Fiskirannsóknarstovan
Faroese Fisheries Laboratory

An experiment on how seismic shooting affects caged fish

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A final project report submitted in part fulfilment for the Degree of Master of Science in Hydrocarbon Enterprise at the University of Aberdeen

16th August 2002

Preface and acknowledgments

This report is the dissertation and thus the final part of the MSc Hydrocarbon Enterprise study at the University of Aberdeen, UK. The author's background in fisheries research prompted the idea to undertake a project that relates aspects of the petroleum industry to fisheries.

The present work is done on behalf of the Faroese Fisheries Laboratory and in cooperation with geoscientists from the Faroese University and Aarhus University, Denmark. A warm thank to the people at the three institutes for providing equipment and for their participation in data collection and data analysis. Also thanks to the Marine Laboratory in Aberdeen for loan of equipment.

Thanks to the Faroes Oil Industries Group (FOIB) for financing the project and thanks to the people at the fish farm pf Gulin for help and kind cooperation.

Thanks to Professor Tony Hawkins at the University of Aberdeen who as the supervisor participated in the data collection and has given valuable guidance and willingly has poured from his huge experience in this field of work.

The text presented including all shortcomings is solely the author's responsibility.

Abstract

The Faroe Islands are on the doorstep to an oil era. The present work deals with a problem in the interaction between the new oil industry and the fishing industry, which has been the only industry in the islands for a century.

Seismic shooting used in petroleum exploration emits loud sound pulses with a frequency spectrum that falls within the range of frequencies to which fish are sensitive. It has been demonstrated that seismic shooting affects fish and catch rates, but little is documented on how caged fish react to seismic shooting.

In early June 2002 a geophysical experiment was conducted on Glyvurnes outside Tórhavn, which included shooting with a small airgun (SL = 229 dB) in the sea around Glyvursnes.

To avoid doing any harm on the fish in the nearby fish farm, pf Gulin, the impact from the seismic shooting on the farmed fish was monitored.

The sound level at the fish cage was recorded by a hydrophone. The reaction of both large rainbow trout (3.5 kg) and small salmon (50 g) was recorded by underwater video cameras.

The sound pulses were measured as 142 dB_{p-p} rel 1 µPa at 4000 m distance and as 186 dB_{p-p} rel 1 µPa at 150 m distance. This is much lower than the sound pressure thought to be lethal to fish (229 dB), but similar sound pressures have been reported to create avoidance and startle reactions in fish (160-180 dB).

The fish seemed to be calm during the shooting. On eight out of 124 sound pulses a few fish reacted to the sound pulses by making sudden movements. These movements were difficult to distinguish from normal behaviour.

The low impact of seismic shooting on the farmed fish was also confirmed by the fact that the fish fed normally after the shooting. Long-line fishing in the nearby area before, during and after the shooting period also confirmed that the shooting had no negative effect on catch rates in the nearby area.

Declaration

This Final Report is my own composition and has not been submitted previously for any other degree. Where the work of others has been utilised this has been clearly indicated and the sources acknowledged

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16th August 2002

Table of contents

List of figures and tables

1. Introduction

The Faroe Islands, an autonomous region within the Kingdom of Denmark, comprises 18 small islands in the North Atlantic and is inhabited by 47,000 people.

The Faroese economy is small measured against most standards. For more than a hundred years, fisheries have been the main (and almost only) industry, but now the Faroes is on the doorstep of an oil era. This might become a much-appreciated opportunity for a diversification of the economy, but if not carefully implemented the oil industry could jeopardise the existing industries in the islands.

The present work is an attempt to clarify one of the problems that could arise in the interaction between the existing fishing industry and the new oil industry.

1.1 Faroese fisheries and fish farming

The sea fisheries began in 1872 when the first ships sailed to East Iceland to fish and soon the backbone of the Faroese economy shifted from agriculture to fisheries. By the 1930, the industry had evolved to such a degree that the majority of the Faroe Islands' male population were on board ships during the peak season from spring to fall (Jacobsen, 1997).

During the 1970s Faroese fishermen were increasingly expelled from distant waters as the fishing limits were gradually extended to 200 nautical miles and old fishing grounds came under national jurisdiction of various coastal states. Faroese fisheries thus became increasingly dependent on territories inside the Faroese EEZ around the islands.

Nowadays the fishing is performed from modern and efficient fishing vessels (although the fleet operating in local waters have a substantial average age) and on land fish processing factories transform raw fish into different fish products for export.

Being experts in fishing and marketing of fish products it was natural for the Faroese industry to enter into fish farming as this technique evolved throughout the North Atlantic from the 1970s and onward. During the last two decades fish farming, mainly of salmon, has had an increasing importance and in recent years one third of the value of total exports has come from fish farming.

During recent decades the export of fish and fish products has accounted for 90-98% of total Faroese exports. The prosperity of the islands thus hinges on the fortunes of the fisheries and fish farming and is extremely vulnerable to ecological changes in the sea and on the market price of fish.

1.2 Petroleum developments in the Faroe Island.

The exploration for petroleum has gradually extended from the North Sea, which has been a major oil province with up to 9% of world production, into the frontier areas west and northwest of the British Isles. After the discoveries of the oil fields west of Shetland and close to the Faroese border, Foinaven in 1992 and Schiehallion in 1993, and after, at the same time, the competence of the Faroese subsoil was handed over from Denmark to the Faroese administration, an intense interest was initiated by oil companies on the Faroese authorities to open up areas for oil exploration activities.

During the middle of the 1990s the Faroese area was opened up for geological surveys and planning commissions were established to develop a legal framework and address issues, such as the influence of a future hydrocarbon industry on the Faroese economy, socio-economic consequences, influence on the environment and the fishing industry, safety issues etc.

Following the election in the spring of 1998, the Faroe Islands got a separate Ministry of Petroleum and their first ever Minister of Petroleum.

In May 1999 an agreement was reached on the settlement of the continental shelf boundary between Faroe Islands and United Kingdom, thus removing the last obstruction to the launching of a Faroese first licensing round.

The first licensing round was closed in May 2000 and the licenses awarded in August 2000. Three exploration wells were drilled during July - September 2001. Two were dry, whereas the third was announced as a significant discovery. Appraisal drilling will be carried out this year and licence holders are committed to drill more exploration wells within the next few years. Generally the Faroese people welcome the petroleum activities and look forward for new opportunities, but as can be seen in the Faroese petroleum legislation, due respect should be paid to other activities such as the fishing industry. Politicians and decision makers seem to have appreciated that fishing will still be important for the Faroe Islands in the future as it relies on a renewable resource, whereas the oil industry could be short-lived and cease within decades.

1.3 Seismic shooting and its impact on fish

In exploring for petroleum a predominant technique used is seismic shooting. This incorporates the generation of short bursts of sound energy that is directed down into the subsoil. The reflected signal is received by hydrophones and analysed to determine the geological structure and possibilities to discover oil- and gas deposits.

In the past chemical explosives were used to generate the sound pulses, but for the last 20 years nearly all marine seismic surveys are performed using tuned airgun arrays (Dragoset, 2000).

Airguns produce low frequency sound and their output above 250 Hz is limited (Gausland, 2000). The frequency spectrum from an airgun therefore matches well with the hearing band in many fish spe cies, see figure 1.1.

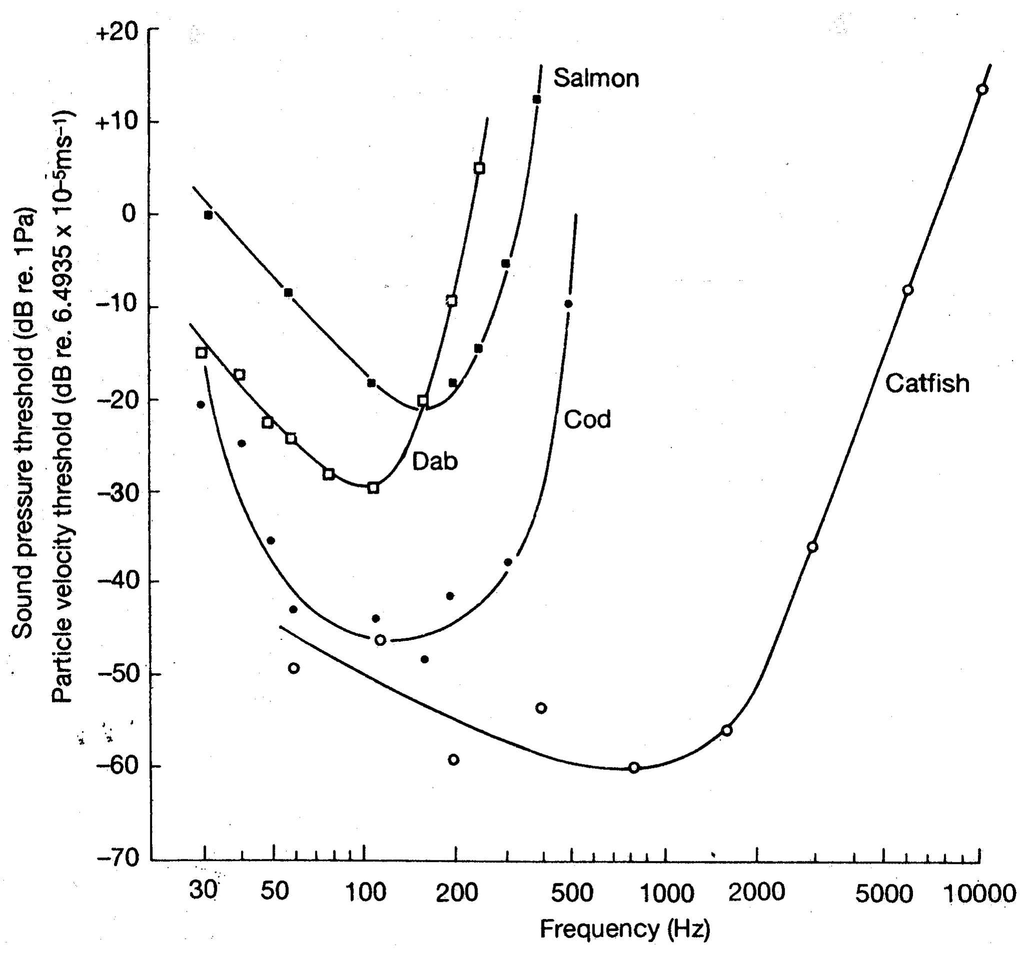

Figure 1.1. Hearing threshold of some fish species (After Hawkins, 1993). To convert dB re 1Pa (y-axis) to dB re 1 µPa add 120 dB.

Fish detect and respond to sound and as they live in an environment where vision is often precluded, they may depend heavily upon the ear for information about their distant surroundings (Hawkins, 1993).

When seismic data is acquired at sea a seismic vessel shoots continuously along tracks several tens of nautical miles long and spaced by a few hundred meters. The vessel works for several days and the potential impact on aquatic animals can therefore be spread over a huge area.

Chemical explosives had potentially lethal effects on fish in the vicinity of the shooting, whereas modern sources are not generally directly lethal to aquatic animals. Concern now centres on the possible, more subtle effects of underwater sound sources on the behaviour of fish, affecting their distribution or catchability (Turnpenny and Nedwell, 1994).

Yelverton et al. (1974) developed a model for lethal effects with range on fish from single underwater explosives, which was confirmed by later experiments, but proved to underestimate when successive explosions were detonated (Larsen and Johnsen, 1992).

In their review of research on lethal effects from sound sources Turnpenny and Nedwell (1994) conclude that lethal threshold for fish begins at sound pressure of 229 dB rel 1 µPa where rise time and decay time is equal to or less than a millisecond. They cite experiments where Caged coho salmon *(Oncorhynchus kisutch)* smolts were subjected to an estimated level of 214-216 dB rel 1 µPa without any lethal effects, whereas a single large airgun (4,916 cm^3) was reported to create swim bladder damage at sound levels of 226-234 dB rel 1 µPa.

Transient stunning has been reported at levels of 192-198 dB rel 1 µPa, which is a potential lethal effect in the wild, owing to predation, but fish in captivity usually recovered within 30 minutes (Turnpenny and Nedwell, 1994).

Fluid in the swim bladder and limited bleedings from the liver has been observed in salmon after detonation of 227 kg explosives at 1200 m distance where the pressure pulse was 173 dB rel 1 µPa (Soldal, 1990 cited in Larsen et al., 1992).

A tank experiment was undertaken by Sverdrup et al. (1994) where Atlantic salmon was exposed to a series of positive shock pulses of ~2MPa (246 dB rel 1 µPa) created by detonations of explosives. The response was cessation of swimming for a few minutes and failure to express a flight reaction. No mortality occurred immediately or during the subsequent 7 days of observation, but several stress factors responded and signs of injury could be revealed.

Dalen and Knutsen (1986) found that a watergun had much more lethal effects on cod fry than an airgun producing similar sound pressure and suggest that the negative pressure pulse from the watergun exposes the fish to a more dangerous expansion of organs than the positive pressure pulse from an airgun.

Various experiments have shown that seismic shooting affects catchability of fish. Løkkeborg and Soldal (1993) observed that catch rates of cod *(Gadus morhua)* on long-line set within a seismic survey area were reduced by 55-80%, and by-catch of cod in shrimp trawl was reduced by 80-88% because of seismic shooting, whereas the by-catch of cod in trawl fishery for saithe increased threefold and returned to normal immediately after the seismic work ended. Engås et al. (1993) found that trawl and long-line catches of cod and haddock was reduced by up to 70% in a shooting area. The effect could be seen to the border of the investigating area 18 nautical miles from the shooting and fish quantity did not increase during the five-day observation period after the end of the seismic shooting.

Skalski et al. (1992) found a 52.4% reduction in hook-and-line fishery for rockfish *(Sebastes spp.)* when aggregations were exposed to peak pressures above 186 dB rel 1 µPa.

In contrast to the findings mentioned above Wardle et al. (2001) found little effect on fish on a reef when exposed to airgun shooting, and fish receiving a 206 dB rel 1 µPa pulse continued to swim against the source with their swimming track apparently unaltered.

The majority of Faroese fishermen have the opinion that seismic shooting affects the fisheries although this could not be verified by catch rates and data from logbooks (Jakupstovu et. al., 2002).

While the impact from seismic shooting on wild fish has been documented from a variety of experiments the information on caged fish is scarce.

From experiments with captured rockfish *(Sebastes spp.)* exposed to an airgun, Pearson et al. (1992) indicate subtle behavioural responses from 161 dB rel 1 µPa, but general threshold for alarm responses about 180 dB rel 1 µPa and startle responses between 200 and 205 dB rel 1 µPa.

While observing caged rainbow trout *(Salmo gairdneri)* and salmon smolts *(Salmo salar)* exposed to sound pulses generated from small explosive charges detonation on land, Urquhart and Johnstone (1984) observed fish reaction to two sound pulses around 165-170 dB rel 1 µPa, but no reaction to other pulses even if these were above 170 dB rel 1 µPa.

The result from research on the impact from seismic shooting on fish has led to some precautionary practices when seismic surveys are undertaken and the Faroese authorities have also adapted such practices, eg. avoiding seismic shooting during the spawning season.

1.4 Background and objectives of present research.

As the preparations for exploration for petroleum in the Faroese area have progressed, interest in geophysical research has developed. One particular challenge in the Faroese area is thick layers of basalts, which are difficult to penetrate using conventional seismic surveying.

A particular experiment addressing this problem was scheduled to take place on Glyvursnes outside Thorshavn in June 2002. The experiment, which was sponsored by the Sindri Group, was to be carried out by the University of the Faroe Islands and Aarhus University. The experiment was a part of the project "Petrophysical and seismic properties of Faroes Basalt (SeiFaBa)", which was accepted under Sindri's call for proposals within "Relevant technologies for imaging within basalt-covered areas" in February 2002.

For the experiment, geophysicists planned to use small explosives on land and a small airgun in the water to generate sound waves. North of Glyvursnes, within a range of 1-3 km from the geophysical experiments, pf Gulin had its fish farm. One problem was that the geophysical experiment could potentially harm the fish in this nearby fish farm.

In parallel with the geophysical experiment outlined above there was a unique opportunity to study the influence of seismic acquisition on caged fish in more detail and the Faroese Fisheries Laboratory decided, in cooperation with the geophysicists, to monitor and record the sound level and the fish behaviour at the fish farm during the seismic shooting. A study of this kind would supplement earlier studies on the behaviour of fish during seismic acquisition. In addition it would enhance the Faroese

Fisheries Laboratory's expertise within this field, thus enhancing the institute's ability to provide guidance to the industry and authorities regarding possible conflicts between seismic acquisition and fishing/fish farming, and how to avoid these conflicts.

The objectives of the present work was twofold:

1) To ensure that the geophysical experiments would do no harm to the fish in the nearby fish farm.
2) To increase knowledge at the Faroese Fisheries Laboratory on:
    a. how seismic shooting affects fish
    b. sound levels and sound propagation from seismic shooting
    c. using relevant techniques for experiments in this field of work.

2. Materials and methods

The geophysical investigations were carried out 3-6 June 2002, on and around Glyvursnes, 3 km south of Tórshavn, the capital of the Faroe Island. Glyvursnes is situated in Nólsoy fjord, which is a 3 nautical mile wide fjord between the southern tip of the island Streymoy and the smaller island Nólsoy, see figure 2.1. The fjord is like a channel with steep slopes on both sides and a maximum depth of 90 m in the centre. The tidal current can be strong in the fjord and runs approximately 4 hours in a northerly direction and 8 hours in a southerly direction.

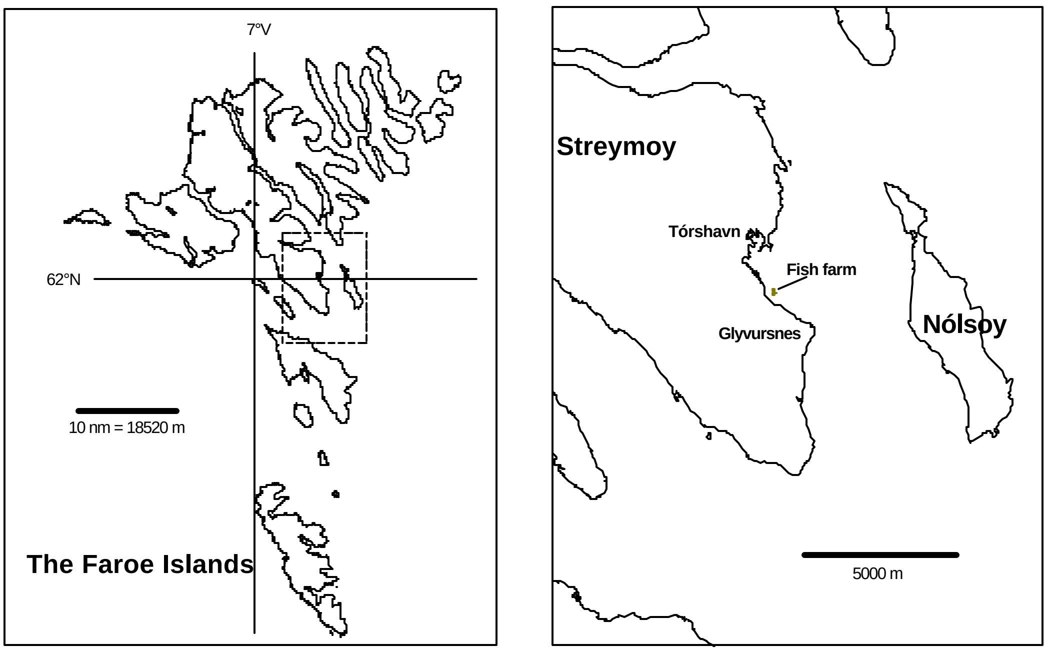

Figure 2.1. Glyvursnes is 3 km south of Tórshavn, on the western side of Nólsoy fjord. The fish farm, pf Gulin, is placed along the coast between, Tórshavn and Glyvursnes.

2.1 The fish farm and experimental animals

The commercial fish farm, pf Gulin, is placed along the coast between Glyvurnes and Tórshavn, over bottom depths of 25-30 m. In the beginning of June pf Gulin had harvested most of its fish and only four cages were left with approximately 140 tonnes each of large adult rainbow trout *(Salmo gairdneri)* of an average fish weight of 3.5 kg. The fish cages were circular with a diameter of 30 m and net depth of 12 m. The rainbow trout in the cage closest to Glyvursnes were selected for observation.

As the effect of sound pulses on fish has been shown to depend on fish size and fish species, it was decided to introduce small fish into the fish farm during the seismic shooting. On June 1st approximately 200 salmon smolts *(Salmo salar)* with an average individual weight of 50 g were transferred from a freshwater smolt rearing station to a purpose built small cage with a diameter of 2 m and a depth of 2.5 m. This cage was anchored floating at a 5 m distance from the rainbow trout cage.

The rainbow trout were fed normally by manual feeding from a boat during the experimental period, however no feeding was done during the actual shooting and observation periods. The salmon smolts were not fed at all after entering the sea.

Equipment for monitoring the sound pressure and fish behaviour was deployed from a 25 feet GRP boat tied between, but free of the fish cages. All equipment was run from batteries to avoid noise from the engines.

The sea temperature at the fish farm was measured as 8.4 °C. Strong tidal currents usually prevent thermoclines to build up and profiles from the database held at the Faroese Fisheries Laboratory indicate no changes of sound velocity with depth (see Appendix A).

The fish farm was under quarantine because of ISA salmon disease confining the observing boat to area of the fish farm. This led to a series of inconveniences and prevented further sound measurements intended for sound propagation investigations at other places in the fjord.

2.2 The airgun and the shooting procedure.

The sound source used for the experiments was an INPUT/OUTPUT INC., SG-I, assembly consisting of two 25 in^3 and two 40 in^3 guns mounted in a cluster and fired simultaneously. The working air pressure was 110 bar, but for a long bang-series the pressure dropped for the last shots. The airgun cluster was said to have 1/20 of the power of a full-scale airgun array (pers. comm. prof. Morten A. Andersen). Assuming a 255 dB level of a full-scale airgun array, this corresponds to a source level of approximately 229 dB at one meter.

The airgun cluster was towed at three meters depth and three meters behind a 30-foot GRP vessel, Biofarið. The towing speed was approximately 2 knots. The location of the vessel was determined by a DGPS, which was accurate within 2 m. Track lines and start-stop points for shooting were recorded on an OLEX plotter system interfaced to the DGPS. The position of each single shot was found by interpolation using the time between start-stop positions. The position of the observing boat was also determined by GPS and the distance to the shooting boat calculated using the formula:

Distance (m) = $1852*60*\sqrt{((B1-B2)^2 + ((L1-L2)*\cos((B1+B2)/2))^2)}$,

where B1, L1 is the first position (latitude and longitude) and B2, L2 is the second position.

The airgun and the towing boat were operated by personnel from Aarhus University, belonging to the geophysical team. For the fish reaction experiments, the author was able to tell the vessel where and when to shoot with the airgun. For communication between the observing boat and the shooting boat, cellular phone and walky-talkies were used.

The airgun was not used for the geophysical experiments until the impact on the fish had been studied. The first shots were fired approximately two nautical miles (4000 m) from the fish farm as this was regarded as a safe distance. The shooting was then gradually performed closer and closer to the fish farm with simultaneous observation of the behaviour of the fish. In the beginning single shots were used to avoid habituation of the fish to the sound, whereas at later stages series of shots were used. The time between shots in each series was set to 10 seconds to reflect practice during normal seismic surveying.

2.3 Sound measurements

The sound level was monitored by a hydrophone that was deployed at 10 m depth between the two cages containing the fish to be observed. The hydrophone was suspended from the edge of the cage as the cage was stable and was not affected by waves and other movement. The hydrophone, an International Transducer Corporation, ITC-6050C, S/N 621, was calibrated to –160 dB rel to 1V/µPa and had a flat characteristic over the expected frequencies.

The calibrated signal from the hydrophone was feed through a Hewlett Packard, 350D attenuator to a preamplifier, a Stanford Research Systems, Low-Noise Preamplifier Model SR560, S/N 49261. The first measurements showed high noise levels between 5 and 20 Hz, and the band pass filter in the preamplifier was consequently set at 30 Hz to 10 kHz.

The signal from the preamplifier was recorded using a Fujitsu Lifebook Laptop with a built in ESS AudioDrive sound card. As a backup a SONY digital audio tape recorder was used in parallel with the Laptop. The signal from the hydrophone was also feed to a loudspeaker in the observing vessel.

For controlling the recording and for subsequent analysis of the sound pulses Avisoft Multi-Channel Triggering Harddisk RECORDER, Version 2.61, 06 May 2002 and Avisoft-SAS Lab Pro, Sound Analysis and Synthesis Laboratory, Version 4.12, 10 May 2002 (Copyright 1998-2002 Avisoft, Raimund Specht, Hauptstr. 52, D-13158 Berlin, Germany) was used on the laptop. The sampling rate was set at a frequency of 8 kHz The laptop was calibrated and found to have a gain of 16.5 dB.

The voltage recorded by the Laptop was converted to pressure level, expressed as dB rel 1 µPa, using the formula: 20 * log(? V/G/1000)-16.5+ 160+A, where

?V is the voltage difference between two points measured in millivolts

G is the preamplifier gain (either 1 or 2)

A is the attenuator setting (either 0 dB, 20 dB, 30 dB or 40dB)

The standard for specifying airgun signal levels is peak to peak (p-p) or the maximum negative-to-positive measurement of the signal (Gausland, 2000).

In the following, the peak-to-peak measurement is expressed in dB rel rel 1 µPa and denoted dB_{p-p}. For conversion to zero to peak and to rms following relationship can be used:

dB_{p-p} rel 1 µPa = dB_{0-p} rel 1 µPa + 6dB

dB_{p-p} rel 1 µPa = dB_{rms} rel 1 µPa + 9 dB

It has been shown that not only the maximum pressure is important for the impact on fish, but also the transition time of pressure changes. Therefore the pulses measured were also investigated for maximum rise time. This was done by visually selecting the steepest slope on the pulse (presented on the screen by the Avisoft software) and then by measuring time and amplitude for both ends of this slope.

2.4 Underwater television equipment and fish behaviour study

Two underwater video cameras were used to monitor the fish behaviour, one in the rainbow trout cage and one in the salmon smolt cage. To increase the contrast of the fish against the background the cameras were facing upwards where possible. The pictures from both cameras were shown in real time on two video screens in the observing boat and in addition the signals were recorded on videotapes (SONY video Walkman, GV-S50E Pal, Video 8) for later confirmation and further study of the observations. The signal from the hydrophone was fed to the left audio channel of the videotape and a microphone in the wheelhouse of the observing boat was fed to the right audio channel to allow comments to be recorded simultaneous with the video signal. The hydrophone sound and the microphone comments proved to be very helpful for synchronisation during the later detailed studies of the fish behaviour.

To determine whether a true reaction occurred or not, five people were asked to observe the video tapes and note down on paper a number representing their view of the fish behaviour for each sound pulse heard on the tape. The graduation of fish behaviour used was as follows:

0: no reaction

1: doubtful reaction (reaction could be casual and not due to seismic shooting).

2: clear reaction of a few fish to the shooting sound

3: very clear reaction of many fish to the shooting sound

2.5 Fishing activity during the seismic shooting.

After the shooting was over it became known to the author that a long-lining fishing vessel, Trýsystkin TN 390 of Nólsoy, had been fishing in Nólsoy fjord before, during and after the shooting experiments. To check whether the shooting had affected the success of the fishing, data was obtained from the owner (skipper) on the fishing area, the number of hooks set each day and the corresponding catch. For day-to-day comparison the catch was calculated in grams of fish per hook per day.

3. Results

Data collection was successful with all equipment working satisfactorily and only minor technical challenges. The very good weather and slack tide during the observing days contributed to successful sound and video recording.

Figure 3.1 gives and overview of the shooting positions relative to the observed fish.

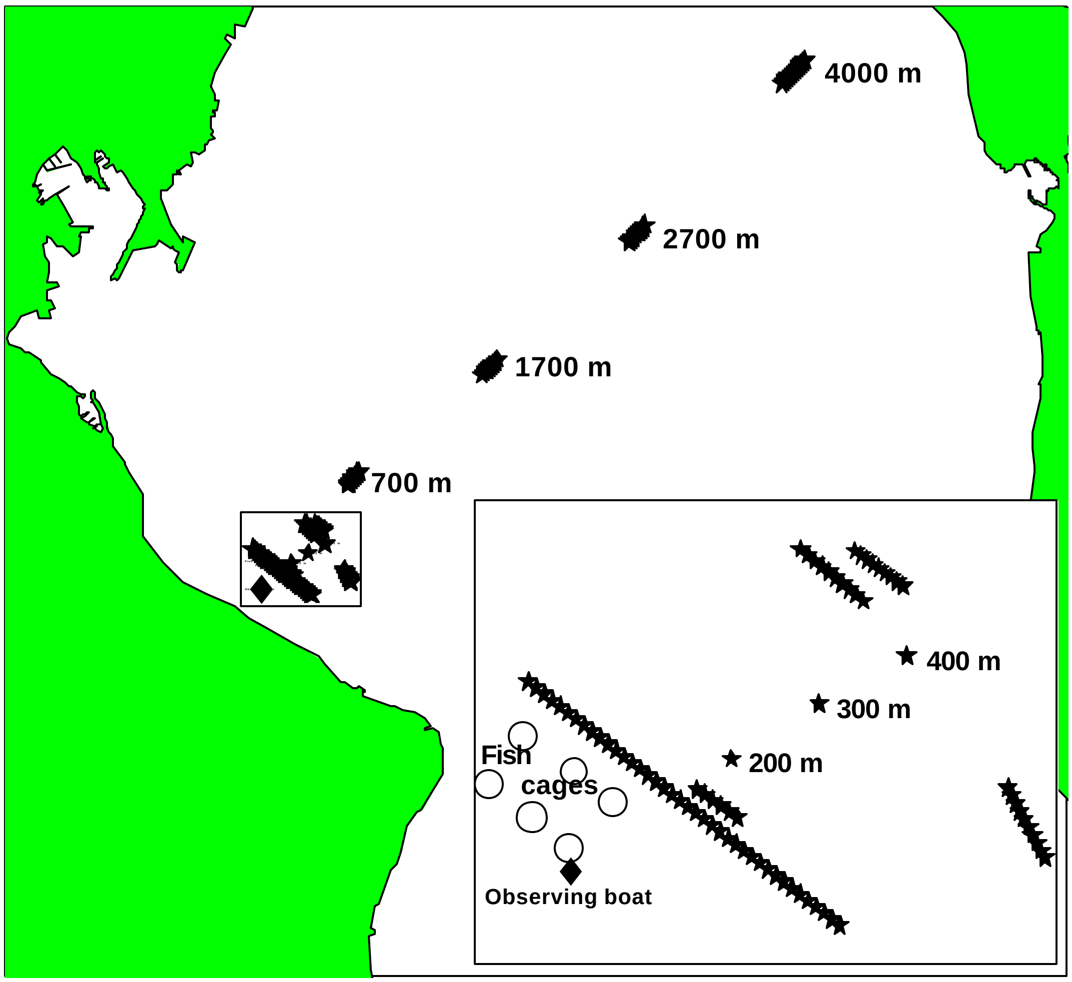

Figure 3.1. Shooting positions relative to observing position at the fish farm. Each star represents a single shot. The inset map shows details of shooting close to the observing boat.

Shooting started the first day (June 4th) at approximately 2 nautical miles (4000 m) distance from the fish farm. First several single shots were fired and then a series of 10 shots. From direct observation of the video screens no reaction was seen. The shooting was then commenced approximately half a nautical mile closer. As the fish reaction was still deemed negligible the distance was decreased further a half nautical mile. This procedure was repeated until the shooting was at a quarter nautical mile (approximately 400 m) from the observed fish. This was the closest that the shooting vessel could come without entering the quarantine area of the diseased fish farm. The last experiment just outside the quarantine area was repeated which also marked the end of the first day.

On the second day the last exercise from the day before was repeated with a series of shots just outside the quarantine area.

On the third day it was decided that the shooting vessel should enter the quarantine area to allow testing at closer range. This implied that the vessel had to be disinfected after finishing the working program. One shot was first fired at 400 m, then one shot at 300 m and then one shot at 200m. As the reaction of the fish in the cage still was negligible firing was performed at 150 m, the closest the shooting vessel could come to the fish cage without colliding with anchoring buoys and tows. At 150 m first one shot and then a series of five shots were fired. As a final exercise a series of 40 shots were fired while the shooting vessel sailed along a line as close as possible to the observed fish.

3.1 Sound pressure measurements

The fish farm is placed in a noisy environment just outside the harbour of Tórshavn. The ambient noise level (background noise) usually had maximum amplitudes up to 124 dB_{p-p}, whereas when vessels were sailing to and from the harbour of Tórshavn the maximum noise amplitudes reached 137 dB_{p-p}. Examples of background noise levels and frequency spectrum are given in figure 3.2.

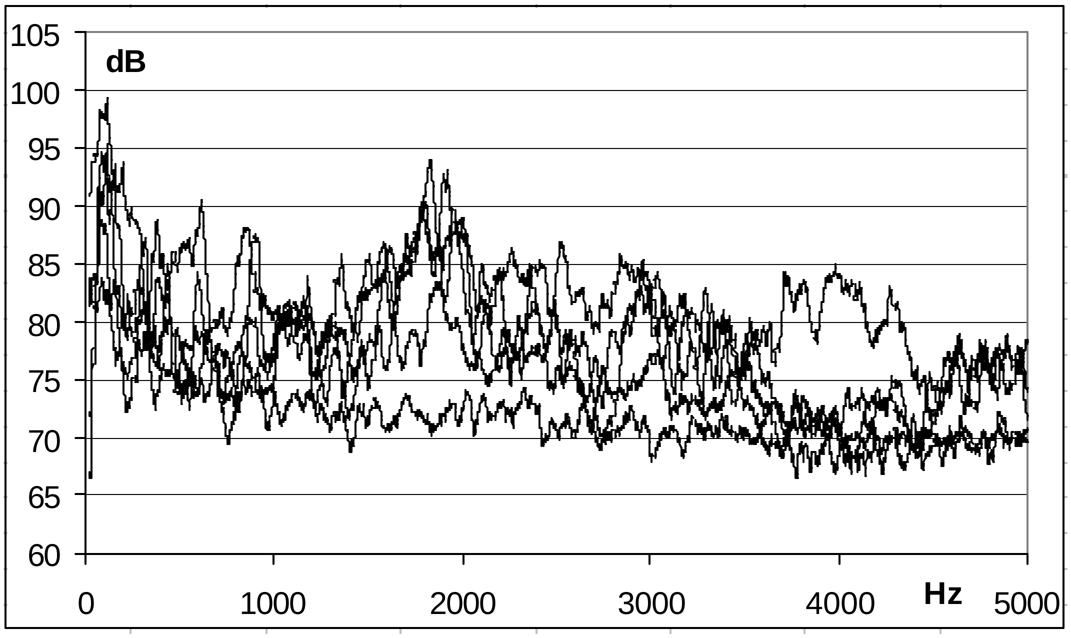

Figure 3.2. Examples of ambient noise levels (in spectrum level units) measured at the fish farm. Higher levels indicate shipping noise.

A total of 124 sound pulses were recorded. At 4000 m distance the sound pressure level was measured as 142 $dB_{p\text{-}p}$ rel 1 µPa at the observation point and at 150 m distance the pressure level had increased to 186 $dB_{p\text{-}p}$ rel 1 µPa. In a free field, with no boundaries, sound spreads from a source along a spherical front (spherical spreading). In relatively shallow water, with reflecting interfaces created by the water surface and sea bed, sound spreads in a cylindrical pattern. Figure 3.3 shows the measured pressure level changes against distance compared to spherical and cylindrical spreading.

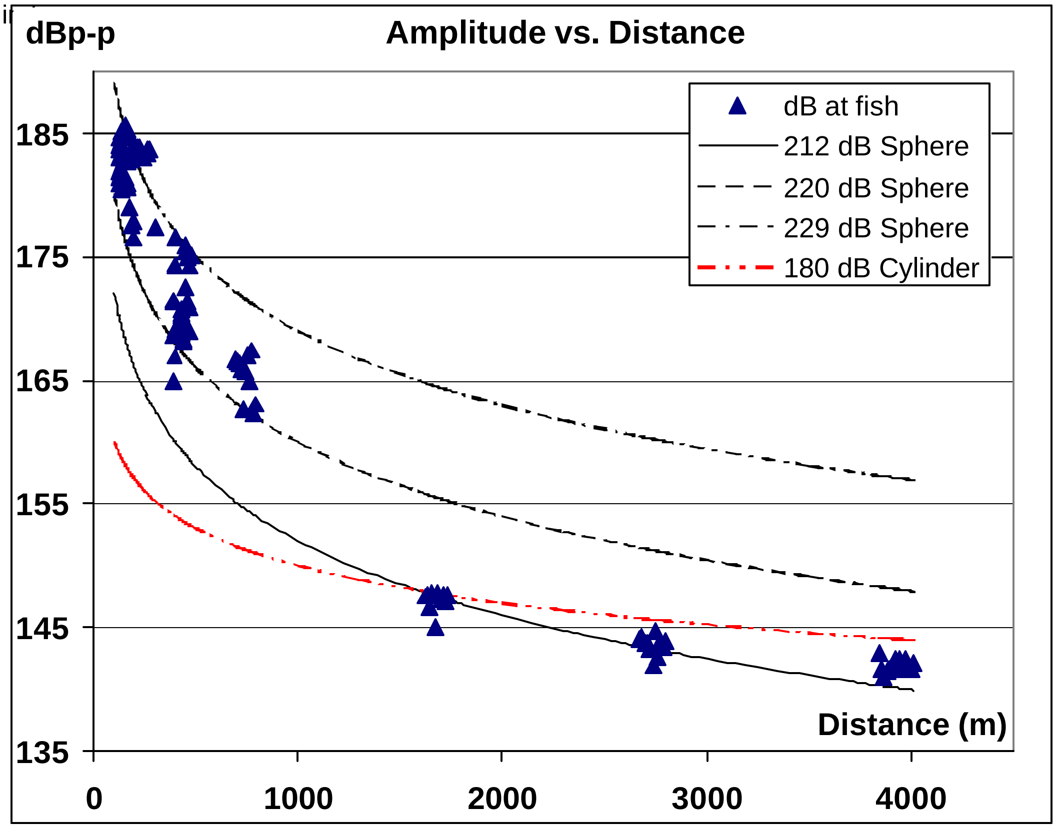

Figure 3.3. Observed peak-peak pressure amplitude with distance. Triangles represent measurements from single shots. For comparison lines indicating spherical and cylindrical spreading attenuation are shown. See Appendix B for further details on measurements.

The pressure level was generally lower than what would be expected from a 229 dB source. Between 150 m and 700 m the transmission loss seems to conform to spherical spreading. The decrease in pressure level from 700 m to 1700 m is more than would be expected assuming spherical spreading, but at longer range the amplitude seems to decay less than spherical spreading, but more than cylindrical spreading.

The variation in pressure amplitude between shots at similar distance was generally low, but in one shot series the difference between shots was as much as 9.5 dB, see table 3.1.

Table 3.1. Variation in amplitude at similar distances.

Number of pulses	Distance (m) Min	Distance (m) Max	Amplitude (dBpp) Min	Max	Diff.	Average	St. dev
14	3842	4014	141	142.9	1.9	141.9	0.52
11	2672	2798	142	144.7	2.9	143.6	0.78
10	1618	1736	145	147.7	2.6	147.2	0.82
11	697	790	162	167.4	5.1	165.3	1.83
10	393	397	165	174.4	9.5	169.9	3.05
10	445	475	169	175.9	6.9	173.1	2.38
9	427	437	168	170.8	2.6	169.5	0.94
6	147	173	181	183.8	2.5	182.6	0.98
21	120	159	181	185.7	5.2	183.4	1.61

3.2 Dynamite shooting

The sound level was also monitored while small dynamite explosions (up to 25 g) were used on land, but these could not be registered on the hydrophone and were assumed to be below the ambient noise (background noise) at the fish farm.

3.3 Video recording and fish behaviour

The camera in the rainbow trout cage showed a section of the upper part of the cage and fish were seen swimming as they were circulating along the cage wall. The camera in the salmon smolts cage showed the whole school of fish present in the cage and most of the time these fish were seen holding position against the tidal current.

At no time during the tests did the fish show any general avoidance reaction by diving or any simultaneous reaction of several individuals. On the other hand, to determine when a reaction occurred as a result of a shot was not very straightforward. The fish (both trout and smolts) were performing calm swimming movements most of the time. However, sometimes sudden movements were seen which not related to any sound pulse, but which were assumed to occur in response to some other stimulus.

The scoring given from five observers on fish reaction to sound pulses is given in table 3.2.

Table 3.2. Scoring given from five observers on trout and smolt reaction to shooting pulses. Scores are given according to the list in section 2.4.Only pulses with total sores of five or more, in either trout or smolts, are listed. Scores for all pulses can be found in Appendix B.

Shot no	Distance m	Amplitude dB	Smolt Observer no 1	2	3	4	5	Trout Observer no 1	2	3	4	5	Total score Smolt	Trout
30	1683	148	0	0	0	0	0	1	0	1	1	2	0	5
36	790	163	0	0	0	1	1	2	2	2	2	1	2	9
38	772	167	1	1	1	1	1	0	0	0	0	0	5	0
66	475	175	1	2	1	0	1	0	0	0	0	0	5	0
77	298	177	1	0	1	2	2	0	0	0	1	0	6	1
87	257	184	3	3	2	1	2	0	2	2	1	1	11	6
90	230	184	1	1	1	1	1	0	0	1	0	1	5	2
101	146	185	3	0	1	1	1	0	0	0	0	0	6	0

On eight out of the 124 shots some reaction was deemed to take place as a consequence of the shooting. Trout reacted on two pulses of 148 and 163 dB_{p-p} rel 1 µPa amplitude, while smolts did not. Smolts reacted to five pulses of 167 dB to 185 dB_{p-p} rel 1 µPa amplitude, while trout showed no reaction. At one pulse at 184 dB_{p-p} rel 1 µPa (shot no 87) both trout and smolts reacted. Generally the reaction was minor and only one or two fish showed a small sudden movement forward. At shot no 87 the most severe reaction was seen in the smolts, when two fish were seen to swim forward and make sudden turns. This is depicted in figure 3.4.

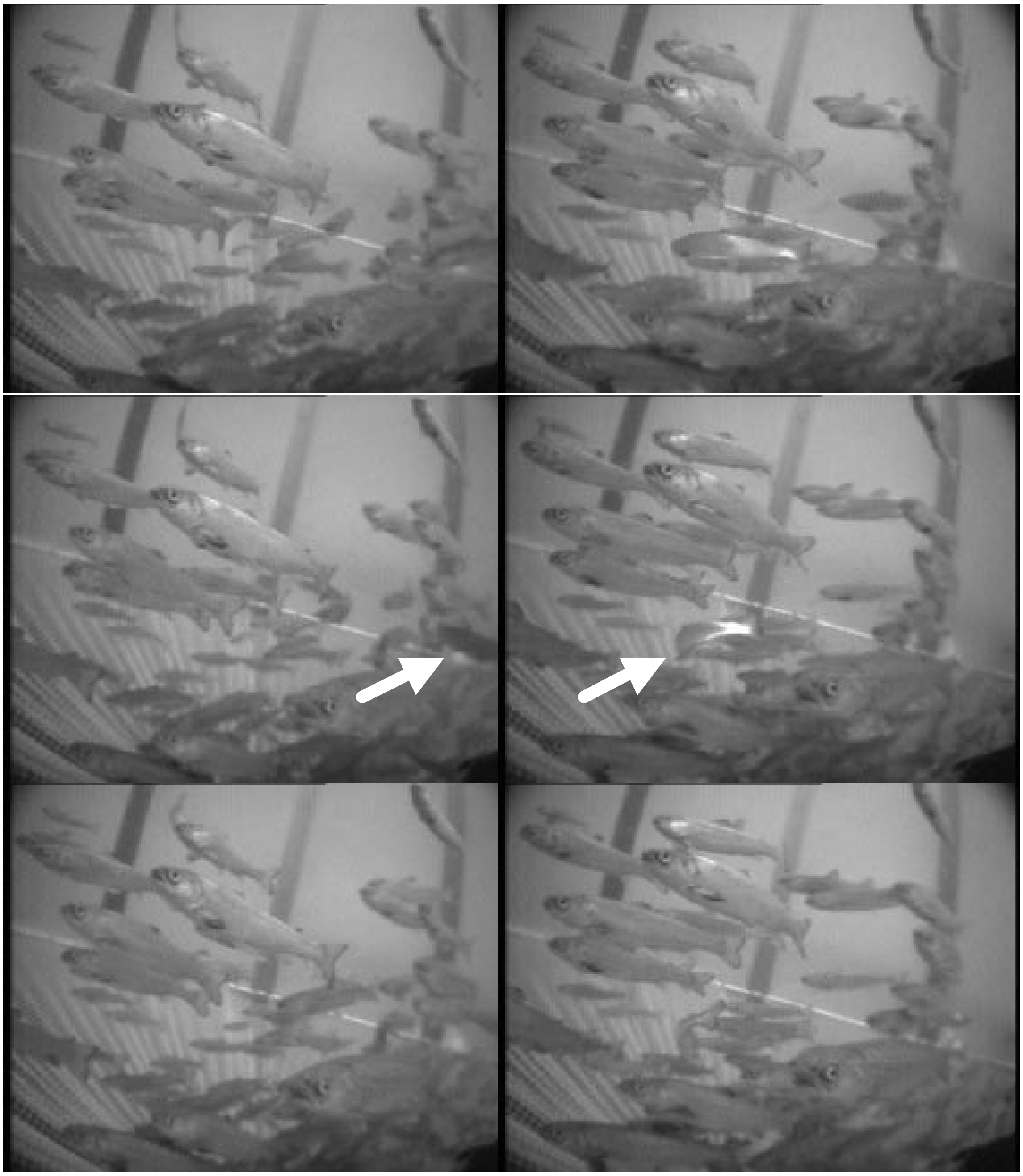

Figure 3.4. Salmon smolts reaction to shoot no 87. One fish to the right and one fish in the middle of the picture are seen to swim forward and make quick turns (indicated by arrows). Notice that otherwise the fish are generally seen to maintain a steady position. The pictures represent frames within one second of the video.

3.4 Pulse shape

The pulse shapes recorded by the hydrophone showed irregular transitions between positive and negative amplitudes of comparable magnitudes with most energy within frequencies below 300 Hz.

The pulses that caused reaction by the fish did not seem to have any particular features compared to pulses that did not cause fish reaction, see figure 3.5

The change in pressure with time was measured to 140-150 dB per millisecond at 2000-4000 m distance from the airgun and to 175-185 dB per millisecond at 150 m distance.

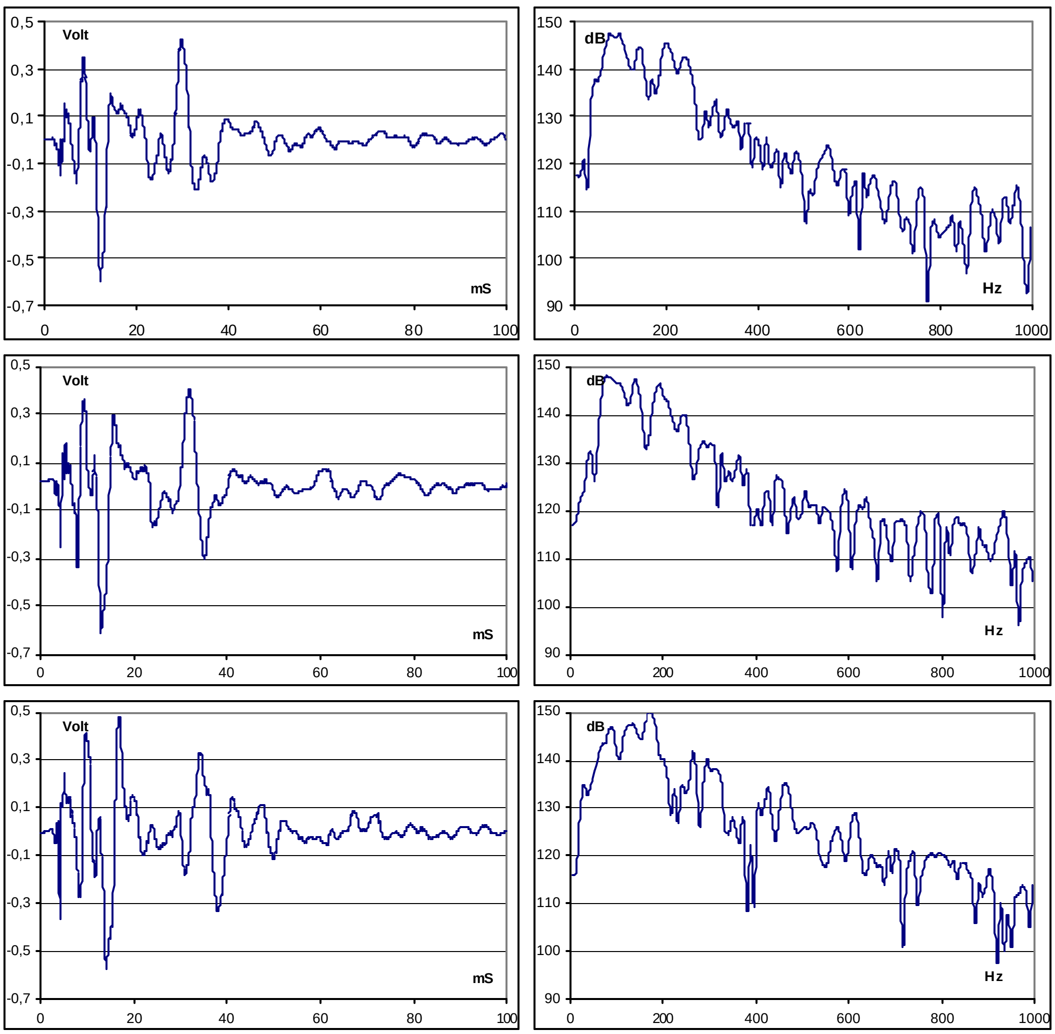

Figure 3.5. Sound pulses shown in time domain (left) and frequency domain (right). Both trout and smolts reacted to shot no 87 (middle) while no reaction was seen to a similar pulse before (above) and after (below).

3.5 Fish feeding

Data on the fish feeding in the weeks after the experiment showed that the seismic shooting did not affect the appetite of the rainbow trout. The salmon smolts were not fed, but killed and discarded when the experiment was over.

3.6 Fishing activity

Between May 17th and June 14th the 28 feet long-lining vessel, Trýsystkin TN390 of Nólsoy, fished for 15 days, including the three shooting days. The fishing was performed similarly from day to day with the line set across the deepest part of Nólsoy fjord, see figure 3.1. The number of hooks set per day was between 1962 and 3924. The catch in grams of fish per hook per day is shown in figure 3.6. Throughout the period there is an increasing tendency in the catch rate. The catch was half and half cod and haddock.

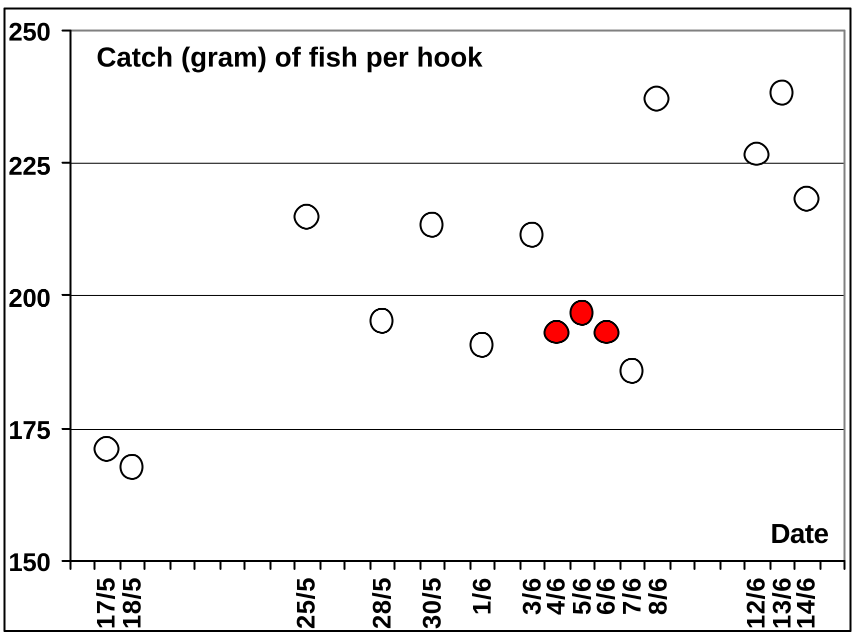

Figure 3.6. Catch of long-lining vessel Trýsystkin TN390 before, during and after the shooting experiments. Filled dots indicate the three shooting days.

4. Discussion

In the following the findings in the present experiment will be discussed and related to theory and the results from similar work reported in the literature.

4.1 Sound pulse attenuation

When sound travels through a medium, transmission loss is experienced and the intensity at some distance from the source will be lower than at closer range.

The basic loss law for spherical spreading giving the intensity I(R) at range R, expressed in dB, is: $I(R) = -20\log_{10}R$. Reflection from sea-surface and sea-floor may result in cylindrical spreading, for which $I(R) = -10\log_{10}R$. A "practical" law often invoked for "first'cut" calculation is an intermediate defined by $I(R) = -15\log_{10}R$ (Coates, 1990).

However, for shallow water the transmission loss has been experienced to be much more than spherical spreading and 35 log(R) has been referred to as typical for shallow water (Turnpenny and Nedwell, 1994).

Wardle et al. (2001) found sharp drop in amplitude over the first 50 m of distance from the airgun (much more than expected from spherical spreading) and little or no change in amplitude from 50 to 200 m.

The present work indicated a transmission loss between 150 m and 700 m, which conformed to spherical spreading. The decrease in pressure level from 700 m to 1700 m was more than would be expected assuming spherical spreading, but at longer range the amplitude seemed to decay less than spherical spreading, but more than cylindrical spreading (figure 3.3). The topography of the experimental site in Nólsoy fjord is complex and the transmission and reflection of sound is difficult to predict.

4.2 Sound pressure level at the fish farm

From previous work it has been concluded that lethal effects on fish occur at sound pressures above 229 dB when the rise time is within 1 millisecond.

The sound pressure level recorded in our experiment had a maximum peak-peak pressure of 186 dB rel 1 µPa and the maximum pressure change within a millisecond had similar magnitudes. This sound pressure therefore should not be expected to have lethal or stunning effects on the fish, which also was confirmed by the observation of the fish.

4.3 Fish reaction

A prerequisite for fish to react to a sound pulse is that it is able to detect the pulse.
Salmon has a high hearing threshold of 100 dB rel 1 μPa at 160 Hz, much higher than for example cod with hearing threshold of 75 dB rel 1 μPa. (figure 1.1). From its anatomy, which is similar to that of the salmon, it is believed that hearing in rainbow trout is similar to hearing in the closely related salmon (pers. comm. Tony Hawkins, UK).

Hearing in Salmon can be linearly masked by an increase in noise level (Hawkins and Johnstone, 1978) and for both cod and salmon to detect a sound stimulus, the stimulus must exceed the ambient noise level by about 20 dB (Hawkins, 1993).

The detection threshold for sound pulses of short duration can be expected to be higher than continuous sound tunes, perhaps by as much as 50 dB for airgun sounds (Pearson et al., 1992).

Much work has been done on the reaction of cod to noise. From information on how cod react to vessel noise Engås et al. (1993) estimated a reaction threshold for cod of 110-120 dB rel 1 μPa /Hz (150-160 $dB_{0\text{-}p}$) and concluded that for such noise it appears that fish react when the level is increased by about 20 dB over the level defined as the detection threshold.

If we assume 50 dB as a detection threshold for airgun sound and another 20 dB between detection and reaction threshold we might expect salmon to react at levels around 170 dB.

The result from our experiment is in agreement with this as subtle reactions were seen in the range of 148-185 $dB_{p\text{-}p}$ rel 1 μPa. Large rainbow trout reacted to two pulses at 148 and 163 $dB_{p\text{-}p}$ rel 1 μPa, while salmon did not. Salmon reacted to three pulses at 167, 175 and 177 $dB_{p\text{-}p}$ rel 1 μPa, while trout did not. Both trout and salmon reacted to one pulse at 185 $dB_{p\text{-}p}$ rel 1 μPa.

Turnpenny and Nedwell (1994) concluded that typical behavioural threshold effects for airgun sources ranged from 160 to 200 dB, but avoidance threshold for other underwater sources designed to deter fish can be effective at levels in the range 100-140 dB, as a result of better targeting of the frequency range and, perhaps, higher duty cycle (50-100%, cf. 0.3% for airguns).

It has been observed that salmon in cages react by diving to sound pulses of 160-170 dB (pers. comm. Tor Larsen, Norway) and Pearson et al. (1992) observed a shift in vertical distribution, and occurrence of alarm and startle responses in captive Rockfish *(Sebastes spp.)* when exposed to seismic shooting at sound pressure as low as 161 dB, although they suggested a general threshold of about 180 dB_{0-p} (186 dB p-p) for alarm responses and a threshold between 200 and 205 dB for startle responses.

In the present experiment no general avoidance or diving reaction was seen. One possible reason for this could be that the rainbow trout, in their noisy environment just outside the harbour, have been habituated to loud noises. This argument does not go for the salmon smolts, as they had been on the site for only few days. On the other hand they were confined in a small cage with clearly visible bottom and had little space to react within.

4.4 Were some sound pulses different?

The results in the present work saw fish reaction to some pulses of peak pressure around 148-185 dB rel 1 µPa, but no reaction to most pulses with peak pressure as high as 186 dB rel 1 µPa. Similar reaction pattern have been reported by Urquhart and Johnstone (1984), who observed responses in salmonids to two pulses with peak pressures around 165-170 dB rel 1 µPa, but saw no reaction to stronger pulses of 170-175 dB rel 1 µPa. A possible reason for this could be that the signatures of the pulses are different.

Dalen and Knutsen (1986) found that a water-gun had much more lethal effects on cod fry than an airgun producing similar sound pressures and suggested that the negative pressure pulse from the water-gun exposed the fish to a more dangerous expansion of organs than the positive pressure pulse from an airgun. This effect should be expected to increase with depth of the fish.

Whether similar effects are important for the reaction of fish is only speculative. From the data in the present experiment it is not possible to determine whether fish will respond more to a negative pulse than a positive one. Pulse no 87, where fish reaction was seen, had a significant negative component, but so had the pulses before and after where no reaction was seen.

An airgun signature sound with an abrupt character is considered most likely to elicit startle responses (Blaxter et al., 1981 in Pearson et al. 1992). Pearson et al. (1992) found this form of pulse close to the airgun, whereas at distance the character had changed from abrupt to ramped.

In the present work pressure changes in the sound pulse of 140-150 dB per millisecond were experienced at 1700-4000 m distance from the airgun, whereas this had increased to 175-185 dB per millisecond at 150 m distance. This change in pulse character may increase fish reaction as well as the change in amplitude.

4.5 Possible effects from a full size airgun array

The sound source used for the present experiment was four airguns mounted in a cluster with a source level around 229 dB. A cluster means guns so close together that when fired they behave as a single larger gun (Dragoset, 2000). The sound source used can therefore be regarded as a point source with little or no directivity.

A 24 airgun array with a total volume of 2250 in^3 and operated at 2000 psi (138 bar) will produce peak strength in the far-field around 57 bar-m (255 dB) (Dragoset, 2000).

The radiation pattern of arrays is concentrated downward (and upward), and amplitude levels emitted horizontally are 15-24 dB lower than amplitude levels emitted vertically (Caldwell and Dragoset, 2000). For fish farms the relevant direction from a seismic survey would be in the horizontal plane.

The peak sound level in the horizontal plane from a full-scale airgun array will therefore be 2-11 dB above the peak sound level from the airgun cluster used in the experiments. The sound level from an airgun array in the horizontal plane would have decreased to similar levels as the airgun cluster used in the experiments at 4 m assuming spherical spreading (5 m ~ 12 dB) or at 13 m assuming cylindrical spreading (13 m ~ 11.1 dB).

4.6 Fishing activity

Commercial fishing before, during and after the seismic shooting showed that there was and increasing trend in the catch per effort throughout the period. Furthermore there was a stepwise increase one day after the shooting ceased.

One form of fish reaction to seismic shooting that has been reported is a diving behaviour and it has been suggested that fish has become more available to bottom trawling after seismic shooting. One explanation in the increase of the catch after the shooting could be that fish were scared into the deeper parts of the fjord where the fishing took place. However fishing may have been affected by other causes, not depending on shooting, for example the increase in day length. The data are not sufficient to make a firm conclusion.

5. Conclusions

The petroleum in the subsoil of the Faroe Islands is not a renewable resource and the income from this industry will cease probably within decades from its start, while the fishing industry is based on a renewable resource and can go on forever. It is thus of paramount importance that petroleum developments in the Faroes do not jeopardise the future of the fishing or fish farming industry.

5.1 General impact from seismic shooting on fish

The seismic shooting technique used in the exploration for petroleum has a potential negative impact on fish. However, using modern airguns, lethal effects will only be expected in the immediate vicinity of large devices.

Several experiments document the scaring effect on fish from seismic shooting and catch rates have been reported to decrease considerably close to shooting areas.

5.2 The experiment on caged fish

The present experiment on caged fish showed very little impact from seismic shooting. The seismic device used in the geophysical experiment on Glyvursnes in June 2002 produced sound levels up to 186 dB_{p-p} rel 1 µPa at the fish farm, which is far below pressure levels thought to be lethal to fish, but in the range of sound levels that can produce alarm and startle responses in fish. However, only occasionally a few fish responded by sudden movements to the sound pulses presented. These movements were difficult to distinguish from normal behaviour.

Although the fish farm is in a noisy environment, rainbow trout was once seen to respond to an airgun shot measured to 148dB_{p-p} rel 1 µPa at the fish cage. It was not possible to find out whether there are special features in the pulse signature that makes the fish react.

The sound attenuation was found not to follow simple theory. The prediction of sound levels from a distant source should therefore be made with care.

The low impact of seismic shooting on the farmed fish was also confirmed by the fact that the fish fed normally after the shooting

The seismic shooting did not reduce the catch in the fishery that was performed in Nólsoy fjord during and after the shooting period.

5.3 Lessons learned

The present project has provided an opportunity for the author and people at the Faroese Fisheries Laboratory to conduct research and review literature on how seismic shooting affects aquatic animals. The experiment has given a first hand experience and details on how seismic shooting affects caged fish.

The experiment has shown that empirical results do not always follow theory, and the importance of consulting existing practical knowledge has been experienced.

By setting up this experiment, valuable experience has been gained in this field of work, including sound and video recording in marine environment and knowledge of the important issues involved. The technical equipment used for sound and video recording can be tricky, and practice in how to adjust controls to suitable levels is important. The experiment also showed the value of backup of technical equipment and personnel.

The knowledge and training gained from the present experiment will be an excellent foundation for success in future experiments.

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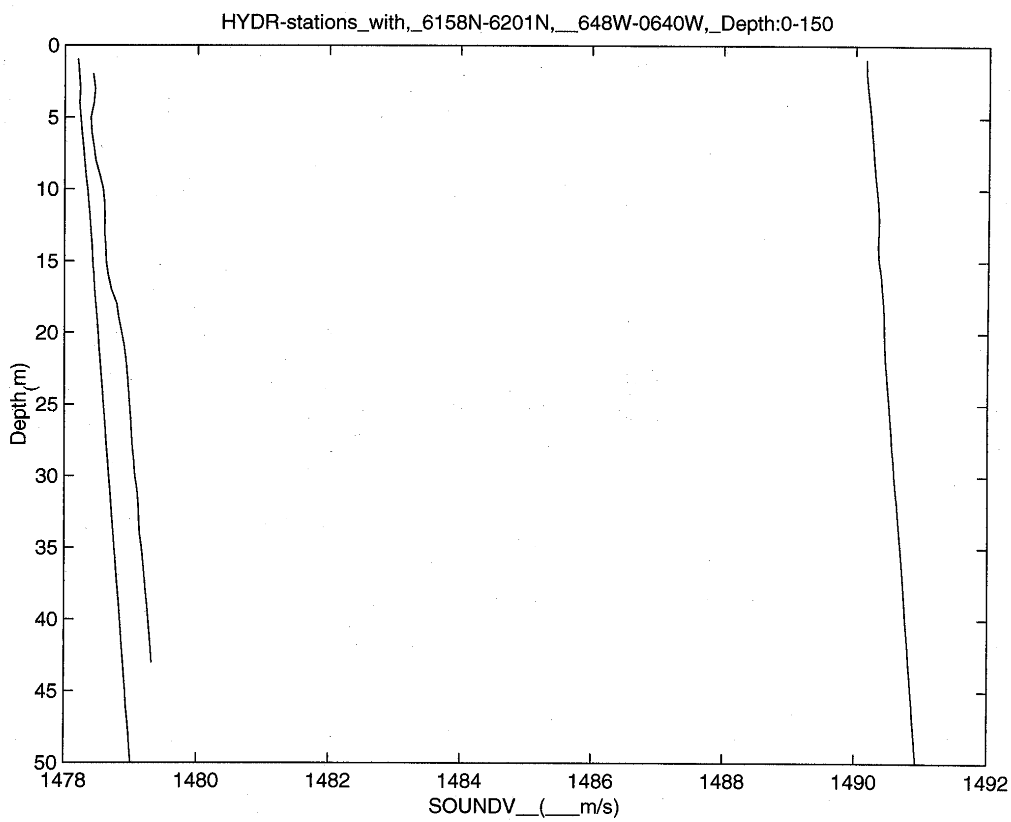
Appendix A. Soundprofiles in Nólsoy fjord, Faroe Island

Following three sound profiles from Nólsoy fjord taken in summertime were available in the database on hydrographic data at the Faroese Fisheries Laboratory.
Thanks to Bogi Hansen, oceanographer at the Faroese Fisheries Laboratory, for making this data available.



Appendix B. Data from 124 sound pulses

Data from observation of caged fish exposed to seismic shooting. Fish reactions to a total of 124 pulses were recorded.
Sound was recorded in files on a laptop (col. 3). Two video tape recorders were used (col. 4-5).
Attenuator and gain setting col. 6-7. Peak pressure is calculated from voltage (col. 10-19) to give pressure at cage in dB rel 1uP (col 20). Position and distance col. 21-23. Five observers judged the reaction seen (col. 24-35).

																							Reaction					Reaction						
Biofarið 2 nm			Tape timer						Max amplitude				Max change										Observer					Observer					Total score	
Date	Time	File	Smolt	Trout	Att	Ga	Shot no		'max	mS	Vmin	mS	'max	mS	Vmin	mS	Vpp	B/mS	B fish	Lon	Lat	Dist	1	2	3	4	5	1	2	3	4	5	Smolt	Trout
20604	1420	28	17:33	25:51	0	2	1	1	925	7.3	-793	7.8	925	7.3	-793	7.8	1718	148	142	-6.6971	62.0135	4014	0	0	0	0	0	0	0	0	0	0	0	0
20604	1421	29	18:39	26:57	0	2	2	1	818	7.8	-793	8.2					1611		142	-6.6973	62.0134	4001	0	0	0	0	0	0	0	0	0	0	0	0
20604	1422	30	19:20	27:38	0	2	3	1	753	4	-843	6.8	703	6.4	-843	6.8	1596	149	142	-6.6974	62.0133	3988	0	0	0	0	0	0	0	0	1	1	0	2
20604	1422	30	19:30	27:48	0	2	4	2	931	6.3	-846	5.8					1777		142	-6.6976	62.0133	3974	0	0	1	0	0	0	0	0	0	0	1	0
20604	1422	30	19:40	27:58	0	2	5	3	829	5.3	-796	5.7	829	5.3	-796	5.7	1625	149	142	-6.6978	62.0132	3961	0	0	0	0	0	0	0	0	0	0	0	0
20604	1422	30	19:50	28:08	0	2	6	4	925		-855						1780		142	-6.6980	62.0131	3948	0	0	0	0	0	0	0	0	0	0	0	0
20604	1422	30	20:00	28:18	0	2	7	5	865		-785						1650		142	-6.6982	62.0130	3935	0	0	0	0	0	0	0	0	0	0	0	0
20604	1423	31	20:10	28:28	0	2	8	6	945		-825						1770		142	-6.6983	62.0129	3921	0	0	0	0	1	0	0	0	0	0	1	0
20604	1423	31	20:20	28:38	0	2	9	7	840		-800						1640		142	-6.6985	62.0128	3908	0	0	0	0	0	0	0	0	1	0	0	1
20604	1423	31	20:30	28:48	0	2	10	8	910		-710						1620		142	-6.6987	62.0128	3895	0	0	0	0	0	0	0	0	0	0	0	0
20604	1423	31	20:40	28:58	0	2	11	9	855	6.9	-740	7.4					1595		142	-6.6989	62.0127	3882	0	0	0	0	0	0	0	0	0	0	0	0
20604	1423	31	20:50	29:08	0	2	12	10	795		-705						1500		141	-6.6990	62.0126	3869	0	0	0	0	0	0	0	0	0	0	0	0
20604	1423	31	21:00	29:18	0	2	13	11	830		-775						1605		142	-6.6992	62.0125	3855	0	1	0	0	1	0	0	0	0	0	2	0
20604	1424	32	21:37	30:55	0	2	14	1	973	6.3	-900	6.6	973	6.3	-900	6.6	1873	153	143	-6.6994	62.0124	3842	0	0	0	0	0	0	0	0	0	0	0	0
	1433																			-6.7023	62.0126	3746												
Biofarið 1.49 nautical mile distance									Max amplitude				Max change										Observer					Observer					Total score	
Date	Time	File	Smolt	Trout	Att	Ga	Shot no		'max	mS	Vmin	mS	'max	mS	Vmin	mS	Vpp	B/mS	B fish	Lon	Lat	Dist	1	2	3	4	5	1	2	3	4	5	Smolt	Trout
20604	1440	35	23:57	31:49	0	1	15	1	539	17	-502	10	472	11	-502	10	1040	146	144	-6.7133	62.0057	2798	0	0	0	1	0	0	0	1	1	0	1	2
20604	1440	35	24:07	31:59	0	1	16	2	445		-545						990		143	-6.7135	62.0056	2785	0	0	0	0	0	0	0	0	0	0	0	0
20604	1440	35	24:17	32:09	0	1	17	3	544	11	-477	14	531	19	-455	20	1021	148	144	-6.7136	62.0055	2773	0	0	0	0	0	0	0	0	0	0	0	0
20604	1440	35	24:27	32:19	0	1	18	4	455		-448						903		143	-6.7138	62.0054	2760	0	0	0	0	0	0	0	0	0	0	0	0
20604	1441	36	24:37	32:29	0	1	19	5	634	11	-519	13	634	11	-519	13	1154	141	145	-6.7140	62.0053	2748	0	0	0	0	0	0	0	0	0	0	0	0
20604	1441	36	24:47	32:39	0	1	20	6	325		-505						830		142	-6.7141	62.0052	2735	0	0	0	0	0	0	0	0	0	0	0	0
20604	1441	36	24:57	32:49	0	1	21	7	435		-535						970		143	-6.7143	62.0052	2723	0	0	1	0	0	0	0	0	0	0	1	0
20604	1441	36	25:07	32:59	0	1	22	8	502		-522						1024		144	-6.7145	62.0051	2710	0	0	1	0	0	0	0	0	0	0	1	0
20604	1441	36	25:17	33:09	0	1	23	9	470		-560						1030		144	-6.7146	62.0050	2697	0	0	0	0	0	0	0	0	0	1	0	1
20604	1441	36	25:27	33:19	0	1	24	10	518		-572						1090		144	-6.7148	62.0049	2685	0	0	0	0	0	0	0	0	0	0	0	0
20604	1442	37	25:37	33:29	0	1	25	11	403		-655						1058		144	-6.7150	62.0048	2672	0	0	0	1	0	0	0	0	0	0	1	0

Biofarið 1 nm									Max amplitude				Max change										Observer					Observer					Total score	
Date	Time	File	Smolt	Trout	Att	Ga	Shot	no	Vmax	mS	Vmin	mS	Vmax	mS	Vmin	mS	Vpp	dB/mS	dB fish	Lon	Lat	Dist	1	2	3	4	5	1	2	3	4	5	Smolt	Trout
20604	1454	40	28:18	35:36	0	1	26	1	820	13	-785	9.6	820	13	-777	15	1605	146	148	-6.7284	61.9992	1736	0	0	0	0	0	0	0	0	0	0	0	0
20604	1454	40	28:28	35:46	0	1	27	2	766	11	-764	12					1530		147	-6.7285	61.9991	1723	0	0	0	0	0	0	0	0	1	0	0	1
20604	1454	40	28:38	35:56	0	1	28	3	838	18	-768	12	706	11	-768	12	1605	149	148	-6.7287	61.9990	1710	1	0	0	0	0	0	0	0	0	0	1	0
20604	1455	41	28:48	36:06	0	1	29	4	800		-760						1560		147	-6.7289	61.9990	1696	0	0	0	1	0	1	0	0	0	1	1	2
20604	1455	41	28:58	36:16	0	1	30	5	845	19	-779	12	730	5.7	-752	6.3	1625	151	148	-6.7291	61.9989	1683	0	0	0	0	0	1	0	1	1	2	0	5
20604	1455	41	29:08	36:26	0	1	31	6	530		-670						1200		145	-6.7292	61.9988	1670	0	0	0	0	0	0	0	0	0	0	0	0
20604	1455	41	29:18	36:36	0	1	32	7	840	12	-785	8.7	614	8.1	-785	8.7	1625	151	148	-6.7294	61.9987	1657	0	0	0	0	0	0	0	0	0	0	0	0
20604	1455	41	29:28	36:46	0	1	33	8	710		-725						1435		147	-6.7296	61.9986	1644	0	0	0	0	0	0	0	0	0	1	0	1
20604	1455	41	29:38	36:56	0	1	34	9	830		-780						1610		148	-6.7298	61.9985	1631	0	0	0	0	0	0	0	0	0	0	0	0
20604	1456	42	29:48	37:06	0	1	35	10	835		-755						1590		148	-6.7300	61.9985	1618	0	0	0	0	0	0	0	0	0	0	0	0

Biofarið 0.5 nm									Max amplitude				Max change										Observer					Observer					Total score	
Date	Time	File	Smolt	Trout	Att	Ga	Shot	no	Vmax	mS	Vmin	mS	Vmax	mS	Vmin	mS	Vpp	dB/mS	dB fish	Lon	Lat	Dist	1	2	3	4	5	1	2	3	4	5	Smolt	Trout
20604	1506	43	32:16	39:20	20	1	36	1	512	8.2	-442	6.4	397	12	-408	11	954	162	163	-6.7425	61.9938	790	0	0	0	1	1	2	2	2	2	1	2	9
20604	1506	44	32:26	39:30	20	1	37	2	474	8.5	-401	6.6					875		162	-6.7426	61.9937	781	0	0	0	0	0	0	0	0	0	0	0	0
20604	1506	45	32:36	39:40	20	1	38	3	832	6.1	-742	7.8	715	14	-683	13	1575	163	167	-6.7427	61.9937	772	1	1	1	1	1	0	0	0	0	0	5	0
20604	1507	46	32:46	39:50	20	1	39	4	525		-645						1170		165	-6.7429	61.9936	762	0	0	0	0	0	0	0	0	0	0	0	0
20604	1507	46	32:56	40:00	20	1	40	5	805		-705						1510		167	-6.7430	61.9935	753	0	0	0	0	0	0	0	0	0	0	0	0
20604	1507	46	33:06	40:10	20	1	41	6	730		-570						1300		166	-6.7431	61.9935	743	0	0	0	0	0	0	0	0	0	0	0	0
20604	1507	46	33:16	40:20	20	1	42	7	520		-390						910		163	-6.7432	61.9934	734	0	0	0	0	0	0	0	0	0	0	0	0
20604	1507	46	33:26	40:30	20	1	43	8	775		-540						1315		166	-6.7433	61.9933	725	0	0	0	0	0	0	0	0	0	0	0	0
20604	1507	46	33:36	40:40	20	1	44	9	665		-730						1395		166	-6.7434	61.9933	715	0	0	0	0	0	0	0	0	0	0	0	0
20604	1508	47	33:46	40:50	20	1	45	10	705		-710	6.6					1415		167	-6.7436	61.9932	706	0	0	0	0	0	0	0	1	0	1	0	2
20604	1508	47	33:56	41:00	20	1	46	11	770		-670	6.6					1440		167	-6.7437	61.9932	697	0	0	0	0	0	0	0	0	0	0	0	0

Biofarið 0.25 nm																							Observer					Observer					Total score	
Date	Time	File	Smolt	Trout	Att	Ga	Shot	no	Vmax	mS	Vmin	mS					Vpp	dB/mS	dB fish	Lon	Lat	Dist	1	2	3	4	5	1	2	3	4	5	Smolt	Trout
20604	1513	48	35:21	42:35	30	1	47	1	273	40	-198	38					471		167	-6.7480	61.9913	394	0	0	0	0	0	0	0	0	0	0	0	0
20604	1513	48	35:31	42:46	30	1	48	2	359	8.7	-217	12	359	8.7	122	8	576	164	169	-6.7479	61.9912	394	0	0	0	0	0	0	0	0	0	0	0	0
20604	1513	48	35:41	42:56	30	1	49	3	285		-290						575		169	-6.7477	61.9912	393	0	0	0	0	0	0	0	0	0	0	0	0
20604	1513	48	35:51	43:06	30	1	50	4	200		-170						370		165	-6.7476	61.9911	393	0	0	0	0	0	0	0	0	0	1	0	1
20604	1513	48	36:01	43:16	30	1	51	5	265		-307						572		169	-6.7475	61.9911	393	0	0	0	0	0	0	0	0	0	0	0	0
20604	1513	48	36:11	43:26	30	1	52	6	506	161	-288	160					794		171	-6.7473	61.9910	394	0	0	0	1	0	0	0	0	0	0	1	0
20604	1513	48	36:21	43:36	30	1	53	7	470		-320						790		171	-6.7472	61.9910	394	0	0	1	0	1	1	0	0	0	0	2	1
20604	1514	49	36:31	43:46	30	1	54	8	648		-460						1108		174	-6.7471	61.9909	395	0	0	0	1	0	0	0	0	0	0	1	0
20604	1514	49	36:41	43:56	30	1	55	9	660		-440						1100		174	-6.7469	61.9909	396	0	0	0	1	0	0	0	0	0	0	1	0
20604	1514	49	36:51	44:06	30	1	56	10	330		-275						605		169	-6.7468	61.9908	397	0	0	0	0	0	0	0	0	0	0	0	0

Biofarið 0.24 nm									Max amplitude				Max change										Observer					Observer					Total score	
Date	Time	File	Smolt	Trout	Att	Ga	Shot	no	Vmax	mS	Vmin	mS	Vmax	mS	Vmin	mS	Vpp	B/mS	B fish	Lon	Lat	Dist	1	2	3	4	5	1	2	3	4	5	Smolt	Trout
20604	1525	54	40:30	47:38	30	1	57	1	607	12	-715	9	607	12	-715	9	1322	167	176	-6.7440	61.9891	445	0	0	0	0	0	0	0	0	0	0	0	0
20604	1526	55	41:09	48:16	30	1	58	1	440		-450						890		172	-6.7440	61.9891	447	0	0	1	1	1	1	0	0	0	0	3	1
20604	1526	55	41:21	48:29	30	1	59	2	515		-725						1240		175	-6.7439	61.9890	450	0	0	0	0	0	0	0	0	0	0	0	0
20604	1526	55	41:34	48:41	30	1	60	3	345		-410						755		171	-6.7438	61.9889	453	0	0	0	0	0	0	0	0	0	0	0	0
20604	1527	56	41:47	48:54	30	1	61	4	328		-459						787		171	-6.7437	61.9889	457	0	0	0	0	1	0	0	0	0	0	1	0
20604	1527	56	41:58	49:06	30	1	62	5	486		-709						1195		175	-6.7436	61.9888	460	0	0	0	0	0	0	0	0	0	0	0	0
20604	1527	56	42:11	49:19	30	1	63	6	350		-395						745		171	-6.7436	61.9887	464	0	0	0	0	0	0	0	0	0	0	0	0
20604	1527	56	42:24	49:31	30	1	64	7	237		-358						595		169	-6.7435	61.9886	467	0	0	0	0	0	0	0	0	0	0	0	0
20604	1527	56	42:35	49:43	30	1	65	8	460		-630						1090		174	-6.7434	61.9886	471	0	0	0	0	0	0	0	0	0	0	0	0
20604	1528	57	42:46	49:54	30	1	66	9	494	7.7	-704	27	421	13	-681	11	1198	169	175	-6.7433	61.9885	475	1	2	1	0	1	0	0	0	0	0	5	0
Biofarið 500m									Max amplitude				Max change										Observer					Observer					Total score	
Date	Time	File	Smolt	Trout	Att	Ga	Shot	no	Vmax	mS	Vmin	mS	Vmax	mS	Vmin	mS	Vpp	B/mS	B fish	Lon	Lat	Dist	1	2	3	4	5	1	2	3	4	5	Smolt	Trout
20605	2113	48	26:38	30:55	30	1	67	1	305	21	-249	30	287	22	-236	25	554	160	168	-6.7461	61.9910	437	1	0	0	0	1	0	0	0	0	0	2	0
20605	2113	48	26:48	31:05	30	1	68	2	250		-295						545		168	-6.7462	61.9910	435	0	0	1	1	0	0	0	0	1	1	2	2
20605	2113	48	26:58	31:15	30	1	69	3	307	22	-280	11	307	22	-186	25	587	161	169	-6.7463	61.9910	434	1	0	0	0	0	0	0	0	0	0	1	0
20605	2113	48	27:09	31:25	30	1	70	4	410		-280						690		170	-6.7464	61.9911	432	0	0	0	0	0	0	0	0	0	0	0	0
20605	2113	48	27:19	31:35	30	1	71	5	396	22	-268	24	396	22	-268	24	664	163	170	-6.7465	61.9911	431	0	0	0	1	1	0	0	0	0	1	2	1
20605	2113	48	27:28	31:45	30	1	72	6	430		-302						732		171	-6.7466	61.9912	430	0	2	0	0	1	0	0	0	0	0	3	0
20605	2114	49	27:38	31:55	30	1	73	7	398	22	-304	24	398	22	-304	24	702	163	170	-6.7467	61.9912	429	1	0	1	0	1	0	0	0	0	1	3	1
20605	2114	49	27:48	32:05	30	1	74	8	303		-278						581		169	-6.7469	61.9912	428	0	0	0	0	1	0	0	0	0	0	1	0
20605	2114	49	27:58	32:15	30	1	75	9	338	21	-294	24	338	21	-294	24	631	162	170	-6.7470	61.9913	427	0	0	0	0	1	0	0	0	1	1	1	2
Biofarið 400, 300, 200 m									Max amplitude				Max change							-6.7437	61.9910	538	Observer					Observer					Total score	
Date	Time	File	Smolt	Trout	Att	Ga	Shot	no	Vmax	mS	Vmin	mS	Vmax	mS	Vmin	mS	Vpp	B/mS	B fish	Lon	Lat	Dist	1	2	3	4	5	1	2	3	4	5	Smolt	Trout
20606	1611	5	33:56	39:08	30	1	76	1	720	24	-699	9.8	517	7.6	-699	9.8	1419	168	177	-6.7460	61.9903	398	0	0	0	1	0	0	0	0	0	0	1	0
20606	1612	6	35:24	40:36	30	1	77	1	812	8.7	-747	11	812	8.7	-747	11	1559	170	177	-6.7477	61.9899	298	1	0	1	2	2	0	0	0	1	0	6	1
20606	1614	8	37:13	42:25	30	1	78	1	866	23	-777	18	773	17	-777	18	1644	176	178	-6.7494	61.9894	194	1	0	0	0	1	0	1	1	1	0	2	3
20606	1615	9	38:05	43:17	40	1	79	1	498	25	-535	18	215	16	-535	18	1033	176	184	-6.7500	61.9891	147	1	0	0	0	0	0	0	0	0	0	1	0
20606	1616	10	39:47	44:59	40	1	80	1	328	21	-466	9.2	158	9.8	-466	9.2	794	184	181	-6.7499	61.9891	152	0	0	0	0	0	0	0	0	1	0	0	1
20606	1617	11	39:57	45:08	40	1	81	2	365		-410						775		181	-6.7497	61.9890	157	0	0	0	0	0	0	0	0	0	0	0	0
20606	1617	11	40:07	45:18	40	1	82	3	399	26	-517	20	278	5.8	-474	4.8	916	181	183	-6.7495	61.9890	162	0	0	0	0	1	0	0	0	0	0	1	0
20606	1617	11	40:17	45:28	40	1	83	4	440		-502						942		183	-6.7494	61.9889	167	0	0	1	1	0	0	0	0	1	0	2	1
20606	1617	11	40:27	45:38	40	1	84	5	480		-480						960		183	-6.7492	61.9889	173	0	0	0	0	0	0	0	0	0	0	0	0

Biofarið line at 150 m									Max amplitude				Max change							-6.7524	61.9884	0	Observer					Observer					Total score	
Date	Time	File	Smolt	Trout	Att	Ga	Shot	no	Vmax	mS	Vmin	mS	Vmax	mS	Vmin	mS	Vpp	dB/mS	dB fish	Lon	Lat	Dist	1	2	3	4	5	1	2	3	4	5	Smolt	Trout
20606	1723	34	03:55	:12:18	40	1	85	1	423	34	-594	16	95	15	-594	16	1018	178	184	-6.7473	61.9879	275	1	0	0	0	0	0	0	0	0	0	1	0
20606	1723	34	04:05	:12:28	40	1	86	2	390		-598						988		183	-6.7474	61.9879	266	0	0	0	0	0	0	0	0	0	1	0	1
20606	1723	34	04:15	:12:38	40	1	87	3	401	32	-616	13	296	16	-616	13	1017	174	184	-6.7476	61.9880	257	3	3	2	1	2	0	2	2	1	1	11	6
20606	1723	34	04:25	:12:48	40	1	88	4	397		-581						978		183	-6.7477	61.9881	248	1	0	0	0	1	0	0	0	0	0	2	0
20606	1724	35	04:35	:12:58	40	1	89	5	352	9.1	-590	13	346	16	-590	13	942	175	183	-6.7479	61.9881	239	0	0	0	0	0	0	0	0	0	0	0	0
20606	1724	35	04:45	:13:08	40	1	90	6	400		-602						1002		184	-6.7480	61.9882	230	1	1	1	1	1	0	0	1	0	1	5	2
20606	1724	35	04:55	:13:18	40	1	91	7	478	18	-571	15	478	18	-571	15	1049	175	184	-6.7482	61.9882	222	1	0	0	0	1	0	0	0	0	0	2	0
20606	1724	35	05:05	:13:28	40	1	92	8	494		-561						1055		184	-6.7483	61.9883	213	0	0	0	0	1	0	0	0	0	0	1	0
20606	1724	35	05:15	:13:38	40	1	93	9	477		-552						1029		184	-6.7485	61.9883	205	1	0	0	0	0	0	0	1	0	0	1	1
20606	1724	35	05:25	:13:48	40	1	94	10	557		-505						1062		184	-6.7487	61.9884	197	0	0	0	1	0	0	0	0	0	0	1	0
20606	1725	36	05:35	:13:58	40	1	95	11	440	18	-493	15	201	4.2	-484	3.7	933	186	183	-6.7488	61.9885	189	1	0	1	0	1	0	0	0	0	1	3	1
20606	1725	36	05:45	:14:08	40	1	96	12	494		-507						1001		184	-6.7490	61.9885	181	1	0	0	0	1	0	0	0	0	0	2	0
20606	1725	36	05:55	:14:18	40	1	97	13	632		-532						1164		185	-6.7491	61.9886	173	2	0	0	0	0	0	0	0	0	0	2	0
20606	1725	36	06:05	:14:28	40	1	98	14	678		-547						1225		185	-6.7493	61.9886	166	1	0	0	0	0	0	0	0	0	0	1	0
20606	1725	36	06:15	:14:38	40	1	99	15	651		-603						1254		185	-6.7494	61.9887	159	1	0	0	0	0	0	0	0	0	0	1	0
20606	1725	36	06:25	:14:48	40	1	100	16	625		-666						1291		186	-6.7496	61.9887	153	2	1	1	0	0	0	0	0	0	0	4	0
20606	1726	37	06:35	:14:58	40	1	101	17	546	24	-682	18	202	17	-682	18	1229	180	185	-6.7497	61.9888	146	3	0	1	1	1	0	0	0	0	0	6	0
20606	1727	37	06:45	:15:08	40	1	102	18	478		-726						1204		185	-6.7499	61.9888	141	2	0	0	0	1	0	0	0	0	0	3	0
20606	1728	37	06:55	:15:18	40	1	103	19	495		-726						1221		185	-6.7500	61.9889	136	3	0	0	0	1	0	0	0	0	0	4	0
20606	1729	37	07:05	:15:28	40	1	104	20	563		-648						1211		185	-6.7502	61.9890	131	1	0	0	0	0	0	0	0	0	1	1	1
20606	1730	37	07:15	:15:38	40	1	105	21	522		-627						1149		185	-6.7503	61.9890	127	1	0	1	0	1	0	0	0	0	0	3	0
20606	1731	37	07:25	:15:48	40	1	106	22	465		-569						1034		184	-6.7505	61.9891	124	2	0	0	0	1	0	0	0	0	0	3	0
20606	1727	38	07:35	:15:58	40	1	107	23	490		-525						1015		184	-6.7507	61.9891	122	1	0	0	0	1	0	0	0	0	0	2	0
20606	1727	38	07:45	:16:07	40	1	108	24	575		-495						1070		184	-6.7508	61.9892	120	0	0	1	0	0	0	0	0	0	0	1	0
20606	1727	38	07:55	:16:18	40	1	109	25	473	4.3	-471	3.7	473	4.3	-471	3.7	943	187	183	-6.7510	61.9892	120	1	0	0	0	0	0	0	0	0	0	1	0
20606	1727	38	08:05	:16:28	40	1	110	26	370		-460						830		182	-6.7511	61.9893	120	1	0	0	0	0	0	0	0	0	0	1	0
20606	1727	38	08:15	:16:38	40	1	111	27	330		-460						790		181	-6.7513	61.9894	121	0	0	0	0	0	0	0	0	0	0	0	0
20606	1727	38	08:25	:16:48	40	1	112	28	331		-500						831		182	-6.7514	61.9894	123	2	0	0	0	1	0	0	0	0	0	3	0
20606	1728	39	08:35	:16:58	40	1	113	29	281		-470						751		181	-6.7516	61.9895	126	2	0	0	0	0	0	0	0	0	0	2	0
20606	1728	39	08:45	:17:08	40	1	114	30	348		-500						848		182	-6.7517	61.9895	129	2	0	0	0	1	0	0	0	0	0	3	0
20606	1728	39	08:55	:17:18	40	1	115	31	280		-430						710		181	-6.7519	61.9896	133	2	0	0	1	1	0	0	0	1	0	4	1
20606	1728	39	09:05	:17:28	40	1	116	32	385		-445						830		182	-6.7520	61.9896	138	1	0	1	0	0	0	0	0	0	0	2	0
20606	1728	39	09:15	:17:38	40	1	117	33	470		-510						980		183	-6.7522	61.9897	143	0	0	0	0	0	0	0	0	0	0	0	0
20606	1728	39	09:25	:17:48	40	1	118	34	468		-551						1019		184	-6.7523	61.9898	149	1	0	1	0	1	0	0	0	1	0	3	1
20606	1729	40	09:35	:17:58	40	1	119	35	437		-491						928		183	-6.7525	61.9898	156	2	0	0	0	0	0	0	0	0	0	2	0
20606	1729	40	09:45	:18:08	40	1	120	36	372		-378						750		181	-6.7527	61.9899	162	1	0	0	0	0	0	0	0	0	0	1	0
20606	1729	40	09:55	:18:18	40	1	121	37	348		-370						718		181	-6.7528	61.9899	169	0	0	0	0	0	0	0	0	0	0	0	0
20606	1729	40	10:05	:18:28	40	1	122	38	275		-320						595		179	-6.7530	61.9900	177	1	0	0	0	0	0	0	0	1	0	1	1
20606	1729	40	10:15	:18:38	40	1	123	39	245		-260						505		178	-6.7531	61.9900	184	0	0	0	0	0	0	0	0	0	0	0	0
20606	1729	40	10:25	:18:48	40	1	124	40	198		-249						447		177	-6.7533	61.9901	192	0	0	0	0	0	0	0	0	0	0	0	0