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SCIENTIFIC BASIS FOR MANAGEMENT OF FISH RESOURCES WITH REGARD TO SEISMIC EXPLORATION

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INTRODUCTION

Seismic prospecting (geophysical surveying) is used to identify geological structures, including structures with the probability of containing oil and gas reservoirs. Low frequency sound waves that penetrate the sediments are reflected from sediment layer boundaries. By processing the echoes properly, cross sections and maps of the geological structure patterns are made.

On its way through the sea, the pressure waves may affect marine life in various ways. During the past 20-25 years effort has been made, with considerable success, to reduce harmful effects of seismic prospecting. Sound sources have been changed from explosives to airguns, source pressure levels are thereby decreased and pressure wave characteristics are altered.

Fig. 1. shows schematically a surveying situation. A survey vessel is towing an array - or arrays - of airguns and a receiver cable in the uppermost water layers. In that same layer small organisms like various types of plankton as well as fish eggs, larvae and fry might be found depending on season and time of the day. In midwater there might be schools and layers of various types of pelagic fish, while specimens of groundfish are found in varying concentrations in the nearbottom layer.

In which way and to what extent may seismic surveying affect fish? What can be done to minimize the eventual harmful effects to fish resources and fisheries? Clearly, the answers to these questions must be based on quantitative knowledge of possible

- increased mortality of eggs and larvae and thereby decreased production in fish stocks as a consequence of seismic activity and/or

- reduced <u>catch rates</u> of fish in areas where seismic prospecting are conducted.

Nowadays airguns are the predominating sound source in seismic surveying and I will therefore restrict my presentation to deal with the effects of airguns.

MORTALITIES OF EGGS AND LARVAE

Seismic activity may effect the production in fish stocks in several ways. Directly through excess mortality because of injuries to the specimens and also through disturbances of spawning fish. Indirectly through injuries or damage to the plankton organisms which are the main food items for all sizegroups of some species of fish as well as larvae and fry of all fish. Experimental results are available regarding the direct effects on eggs larvae, juveniles and adult fish while virtually no knowledge exists regarding possible indirect effects. Possible disturbances of the fish during spawning time can be deduced from results showing scaring effects on adult fish.

<u>Injury and mortality of eggs and larvae - Experimental results</u>

During the past 20 years - particularly during the last 5 years period - controlled experiment have been carried out on a limited number of species in order to observe the injuries and to quantify the mortalities that airgun shooting causes on fish eggs and larvae. Airgun set ups of various types have been used in these investigaions and the test specimens have been placed at various distances from the source. Table 1 summarizes the results.

Table 1. Injuries of eggs and larvae caused by airgun.
Results from controlled experiments.

Author	Results and conclusions
Kostyuchenko, 1972.	Injuries of larvae up to a distance of 5 m.
Holliday et al. 1987.	Damage to eggs at distances up to 2 m. "Possible" mortality of larvae at 2 m.
Dalen and Knudsen, 1987.	No mortality of eggs and larvae (small airgun Bolt 600B)
Dalen et al. 1991 (ongoing). Personal Communication	No observations of eggs and larvae. Injuries and mortalities of older fry (cod, herring and sprat) at distances up to 1.3 m.

It appears that injuries and mortalities to eggs and larvae have been observed at distances out to 1.5 - 2.0 m from the airgun. The real "injury risk-ranges" for larvae of various size and species are not satisfactorily known. In 1991 it was therefore decided to conduct extensive experiments in Norway in order to investigate the matter more comprehensively.

The main question is: Can airgun generated injuries during seismic surveying cause excess mortality to the egg and larvae populations?

In order to answer the question we should examine both the way airguns are operated during a survey as well as the spatial distribution on eggs and larvae. This will enable us to at least indicate wether or not egg and larval mortality during surveys may be of significance.

Operations of airguns

Fig. 2 shows a surveying situation (Dalen and Knutsen, 1987). 40 airguns were distributed along 8 arrays (5 guns in each array) and towed at 6 m depth at a speed of 5 knots. The firing period was 10 sec corresponding to firing intervals of 25 m. The configurations used at present are more or less similar, apart from a tendency towards narrowing the extension of the airgun configuration in the fore/aft direction.

Vulnerable size

The risk that fish above a certain size might be injured during operations as shown in Fig. 2 seems low. Fishes detect airgun shots at large distances and will avoid the vessel as it approaches. Their avoidance capability is largely determined by their size, and it is expected on the basis of established knowledge of swimming capacity that most fishes bigger than 30-50 mm swim away and keep safe distances to the passing seismic system. Hence we expect injuries caused by seismic activity in a survey situation to be restricted to the egg- and larval stages, i.e. fish less than 50 mm in length.

Egg and larvae distribution

Most fish stocks in our waters spawn in late winter early spring, just prior to the plankton bloom. Species like cod, haddock and saithe release their eggs in midwater at depths of 80-150 m. The eggs ascend rapidly towards the surface and are found in the upper 30 m after few days. Herring and capelin spawn at the bottom and their eggs remain there throughout the egg stage. After hatching the larvae will almost immediately ascend towards the upper layer and remain there for several months while they drift northwards (Fig. 3).

Fig. 4 show schematically the vertical distribution of larvae in northern waters in various seasons. Larvae size is indicated at the lower edge of the figure.

The density profile of eggs and larvae within the upper layer varies with weather conditions and time of the day. In calm weather most eggs and larvae often are found in the uppermost 10 m and thus concentrated in the very depth layer where airgun firing take place.

Conclusions

It can be concluded that significant mortality of eggs and larvae may occurr during a seismic survey and that care should be taken to limit seismic operations in areas and at times when high densities of eggs and small larvae are present in the upper water layers. Bjørke et al. (1991) have, on the basis of detailed knowledge of spawning grounds, larval drift patterns and larval growth, established criteria to be used for planning and conduct of seismic surveying in Norwegian waters.

However, more knowledge are needed particularly regarding "injury risk ranges" and detailed vertical density profiles of various stages (sizes) of larvae from a variety of species in order to quantify more precisely the effects on eggs- and larvae populations. Research are therefore conducted now in 1992 in cooperation between the oil industry and several Norwegian research institutions on the matter. Until results from this research is available caution should be exerted in the management of seismic exploration.

FISH AVOIDANCE - SPAWNING GROUNDS AND FISHING GROUNDS - REDUCED CATCH RATES

As already stated, on the contrary to larval fish, we do not expect direct harmful effects on adult fish from airguns or air gun arrays. The fish can detect the seismic source at large distances, and effectively avoid the most intense parts of the seismic signal. Hence, the spawning activity is potentially disturbed and avoidance may also lead to reduced catch rates at fishing grounds and generate conflicts with fishery interests.

Background. (Fig. 5)

Fish detect and respond to sounds in the low frequency region from 50-3000 Hz (Platt & Popper, 1981), and can sense the direction to a sound source quite well (Hawkins, 1981).

Although measurements of the hearing of fish have varied, the hearing ability of cod appears well established. Cod are sensitive to sound frequencies between 10 and 250 Hz (Buerkle, 1968; Chapman & Hawkins, 1973; Offutt, 1974), with a detection threshold in the most sensitive portion of the frequency range which enables the fish to detect sound sources like airguns at long distances.

The louder the sound, the easier is it to detect, but the detection threshold is also affected by the duration of a sound; the shorter the pulse, the louder it must be for detection. For cod Hawkins (1981) found that the detection threshold for pulsed sound was considerably higher than for continuous sound. The background noise also limit the detection of sound signals (Hawkins 1981, Myrberg 1980). The levels indicated in Fig. 5 corresponds to an average noise level in the sea.

The sound source

We know that the frequency spectrum from an air gun and the sensitivity spectra for sound detection in fish match closely. The distance of detection may be estimated on the basis of the detection threshold, the source level of the air gun array and the background noise level.

Source levels of a series non-explosive seismic sources are listed in Malme et al. (1986). They found typical values of 222 and 250 dB re 1uPa at 1 m for single - and arrays of air guns, respectively. Greene (1985) reported a source level of 255 dB re 1uPa at 1 m for a 28-gun array in their experiment.

Detection and reaction

The sound level at a distance (R) from the source can be calculated by allowing for geometrical spreading and attenuation of the signal. At low frequencies, the geometrical spreading dominates totally, and experiments have shown that a 20 logR or 25 logR transmission loss can be expected at deep water. Greene (1985) found approximately a 26 log R loss in his experiment using 28 air gun arrays.

If we assume a 25 log R transmission loss, a source level of 250 dB re 1uPa is detected by fish over a range of 55 nautical miles (100 km) provided a detection threshold of 125 dB (Fig. 5).

Now, even though it is likely that fish can detect the seismic source over large distances, they seldomly react to the sound before the sound level is well above the detection threshold

(Blaxter et al. 1981). How far from the source we can expect behavioural responses depends largely on the fish species and the nature of the signal. Experiments with herring show "startle" response at 125-145 dB re 1uPa, (Blaxter & Hoss 1981) (typical behaviour for antipredator avoidance with a single flextion of the body followed by rapid swimming).

The reaction threshold have also been recorded in a number of investigations of fish reaction to vessel noise. Typically, a steaming vessel units low frequency noise of a source level of about 150 dB re 1uPa, and avoidance are often seen at the 110-130 dB re 1uPa-level, both for clupeoids and gadoids. (Olsen 1969, Ona & Godø 1990, Ona & Toresen 1988).

Fig. 5 is a brief summary of some of the available information and may serve as a tool for conducting seismic activity in areas with adult fish.

Based on the experimental data, we should thus expect reaction distances from full arrays of air guns to more than 16 nautical miles (30 km) from the source. (Fig. 5).

Alarm responses, with vigorous avoidance are expected at about 0.8-3 nautical miles (1-5 km) distance from the arrays, depending on the detection threshold and the transmission loss.

Gradual habituation over long periods of soundings may affect the reaction pattern, and effectively reduce the reaction distances indicated above.

Spawning grounds.

We must assume that fish stocks release their spawn in areas (spawning grounds) which are optimal with respect to larval survival. Hence, it seems reasonable that spawning fish should not be disturbed to an extent that make it move away from the spawning grounds.

Seismic activity with large air gun arrays should therefore not be allowed closer than about 31 nautical miles (60 km) to any point of the actual spawning ground during the period when fish concentrate for spawning.

Conflicting interest with fishery - reduced catch rates

Within the indicated reaction distance from a seismic survey, we expect to find a gradually reduced fish density because of fish moving away from the seismic system. A large descriptive material is available to support this view, but also a few quantitative measurements (Fig. 6).

Chapmann & Hawkins (1969) reported reaction of whiting using a single air gun. Dalen & Raknes (1915) found an average of 36% reduction of bottom fish abundance within a seismic survey area. Greene (1985) found a consistent decrease in the number of fish after air gun operations. Pearson et al. (1987) found a reduction of the CPUE of 52.4% for rockfish after using a single air gun during their experiment.

Løkkeborg (1991) found an average reduction in catch of 50-80% in the long line fishery for cod off Northern Norway in the middle of a seismic survey area. The reduction in catches were significant over a 24 hour period after the survey, out to about 5 nautical miles. Soldal & Løkkeborg (1992 unpublished) found no reduction in shrimp catches, but up to 90% reduction in the by catch of cod close to a seismic survey in 1991 (Fig. 7 and 8).

Field experiments in 1992, will investigate the behavioural response of fish and catch success of long line and trawl as a function of distance from a full scale seismic survey. In these experiments (Fig. 9), the main goal will be to investigate some of the effects, which up to now are unclear:

- Catch rates in longline and trawl as a function of distance and time.
- Reaction distance of fish.
- Distribution changes.
- Habituation.

Conclusions

Seismic surveys will affect and disturb adult fish. Hence effective safety zones should be established to protect spawning fish. Until more scientific data are accumulated on reaction distance and habituation, we also must conclude that significant reductions in catch rates may occur in areas of seismic activity.

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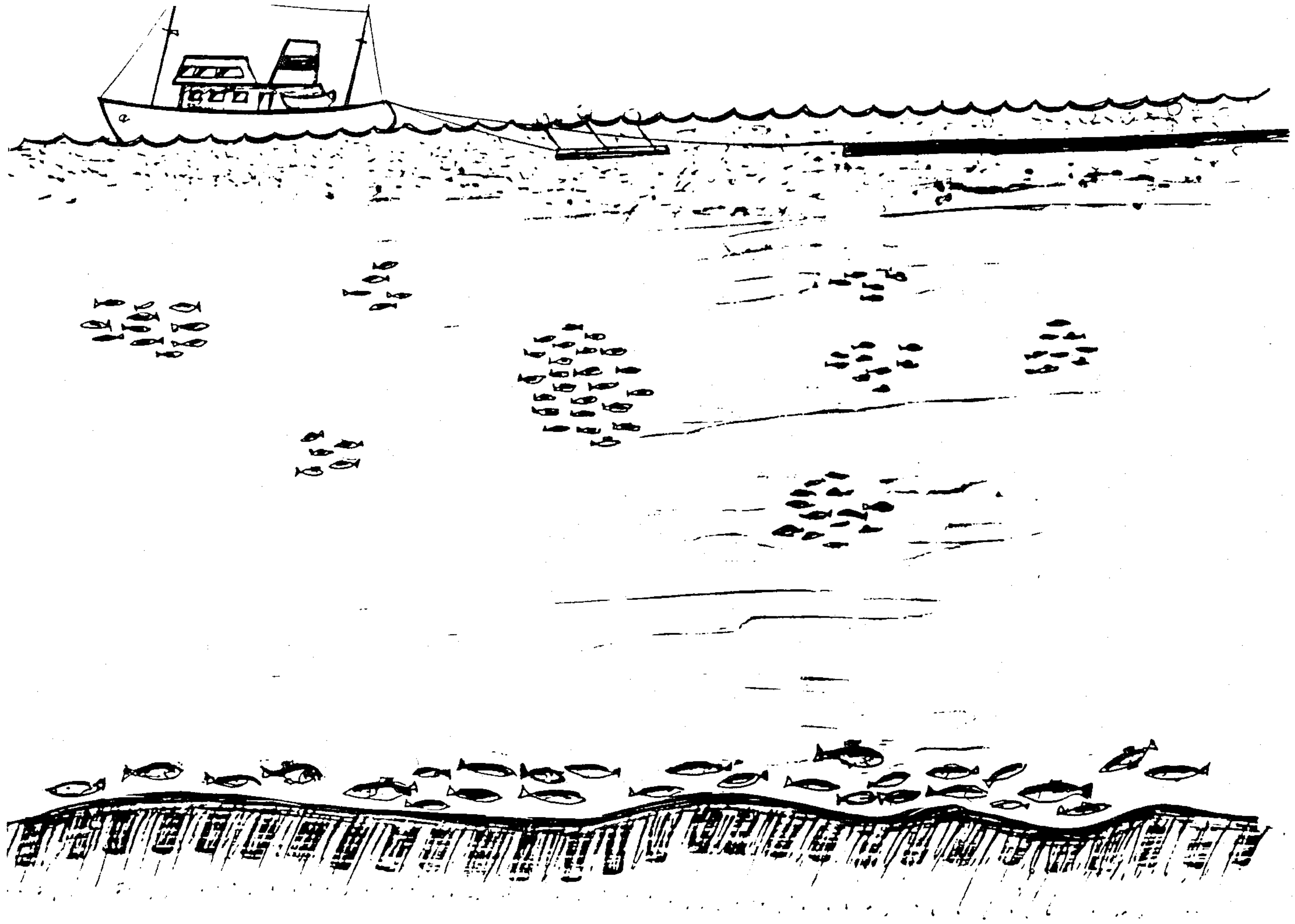

Fig. 1. Schematic representation of a seismic surveying situation.

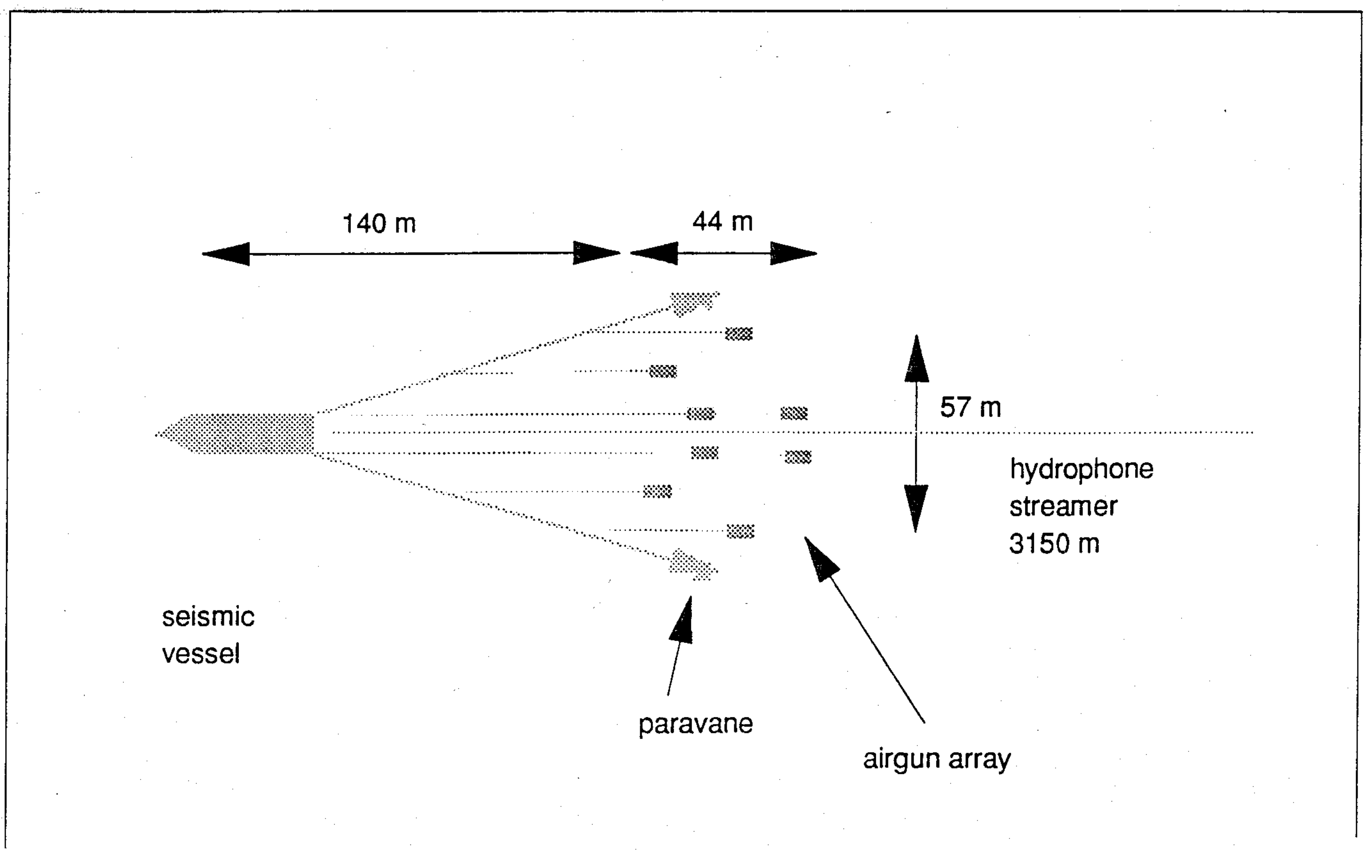

Fig. 2. Seismic vessel with airgun arrays in "super wide" configuration (Dalen and Knutsen 1987).

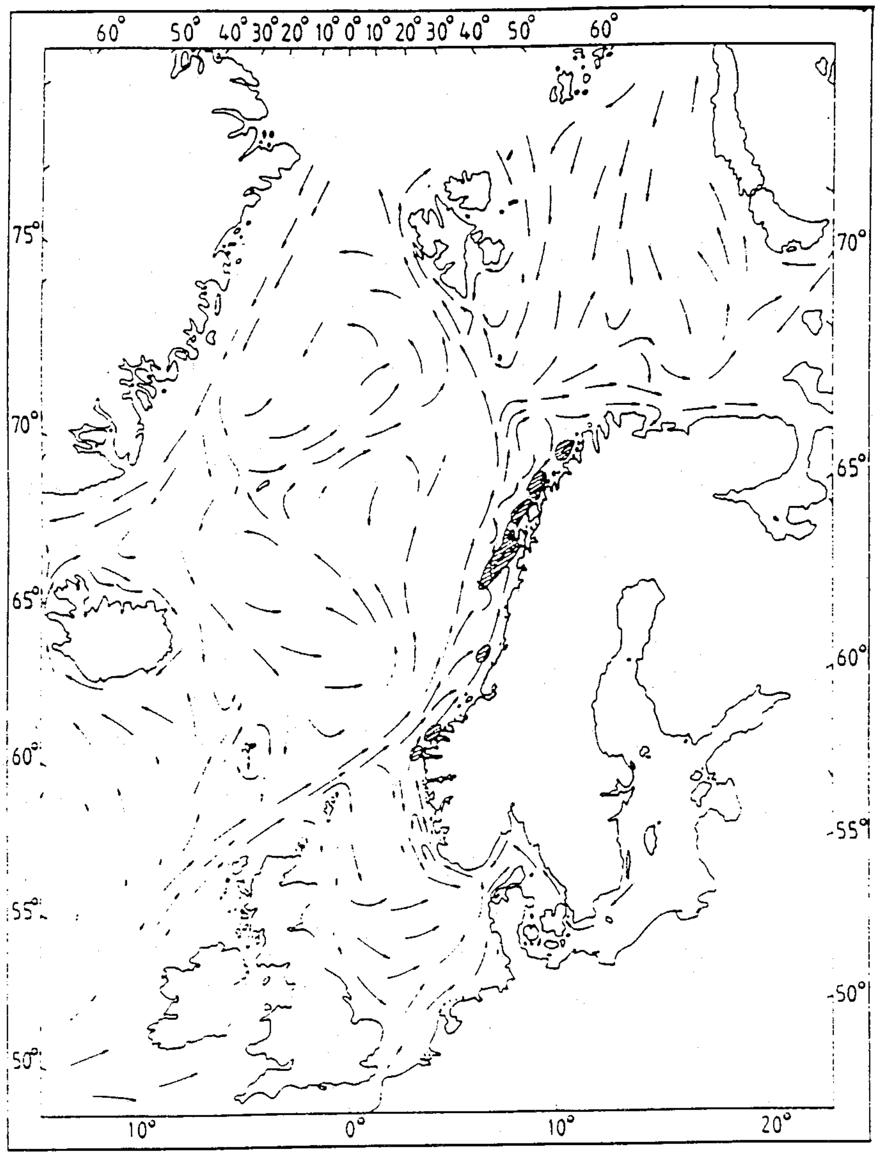

Fig. 3. Spawning grounds of northeast-arctic cod.

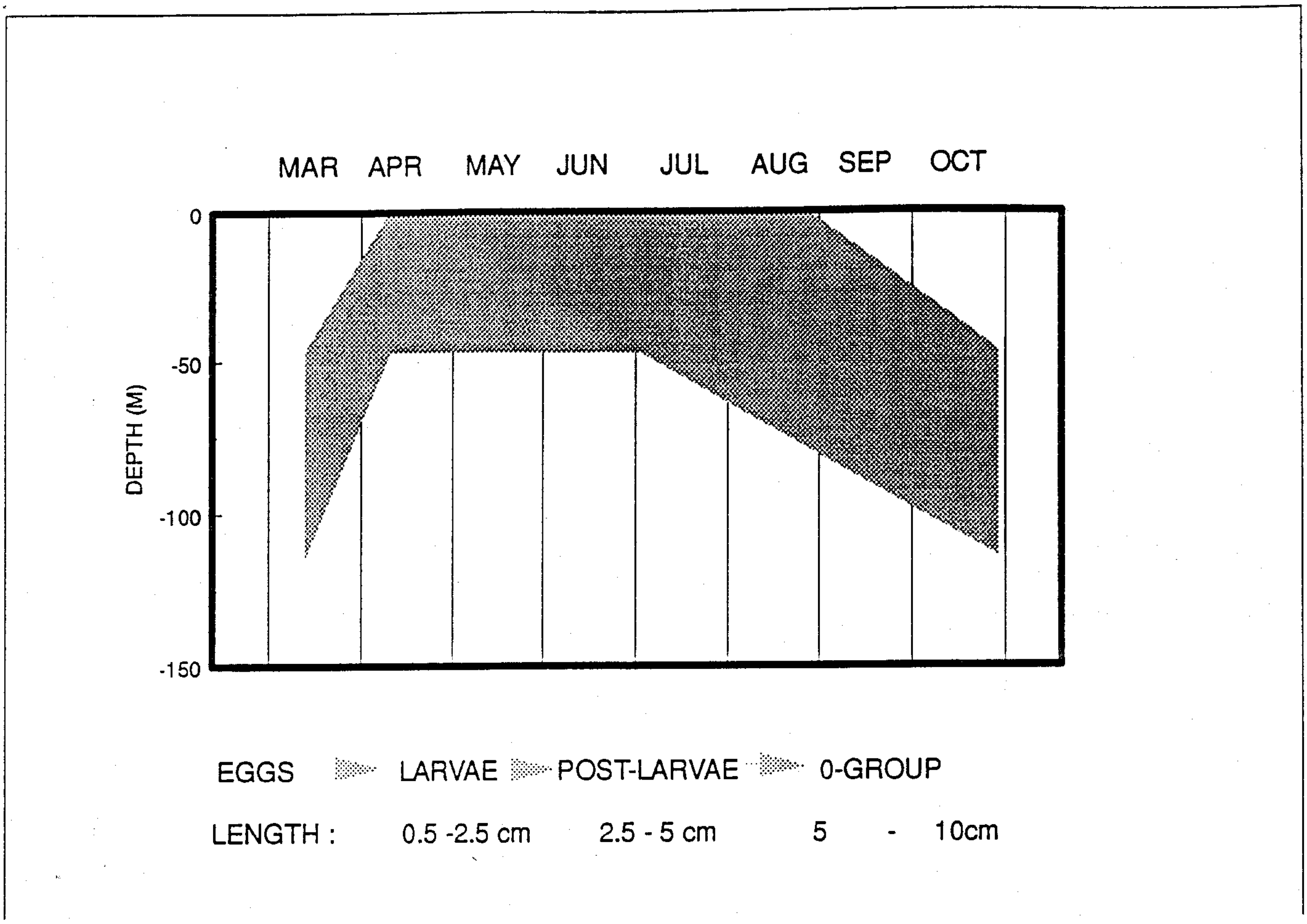

Fig. 4. Schematic representation of vertical distribution of eggs and larvae.

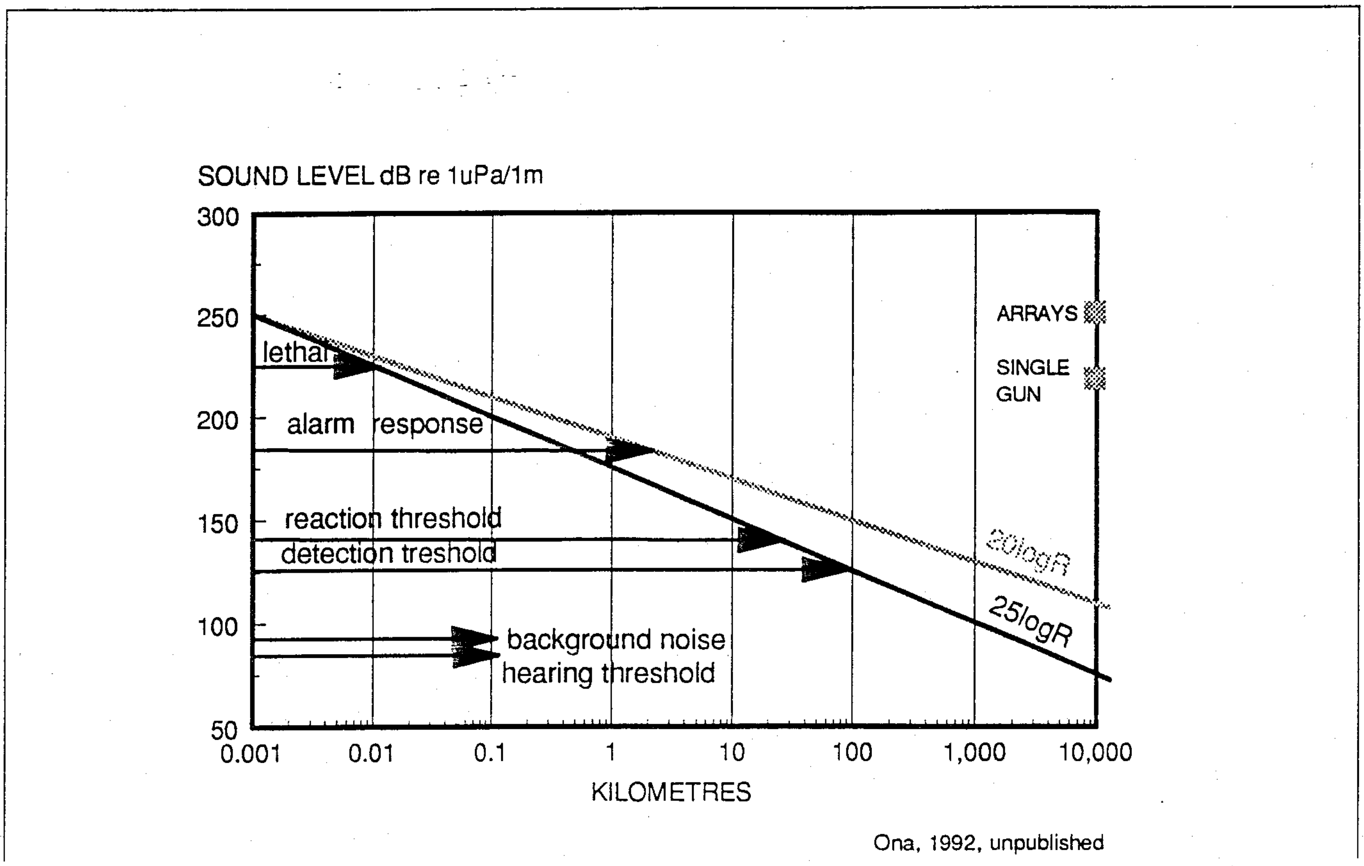

Fig. 5. Distances at which fish can detect and will react to the sound from a given source. (Made by Egil Ona, unpublished).

FISH SPECIES	GEAR	REDUCTION	REFERENCE
Whiting Merlangius merlangus	acoustic mapping	36%	Dalen & Raknes (1985)
Rockfish Sebastes sp.	Trawl	unspec	Greene (1985)
Rockfish Sebastes sp.	Trawl	52%	Pearson et al. (1987)
Cod Gadus morhua	Longline	55 - 80 %	Løkkeborg (1991)
Cod Gadus morhua	Trawl	0-90%	Soldal & Løkkeborg (1992) (unpupl)

Fig. 6. Scientific data on reduced fish density or catch during seismic activity.

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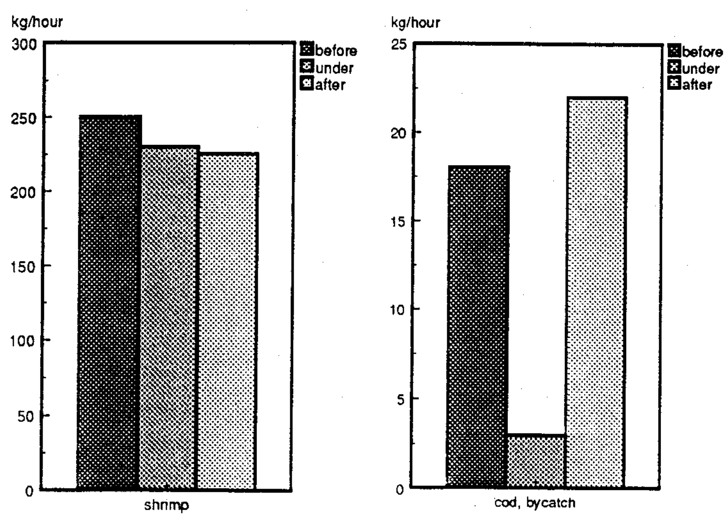

Soldal & Løkkeborg, 1992, unpublished

Fig. 7. Catch rates in shrimptrawls before, during and after seismic surveying.

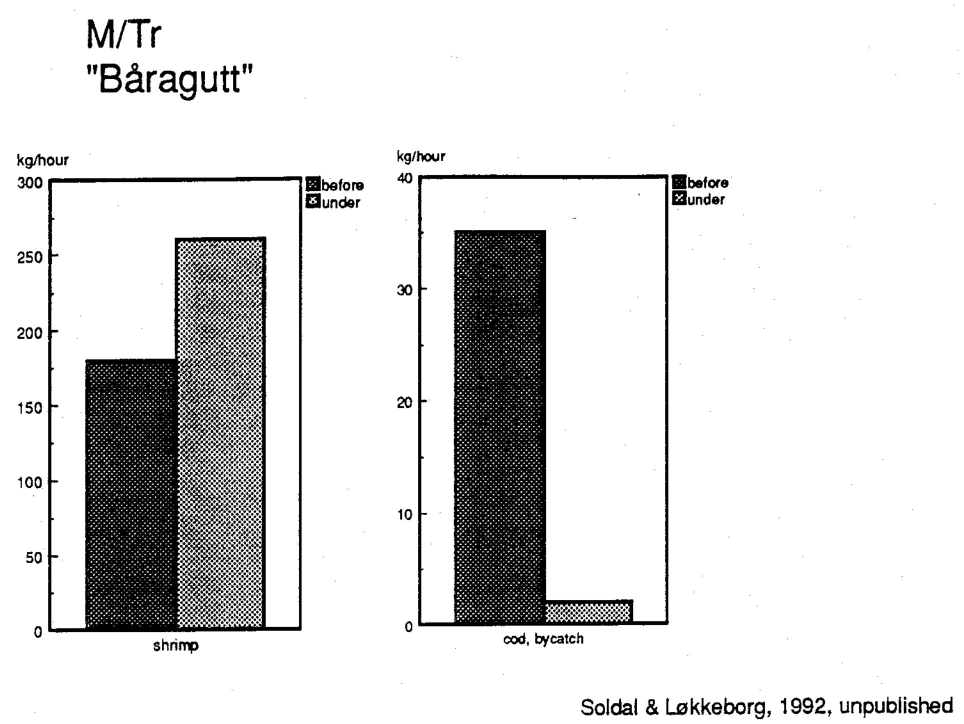

Fig. 8. Catch rates in shrimptrawls before, during and after seismic surveying.

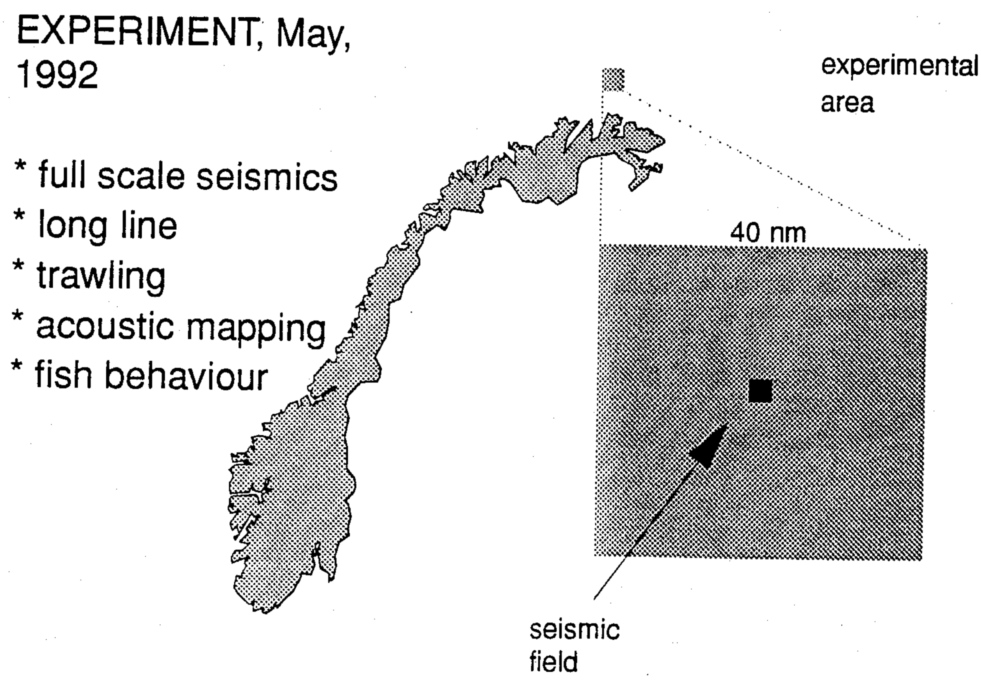

Fig. 9. Planned experiment in May 1992.