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Reaction of sandeel to seismic shooting: A field experiment and fishery statistics study.

Forfatter(e):
Arne Hassel, Tor Knutsen, John Dalen, Kristian Skaar, Øivind Østensen, Eli K. Haugland, Merete Fonn, Åge Høines og Ole A. Misund

Sammendrag:
Atferden hos tobis (Ammodytes marinus) ble undersøkt ved å stenge fisken inne i stålbur og overvåke den under seismisk skyting fra et seismikkfartøy i Nordsjøen. Til dette ble det anvendt en ROV påmontert videokameraer, og opptakene ble senere analysert. Det ble påvist atferd som kan tolkes som fluktreaksjoner, men tobisen svømte ikke mot bunnen for å grave seg ned. Det ble heller ikke påvist skade eller død som skyldtes seismikk. Under eksperimentet syntes fiskeflåten i noen grad å søke vekk fra området, og de leverte fangstene sank midlertidig et par dager.

Summary:
The reaction to seismics of lesser sandeel (Ammodytes marinus) was investigated in the North Sea using steel cages to enclose the fish while burried in the sand. Three cages were exposed to seismic shooting from SV "Falcon Explorer" during two days in May 2002. The sandeel behaviour was recorded on video from an ROV, and data analysed. The sandeel seemed to react slightly, but did not flee to the bottom. No injury or mortality caused by seismic shooting was observed. The fishing vessels tended to avoid the seismic area, and the days after the shooting the landings of sandeel declined temporarily.

Emneord:	Subject heading:
1. Tobis	1. Sandeel
2. Seismikk	2. Seismics
3. Adferd	3. Behavior

Ole Arve Misund
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prosjektleder

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seksjonsleder

Reaction of sandeel to seismic shooting: A field experiment and fishery statistics study

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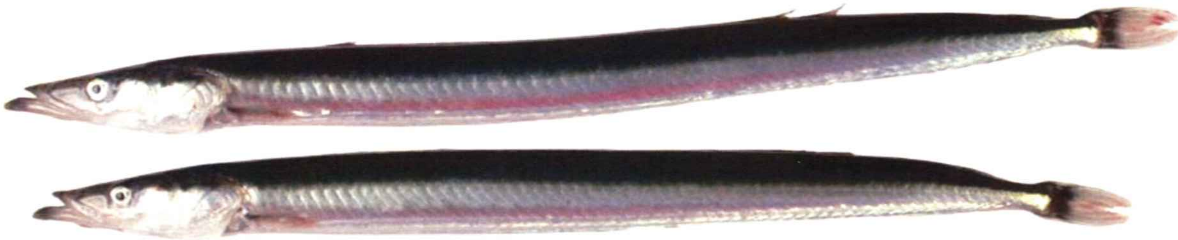

Ammodytes marinus

Responsible: Ole Arve Misund, research director

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1. INTRODUCTION

Seismic exploration is essential for the localisation of offshore oil and gas reservoirs. Given that offshore exploratory drilling for petroleum is a technically complex and extremely expensive process, it is essential to have precise knowledge of the likely presence of oil and gas from areas in which drilling will be initiated. Additional seismic data from surveys in areas where oil and gas are already being produced may extend the knowledge of where the resources are located within the reservoirs, so that drilling can be optimised during production.

Seismic exploration activities and later, oil and gas production, have taken place and still take place in areas where there are significant fishing activities. This may create conflicts of interest between the offshore industries and the fisheries while seismic shooting may directly affect both fish and fisheries. The management of seismic exploration activities in relation to fish resources and fishing activities is to a greater extent taken care of through "The License of Petroleum Exploration" (ANON, 1995).

Confident advices concerning management of seismic activities require scientifically based knowledge of how seismic exploration activities may affect fish resources and fisheries. As a consequence of a growing number of conflicts of interest between seismic surveys and fisheries, the Institute of Marine Research (IMR) carried out its first scientific study of how seismic shooting affected fish distributions in the North Sea during 1984 as well as studies of lethal impacts of fish eggs, larvae and fry from airgun and watergun during 1985 (Dalen and Knudsen, 1987). Since then IMR has performed a number of studies in order to gain more knowledge of how seismic sources and exploration activities may affect fish and fisheries (Bjørke *et al.*, 1991, Løkkeborg and Soldal, 1993, Engås *et al.*, 1996, Booman *et al.*, 1996, Sætre and Ona, 1996).

Dalen *et al.* (1996) summarise the stock management implications based on national and international knowledge of impacts on fish and fisheries from seismic explorations. Main elements of their recommendations were:

- Airgun shooting should be avoided in areas where fishing is taking place in order to reduce potential economic loss to fishermen.
- In order to safeguard spawning, and in accordance with the precautionary principle, spawning grounds during spawning periods and spawning migration routes must be protected against seismic shooting for species whose spawning grounds and migration routes are concentrated.
- Studies of impacts from airgun shooting to eggs, larvae and fry, and the consequences lethal impacts might have on population recruitment compared to natural mortality, indicated that there was no need for restrictions on seismic investigations on the basis of the rather low lethal effects and injuries to eggs, larvae and fry.
- A number of unanswered questions required more research into the impacts of seismic exploration on fish and fisheries including pelagic species and industrial fish.

The latter case was already brought forward to The Ministry of Fisheries in a letter from the Institute of Marine Research in 1994 (Sætre, 1994) as basis for continuing research. The inquiry did not entail new grants for more field directed research effort into the matters.

In course of the past two decades there has been an increasing number of conflicts of interest between Norwegian industrial trawlers fishing for sandeel and seismic exploration activities in the North Sea. Through correspondence and at contact meetings between the fisheries authorities and the offshore industry during the late 90's and 2000 these conflicts were discussed, as they were at the yearly Seismics and Fish Conference organised by the Norwegian Oil Industry Association (OLF) in February 2001 in Bergen.

At a meeting in Haugesund, August 17 2000, between the Southern Norway Trawlers' Association (initiator), OLF, the International Association of Geophysical Contractors, Scandinavia (IAGC, Scandinavia), the Directorate of Fisheries, and IMR the first concrete outlines of four research projects into the field of "sandeel and seismic explorations" were presented from the IMR's representative. The meeting resulted in a mutual agreement to continue the work of drawing up outlines of projects to provide knowledge on a satisfactory scientific basis to many of the questions brought forward from the partners of interest. As the major part of the work was to be done by IMR this was organised through a pilot project mainly financed by OLF.

During 2001 several activities took place of which the main ones are:

On February 27 a representative from the IMR presented a summary of "Research results regarding effects of seismic shooting on fish and fisheries" at OLF's Seismics and Fish Conference in Bergen. On April 4 a contact meeting between the IMR and OLF was organised in Bergen in order to identify the capacity for drawing up a project proposal on relevant problems in the field of conflicts between seismic activities and the fishermen.

On May 15 a pilot project seminar was held at the IMR, in which representatives of OLF took part in order to develop one or more project outlines that could be both relevant and scientifically justifiable for the purpose of providing better insight into how seismic shooting affects fish, fish distribution and catchability. At this seminar, presentations were made on stocks and biology of sandeel, and project outlines were presented for projects on impacts of seismic explorations on demersal fish (replicate of the North Cape Bank experiments (Engås *et al.*, 1996)), impacts of seismic explorations on sandeel distribution and catchability, and impacts of seismic explorations on sandeel behaviour close to and into bottom sediments. The subsequent discussion produced a consensus that the development of a project outline for field studies related to seismic shooting and sandeel should be given highest priority. A set-up for developing this project outline was also agreed.

The field of interest had also acquired a political dimension, and on May 23 Einar Steensnæs, a Member of Parliament and also a member of the Parliamentary Foreign Affairs Committee, asked the following question to the Minister of Petroleum and Energy at The Question Hour in the Storting (the Parliament): " …the effects of seismic shooting on the sandeel fishery is a matter of dispute. The lack of scientific studies means that decisions are not being made on an adequate scientific basis. Will the Minister take the initiative to launching a relevant scientific study?"

In order to ensure that the project outline would enjoy the support of the parties involved, a further pilot project meeting was held in Bergen on June 18, attended by representatives from IMR, OLF, the Directorate of Fisheries and the Southern Norway Trawlers' Association. Agreement was reached that the project for the field studies of "seismics and sandeel" should be divided into an experimental part of studying sandeel behaviour close to and into bottom sediments in cages resting at the bottom (phase 1) and a subsequent full-scale study of sandeel distribution and catchability (phase 2) - all in relation to seismic shooting. The problems defining these studies is a highly current area of conflicting interests, in which it is a matter of urgency to obtain scientifically based knowledge for rational management. The proposal should be developed into a complete project description to be sent to OLF by August 20, 2001 (Anon 2001). The project proposal was accepted for partly financing (phase 1) by OLF by September, 2002.

The project group was formed at IMR in February 2002. During early spring the group discussed how the project could be conducted and practically carried out. It was decided to design and produce several large steel cages to be placed on the bottom in an area where sandeel was likely to occur. During night time the sandeel inhabits the sandy seafloor, and a cage with open bottom would trap the sandeel. During the experiment a seismic vessel was planned to cover the area, operating the airgun array as during ordinary seismic surveys in the North Sea. The behaviour of the sandeel would be carefully monitored and recorded, using an ROV (Remotely Operated Vehicle) with video camera, and video camera inside the cages.

The survey with RV "Håkon Mosby" took place during May 2-20 while the seismic vessel "Falcon Explorer" was active in the area during May 13-15. Prior to and after the seismic shooting period we made 193 grab sampling stations to catch sandeel and to describing the bottom substrates. Three predefined short echosounder surveys covering the seismic area were carried out - one survey prior to and two surveys after the seismic shooting. Altogether good weather conditions, proper planning and clever work execution contributed to the success of the survey.

The data analysing and processing started at the very time the survey was finished followed by the documentation. A preliminary report was delivered to OLF on November 1st 2002. During the succeeding meeting with OLF on November 11 it was decided to extend the report incorporating data from the fishery catch statistics from the experiment area and adjacent areas during a suitable period including the survey period. The planned phase 1 of the project conducted during 2002, and described in this report, was not designed to include information from the fishery catch statistics. Although this was a task already proposed at the Haugesund meeting in August 2000, these kind of studies are more strictly related to phase 2 of the project planned for 2003 or later i.e. the large scale field study of how seismic activities may have impacts on the large scale distribution, availability for capture and catch rates of sandeel. The suggested important phase 2 of the project has not been funded.

2. THE LESSER SANDEEL – ITS DISTRIBUTION, BIOLOGY AND BEHAVIOUR

"Sandeel" is a collective term for a number of species in the family Ammodytidae, which are fish characterised by a slim, eel-like body, which is somewhat laterally compressed. The fish are usually silvery in colour with a darker dorsal region. The head is pointed with a distinctly outthrust lower jaw, the dorsal and tail fins are long and low, and there is no ventral fin. The tail fin is deeply split, and the lateral line organs are located high on the body. Sandeels are schooling fish which usually occur in coastal and shallow open-ocean waters. Five species have been registered in our waters: the smooth sandeel (*Gymnammodytes semisquamatus*), small sandeel (*Ammodytes tobianus*), lesser sandeel (*Ammodytes marinus*), greater sandeel (*Hyperoplus lanceolatus*) and Corbin's sandeel (*Hyperoplus immaculatus*). The first three species are the smallest, being 20 to 25 cm in length, while the last two may reach 40 cm in length.

Several of these species play important roles in the marine food chain, since they are extremely important sources of food for birds and other fish. Nutritional ecology studies on the coast have shown that these species are important for most large fish species in the coastal ecosystem, i.e. for cod, saithe, haddock and flatfish species, particularly plaice (Høines *et al*., 1995). In the North Sea, the lesser sandeel is the dominant prey of seabirds such as cormorants and auks during the early part of the year, while herring and sardines are important during autumn and winter (Baily *et al*., 1991).

The commercial industrial sandeel fishery began in the early 50s and remained at relatively modest levels until the mid 60s, when catches were below 200.000 tonnes. Towards the mid 70s catches rose dramatically as catches of other pelagic fish, especially herring, fell. Since 1975, catches have generally fluctuated between 600.000 and 900.000 tonnes, with some years exceeding one million tonnes (Figure 2.1).

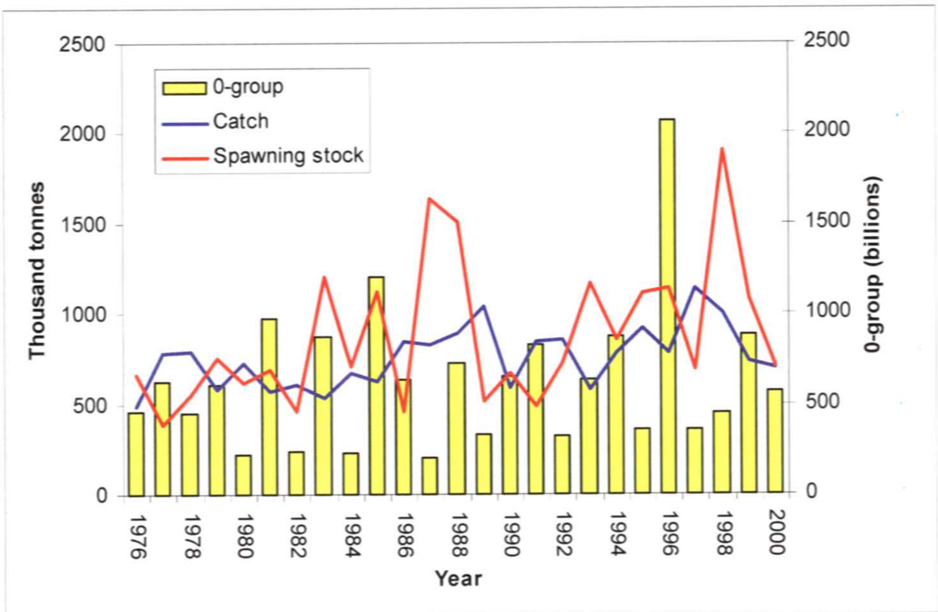


Figure 2.1. Trends in stocks and catches of lesser sandeel (*Ammodytes marinus*) from 1976 to 2000 (ICES 2001).

The individual species display some differences in their biology, i.e. differences in behaviour, patterns of growth, spawning season and age at first spawning. The following paragraphs describe in more detail the biology, behaviour and distribution of the lesser sandeel, since this is definitely the most important species both in terms of stocks and for the commercial industrial fishery.

The lesser sandeel is the most common species in the North Sea, and is widely distributed throughout the whole of the North Sea region, with the exception of the deeper parts of the Norwegian trench. In the north, the lesser sandeel occurs in large numbers all along the coast as far as the Kola Peninsula. We also find this species near the Faeroes, Iceland and as far as Greenland. In the Baltic it is found as far east as Bornholm. Sandeel density can be extremely high in the most suitable areas. In January 1998, at a location in the North Sea (Inner Shoal, Figure 2.2), experiments were carried out on collecting buried sandeels using a Van Veen grab, with mean catch rates of 61 individuals per square meter (Høines and Bergstad, 2001). When the same spot was visited again in January 1999 no sandeels were caught, indicating the wide variations in density that can occur, but the results do demonstrate that geographical and temporal variations in density can be studied by means of grabs.

The most important fishing grounds are the area from the Dogger Bank northwards along the coast of England and Scotland, and central parts of the North Sea. The Norwegian industrial trawler fishery has largely taken place in central regions of the North Sea, more specifically the Eastern Bank, Klondyke and Inner and Outer Shoals (Figure 2.2), and in this fishery, lesser sandeel account for more than 95% of the catch.

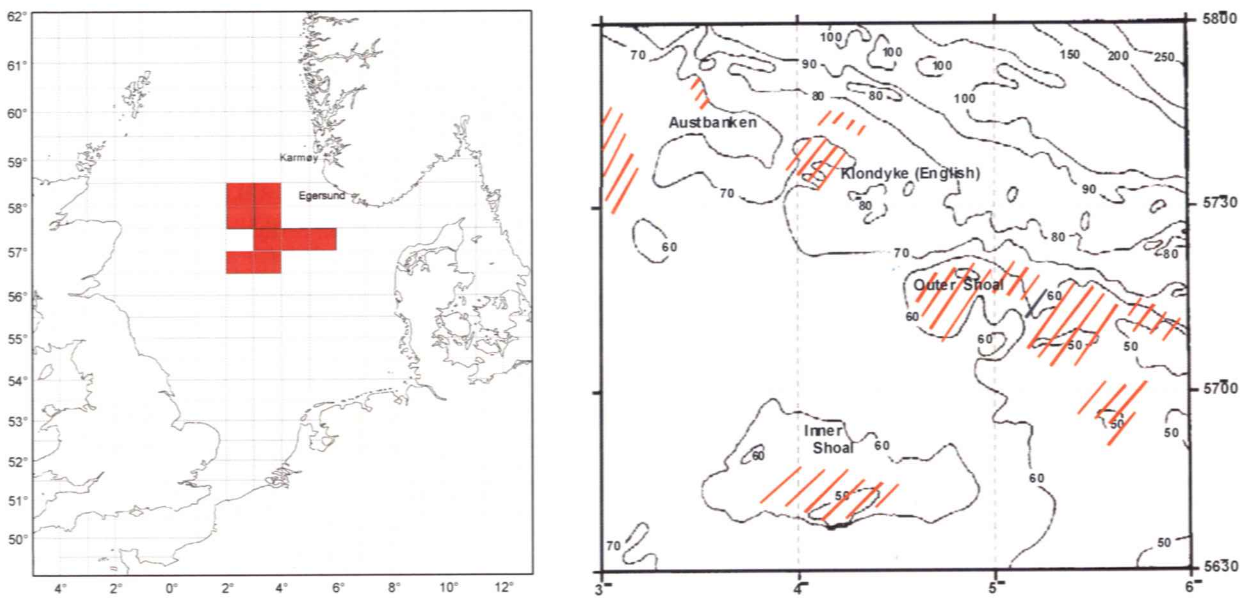


Figure 2.2. The most important areas for the Norwegian industrial trawler sandeel fishery during the past few years.

The most recent stock estimates show that the spawning stocks of lesser sandeel in the period between 1976 and 2000 fluctuated around a level of about one million tonnes (Figure 2.1).

After a decline to about 500.000 tonnes in 1991 it increased during the following years to more than two million tonnes in 1998.

This level of catches was due to the extremely strong year-class of 1996, which has been estimated to be the strongest of the whole period during which ICES has made estimates of this stock. Recruitment has fluctuated, with a pattern of alternating strong and weak year-classes, which may reflect the need of this species for a suitable substrate if it is to survive. After a strong year-class, it is conceivable that all locations with good substrates are occupied by sandeels, which means that the recruiting class of larvae meets extremely tough competition for space when they are ready to settle on the bottom, with the result of extremely high mortality. A lack of suitable substrates seems to be one of several limiting factors for this stock.

In Denmark, the sandeel is also known as the "sand badger", a name that much better reflects its biological peculiarities. This is because the sandeel stays on sandy bottoms, ranging from fine sand to coarse shell sand, which share the characteristic of good oxygen conditions in the substrate. During the winter the sandeel is buried in the sand in a state of hibernation. In the summer, when it is otherwise active, it spends both the hours of darkness and dark cloudiness in this manner. It digs itself into fine substrate extremely rapidly, usually at an angle of 60^{o}, and once it is buried the sandeel can move both backwards and in other directions by turning its head (Popp Madsen, 1994). Its slim, torpedo-shaped body is particularly suitable for burying, and as a further adaptation, the tip of the lower jaw forms a little "bulb" (as in ships' bows) that projects slightly ahead of the upper jaw. This acts somewhat like a drill bit, at the same time as it locks off the mouth to prevent sand particles from entering from in front of the fish. The sandeel is also equipped with an elongated gill-cover which effectively closes the gill opening, thus preventing sand from entering the gills from behind when the fish is moving backwards in the sand. A third adaptation to its self-burial behaviour is a row of diagonal stripes laterally along its body. These are folds of skin on whose rear surfaces the scales sit, well protected against being worn loose by friction with the sand.

The sandeel also lacks a swimbladder, though this is less important since it spends most of its time on or near the bottom, but this also means that in order to avoid sinking to the bottom all the time it has to remain in movement when it is in the water column. The lack of swimbladder also means that it can be difficult to detect on the echosounder among other fish species.

A characteristic feature of the three small sandeel species is that they are toothless and that the upper jaw parts are connected in such a way that the whole of the mouth can be shot forward to form a sort of tube (Figure 2.3). In conjunction with the large gill covers this creates an underpressure in the bucal cavity, which sucks in prey animals.

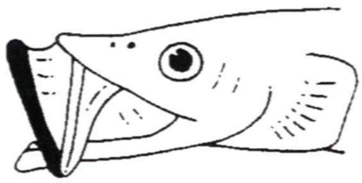


Figure 2.3. The lesser sandeel has the ability to shoot forward its upper jaw to form a tube.

The sandeel's feeding period is mainly from the early morning and throughout the day, i.e. the fish emerge from the sand relatively synchronously in the morning and feed throughout the day, returning to the sand when it is satiated or when the availability of food decreases. This is to say that the sandeel returns to the sand in a relatively unsynchronised pattern throughout the day, but the youngest fish always spend most time out of the sand. Swimming activity is associated with feeding, and the sandeel evidently depends on vision to catch its food. The level of swimming activity during the hours of daylight is largely determined by the availability of food, light intensity and temperature (Winslade, 1971). In the North Sea there are large local concentrations of sandeels as a result of tidal currents, which concentrate large quantities of plankton, on which the sandeels feed. The prey is mainly crustaceans and bristle worms, but fish eggs and fry are also taken. Generally speaking, larger fish tend to take larger prey (Macer, 1966).

As mentioned earlier, sandeels remain in a form of hibernation during the winter, though there are exceptions to this rule. The lesser sandeel is a winter spawner and therefore it has to leave the sand in order to spawn. This happens around the turn of the year, though with some local variations. The gonads begin to grow in September and spawning takes place in December and January. The length and age at which 50 % of the fish are mature is 14 cm and 3 years respectively (Bergstad *et al.*, 2001). The Corbin's sandeel is also a winter spawner, while the other sandeel species generally spawn during the summer. During the long period of "hibernation", the metabolic rate has to be reduced to enable the fish to survive on the fat deposits it has laid down in the course of a relatively short feeding period. In adult fish, the feeding period lasts from about the beginning of April until July, while the younger fish, which have to grow as much as possible, begin earlier and finish later. This means that young fish may feed until October.

The lesser sandeel spawns on the seabed, where its eggs attach themselves to grains of sand. However, they are easily torn loose and can therefore be found in the plankton. It appears that spawning takes place on the same sites as the sandeels occupy at other times of the year. Currents often cover the eggs with sand, but British aquarium experiments have shown that the eggs are still capable of developing to the hatching stage, with the result that they hatch as soon as the current uncovers them again (Winslade, 1971). Eggs which have been buried under the sand have to put up with poor conditions such as reduced current flow and thus lower oxygen tension. Eggs of lesser sandeel are adapted to such conditions, but the hatching is delayed when the oxygen tension is low. In the course of several months, therefore, we can find larvae of all sizes in the plankton until they reach a length of about 5 cm. At that point the larvae adopt an adult lifestyle and behaviour, and settle down in the sand.

The somatic growth of the lesser sandeel is extremely seasonal, with the highest rate of growth in weight and length occurring between March and June (Bergstad *et al.*, 2002). The observed mean length decreased during the latter part of the year in adult fish. The mean length and weight of the recruits, i.e. the 0-group, increased between the first time they were registered in bottom trawl catches in June and the very end of October. Lesser sandeels on the fishing banks in the northern North Sea are usually larger at the same age than sandeels from areas in which there is no fishery, coastal regions off the County of Rogaland. The mean length, weight and condition factor vary from one year-class to another. The extremely strong 1996 year-class in the North Sea were short, weighed less and had a lower condition factor at given size than previous year-classes. The 1996 year-class from the North Sea did not differ in terms of population parameters from the same year class from the coastal region of the western Norway. Comparisons of new and historical growth data from the North Sea have shown that both geographical variation and variation over time could be significant. Variation, both geographical and temporal, in the availability of food is probably an important factor in determining differences in patterns of growth, but the lower mean size of the strong 1996 year-class also suggests that density-dependent processes are other important factors in relation to weight.

The mechanisms that control recruitment to the most important fishing banks, which are fished year after year, are not well understood. The sandeel larvae drift more or less passively with the currents until they settle on the seafloor. There are some indications that the northern areas of the Skagerrak receive higher concentrations of fish in years with powerful northerly currents that transport the larvae northwards from the southern part of the North Sea. Studies carried out near the Shetlands have shown that the sandeel stock east of the islands largely recruits from the stock around the Orkneys, where a strong easterly current carries the larvae into the North Sea (Proctor *et al.*, 1998). From February until May we find sandeel larvae in most parts of the North Sea, including large areas that are not suitable for sandeels. This obviously means that the larvae must be able to concentrate in suitable areas when the time comes for them to settle into the seabed. There are limits to how far these larvae can move actively in the horizontal plane, but it has been shown that larvae can perform vertical displacements several times a day. It is therefore possible that the larvae can find and keep themselves over suitable sites by exploiting selective current transport, i.e. by utilising variations in the direction of the tidal currents by placing themselves in appropriate layers of the water column. After the larvae have settled into the seabed they stay very much in the same place, i.e., for the rest of their lives they do not move to any great extent from where they originally settled down. This has been demonstrated by marking experiments (Kunzlik *et al.*, 1986).

3. EXPERIMENTAL SET-UP AND DESIGN

3.1 Design of experiment

The aim of the investigation was to find out if the lesser sandeel would react to seismic shooting. In order to do this, a number of sandeel had to be trapped in a cage and monitored using underwater video-cameras during the impact from seismic shooting. The cage had to be large enough to enable the sandeel to swim freely and bury into the substrate. Thus, the cage should be made without bottom to trap the sandeel when placed on the seafloor during the night. When recovered after the shooting survey was finished, the sandeel had to be trapped in the cage for further examination on deck. Three cages should be placed in the seismic area, in addition three cages should be placed outside the area as a control group. To find a proper site where sandeel was abundant, echosounder and grab would be used.

3.2 Investigation area

The southern North Sea was the most promising area to conduct the experiment, as the main sandeel grounds are located here. Based on experience from earlier investigations (Høines and Bergstad, 2001) and informations from the fishing vessels in the area, the grounds Innershoal, Outershoal, Korridor, Diana, Karussell and Vestbanken were studied using acoustic observations at daytime, and grab samples with van Veen grab during the night. The Diana ground seemed promising and was chosen as experimental area, centred at N57°12,5' E05°19,1'. An area about 25 nautical miles to the southeast, localized at N56°55,4' E05°41,0', was defined as the control area (Figure 3.1).

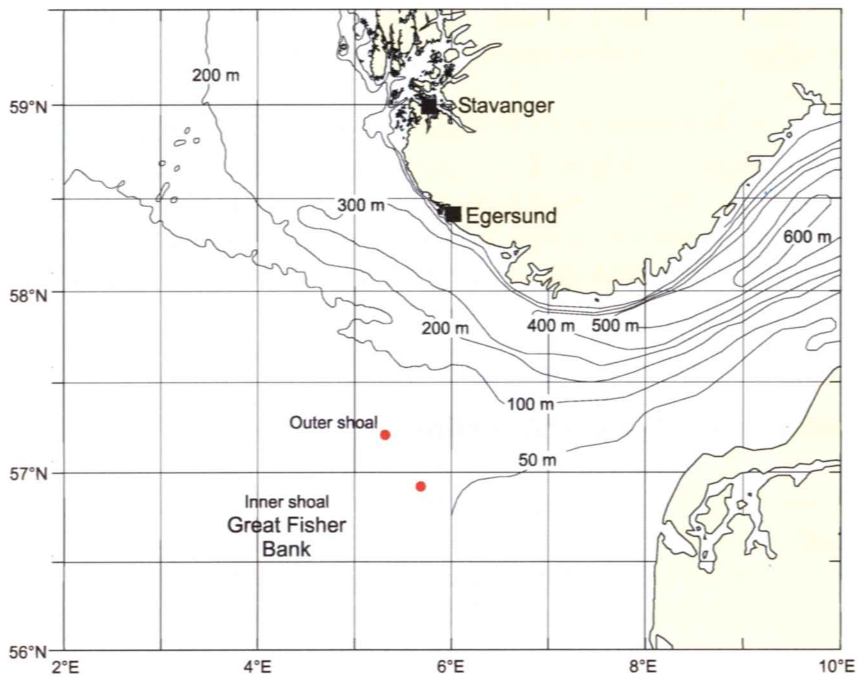


Fig. 3.1. Localization of experimental- and control area (upper and lower red mark respectively) southwest of Egersund on the Diana ground.

3.3 Technical description and function of the cages

The dimension of the cages was calculated according to physical models (NORWECOM) run by Morten Skogen (Svendsen *et al.*, 1996) at the Institute of Marine Research. This model showed that according to previous studies from the area, the expected hourly average current at 50-70 m depth was 14 cm s^{-1}. The highest hourly average during the last 50 years was 28 cm s^{-1}. The cages were designed with sufficient weight to sink 10 cm into the sand were the sandeel was expected to stay during the night. The total weight of the cage was estimated to be about 300 kg, and more weight could be added if necessary. The framework was dimensioned properly to withstand impact from the ships hull even in rough weather during deployment and retrieval.

The cages were constructed of 50 mm steel pipes connected at the corners by outside bends that were bolted to the pipes. Inside the steel frame was attached a sandeel net with walls and roof having dimensions 2.0 m x 1.8 m x 2.0 m. The pipe cage was mounted on a welded steel frame made from 12 mm steel plates. It was 0.3 m high, and with a base measuring 2.0 m x 2.5 m. Inside the frame, along the shortest side, was a ventilated sand box, 0.5 m wide, 0.19 m high and 2.0 m long, with a 45° cutting edge towards the bottom. On top of this frame was welded a 3 cm L-shaped steel profile covered with a rubber plate on the horizontal surface. The sandeel net was attached to this surface using a flat steel profile and bolts.
Inside the cage, the floor could be closed by a curtain contained inside the frame at the front end. The curtain was made from sandeel net, and the sides were attached to 3 mm wires inside U-shaped stainless steel profiles by means of 25 steel rings on each side, thus enabling the curtain to slide easily. The curtain was closed by three wires attached. The wires went through the ventilated backwall in the sandbox to a dragged weight made of a 2.0 m long steel bar and 20 kg chain.
The cages were equipped with an inspection window made from plastic. The windows were glued and sewn to a frame of sandeel net that was later sewn to the walls above the sand box. The design and use of the cages is demonstrated in Figures 3.2-3.4.

A prototype was tested at Herdlaflaket north of Bergen during a cruise with RV "Håkon Mosby". The pictures (Figure 3.5) show deployment and retrieval of the cage. The test proved that the cage functioned as expected, except the penetration into the sand was poor. The underside of the frame was therefore sharpened changing the plate thickness gradually from 12 mm to 3 mm. The cages were also equipped with three hooks to fasten a heavy duty chain to add more weight if necessary.

3.4 Deployment and retrieval procedures

After the echo observation, grab sampling and verification by ROV (Remotely Operated Vehicle) that sandeel was present in the sand, the cages were lowered to the bottom using ropes attached to eye bolts on the top of the frame. A 290 kg load (railway carriage wheel) was first deployed, then 200 m rope from the load to the front of the cage frame (opposite the chain box). At this time the closing curtain was contained inside a magazine in the front of the cage, where it was secured by magnesium rods being dissolved after about 24 hours immersion in seawater. The cage penetrated about 5-8 cm into the sand and trapped the sandeel for observation. The deployment rope from the pipe cage top was attached to a buoy. Cage with video link had cable running in steel carabine mounts along the rope to a barrel at the surface.

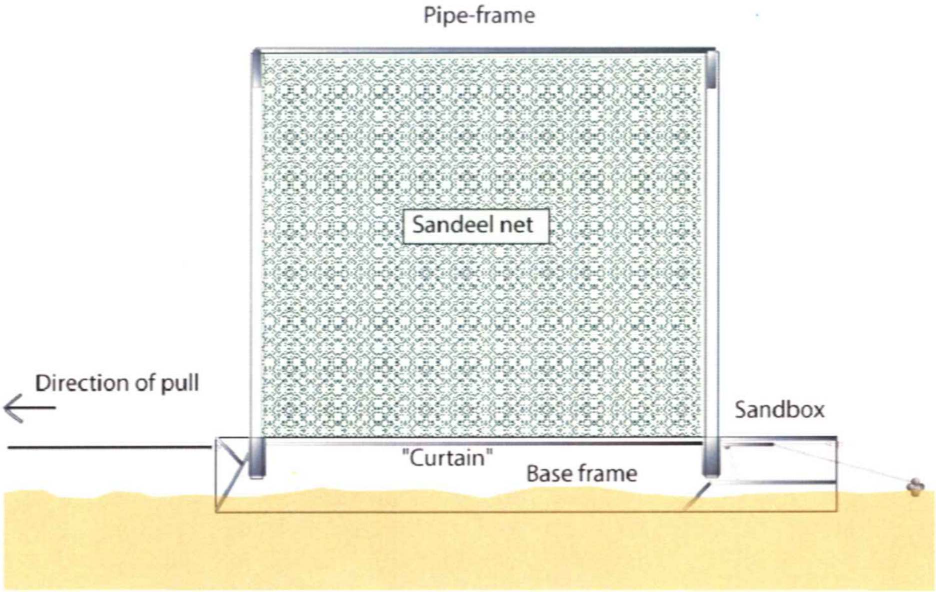


Figure 3.2. General design of the cage. When the cage is pulled to the left, the curtain is closed by the weight to the right, and sand is collected in the box.

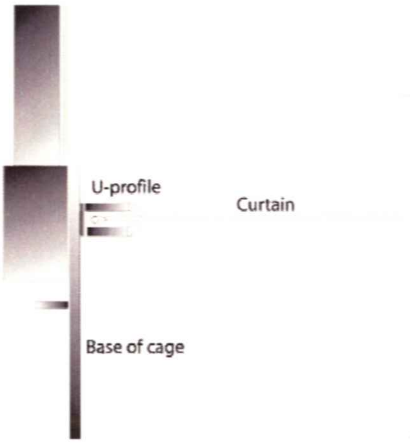


Figure 3.3 (left). Detail showing the design of the closing curtain.
Figure 3.4 (right). Retrieval procedure: The cage is pulled to the left to fill the sandbox before lifting the cage to the surface.

Before the cage was closed, the ROV was used to cut the security rope to the dragging weight for the curtain. The flashlight buoy was recovered, and the rope used for pulling the cage was lengthened by 220 m. The closing was done by pulling the cage forwards as close to the bottom as possible, at least a distance of 3 m. The curtain was pulled out of the magazine by the dragging weight and closed the bottom of the cage. The heavy wheel gave pulling direction and low pulling force angle to the cage. During the displacement the steel frame scraped off the upper 10 cm of the bottom as the frame angled slightly and moved deeper until the sandbox steel floor touched the bottom. The substrate was collected in the sandbox.

The sandbox had a hinged lid that could be opened inwards behind the cutting edge during the movement. It was mounted inside the box 5 cm under the upper surface of the frame. Above the lid a plastic cover was placed so that the closing net could be pulled between the lid and the plastic cover using wires passing through the ventilated wall of the sandbox. In this way sandeel could be trapped and brought to the surface while the cage was lifted sideways with the front up. The weight closing the curtain was hanging down keeping the cage tightly closed.

Figure 3.5. Deployment and retrieval of the test cage at Herdlaflaket

3.5 Deployment of cages in experimental area and control area

The experiment group cages were launched late in the evening to assure the sandeels were buried in the sand and trapped in the cages next day. Three cages were left in the experimental area at 54-56 m depth on May 4-6 (Table 3.1). One of these was retrieved before the seismic shooting started because of technical problems, and was redeployed on May 12. Figure 3.6 shows a cage placed on the bottom.

In the control area two cages were deployed at 51 m depth on the May 12. The sandeel concentrations in the control area were too low to obtain a proper number of fish captured by lowering the cages to the bottom. Instead the fish were caught with trawl and immediately transferred to a large bucket attached inside the cages. The open end of the bucket was covered with a fine meshed piece of net that was secured by means of a magnesium bar that dissolved a few hours after exposure to the seawater, thus releasing the fish to the cage.

Table 3.1. Positions of the cages deployed in the seismic and control areas.

Cage no.	Group	Latitude	Longitude	Date Deployed	Retrieved
1	Seismic	57,2097	5,3190	04.05.2002	19.05.2002
2	Seismic	57,2095	5,3160	04.05.2002	19.05.2002
3 (with camera)	Seismic	57,2087	5,3200	12.05.2002	19.05.2002
Cage with camera	Control*	57,2092	5,3210	06.05.2002	12.05.2002
4	Control	56,9233	5,6833	12.05.2002	18.05.2002
5	Control	56,9220	5,6815	12.05.2002	18.05.2002

* Cage was placed in the seismic area, but was recovered before shooting

3.6 Grab sampling

To locate areas suitable for the experiment, a 0,2 m^2 van Veen grab (Figure 3.7 right) was applied extensively during the first part of the investigation to find suitable concentrations of sandeel and to obtain sand samples. Later, grab samples were taken every night before, during, and after seismic shooting, in a confined area in the center of the experimental area. The aim was to detect possible changes in behaviour or mortality of sandeel as a result of seismic activity.

Sediment samples were collected and analysed with respect to particle size in the lab at IMR. The samples were dried for 24 h at 100°C and then sieved trough a standard Retsch series of sieves ranging from 2000 to 63 μm mesh, with the aid of a mechanical shaker.

Figure 3.6. One of the cages resting on the seafloor. The manipulator on the ROV is visible on the right side (left picture). The sandeel could be seen through the observation window (right).

3.7 Video equipment and monitoring techniques

Observations on fish behaviour were obtained using the ROV "Aglantha" (Figure 3.7 left) and a fixed mounted video camera inside one of the experiment group cages. The camera was mounted in the upper corner to give an observation field covering most of the bottom and 2/3 the distance up two of the walls. It was connected by cables to a video link placed inside a plastic container floating at the surface. The container was also supplied with batteries, and the video signals were transferred to a monitor and a recorder on board RV "Håkon Mosby". When the vessel was outside the range of the video link signals, the recording was done using a recorder inside the container.

The ROV was able to make observations at all cages. By pointing the cameras in different directions it was possible to monitor the fish in most parts of the cage. During the day, the video observations were done without use of artificial light, which might affect the behaviour of the fish. At dawn and night the ROV's electric lamps had to be turned on to achieve proper recordings.

The ROV was equipped with a manipulator, enabling us to release the curtain in the bottom of the cages to close them prior to retrieval.

The recordings were divided into two categories, recordings from ROV and recordings from the camera inside one of the experiment group cages. These categories were named "Aglantha videos" and "Video link videos", respectively. The camera on the ROV were manoeuvrable and equipped with a zoom function. The "Aglantha videos" were divided into 10 min time blocks were the picture was stable and the quality was equal from block to block.

The video observations were used to detect changes and abnormalities in the behaviour of the sandeel before, during and after the seismic shooting. To measure the behaviour, three categories were made. The tail beat frequency, the number of irregular happenings on the swimming behaviour (see below), and the position of the fishes in the cage. The tail beat frequency and the registration of abnormalities were counted from the "Aglantha videos", while the positions of the fishes were registered from the "video link videos".

By counting the frequency of the tail beats it is possible to notice if the activity level changes during the experiment. Another solution to detect changes in activity level could have been measuring the distance swum per time unit, but the fish swam in all directions and seldom in a straight angel to the camera. The distance between the camera and the fish was also unknown, and this makes it difficult to apply this method. Therefore the tail beat frequency method was chosen and the procedure of this method was as follows. Each minute a randomly chosen fish was counted for numbers of tail beats, until the fish went out of visual range. When selecting fish randomly the monitor image was divided into six squares. A dice was thrown, and the fish in the square with number corresponding to the side of the dice was then observed. Most often it was only one fish in the square, but when there were more than one fish, the most visible one was observed.

During the shooting period some irregular swimming behaviour were observed. The behaviour started with a sudden jerk where the fish bended their body in a C-shape like form and then continued swimming, often in a different direction. Sometimes the jerk and bending part was repeated and lasted up to 10 seconds before the fish resumed swimming in a normal manner. This behaviour partly looked like a Mauthner cell induced C-start, although the reaction was not identical to the reaction described by Wardle *et al.* (2001) for saithe (*Pollachius virens*). It does however suggest that the fish was scared or disturbed. To find out what caused this response, the videos were checked for this behaviour, and by comparing results for the different categories, before, during and after seismic shooting, it has been explored whether there could exist a possible link between fish behaviour and seismic shooting activity.

The fish location was registered by counting the fish observed by that camera in the lover part of the cage. Supposing that no fishes were hiding in the sand, the other fishes stayed in the upper part of the cage. During the experiment it was possible to see if the fishes changed their position in the cages.
The analysis of the video recordings has been a very time consuming task, and the results were not finished before this report was printed. A comprehensive work will be published later as part of a M. Sc. Thesis (Kristian Skaar, UiB).

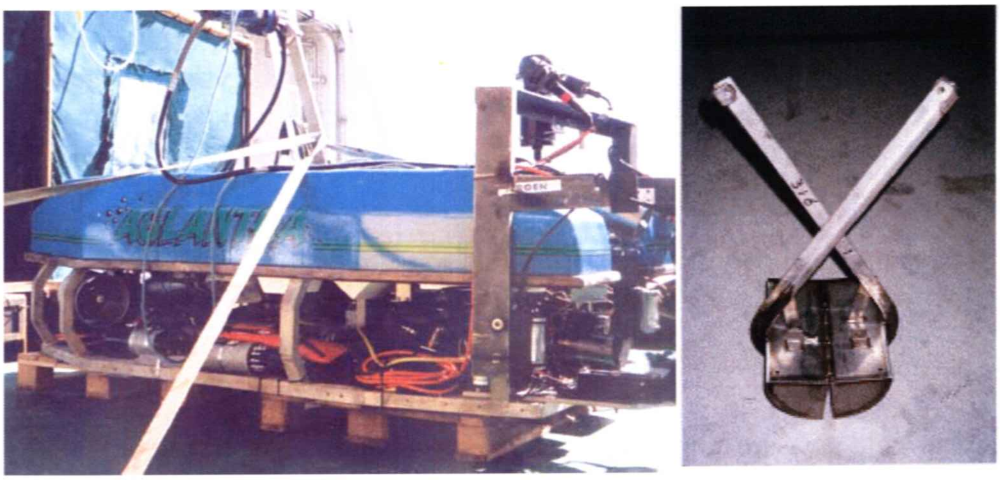


Figure 3.7. Left: The ROV "Aglantha" on board RV "Håkon Mosby". In the background a cage showing the observation window. Right: Van Veen grab, in closed position.

3.8 Seismic equipment and acoustic characteristics

One of the main requirements to the seismic equipment and instrumentation was that it should be typical for what is being applied during 3D investigations on the Norwegian shelf and have equivalent acoustic performance and characteristics. After formal requests to 6 seismic operators and 9 oil companies working at the Norwegian shelf we established a constructive cooperation with PGS AS. After preliminary contacts, exchange of information and contract negotiations the SV "Falcon Explorer" was hired to be available for approximately 3 days of seismic shooting in the period May 10-13, 2002.

The operative parameters of the applied airgun set-up are presented in Table 3.2. The airgun array was configured as follows:

- 11 single airguns ,
- 10 airgun clusters each of 2 guns.

All together 31 airguns of which 3 guns were inactive (spare) i.e. 28 active guns.
Figure 3.8 shows how the airgun array was configured. Inside each airgun symbol the volume of each gun is given in cubic inches. Figure 3.9 displays the ordinary expressed far field pressure signature of this set-up. Note that the near field/far field transition range is at ca. 9000 m from the array centre. This means that at actual distances between the array and fish in the investigation area, we are in the near field of the airgun array. This implies that the

Table 3.2. Type and magnitudes of main parameters of the applied airgun set-up (Schoolmeesters, 2002).

Parameters	Type/magnitudes
Array (source)	3090T_60_2000_100
Airgun type	Bolt 1900 LLXT
Total source volume	50,6 l (3090 cu.in.)
Operation pressure	140 kg/cm^2 (2000 pound/sq.in)
Depth of source	6,0 m
Distance between sub-arrays	12,5 m
Extension of array (l x w)	15 x 25 m

displayed pressure signature only adjusted for actual range is not representative for the actual pressure at the fish. The actual pressure amplitudes may be highly variable and is usually lower at near field distances compared to what comes out from the signatures displayed in Fig. 3.9 (Clay and Medwin, 1977).

Recalculating to SI units the maximum figure expressed as sound pressure level will be:
Sound pressure level of the primary pulse amplitude of the far field (9000 m):

$$L_{pff} = 256.9 \text{ dB re. } 1\ \mu\text{Pa re. } 1\text{ m} \quad (1)$$

The more relevant near field pressure amplitude is displayed in Figure 3.10. The sound pressure level of the primary pulse amplitude is now:

$$L_{pnf} = 256.1 \text{ dB re. } 1\ \mu\text{Pa re. } 1\text{ m} \quad (2)$$

Note that the displayed figures and the distributions in Figs. 3.9-3.13 are from simulations. Based on high quality mathematical models the model tools being used to day, the simulated results are found representative for real measured figures as evaluated both by the seismic operators (producers/users) and the oil companies (users) as have been verified through controlled measurements.

To get an impression of how the sound energy is distributed by frequency Fig. 3.11 shows the amplitude-frequency spectrum of the pressure signature of Fig. 3.10. Such a spectrum (for seismic applications) does not show the total real energy distribution by frequency of the sound stimulus while the received signal may be both high pass and low pass filtered. In this case a low pass filter of cut-off frequency 999 Hz (-3 dB) with 18 dB/octave attenuation is applied. This is also the case for the pressure signature of Fig. 3.10. Particularly for higher frequencies this may yield a distorted presentation of the energy distribution of the stimulus while the hearing width or ability of many fish species extends up to 1000 Hz and beyond that.

The sound energy will have a spatial distribution in the hemisphere below the sea surface as is important to know. This means that the strength of the sound stimulus may be equal to or above the hearing threshold and reaction threshold at long distances before the seismic vessel passes the fish distributions of interest. Fig. 3.12 shows the relative directivity diagram of the pressure along ship and Fig. 3.13 shows the corresponding athwart ship diagram. In the simulations the sound speed is constant over the total depth range and equal to 1506.9 m/s.

Another useful illustration is to see how the stimulus i.e. the sound pressure distributes over the bottom at the present depth (60 m). This is displayed in Fig. 3.14 for an area of extension 60x60 m below the airgun array which centre being at coordinates 0,0.

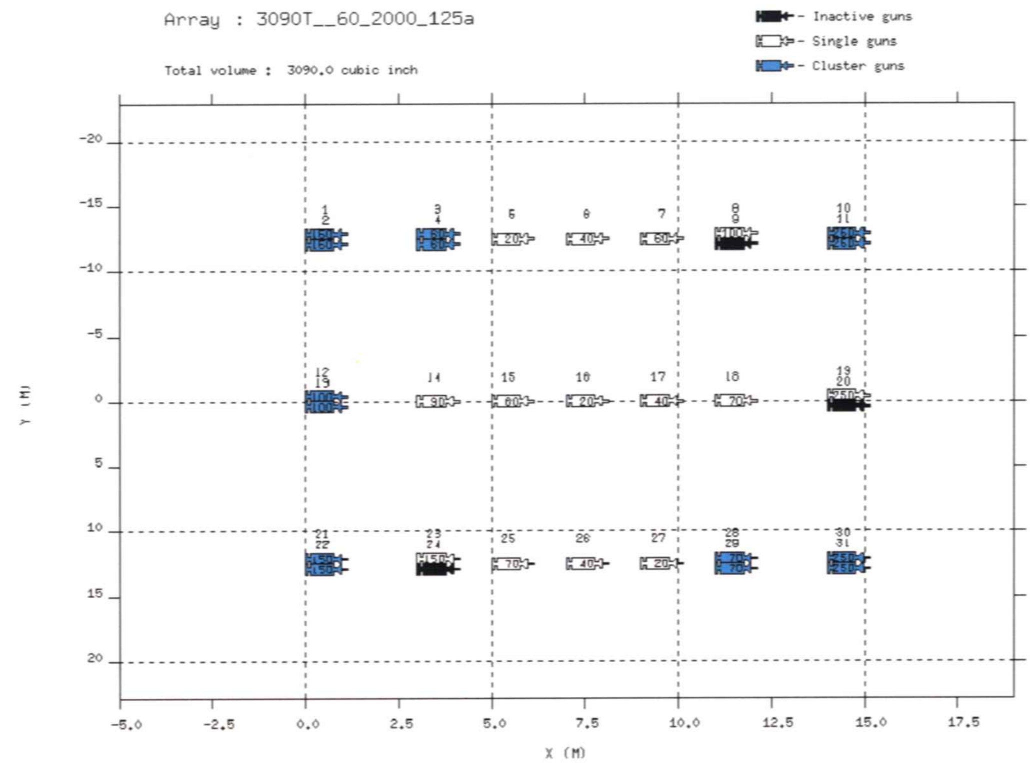


Figure 3.8. Configuration of the airgun array with single airguns, airgun clusters, active and inactive airguns (Schoolmeesters, 2002).

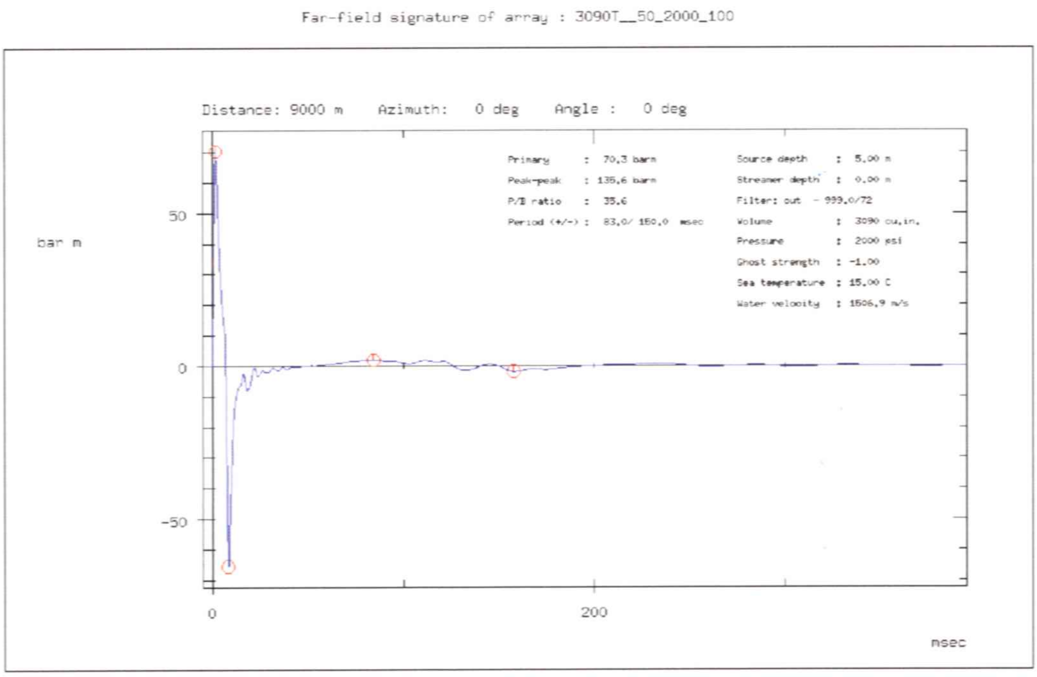


Figure 3.9. Far field pressure signature from the airgun array in barm (pressure in bar referred to 1 m from the source centre) versus time [ms] (Schoolmeesters, 2002).

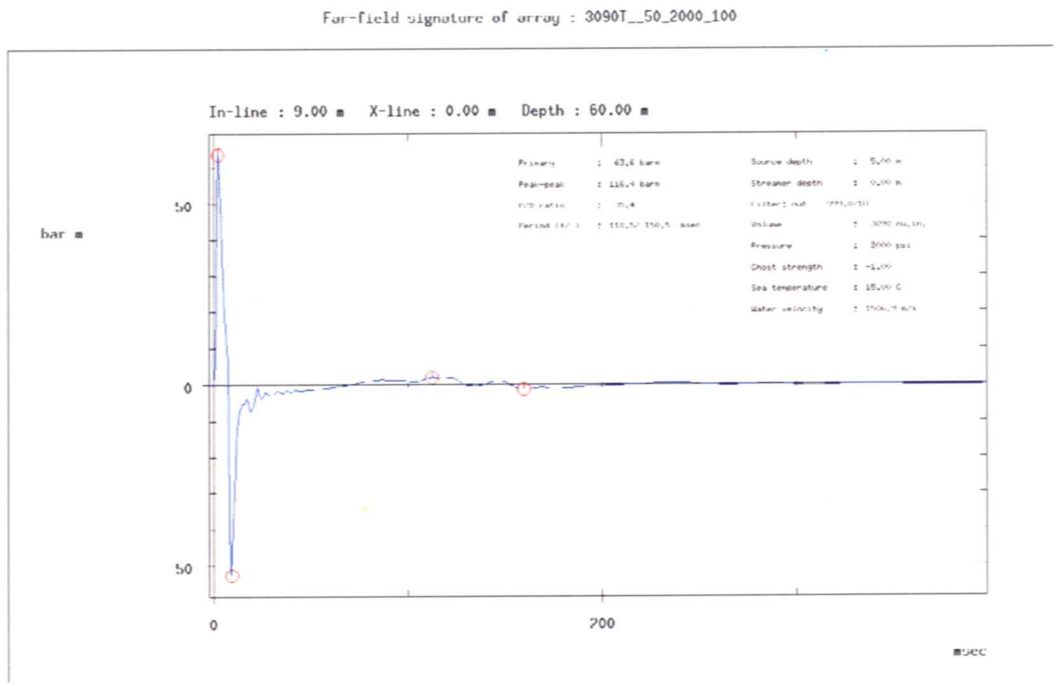


Figure 3.10. Near field pressure signature from the airgun array in barm (pressure in bar referred to 1 m from the source centre) versus time [ms]. Measurement position is x = 9.0 m y = 0.0 m, and depth, z = 60.0 m which means vertically underneath the centre of gravity of the array (Schoolmeesters, 2002). (Note: PGS/"NUCLEUS" expresses this as "far-field signature").

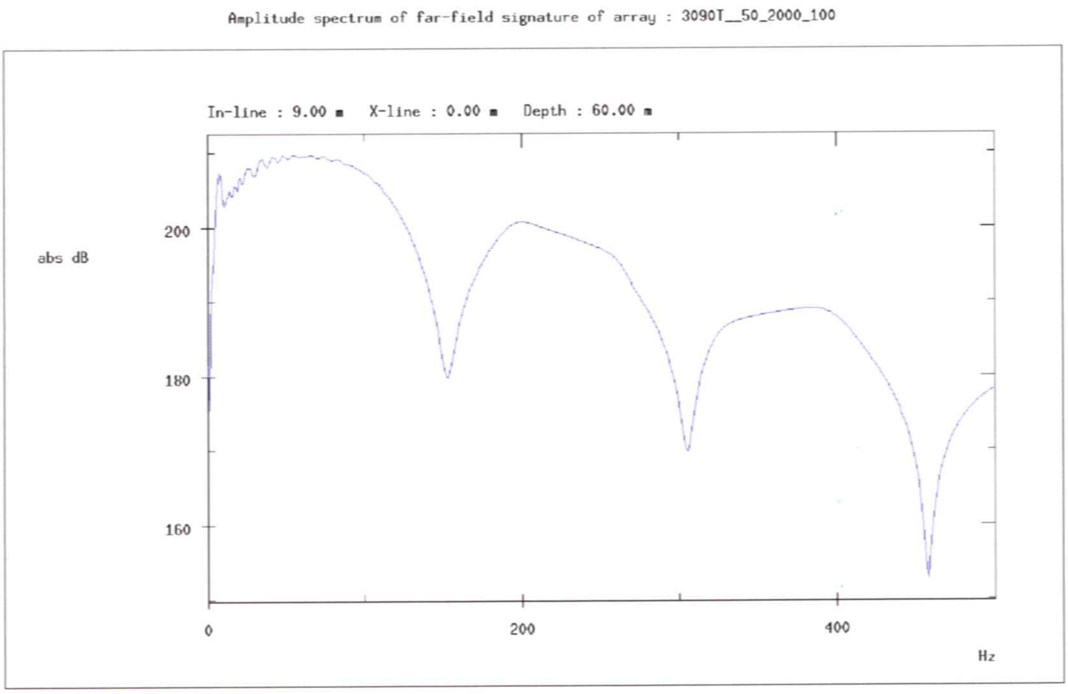


Figure 3.11. Amplitude-frequency spectrum of the pressure signature of Figure 3.13 (Schoolmeesters, 2002).

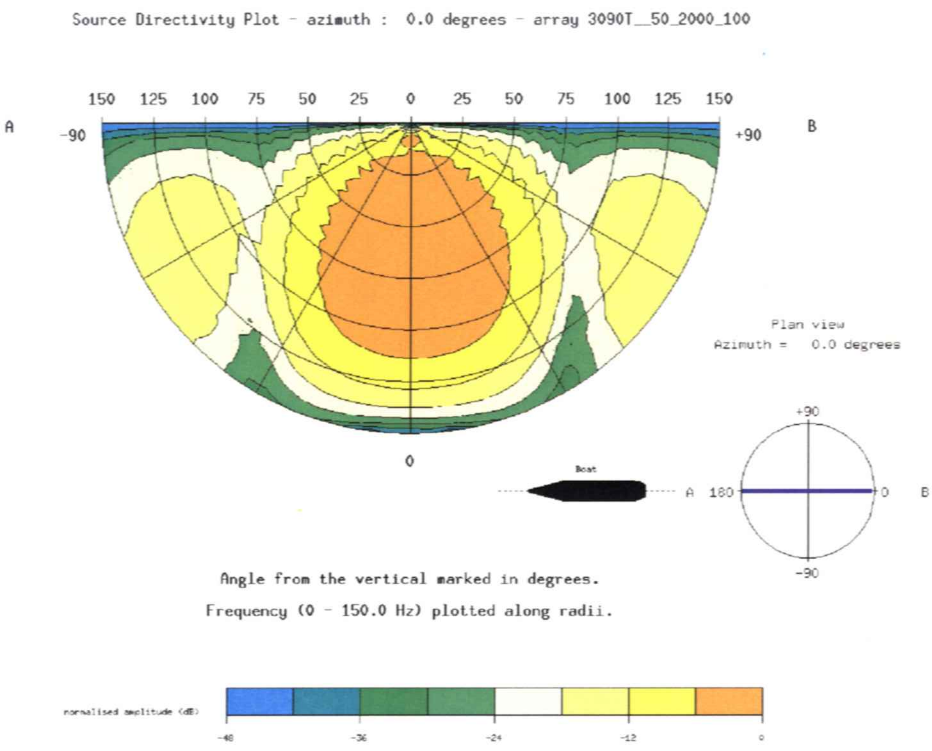


Figure 3.12. Relative directivity diagram along ship. The numbers along the abscissa axis (A-B) indicate frequencies as the directivity response of a given source at a certain angle is frequency dependent. (Schoolmeesters, 2002).

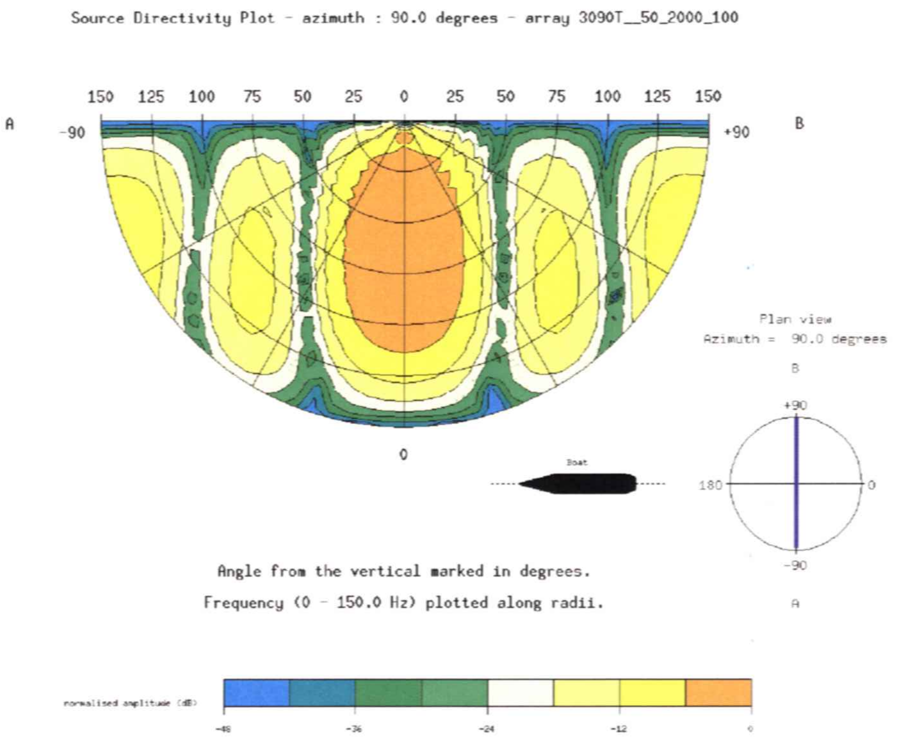


Figure 3.13. Relative directivity diagram of the pressure distribution athwart ship. The numbers along the abscissa axis (A-B) indicate frequencies as the directivity response of a given source at a certain angle is frequency dependent. (Schoolmeesters, 2002).

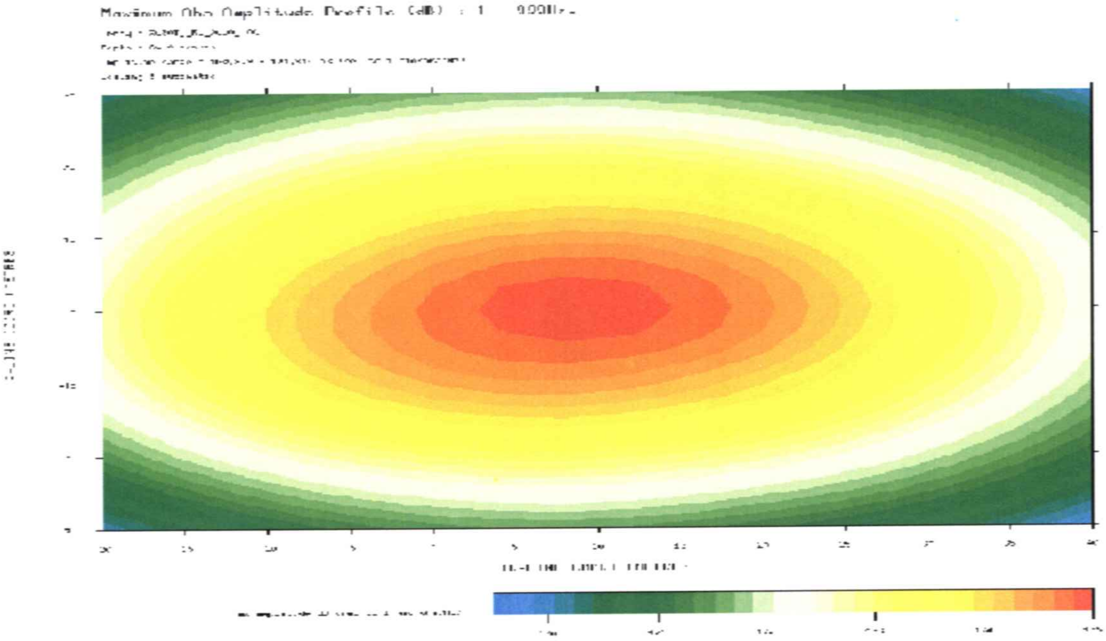


Figure 3.14. Sound pressure as maximum absolute amplitude profile distribution at the bottom at 60 m depth for the frequency range 1-999 Hz. Covered extension area is 60x60 m right below the airgun array which centre being at coordinates 0,0.

3.9 Shooting area

The seismic shooting with airguns was carried out by the seismic vessel SV "Falcon Explorer". The procedures were the same as for 3D-investigations, except that hydrophones for receiving data were not used. The shooting was confined to an area measuring 10x10 km with centre at the position of the experiment cages (Figure 3.15-3.17). The shooting was done along lines 10 km long, with courses 45°/225°. Distance between lines was 300 m, and the number of lines was 33. The lines close to the cages were adjusted to avoid too close passage.

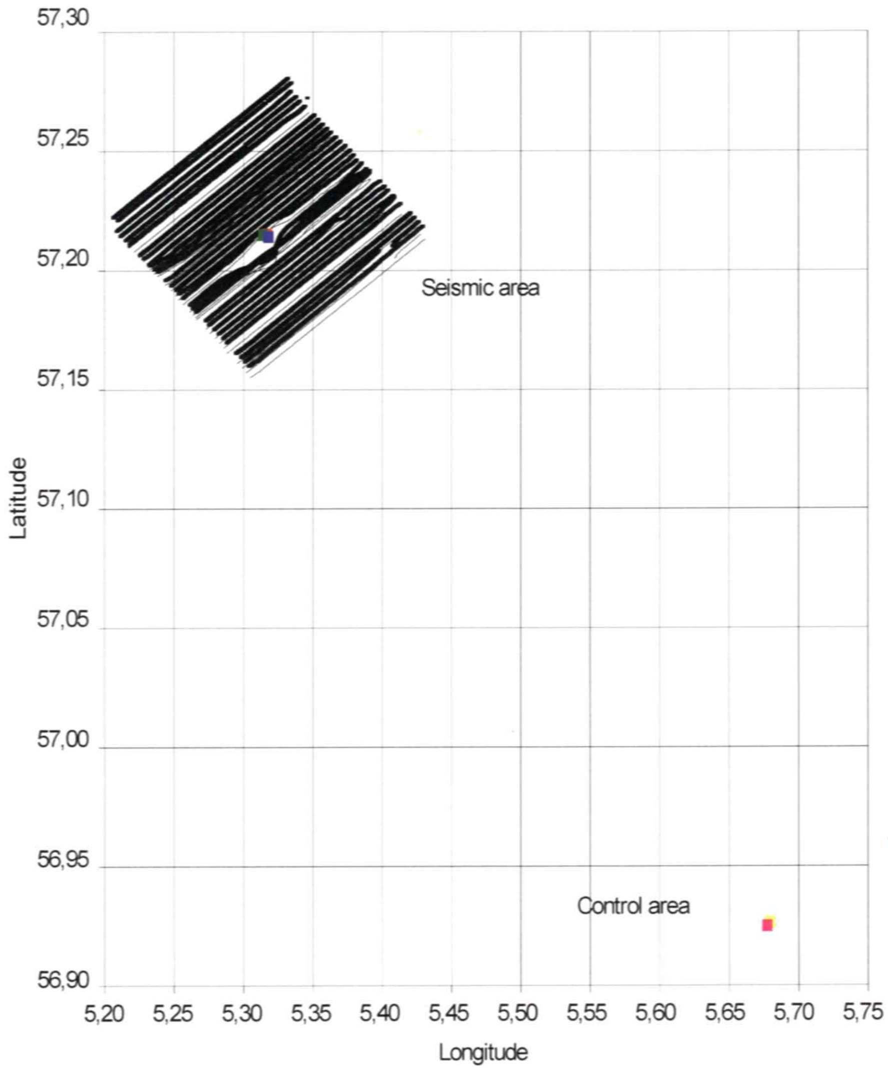


Figure 3.15. Seismic shooting lines and cages (squares) in the seismic area and control area.

The seismic shooting started in the western corner of the seismic field on May 13 at 10:30 UTC, and lasted until May 15 at 18:13. The shooting order of the lines is shown in Table 3.3. During the first and the last day of shooting one of the cages was surveyed using the ROV at daytime, but bad weather conditions prevented the use of ROV on the second day. However, continuous recordings were obtained from the video cage during daytime through out the shooting experiment.

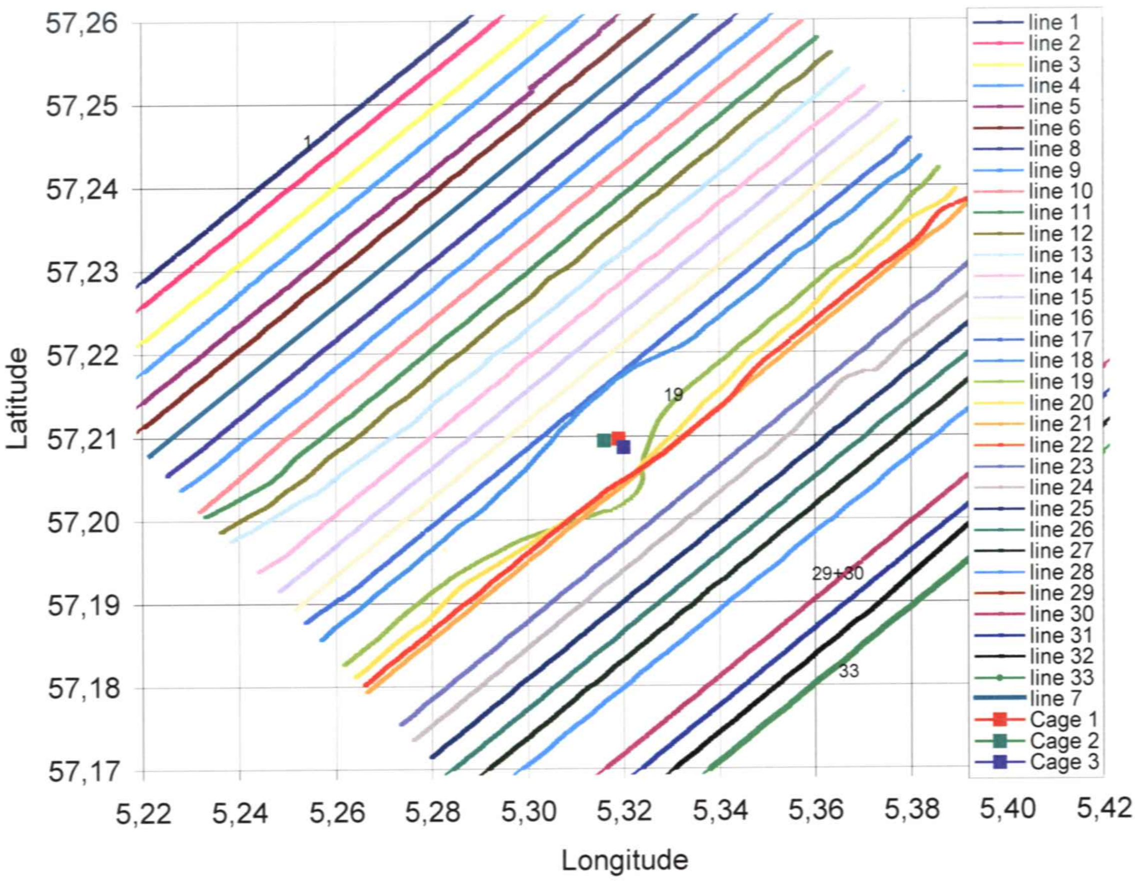


Figure 3.16. Seismic lines in the experimental area. Line 29 and 30 along same transect.

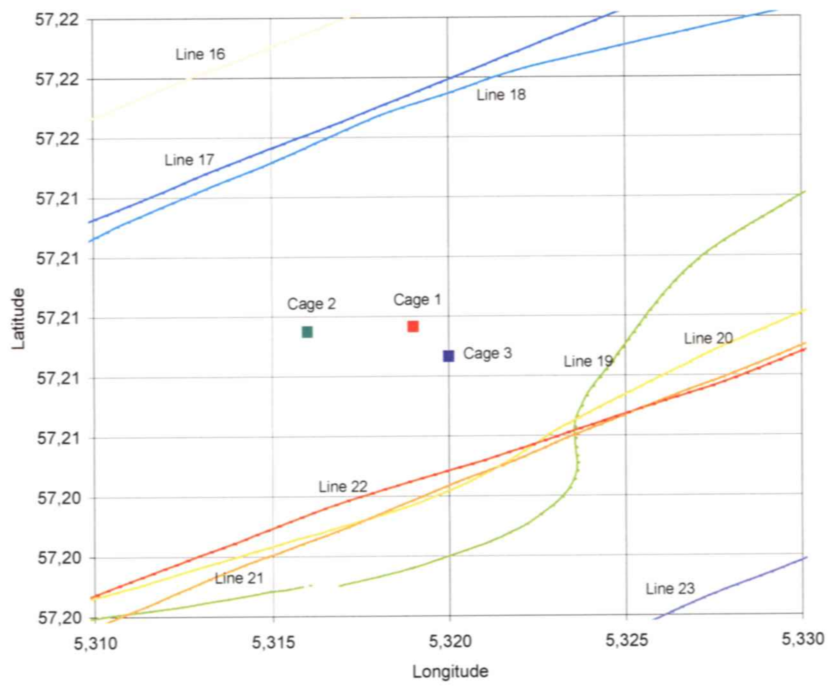


Figure 3.17. Details of seismic lines in the area of the experimental cages

Table 3.3. Shooting sequence of the seismic lines. Time as UTC.

Sequence	Line ID	Date	Soft-Start	Full Volume	End of line
1	fishoot01	13/05/02	10:09	10:30	11:43
2	fishoot07	13/05/02	11:55	12:10	13:20
3	fishoot02	13/05/02	13:33	13:48	14:56
4	fishoot08	13/05/02	15:10	15:25	16:36
5	fishoot03	13/05/02	16:45	17:02	18:18
6	fishoot09	13/05/02	18:30	18:45	19:55
7	fishoot04	13/05/02	19:00	19:15	21:36
8	fishoot10	13/05/02	21:45	21:57	23:12
9	fishoot05	13/05/02	23:20	23:40	00:53
10	fishoot11	14/05/02	01:09	01:21	02:35
11	fishoot06	14/05/02	02:49	03:01	04:15
12	fishoot12	14/05/02	04:42	04:46	05:56
13	fishoot18	14/05/02	06:19	06:31	07:45
14	fishoot13	14/05/02	08:02	08:19	09:23
15	fishoot19	14/05/02	09:41	09:50	11:05
16	fishoot14	14/05/02	11:14	11:29	12:43
17	fishoot20	14/05/02	12:53	13:10	14:22
18	fishoot33	14/05/02	14:45	15:00	16:16
19	fishoot28	14/05/02	16:26	16:43	17:59
20	fishoot32	14/05/02	18:10	18:30	19:44
21	fishoot27	14/05/02	19:59	20:12	21:30
22	fishoot31	14/05/02	22:58	23:07	23:09
23	fishoot26	14/05/02	23:26	23:35	00:51
24	fishoot30	15/05/02	01:10	01:17	02:33
25	fishoot25	15/05/02	02:46	02:56	04:13
26	fishoot29	15/05/02	04:30	04:39	05:53
27	fishoot24	15/05/02	06:09	06:19	07:35
28	fishoot17	15/05/02	08:00	08:10	09:25
29	fishoot23	15/05/02	09:44	09:59	11:14
30	fishoot16	15/05/02	11:24	11:38	12:58
31	fishoot20II	15/05/02	13:10	13:25	14:40
32	fishoot15	15/05/02	15:03	15:18	16:29
33	fishoot21	15/05/02	16:39	16:57	18:13

3.10 Echosounder measurements

More or less continuous echosounder measurements were performed during the experimental period using the Simrad EK500 scientific echosounder operating at 38 and 120 kHz. The Bergen Echo Integrator (BEI) was used to store the relevant acoustic data in a database, as well as for inspection of the acquired data during the cruise (Foote *et al.*, 1991). The shallow experimental region favoured a 0-100 m echosounder range setting.

The sandeel has no swimbladder and from an acoustic point of view they are less subject to being detected than fish having swimbladders by usual settings of the echosounders i.e. total amplification and threshold figures. In this context the amplification should be increased and the threshold should be reduced.

The narrow beam width (approximately 7°) of the 38 and 120 kHz transducers makes the observation volume down to depths of 50-60 m somewhat restricted. Hence, extracting small shoals of the target species using the present post-processing software (BEI), was sometimes difficult. Special software was needed to pre-process the acoustic data (Korneliussen, pers. comm.), applying an averaging scheme that used the information in every ping return within a 5-nautical mile sailed distance. This resulted in 1000 averaged returns to be processed instead of using only a subset of 1000 equidistant returns, which is the default in BEI.

Echo integration

The primary acoustic datum is a value of volume backscattering strength, S_v, for a particular range interval. Mathematically, this quantity is the logarithm of the corresponding volume backscattering coefficient s_v,

$$S_v = 10 \log_{10}(s_v) \qquad \text{dB re 1 m}^{-1} \qquad (3)$$

The coefficient is the cumulative backscattering cross section of all scatterers per unit volume in the defined volume

$$s_v = \rho \langle\sigma_{bs}\rangle \qquad \text{m}^{-1} \qquad (4)$$

where ρ is the volume density of scatterers and $\langle\sigma_{bs}\rangle$ is their mean backscattering cross section. The quantities S_v and s_v may be referred to differential volume slices, hence be expressed as continuous functions of range r.

It is often convenient to combine individual values of s_v over a particular range interval in order to define a total measure of backscattering. This is done through the area backscattering coefficient s_a, which is the definite integral of s_v over a certain depth range, r_1-r_2. For reasons of convenience, this quantity is multiplied by the quantity $4\pi 1852^2$, thus defining the nautical area scattering coefficient (NASC), s_A (Foote and Knudsen, 1994, MacLennan *et al.*, 2002),

$$s_A = 4\pi 1852^2 \int_{r_1}^{r_2} s_v(r)\,dr \qquad (5)$$

with the units of square meters of backscattering cross section per square nautical mile.

Because of the intrinsic variability of echoes and their energy due to minute differences in position or orientation of scatterers, it is additionally convenient to average values of s_A over a number of pings. This derived quantity is denoted $\langle s_A\rangle$:

$$\langle s_A\rangle = n^{-1} \sum_{i=1}^{n} s_{A,i} \qquad (6)$$

where $s_{A,i}$ is the figure s_A for ping return i, over which n are averaged.

Resultant numbers of the nautical area scattering coefficient, s_A, were stored in the BEI database with resolutions in depth and horizontal distance of 0.5 m and 0.1 nautical mile respectively, but only the total integrator numbers for the pelagic domain and bottom per 0.1 nautical miles have been used in the present analysis.

The scrutinizing S_v lower limit was –79 dB re 1 m^{-1} for the Bergen Integrator system.

3.11 Fish hearing

Fish can sense both sound strength and direction to sound sources (Hawkins, 1981). The primary signal strength, its frequency distribution and duration, the distance between the sound source and the fish, and the natural background noise are critical factors for sound sensing. Fish reacts stronger to pulsed sound signals (Blaxter *et al.*, 1981) and to signals with rapid rise time (Schwartz, 1985) compared to continuous sound waves. Another important feature to be aware of is that fish often habituates to artificial sound signals which means that reactions to a lasting sound stimulus may diminish by time.

When the source level, SL, is known a very simplified equation calculates the sound pressure level, SPL, as a function of distance, r, for spherical spreading (Engås, *et al.*, 1993). A directivity factor of -10 dB was assumed.

$$SPL = SL \div 20\log r \div 10 \qquad (7)$$

For a fish to detect a sound source the sound strength has to be about 20 dB above the background noise (Olsen, 1969, Engås *et al.*, 1993). A special feature is that fish integrates the actual sound pressure spectrum level both for the prevailing noise and for the sound stimulus over its frequency range of hearing so to represent the sensed sound stimulus the frequency range of hearing should be known. For sandeel the hearing threshold as a function of frequency is not known. For the following rough estimates of detection and reaction distances the pressure spectrum levels are adequate.

A usual applied approximation of the ambient noise spectrum level is about 80 dB re 1 $\mu Pa^2/Hz$ in the frequency range 20-1000 Hz (Clay and Medwin, 1977, Engås *et al.*, 1993), which means that fish can detect a sound signal having spectrum level above 100 dB re 1 $\mu Pa^2/Hz$. The reaction threshold to sound stimuli is higher than the detection threshold and in a low to medium noise environment the difference is estimated to be about 20 dB higher (Hawkins, 1981, Engås *et al.*, 1993). These relations are typical for gadoid fishes having swim bladders.

The estimated sound pressure level of the primary pulse from the airgun array was 256.1 dB re 1 μPa re 1 m (Fig 3.10, equation (2)). The corresponding maximum spectral level is 210 dB re 1 $\mu Pa^2/Hz$ (Fig. 3.11). For both parameters a low pass filter of cut-off frequency of 999 Hz (-3 dB) with attenuation 18 dB/octave has been applied (Schoolmeesters, 2002). By applying the simplified equation (7) to calculate the detection and reaction distances given the sound level, SPL (Engås, *et al.*, 1993), an example under ideal conditions with no bottom boundary yields an estimated detection distance of gadoid fish of 100 km and the corresponding reaction distance of 10 km (Table 3.4).

The sandeel lacks swim bladder and have thus poorer hearing abilities i.e. higher hearing threshold than species with swim bladder (Hawkins, 1981), so the distances may likely be shorter than those presented in Table 3.4. It is also known that reaction thresholds of fish may vary depending on physiological state, condition and time of the year.

Table 3.4. Estimated detection and reaction distances as a function of source spectrum level and estimated detection and reaction sound spectrum levels for gadoid fish.

Source spectrum level [dB re 1 μPa^2/Hz]	Detection distance [km] at 100 dB re 1 μPa^2/Hz	Reaction distance [km] at 120 dB re 1 μPa^2/Hz
210	100	10

3.12 Fishery data collection

Data on landed sandeel catches were obtained from the Norwegian Directorate of Fishery. The catch data were sorted according to the geographical region according to catch location. The landed catch (in Norway or other countries) from the geographical regions closest to the shooting area (Figure 4.14) were analysed on a day-by-day basis and for 7 days periods to reveal possible change in the catches before/during/after the shooting period. The general trend in the fishery on a monthly scale from the whole sandeel fishery in the North Sea and Skagerrak is also shown to expose general trends.

The movement of commercial sandeel fishing vessels was studied on the basis of automatic satellite tracking transmitters placed onboard the vessels. During the shooting period 41 vessels were inside an area of about 34x84 nautical miles covering the shooting centre, data for these vessels were obtained from the Norwegian Directorate of Fishery. The movement of the fleet three days before shooting (10/05; 10:30 - 13/05; 10:30), during the shooting (13/05; 10:30 - 15/05; 18:13) and three days after (15/05; 18:13 - 18/05; 18:13) was studied to reveal possible escapement or attraction of the vessel to the shooting area. The number of received positions varies between vessels and the three time periods. The frequency of received signals is not affected by the shooting, so the positions and number of signals are interpreted to represent movement of the vessels and time they spent at different locations.

4. RESULTS

4.1 Comparing acoustic surveys for sandeel

Predefined acoustic surveys were conducted in the shooting region on 11, 17 and 19 May (Figure 4.1-4.3). An overview of these surveys is given in Table 4.1. An additional acoustic survey was conducted at the end of the experimental period in parallel with a grab survey that covered the entire seismic shooting area. This last survey covered a larger region and has not been included in the present analysis.

In general, the first survey conducted for lesser sandeel (*Ammodytes marinus*) on 11 May prior to the seismic shooting in the seismic shooting region, showed quite low values on all major transects (Line 1-2, Line3-4, Line 5-6, Line 7-8 and Line 9-10, but with a few higher values irregularly spaced along the survey track (Figure 4.1 and Table 4.1). The lesser sandeel seemed to have a quite patchy distribution, as was also evident from the echosounder during survey time. Most typically schools of sandeel, when observed, were extending from very close to the bottom and 20-30 m into the pelagic domain, but sometimes schools were seen in the water column only, clearly "cut-off" from the bottom region. In Table 4.1 the average values of acoustic backscattering are given and some additional statistics for individual survey transects.

In Figure 4.2 the integrated acoustic backscattering for the second survey conducted in the seismic shooting region on 17 May 2002 is shown. That is, after the seismic experiment was terminated. Again it is observed that the majority of acoustic abundance values for lesser sandeel are quite low, but with irregularly spaced values that are significantly higher, again evidence of a quite patchy distribution.

Comparing the sandeel abundance, as an overall mean per 0.1 nautical mile sailed distance, we obtain an average s_A of 29.16 m^2/nm^2 and 46.1 m^2/nm^2 for the pre-seismic shooting and post-seismic shooting survey respectively. This means that for both surveys the acoustic abundance of sandeel was quite low in the experimental region, but in fact slightly higher after the seismic shooting. A particular feature can be seen from Figures 4.1 and 4.2 that transect 5-6 on 17 May seem to have higher values of sandeel abundance than what was observed prior to seismic shooting.

The third and last acoustic survey presented here in the seismic shooting area was conducted on 19 May about three days after the seismic shooting was terminated. Figure 4.3 gives an overview of the acoustic registrations of sandeel during the survey. Again we observe the patchy nature of the registrations, quite in concordance with the raw echosounder registrations seen during survey time, where scattered schools were located irregularly along the survey track.

Compared to the previous surveys but with the exception of transect 5-6, Survey 3 had significantly higher abundance values for sandeel then any of the other surveys (See Table 4.1). Also during this survey the patchy nature of the registrations stand out as a characteristic feature. The overall mean sA per 0.1 nm was as high as 272.34 m^2 nm^2, being nearly 10 times as high as the comparable figure for Survey 1, although smaller differences can be found if individual transects are compared.

Table 4.1. A compilation of the echo integration results on sandeel presented as the Nautical area scattering coefficient sA for each separate survey transect during the three surveys on 11 May, 17 May and 19 May. The survey transects are numbered from north-west to south-east. The numbers from 1 (start) to 10 (end) represent each corner of the survey. * One single extreme value was found near the end of transect 9-10. This value is considered an outlier and has been replaced by a value of 29 identical to what was measured prior to and just after the extreme value.

11 May 2002	Transect 1-2	Transect 3-4	Transect 5-6	Transect 7-8	Transect 9-10
Average sA	22.15	58.20	16.50	24.62	24.25
Std	11.83	104.78	26.33	51.90	74.84
Numbers	62	61	60	61	61
Median	19.0	23.0	8.0	10.0	14.0
Sum sA	1373	3550	990	1502	1479
Overall mean sA	29.16				
17 May 2002	Transect 1-2	Transect 3-4	Transect 5-6	Transect 7-8	Transect 9-10
Average sA	32.40	39.92	84.89	40.12	33.83
Std	113.33	32.73	193.62	167.87	68.39
Numbers	77	77	76	77	78
Median	16.0	29.0	13.5	3.0	7.0
Sum sA	2495	3074	6452	3089	2639
Overall mean sA	46.10				
19 May 2002	Transect 1-2	Transect 3-4	Transect 5-6	Transect 7-8	Transect 9-10*
Average sA	362.90	339.57	35.36	614.77	59.84
Std	1542.90	2206.27	86.63	2829.87	290.69
Numbers	62	61	61	61	76
Median	16.5	22.0	8.0	15.0	14.5
Sum sA	22500	20714	2157	37501	4548
Overall mean sA	272.34				

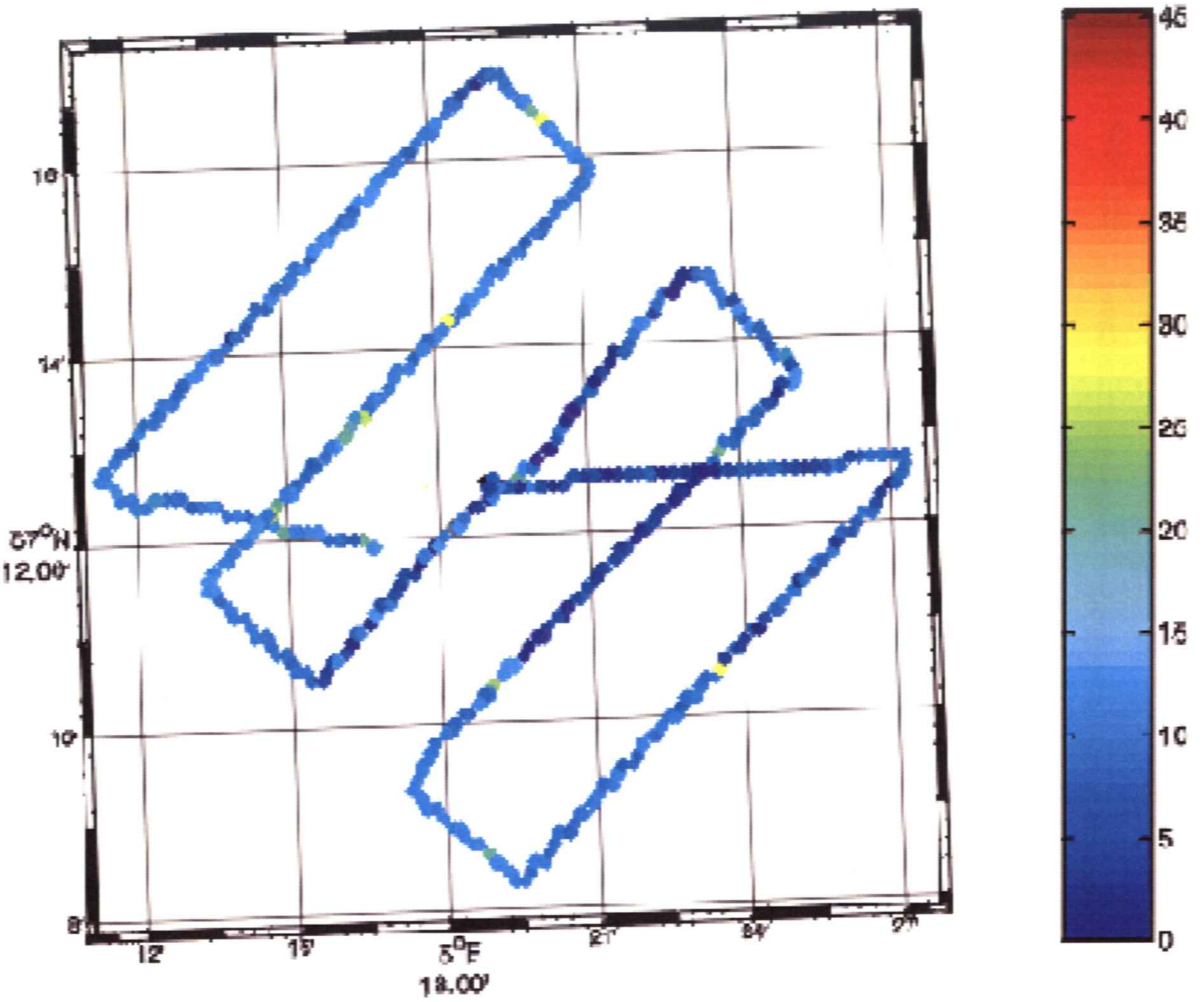


Figure 4.1. Integrated acoustic backscattering at 38 kHz for the lesser sandeel (*Ammodytes marinus*) in the seismic shooting area on 11 May 2002. The panel shows integrated values in the pelagic domain from 10 m below the ship to the bottom. A coloured circle is presented for each 0.1 nm sailed distance along the survey-track.. The colour scale represent the Nautical area scattering strength $S_A = 10 \log 10(s_A)$, where s_A is the Nautical area scattering coefficient (NASC) in m^2/nm^2.

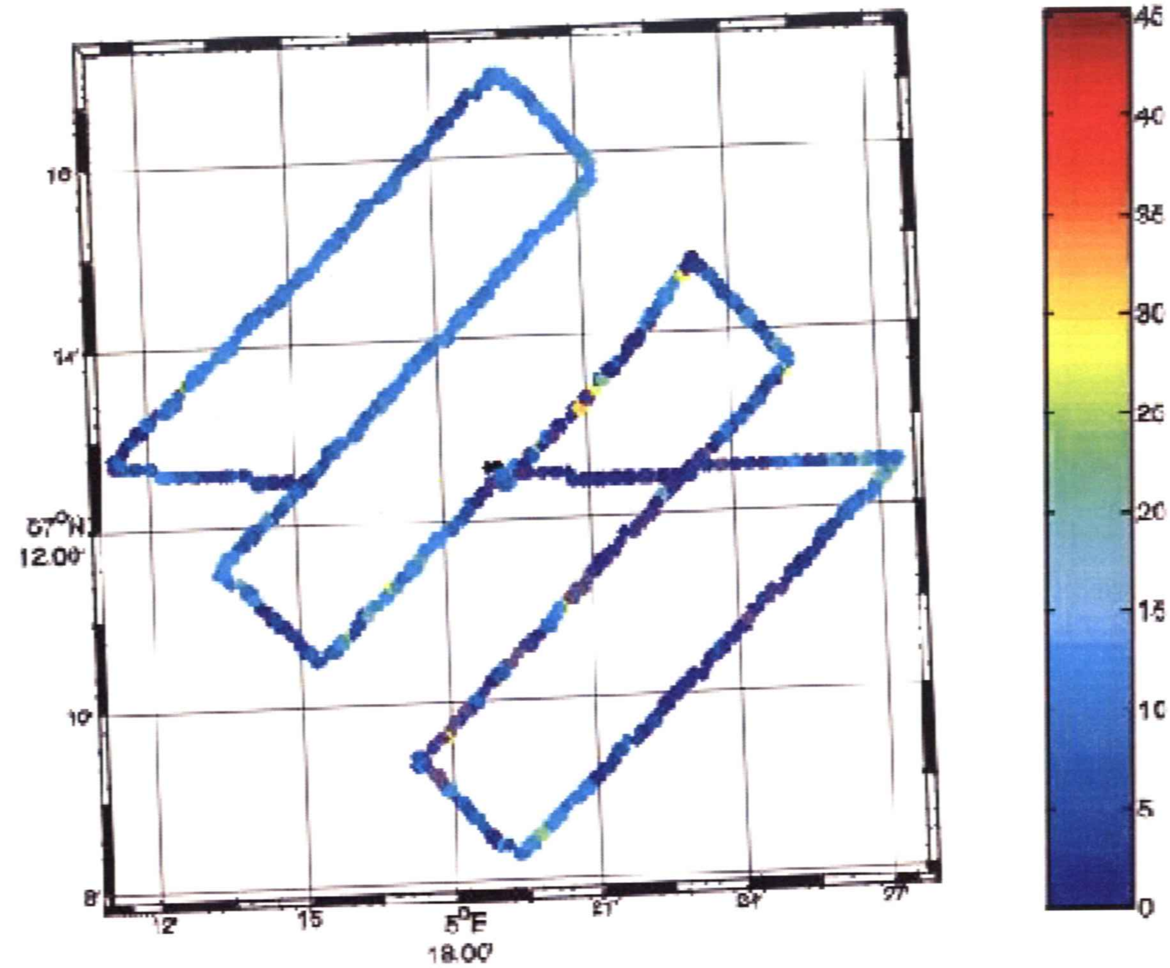


Figure 4.2. Integrated acoustic backscattering at 38 kHz for the lesser sandeel (*Ammodytes marinus*) in the seismic shooting area on 17 May 2002. The panel shows integrated values in the pelagic domain from 10 m below the ship to the bottom. A coloured circle is presented for each 0.1 nm sailed distance along the survey-track.. The colour scale represent the Nautical area scattering strength S_A = 10 log 10(s_A), where s_A is the Nautical area scattering coefficient (NASC) in m^2/nm^2.

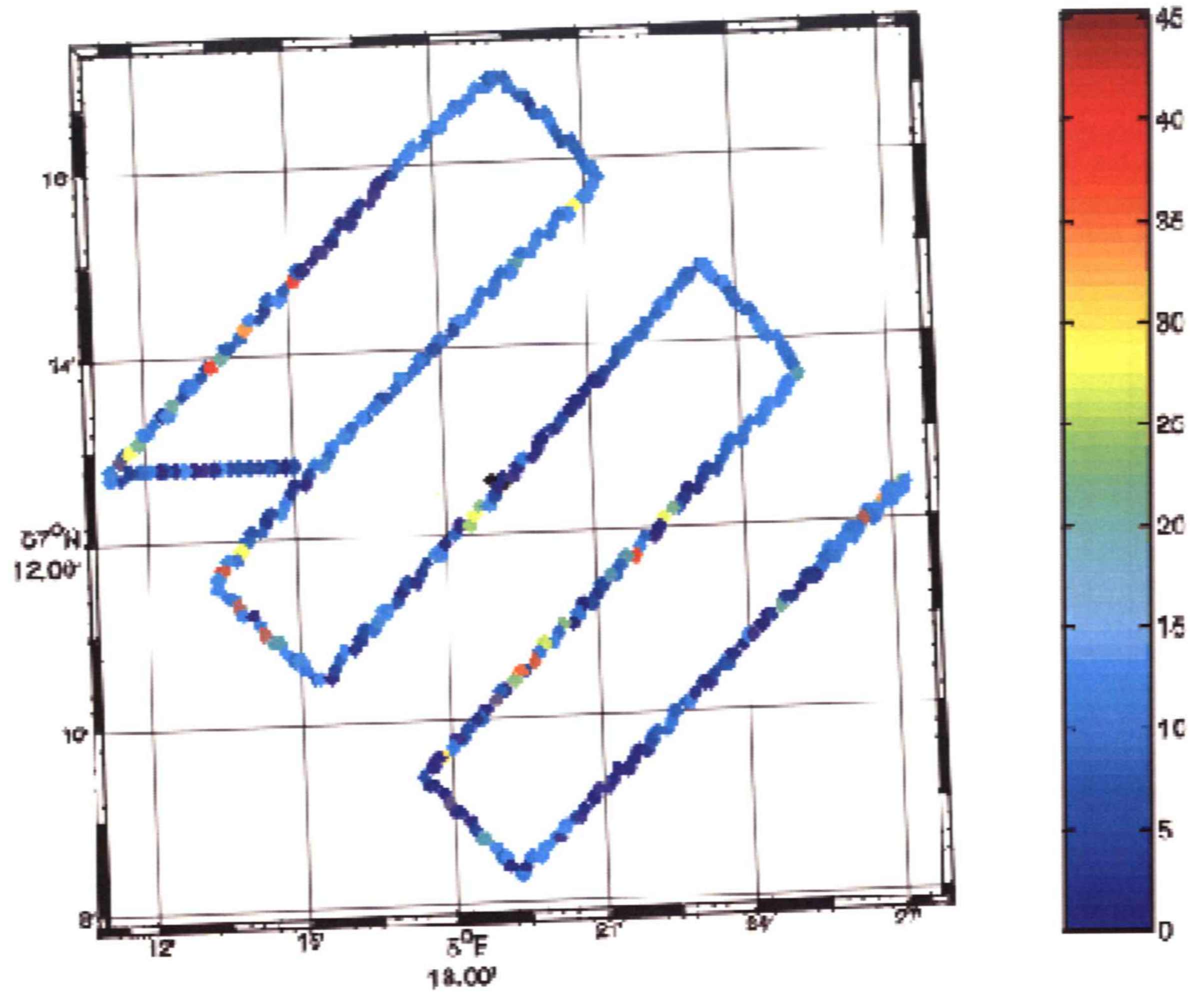


Figure 4.3. Integrated acoustic backscattering at 38 kHz for the lesser sandeel (*Ammodytes marinus*) in the seismic shooting area on 19 May 2002. The panel shows integrated values in the pelagic domain from 10 m below the ship to the bottom. A coloured circle is presented for each 0.1 nm sailed distance along the survey-track.. The colour scale represent the Nautical area scattering strength $S_A = 10 \log 10(s_A)$, where s_A is the Nautical area scattering coefficient (NASC) in m^2/nm^2.

4.2 Grab catches

The sand quality was checked during grab sampling by noting "fine sand", "medium sand" and "coarse sand". In addition sand samples were collected for grain size distribution analysis in the lab. The results for the three groups are shown in Figure 4.4. The medium sized sand was dominated by particle sizes at about 0,3 mm. The large majority of samples contained pure sand; gravel or stones were present in a few cases (Appendix table 1 a-d).

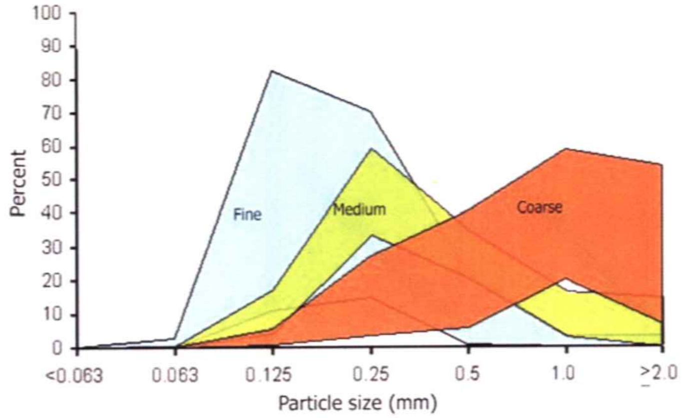


Figure 4.4. Distribution of particle size in three categories of sand from the grab. Upper lines, maximum percent. Lower lines, minimum percent.

With exception of some sandeels that were killed by the closing jaw of the grab, all individuals captured were alive and seemed to be in good condition, both before and after the seismic shooting. The total numbers of sandeel present in the samples are listed in Appendix 1a-d. The horizontal distribution of the grab stations and the fish cage positions is shown in Figure 4.5. The highest frequency of grab samples containing fish was observed in the seismic (experimental) area, and the numbers of fish were also higher here than other places (Figures 4.5-4.8).

When all 195 grab samples are considered, only 27 where taken at daytime between 05:00 and 21:59. Out of these 25 were empty. During the nights, 117 out of 168 grabs contained no fish. Figure 4.9 clearly demonstrates the presence of sandeel in the sand during the night, and the absence during the day, when all samples are plotted along a 24 hour axis.

The central seismic area between 57,205 and 57,214°N, and between 5,308 and 5,328°E was sampled with grab on successive nights from May 12 to May 19, except on May 14 and 15 (Figure 4.8). All the sampling was done from about midnight until early morning when the sandeel was buried, thus the results from the different days could be compared. The number of grabshots varied from 11 to 16 (only 4 on May 13). Throughout the period the highest concentrations of sandeel were found north of the seismic cages, indicating that the sandeel was relatively stationary or preferred the substrate in this area. The distribution of fish before and after the seismic shooting is compared in the lower panels in Figure 4.8. The number of samples was lower before seismic shooting (18) than after the shooting (58). The highest numbers of fish were observed after shooting, with 15 or more fishes in 9 of the grab samples. There were no observations of dead sandeels or signs of reduced condition in the latter group. Numbers of individuals before and after shooting are also shown graphically along a 24 hours time axis in figure 4.10. The span in numbers seems to be about the same for the two groups, but the average catch was somewhat higher after shooting than before shooting (Table 4.2). During the night, the proportion of number of samples without sandeel to total number of samples was roughly the same before (5 out of 14) and after shooting (25 out of 58).

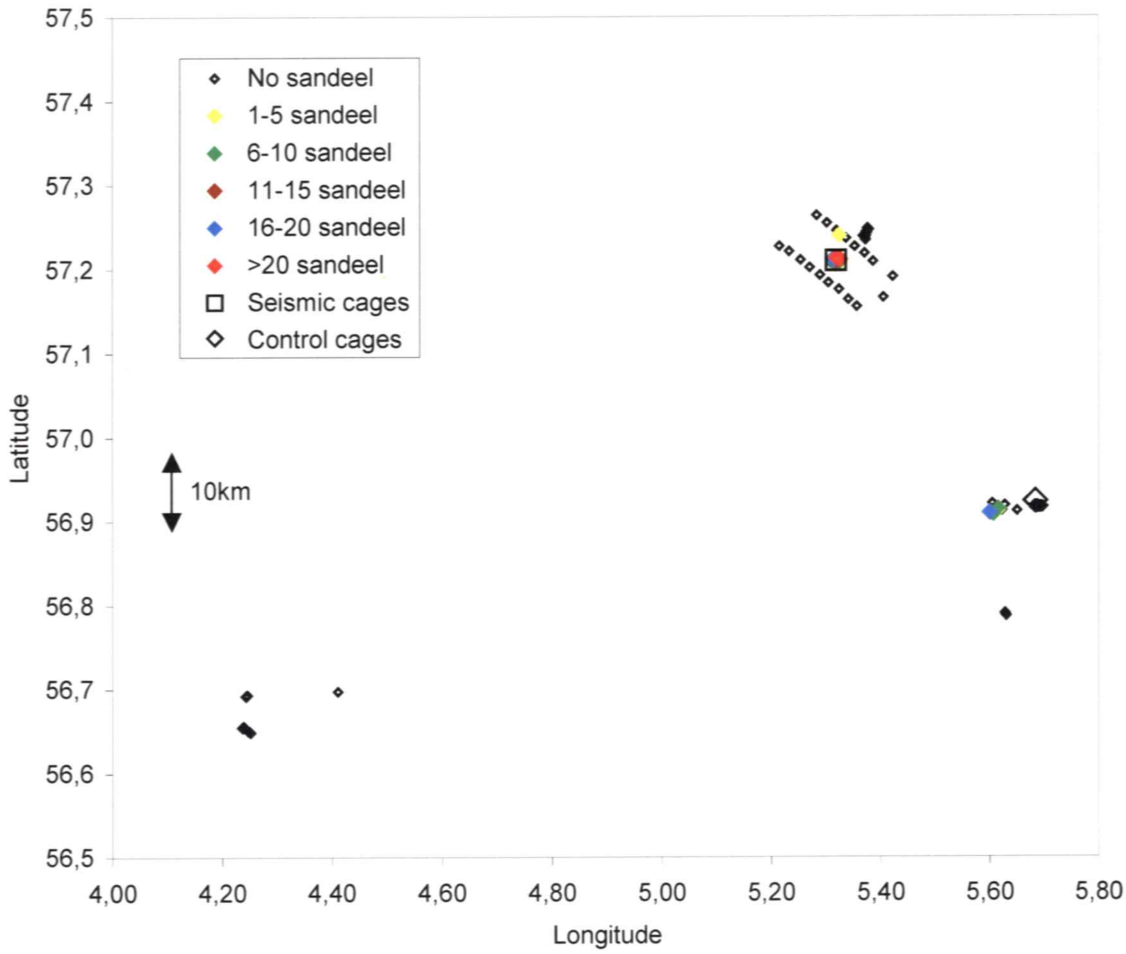


Figure 4.5. Distributions of cages and grab catches from the whole area.

Table 4.2. Numbers of sandeel caught with grab in the seismic area before and after seismic shooting.

		Before shooting	After shooting
Day and night	Average catch size	3,22	5,53
	Nos. of grab samples	18	58
	Nos. of samples without sandeel	8	25
Night (22:00 - 04:59)	Average catch size	4,07	5,53
	Nos. of grab samples	14	58
	Nos. of samples without sandeel	5	25

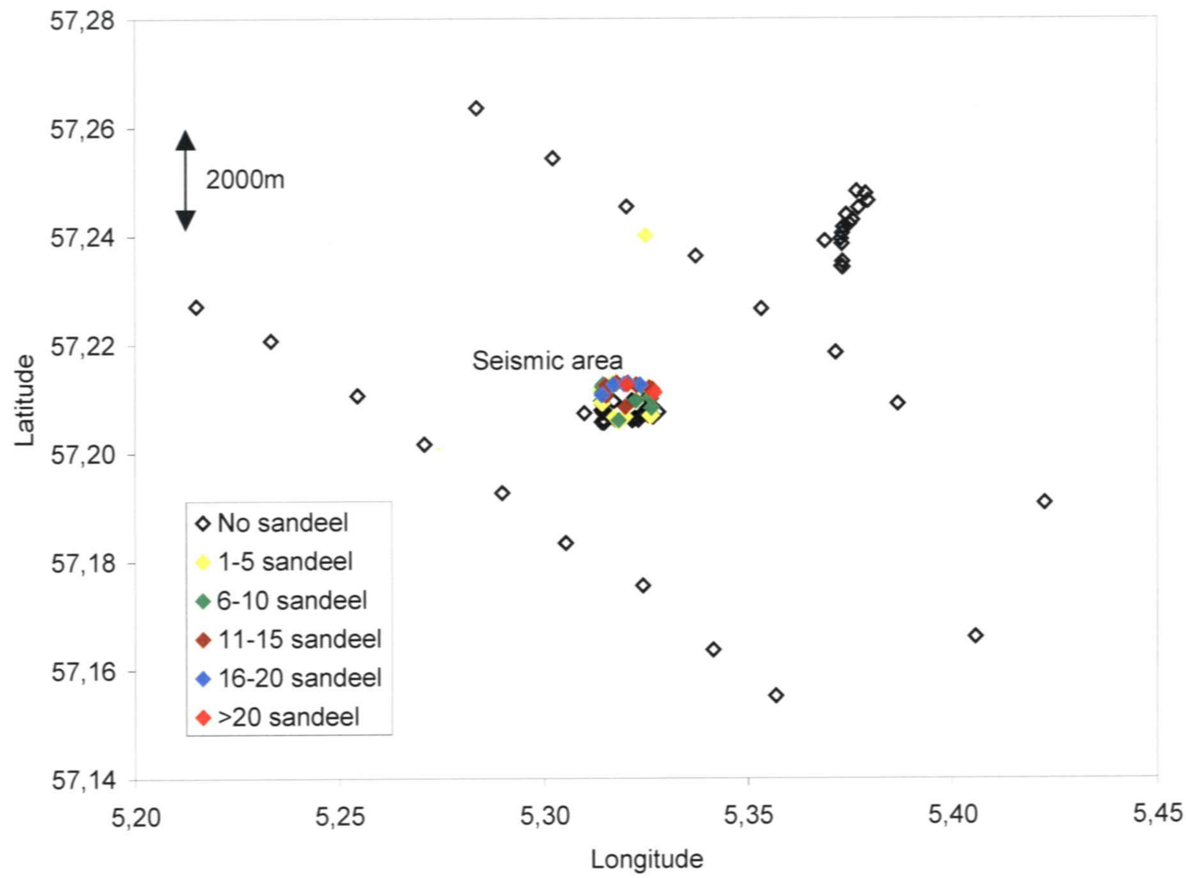


Figure 4.6. Sandeel catches in the seismic area.

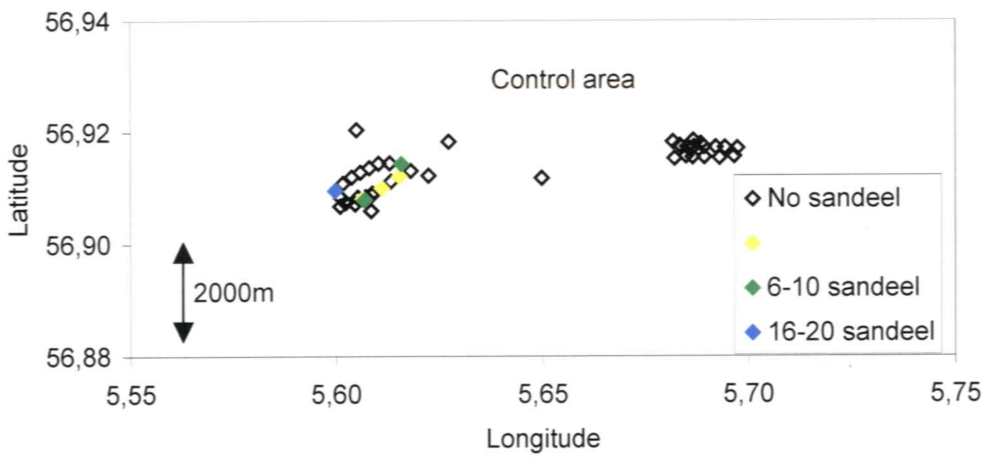


Figure 4.7. Sandeel catches in the control area.

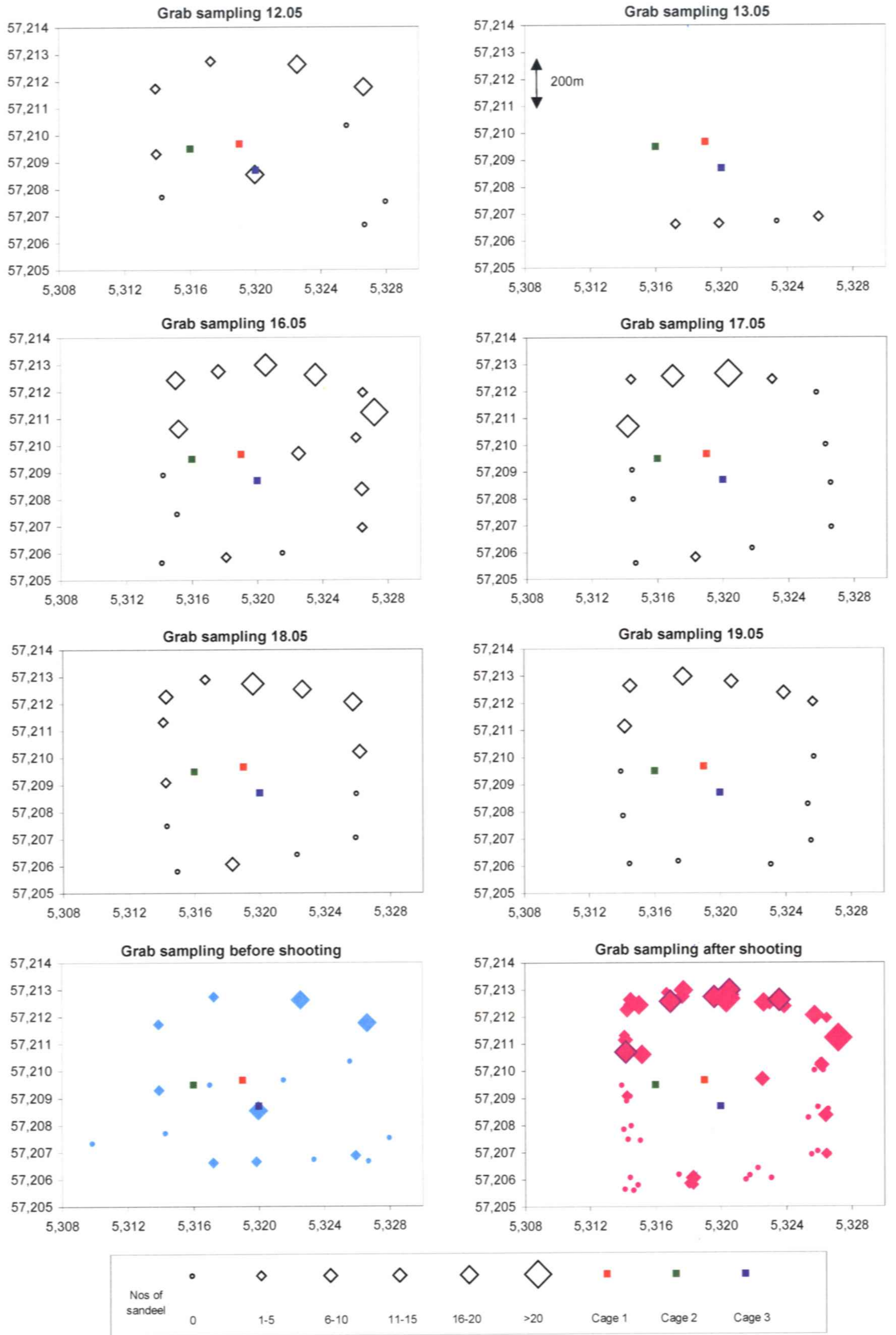


Figure 4.8. Catches of sandeel with grab during six coverages of the seismic area (upper six frames), and catches before and after the shooting, by combining data from the upper six frames (lower frames).

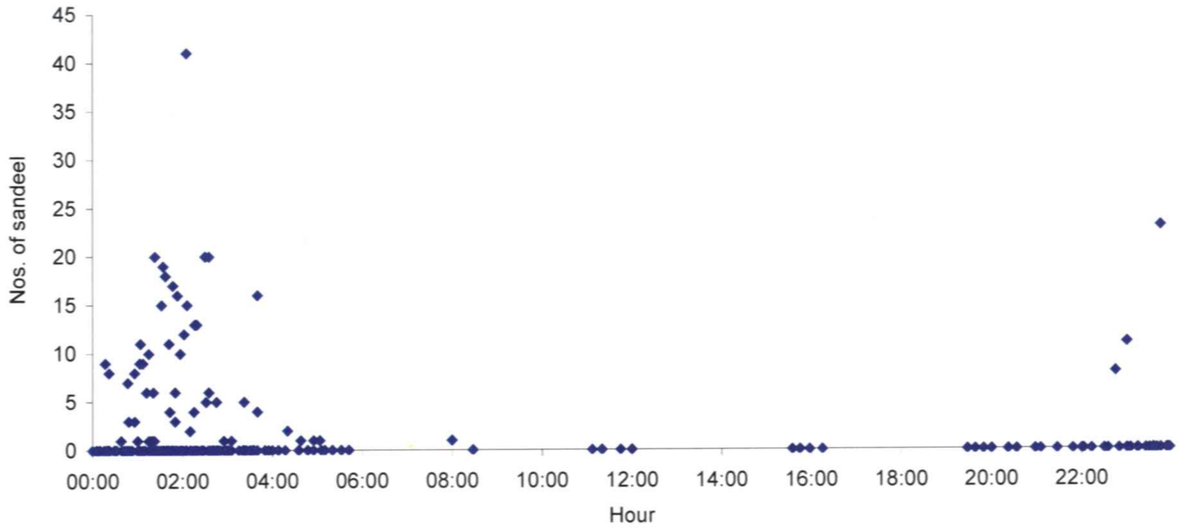


Figure 4.9. Catches of sandeel along a 24 hour time scale. Data from all days and areas included.

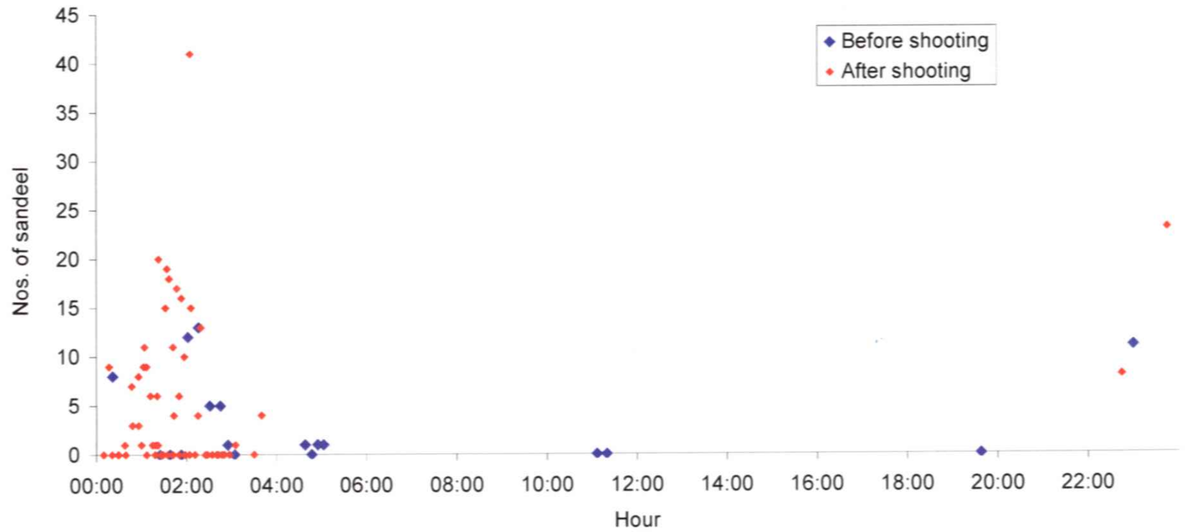


Figure 4.10. Catches of sandeel along a 24 hour time scale, before and after seismic shooting. Data from seismic area only.

4.3 Survival of sandeel in the cages

Cages 1-3 were deployed a few hundred meters apart in the experimental area in the center of the seismic experiment. "Cage with camera" was recovered before the seismic shooting and should thus be considered to belong to the control group (Table 4.3). Cages 4-5 made up the control group, about 40 km southeast of the seismic centre (Figures 3.1 and 3.15). A more detailed map showing the position of the experimental cage group relative to the seismic shooting lines is shown in Figure 3.16-3.17.

Cage 1 and 2 were deployed for 15 days, a longer time than the other cages (Table 3.1). The differences in time of enclosure does not seem to have much influence on the survival rate (Table 4.3). The highest mortality was observed in cage 2 with 50% dead fish, while the mortality in the other cages varied from 19 to 39%. Included in the number of living individuals from the cage experiment was a number of fish with reduced swimming activity. When these sandeels were transferred to containers with running water, many of them still swam slowly and were easy to capture by hand.

Table 4.3. Mortality and condition of sandeel in cages observed after the seismic experiment.

Cage no.	Group	Nos. of sandeel	% alive	% dead	% with mouth injury
1	Seismic	154	68,8	31,2	20,8
2	Seismic	114	50,0	50,0	26,3
3 (with camera)	Seismic	69	81,2	18,8	ca.10
Cage with camera	Control*	378	64,3	35,7	?
4	Control	32	65,6	37,5	?
5	Control	51	60,8	39,2	?

* Cage was placed in the seismic area, but was recovered before shooting

The reduced activity and condition of many individuals can be explained as a result of stress from being enclosed for a long period when normal feeding might have been prevented. Also, the initial condition of sandeels captured with trawl for the control cages was probably not very good.

During video-examination with the ROV many fishes were observed to swim against the net, and even to "hang" with the mouth from the meshes. Many fishes were observed to have damaged mouthparts after the experiment, probably as a result of this behaviour (Table 4.3). This fact may partly explain the mortality and poor condition observed. However, there is no indications from the results in Table 4.3 that the seismic exposure to the fishes in cage 1-3 and the video cage resulted in higher mortality. Practically all fishes were collected from the curtain in the bottom of the cages, and only very few individuals were found inside the closed sandbox.

The fish from the control area (cage 4 and 5) were shorter than fish from the experimental area (Figure 4.11), and the smaller fish seemed to suffer the highest mortality (the number of individuals was low). In the other cages the mortality did not seem to be size dependant. The mortality, and the size/mortality relationship was about the same for sandeels in the seismic area and the control area (Figure 4.12). When the percentage of dead and alive fishes is compared between the experimental and the control group, the result is about the same with approximately 65% survival in both groups (Figure 4.13).

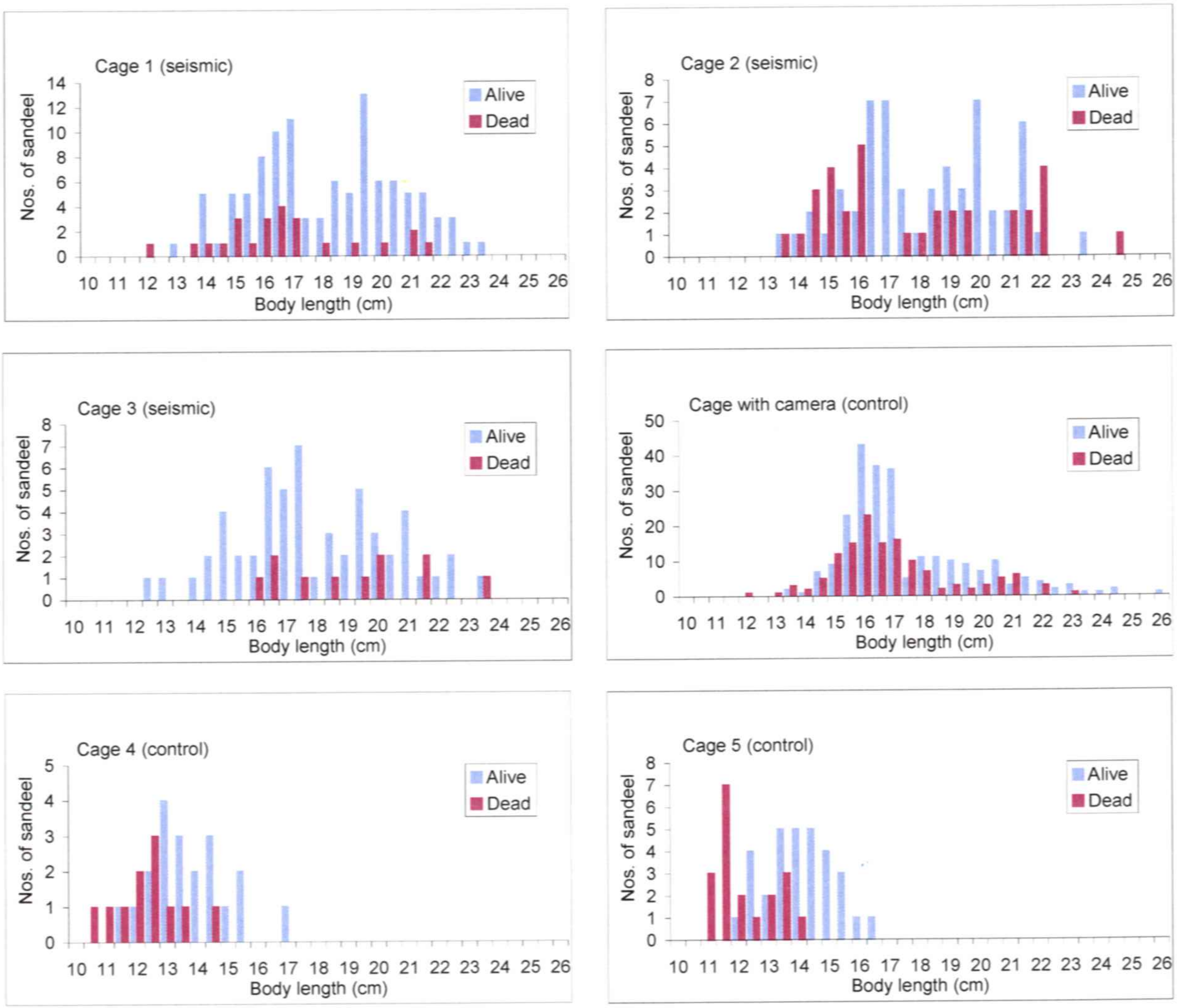


Figure 4.11. Distribution of body length and mortality in the cages.

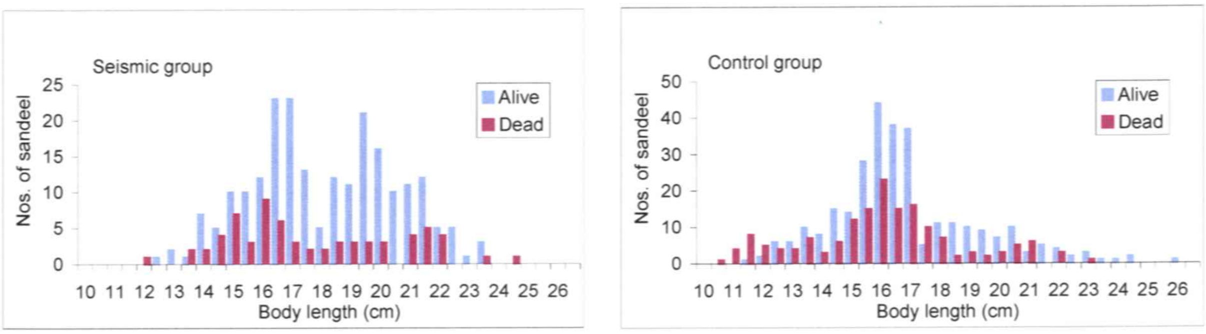


Figure 4.12. Distribution of body length and mortality in seismic cages versus control cages.

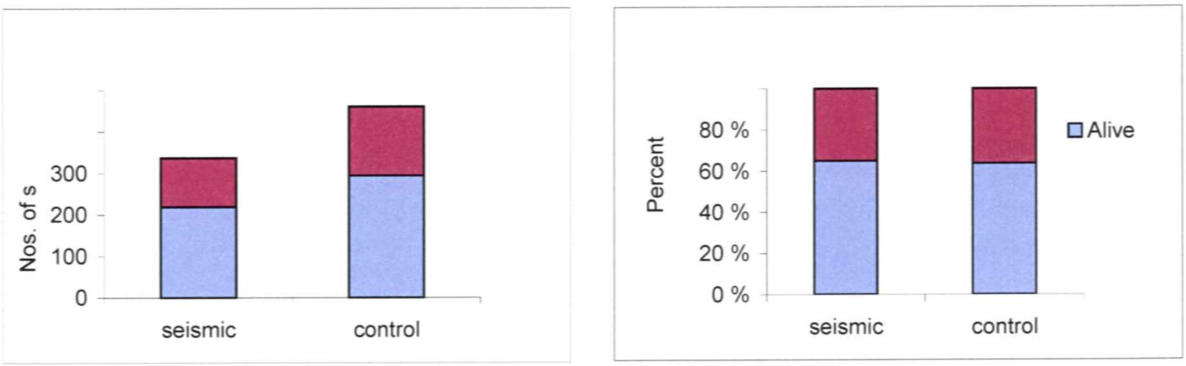


Figure 4.13. Comparison of mortality between the seismic (experiment) group and the control group.

4.4 Video observations

The division of the video recordings into time blocks resulted in 4 blocks before, 59 during and 16 after the shooting period. The total video link recording is approximately 86 hours, where about 40 hours were recorded in sufficient light conditions. Most of the video was recorded during and after the shooting period. A qualitative evaluation on the sandeel behaviour built on the behaviour categories (3.7) is given here.

The fish remained calm in the cages for a long period, but when the seismic vessel had shot half of the lines close to the cages, line 15, 16, 17, 22 and 23, a slight increase in the tail beat frequency was seen. When the distance to the vessel increased, the tail beat decreased to the level before the approach of the vessel. After the shooting period, the fish was still swimming calmly in the cages.

No irregular swimming pattern was observed before the shooting began. During the shooting many individuals performed startles by bending the body and fleeing out of sight. This behaviour was counted as C-start like responses, and is marked in Figure 4.14 as red dots. It should be noted that the plotting could only be done in the time blocks when proper video observations were available. There seem to be no definite trends in the occurrences of the C-start like responses. These responses are spread all over the experimental area, with some indications that the frequency of occurrence is higher on the lines closest to the cages (Table

4.4). After the shooting period the fish calmed down, and only one C-start like response was observed during 16 time blocks or 160 minutes. Appendix table 2 lists the time blocks used for observation of the fish behaviour.

Before and after the shooting, the number of fish below the camera in the video cage was highest, indicating that the fish stayed higher up in the cages during the seismic experiment.

Table 4.4. C-start responses before, during and after seismic shooting.

Period	Seismic line	Time blocks (nos)	Observing time (nos)	C-starts (nos)	C-starts / hour
Before		4	40	0	0
During	1	5	50	9	10,8
During	2	4	40	3	4,5
During	7	4	40	6	9
During	8	4	40	2	3
During	15	5	50	6	7,2
During	16	4	40	10	15
During	17	8	80	14	10,5
During	22	6	60	9	9
During	23	4	40	7	10,5
After		16	160	1	0,38

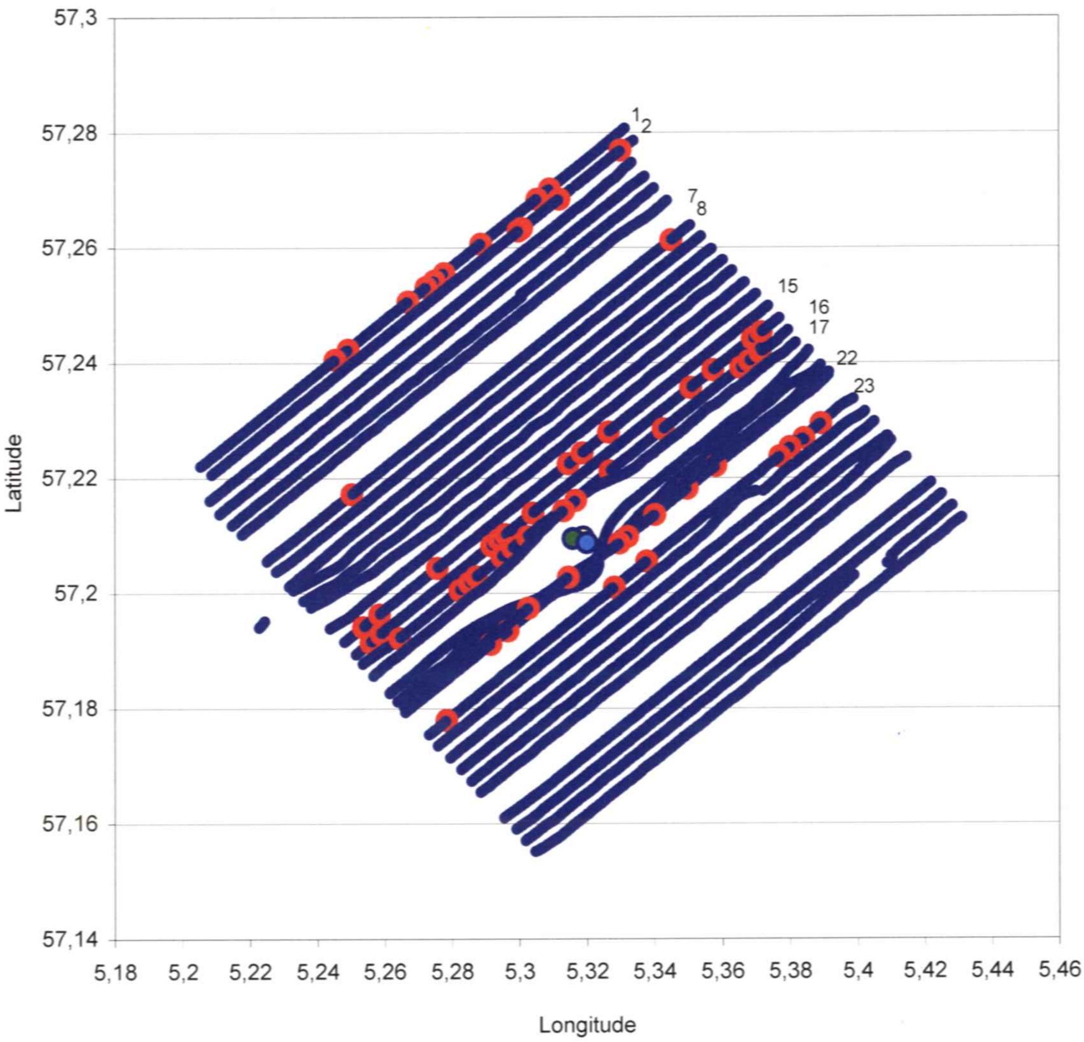


Figure 4.14. Shooting area and seismic lines with red dots indicating the position of the seismic vessel at the time of observation of C-start responses in the time blocks (see Appendix table 2). The number of time blocks varies between the lines.

4.5 Landed sandeel catches

The landed sandeel catch in the different geographical regions close to the shooting area (Figure 4.15) was analysed to reveal possible changes in the catches before/during/after the shooting period (Figure 4.16). Two days (16/05 and 17/05) after the shooting period the sandeel catch from the locations nearby the shooting area was reduced. From 18/05 the catches increased for a few days followed by a general reduction until 29/05. The decreasing trend in landed catches appears clearly when looking at the 7 days periods (Figure 4.16). On a monthly scale, the fishery is still high in June, but the decline due to the seasonal reduction has started (Table 4.5).

Table 4.5. Landed catch of sandeel from the North Sea and Skagerak in 2002.

Month	February	March	April	May	June	July	August	September
Catch (tons)	0	700	62100	83500	24600	100	300	0

4.6 Satellite tracking of fishing vessels

By satellite tracking we received position of 41 different commercial vessels near the shooting area, before, during and after shooting. Vessels with very few registrations or registrations in only one of the time periods were sorted out and 30 vessels were left (Figure 4.17-4.19). The mean distance between the vessels and the shooting centre was calculated for the three time periods (Table 4.6). Before the shooting the mean distance was 27.7 km, increasing to 38.6 km during the shooting and remained nearly identical (38.4 km) in the three day period after the shooting (Table 4.6).

The vessels that were furthest away from the shooting ground were excluded in several steps, by reducing the radius for including the observations from the vessels. With radius e.g. of 9 nautical miles this means that only vessels with registrations closer than 9 nautical miles from the shooting centre was included in the distance calculations. The number of vessels included in the calculations is therefore declining when the radius from the shooting centre is reduced. Twenty vessels had observations closer than 9 nautical miles from the shooting centre. These vessels increased their mean distance to the shooting centre with 10.6 km during the shooting compared to their position prior to shooting (Table 4.6). When the radius for including vessels is reduced from 6 to 1.5 nautical miles from the shooting centre the difference in mean distance before and during shooting increases from 10.1 km to 27.5 km.

Table 4.6. Satellite positions of 30 commercial fishing vessels in an area of 66x84 nautical miles^2 were used to calculate the mean distances to the shooting centre 3 days before, during

and 3 days after shooting. The distances for the 14 vessels with registrations closer than 6 nautical miles from shooting centre are also given individually. The number in parentheses is based on one registration, and is not included in further calculations of the mean. "-" indicates that no satellite position was received for these vessels in the actual time periods.

Scale	Nos. of vessels	Distance(km) Before	During	After
Area ($n.m^2$)				
66x84	30	27.7	38.6	38.4
Radius (n.m)				
9	20	25.1	35.7	35.7
6	14	24.7	34.8	33.8
3	6	17.9	35.1	39.1
2.5	4	15.6	42.1	37.2
2/1.5	2	21.5	49.0	41.1
Individually				
Vessel 10		20.0	43.1	(47.6)
Vessel 12		6.4	54.1	51.4
Vessel 16		21.2	-	25.6
Vessel 18		23.0	55.0	41.1
Vessel 23		-	53.8	53.7
Vessel 25		21.7	34.7	-
Vessel 27		13.0	16.1	19.0
Vessel 29		21.9	17.6	39.3
Vessel 30		24.0	21.0	25.0
Vessel 31		22.3	54.0	27.5
Vessel 34		44.7	-	15.0
Vessel 35		23.0	7.4	45.0
Vessel 36		29.2	-	34.4
Vessel 40		50.3	26.2	28.8

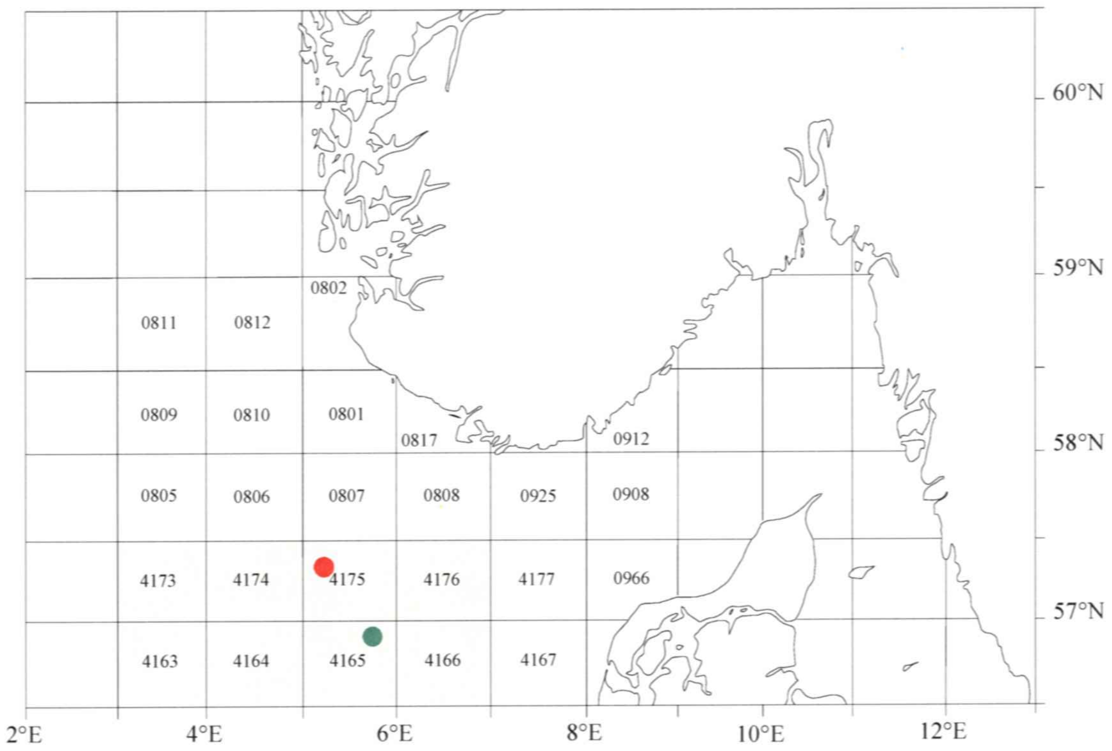
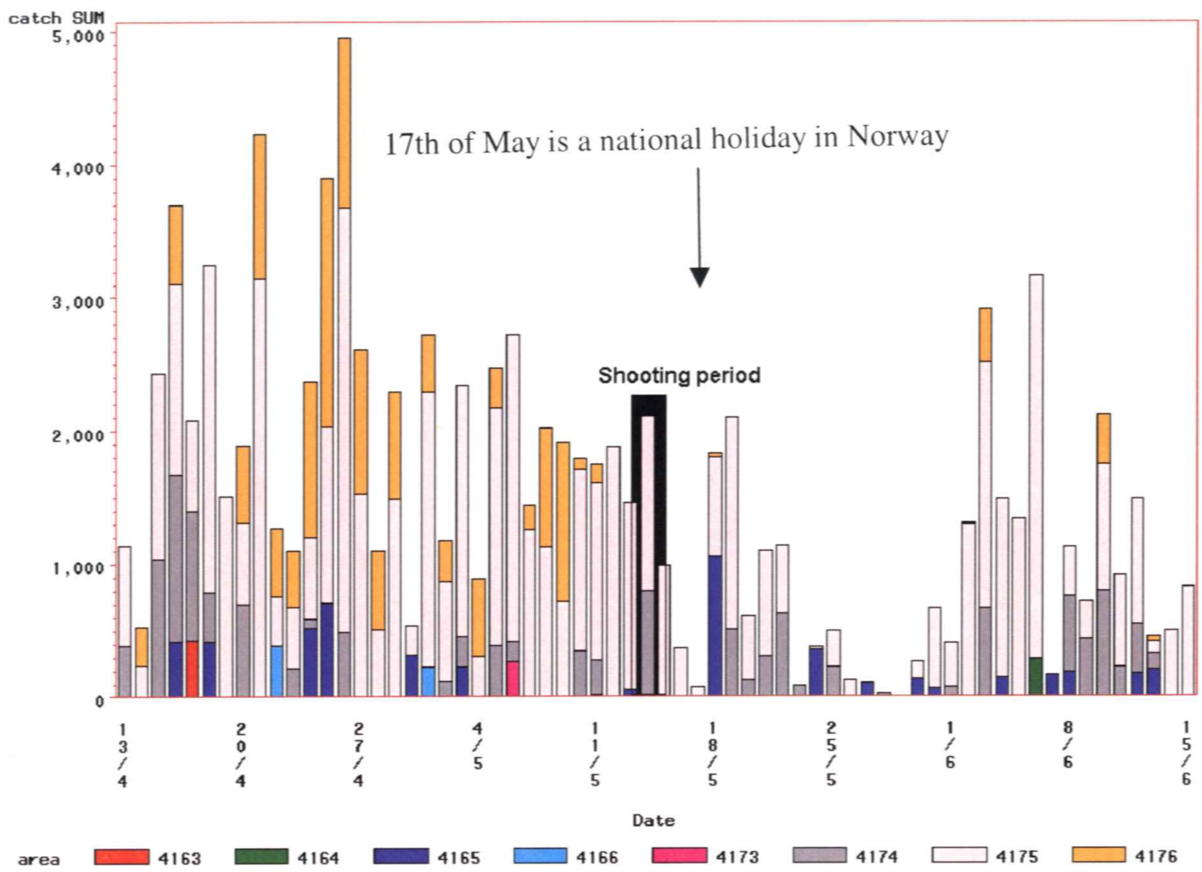


Figure 4.15. The localizations of the fishery areas. Red and green dot indicates shooting centre (N57°12.5' E05°19.1') and control cages (N56°55,4' E05°41,0') respectively. The grey shadow marks areas with landed sandeel catch (close to the shooting ground) during the period 13/4-15/6/02, to Norwegian or foreign landing sites. Low catches may have been captured in other fishery areas, e.g. lower than 30% sandeel in the catch will be reported as other industrial species to the Norwegian Directorate of Fishery.



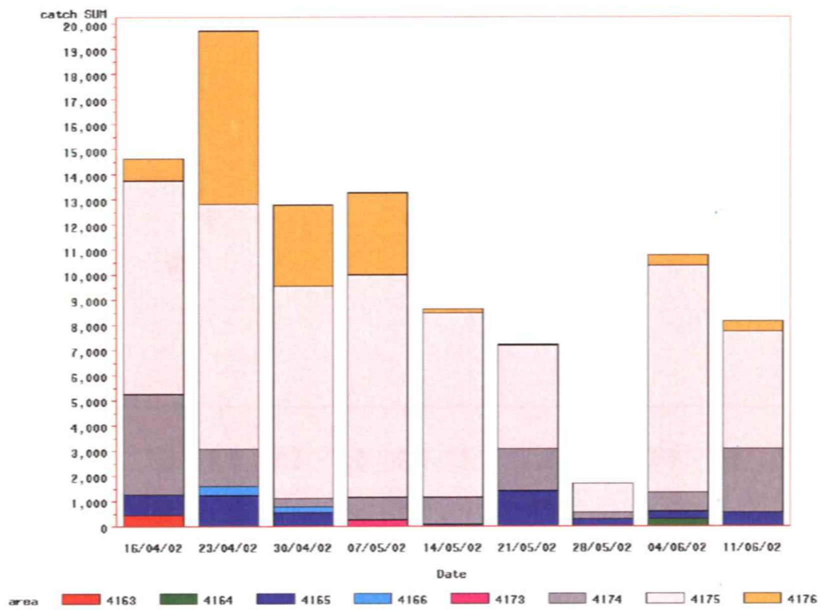


Figure 4.16. Landed sandeel catches in thousands tonnes for the different geographical areas (see Figure 4.15) close to the shooting ground, analysed on a day-by-day basis (above) and 7 days periods (below). The shooting was done in area 4175 (pink), and the control experiment in area 4165. The shooting period was from 13/05 (10:30) - 15/05 (18:13), indicated by the black rectangle. The dates are landing days, not the day of the catch, and the reported catches are therefore captured the days (usually 4-6) before the day of landing.

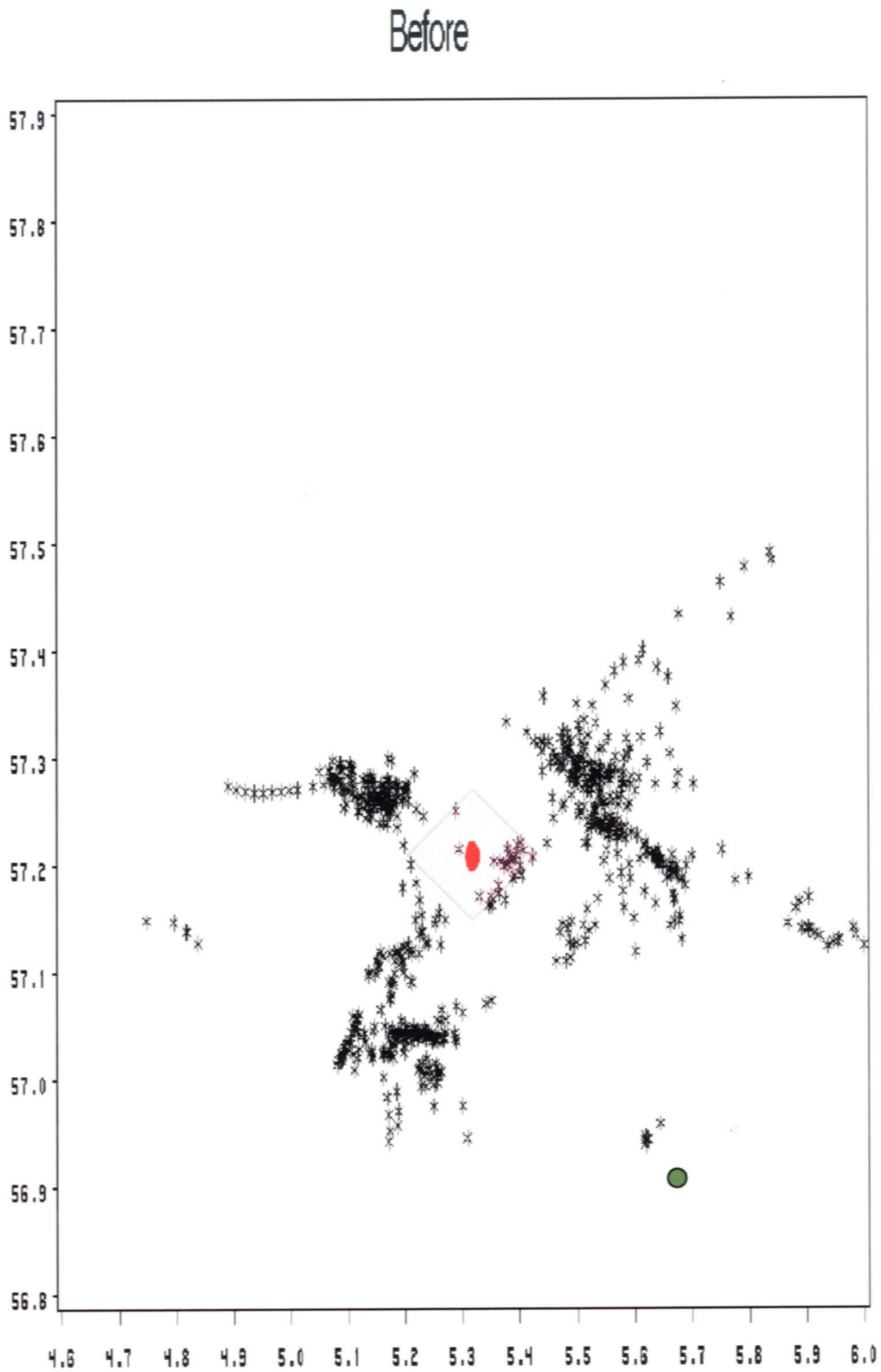


Figure 4.17. Satellite positions of the commercial sandeel fleet three days before the shooting (10/05; 12:30 - 13/05; 12:30). The registrations are from 30 different vessels from an area of 66x84 nm (see Table 4.6). The position of the shooting centre (N57°12.5' E05°19.1') is indicated with a red dot, the control area with a green dot. The seismic line area is presented as a pink square.

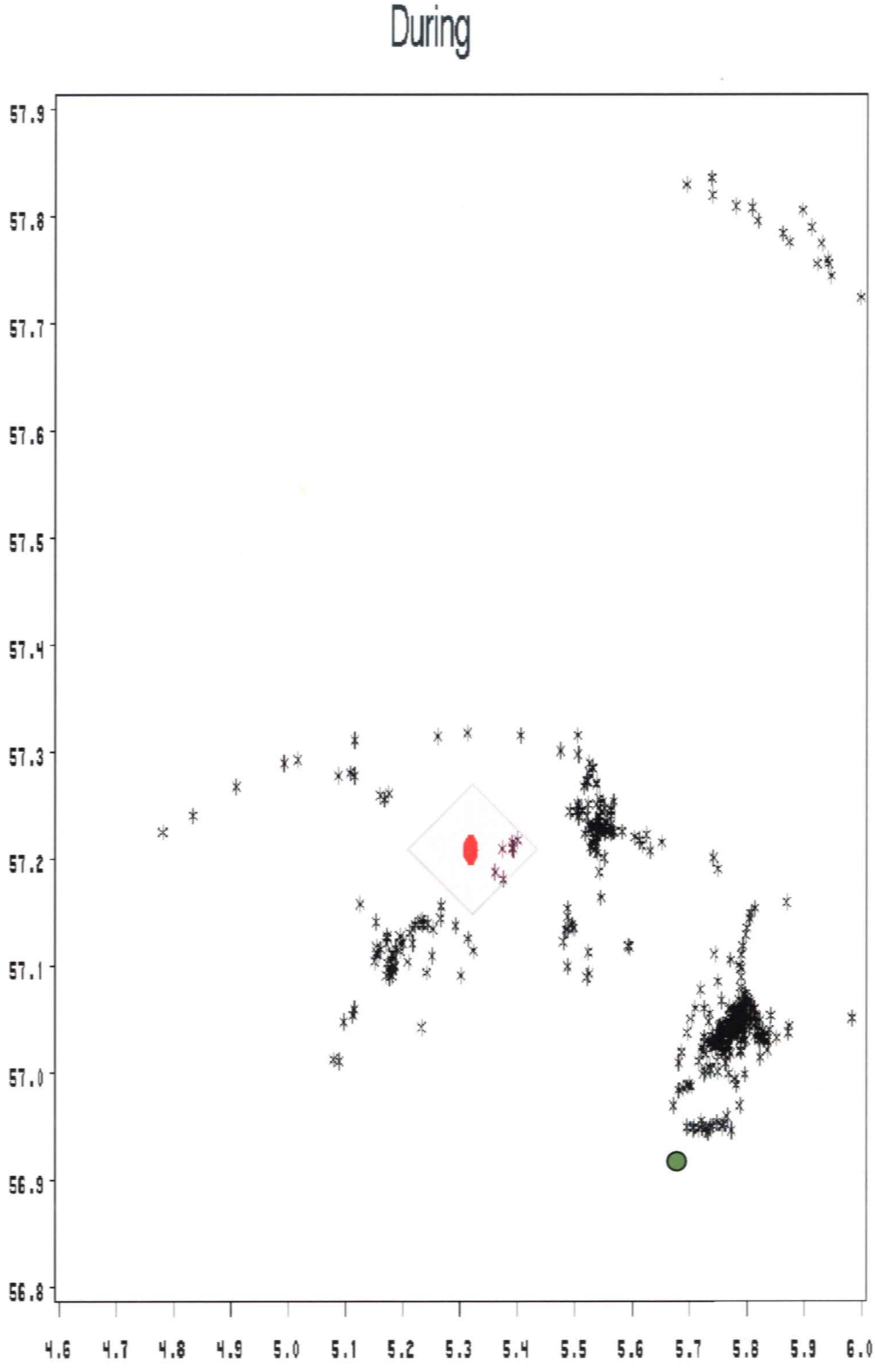


Figure 4.18. Satellite positions of the commercial sandeel fleet during the shooting (13/05; 12:30-15/05; 18:12). The registrations are from 30 different vessels from an area of 66x84 nm (see Table 4.6). The position of the shooting centre (N57°12.5' E05°19.1') is indicated with a red dot, the control area with a green dot. The seismic line area is presented as a pink square.

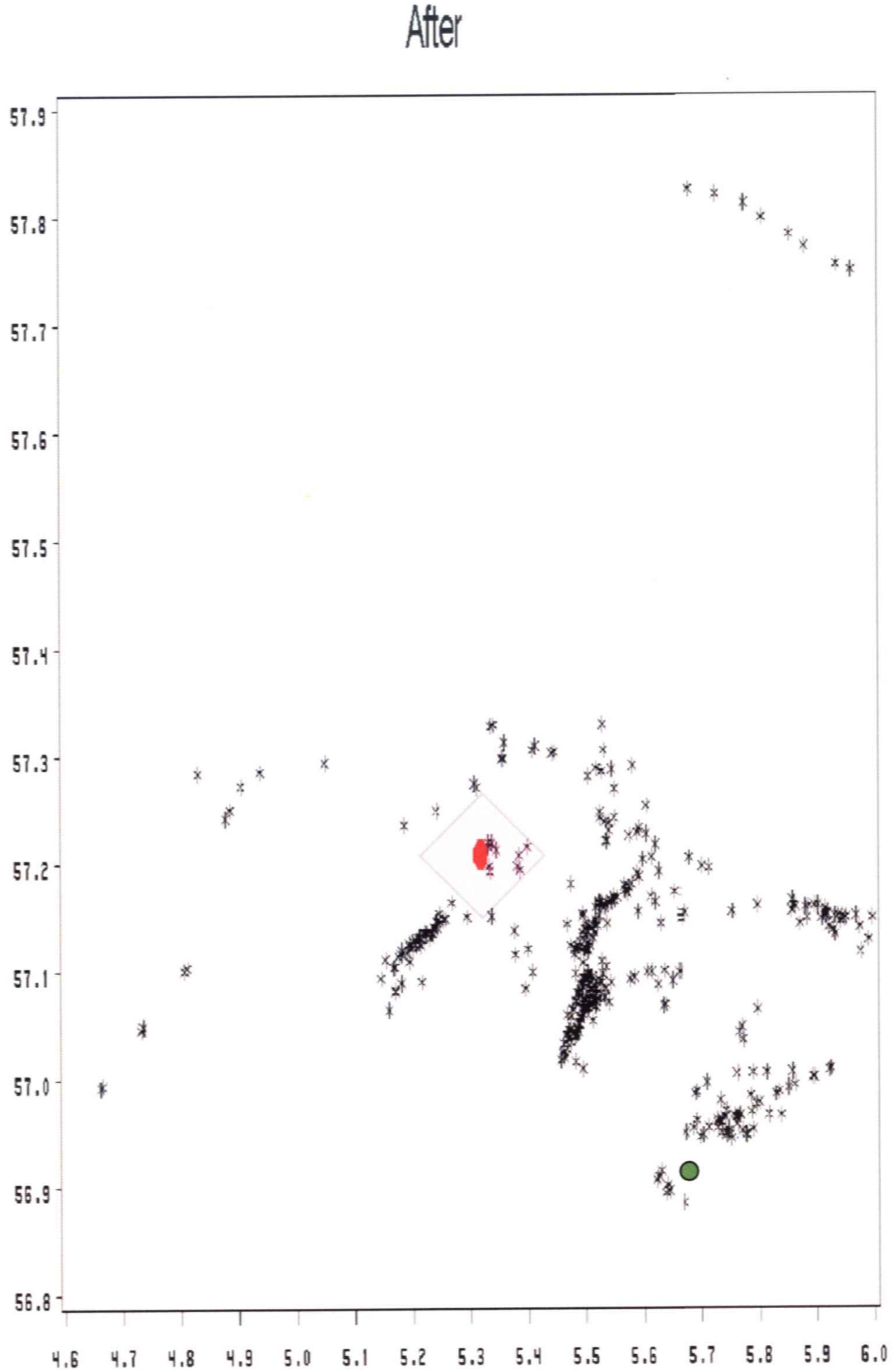


Figure 4.19. Satellite positions of the commercial sandeel fleet after the shooting (15/05; 18:12 - 18/05; 18:12). The registrations are from 30 different vessels from an area of 66x84 nm (see Table 4.6). The position of the shooting centre (N57°12.5' E05°19.1') is indicated wit a red dot, the control area with a green dot. The seismic line area is presented as a pink square.

5. DISCUSSION

The results from the grab sampling show clearly that the sandeel is buried in the sand during the night. The grab catches during the nights were not significantly different before and after the seismic shooting. In both cases about half of the samples were without sandeel. On average the catches were somewhat higher after shooting than before shooting, but the difference may be occasional, and the number of samples before shooting was relatively low. None of the grab samples showed any dead or paralysed fish before or after shooting, but the experiment design could not tell about any possible long term effects.

The observations with ROV or video inside the cage did not reveal any direct lethal effects from the shooting. There were observations of some dead sandeel on the bottom of the cages shortly after the cages were deployed. Probably these sandeels were killed when the cages penetrated into the sand. The mortality observed at the end of the experiment was about the same in the cages from the experimental area and the control area. The general stress experienced during the confinement probably was a major reason for this mortality. Video recordings show that the sandeel frequently swam against the meshes. This behaviour may have lead to mouth and skin damages that caused subsequent death.

The seismic shooting seemed to have a slight effect on the behaviour of the lesser sandeel. When the seismic vessel approached the cages, the sandeel increased the tailbeat frequency, swam higher in the cages and performed C-start responses. No fish were observed to flee into the sand when the shooting was most intense. A small group of sandeel was observed in the sand outside one of the cages on May 15th, the third day of shooting. On the same day, a school was observed passing seemingly undisturbed above the ROV. This may indicate that seismic shooting affects the behaviour of the lesser sandeel, but not in a serious or permanent way.

When the seismic vessel passed close to the cages, the shooting had already lasted for a while, and the habituating effect might have reduced the behavioural response. Further examination of the video recordings is necessary to give a broader picture of the responses to seismic shooting.

The use of light on the ROV did not result in any immediate swimming reactions, but it is not impossible that the light caused the sandeel to concentrate in certain parts of the cages. All time blocks were chosen with this problem in mind, and if the searchlight had to be used, the following time block was rejected. Other possible scaring effects could be noise from the ROV's propellers, but as a rule the engines were turned off before video monitoring started. When approaching the cage with the ROV, no such scaring effect was observed.

All surveys with echosounders in the experimental area were conducted during daytime to ensure the availability of sandeel for acoustic detection. Combined with use of van Veen grab during the nights, some high concentrations of sandeel were located. However, only short distance off such sites, no fish could be observed at all, illustrating the patchy distribution of the species. There might be several explanations to such observations. It is well known that habitat preference of sandeel is strong , suggesting that if type of sediment or sand quality for burrowing during night time is not adequate, very few fish will be found at a particular site.

A possibly high mobility of sandeel within the experimental area might also aid to explain that at a given location high abundance of fish were detected, while a few days later no fish could be located in the same area. The changes in the occurrence of higher abundance regions as observed by the echosounder might support such ideas.

The lowest abundances of sandeel within the seismic shooting area were observed acoustically prior to seismic shooting, in fact increasing thereafter. It should be kept in mind that the area overlap between repeated acoustic transects is probably not perfect, meaning that between transects runs a 20-40 m offset between lines might be possible. The patchy distribution of sandeel thus might result in no fish being observed during a first transect run (Figure 4.1, Line 5-6), while significantly more are observed during a second pass (Figure 4.2, Line 5-6), and again less during the third pass (Figure 4.3).

Overall the highest abundance of sandeel was found during the last echosounder survey conducted on 19 May. From an acoustic point of view this means that the abundance of sandeel actually increased significantly after the seismic shooting was terminated. This increase must have been caused by horizontal migration of sandeel into the experimental area. However, an alternative explanation is that the increased recordings were caused by horizontal migration of herring or other species into the experimental area. During daytime, herring form dense, well defined schools behaving quite similar to the sandeel concentrations. It is commonly known from fishing in this region at this time of year that herring schools are found in between the sandeel schools. Herring is a swimbladder fish, and herring schools therefore give acoustic back scattering about 10 times that of similar sandeel schools. Presence of a few herring schools that had migrated into the experimental area after shooting can therefore explain the observed increase in the acoustic recordings.

The abundance of sandeel in the seismic shooting area was quite low prior to shooting, with the exception of the cage region and some local irregularly spaced occurrences along the survey tracks of Survey 1. Thereafter the abundance of sandeel increased. Hence, our results indicate that the seismic shooting did not seem to have any significant scaring effect that resulted in horizontal migration of the lesser sandeel out of the experimental area. Though difficult to compare, the results from the grab sampling also indicated higher concentrations of fish after shooting in the seismic area.

However, the present study was not originally designed to explore how the potential scaring effect caused by seismic shooting might affect the horizontal distribution of sandeel. To conduct such a study, more thought should be given to synoptic sampling, maybe with more than one research vessel involved. The survey design might also differ with more tightly spaced track lines, using a less noisy research vessel and more frequent biological sampling to verify the acoustic registrations. A control area should be studied in an identical manner, which was the intention also during the present study, but which was not fully accomplished. Especially, more biological sampling by scientific trawling to identify the acoustic recordings should have been performed. In fact only one trawl station was taken during the whole experiment, and that station was taken in the control area to obtain fish to put in the control cages before the experiment. In this catch, a smaller percentage (5%?) was herring, but the distribution of species was not recorded. However, sandeel was caught in about half of the grab samples in the experimental area, and fishing vessels were seen in active fishing in the experimental area both before and after the seismic shooting experiment. We are therefore rather sure on the validity of the allocation of acoustic recordings of fish shoals to sandeel. As discussed above, some of the shoals could have been herring that give a much stronger echo.

The hearing thresholds for sandeel are not known so the detection- and reaction distances are estimated to give an idea of the sizes. The cages with the sandeel were placed in the centre of the shooting area. The estimated reaction distances for sandeel (10 km) therefore exceed the whole shooting area, and the sandeel in the cages did also show reaction to the shooting from the seismic line furthest away.

The satellite tracking data showed that the fleet moved to other regions, and the average distance to the seismic centre increased. This is well documented for the different categories in Table 4.6. When individual vessels are considered, the majority also seem to increase the distance. However, the map of the horizontal distribution (Figure 4.17-4.19) does not display a convincing trend of escaping the seismic area, the movements may also be interpreted as a result of casual changing of fishing grounds. If we disregard the idea of casual movements, there are several reasons for the fishermen to avoid the seismic field: They know that seismic shooting reduces the chances for good catches, and hence they move to other regions without seismic activity. They may also leave the area to avoid making problems for the investigators.

The reduced landings in Figure 4.16 can be explained by reduced captures during and after the shooting. The fishing fleet seemed to move away from the area or undertake a displacement, thus more time was spent for travelling and less time for fishing. Reduced captures may also reflect reduced availability of sandeel, as a result of changed fish behaviour that we have not been able to observe in our experiment. Our acoustic data, indeed, indicate that the fish density increased significantly the days after the shooting. We are not sure how much originated from sandeel, and how much from other species.

The sandeel fishery may also have been influenced by the fact that the fish landing sites in Norway were closed on the national day on the 17. of May. The catch on 17. of May was probably delivered outside Norway (Denmark). The following three days were also holidays, but this probably had little effect on the fishery effort.
The increase in the catches of sandeel from area 4175 on the 18/5 and 19/5 does not suggest a permanent reduced availability, these landed catches were probably taken at the time of shooting and thereafter. A new decline with very low landings from 26/5 – 29/5 rather indicates natural fluctuations in the fishery than a sustained problem caused by the seismic shooting.

6. CONCLUSIONS

1. The video recordings of the sandeel in the experimental cages showed that the fish reacted slightly to the seismic shooting. During shooting, the sandeel reacted with a changed behaviour by increasing the tailbeat frequency and thereby swimming faster, by swimming higher in the cages and by performing frequent C-start responses, a behaviour pattern fish perform when exposed to significant noise stimuli. After the seismic shooting the sandeel returned to the same swimming pattern in the cages as before the shooting. However, there were no observations of the exposed sandeel being frightened to take refuge in the sand during the seismic shooting.

2. The average catch size of sandeel in the grab samples increased slightly from the samples taken before the seismic shooting to the samples taken after the seismic shooting. The sandeel caugth with the grab were alive when brought on deck both before and after the seismic shooting.

3. The mortality of about 35 % of the sandeel in the cages, both in the experimental and control area, indicate that this mortality was a consequence of the confinement in the cages, caused by stress and injury.

4. The three successive acoustic surveys in the experimental area conducted on the 11th, 17th and 19th of May showed an increase in the abundance of sandeel from one survey to the other. The abundance of sandeel increased by a factor of 1.6 from 2 days before the seismic shooting to 2 days after the seismic shooting ended. The abundance of sandeel increased further by a factor of 5.9 from 2 days after the seismic shooting ended to 4 days after the seismic shooting had ended. The most probable explanation for this increase is migration of sandeel and possibly of other pelagic schooling fish like herring into the experimental area.

5. Fishery statistics reveals that there was reduction in the reported landings the following two days after the shooting. Closing of the Norwegian landing sites on the 17/5 partly explains the reduction. Several days with landings from the seismic area followed by a new decline makes it difficult to interpret the reduced landings as a direct result of the seismic shooting. The report can not exclude a negative effect from the shooting, but the field observations were not designed to reveal long term effect and large scale behaviour changes of sandeel in the free water masses.
The data from satellite tracking of fishing vessels show that most of the vessels increased the distance to the seismic centre after the shooting, but the change in the distribution pattern might appear casual.

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9. APPENDIX

Appendix table 1a. Type of bottom substrate and catch of sandeel with grab

Date	Station	Latitude	Longitude	Hour	Sand type	Nos. of sandeel
02.05.2002	1			11:45	Fine	0
02.05.2002	1			12:00	Fine	0
02.05.2002	2			15:35	Fine	0
02.05.2002	3			23:35	Fine	0
03.05.2002	4	56,6919	4,2425	00:09	Fine	0
03.05.2002	4	56,6919	4,2425		Fine	0
03.05.2002	4	56,6919	4,2425		Fine	0
03.05.2002	5	56,6919	4,2426	00:42	Fine	0
03.05.2002	6	56,6916	4,2437	00:50	Fine	0
03.05.2002	7	56,6923	4,2449	01:00	Fine	0
03.05.2002	8	56,6932	4,2462	01:10	Fine	0
03.05.2002	9	56,6933	4,2442	01:23	Fine	0
03.05.2002	10	56,6924	4,2432	01:34	Fine	0
03.05.2002	11	56,6550	4,2385	02:05	Fine	0
03.05.2002	11	56,6550	4,2385		Fine	0
03.05.2002	12	56,6542	4,2371	02:20	Fine	0
03.05.2002	13	56,6549	4,2369	02:27	Fine	0
03.05.2002	14	56,6556	4,2379	02:40	Fine	0
03.05.2002	15	56,6558	4,2394	02:50	Fine	0
03.05.2002	16	56,6551	4,2405	03:00	Fine	0
03.05.2002	17	56,6579	4,2830	03:25	Fine	0
03.05.2002	18	56,6584	4,2843	03:40	Fine	0
03.05.2002	19	56,6575	4,2843	03:50	Fine	0
03.05.2002	20	56,6574	4,2823	04:00	Fine	0
03.05.2002	21	56,6583	4,2812	04:08	Fine	0
03.05.2002	22	56,6588	4,2825	04:17	Fine	0
03.05.2002	23	56,6964	4,4106	04:55	Fine	0
03.05.2002	24	56,6957	4,4122	05:10	Fine	0
03.05.2002	25	56,6954	4,4102	05:20	Fine	0
03.05.2002	26	56,6972	4,4073	05:32	Fine	0
03.05.2002	27	56,6974	4,4109	05:42	Fine	0
03.05.2002	28	57,2342	5,3732	23:00	Empty	0
03.05.2002	29	57,2343	5,3729	23:05	Empty	0
03.05.2002	30	57,2343	5,3729	23:15	Empty	0
03.05.2002	31	57,2352	5,3731	23:30	Stones	0
03.05.2002	32	57,2385	5,3730	23:40	Coarse	0
03.05.2002	33	57,2395	5,3728	23:55	Fine	0
04.05.2002	34	57,2404	5,3731	00:06	Fine	0
04.05.2002	35	57,2416	5,3733	00:18	Fine	0
04.05.2002	36	57,2422	5,3748	00:47	Coarse	0
04.05.2002	37	57,2428	5,3755	01:03	Coarse	0
04.05.2002	38	57,2439	5,3740	01:40	Medium	0
04.05.2002	39	57,2451	5,3770	01:57	Stones	0
04.05.2002	39	57,2451	5,3770		Stones	0
04.05.2002	40	57,2464	5,3793	02:10	Coarse	0
04.05.2002	41	57,2477	5,3788	02:27	Coarse	0
04.05.2002	42	57,2482	5,3766	02:47	Empty	0
04.05.2002	43	57,2390	5,3688	08:28	Empty	0
04.05.2002	43	57,2390	5,3688		Coarse	0
04.05.2002	43	57,2390	5,3688		Coarse	0
06.05.2002	44	57,2095	5,3170	11:07	Medium	0

Appendix table 1b. Type of bottom substrate and catch of sandeel with grab

Date	Station	Latitude	Longitude	Hour	Sand type	Nos. of sandeel
06.05.2002	45	57,2097	5,3215	11:20	Medium	0
06.05.2002	46	57,2073	5,3098	19:38	Fine	0
07.05.2002	47			01:35	Empty	0
07.05.2002	48			01:45	Fine	0
07.05.2002	49			02:00	Coarse	0
07.05.2002	50			02:10	Coarse	0
07.05.2002	51			02:17	Coarse	0
07.05.2002	52			02:30	Fine	20
07.05.2002	52			02:35	Fine	20
07.05.2002	53	56,7883	5,6290	15:45	Fine	0
07.05.2002	54	56,7867	5,6298	15:58	Fine	0
07.05.2002	55	56,7902	5,6282	16:15	Fine	0
08.05.2002	56	56,9072	5,6046	01:00	Fine	0
08.05.2002	57	56,9080	5,6068	01:15	Fine	10
08.05.2002	57	56,9080	5,6068		Fine	4
08.05.2002	58	56,9089	5,6087	01:35	Fine	0
08.05.2002	59	56,9100	5,6111	01:50	Fine	3
08.05.2002	60	56,9113	5,6132	02:00	Fine	0
08.05.2002	61	56,9122	5,6153	02:10	Fine	2
08.05.2002	62	56,9131	5,6180	02:20	Fine	0
08.05.2002	63	56,9144	5,6158	02:35	Fine	6
08.05.2002	64	56,9145	5,6130	02:45	Fine	0
08.05.2002	65	56,9145	5,6102	02:55	Fine	0
08.05.2002	66	56,9137	5,6080	03:05	Fine	0
08.05.2002	67	56,9129	5,6059	03:15	Fine	0
08.05.2002	68	56,9120	5,6038	03:22	Fine	0
08.05.2002	69	56,9109	5,6016	03:35	Fine	0
08.05.2002	70	56,9096	5,5997	03:40	Fine	16
08.05.2002	71	56,9083	5,6012	03:55	Fine	0
08.05.2002	72	56,9074	5,6023	04:00	Fine	0
08.05.2002	73	56,9183	5,6817	20:00	Fine	0
08.05.2002	74	56,9169	5,6859	22:00	Fine	0
08.05.2002	75	56,9173	5,6852	22:30	Fine	0
08.05.2002	76	56,9174	5,6852	23:25	Fine	0
08.05.2002	77	56,9176	5,6834	23:36	Fine	0
08.05.2002	78	56,9174	5,6868	23:53	Fine	0
09.05.2002	79	56,9185	5,6866	00:00	Fine	0
09.05.2002	80	56,9179	5,6885	00:05	Fine	0
09.05.2002	81	56,9174	5,6893	00:15	Fine	0
09.05.2002	82	56,9173	5,6921	00:23	Fine	0
09.05.2002	83	56,9173	5,6944	00:32	Fine	0
09.05.2002	84	56,9172	5,6974	00:45	Fine	0
09.05.2002	85	56,9157	5,6966	00:53	Fine	0
09.05.2002	86	56,9155	5,6930	01:07	Fine	0
09.05.2002	87	56,9156	5,6893	01:15	Fine	0
09.05.2002	88	56,9156	5,6865	01:25	Fine	0
09.05.2002	89	56,9158	5,6849	01:32	Fine	0
09.05.2002	90	56,9153	5,6821	01:47	Fine	0
09.05.2002	91	56,9118	5,6498	02:15	Fine	0
09.05.2002	92	56,9068	5,6010	02:37	Fine	0
09.05.2002	93	56,9205	5,6049	03:03	Fine	0

Appendix table 1c. Type of bottom substrate and catch of sandeel with grab

Date	Station	Latitude	Longitude	Hour	Sand type	Nos. of sandeel
09.05.2002	94	56,9184	5,6272	03:20	Fine	0
09.05.2002	95	56,9123	5,6223	03:34	Fine	0
09.05.2002	96	56,9060	5,6085	03:55	Fine	0
09.05.2002	97	56,9082	5,6065	04:20	Fine	2
09.05.2002	97	56,9082	5,6065		Fine	1
09.05.2002	98	56,9091	5,6087	04:35	Fine	0
09.05.2002	99	56,9084	5,6052	04:47	Fine	0
09.05.2002	100	56,9085	5,6071	05:05	Fine	0
09.05.2002	100	56,9085	5,6071		Fine	0
11.05.2002	101	57,2085	5,3200	23:00	Fine	11
12.05.2002	102	57,2086	5,3200	00:22	Fine	8
12.05.2002	103	57,2067	5,3267	01:25	Fine	0
12.05.2002	104	57,2075	5,3280	01:38	Fine	0
12.05.2002	105	57,2104	5,3256	01:53	Fine	0
12.05.2002	106	57,2118	5,3266	02:02	Fine	12
12.05.2002	107	57,2126	5,3226	02:16	Fine	13
12.05.2002	108	57,2127	5,3173	02:31	Fine	5
12.05.2002	109	57,2117	5,3139	02:45	Medium	5
12.05.2002	110	57,2093	5,3139	02:55	Medium	1
12.05.2002	111	57,2077	5,3143	03:04	Medium	0
13.05.2002	112	57,2069	5,3259	04:38	Fine	1
13.05.2002	113	57,2067	5,3234	04:47	Fine	0
13.05.2002	114	57,2067	5,3199	04:55	Medium	1
13.05.2002	115	57,2066	5,3172	05:03		1
15.05.2002	116	57,2097	5,3225	22:45		8
15.05.2002	117	57,2112	5,3272	23:45		23
16.05.2002	118	57,2069	5,3264	01:00	Fine	1
16.05.2002	119	57,2084	5,3264	01:07	Coarse	9
16.05.2002	120	57,2103	5,3261	01:19	Fine	1
16.05.2002	121	57,2120	5,3265	01:22	Medium	1
16.05.2002	122	57,2126	5,3236	01:37	Fine	18
16.05.2002	123	57,2130	5,3205	01:47	Medium	17
16.05.2002	124	57,2128	5,3176	01:57	Fine	10
16.05.2002	125	57,2124	5,3150	02:06	Medium	15
16.05.2002	126	57,2106	5,3152	02:19	Fine	13
16.05.2002	127	57,2089	5,3142	02:28	Coarse	0
16.05.2002	128	57,2075	5,3151	02:40	Fine	0
16.05.2002	129	57,2057	5,3141	02:47	Fine	0
16.05.2002	130	57,2401	5,3248	03:22	Fine	5
16.05.2002	131	57,2060	5,3215	03:30	Fine	0
16.05.2002	132	57,2059	5,3181	03:40	Medium	4
16.05.2002	133			08:00		1
17.05.2002	134	57,2056	5,3147	01:07	Coarse	0
17.05.2002	135	57,2080	5,3145	01:18	Fine	0
17.05.2002	136	57,2091	5,3145	01:26	Fine	0
17.05.2002	137	57,2107	5,3142	01:34	Fine	19
17.05.2002	138	57,2125	5,3144	01:43	Fine	4
17.05.2002	139	57,2126	5,3169	01:53	Fine	16
17.05.2002	140	57,2127	5,3203	02:05	Fine	41
17.05.2002	141	57,2125	5,3230	02:15	Fine	4
17.05.2002	142	57,2120	5,3257	02:25	Fine	0

Appendix table 1d. Type of bottom substrate and catch of sandeel with grab

Date	Station	Latitude	Longitude	Hour	Sand type	Nos. of sandeel
17.05.2002	143	57,2100	5,3263	02:34	Fine	0
17.05.2002	144	57,2086	5,3266	02:42	Coarse	0
17.05.2002	145	57,2069	5,3266	02:50	Fine	0
17.05.2002	146	57,2062	5,3218	02:57	Fine	0
17.05.2002	147	57,2058	5,3183	03:05	Fine	1
18.05.2002	148	57,2061	5,3183	00:17	Fine	9
18.05.2002	149	57,2058	5,3149	00:30	Medium	0
18.05.2002	150	57,2075	5,3143	00:39	Fine	0
18.05.2002	151	57,2091	5,3143	00:48	Grov	3
18.05.2002	152	57,2113	5,3141	00:56	Medium	3
18.05.2002	153	57,2123	5,3143	01:03	Medium	9
18.05.2002	154	57,2129	5,3167	01:15	Fine	1
18.05.2002	155	57,2127	5,3196	01:23	Fine	20
18.05.2002	156	57,2125	5,3226	01:32	Fine	15
18.05.2002	157	57,2121	5,3257	01:42	Fine	11
18.05.2002	158	57,2102	5,3262	01:50	Fine	6
18.05.2002	159	57,2087	5,3259	01:58	Fine	0
18.05.2002	160	57,2070	5,3259	02:04	Fine	0
18.05.2002	161	57,2064	5,3223	02:11	Fine	0
19.05.2002	162	57,2069	5,3255	00:10	Fine	0
19.05.2002	163	57,2083	5,3253	00:21	Fine	0
19.05.2002	164	57,2100	5,3257	00:29	Fine	0
19.05.2002	165	57,2120	5,3256	00:38	Fine	1
19.05.2002	166	57,2124	5,3239	00:47	Fine	7
19.05.2002	167	57,2128	5,3207	00:56	Fine	8
19.05.2002	168	57,2130	5,3177	01:04	Fine	11
19.05.2002	169	57,2126	5,3145	01:12	Medium	6
19.05.2002	170	57,2112	5,3142	01:21	Medium	6
19.05.2002	171	57,2095	5,3139	01:29	Coarse	0
19.05.2002	172	57,2079	5,3141	01:35	Medium	0
19.05.2002	173	57,2061	5,3145	01:42	Fine	0
19.05.2002	174	57,2062	5,3174	01:50	Fine	0
19.05.2002	175	57,2061	5,3231	01:58	Fine	0
19.05.2002	176	57,1908	5,4224	19:28	Fine	0
19.05.2002	177	57,1552	5,3569	19:49	Fine	0
19.05.2002	178	57,1637	5,3415	20:00	Fine	0
19.05.2002	179	57,1661	5,4056	20:22	Fine	0
19.05.2002	180	57,2090	5,3867	20:33	Fine	0
19.05.2002	181	57,1756	5,3242	20:58	Fine	0
19.05.2002	182	57,1834	5,3053	21:05	Fine	0
19.05.2002	183	57,2185	5,3714	21:27	Fine	0
19.05.2002	184	57,2265	5,3532	21:48	Coarse	0
19.05.2002	185	57,1927	5,2898	22:02	Coarse	0
19.05.2002	186	57,2016	5,2708	22:13	Fine	0
19.05.2002	187	57,2363	5,3372	22:35	Fine	0
19.05.2002	188	57,2454	5,3201	22:50	Medium	0
19.05.2002	189	57,2106	5,2545	23:14	Fine	0
19.05.2002	190	57,2207	5,2334	23:30	Fine	0
19.05.2002	191	57,2543	5,3022	23:45	Stones	0
19.05.2002	192	57,2635	5,2836	23:57	Fine	0
20.05.2002	193	57,2271	5,2152	00:20	Stones	0

Appendix table 2. 10 minutes time blocks used in identification of C-starts in video recordings from "Aglantha".

Cassette 4 13.05.02 Cage 1				
	Block 1	Block 2	Block 4	Block 5
Before	12:06:03 12:16:03	12:16:03 12:26:03	12:26:03 12:36:03	12:36:30 12:46:30

Line	1	1	1	1	1	7	7	7	(Cassette 5) 7	Turns	2
	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9	Block 10	Block 11
During	12:46:30 12:56:30	12:56:30 13:06:30	13:06:30 13:16:30	13:16:30 13:26:30	14:06:00 14:16:00	14:16:30 14:26:00	14:26:00 14:36:00	14:43:00 14:53:00	15:15:30 15:25:30	15:25:30 15:35:30	15:45:30 15:55:30

Line	2	2	2	Turns	Turns	8	8	8	(Cassette 6 15.05.02) Turns			17
	Block 12	Block 13	Block 14	Block 15	Block 16	Block 17	Block 18	Block 19	Block 20	Block 21	Block 22	Block 23
During	15:55:30 16:05:30	16:05:30 16:15:30	16:54:00 17:04:00	17:04:00 17:14:00	17:31:00 17:41:00	17:41:00 17:51:00	18:01:00 18:11:00	18:40:00 18:50:00	09:43:30 09:53:30	09:53:30 10:03:30	10:03:30 10:13:30	10:13:30 10:23:30

Line	17	17	17	17	17	17	17	Turns	Turns	23	23	23
	Block 24	Block 25	Block 26	Block 27	Block 28	Block 29	Block 30	Block 31	Block 32	Block 33	Block 34	Block 35
During	10:23:30 10:33:30	10:33:30 10:43:30	10:46:00 10:56:00	10:56:00 11:06:00	11:06:00 11:16:00	11:16:00 11:26:00	11:26:00 11:36:00	11:36:00 11:46:00	11:46:00 11:56:00	11:56:00 12:06:00	12:06:00 12:16:00	12:34:00 12:44:00

Line	23	(Cassette 7) Turns	16	16	16	16	Turns	22	22	22	22	22
	Block 36	Block 37	Block 38	Block 39	Block 40	Block 41	Block 42	Block 43	Block 44	Block 45	Block 46	Block 47
During	13:10:00 13:20:00	13:27:00 13:37:00	14:02:00 14:12:00	14:30:00 14:40:00	14:40:00 14:50:00	14:50:00 15:00:00	15:14:00 15:24:00	15:44:00 15:54:00	15:54:00 16:04:00	16:04:00 16:14:00	16:14:00 16:24:00	16:24:00 16:34:00

Line	22	Turns	Turns	Turns	15	15	15	(Cassette 8) 15	15	15	Turns
	Block 48	Block 49	Block 50	Block 51	Block 52	Block 53	Block 54	Block 55	Block 56	Block 57	Block 58
During	16:34:00 16:44:00	16:44:00 16:54:00	16:54:00 17:04:00	17:04:00 17:14:00	17:14:00 17:24:00	17:24:00 17:34:00	17:34:00 17:44:00	17:55:00 18:05:00	18:05:00 18:15:00	18:15:00 18:25:00	18:36:00 18:46:00

17.05.02				Cage 2			(Cassette 9)					
	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9	Block 10	Block 11	Block 12
After	09:39:00 09:49:00	09:49:00 09:59:00	09:59:00 10:09:00	11:00:00 11:10:00	11:10:00 11:20:00	11:20:00 11:30:00	11:37:05 11:47:05	11:47:05 11:57:05	11:57:05 12:07:05	12:07:05 12:17:05	12:17:05 12:27:05	12:27:05 12:37:05

18.05.02 Cage 1			Cage 2	
	Block 13	Block 14	Block 15	Block 16
After	09:59:00 10:09:00	10:09:00 10:19:00	10:54:00 11:04:00	11:04:00 11:14:00