

Active sonar and the marine environment

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Abstract. A study of the effects of active sonar transmissions on fish and marine mammals in Norwegian waters has been launched following the ordering of new frigates by the Royal Norwegian Navy (RNoN). The frigates will be equipped with active sonars operating at lower frequencies than those of the sonars currently in operation in the RNoN. Lower frequency sonar transmissions are believed to be potentially more harmful to marine life than higher frequency transmissions. The objective of the study is to acquire knowledge about the effects of active sonar on marine life, and produce a set of recommended rules for naval sonar operations in Norwegian waters based on scientific grounds.

INTRODUCTION

We started work on project LFAS (Low Frequency Active Sonar) and the Marine Environment in March 2003. The project, which is sponsored by the RNoN, aims at investigating the effects of lower frequency active sonars on marine mammals and fish. The RNoN has ordered five new frigates, the first one to be delivered in early 2006. The frigates will be equipped with towed array sonars, hull-mounted sonars and helicopter-operated dipping sonars. Frequency range of the sonar system will cover 1 to 8 kHz.

The main purpose of the project is to enable the RNoN to operate its lower frequency active sonar equipment in an environmentally safe way with as few operational restrictions as possible.

To achieve this result we have to

- establish what is known about the effects of sonar transmissions on fish and marine mammals, particularly at lower frequencies,
- create a forum for cooperation among military and civilian experts to discuss and agree on what we know and do not know about the effects of active sonar transmissions on marine mammals and fish found in Norwegian waters,
- conduct field studies recommended by the cooperative forum
- set up a national environmental database containing available information on the presence of fish and marine mammals with their known sensitivities to sonar transmissions, and
- produce a set of recommended rules for naval sonar operations in Norwegian waters based on scientific arguments.

THE EXPERT GROUP

Project work started with a search for available information on fish and marine mammals in Norwegian waters. We must know about the most important species found in Norwegian waters, economically and biologically, how they are distributed and what is known about their sensitivity to acoustic influences, noise in general and active sonar transmissions in particular.

To achieve these ends we have to cooperate nationally and internationally. The first step in this process was to establish a national forum for collaboration and discussions among military and civilian experts, “the Expert Group on Sonar Effects on Marine Life”. The Expert Group held its first meeting in Horten 7. October 2003. Experts from the following institutions were invited:

- Department for Arctic Biology, University of Tromsø,
- Department for General Biology, Institute of Biology, University of Oslo,
- OLF/OGP (Association of Norwegian Oil Producers/Oil and Gas Producers International, Stavanger)
- Institute of Marine Research (IMR), Bergen
- The Norwegian College of Fishery Science (NCFS), University of Tromsø.
- Norwegian Polar Institute, Tromsø
- The Norwegian School of Veterinary Science, Tromsø/Oslo
- Norwegian Naval Training Establishment (KNMT), Haakonsværn, Bergen
- FFI (Norwegian Defence Research Establishment), Horten

The Expert Group agreed that we do have considerable information on abundance and distribution of various species in Norwegian waters, particularly the economically important types of fish like cod, herring etc., but also whales and seals. This information is stored at IMR in Bergen. The abundance estimates of fish are based on acoustic methods (echo integration) and trawl sample data. Marine mammal distribution estimates are based on random observations from ships, whereas population estimates of whales are based on the recognized line transect method [1].

The Expert Group also agreed that there is very little information available regarding fish or marine mammal sensitivity to sonar signal exposure. Some knowledge is available on hearing in fish, seals and dolphins.

We do not know much about the great whales' hearing. Their vocalization is known, and it is generally assumed that the mammals have their most sensitive range of hearing in the frequency range of their vocalization. However, since predators like the killer whale vocalize or echo-locate at considerably higher frequencies, it is possible that the great whales are able to hear sounds also in this range of frequencies.

Based on the available information on distribution of important species in Norwegian waters and the insufficient information on sensitivity to acoustic signals of

these species, the Expert Group agreed to recommend that the following field studies be undertaken by the project:

1. Effects of sonar signals on survival and development of fish fry (spawn). This study can be continued using the same infrastructure to study behavioral and physiological effects of sonar exposure on adult herring and cod
2. Behavioral effects of sonar exposure on killer whales and minke whales
3. Effects of sonar exposure on seals

These proposals are based on a scientific evaluation of what we know and do not know and how we can harm animal life in the sea most by not knowing the effects of what we do.

RESOURCE DATA BASE

The information on marine life collected from areas within the Norwegian economic zone (see Fig 1) must be stored in a data base accessible for the RNoN. This data base shall contain resource data and data on sonar signal exposure sensitivity for species found in Norwegian waters.

In more detail the data base should contain all available information on

- 1) which species (of fish and marine mammals) are statistically found in given areas within the Norwegian economic zone at a specific time period of the year. The time period could be season (winter, spring, summer, fall), month or any other given period,
- 2) what are the animals actually doing in the area
 - migration
 - feeding
 - spawning/breeding
 - calving etc.
- 3) the best available information on sensitivity to sonar signal exposure for the various animals and fish related to activity and time of the year

This information shall be made available for planning of sonar exercises and for the naval vessels actually performing the exercises. Tactical decisions concerning the environment must be made based on the available statistical information found in the resource data base, updated information from external sources like the Institute of Marine Research (IMR) and actual observations from the chosen exercise area. Such observations (of marine mammals) could be visual or from passive sonar or active (whale) sonar. Active sonar exercises may be started by going through a ramp-up sequence of transmitted sonar signal levels if this is found to be a suitable procedure.

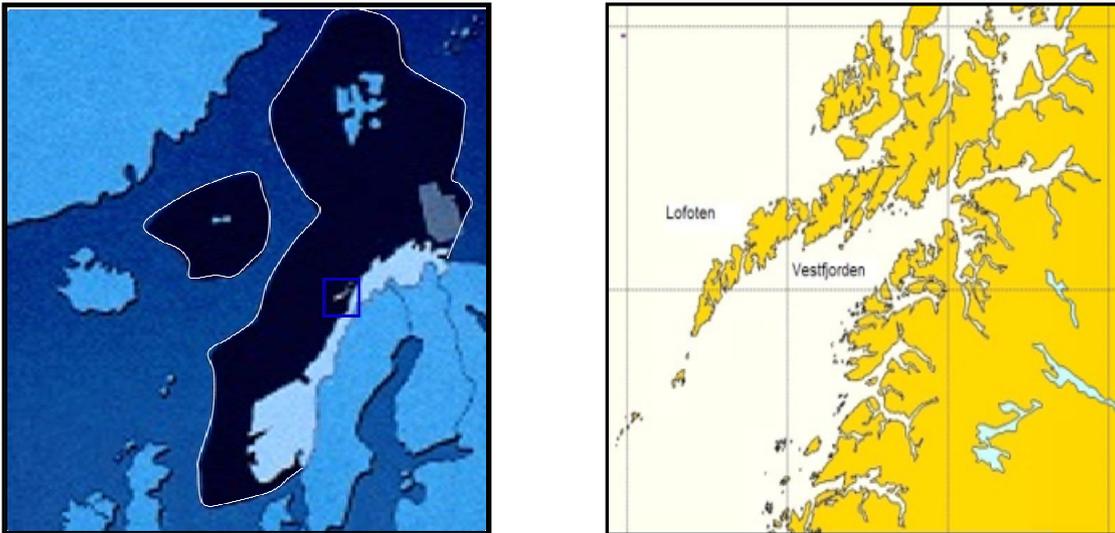


FIGURE 1. Map of the Norwegian Sea with Norway and the Norwegian economic zone. The section extract shows the Lofoten-Vestfjorden area where we intend to do behavioral tests on whales

The structure and format for the resource data base have not been decided on yet. Our solution must comply with the systems to be installed onboard the new frigates. We tend to favor a web-based system connected to a server via satellite telephone. A Web Map Service (WMS) system from Open GIS Consortium Inc. presents a geographical display system with additional layers. It can handle dynamic data with large variability. Our environmental data are semi-static.

EFFECT STUDIES

The first meeting of the Expert Group on Sonar Effects on Marine Life recommended that the three effect studies listed above should be undertaken by the project:

Study of Fish Fry and Fish

Fish fry (spawn): The background for this study is that many types of fish fry (and larvae) are pelagic and contrary to adult fish do not have the ability to escape from unpleasant or harmful sound sources. It is likely that fish fry's swim bladders have resonance frequencies that may be excited by one or more of the frigate sonars. At resonance, the swim bladders may absorb much of the acoustic energy in the impinging sound wave. The resulting oscillations may harm the swim bladder itself if the vibrations become too strong. The swim bladder is also part of a system that amplifies the vibrations which reach the fish's hearing organs, and at resonance the vibrations may become so intense that the hearing organs may be injured. Additionally, species like herring have a thin duct from the swim bladder expanding into an air-filled bullae close to each ear (Fig. 2). The hearing organ may therefore be particularly vulnerable in herring.

When aquatic organisms are being exposed to strong sound pressure waves, shear forces may develop between different types of tissue having unequal density and acoustic impedance. Tissue under development and growth, as in fish fry, will be more vulnerable than tissue in adult fish. Injury to nerve tissue can hamper development of the fish and make the adult fish less likely to survive.

If sonar exposure turns out to be harmful for fish fry, one should avoid sonar exercises in areas of high fish fry density. On the other hand, if it turns out that fish fry are not harmed by sonar exposure, it is very likely that adult fish are not harmed either. The reason for this is that fish fry is believed to be much more sensitive than adult fish to this kind of influence.

Adult Fish: Can active sonars scare away fish from fishing grounds?

To be scared by a sound signal, it is a prerequisite that the sound signal be audible. The frigate sonars operate in the frequency band 1 – 8 kHz. Fig. 3 shows hearing curves for some species of fish. Most fish do not hear sounds above 1 kHz, but herrings have this ability. The herring has two air-filled sacks (bullae) coupled to the hearing organs, and the sacks are connected to the swim bladder via two narrow air canals (Fig. 2). This fact causes herring to have particularly good hearing, up to 2-3 kHz (Fig. 3). But this again causes herring to be vulnerable to hearing damages over a wider frequency band than other fish, which implies that herring might be scared away and even harmed by the sonar signals.

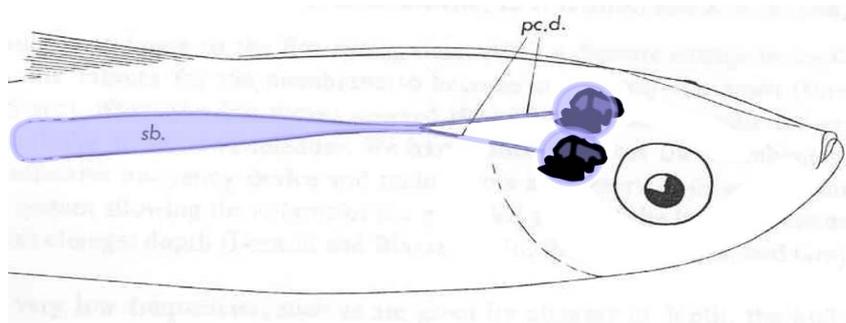


FIGURE 2. Swim bladder with connection to the hearing organs in herring (modified from Blaxter *et al.* (3))

It is not likely that herring will be scared away permanently from a geographical area by a mobile sonar. However, because of its importance, biologically and economically we will include herring in our sonar effect study.

Fish and Fish Fry Studies: These studies will be carried out in collaboration with the Norwegian College of Fisheries Sciences, Institute of Marine Research and University of Oslo. Several groups of fish will be kept in fish net cages, fish fry will be kept in bags in the net cage. Some groups of fish will be exposed to sonar signals. Control groups will be treated the same way, but without sonar exposure.

Sonar exposure will be conducted at several frequency bands and at several exposure levels. Behavior will be recorded acoustically and by video. Fish showing signs of harm will be dissected to examine for histological changes.

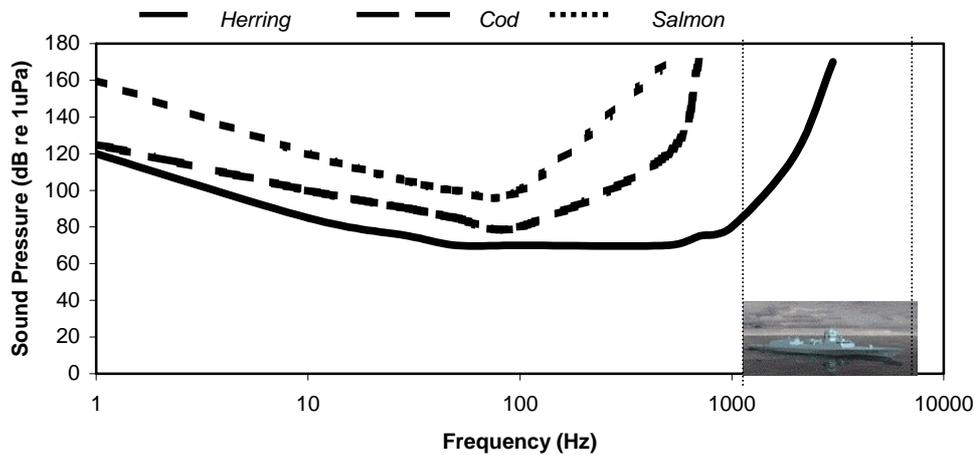


FIGURE 3. Audiograms for some important species of fish (data from Mitson (2)). Frequencies of frigate-sonars are also indicated.

Whale Behavioral Studies

Mass strandings of whales (beaked whales) in Greece 1996, Bahamas 2000 and the Canaries 2002, have been linked with naval sonar exercises. This has resulted in a massive international focus on how active sonars can harm whales.

Some knowledge exists from previous studies on blue whale, humpback whale, fin whale and grey whale. These studies indicate that (LF) sonars do not have any vital negative influence neither on migration nor foraging or vocalization behavior. For these reasons, we find it important to focus on other species. Minke whales and killer whales are very numerous in Norwegian waters and often populate the same area, like the Vestfjorden area (Fig. 1). The two species are biologically very different; one solitary, the other social, living in groups, one is prey, the other predator, one is very vocal, the other less vocal, one is a baleen whale, the other a toothed whale. Because both these very different whale species appear in the same area, we find it interesting to study them both. Fig. 4 shows a killer whale in Vestfjorden.

Behavioral studies of whales are difficult. It is not easy to study behavioral change when we really do not know their normal behavior. Changes in behavior are not harmful to whales, provided that the changes are not biologically vital, i.e. related to migration, foraging or reproduction. Whale behavioral studies are planned to be performed in collaboration with Woods Hole Oceanographic Institution, USA, and IMR, Bergen, Norway, by placing a sensor package containing a data logger which will record movements, incoming sonar signals, depth, time etc., and a VHF transmitter which makes it possible to track the whale. After a period of recording of normal behavior sonar transmissions starts. The animal's reactions are now recorded

together with the sonar signals. Finally, the data logger can be remotely released and recovered by localizing the VHF transmitter.



FIGURE 4. Killer whale in Vestfjorden, Norway

Seal Studies

Seal studies will be carried out in collaboration with Department of Arctic Biology, University of Tromsø. Seals will be studied for their own sake and as a testable marine mammal species.

Hearing in Seals: Like fish, we will study seals in fish net cages with and without sonar exposure. The purpose is to observe behavioral changes with increasing sonar exposure level for several frequency bands. If strong behavioral changes are observed, we will proceed to examine if physiological injuries to the animal's hearing organs or brain have occurred.

Seals and Diver's Disease (the bends): From the Canary Island whale stranding in 2002, which occurred during a naval sonar exercise, it has been reported pathological symptoms in the dead whales which indicate that the whales may have suffered from diver's disease [4]. Two theories have been put forward to explain this phenomenon:

- 1) The animals getting scared by the sonar signals while diving and then surfacing too quickly.
- 2) The sonar sound waves cause existing micro bubbles in the blood to grow to harmful sizes.

The phenomenon described in Jepson *et al.* [4] is not well documented. However, from Fig. 5, excerpted with permission from [Fig. 2a from KJ Falke et al., *SCIENCE* 229:556-558]. Copyright [1985] AAAS, it does not seem obvious that rapid surfacing of seals (and marine mammals in general) should increase the risk for diver's disease. On the contrary, because of lung collapse at a certain depth (30 m in Fig. 5), nitrogen content in the blood will be limited, and in fact, be less at the surface after a rapid ascent following a deep dive than after a normal more slow one. This discussion indicates that the first theory is not very likely. The second theory is not well explained and understood.

However, it cannot be ruled out that sonar signals can cause diver's disease to develop in marine mammals. Therefore we will conduct diver's disease experiments on seals. The seal will be put in water in a pressure chamber and pressurized and depressurized to simulate alleged risky diving behavior such as accelerated ascent

rates. In addition, a possible physical effect of sonars will be tested by exposing the animals to sonar sound during diving. As in the other tests the exposure will be at several frequency bands and several sound levels. Formation of gas bubbles in the body, *i.e.* development of decompression sickness, will be monitored during the trials using ultrasound Doppler [6].

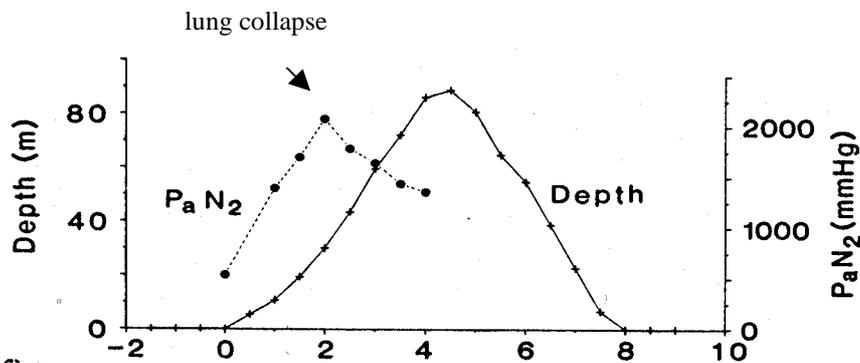


FIGURE 5. Weddell seal diving profile and content of Nitrogen in the seal's blood after Falke et al. (5)

CONCLUSION

After one year of project work, we have established that the resource situation in Norwegian waters is quite well known, and that very little is known about sonar signal effects on marine life. To increase our knowledge on sensitivity to sonar transmissions field tests are planned on biologically and economically important species. Our intention is to start with tests on fish fry (spawn) this spring. Initial tests of sonar effects on whale behavior are planned for late summer/fall 2004, and tests with seals are scheduled for spring 2005. The remaining tests will take place during 2005.

REFERENCES

1. Skaug, H.J., Øien, N., Schweder, T., Bøthun, G. "Current Abundance of Minke Whales in the Northeastern Atlantic; Variability in Time and Space" in *Can. J. Fish. Aquat. Sci.* (in press, 2004).
2. Mitson, R.B. "Underwater Noise of Research Vessels" in *ICES Coop. Res. Rep.*: **209**: 61p (1995)
3. Blaxter, J.H.S., Denton, E.J., Gray, J.A.B. "Acousticolateralis System in Clupeid Fishes" in *Hearing and sound communication in fishes*, edited by Tavolga W.N., Popper, A.N., Fay, R.R., Springer-Verlag, New York (1981).
4. Jepson, P.D., Arbelo, M., Deaville, R., Patterson, I.A.P., Castro, P., Baker, J.R., Degollada, E., Ross, H.M., Herraez, P., Pocknell, A.M., Rodriguez, F., Howiell, F.E., Espinosa, A., Reid, R.J., Jabert, J.R., Martin, V., Cunningham, A.A., Fernandez, A. "Gas-bubble Lesions in Stranded Cetaceans", *Nature* **425**: 575-576 (2003).
5. Falke, K.J., Hill, R.D., Qvist, J., Schneider, R.C., Guppy, M., Liggins, G.C., Hochachka, P.W., Elliott, R.E., Zapol, W.M. "Seal Lung Collapse During Free Diving: Evidence from Arterial Nitrogen Tensions" in *Science* **229**: 556-558 (1985).
6. Nishi, R.Y., Brubakk, A.O., Eftedal, O.S. "Bubble Detection" in *Physiology and Medicine of Diving*, edited by Brubakk, A.O., Neuman, T.S. Elsevier Science, London (2003).