Fact sheet from

OLF The Norwegian Oil Industry Association

Seismic surveys and fish

Seismic surveys are the oil industry's most important tool in mapping potential deposits of oil and gas several thousand meters below the surface of the earth.

Different kinds of seismic data are needed for the various activity phases, from the early exploration phase to development and production of potential reserves in a field. It may therefore be necessary to collect seismic data several times in the same area.

This fact sheet describes the principles involved in seismic surveys and gives a summary of research conducted on their effect on fish. Most of the information comes from the report "Seismic Surveys' Impact on Fish and Fisheries", which is available at www.olf.no/?14772.pdf.

Seismic surveys

A signal source and one or several cables are trailed behind the seismic vessel. The sound signals from the air gun are sent into the seabed and reflected by the various layers in the seabed before being registered by the hydrophones inside the cables.

A seismic survey functions as shown in the illustration above. A seismic transmitter is towed behind the vessel and emits a signal that penetrates deep into the seabed. This signal will be reflected back from all transitions between the different geological layers in the seabed. The reflected signals are registered by a number of hydrophones that are towed in a several kilometers long "seismic cable". Simplifying it a little, one might say the whole system works like a large echo sounder.

The signals from the seismic cable are recorded on magnetic tape and sent to a large data facility for processing. Here noise and unwanted signals are removed, and the data is presented in a form suitable for interpretation.

Seismic surveys are planned according to current knowledge of the area's geology.

Once the survey has been planned, it is important for the seismic vessel to follow the predetermined lines. This means that other vessels in the area will have to give way, and so it is important to maintain good communication with these vessels to ensure their cooperation.

There is normally a fisheries expert approved by the Ministry of Fisheries on board the seismic vessels.

Air guns

Marine seismic surveys have been conducted since the 1950s, and to begin with explosives were the only known signal source. The 1960s saw the development of new signal sources, primarily in order to make the operations safer. The new signal sources also had a much less damaging effect on the environment. Since the early 1970s, air guns have been the prevalent seismic signal source, and they are now the only type used.

Each air gun will produce a powerful ”bubble effect” as the air is let out. The air will contract and then expand on its way up to the surface. In practice, many air guns will be combined in a so-called ”array”. This is done to produce a better signal and to focus the sound energy down into the seabed. The array effect means that there is a considerable difference between the energy that is sent downwards and sideways, and that the bubble effect is considerably reduced.

Seismic cable

The seabed and the layers below are built up of many different geological materials, from sand and slate to chalks and, in some areas, igneous rocks. The seismic signals are reflected from the transitions between these geological materials, and the reflected signal is registered on the seismic cable, which can be from three to eight kilometers long.

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The seismic cable must be towed at a constant depth, normally between six and eight meters. This is achieved by filling the cable with a special oil which gives it the same specific weight as the surrounding water. Minor deviations from the correct depth are corrected by using small wings on the cable.

The end of the seismic cable is marked by a tail buoy which lets other vessels in the area see where the cable is located. Another important function of the tail buoy is to keep the seismic vessel informed of where the end of the cable is. The personnel need to know this in order to control where all cable sections are at all times.

The length of the seismic cable reduces the seismic vessel’s maneuverability, and it therefore needs a large area to turn from one line to the next. Apart from potential traffic control problems, however, the seismic cable is not considered an environmental problem.

Sound in water

Sound is created by small pressure changes that vary so rapidly that the ear is able to hear them. Pressure changes are measured in Pascal (Pa). It is more common to indicate sound pressure in terms of a ratio, however, and decibel (dB) is the one most commonly used. Decibel is not a measuring unit, but a ratio that describes for instance the pressure in relation to a reference level. There is a considerable difference between the acoustic conditions in air and water. A different reference level is also used, making it impossible to draw a direct comparison between measurements of sound pressure made in air and water. This is very important for environmental assessments.

The information collected by the seismic vessels is vital in the mapping of potential deposits of oil and gas and in planning exploration drilling.

Foto: Petroleum Geo-Services

To a large extent the strength of the seismic signal will depend on the distance from the source. Generally speaking, the signal strength is inversely proportional to the distance. Over greater distances the signals will be somewhat more subdued, depending on the local conditions on the seabed and the geological conditions in the underground.

Noise can appear as continuous signals, for instance from engines or as pulses from a shooting range. Seismic signals are short pulses repeated every ten seconds during the operations, and they must therefore be classified as pulsed noise.

There is a big difference in the way sound pressure from these signals is indicated. Pulsed noise is often indicated in terms of the maximum sound pressure (peak value) plus duration of the noise, while continuous noise is indicated either as an RMS level or as a spectral level. It is important to be aware how sound levels are indicated when strong sounds are assessed in relation to the environment.

Sound in water is less muffled than it would be in air, and underwater sound may in certain conditions be heard across enormous distances. The sound from seismic surveys is emitted by a source very close to the surface, and this means that the sound is much more muffled than if the source had been located deeper down in the water. Hence the sound pressures from seismic signal sources can only cause physical damage very close to the source. However, the sound may scare or cause discomfort across somewhat greater distances.

The effect of seismic surveys on fish

Many studies have been conducted on the effect of seismic signals on fish in all stages of life. There are studies of possible direct damage to fish in its very early stages (eggs and fry), but since adult fish can move away from the sound source, the studies for this group concern behavioral effects.

Direct damage

Many studies have shown that organisms can be damaged when exposed to sound pulses with a rapid rise time (i.e. rapidly increasing sound pressure) and a peak value of 230 dB or more.
Sound pulses from air guns will often have a relatively slow rise time, and for this reason organisms can tolerate a higher peak pressure from these than from for instance underwater explosions.

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Sound pressures with a peak pressure of more than 230 dB only occur in the immediate vicinity of the air guns, within a radius of just a few meters.

The Norwegian Institute of Marine Research concluded in a report (Dalen et.al., 1996) that there is such a small amount of eggs and fry present within the danger zone that damage caused by air guns will have no consequences for the fish stocks. They calculated that the mortality caused by air guns might amount to an average of 0.0012 percent a day. In comparison with the natural mortality rate of 10 percent a day, the effects of damage from air guns seem very slight.

An Australian study published in 2003 shows that air gun signals may damage fish hearing. Local damage to fish auditory sensory cells was studied through an electron microscope, and after 54 days the hearing organs were found to have considerable damage. However, one conclusion drawn by the study is that further investigation is required to understand the processes that lead to such damage.

Scare-off effects and impact on the fish

When a seismic survey is conducted, fish in the area will hear the sound of the air guns and will often react to it. How the fish react, however, will depend on many factors, and it is difficult to conduct unambiguous studies in order to map the reaction patterns.


Foto: Petroleum Geo-Services

In 1993 the Institute of Marine Research conducted a major study, "Effekter av seismisk skyting på fangst og fangsttilgjengelighet av torsk og hyse" (Effects of seismic shooting on catches and catch availability of cod and haddock, published in *Fisken og Havet* no. 3, 1993), where the catches per trawl and line were studied before, during and after seismic operations in an area of Tromsøflaket.

The study was very thorough and showed a clear negative effect of seismic surveys in the area around a seismic vessel. However, it is hard to say specifically how far this effect is felt. The investigations showed reduced trawl catches of cod as far away as 33 kilometers from the sound source, but an analysis of the numerical data does not give evidence of a scare-off radius beyond one to two kilometers from the seismic vessel.

The Marine Laboratory of the Fisheries Research Services in Aberdeen, Scotland, conducted a study in 1998 of air gun scare-off effect on a shoal of fish around a reef in one of the Scottish fiords. A TV camera was used to study how fish reacted to the sound pulses of an air gun. This study showed very little reaction to the sound pulses, even though they had a peak value near 229 dB. The greatest reaction was observed when the air guns were placed right on the bottom, where the firing caused a big cloud of air and bottom sediments.
This visual effect had a considerably greater scare-off effect than the sound pulses themselves, even though these were very powerful.

A study conducted by the Institute of Marine Research in 1999, looked at the scare-off effect of seismic surveys on herring in an area in the western Norwegian Sea. Even though herring is thought to have better hearing than many other species of fish, no significant changes were observed in the amount of herring in the area in spite of the seismic operations.

The Faroese Fisheries Laboratory conducted a major study in 1999 to map the effects of seismic surveys on the fishing results. The study was based on the activities in 1997, as this was the last year when no advance warning of seismic operations was given in this area.

The study included interviews with the Faroe Islands fishermen and a review of their catch logs. The catches varied greatly throughout the period, and it was impossible to register any seismic effect on the basis of the catch logs.

The study shows that the seismic operations in Faroese territorial waters in 1997 had no long-term effect on the local fisheries or the fish stocks.

Corresponding results are noted in an Australian study covering the period 1996 to 1999. This study shows scare-off effects reaching one to two kilometers away from the seismic vessel, but also that these effects will not necessarily be detrimental to the fishing or the fish stocks.

The effect of seismic surveys on tobis fishing has long been considered a potential problem, and this was carefully investigated in a study conducted by the Institute of Marine Research in 2002. Here the tobis was mapped acoustically, it was observed in the cage, and its potential mortality was mapped by collecting the tobis using a grab and from the cages.

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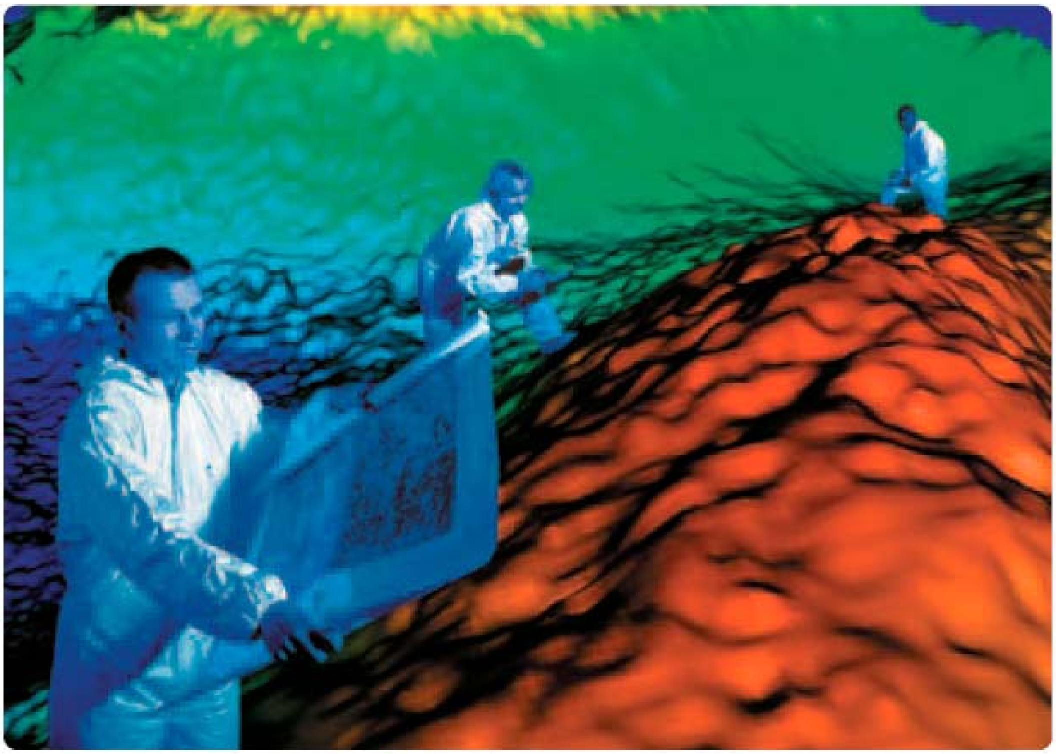
Sound pressure is only dangerous for sea organisms in the the air guns' immediate vicinity. The Institute of Marine Research has concluded that the amount of fish eggs and fry found in the danger zone is so small that the potential damage is of no significance for the fish stocks.



Once seismic data has been collected and interpreted, the oil company experts can make up a detailed picture of the reservoirs and how they can best be drained of oil and gas.

The study shows that there is no increased tobis mortality in the area due to seismic operations. A certain scare-off effect has been observed, but this effect is difficult to quantify. The acoustic measurements show that the amount of tobis was greater after the seismic operations than before it. This may have other reasons, e.g. other fish drifting in. The study concludes, however, that seismic surveys have no demonstrable negative effects on tobis.

Neither was there any demonstrable reduction in fish catches in the period following the seismic operations.

Different types of seismic surveys

Seismic surveys may be conducted as so-called two-dimensional (2D) or three-dimensional (3D) operations.

2D surveys are relatively cheap, and today they are mostly used in the early exploration phase.

3D surveys give a much better picture of the underground and are used in mapping oil and gas fields. Drilling locations are often selected on the basis of 3D surveys.

Repeated 3D surveys (often called 4D) are used to map how hydrocarbons are taken out of a reservoir during production. This method is relatively new and has contributed to increased oil and gas production from existing fields.

2D surveys are planned with long single lines, or lines forming an open net with a line distance of one kilometer or more.

One signal source and one seismic cable are used in 2D seismic surveys. The source is set up to emit the strongest possible signal and is normally fired every 25 meters, or roughly every ten seconds.

In 3D surveys the seismic vessel will sail along parallel lines, and frequently there are two signal sources and from four to eight seismic cables. The distance between the lines is normally 25 meters, and the signal source is fired every 25 meters. By using several cables and signal sources, many seismic lines can be registered at the same time, making data collection much more efficient. By registering eight to 16 lines every time the vessel crosses an area, the number of sailings is significantly reduced. This means that the time needed for a 3D survey is much shorter today than it used to be when the 3D technology was new and one normally used two sources and one seismic cable.

Foto: Petroleum Geo-Services

New seismic vessels can pull more and longer cables, thus covering a larger area. This makes the vessel much harder to maneuver, but it also reduces the number of sailings needed.

The current technique with many seismic cables makes the vessel much harder to maneuver, and it needs a great deal of space to turn around and return to the individual sailings in the seismic program. The time between two neighboring lines can be from eight to 12 hours, but for operational reasons it often takes even longer.

The seismic vessel used for both 2D and 3D operations can function as a complete geophysical laboratory and is equipped with everything necessary to work 24 hours a day. The vessel has very accurate navigation equipment and can communicate with everyone they might need to get in touch with.

Published September 2004

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Research shows that seismic operations damage fish eggs and larvae in the air guns' immediate vicinity, but that the activities have no negative effects on fish stock levels.

Seismic operations affect shoals of fish in the local area. The discussions continue as to how far this effect is felt. There is no research indicating considerable negative effects on local shoals of fish.

Studies show that seismic operations scare the fish. Such an effect has been proven in a radius of at least two to three kilometers from the vessel, but it is not clear to what extent the scare-off effects have a negative influence on the fishing.

For many years the oil industry has financed considerable research into the effects of seismic surveys on fish and fisheries. Based on the research conclusions, recommendations and regulations have been made in order to protect spawning fields and spawning migration routes and to minimize the drawbacks for the fisheries.

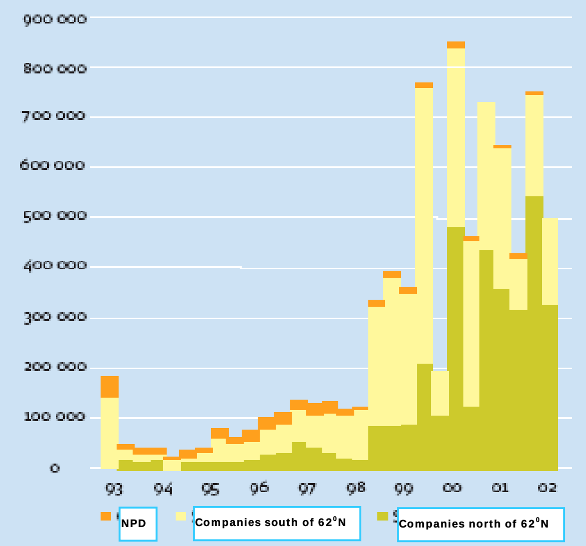
For some licensees in the Norwegian Sea and the Barents Sea, collection of seismic data is subject to seasonal limitations. This is to avoid damage and conflicts in periods of spawning and intensive fishing.

The extent of seismic operations on the Norwegian Shelf varies from year to year. After 1990 the annual collection has varied from just under 200 000 to more than 800 000 line kilometers. During 2002, 502 506 kilometers of seismics were collected, 172 612 kilometers in the North Sea and 329 894 kilometers in the Norwegian Sea.

New seismic vessels, with many long cables, have made the data collection much more efficient and have reduced the number of sailings needed.

OLF has initiated annual seminars for the fishing industry, the authorities, research institutions and representatives from the oil industry, where those attending discuss points of view, experiences and knowledge of seismic operations and their relationship to the fisheries.

Seismic data collected on the Norwegian Continental Shelf 1962-20



The collection of seismic data on the Norwegian Shelf has increased considerably after 1990. New advanced vessels have led to more efficient data collection.

This fact sheet is based on a report written by Ingebret Gausland. Gausland is a graduate engineer who has worked in geophysics and seismics since 1969, first in the Royal Norwegian Council for Scientific and Industrial Research and then from 1973 in Statoil, where he has held positions such as chief geophysicist and special adviser on seismic surveys and the environment. He is engaged by both OLF and the international organisation OGP (International Association of Oil and Gas Producers) as an adviser on seismic surveys and their effects on the marine environment.

Read more about seismic surveys and fish at **www.olf.no/miljo**