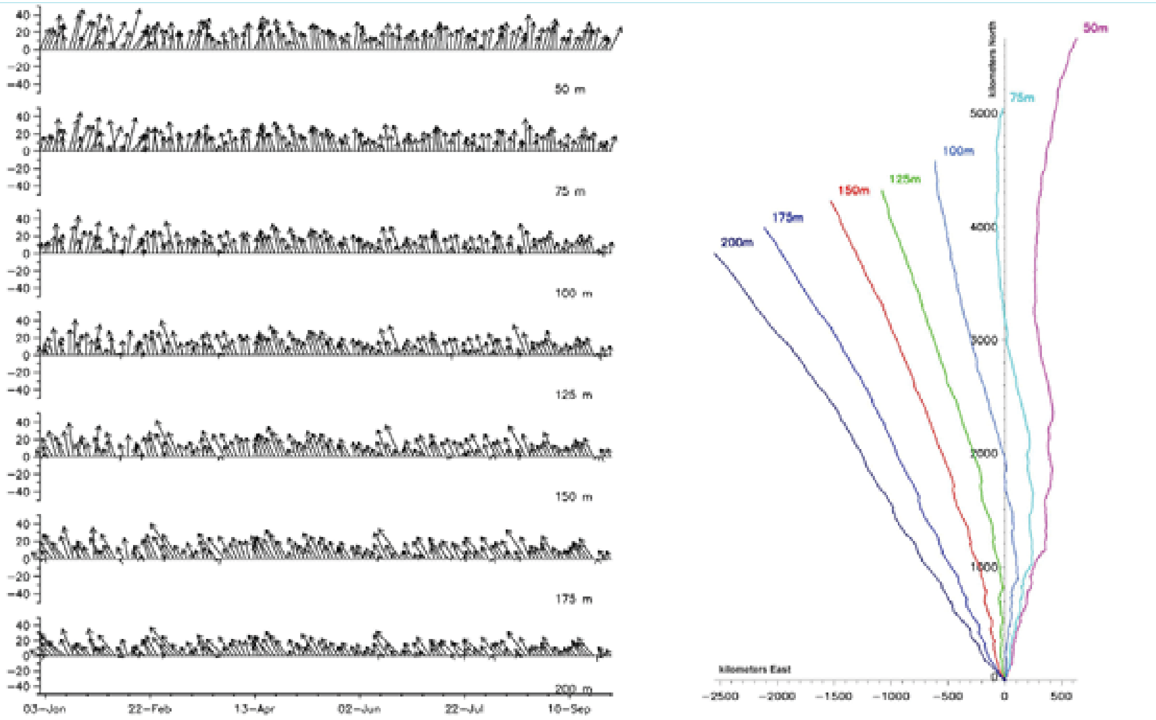

Figure 27. Stick plot (left) and progressive vector diagram (right) of the simulated current in the NordKyst-800m model. Simulation period: 1.01-1.10.2010. . Both plots display current at the same depth levels between 50 and 200 m. In the left panel, the plots for each depth are stacked one on top of the other. The vertical axis denotes the northwards velocity component. The original hourly vectors smoothed with the 24-hour running mean moving average and decimated by 24 hours.

Data from the near-bottom chlorophyll and turbidity sensors were analyzed but are not presented here. Chlorophyll was measured during Deployment II only. All recorded data indicated zero chlorophyll concentrations. This is an expected result, as the instrument was located beyond the depth range of light penetration; too deep for primary production to occur. The turbidity measurements indicated clear water conditions (< 0.1 nephelometric turbidity units or NTU) during both observational periods.

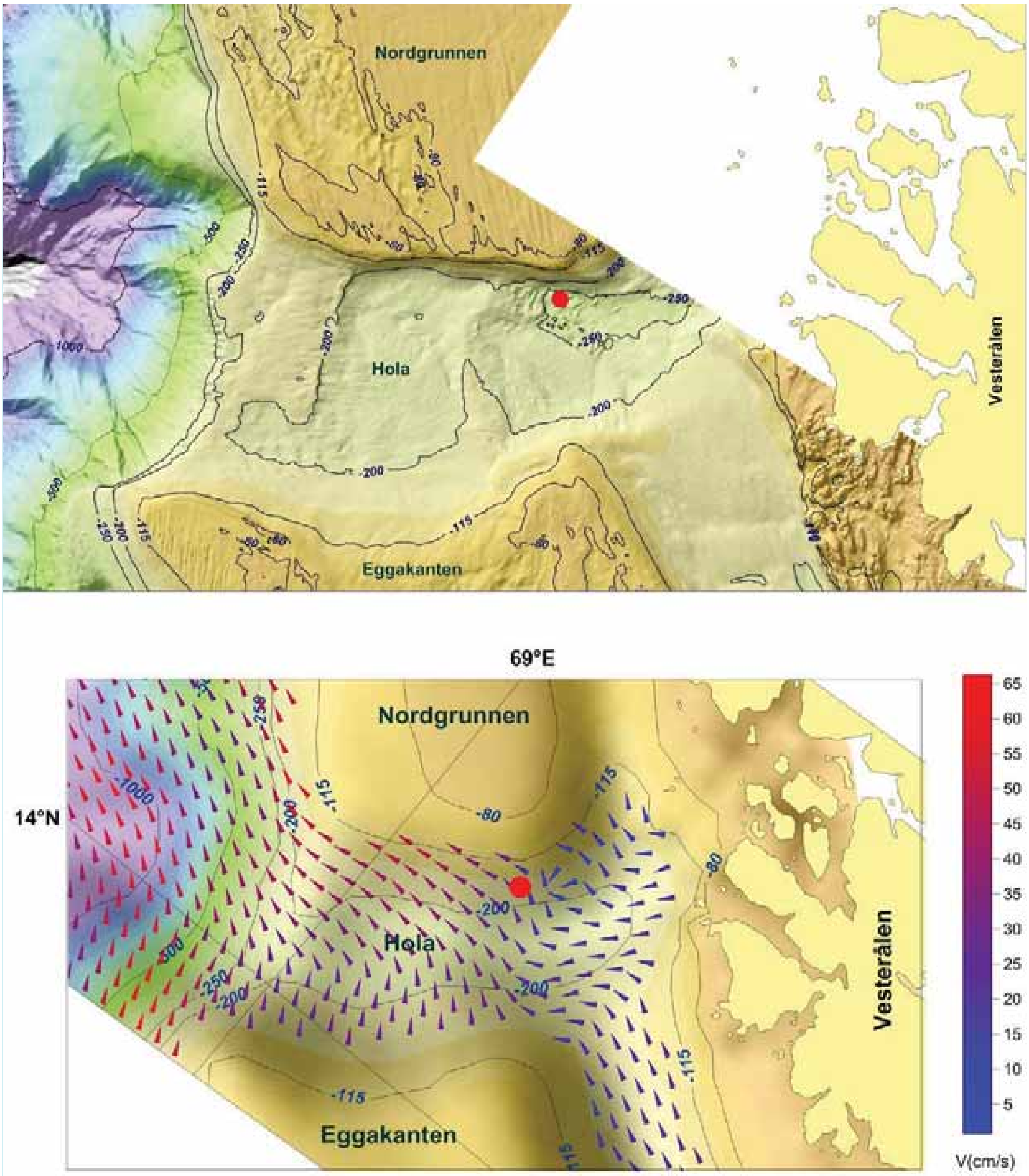

Figure 28. High-resolution multi-beam bathymetry at the Lander site (top) compared with the NordKyst-800m simulated current at the depth of 150 m on 11 Feb 2010 16:00 (bottom). The position of the Lander is marked by the red circle. The triangles denote the direction of the current. The speed is represented by the colour scale. Both maps in UTM 33 projection rotated 30 degrees anti-clockwise from the north. The multi-beam bathymetry data was derived from xyz data courtesy of the MAREANO project. The modelled bathymetry and current were retrieved from the NordKyst-800m output and reprojected. The resolution of the reprojected map is 1.6 km –half of the original resolution used in the model.

4.5 Supporting vessel data

4.5.1 Acoustics

The acoustic data from research vessels have been used to answer three questions:

1. Are the vertical distributions seen from surface and from bottom similar?
2. How representative is the platform location compared to the area around it?
3. How can we use vessel information to interpret stationary information?

Data sets from the individual cruises (see 3.2.3) are from different time periods and, thus, are not comparable. They all need to be analysed and compared to density distribution patterns at the Lander location during the same time period. Not surprisingly, we found that the data from 'Location' coverage were more comparable to the Lander data than data from 'Area' coverage. Examples of both types are shown below.

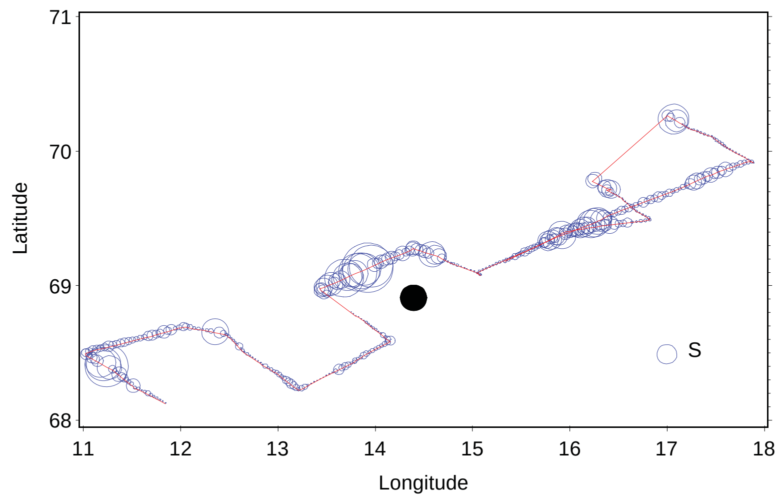

Figure 29. Survey grid of G.O. Sars during April 17-19 relative to Lander position (black dot). Bubbles indicate geographical variation in acoustic density of pelagic fish distribution (bubble marked S represents s_A=1000).

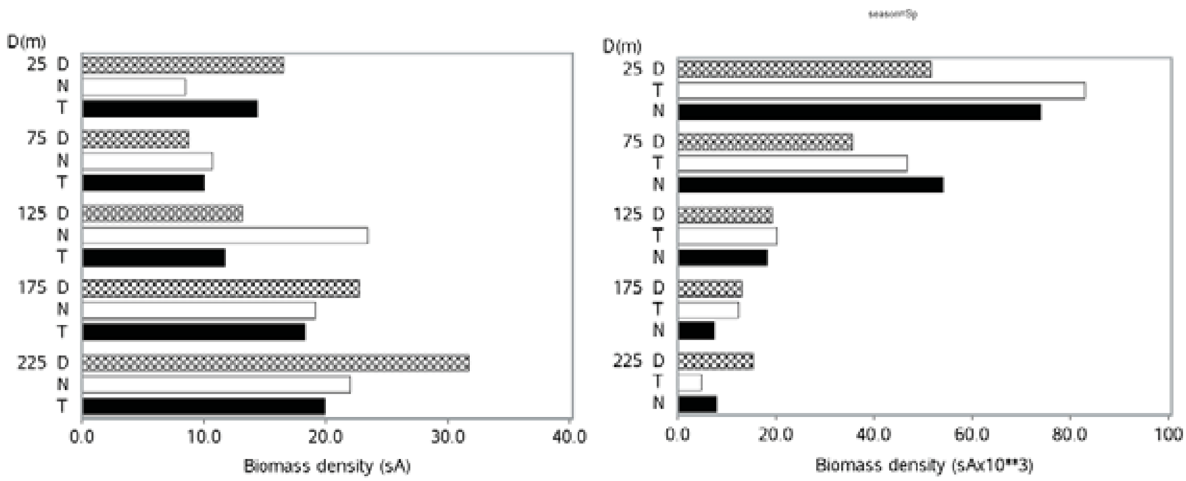

Figure 30. Comparison of vertical distribution over the diel cycle for research vessel (left) and stationary system ght) on 17-19 April. Only data between longitudes 14 and 15 were used.

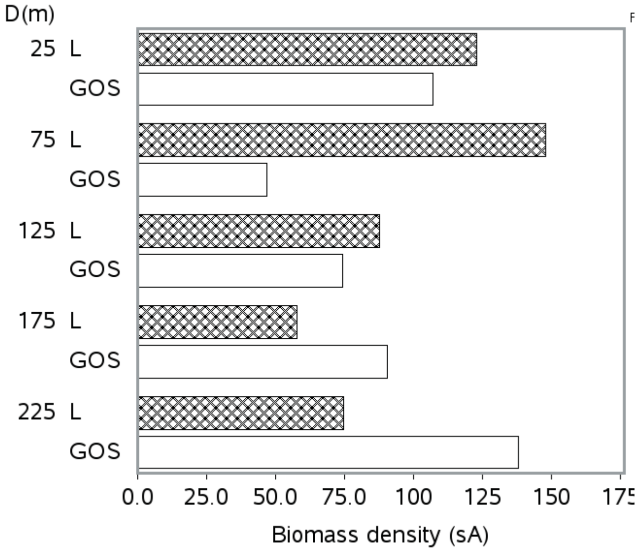

Figure 31. Comparison of vertical distribution from the Lander and R/V G.O. Sars in April 2010. Only data between longitudes 14 and 15 were used.

R/V G.O. Sars covered the Lander location on 17-19 April (Figure 29). The data from this track were compared with stationary data during the same days (Figure 30; 31). The Lander and vessel data can be compared in relative terms only because of the difference in scaling of the echo integration; vessel echoes were integrated over distance while Lander data were integrated over time. It is interesting to note that the highest biomass density was observed at the surface when viewed from the bottom, while this peaking density is apparently lost by the vessel. This is easily explained by the depth of the vessel's transducers, which caused integration to start at a depth of 12 m. A similar effect seems to apply to the bottom biomass, as echo integration values from the vessel peak at the bottom, where the Lander data are at a minimum. No diel dynamics are apparent in either of the data sets (Figure 30). Although the same trends are seen in the Haakon Mosby data (Figure 32, Figure 33) the impression is that 'Location' data are more comparable to the Lander data than 'Area' data.

The main lesson to be learned from this comparison is that near-boundary (surface and bottom) data will always involve substantial errors. Bottom-mounted systems can become a tool for identifying and evaluating errors in standard vessel-based surveys, caused by the surface blind zone (Aglen 1994). In the Lander case we have a bottom blind zone for which we hope to be able to compensate by using data from the horizontally pointing transducer. Dedicated vessel experiments should be run comparing vessel acoustics with the results from the horizontal beam with the aim of developing procedures for near-bottom biomass compensation. Moreover, more systematic vessel-based horizontal coverage, e.g. by repeatedly covering the same transect over the Lander in the course of the annual cycle, would give a better understanding of spatial variability in relation to the Lander results.

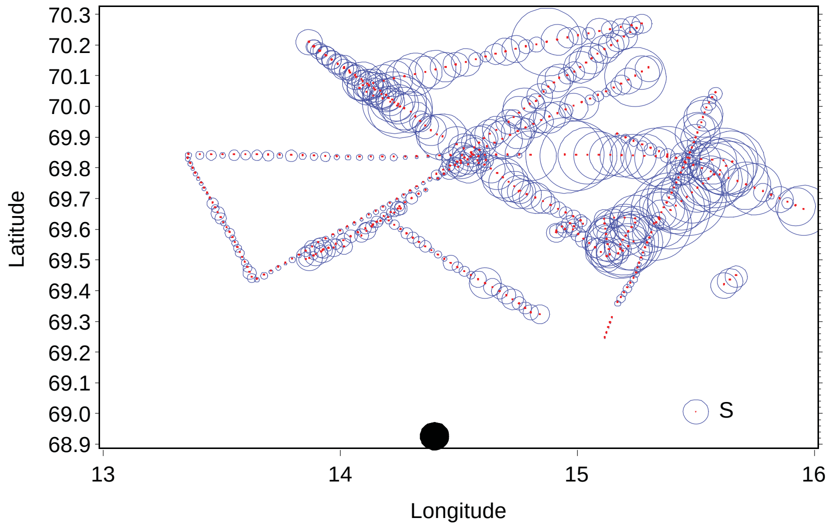

Figure 32. Survey grid by R/V Håkon Mosby in a neighbouring area to the observation platform during July 10-16 2010. Bubbles indicate density distribution of mesopelagic fish(bubble marked S represents s_A=100. Dot shows position of Lander.

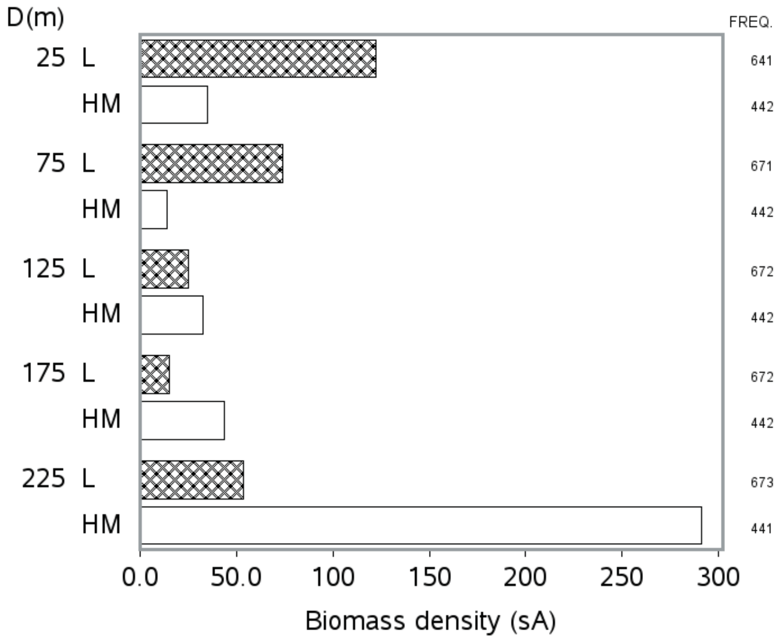

Figure 33. Comparison of vertical distribution of biomass observed by the stationary system (L) and R/V Håkon Mosby (HM) during the July cruise.

4.5.2 Net sampling from research vessels –how to identify acoustic targets?

Single-frequency acoustics gives poor information about species composition. In standard Norwegian survey practice (Jakobsen et al. 1997, Toresen et al. 1998), characteristics of the recordings as seen on the screen are used to distinguish between species, but net sampling is regarded as a basic need while continuous acoustic target evaluation supports the scrutiny process between net stations. In our case, net sampling was available on an *ad hoc* basis to support our acoustic sampling. Furthermore, these samples were mostly taken at various distances from the Lander position, which reduced their value in the scrutiny process.

In March only shrimp trawl catches are available. These catches (Table 5) were taken at some distance from the Lander (Figure 7) and at bottom depths much shallower (140-220 m) than the Lander position, thus reducing their comparability with the Lander data.

However, the deepest station in Table 5 indicated substantial numbers of Norway pout (*Trisopterus esmarkii*). This fits with the recording we see on this echogram, while large cod and haddock targets are not apparent, although these species were present in the catches. The same indications are given by the horizontal transducer during the same period.

In April, IMR carried out a herring larvae survey (Figure 4). Both the gears used demonstrated that herring larvae were present in substantial quantities in the Lander area. There was a tendency for densities to increase from south to north, so there were no indications that larvae accumulate in the Lander area. As these herring had not yet developed swimbladders, they produced very weak reflections at 38 kHz. As expected, we were unable to find signals in the echogram that could be distinguished from other planktonic targets as herring larvae. During the spring there were always some pelagic recordings in midwater, as shown in Figure 34.

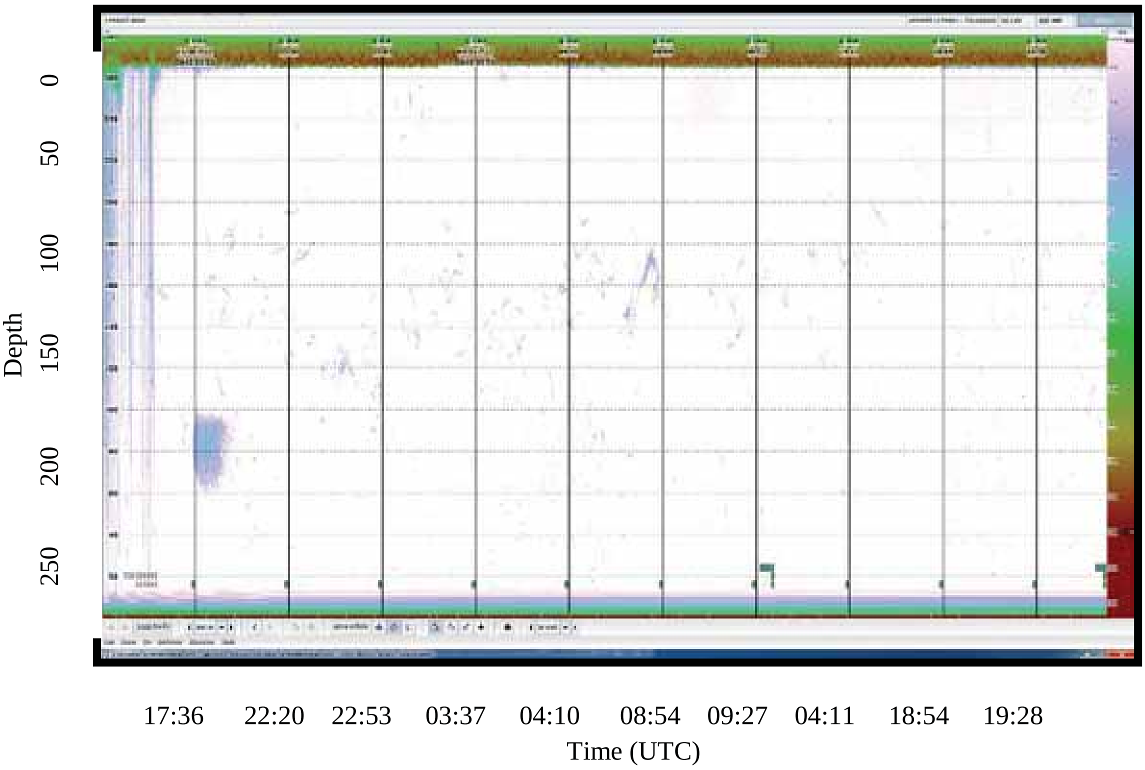

Figure 34. Echogram from the period immediately after deployment (causing the noise at start), showing some pelagically distributed fish at depths of 100-250m.

The pelagic trawls taken in late summer demonstrated herring, mackerel and 0-group fish (Table 5). The associated echogram from the Lander demonstrated relatively weak echoes of schooling fish (Figure 35). As the herring is a swimbladder fish with high target strength giving very strong echoes at 38 kHz, we identified these targets as mackerel, a species without swimbladder which gives weak echoes at 38 kHz. When tidal waves approach the shelf internal waves are created (Figure 35). These set up large vertical transportation and mixing of marine life as shown in the figure, but although this phenomenon is well known (Farmer and Armi 1999, Grue 2005) quantitative ecosystem impacts are poorly documented in the literature. Acoustic observation techniques using ADCP and calibrated echosounders represent an approach that might shed light on this important phenomenon for marine production in coastal areas. The pelagic trawl in deep water taken in July produced substantial numbers of fish like silverside and blue whiting. The acoustic targets in midwater (marked Silverside) and close to bottom (marked Demersals) were comparable to what would be expected from these species.

The commercial catch samples from the neighbouring areas were mostly taken too far away or at too different depths to be comparable to the echograms of the Lander (Figure 8, Table 6). The dominance of commercial species like cod, saithe and haddock in these catches indicates that these species were not distributed in the Lander area this year. This could be due, for example, to the hydrographical conditions. For example, the distribution of skrei (mature oceanic cod) follows the influx of Atlantic water, but this influx to the Lander position probably arrived too late (late April) for the fish to use Hola for spawning in 2010 (see 4.4, Figure 24).

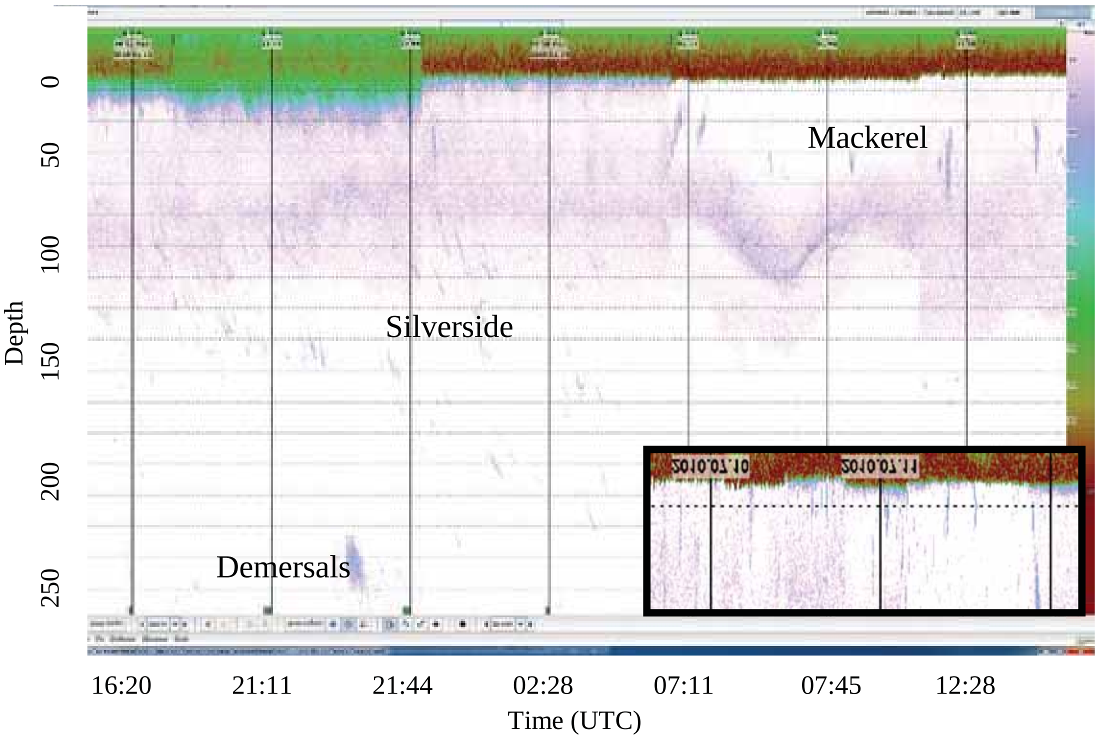

Figure 35. Echogram from July 12-13 2010. Mackerel, a species without a swimbladder, is weak on the echosounder at 38 kHz. The targets in the upper right part of the echogram show weak schools that we scrutinize as mackerel. Similar targets were found very close to surface during this period of the year (inserted example from the upper 20m taken from previous day) sometimes out of reach for vessel acoustics. Also note the internal wave depressing the plankton biomass almost 50m during about 30 minutes between 07:11 and 07:45 UTC.

4.5.3 Larvae sampling by University of Nordland

Sampling during the spring showed concentrations of larvae in both the Lander area and the reference area (Figure 5-6). The vertical distribution indicated peak densities in the upper 50 m and closer to the surface during night than the day (Figure 36). Close studies of near-surface recordings revealed no targets that could be identified as fish larvae. This is not unexpected, as the larvae at this stage have yet to develop a swimbladder. Their contrast with seawater is small and is easily mixed with other plankton reflections.

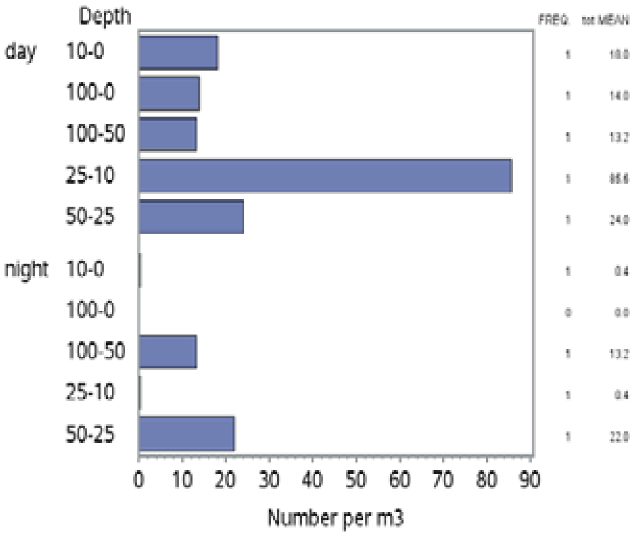

Figure 36. Vertical distribution of larvae in early April 2010.

4.5.4 Echograms and oceanographic measurements

Physics shapes ecosystems. In Figure 35 we showed that an internal wave (soletone) can be imaged by acoustic techniques because recorded organisms are structured by the wave form. Current direction and velocity can be observed when particles or small organisms are moved passively by currents. The echograms from the horizontally pointing transducer are replete with such examples. These data will be used in target tracking, where position and movements in the beam can be estimated with high precision over time. These data are essential information for understanding animal orientation in relation to currents. Passive particle movements can also be used as a proxy for water movements. A set of echogram examples is presented in Appendix 1.

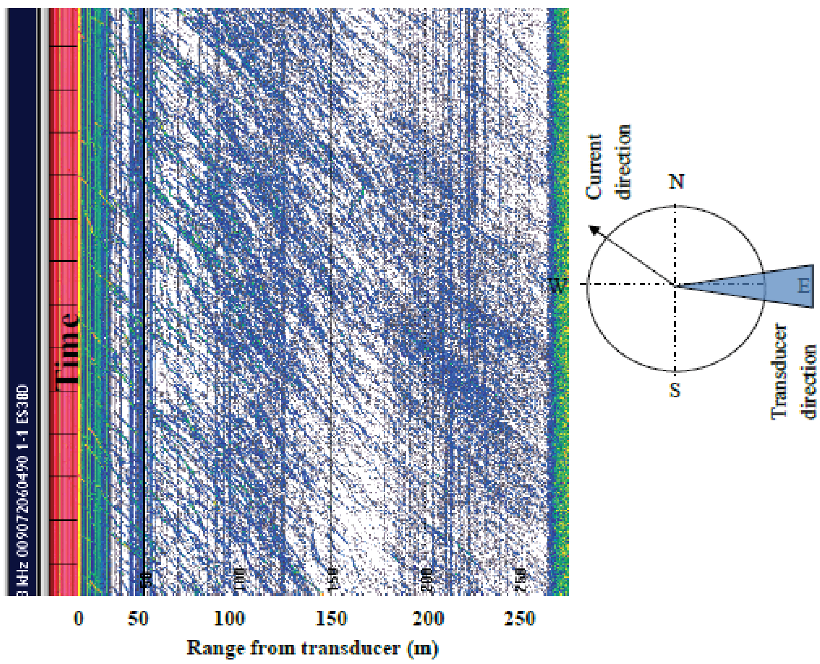

Figure 37. Echogram (left) of individual organisms passively moved towards the transducer by the prevailing current direction. The right panel shows the transducer orientation towards the east while the prevailing current runs towards northwest (~300°) creating the systematic line pattern seen in the echogram.

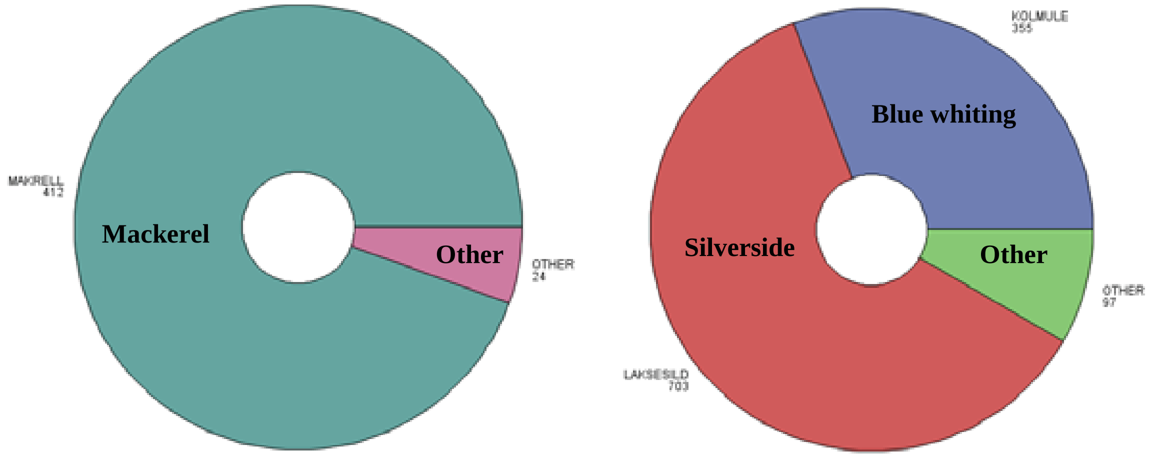

Figure 38. Examples of species compositions in pelagic trawls at the surface (left) and at 250m.

4.5.5 Sampling from commercial fishing

Samples from commercial catches taken by various gears showed that fishing is taking place at distances to the Lander (Figure 8) making it difficult to do any comparison between commercial catch data and echo sounder information.

5 Synthesis

Marine ecosystems are in general monitored annually with standardized routine surveys using sampling gears and instrumentation according to the target species survey objectives (Gunderson 1993, Simmonds and MacLennan 2005). Such surveys depend on the relative stability of target species with respect to distribution and migration. Furthermore, along the ship's track, temporal and spatial variability of stock properties are mixed so that changes are impossible to adjust for in quantitative terms during assessment (Hjellvik et al. 2002a, Hjellvik et al. 2004, Godø et al. 2005). Observatory technology records ecosystem properties with true temporal resolution, but suffers from spatial limitations. However, as temporal variability is often as high as spatial (Hjellvik et al. 2002b), observatory techniques may well contribute to resolving the problem of time variability in marine surveys. Furthermore, the observatory approach provides a tight connection between environmental and biological data, thus supporting our understanding of the processes involved in physical forcing on ecosystem components. Finally, stationary acoustic data offer behavioural details of the insonified animals (Onsrud et al. 2004, Kaartvedt et al. 2005). This report does not aim to exhaust the full potential of the material from the 2010 mission, but rather to put the results into a context where the technology and operational experience, as well as the scientific outcome, may help us to understand this key location along the coast as well as enlighten our planned operations with a cabled system in the years to come. The following paragraphs evaluate the results in terms of the defined objectives of the project.

To establish an autonomous multisensory platform with emphasis on acoustic technology that enables simultaneous data collection of zooplankton and fish and some of the major physical drivers regulating their distribution

The Hermes Lander project was established with multiple compelling aims. The first and most basic aim was to establish an autonomous multisensory platform with emphasis on acoustic technology. The vision, based on earlier scattered experiments, was that such systems will allow simultaneous data collection of zooplankton and fish and some of the major physical drivers that regulate their distribution. Furthermore, we envisioned that data acquisition of this sort may contribute to fundamental new knowledge, as well as to a renewal of approaches to ecosystem monitoring. After substantial effort and trial-and-error experiences, IMR has fundamentally enhanced its basic competence in building and operating observatories, which would not have been possible without the strong interest and financial support of Statoil. The experience and technology gained in the course of the project have been commercialized through a spin-off company, Marin Ecosystem Technologies AS (www.metas.no), which should strengthen further development and operations in the future. Our operational experience clearly demonstrated that long-term operation should not be performed in such rough areas with equipment that has only been tested for short-term experimental missions. Systems can be built as multiple-sensor systems and operated with their sensors integrated into a common platform. The initial failures (3.1.1) were mainly due to time constraints, as the equipment was assembled at the last minute and did not undergo comprehensive testing prior to launch. Lesson number one is that observatory complexity should not go beyond what can be thoroughly tested before field operation. It is of utmost importance that the LoVe cabled observatory is developed with this experience in mind.

To collect information over an annual cycle to capture variability and trends in physical and biological variables, with particular emphasis on distribution of biomass in the coral reef neighbourhood and factors of importance for the establishment and further development of cold-water coral reefs (i.e. production and hydrodynamics)

The power supply supported data-acquisition over various time periods and seasons, but the aim of covering a full annual cycle could not be fulfilled. Nevertheless, the data adequately reflect the dynamics of the area over three out of four seasons, and offer a first insight into temporal variability in its physics and biology. The pelagic and bottom habitats in the Hola area have certain characteristics that distinguish the location of the Lander from surrounding waters. First, as the name indicates, the bottom depth is larger. The oceanographic conditions indicate strong currents whose prevailing direction is to the northwest. The pelagic habitat may well be dominated by a permanent or semi-permanent eddy. The observed current pattern contradicts model predictions, underlining the high complexity of the physical environment. As described in sections 2.2 and 2.3, the bottom habitat is typified by cold-water corals. The original plan was to launch two platforms, one in the Hola area and one west of Hola. This design would have given us a much better basis for understanding the coral habitat in Hola, and would have provided some perspectives on the local spatial variability. Moreover, visual monitoring of one of the reefs with a time-lapse camera, if realised as planned, would have provided information about coral behaviour in relation to the physical and biological environments. These are important shortcomings that must be compensated for in the new cabled system. This is the most plausible way to respond to the requirements set by the second objective of our report.

The echosounder sampling horizontally was not positioned in an optimal manner in relation to the coral reefs. At a range of 300 m, the horizontal beam theoretically sampled from slightly above the seabed to about 50 m above it. Just as importantly, the precise pointing direction was not available, just roughly determined visually by the ROV operator, leaving us unsure about the coverage of the beam relative to the coral reefs. It is therefore difficult to directly evaluate the formation of schools of fish as a response to coral reefs; for example redfish and fish larvae. As a result, it is difficult to draw firm conclusions regarding whether schooling fish use the Hola reefs as habitat. However, the Hermes Lander was a first attempt to apply stationary hydroacoustics techniques to the study of possible relationships between cold-water corals and fish. The high temporal resolution of the data represents a unique opportunity to study seasonal variations in the use of a deep-water coral habitat by fish.

ROV video surveys of CWC sites around the NE Atlantic have shown that adult fish of several species occur more frequently in CWC habitats than in nearby habitats without corals. These include species such as *Trisopterus minutus*, *Pollachius virens*, *Sebastes viviparus*, *Brosme brosme Lepidion eques* (Costello et al. 2005), *Neocyttus helgae* and *Guttigadus latifrons* (Soffker et al. 2011). Fishing experiments with long-line and gill-nets on the Norwegian shelf showed that adult *Sebastes norvegicus* occurred more abundantly in CWC habitats than in habitats without corals (Husebø et al. 2002). The species observed in these surveys are all widely distributed in the region (Whitehead et al. 1986), and contrasting results yielded by other studies indicate that the usage of CWCs as a habitat is of a facultative nature. As opposed to the finding of Costello et al. (2005), Husebø et al. (2002) recorded equal abundance of tusk on CWC reefs and in nearby habitats without corals, and Soffker et al. (2011) recorded equal abundance of *Lepidion eques* on and off coral.

There are several reasons why CWCs can be important habitats for fish; for example, they may offer protection from predators and the reef-associated invertebrate biomass is high, which make CWCs attractive as foraging areas. CWC habitats may also function as nurseries, and breeding and spawning areas for fish. Fosså et al. (2002) observed presumably gravid females of *Sebastes norvegicus* in close association with the corals at the Sula reef complex. So far, there have been no other reports of gravid *Sebastes* on *Lophelia*-reef.

The acoustic data showed that the biomass of fish in the monitored depth layer was very low. No aggregations of larvae or juvenile fish were detected on the echograms. However, due to the uncertainty of the volume covered by the echosounder in relation to the coral reef, we cannot rule out that, for example, *Sebastes* schools close to the reefs.

Low fish biomass in the near-bottom layer is consistent with the results of recent large-scale surveys performed using hull-mounted echosounders on the Norwegian and Icelandic continental shelves. These studies indicated that large populations of fish detectable with acoustics are not particularly associated with CWCs (Kutti et al. 2012). The largest aggregations of *Sebastes* spp. seem to occur in association with topographic features such as the shelf break or rocky outcrops, rather than in association with CWC reefs. *Sebastes* also forms smaller, loose aggregations around and above coral mounds, but equally often on flat seabed that lack habitat-forming species such as corals and sponges. Similar small shoals and aggregations of *Pollachius virens* can be observed around coral mounds. However, from the acoustics it is evident that on a larger spatial scale, *P. virens* is not associated with either the corals or any other large-scale topographical features, as the largest echo registrations are found on the banks. This is as expected because *P. virens* is widely distributed in the region (Olsen et al. 2010), and is only partly associated with the benthic system (Bergstad 1991). Clear differences in fish abundance between repeated sampling events at the same CWC sites indicated that other factors (such as migration and food availability) may have a stronger influence on fish distribution than the seabed habitat. The data from this study also showed that the fish biomass was slightly higher in the autumn, although it remained low in the near-bottom layer. Our vessel data also confirmed the observed low densities in the bottom layers in the neighbourhood of the Lander.

Our data have revealed atypical biomass distributions and dynamics that are important for the choice of strategies and hypotheses for the development of the cabled system. Clear seasonal trends in the data were found, indicating that spring and autumn host the highest standing stocks. Furthermore, and most surprisingly, no clear diel trend was detected in the data, with respect to either vertical migration or density. This must be linked to the chaotic physical environment, but is definitively an issue that needs further attention.

To evaluate the collected information and propose further development and improvement of the approach.

The Hermes Lander system produced information with high temporal resolution at a fixed location. Nevertheless, the outcome leaves us with several new questions and unresolved issues that need to be taken into account in the technology and design of the new cabled system. First, no accumulation of biomass in strong association to the coral reefs was recorded, but system limitations prevented strong conclusions to be drawn. The original design had a movable transducer that could scan over the coral reef area and thereby map distribution patterns at given coordinates. It is absolutely necessary to establish this design in the permanent observatory, in order to permit detailed mapping of biomass in relation to bottom habitat features.

To evaluate coral reef dynamics in relation to the physical environment it is absolutely necessary to establish high-quality photographic techniques, preferably stereo photo-grammetry, in order to improve distance estimates and object sizing. Earlier monitoring of coral reef with a time-lapse camera has already demonstrated the potential of such techniques (Tenningen 2011). A combination of visual and acoustic data with high spatial and temporal resolution and correlated with environmental observations (light, temperature, salinity, currents, etc.) will enable us to substantiate information of importance to our understanding of coral reef welfare and development.

The oceanographic situation in Hola is affected by surrounding waters and seems to be an area of water mixing (see 4.4.3). When the area is influenced by Atlantic water during cod spawning, for example, cod might follow this preferred water mass and congregate at the location of the Lander as was observed during the March 2009 cruise (unpublished material). This apparently did not happen in 2010 early enough to trigger an influx of spawning cod. Similarly, the presence of other oceanic fish species probably depends on the physical environment at the time when they pass Hola. The Hola observatory's impact on studies of migration and distribution of adult fish will depend on studies of a larger area, either by extending the observatory towards the west (see below) and/or systematically using vessels to gather complementary information about fish densities and environmental conditions around the observatory. Therefore, we have already started discussions and planning of how we can involve IMR vessel effort in the short term to collect data along a transect through the observatory position to deep waters off the shelf and, in the longer term, extend the cable and number of sensor locations to do the same thing automatically.

The potential for the observatory acoustics to observe and monitor young of the year fish and their behaviour has aroused a great deal of interest, as exemplified by Johansen et al. (2009). The echograms have been studied closely for this purpose, without being able to confirm that larvae were seen during March-May period. This is as was expected, as larvae are small and without a gas-filled swimbladder until the second half of May. The lack of adequate sampling later in the summer prevents us from drawing any conclusions regarding this issue. On the other hand, without net sampling it might be difficult to be sure how larvae appear on the echograms during the season. We therefore strongly recommend direct sampling of the echosounder sampling volume as a learning process to enhance automated identification in the future. Such automation must be linked to acoustic data over a greater acoustic bandwidth, as is planned for the new cabled observatory. IMR will plan several visits to the observatory location during 2013 in order to ensure the acquisition of sufficient biological material as part of this process.

The establishment of cold water coral (CWC) colonies and the further development of CWC reefs are hypothesised to be strongly regulated by food supply (vertical or horizontal flux). The few studies that have been performed tracing the origin of CWC food items using fatty acids and stable carbon and nitrogen isotopes suggest that the corals feed on fresh phytodetritus (Duineveld et al. 2007), zooplankton faecal pellets (Duineveld et al. 2004, Duineveld et al. 2007), and zooplankton (Kiriakoulakis et al. 2005). Some CWC reef systems are known to occur in areas with enhanced phytoplankton productivity (White et al. 2005, Duineveld et al. 2007). Linking primary and secondary productivity and CWC occurrences is difficult using the low temporal resolved data generated by ship based surveys. The LoVe observatory offers a unique chance to bridge this knowledge gap and quantify the link between corals and zooplankton. Using multiple senor observations and including high frequency acoustics with cm and second resolution suitable to measure zooplankton clusters in the water column over all seasons. New knowledge will be generated by combining information of zooplankton densities in the bottom boundary layer with the coral polyp feeding activity gained from time–laps cameras.

This report demonstrates that Hola is a habitat that stands out from its surroundings. The Lander was originally designed as a coral reef observatory, and this will be a major task also in the future. Observatory technology is indeed a key to collecting information about interesting and vulnerable habitats. For example, there is a pock-mark area with a methane seep south of the coral reef, and the University of Bergen wishes to attach an observatory to our LoVe cable. Continuous data from these two locations will in combination generate new knowledge about the dynamics of these habitats. On the other hand, if the idea is to collect data for studies of water and biomass flux back and forth to the Barents Sea through this narrow shelf area, there is a great need to extend the observation framework. We plan to establish a consortium that will ensure competence and funding to extend the cable to an off-shelf location, and position at least three more sensor platforms along the transect. In that way we can provide substance to the statement “Gateway to the high north”.

6 Conclusions

Overall evaluation: The Hola observatory could never be developed to the level originally planned due to technical difficulties and lack of experience. Nevertheless, the failures and successes of the project have given us valuable experience that certainly makes us better prepared to plan and develop a cabled system. If the scientific community is to obtain maximum from a cabled system, it will be essential to systematically build up competence and capacity in both technology and science. In the future, such capacity building may lead to more efficient use of expensive vessel time for marine monitoring and research.

Point observation versus spatial variability: Valuable experience has been gained regarding how to use a single-point observation location. An expected product was modelling of diel and seasonal signals in the data. While these were present as expected in the oceanographic data, the biggest surprise in the acoustic data was the lack of systematic diel redistributions and migrations. We believe that this is a result of choosing a very special habitat. Future work will need to ensure proper spatial information in order to enhance our understanding of the processes involved at the site. We plan to do this through a combination of extending the cable system and using IMR vessels that pass through the area.

Modelling: Modelling can help minimising the negative impact of limited spatial information. Little attention has been paid to this aspect in this report, but we regard it as a major task in the forthcoming cabled system, where the quantity of data will be much greater and the period of observation longer. This will include modelling of oceanographic conditions, fish behaviour and migration, habitat, etc., and interactions between physics and biology. The lack of consistency between observations and models presented in this report supports this need.

Experimental design: Observatory technologies are designed not only for continuous monitoring, but can also be used to solve scientific questions differently from vessel-based studies. This demands a certain flexibility of instrumentation and operational capabilities, which needs attention. For example, the impact of coral reefs on fish distribution and behaviour may require an experimental setup involving multiple acoustic and imaging systems for a limited period of time, operated according to the hypothesis to be tested. Such approaches might become important in assessing parameters to be used in coupled ecosystem models in the future.

Outstanding matters: Two important sources of data are not included in this report. The hydrophone data could not be processed due to formatting complications. This is expected to be resolved in the near future through collaboration with Naxys and the Universitat Politècnica de Catalunya. Analysis of the acoustic target tracking data has also been delayed, in this case due to software difficulties. IMR is developing software that will facilitate more efficient processing of target-tracking data. The development met obstacles that needed to be overcome, but unfortunately too late for this report. These analyses are crucial for understanding fish orientation relative to currents and also in comparisons of passive particle transportation in relation to current measurements from ADCPs. We aim to complete these analyses ahead of the LoVe cabled observatory project, as both will provide important basic data and experience for the development of this new project.

Table 5. Catch information from research vessels

Lat	Lon	Min. depth	Max depth	Month	Species	Weight	Numbers	Gear	Size	Length
68.59	14.16	0		08	Lumpfish	8,890	4	PT	large	36.3
68.59	14.16	0		08	Lumpfish	8,890	4	PT	small	5.0
68.59	14.16	0		08	Herring	0,266	3	PT	large	21.5
68.59	14.16	0		08	Cod	0,002	2	PT	small	5.5
68.87	14.43	0		08	Lumpfish	9,755	7	PT	large	30.3
68.87	14.43	0		08	Herring	0,813	2	PT	large	36.8
69.13	14.38	0		08	Grey gurnard	0,545	2	PT	large	30.5
69.13	14.38	0		08	Mackerel	172,190	412	PT	large	34.8
69.13	14.38	0		08	Lumpfish	1,290	1	PT	large	29.0
69.03	14.97	0		08	Haddock	1,595	6	PT	large	54.0
69.03	14.97	0		08	Haddock	1,595	6	PT	small	9.8
69.03	14.97	0		08	Grey gurnard	0,525	1	PT	large	40.0
69.03	14.97	0		08	Lumpfish	7,735	10	PT	large	29.4
69.03	14.97	0		08	Herring	1,177	11	PT	large	23.1
69.16	14.39	250	220	07	Blue whiting	50,000	355	PT	large	28.3
69.16	14.39	250	220	07	Silverside	0,750	703	PT	small	3.9
69.16	14.39	250	220	07	Mesopelagics	0,424	20	PT	large	23.1
69.16	14.39	250	220	07	Mesopelagics	0,003	3	PT	small	3.7
69.16	14.39	250	220	07	Mesopelagics	0,050	29	PT	small	4.8
69.16	14.39	250	220	07	Lumpfish	3,511	2	PT	large	31.0
69.16	14.39	250	220	07	Saithe	8,961	5	PT	large	60.8
69.16	14.39	250	220	07	Redfish	9,243	9	PT	large	42.4
69.16	14.39	250	220	07	Great silver smelt	10,177	29	PT	large	34.3
69.19	14.63	153	137	03	Tusk	3,800	2	RT	large	56.0
69.19	14.63	153	137	03	Haddock	800,000	826	RT	large	45.6
69.19	14.63	153	137	03	Ling	2,595	1	RT	large	76.0
69.19	14.63	153	137	03	Saithe	138,160	159	RT	large	42.6
69.19	14.63	153	137	03	Cod	56,075	26	RT	large	60.7
68.99	14.25	241	224	03	Long rough dab	0,830	14	RT	large	17.9
68.99	14.25	241	224	03	Long rough dab	0,830	14	RT	small	14.0
68.99	14.25	241	224	03	Whiting	1,400	6	RT	large	31.5
68.99	14.25	241	224	03	Haddock	38,400	56	RT	large	38.4
68.99	14.25	241	224	03	Lemon sole	0,190	1	RT	large	26.0
68.99	14.25	241	224	03	Saithe	11,600	9	RT	large	52.8
68.99	14.25	241	224	03	Herring	0,385	3	RT	large	25.5
68.99	14.25	241	224	03	Silver pout	0,020	4	RT	small	7.3
68.99	14.25	241	224	03	Cod	30,600	8	RT	large	74.3
68.99	14.25	241	224	03	Great silver smelt	1,865	59	RT	large	17.6
68.99	14.25	241	224	03	Great silver smelt	1,865	59	RT	small	13.5
68.99	14.25	241	224	03	Norway pout	45,200	1350	RT	large	17.7
68.99	14.25	241	224	03	Norway pout	45,200	1350	RT	small	10.8
68.51	14.06	189	169	03	Tusk	0,214	1	RT	large	28.0
68.51	14.06	189	169	03	Long rough dab	0,081	2	RT	large	17.5
68.51	14.06	189	169	03	Haddock	18,950	32	RT	large	38.4
68.51	14.06	189	169	03	Lemon sole	0,752	2	RT	large	31.0
68.51	14.06	189	169	03	Saithe	350,000	958	RT	large	34.6
68.51	14.06	189	169	03	Herring	0,579	5	RT	large	25.9
68.51	14.06	189	169	03	Herring	0,579	5	RT	small	12.0
68.51	14.06	189	169	03	Cod	10,395	4	RT	large	61.8
68.51	14.06	189	169	03	Norway pout	4,200	496	RT	small	9.8

Table 6. Commercial catch information

Lat	Lon	Fishing depth maximum	Fishing depth minimum	Month	Species	Weight of catch	Catch in numbers	gear	Length
68.75	14.17	113	79	3	Cod	3500	492	GN	91.1
68.75	14.17	113	79	3	Cod		2	GN	91.1
68.75	14.17	122	73	3	Cod	3		GN	93.1
68.75	14.17	122	73	3	Cod		20	GN	93.1
68.75	14.17	161	82	3	Cod	5700	689	GN	92.7
68.75	14.17	161	82	3	Cod		25	GN	92.7
68.78	14.05	90	80	7	Haddock	1450		LL	51.2
68.78	14.05	90	80	7	Saithe	100		LL	78.3
68.78	14.05	90	80	7	Cod	100		LL	79.7
69.07	14.13			4	Atlantic wolffish	2	1	BT	68.0
69.07	14.13			4	Whiting	21	20	BT	48.4
69.07	14.13			4	Haddock	22	15	BT	53.1
69.07	14.13			4	Skate	1	1	BT	40.0
69.07	14.13			4	Kveite	27	7	BT	65.6
69.07	14.13			4	Ling	11	3	BT	86.0
69.07	14.13			4	Saithe	1300	718	BT	57.7
69.07	14.13			4	Cod	8800	3079	BT	69.4
69.07	14.13			4	Redfish	16	16	BT	40.6
69.07	14.13			4	Silver smelt	20	47	BT	38.3
69.13	14.45			4	Saithe	2492	2078	BT	48.9
69.13	14.45			4	Cod	4396	1219	BT	75.1
69.20	14.63			4	Tusk	1	1	BT	51.0
69.20	14.63			4	Haddock	442	309	BT	51.8
69.20	14.63			4	Saithe	4455	3710	BT	48.8
69.20	14.63			4	Cod	2799	733	BT	77.2
69.20	14.63			4	Redfish	3	3	BT	42.0
69.07	14.22			4	Tusk	15	7	BT	57.9
69.07	14.22			4	Whiting	25	23	BT	47.7
69.07	14.22			4	Haddock	80	70	BT	48.5
69.07	14.22			4	Halibut	3	2	BT	51.0
69.07	14.22			4	Redfish			BT	24.6
69.07	14.22			4	Saithe	5600	1613	BT	69.5
69.07	14.22			4	Redfish	1	4	BT	25.0
69.07	14.22			4	Cod	1676	566	BT	70.6
69.07	14.22			4	Redfish			BT	40.9
69.07	14.22			4	Silver smelt	2	7	BT	33.3

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Appendix I

In this appendix some of the interesting Lander echograms are presented. Note that many of the echograms are presented with higher sensitivity than the figures in the report. Figure 1 show typical echograms of the two transducers. The two left panels represent full range echograms from the upward pointing transducer and sideward pointing transducer (lower panel). Note that the upward looking transducer (being at the seabed) is located at top of echogram (0m) while surface is at bottom of the echogram (265m). The right panels are zoomed versions of the left panels of interesting feature on the echograms. Range from transducer is shown on the left vertical axis. The sudden change towards the end of the echogram, here indicated by a red line, shows the change in biomass from prior to after the echsounder paused for 4 hours.

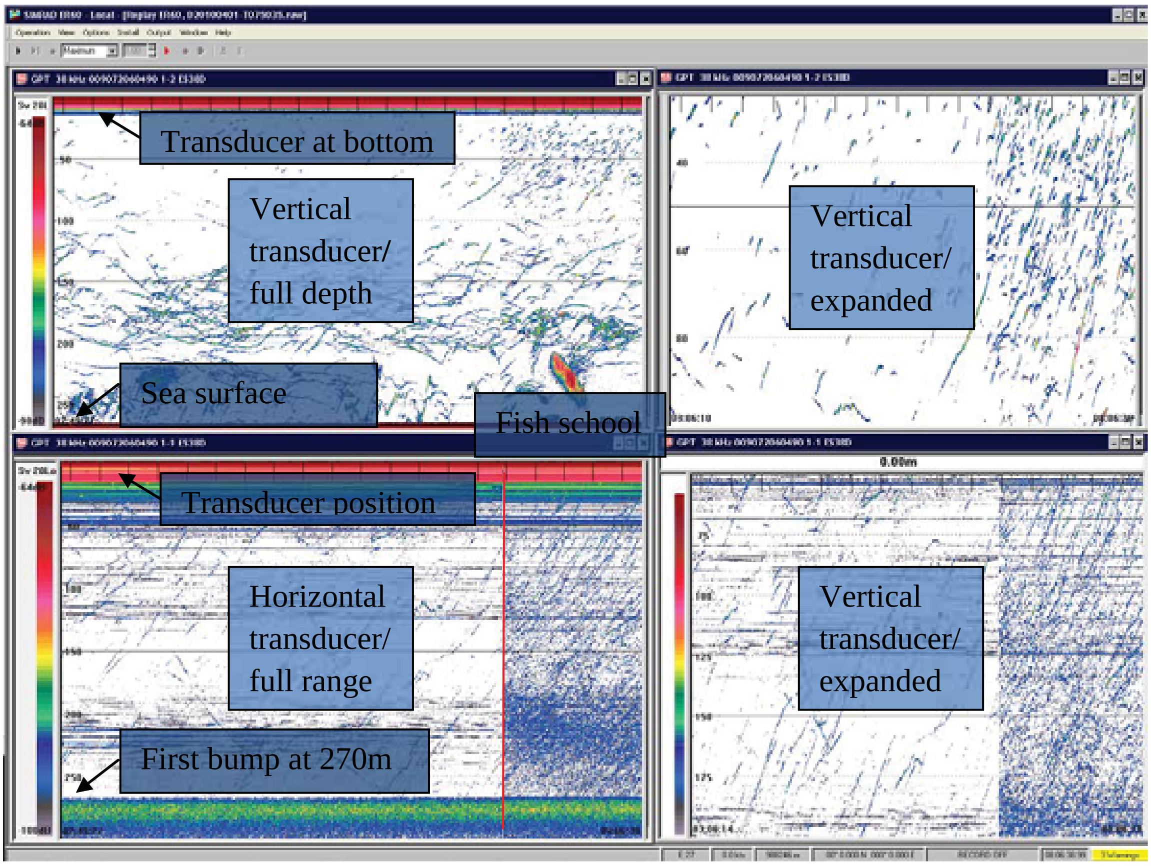

Figure 1 Example of echogram showing the vertical profile (top left panel), horizontal profile (bottom left panel), details from the vertical profile (top right panel) and details from the horizontal echogram (bottom right panel). 1 April 02:49-08:06.

A school of fish can be seen close to the surface (red color) towards the end of the echogram. The upper right panel is a zoomed version of the upper the upper left panel, in this case showing the range from 20-100 m. Here we see single targets (small fish) swimming towards the transducer, i.e. towards bottom. In the bottom right panel we see single targets moving towards the transducer. The horizontal transducer pointed in an eastward direction. The horizontal grey stripes are constant bottom features (probably stones). All echograms in this appendix follow the same layout as Figure 1.

In Figure 2 we see particles drifting towards the horizontal transducer (lower left panel). The transducer is pointing eastward so the particles are drifting from east to west. This is in accordance with dominant current directions as measured by Doppler current meters (chapter 4.4).

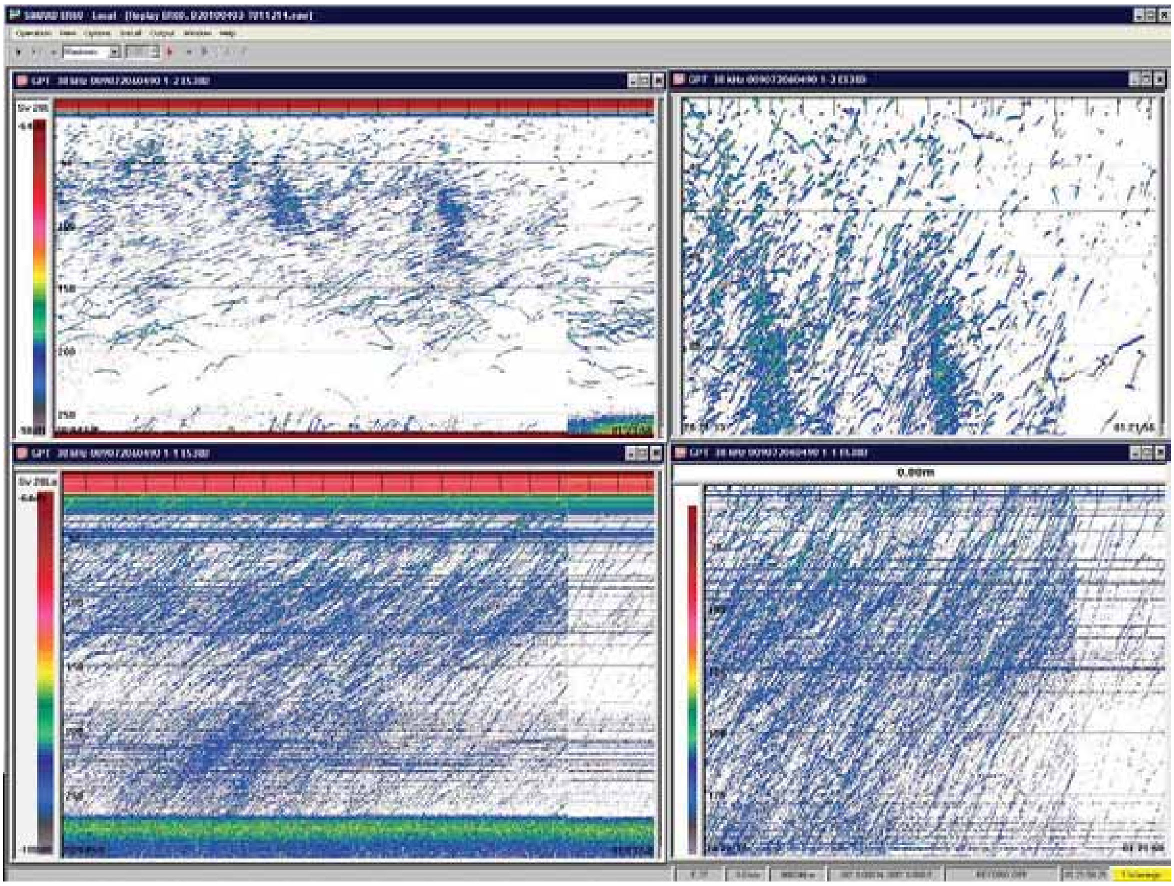

Figure 2. Small particles drifting towards the horizontal transducer (lower left panel). 3 April 20:04 – 4 April 01:21.

In Figure 3 we observe a situation where the current is changing direction during the lander off-time. Prior to this, the particles are drifting towards the Lander (east to west). After the Lander has been off for 4 hours the particles are drifting away from the Lander (west to east). The Lander-off time is indicated by a red line in Figure 3.

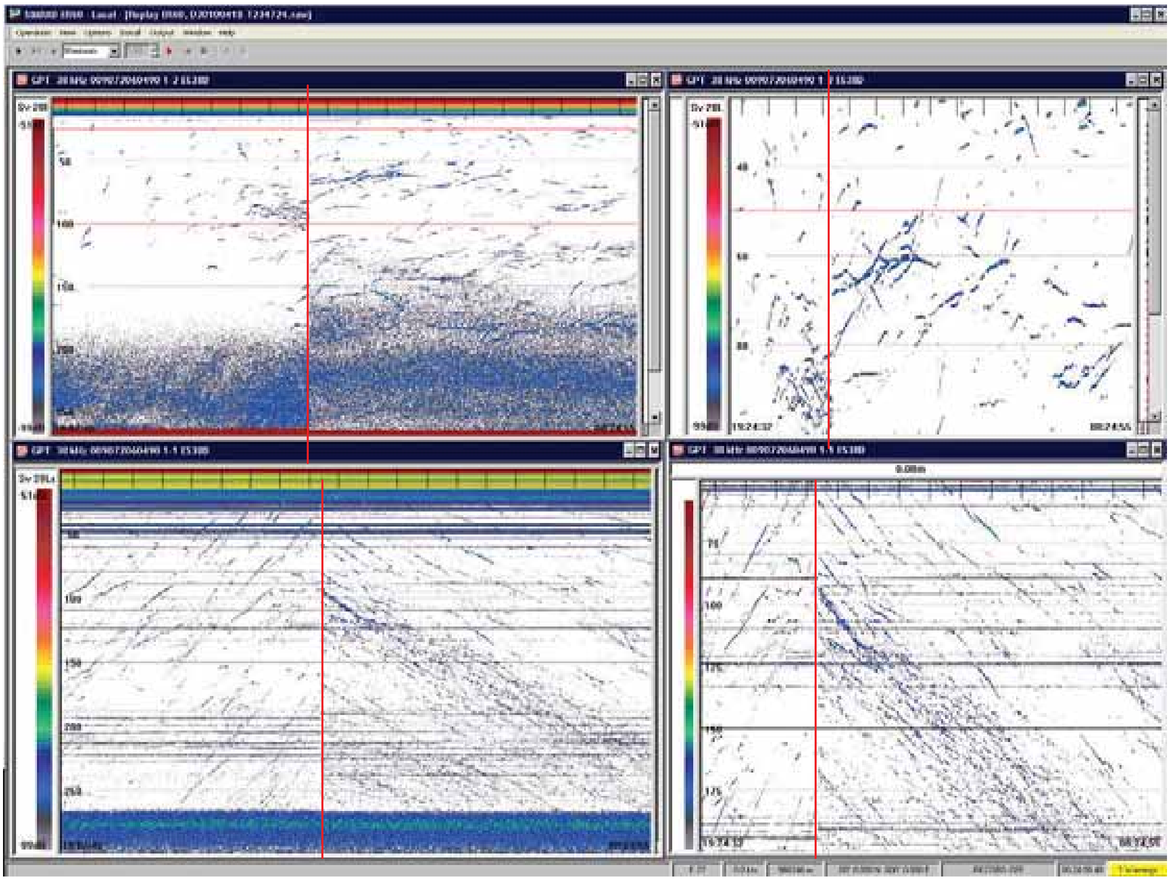

Figure 3. The current direction is shifting during the pause time of the Lander (red line). 18 April 19:07 – 19 April 00:24.

Noise from passing ships is easily picked up by the Lander. Figure 4 shows ship noise both on the vertical and horizontal echosounder.

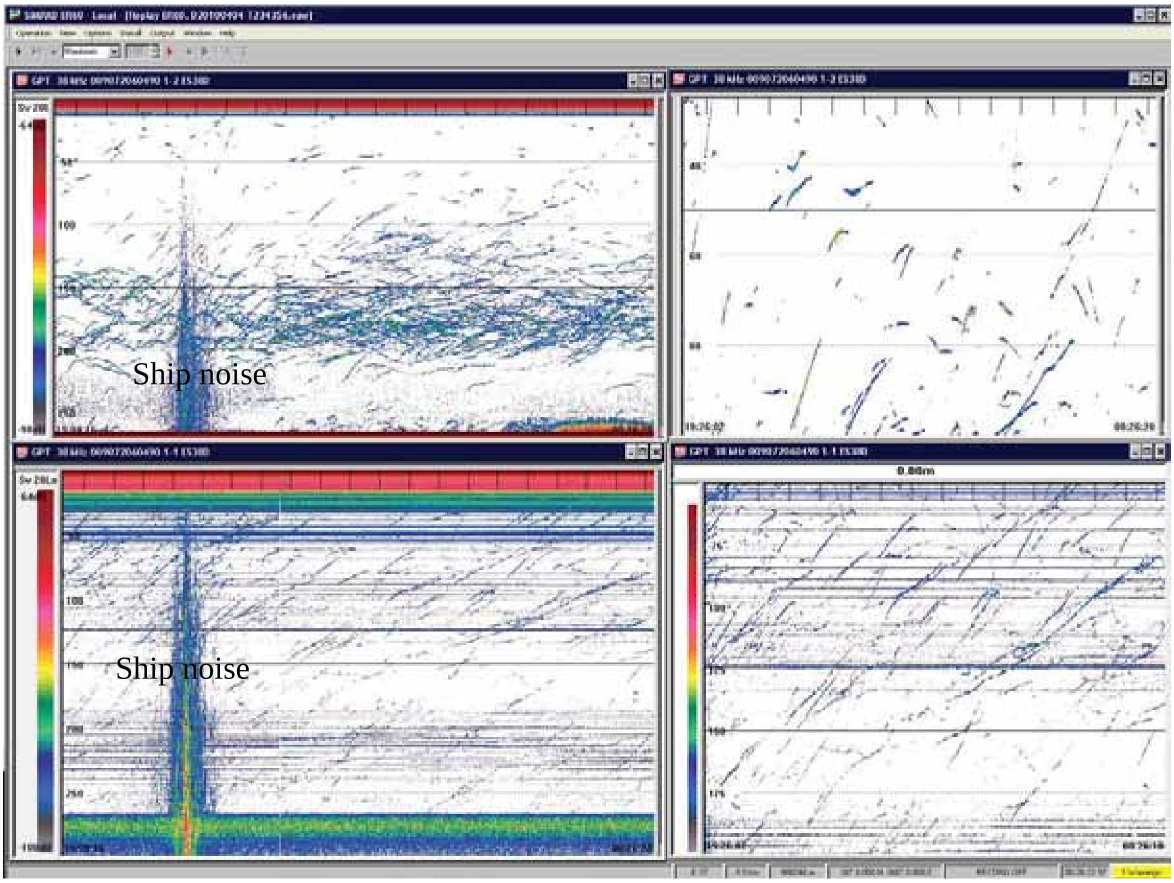

Figure 4. Noise from a ship passing the Lander. 4 April 19:09 – 5 April 00:26.

The two following echograms illustrate one of the great advantages of using a Lander versus a ship. Due to the noise produced by the ships themselves, a low signal-to-noise ratio is obtained. Smaller particles are impossible to extract from the background noise. Figure 5 shows a Lander echogram set with a lower threshold of -80 dB. This threshold is typically used on noisy vessels.

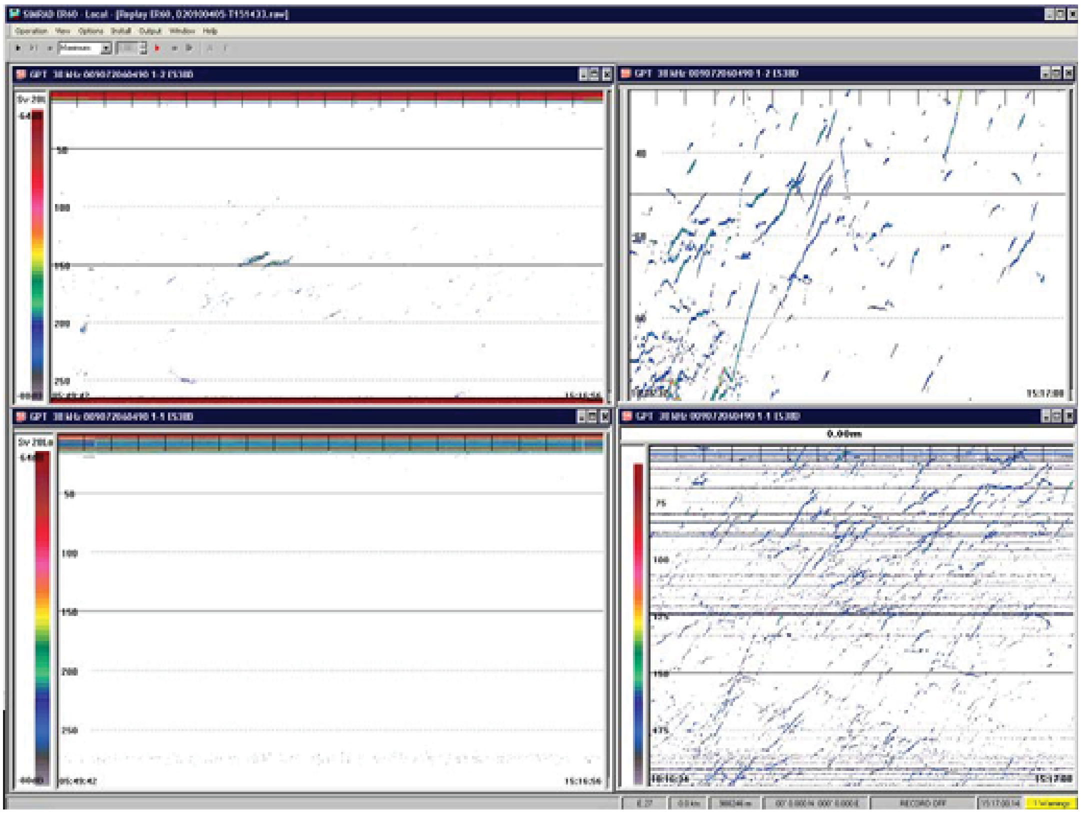

Figure 5. The lower treshold is set to -80 dB to illustrate what a ship mounted echosounder would observe. 5 April 05:49 – 15:16.

Figure 6 is showing the same echogram as Figure 5, but now the lower threshold is set to -98 dB. The finer details that can be observed by Landers are clear.

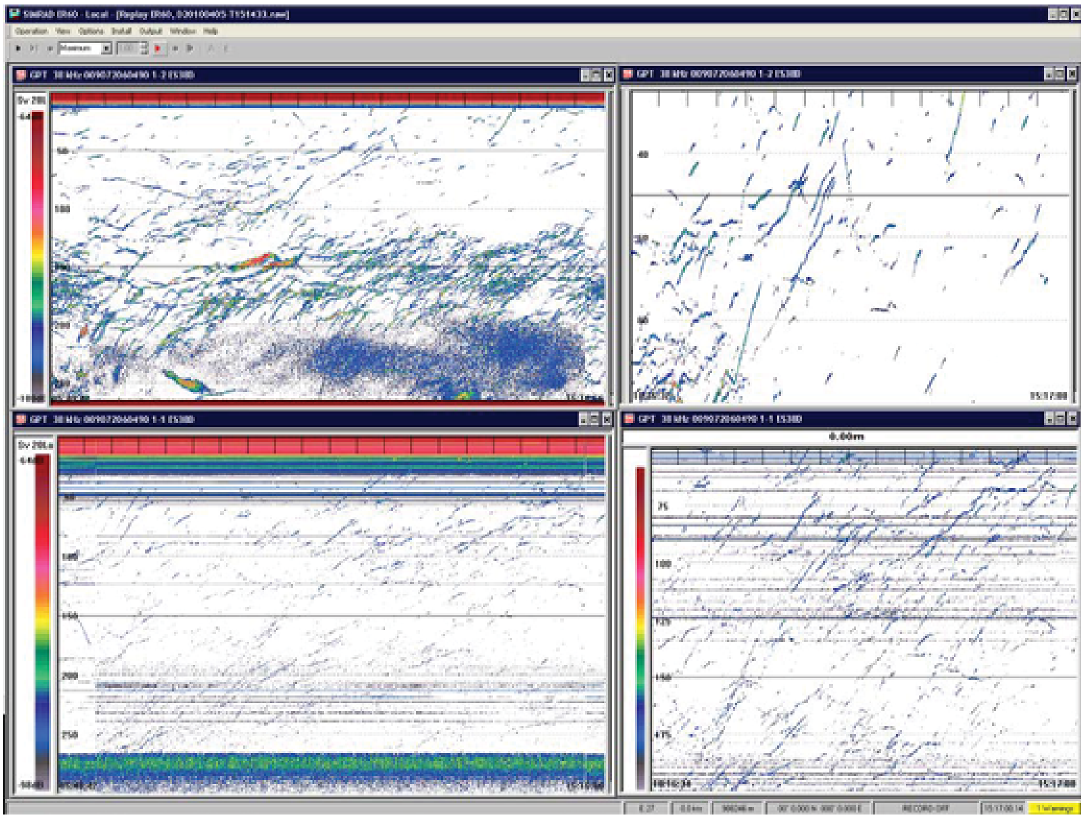

Figure 6. The same echogram as Figure 5, with a lower threshold of -98 dB, illustrating the level of details that can be obtained using Landers. 5 April 05:48 – 15:16.

In Figure 7 we observe that all fish are swimming downwards. The upper right panel shows how we are able to observe single targets swimming towards the transducer.

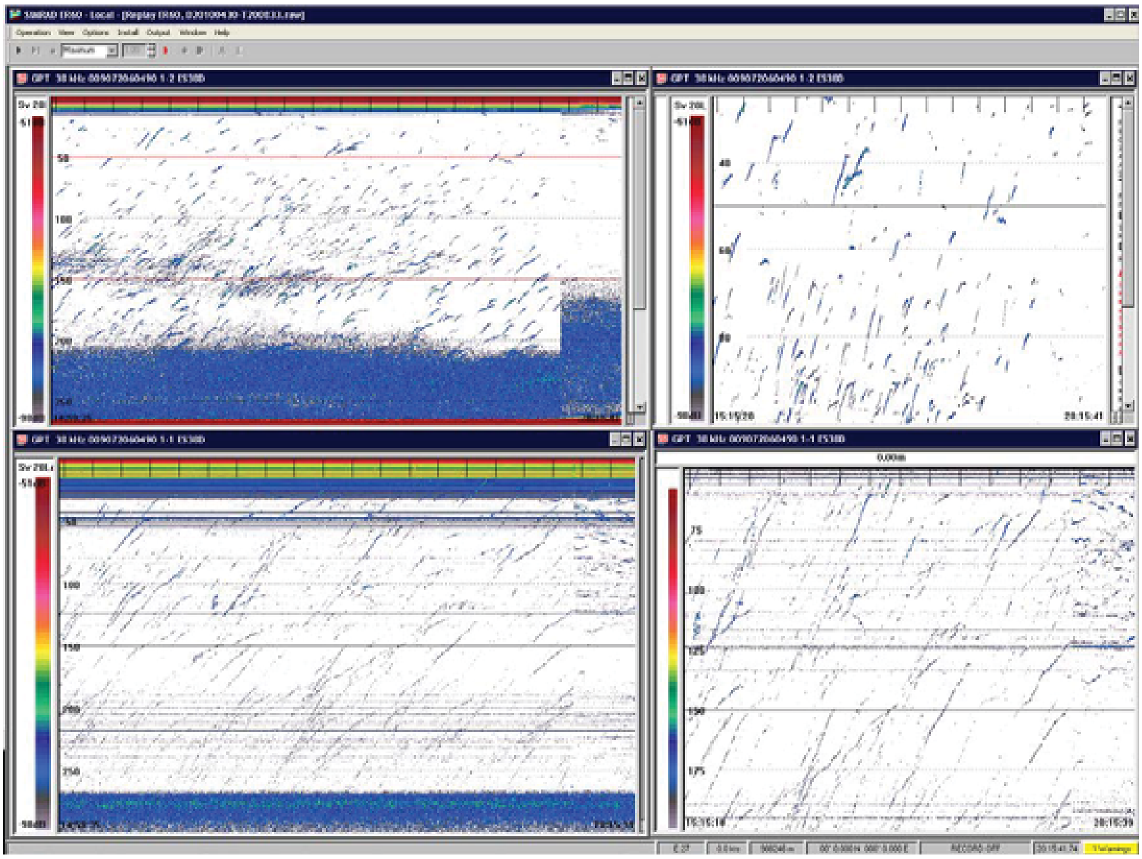

Figure 7 Single fish swimming downwards. April 30 14:58 – 20:15.

Figure 8 shows the change in biomass close to the bottom from night till day. In the first part of the echogram (night) there is a higher biomass close to the bottom than in the latter part (day). The surface biomass, however, does not change much.

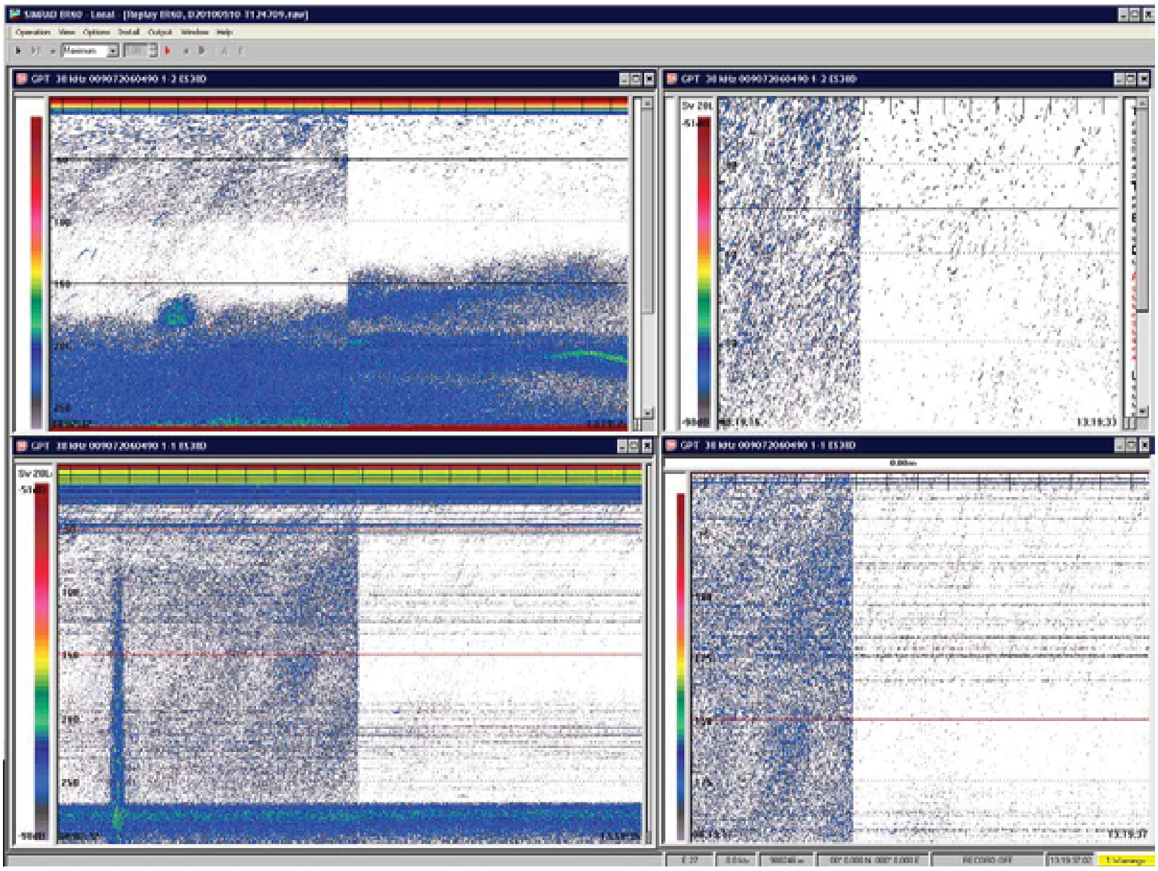

Figure 8. The change from night to day. 10 May 08:02 – 13:19.

The change from day to night is even more evident in Figure 9. Here we see that also the surface biomass is changing. Although such phenomena were observed the general picture was that diel migration did not dominate the temporal variability of biomass.

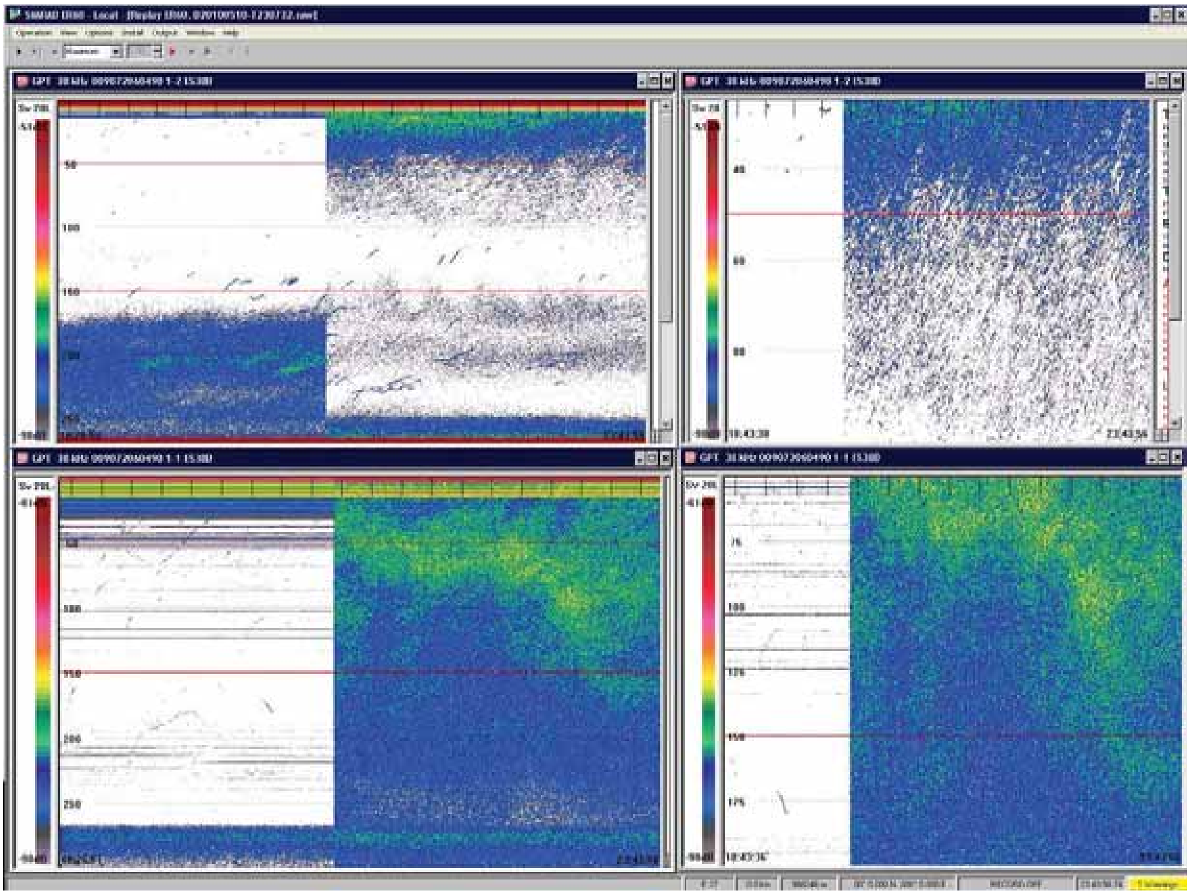

Figure 9. The change from day to night. 10 May 18:26 – 23:43

In the lower left panel of Figure 10 a fish school is observed at 500-600 m range from the horizontal transducer (lower left panel). We also see two horizontal lines in this echogram. The lines being horizontal over the entire echogram mean that these objects are stationary, probably coral reefs or other elevation on the seabed.

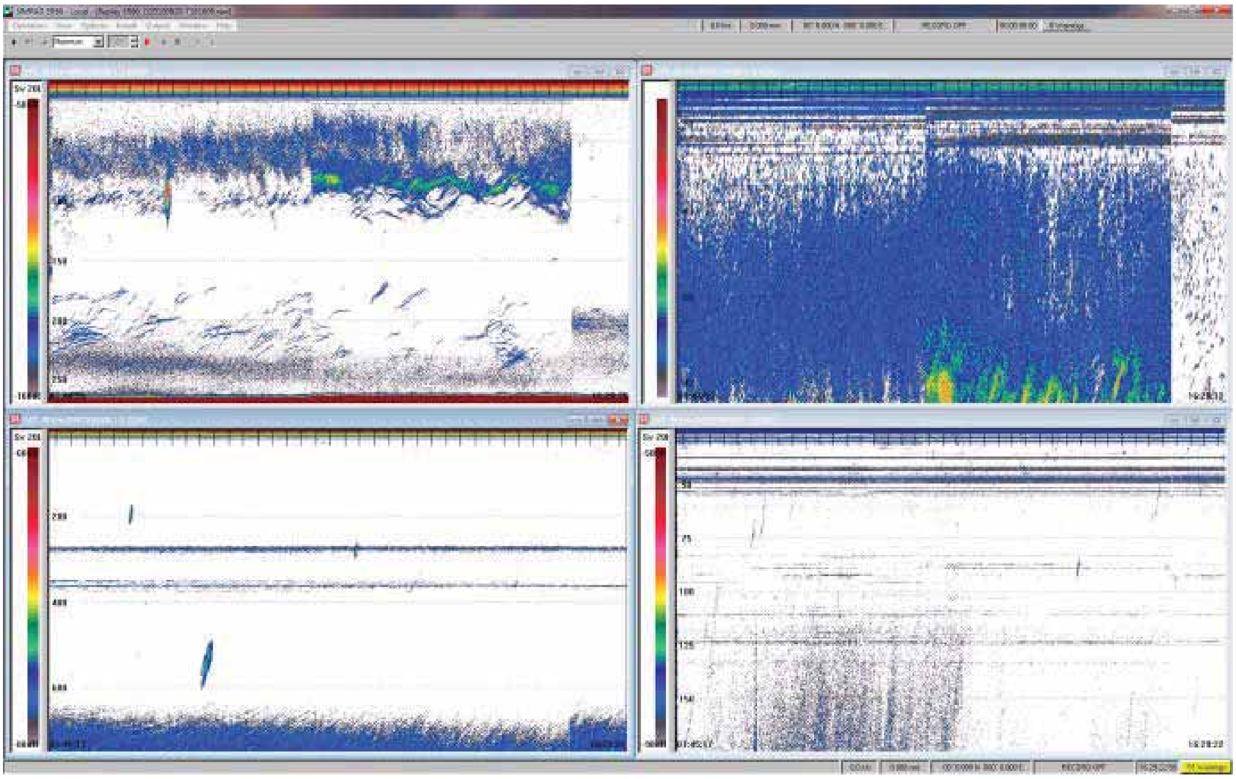

Figure 10. A fish school observed at 500-600 m range from the horizontal transducer (lower left panel). 20 June.

Figure 11 and Figure 12 show some significant recordings of fish schools both at the vertical and horizontal transducer.

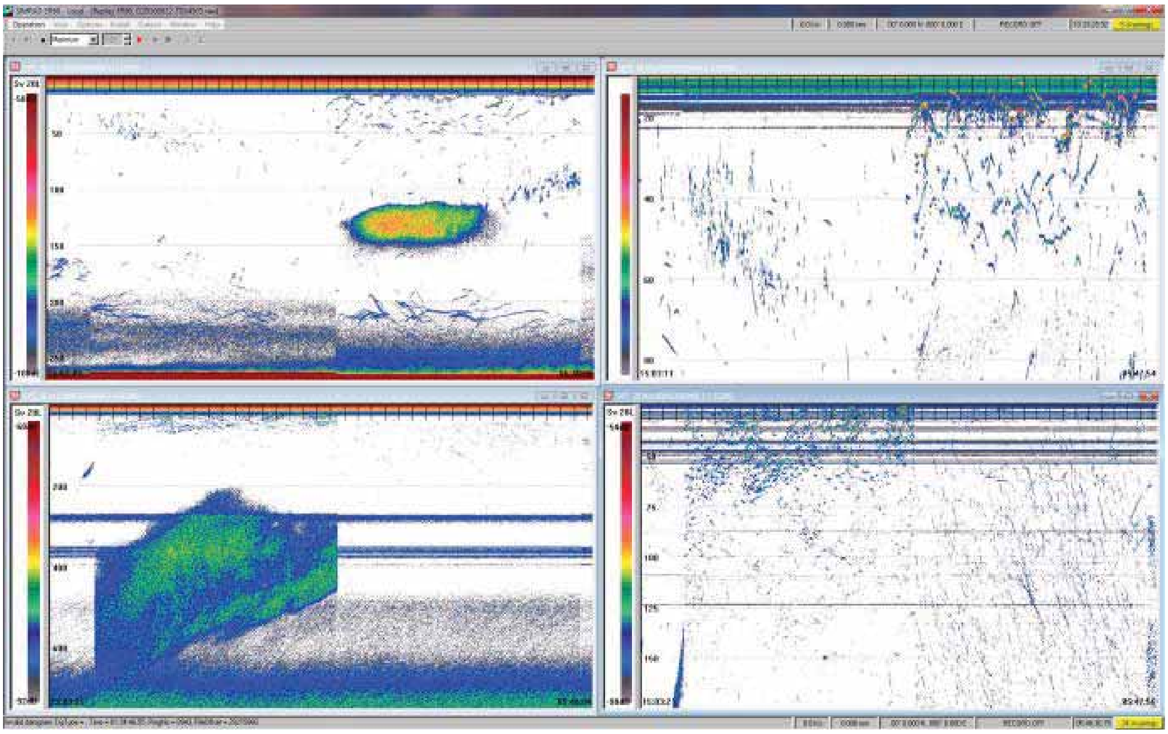

Figure 11. Schools of fish both at vertical and horizontal echosounder. 12 August.

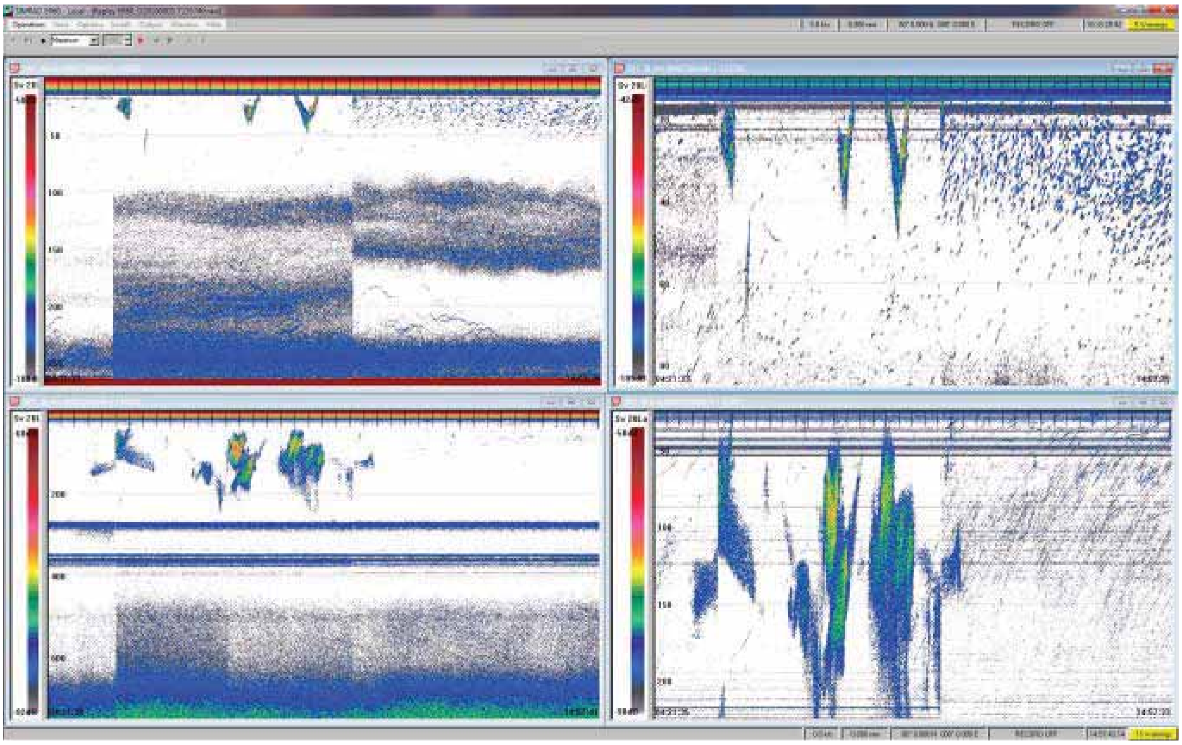

Figure 12. Schools of fish both at vertical and horizontal echosounder. 5 September.

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