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Offshore seismic surveys may impair hearing and cause ear damage in marine fish and mammals.

-Critical new aspects to be considered in the discussion on future petroleum operations in Norway (The North Sea, Norwegian Sea and Barents Sea)

NORGES NATURVERNFORBUND
FRIENDS OF THE EARTH NORWAY

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FoEN was founded in 1914 and is Norway's largest environmental conservation organization with a total of about 28,000 members. FoEN is a nationwide organization with branches in all counties, and 155 local groups scattered throughout Norway.

"There are local 'hot-spots' of ambient noise all over the globe, of course. We have been in the North and Norwegian Seas on many acoustic experiments, and listening to the raw output from hydrophones deployed from the research vessel, the entire soundscape is often dominated by the repetitive 'boom...boom...' of distant geophysical surveying."

Potter and Delory (1998),
Acoustic Research Laboratory of the University of Singapore

Table of contents

1 Introduction

Seismic airgun arrays used by the offshore oil and gas industry introduce one of the strongest known sources of noise into the marine environment. Several marine fish, whales and other animals have been shown to react to this noise up to several kilometres away from the source (IACMST 2006). Norwegian waters are among the areas most extensively used for petroleum exploration in the world (NRDC 2005), and have been so for more than thirty years. It has been a continuous growth in the number of applications for seismic surveys on the Norwegian shelf the latest years (OD 2006). The main companies are the two Norwegian ones, Hydro and Statoil, followed by well-known international oil companies like Elf, Shell, Esso and BP. The main geophysical contractors are PGS and WesternGeco (see Figure 1 and 2).

These companies are currently claiming to proceed with a zero-emission policy in Norwegian waters, regarding pollution. However, there are few measures taken to avoid adverse impacts on marine life during the Norwegian seismic surveys. No formal guidelines are yet established other than for avoiding direct conflicts with fisheries. This in contrast to an international movement the last few years towards encouraging the nations to take a stricter attitude against noise pollution in the oceans, exemplified by clear statements from both UN (2005), IUCN (2004) and IWC (2004). Norway was in fact the only nation not sharing the concerns of the IUCN declaration, by stating for the record: "We think the resolution is premature and the extent of the problem first should be identified." (IUCN 2004)

The current situation is hence that while low energy seismic used by biological ocean researchers some places in the world go through a rigid procedure of environmental impact assessment (Breitzke *et al.* 2006, Boebel *et al.* 2005, LGL 2005), and some commercial surveys face very strict rules for avoiding harassment of marine mammals (US National Marine Fisheries Service 2006), yet the extensive high power seismic surveys in Norwegian waters go on in a way that seems to be determined solely by industrial demands.

This paper aims to contribute towards a reconsideration of the Norwegian positions and practices regarding seismic surveys, by describing the potential extent of the problem regarding sea animal hearing impairment. It is based on the latest biological knowledge and should disturb all actors in this field. We conclude that seismic surveys are at risk of causing hearing loss in particular for stationary fish, and we challenge Norwegian authorities and oil companies to immediately provide a full impact assessment for this.

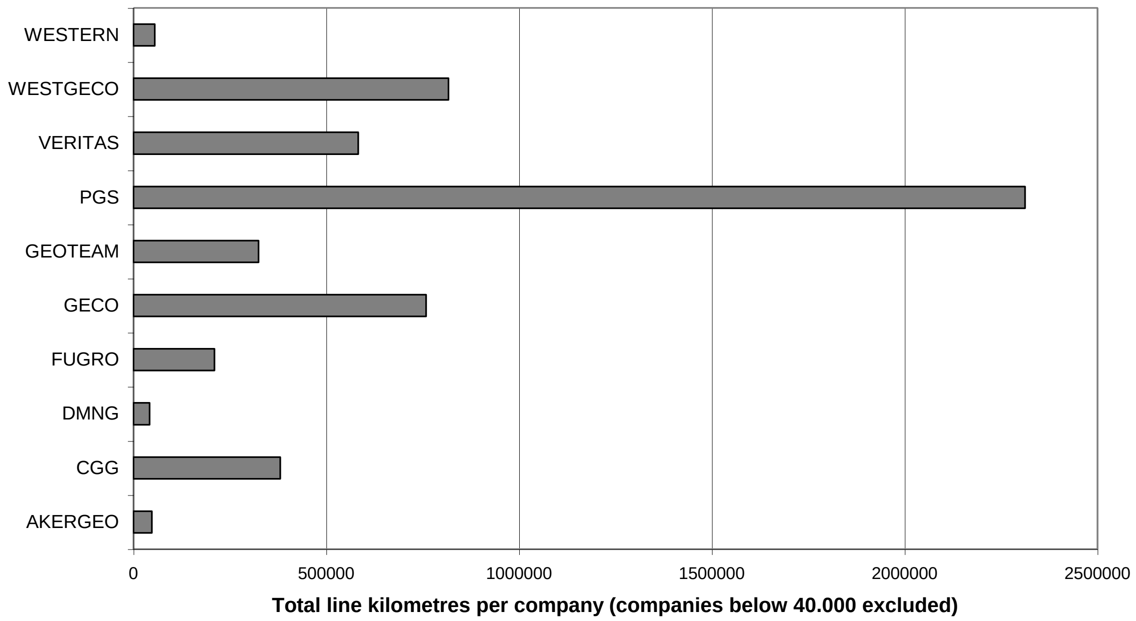

Figure 1. Seismic surveying on the Norwegian shelf 1997-2006, by surveying company.

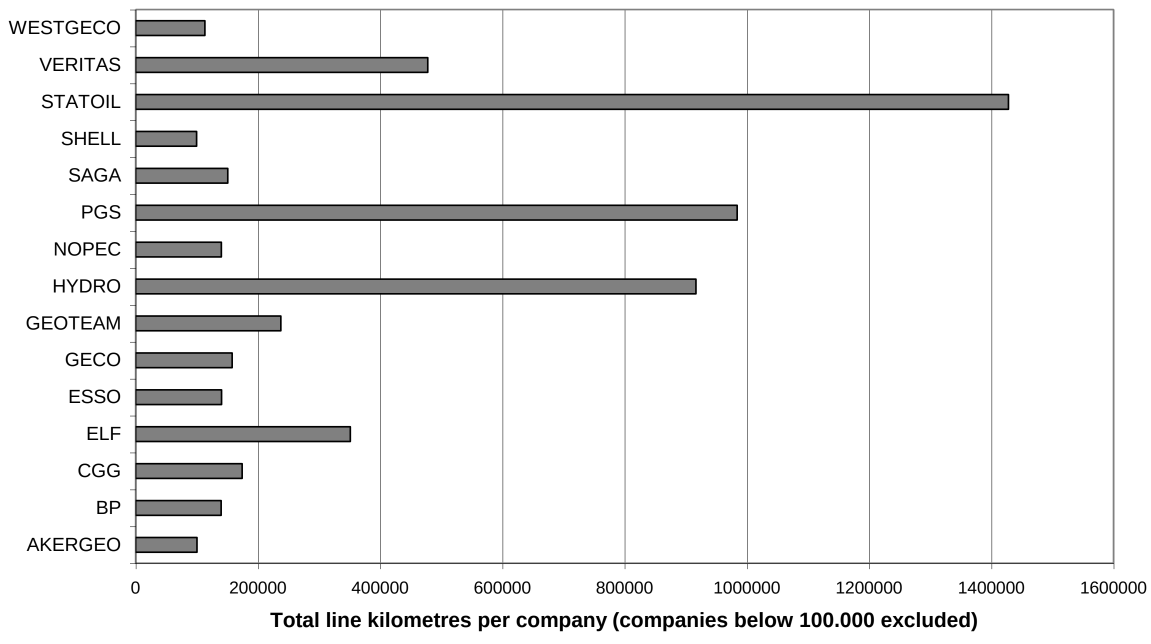

Figure 2. Seismic surveying on the Norwegian shelf 1997-2006, by ordering company.

2 Animal hearing in a noisy ocean

Far from traditional beliefs of the ocean as a quiet place, most marine organisms rely to a great extent on sound both for communication, feeding, predator avoidance and navigation (see for example Popper 2003, NRC 2003 or Hasting and Popper 2005). In a large part of the world's oceans there is either little light or low visibility. Here the animal's ability to listen in to, and sophisticatedly process and analyse, sound cues from the environment is probably their most central sense. Several marine animals experience both the near and far environment through auditory senses. It is also evident through for example whale communication across oceans that sound signals in general are propagating much further in the marine than in the terrestrial environment.

Man made marine noise is evident almost everywhere in the marine environment, and clearly has the potential to affect marine life. Noise levels have increased significantly in the world's oceans since industrialization, and have been compared to creating a "fog" which limits the natural auditory "visibility" (see NRDC 2005 for a review). The potential adverse direct impacts have received increased interest the last few years, partly due to new findings linking some mass strandings of cetaceans to the use of naval sonar. Coincidence in time and space between such strandings and naval exercises, together with noise induced pathological findings, has been seen as a general warning that noise has the potential to cause direct physical damage to sea animals in ways not earlier comprehended (ASOC 2005, NRDC 2005, NRC 2005).

The strandings together with what seems a generally growing public interest in marine sound has sparked a great number of literature reviews on marine noise from 2003 up to today: Lincoln 2002, Gausland 2003, Popper 2003, SCAR 2003, 2005 and 2006, Popper *et al*. 2004, Wahlberg *et al*. 2005,Cummins and Brandon 2004, Moriyasu *et al*. 2004, Smith *et al*. 2004, NRC 2003 and 2005, Fisheries and Ocean Canada 2004, ASOC 2005, Hastings and Popper 2005, LGL 2005(annex), IACMST 2006, Madsen *et al*. 2006). This literature goes into details about for example the scaring effects expected for different species in certain scenarios, and summarizes a number of important unknowns and how these ones could be further investigated.

The purpose of this paper is not to provide yet another review, but to direct the attention of the Norwegian petroleum community towards certain parts of the new information: on hearing loss and ear damage, and on the possibility to predict the potential survey impacts.

3 The seismic airgun array

Seismic surveying (seismic) is a geophysical way of mapping the geological structures under the earth’s surface. The oil industry is using seismic to look for oil and gas in the ocean bed. A strong sound pulse is sent from an artificial source, often created by arrays of airguns, down towards the sea bottom. The sound pulse is reflected from the boundaries separating the geological layers in the subsurface. The signal will re-surface in a few seconds and be picked up by hydrophones. The airguns and hydrophones are usually attached to long cables that are dragged behind the research vessel, which travels in straight survey lines. How long time the signal is using to return tells how far down the different geological structures are. With modern technology it is possible to make big three-dimensional maps of the sub-surface, and thereby find areas that may be a source of oil and gas.

In seismic exploration it is both used two dimensional (2D) and three dimensional (3D) operations. 2D is the simplest and by far the most inexpensive method, as only one air gun array and one seismic cable are used for mapping two-dimensional slices of the sea bottom, with several kilometres distance between each survey line. When performing 3D explorations, the operating vessel is sailing along more closely separated parallel lines (100-500 meters), and most often uses two air gun arrays and 4-10 hydrophone cables. Normal surveys are usually travelling along their survey lines at speeds of around 5 knots (2.5 metres per second), firing a sound pulse every 10 seconds (25 metres), and each survey can go on for weeks covering many hundred square kilometres. It is as well now common to do 4D operations. These are repeated 3D explorations, often used to map how hydrocarbons are moving in the reservoir during exploitation. This is a new method and may lead to increased seismic activity through the exploitation process, and not only in the exploration phase. (Gausland 2003, OLF 2005)

When a new area is being opened for oil exploration, it might be many oil companies interested in mapping the potential of the area. In that way, many companies end up noise polluting the same area.

4 State of the Norwegian public debate on seismic

The Norwegian Oil Industry Association (OLF) have shown some interest in the biological effects of seismic surveys, and are arranging an annual seismic conference together with fishery representatives and fishery management representatives. They also support research on fishery effects, and participate in a recent international research initiative by the Organization of Oil and Gas producers (OGP-E&P Sound and Marine Life JIP), in addition to publishing some general information in reports and on the web.

The Norwegian government included seismic in the recent environmental impact assessment (EIA) for new petroleum activities in the northern parts of Norway and the Barents Sea (Norwegian ministry of oil and energy 2003), where it was concluded that effects on any population would be very limited. No new firm guidelines were suggested other than; like before, limit the extent of surveys near large spawning aggregations of fish, and “where possible” avoid interference with known large aggregations of marine mammals such as the Norwegian killer whales. Interestingly the EIA showed that core habitats of resident species of fish and marine mammals exist within most of the major targeted exploration areas in the north. Nevertheless, this did not lead to any precautionary action.

Compared to the international debate Norway lacks public statements about that regular seismic surveys could have any impacts on marine life. That is, other than what is regarded as temporal and ecologically insignificant behavioural reactions. As exploration in the Arctic has been pushed forward over the last years, OLF has summarized their thirty years of experience of petroleum activity in the North Sea slightly provocative to be that there has been no major adverse environmental impacts" (communicated in several direct meetings with FOEN, and also press releases the last few years). Regarding the seismic issue, this leaves a contrast to the opinions of internationally respected and leading scientists on marine sound, exemplified with the following personal communication to the authors:

> *"At this point, given the incredible high levels of seismic survey activities that have occurred in the Norwegian Sea area over the past 5-6 years, my guess is that most baleen species and some odontocetes would have experienced permanent hearing losses at selected frequency bands. Fish would be of particular concern… There are times when the level and amount of seismic is so extreme that there is almost no place without noise exposure."*
>
> Dr. Christopher W. Clark, 2003,
> Senior Scientist, Dept. Neurobiology and Behaviour, Cornell University

One reason supporting the Norwegian confidence in no effects from the petroleum exploration might be that the seismic topic have simply not been considered among "regular emissions" during the retrospective environmental impact assessment programme for the North Sea (Myhre *et al*. 2006). Another reason might be the rather narrow definition of what should be regarded as significant environmental impacts. The Norwegian public debate on seismic up to now has centred solely on potential negative impacts on fisheries due to scaring effect and direct impacts on hot spots of spawners and recruits of major fish stocks. This despite the international growing consensus that not only population level effects but also effects on an individual level such as behavioural impacts (harassment, masking of hearing), and physiological impacts (stress, displacement from optimal areas, temporal or permanent hearing loss) could be regarded as significant environmental impacts.

The principle of "all living being's own intrinsic value" and right to not be unduly harassed could add even a new perspective to the discussion. Of course when it comes to human life quality we set the acceptable limits of noise pollution far lower than what is expected to have any severe direct effects of the individual, and even less has anything to do with population decimations. The threat of fatal injury due to noise should hence be largely irrelevant also to the discussion regarding marine life, and the acceptable impact limits rather be set to ensure a certain quality of life. Regulations could be introduced for example to avoid hearing loss, rest deprivation, or displacement to low quality habitats, in the general marine populations or for endangered species in particular.

5 Seismic surveys on the Norwegian shelf, regulations and practises

To our knowledge no seismic surveys in Norway has ever been restricted due to pure animal welfare concerns, while potential impacts on fisheries has been a major issue. The main criteria is hence that the survey should be planned to keep justifiable distance from known spawning activity, and from aggregations of boats that are fishing, and from floating and standing fishing gear.

The seismic vessels are obliged to have a person on board that represents the interest of the fisheries. This person has experience from fisheries and is approved by the Directorate of Fisheries. The fishery representative follows a manual made by the Directorate of Fisheries (Fiskeridir 2005). However, the person is chosen and hired by the company that is undertaking the seismic activity. The fishery representative is obliged to write a report to the Directorate of Fisheries, the Direcctorate of Petroleum, and to the company in question. The person function as an advisor and does not have the power to for instance arrest the activity.

There is a fairly simple application procedure prior to a seismic survey in Norway, not including any public hearings or any environmental impact assessment. The seismic company shall at the latest five weeks before the activity takes place simply send a notification to the Norwegian Directorate of Petroleum, the Directorate of Fisheries and the Ministry of Defence. It is a common procedure to send this information to other involved parties as well, such as the Institute of Marine Research and the national fishery organisations.

The Directorate of Fisheries is giving comments regarding the applications for seismic activity. Their advice is based on tracking and catch data (historic fishing activity in the area in time and space) and tries to prevent possible conflicts with the fisheries. Usually, the suggestions from the directorate are implemented. The directorate has not made a manual for how they should handle the applications, and the comments are therefore based on their officers' judgement in each case (pers. comm. G Langedal).

The Institute of Marine Research (IMR) on their hand has partly guidance for how they should handle the applications, based on a report from 1991 (Bjørke *et al.* 1991). IMRs main advice is to keep a security zone around the biggest aggregations of spawners. However, the occurrence of egg/larvae for the major fish stocks like cod, herring and saithe is not found, by IMR, to be important regarding seismic activity (Dalen *et al*. 1996).

Norwegian fishermen have often expressed conflicts with seismic activity, like equipment interference or reduced catches. However, these observations are more often reported verbally and are therefore difficult to synthesize (Pers. Comm. Directorate of Fisheries).

6 The noise from seismic surveys listened to from a fish ear

There are several issues with the design of the air gun arrays that should give rise to concern if the aim is to protect and and ensure sustainable management of marine life. Firstly, the sound pulses have a very rapid rise time, and can hence best be compared with known deleterious impacts such as explosions or pile driving (Popper *et al.* 2005). They also contain a lot of energy compared to equivalent natural pulses of sounds such as whale clicks (Madsen 2005). In the near range (some hundred metres for example) of the airgun array, the sound received at the animals also have a very short duration, and the animals might hence not be able to comprehend its true and potentially deleterious power (Boebel et. al. 2005, SCAR 2003). At longer ranges the received sound pulse may grow into a duration of up to 0.5 second or more due to the way it is reflected and propagated (McCauley *et al*. 2000) and at very long ranges it contributes as longer hums significantly to the background noise levels (see for example studies as described in Moore and Angliss 2006 and Cummins and Brandon 2004).

An airgun array directs it's sound-energy downwards to a focus zone at the seabed below (Caldwell and Dragoset 2000, Dragoset 2000). The sound pressure decreases with distance both horizontally and vertically, but due to the way noise propagates in the ocean, noise levels measured from midwater and down to the seabed are always much higher than in the surface waters around the seismic vessel (see for example measured by McCauley *et al*. 2000 and 2003, Tolstoy *et al*. 2004, or modelled by Alexander *et al*. 2005).

The sound pulse from the air gun penetrates the seabed. It will travel through the seabed not only vertically and return to the hydrophones, but also horizontally in the seabed substrate. This head wave may affect bottom dwelling animals more strongly and directly than the waterborne sound itself (McCauley *et al*. 2000, 2003), but biological implications have never been studied.

The majority of the sound energy in the airgun pulse is within the low frequency spectrum below 1000Hz. This frequency coincides with the frequency region many marine animals uses for communication, and where most of them (fishes and baleen whales in particular) have their best hearing sensitivity.

In the waters at the continental shelves, each single seismic survey creates intense and repetitive noise, tens of times above natural background levels, day and night, for hundreds of square kilometres during the length of each survey (Potter and Delory 1998, Moore and Angliss 2006, references therein). The noise also propagates far away. Recent studies on ocean sound in the middle of the Atlantic Ocean have shown that even here noise from very distant seismic surveys along the Atlantic coasts actually dominates the sound field during the survey season. In Norwegian waters the season is usually from May throughout the autumn, which is a period with naturally low background noise levels (for example absence of storms, heavy rain and ice scouring). The airgun noise received at a marine animal such as a cod or a whale will then typically be loud enough to be detected by them above background noise tens or hundreds of kilometres away. The naturally low background noise level might be important for marine animals during this season of offspring nursing and hectic feeding, but are hence compromised by seismic surveys.

The most easily comprehendible effect of artificially increased background noise, because we can ourselves experience it daily, is that it decreases the effective hearing range. It might hence mask biologically important sound for example used for communication and navigation. Marine animals in areas exposed to a mix of human made noise from seismic surveys together with noise from ferries, super tankers and fishing vessels will have the same problem. We will not expand on this interesting topic here other than noting that the expected ranges of masking has been calculated for a typical species like cod in an environmental impact assessment for Swedish offshore windmill projects (Wahlberg and Westerberg 2005) and hence likewise could be calculated for the petroleum activities in Norwegian waters. Masking would probably cover extensive areas and because of this should be an effect of major concern (Fisheries and Ocean Canada 2004). It could for example interfere with sound based navigation of both adult fish and larvae, and interfere with spawning rituals.

7 Affected marine life's dilemma of staying or going

The Norwegian debate up to now has as already mentioned mainly been concerned with if there is a scaring effect of seismic surveys on fish stocks making them unavailable to fisheries. As we will elaborate on here this might though not be the most relevant biological impact. It seems to be general consensus in the scientific community about that many different marine animal species have a reaction distance to the airgun noise of several kilometres, and then respond with some kind of predictable behavioural change, this being for example swimming away, standing off, gathering in tighter schools or huddling at the bottom (compare for example Caldwell 2003 and Gausland 2003 representing the industry, McCauley *et al.* 2003 representing marine biologists, Cummins and Brandon 2004 and NRDC 2005 representing environmental NGOs)

At a certain noise level most fishes displays the C-turn reflex (McCauley *et al.* 2000, Wardle *et al.* 2001, Hassel *et al*. 2004) that is evolutionary designed to make them dart away from a close range approaching predator. For some species this rapid muscle contraction of the whole body takes place at every single airgun shot nearby, for example every ten seconds. This clearly constitutes an undue and unnatural stress of which consequences should be further investigated. Squids similarly show strong startle responses and the characteristic emission of ink, sea turtles initiate erratic swimming, and both fishes and marine mammals show more erratic swimming and diving patterns. Physiological effects such as increased heart and breathing rate are also found to occur.

For highly mobile pelagic species of both marine mammals and fish it has been suggested that they may avoid the survey area and be saved from any severe direct damage such as hearing loss or physical injury. There is quite a body of evidence that many marine mammals actively avoid seismic vessels, but there is no convincing evidence of a large scale and multispecies migration being the normal reaction among fish (see for example Gausland 2003 and Hasting and Popper for review of earlier studies). The oil industry has been first in line to deny that any such large scale scaring effect takes place, and have found support for this view in several large-scale studies. What is clearly shown is though a decrease in some fisheries in the area closest to a seismic survey, but this might be due to other reasons than migration. Studies that have actually tagged and video monitored more demersal fish, like Wardle *et al*. (2001) and Hassel *et al*. (2003), has not been able to show that most fish actually leave the area. Alternative explanations to the reduced fishery catches might hence be some local behavioural reaction making the fish unavailable to the fishing gear, involving for example hiding or temporary stop in foraging.

A highly important point is to discuss what happens to species and individuals that do not leave the area, but of some reason remains in the area. There might be several scenarios where an animal will not leave even if it can hear that a strong noise source is approaching:

- The noise source is not naturally regarded as a threat (e.g. habituation, attraction or even annoyance inviting counterattack).
- The signal might have a confusing direction and duration.
- Species and life stages with very limited movement ability (sessile animals, juveniles).
- Species with an instinctive alarm response to hide at the seabed freeze in the water column or at the surface rather than flee.
- Individuals within species that establish home ranges.
- Individuals performing certain important tasks such as hiding, feeding, resting, digesting, giving birth or nursing young (all of which animals arguably spend a lot of their time on) and where leaving the area may constitute an not optimal energy expenditure or even a great risk due to for example predation.

With a seismic study area normally covering many hundred square kilometres it is also a question for the marine animal where to go. A major Australian seismic survey studied by McCauley's research team (2000, 2003) was estimated to expose the present marine animals to tens of thousand airgun shots above a biologically relevant level trough the course of the survey. Several researchers have suggested that the reason why you can often sight marine mammals surfacing at surprisingly close range to a seismic vessel is because the earlier described noise shadow here is the nearest place for them to escape to (Wolfgang Dinter, Federal Agency for Nature Conservation (BfN), Germany, personal communication). For a cod it may not be very meaningful to swim tens of kilometres to avoid a noise source they do not naturally know how to react to. In this case it seems a more parsimonious ecological option to stay put and hide in the seismic survey area, and take the beating.

This scenario is supported by common descriptions in several studies on the reactions of both fish and marine mammals on how any initial startle responses seem to fade by time (McCauley *et al*. 2000,Wardle 2001). The animals then simply continue normal activity even with the seismic survey noise being present at very high levels.

8 What is the new knowledge about hearing loss

All vertebrates both on land and sea share some common basics in their hearing system, one of them being the sensory hair cells in the ear designed to mechanically pick up the motion energy of sound at different frequencies and transform them to nerve impulses. These are sensitive structures and for some time it has been known that extremely high sound for even a short period of time, may result in hearing loss and mechanical destruction of some of these sensory cells in sea animals as in terrestrial animals and humans. But until recently it was unknown if the short pulsed seismic noise also could have such effects (reviewed by Hasting and Popper 2005).

In 2005, Popper`s research team published a field study where two out of a total of three investigated species of Canadian estuarine fish showed a temporally elevated hearing threshold after being exposed to just a few (five and 20) airgun pulses. This was the first study investigating how airgun arrays might affect fish hearing. Other studies have found similar elevated hearing thresholds in fish exposed to even much lower levels of outboarder engine noise, pure tones and white noise (reviewed by Popper *et al*. 2005 and Hastings and Popper 2005). In some of these studies the fish needed more than two weeks to return to normal hearing after a single impact period. It is not known what regeneration abilities the fish ear has after more severe impacts.

Two years prior to this, in 2003, Rob McCauley's Australian team published the first study that dissected the inner ear of a fish (pink snapper) after exposure to what was designed to be an environmentally relevant level of airgun noise (at a smaller scale and with a smaller airgun array mimicking the noise of a 3D airgun array passing by 500 meters away 6 times during a day). The pink snapper ears showed a severe damage and death to a portion of their sensory hair cells. The damage did not recover but grew more severe during the post exposure period up to 58 days, when the study was ended. Similar ear damage from noise other than seismic has been found in different fish species such as gold fish, oscar and cod (see McCauley *et al*. 2003 and Hastings and Popper 2005). It is no reason to believe that this does not apply to fish in Norwegian waters exposed to man made marine noise, and McCauley's study hence desperately needs to be repeated here.

These studies together, even if they are still to be regarded a pilot glimpses into a large research field, are very disturbing as they might indicate a scenario where there is a wide-ranging but hidden impact on fish from seismic surveys. The importance of these recent studies is not that they give any definitive general answer, but simply lay with the observations that temporary hearing loss and ear damage takes place in fish exposed to seismic airguns, and at levels not far from what might actually be encountered during seismic surveys. The studies also prove that with any heavy noise exposure (duration and/or amplitude) above certain thresholds the adverse effect may become more severe and last for considerable time after the termination of the sound source.

Also the studies has shown that even if the hearing loss thresholds varies among species, it seems to often appear at a predictable level above each species basic hearing threshold. It might therefore be possible to establish damage thresholds for a wide range of species just by charting their general hearing ability and not having to expose them to deleterious noise (review Smith *et al.* 2004).

Simultaneously to this, several groups of marine mammal researchers have the last few years for the first time published information about the sound levels needed to cause temporarily threshold shifts in marine mammals. It is here established for some different species at what levels a single exposure might cause an effect, and also found that each doubling in exposure time seem to linearly lower the effect threshold (with about 3 dB). (Reviewed by NRC 2005 and Boebel *et al.* 2005)

9 How much of a Norwegian seismic petroleum survey can an animal stand before a hearing damage will occur?

Both the advances of researchers on fish and marine mammals have allowed preliminary general models to be developed on how marine noise energy and duration may interact to cause temporal hearing loss for different groups of marine animals. So while earlier concerns about the potential adverse effects of human made noise on the hearing of marine animals were based mostly on general knowledge about hearing damage in vertebrates and the precautionary principle, it is now for the first time possible for a given seismic airgun array, survey layout and geographical area to more directly evaluate the risk of adverse hearing impacts on the marine animals present (see applied for example by NRC 2005, Boebel *et al*. 2005, Breitzke *et al*. 2006, LGL 2005 and 2006). This kind of risk assessment is though yet to be done for any commercial petroleum seismic survey in Norwegian waters.

As a simplified example on how to go ahead with exposure based risk assessment we will now provide a closer look at how a typical Norwegian 3D survey will impact on sea animals not fleeing. As a starting point, it is neither for fish nor marine mammals entirely unlikely that an underwater sound level of about 180 dB re 1µPa (rms) is about the threshold to trigger temporal hearing loss when the sound has some duration (seconds to minutes of total exposure time). Consider for example information reviewed in Boebel *et al.* (2005) for marine mammals, and McCauley 2003, 2000a,b as well as Popper *et al*. (2005), Popper (2003) and Smith *et al*. (2004) for fish. The 180 dB (rms) level has in different studies of commercial airgun arrays been measured to have an impact zone with a radius of 1-3 kilometres (McCauley *et al*. 2000, Tolstoy *et al*. 2005, Austin *et al*. 2006, Turner *et al*. 2006) around the slowly moving seismic vessel. We will here use 1,5km as an average impact range. Each animal will every time the ship passes within this range be exposed to tens to hundreds of potentially hazardous airgun shots, repeatedly within a few days time.

For a survey with e.g. 300 metres between each transect line of the seismic vessel, which is typical on the Norwegian shelf (Gausland 2003,IMR 200x), it is straightforward to estimate that a sedentary sea animal (position fixed as the survey moves by for the purpose of this exercise) would be exposed to about 1000 airgun shots above the 180dB(rms) level, and of these about hundred shots above 190dB (rms) (Figure 3). On average, the duration of each pulse will be about 100 ms at these distances (McCauley 2000, MacGillivray and Chapman 2005).

A pressing question is if such an exposure is enough to cause any hearing damage on marine species in Norwegian waters. (Appendix 1 gives a list of some of the most common species, for those interested.) Adding the different pulses of sound together to a total exposure the animal will be exposed to a total sound duration of about 90 s at between 180 and 190dB (rms) and several seconds above 190dB (rms) which when compared to the recently developed thresholds data for marine mammals clearly indicates temporally hearing loss will occur (following SCAR 2003 and 2005). Also for fish the estimated total exposure on each individual during a Norwegian 3D survey is arguably well above what might be expected to cause temporally hearing loss and ear damage when compared to the much more moderate exposure levels (level an duration combined) in the Popper (2005) and McCauley (2003) studies respectively.

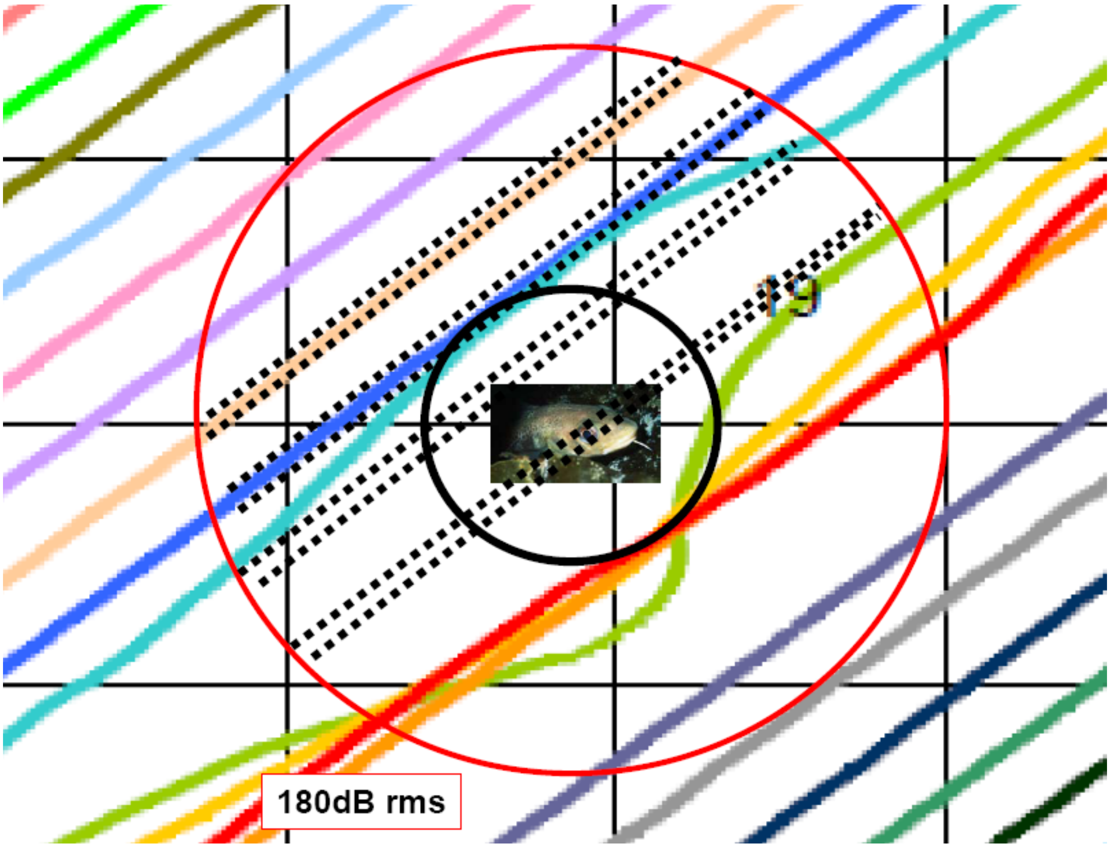

Figure 3. View from above. Simple modelling of deleterious noise around a marine fish when staying in a fixed position at the seabed with a seismic vessel passing above along transect lines. Each black dot is one firing of the airgun array. The red circle (the "danger zone") is 3 km in diameter.

Even for low energy seismic equipment used by some ocean research institutions (with source levels about ten times lower than a typical 3D array), it was last year estimated that temporary hearing loss might appear for animals passed at some hundred meters range by the vessel (Breitszke *et al* 2006). In the shallow North Sea, the oilfields typically are found at 60 to 200 meters ocean depth and bottom living sedentary fish would surely be within the impact zone of a commercial 3D survey. We can hardly see any other interpretation than that almost every single animal staying put within the survey area would be affected. Then simply knowing the abundance of different marine animal species within the area will also tell a lot about the number of animals affected (see method applied in EIAs on seismic by LGL 2005 and 2006).

Being exposed to temporally threshold shifts repeatedly will increase the chance of developing a permanent hearing loss (Hastings and Potter 2005, NRC 2005), and this is what some researchers guess already have happened to sea animals in the North Sea due to the 30 years of North Sea oil boom. Importantly and unfortunately, there is reason to believe for sea animals such as for terrestrial animals that the threshold for pain from noise is higher than the threshold for hearing loss. There is hence no reason to trust that any animal automatically will flee an area in due time before there is risk for a hearing loss to occur (Ketten 2002 as personally communicated by W.Dinter).

It is also expected that even exposure to lower noise level than the above mentioned critical levels for acute damage might cause hearing loss if the exposure is of long enough duration (such as for humans in a working environment). It is therefore very important to allow the cumulative exposures to be calculated when several seismic surveys are done in the same area within a short time, and other noise sources such as ship traffic also adds to the total exposure. This points towards that it is a cooperative task between several companies at national, or maybe circum-oceanic level to perform the full environmental impact assessment of the seismic survey activities. Important players such as Norway would hence have much to win on actively supporting international initiatives.

10 Major recommendations for further work

Noise from seismic surveying evidently impacts on the lives of many individuals of marine organisms, and might even give them the handicap of lost hearing ability. If so this could adversely affect both animal health and the viability of populations in very extensive ocean areas. Recognizing man made noise as a polluting and potentially hazardous substance in the marine environment, it is through Norwegian law the oil contractors' responsibility to ensure that no serious harm is made.

Because the oil industry and seismic companies are experts on interpreting marine sound, and actually records both background levels and airgun levels continuously through their surveys, they should be the first to **provide exposure models showing the cumulative noise impact on marine animals in the areas covered by seismic surveying**. Any further hesitance to do so is very disappointing. Useful modelling tools already exist.

Such realistic noise exposure information, together with the oil industry contributing more actively towards **studies on the hearing sensitivity and noise induced hearing threshold shifts in a range of different common species**, would be a major step forward. It is to our understanding possible to assess actual risks of physical impact on marine animal hearing, and possible to model the risk of masking biologically important sound. This should be done ahead of giving a go to any major future seismic programmes.

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Appendix 1. List of some important marine fish and mammals in Norwegian Waters possibly affected by the seismic surveys.

Norwegian name	English name	Latin name	North Sea	Norwegian Sea	Barents Sea
Torsk	Cod	*Gadus morhua*			
Hyse	Haddock	*Melanogrammus aeglefinus*			
Sei	Saithe	*Pollachius virens*			
Hvitting	Whiting	*Merlangius merlangus*			
Tobis	Sandeel	*Ammodytes*	present	absent	
Øyepål	Norway pout	*Trisopterus esmarkii*			
Kolmule	Blue whiting	*Micromesistius poutassou*			
Makrell	Mackerel	*Scomber scombrus*			
Brisling	Sprat	*Sprattus sprattus*			
Sild	Atlantic herring	*Clupea harengus*			
Breiflabb	Anglerfish (monk)	*Lophius piscatorius*			
Lange	Ling	*Molva molva*			
Blålange	Blue ling	*molva dypterigia*			
Brosme	Tusk	*Brosme brosme*			
Gråsteinbit	Wolf-fish	*Anarhicas lupus*			
Flekksteinbit	Spotted wolf-fish	*Anarhicas minor*			
Rognkjeks	Lumpsucker	*Cyclopterus lumpus*			
Lodde	Capelin	*Mallotus villosus*			
Blåkveite	Greenland halibut	*Reinhardtius hippoglossoides*			
Gapeflyndre	Long rough dab	*Hippoglossoides platessoides*			
Knurr	Grey gurnard	*Eutrigla gurnardus*			
Lomre	Lemon sole	*Microstomus kitt*			
Lyr	Pollack	*Pollachius pollachius*			
Lysing	Hake	*Merluccius merluccius*			
Polartorsk	Polar cod	*Boreogadus saida*			
Rødspette	European plaice	*Pleuronectes platessa*			
Smørflyndre	Witch flounder	*Glyptocephalus cynoglossus*			
Snabeluer	Deep-sea redfish	*Sebastes mentella*			
Taggmakrell	Horse mackerell	*Trachurus trachurus*			
Tunge	Sole	*Solea vulgaris*			
Vanlig uer	Golden redfish	*Sebastes marinus*			
Piggvar	Turbot	*Scophthalmus maximus*			
Slettvar	Brill	*Scophthalmus rhombus*			
Sandflyndre	Sand dab	*Limanda limanda*			
Kveite	Halibut	*Hippoglossoides hippoglossus*			

Norwegian name	English name	Latin name	North Sea	Norwegian Sea	Barents Sea
Elasmobranch					
Havmus	Rabbitfish	*Chimaera monstrosa*			
Kloskate	Starry skate	*Raja radiata*			
Piggskate	thornback skate	*Raja clavata*			
Småflekket rødhai	Small-spotted catshark	*Scyliorhinus canicula*			
Svarthå	Velvet belly lantern shark	*Etmopterus spinax*			
Pigghå	Spurdog	*Squalus acanthius*			
Brugde	Basking shark	*Cetorhinus maximus*			
Håbrann	Porbeagle shark	*Lamna nasus*			
Cetaceans					
Spermhval	Sperm whale	*Physeter macrocephalus*			
Nebbhval	Northern bottlenose whale	*Hyperoodon ampullatus)*			
Sowerbys spisshval	North Atlantic Beaked Whale	*Mesoplodon bidens*			
Narhval	Narhval	*Monodon monoceros*			
Beluga/kvithval	Beluga whale	*Delphinapterus leucas*			
Nise	Harbor porpoise	*Phocoena phocoena*			
Spekkhugger	Killer whale / Orca	*Orcinus orca*			
Grindhval	long-finned pilot whale	*Globicephala melaena*			
Kvitskjeving	Atlantic white-sided dolphin	*Lagenorhynchus acutus*			
Kvitnos	Whitebeaked Dolphin	*Lagenorhynchus albirostris*			
Tumler	Bottlenose dolphin	*Tursiops truncalus)*			
Nordkaper	Right whale	*Eubalaena glacialis)*			
Grønlandshval	Bowhead whale	*Balaena mysticetus)*			
Blåhval	Blue whale	*Balaenoptera musculus)*			
Finnhval	Fin whale	*Balaenoptera physalus)*			
Seihval	Sei whale	*Balaenoptera borealis)*			
Vågehval	Minke whale	*Balaenoptera acutorostrata*			
Knølhval	Humpback whale	*Megaptera novaeanglia)*			
Vanlig delfin	Short-beacked common dolphin	*Delphinus delphis*			
Stripedelfin	Striped dolphin	*Stenella coeruleoalba*			
Rissodelfin	Rissos dolphin	*Grampus gruseus*			
Retthval	Northern right whale	*Eubalaena glacialis*			
Småhodehval	Cuviers beaked whale	*Ziphius cavirostris*			