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Seismic testing and monitoring of farmed fish – Storfjorden 2009-2010

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Summary

From June 2009 until June 2010 Petroleum GeoServices (PGS) conducted tests of seismic equipment in a region of Storfjorden, Møre and Romsdal county, Norway. During testing passive and active monitoring of fish were conducted by Møreforsking Marine at the fish farms Skotungneset and Overåneset øst, owned and run by Fjordlaks Akva AS. The aim of the monitoring was a precautionary approach to identify any negative impacts by the tests on fish in the fish farms. Long term effects was planned to be investigated by analyzing the production parameters (fish growth, appetite and mortality) in relation to previous production cycles at the fish farms. Long term environmental monitoring of the fish farms was conducted to identify if any environmental factors could be the reason for a potential discrepancy. Production data from the fish farms were however unavailable at the time of writing, but feedback from Fjordlaks was that the fish farms have not been influenced by the testing activity. To observe more immediate responses fish were monitored with underwater camera at selected days when testing was conducted to try to observe any behavioral changes as a response to the discharges from the air cannon. No such behavioral changes could be observed.

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SUMMARY

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1 BACKGROUND INFORMATION

Petroleum Geo-Services (PGS) needed to conduct testing of seismic equipment in an appropriate area with low physical disturbance and with minimum risk of causing conflict of interest. A defined area in Storfjorden, Møre and Romsdal county, Norway, was previously suggested through an evaluation process conducted by Møreforsking Marine (Bakke and Dyb, 2009)(Figure 1 and Figure 2). The area was evaluated to be suitable in terms of required depth, relatively low wind and wave activity and periodically low ship traffic. The area also had a significant distance to any aquaculture activity since most of the fish farms in the area were laying fallow due to disease outbreak at the time of intended testing. The area were however closer to an active fish farm then what has previously shown not to affect the behavior of farmed Atlantic cod (Dyp, unpublished). As a precautionary measure PGS therefore wanted a monitoring of the fish at the closest active fish farm to be conducted to identify if their activity might have any effect on the fish.

Figure 1 - Map showing location of test area.

Møreforsking Marine (MM) was asked by PGS to conduct an extensive monitoring before, during and after the testing period of the fish farm Skotungneset (Figure 2). During the period when PGS was operating fish was also put out on the fish farm locality Overåneset øst (Figure 2). The monitoring program was therefore extended to include also this fish farm.

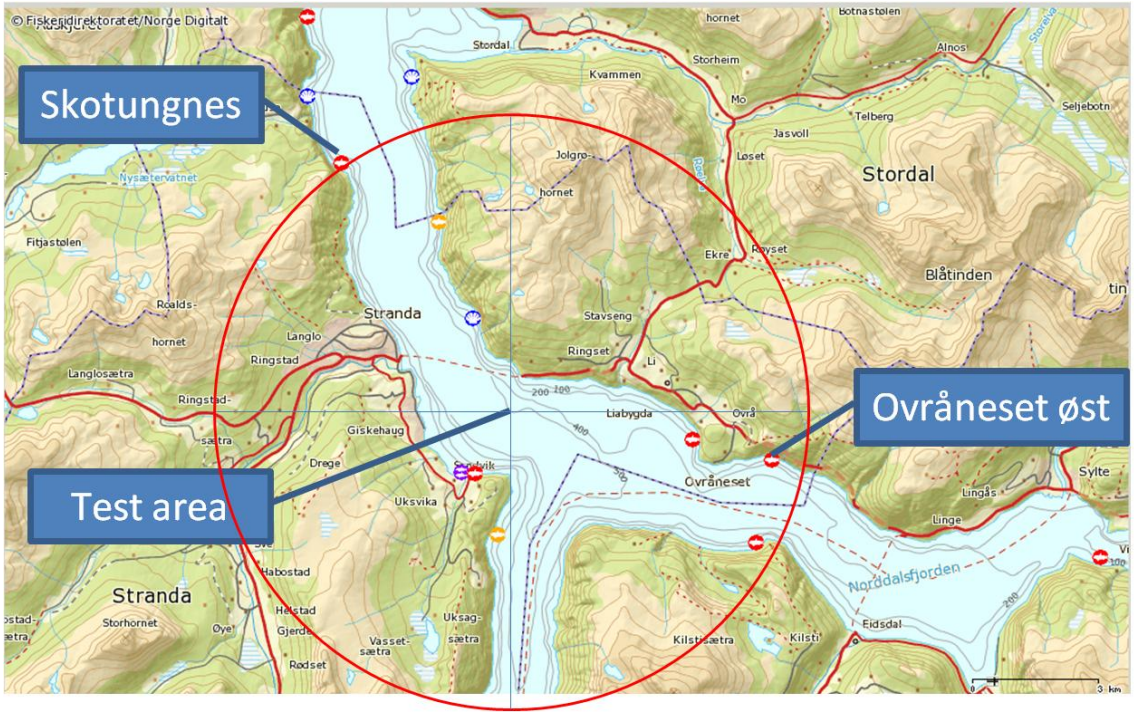

Figure 2 - Location of test area and fish farms (Skotungneset (Location nr. 23695, 62° 20.9370N / 6° 54.6460E) and Overåneset (Location nr. 13554, 62° 17.8321N/ 7° 7.4301E)). Red circle show 7 km radius from centre of test area.

In the event that it was found that fish were affected by the discharges, testing would be stopped and the progress further discussed between PGS, MM and the fish farmers. The purpose of the monitoring was strictly precautionary and observational and not with the intent of conducting scientific investigations on the effect of seismic airgun use on farmed fish. For detailed discussion regarding the effect of such activities on fish the reader is recommended to look at other studies (see e.g. Dalen *et al.* 2008, Thomsen 2002 or Wardle *et al.* 2001)

Hearing and sound perception in fish is a widely studied area of fish physiology (for reviews see e.g. Hastings and Popper 2005 and Higgs *et al.* 2006), and the effect of seismic surveys on marine life has received more and more attention (se previous references). Depending on the distance from the source and the strength of output from the source, effects on fish can vary from no response, mild behavioral responses (increased swimming speed), strong behavioral responses (c-start response) to physical damage (Dalen *et al.* 2008). All these effects are immediate responses. In the long term, stress can cause reduced reproductive potential and growth, and can sometimes result in mortality (Iwama *et al.* 2006). Thru the monitoring process it was therefore desirable to try and identify both potential long term effects (Passive monitoring) as well as more immediate responses of the fish during the period of testing (Active monitoring).

2 METHODS

2.1 Area and fish farms

Figure 2 show the test area and the location of both active fish farms (Skotungneset and Overåneset). Both fish farms are run and owned by Fjordlaks Aqua AS and produce rainbow trout (*Oncorhynchus mykiss*) with production capacity of 1.560 tons each. Skotungneset is situated approximately 7 km north west from the center of the test area and contained about 850 thousand fish at the start of the test period. The last fish were slaughtered in December 2009. Overåneset is situated approximately 6 km to the east from the center of the test area, and in late September 2009 fish were put out also at this location.

2.2 Monitoring

2.2.1 Passive monitoring

Comparison of historical data on growth, appetite and mortality with data from the ongoing production at the fish farms was planned to identify any discrepancy that could be caused by the testing. To identify if any environmental factors could be the reason for a potential discrepancy an environmental monitoring station was put out on both fish farms. Every 10 minutes water current (SD-6000, Sensordata AS, Bergen, Norway), salinity (Conductivity Sensor 319, Aanderaa Data Instruments Inc, Bergen, Norway or CTD SD204,SAIV AS, Bergen, Norway), temperature and oxygen (Oxygen Optode 3830 and 3835, Aanderaa Data Instruments Inc, Bergen, Norway) was registered. On both fish farms the monitoring station was put out at approximately 7 meters depth just outside a cage with fish. (Due to technical and operational reasons it was decided not to put the station within the cages). On Skotungneset the station was put out on the south side of the fish farm (Figure 3) while on Overåneset the monitoring station was put out on the west side of the fish farm (Figure 4), both facing the test area. Passive monitoring was conducted at Skotungneset from the beginning of June 2009 (2 weeks before first day of testing) until the last fish were slaughtered in December 2009. Monitoring at Overåneset started in the beginning of October 2009 (right after fish were put out) and continued until the end of June 2010 (two weeks after last day of testing).

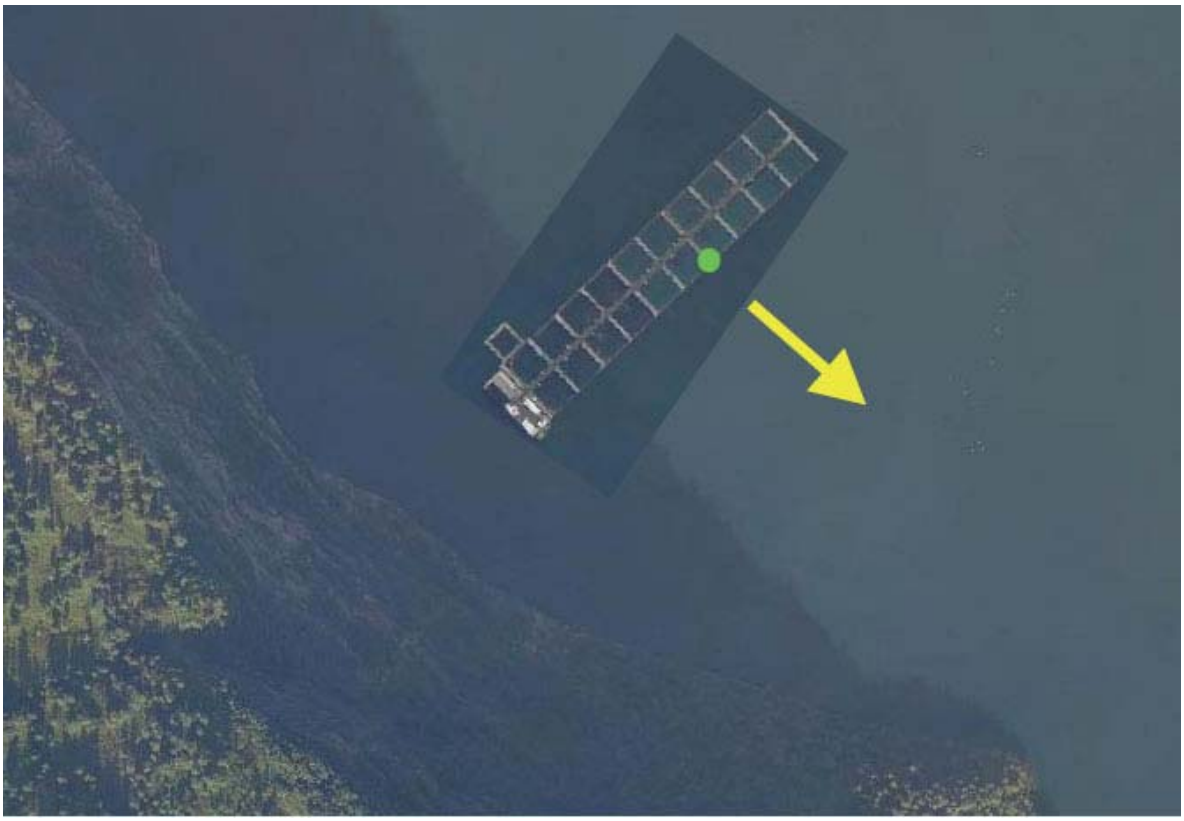

Figure 3 - Location of monitoring station at fish farm Skotungneset (green point). Yellow arrow shows direction towards test area (~7km). (Dimension and location of fish farm not exact as pictured was edited for illustrative purposes).

Figure 4 - Location of monitoring station at fish farm Overåneset (green point). Yellow arrow shows direction towards test area (~6km).

2.2.2 Active monitoring

On selected days when testing of seismic equipment were conducted fish where monitored by underwater video camera during shooting sequences. To record sound a standard hydrophone was used (H2a Hydrophone, Aquarian Audio Products, Anacortes, WA, USA) and in order to measure sound level a calibrated reference hydrophone was used (REFTEK-17, High Tech, Inc., Gulfport, MI, USA). Previous monitoring of fish farms conducted by MM have shown that surveillance with video monitoring of the fish with parallel audio recordings is a reliable way of detecting behavioral changes.

The oxygen level in the proximity of the fish cage was also monitored in order to detect any reduction in oxygen concentration in the water (caused by increased oxygen consumption by the fish as a stress response).

During the three first days of testing active monitoring was conducted at the fish farm. At following days of testing active monitoring was only conducted when strength of source output were increased or on the request by PGS.

3 RESULTS/OBSERVATIONS

3.1 Monitoring

3.1.1 Passive monitoring

At the time of writing data on the growth of fish, appetite or mortality at the fish farms were unfortunately unavailable. However, compared to previous years, Fjordlaks have not observed any difference in growth or mortality at the two fish farms that were monitored, and their opinion is that they have not been affected during the period with testing. (Svein Flølo, Quality manager, Fjordlaks, pers. com.).

Graphs showing measured environmental parameters before, during and after test period are presented in Appendix 3. The measurements are conducted at a given depth and at one specific location and should not be used as a general description of the environmental condition in and around the fish farm.

Due to technical problems during environmental monitoring one or more parameter are missing. (Shown in graph as gaps).

At Overåneset in March 2010 a sudden rise in salinity can be observed. This is believed to be caused by a change in depths of measurements. At the time of change in salinity the current sensor on the monitoring station was changed and the station most probably redeployed at a greater depth (below a top layer of water with lower salinity).

The observed changes in oxygen over relatively short periods might be caused by changing directions of the water current and can therefore not be used as a measure of the concentration of oxygen within the fish cages.

At certain times oxygen levels rise above 100 % saturation (see. graphs from Overåneset March, May and June 2010). This is likely to be caused by phytoplankton blooms generating oxygen through photosynthesis (Johansson *et al.* 2006, and references within). This theory is enforced by the observation of what appear to be a strong stratification of the water column at about 7 meters during this period (cf. the salinity rise observed in March once station was redeployed).

3.1.2 Active monitoring

Different levels of oxygen concentration was observed between days when current were exiting the fish cages into the measurement area compared to when water moved into the cages away from the measurement area. It was however not possible to detect any obvious changes in oxygen level in the water during periods of testing (se figures for each day below). It should however be noted that measured oxygen level might not reflect actual concentration within fish cage as measurements were conducted outside the cage.

In the following pages the results from days with active monitoring is presented. At selected points where sound signals from the airgun are detected graphs showing sound wave is presented. Reference are also given to Appendix 1 showing related snapshots of the fish 2 and 1 seconds before recorded signal, at the time of recorded signal and 1, 2, 3, 4, 5, 6, 7, 8 and 9 seconds after recorded signal. Although the behavior of the fish was studied for all detected airgun sound signals, data is only presented for selected points. Points were selected based on airgun output strength, time of discharge (early signals were preferred since it was anticipated that the fish would adapt to the sound over time) or for signals with affiliated video sequence that gave good visualization. Sound level measured with calibrated reference hydrophone at the fish farms during sequences of discharges are also presented for selected points in Appendix 2.

Skotungneset

16. June 2009

Fish monitored at Skotungneset by Møreforsking during testing. Sound recorded with standard hydrophone. No reference hydrophone where used due to technical problems. Times of airgun discharges are shown in Table 1. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 5.

Table 1- Signal log 16.June showing time of discharges

Time	Gun-type	Volume	Pressure	Depth
14:53:30	G-Gun	60 Cu.in.	1200 psi	8 meters
14:56:30	G-Gun	60 Cu.in.	1500 psi	8 meters
14:57:30	G-Gun	60 Cu.in.	1500 psi	8 meters
14:59:30	G-Gun	60 Cu.in.	1500 psi	8 meters
16:00:00	G-Gun	60 Cu.in.	2000 psi	5 meters
16:01:00	G-Gun	60 Cu.in.	2000 psi	5 meters
16:02:00	G-Gun	60 Cu.in.	2000 psi	5 meters

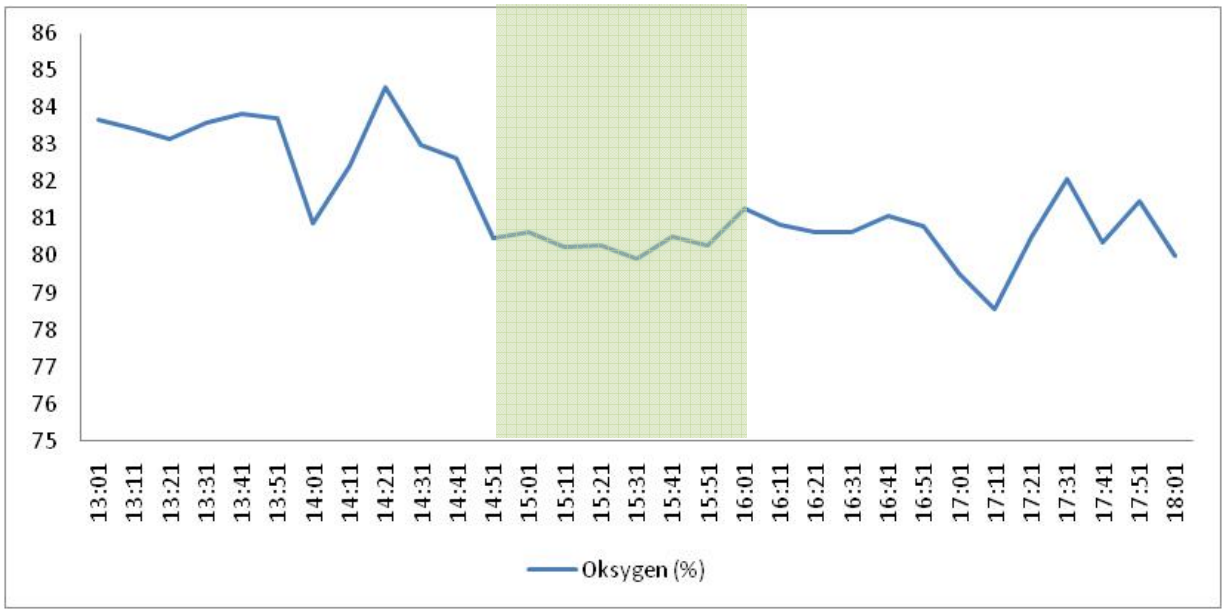

Figure 5 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. SE current direction (130-138°), water exiting fish cages into measurement area.

14:53:30

Not able to identify any sound after discharge. Testing conducted behind Gravaneset and not in view from fish farm. No behavioral changes in fish.

14:56:30

Sound signal detected after discharge but uncertain if airgun tests are the source (Figure 6). Not able to detect any behavioral changes in fish.

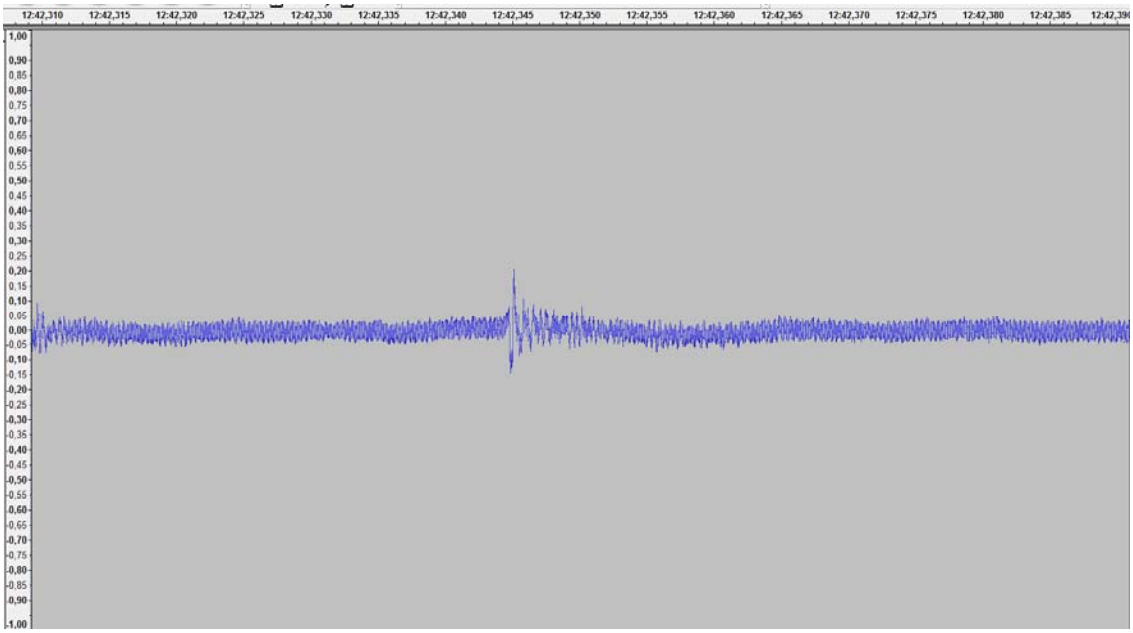

Figure 6 - Sound signal recorded after 14:56:30 discharge.

14:57:30 and 14:59:30

Not able to identify any sound after discharge. Testing conducted behind Gravaneset and not in view from fish farm. No behavioral changes in fish.

16:00:00

Possible airgun sound signal detected (Figure 7). Not able to detect any behavioral changes in fish (Appendix 1 - Skotungneset 16.June 2009 - Snapshot sequence 1).

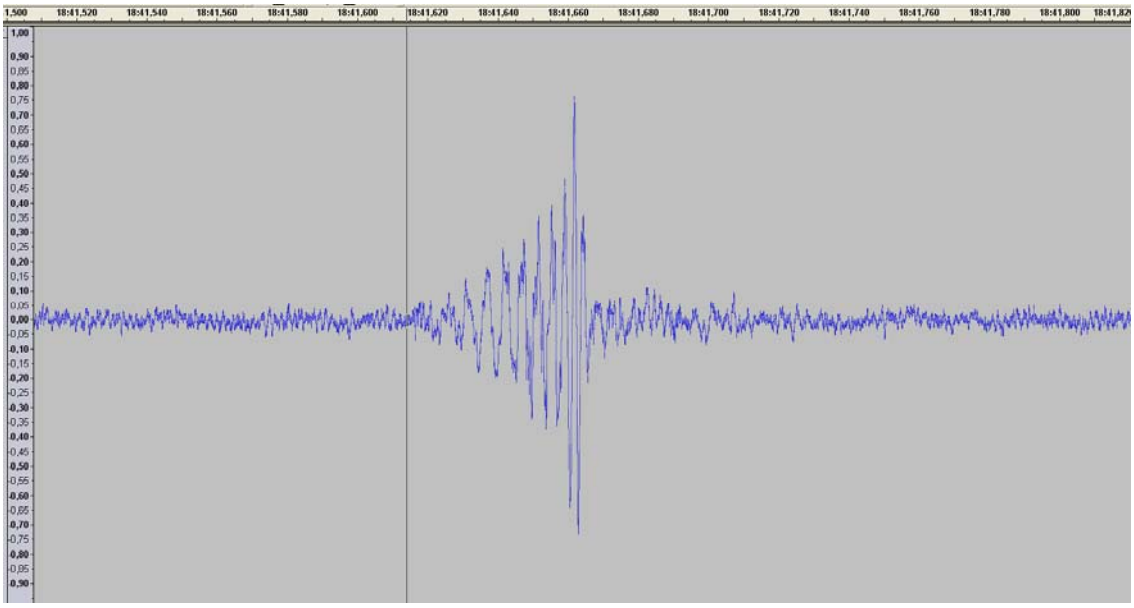

Figure 7 - Sound signal recorded after 16:00:00 discharge.

16:01:00

Possible airgun sound signal detected (Figure 8). Not able to detect any behavioral changes in fish (Appendix 1 – Skotungneset 16.June 2009 - Snapshot sequence 2).

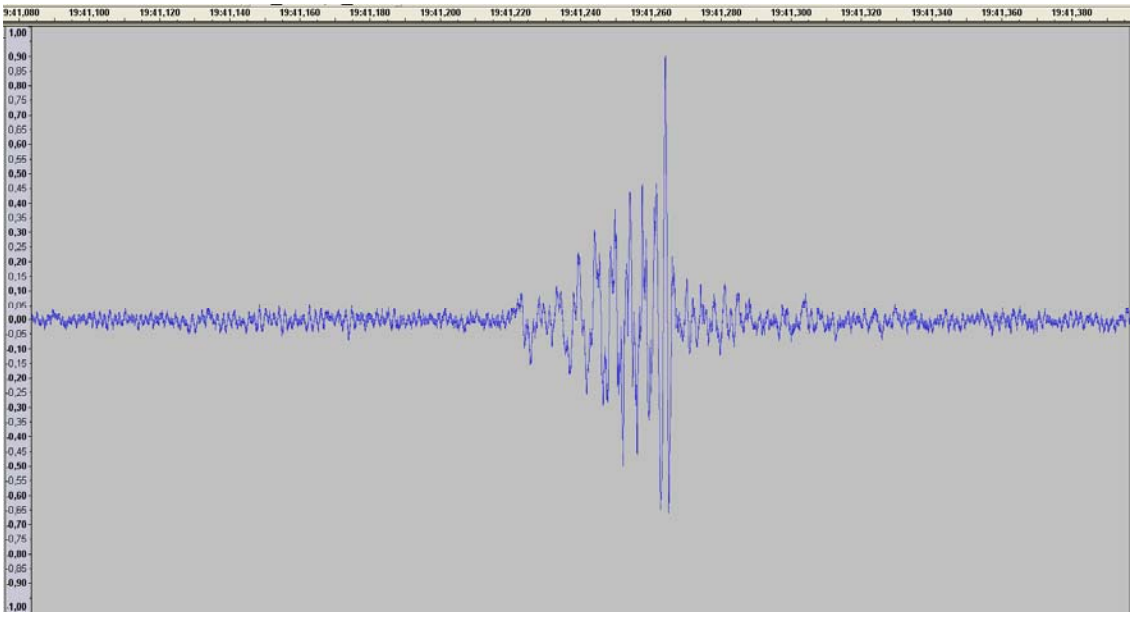

Figure 8 - Sound signal recorded after 16:01:00 discharge.

16:02:00

Possible airgun sound signal detected (Figure 9). Not able to detect any behavioral changes in fish (Appendix 1 – Skotungneset 16.June 2009 - Snapshot sequence 3).

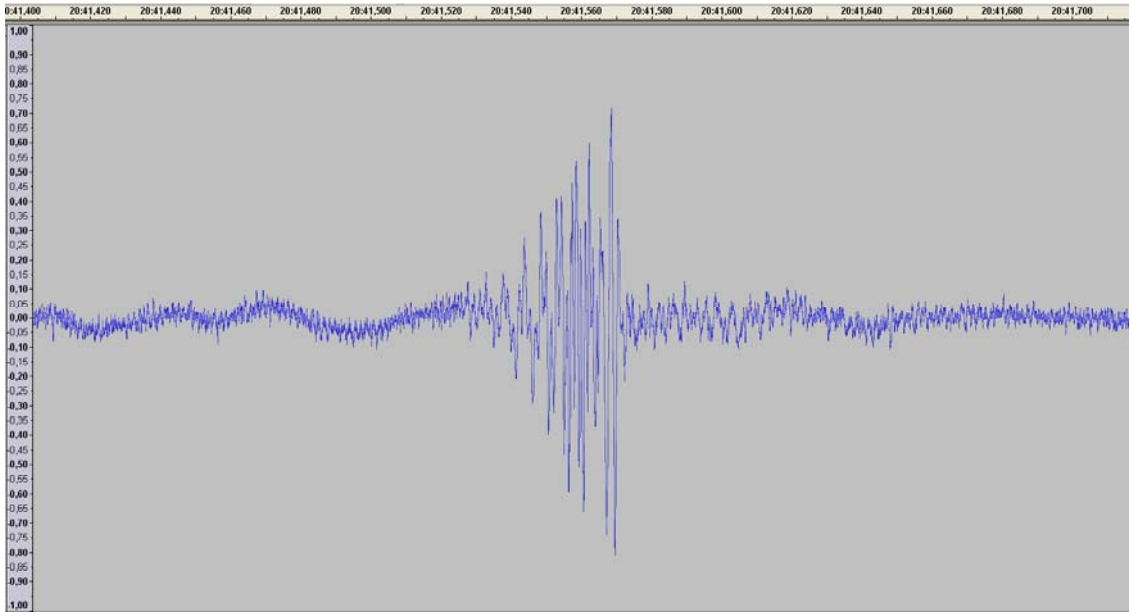

Figure 9 - Sound signal recorded after 16:02:00 discharge.

24. June 2009

Fish monitored at Skotungneset by Møreforsking during testing. Barge with seismic source located behind Gravaneset and not in direct view of fish farm. Sound recorded with standard hydrophone and calibrated reference hydrophone. Times of airgun discharges are shown in Table 2. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 10.

Table 2 - Signal log 24.June showing time of discharges

Time	No. of shots	Gun-type	Volume	Pressure	Depth
18:15 – 18:25	25	G-Gun	250 Cu.in.	1000 psi	5 meter
18:25 – 18:35	25	G-Gun	250 Cu.in.	1500 psi	5 meter

18:15 – 18:25 sequence

Sound signal detected right after start of 18:15-18:25 sequence but uncertain if airgun are the source (Figure 11). In general it was difficult to identify the airgun signals due to noise from rough weather and wind. Not able to detect any behavioral changes in fish during period of testing (Appendix 1 - Skotungneset 24.June 2009 - Snapshot sequence 1). Sound level recorded with reference hydrophone during shooting sequence is presented in Appendix 2 – Skotungneset 24.June - Airgun sequence 1 (18:15 – 18:25).

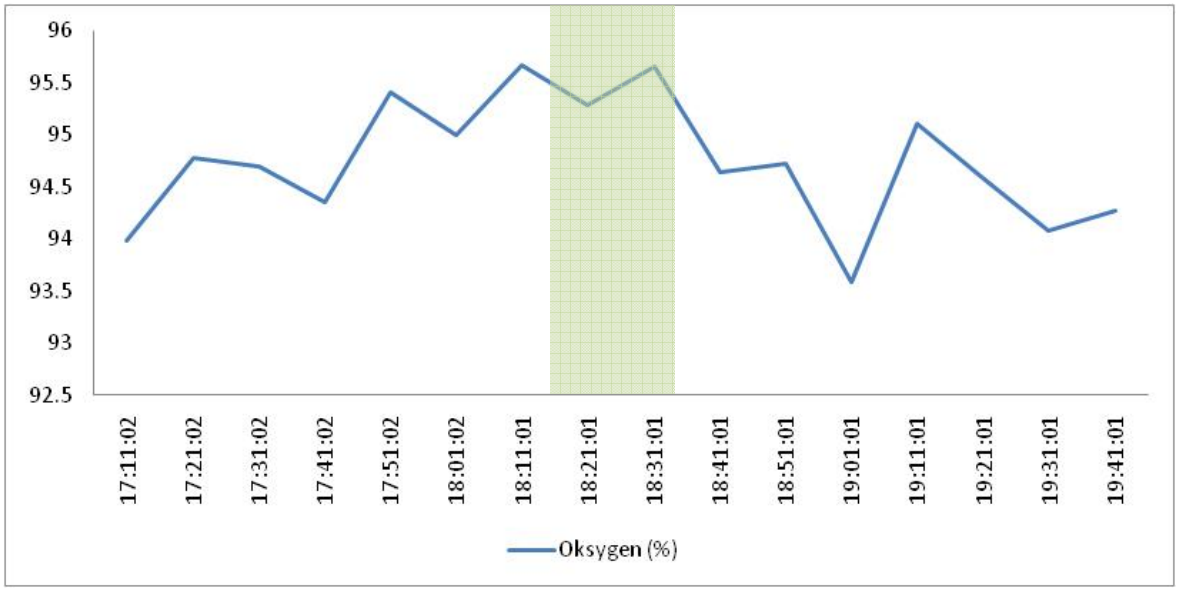

Figure 10 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. NW water current direction (304-307°), water exiting fish cages away from measurement area.

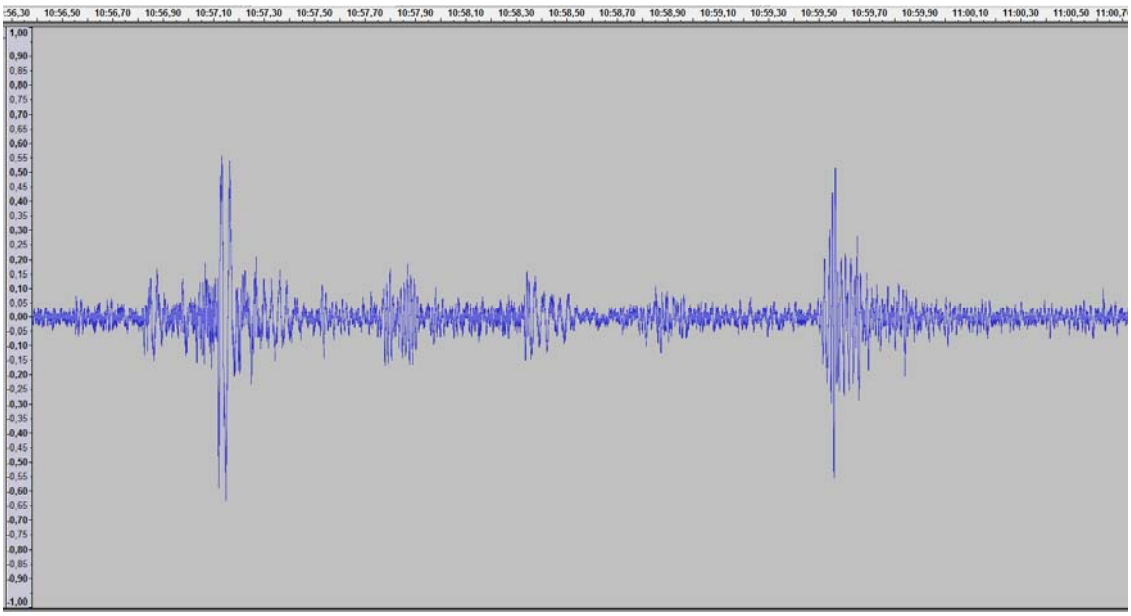

Figure 11 - Sound signals recorded after start of 18:15 – 18:25 shooting sequence 24. June.

18:25 – 18:35 sequence

Not able to identify signals caused by airgun. Not able to detect any behavioral changes in fish during period of testing. Sound level recorded with reference hydrophone during shooting sequence is presented in Appendix 2 - Skotungneset 24.June - Airgun sequence 2 (18:25 – 18:35)

25. June 2009

Fish monitored at Skotungneset by Møreforsking during testing. Sound recorded with standard hydrophone and calibrated reference hydrophone. Times of discharges are shown in Table 3. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 12.

Table 3 - Signal log 25.June showing time of discharges

Time	No. Of shots	Gun-type	Volume	Pressure	Depth
13:30 – 13:37	5	G-Gun	250 Cu.in.	2000 psi	5 meters
14:58 – 15:05	6	G-Gun	250 Cu.in.	2000 psi	5 meters
15:53 – 15:57	10	G-Gun	250 Cu.in.	2000 psi	5 meters
16:01 – 16:05	10	G-Gun	250 Cu.in.	1750 psi	5 meters
16:07 – 16:17	23	G-Gun	250 Cu.in.	1500-500 psi	5 meters
17:20 – 17:38	24	G-Gun	250 Cu.in.	500 psi	5 meters

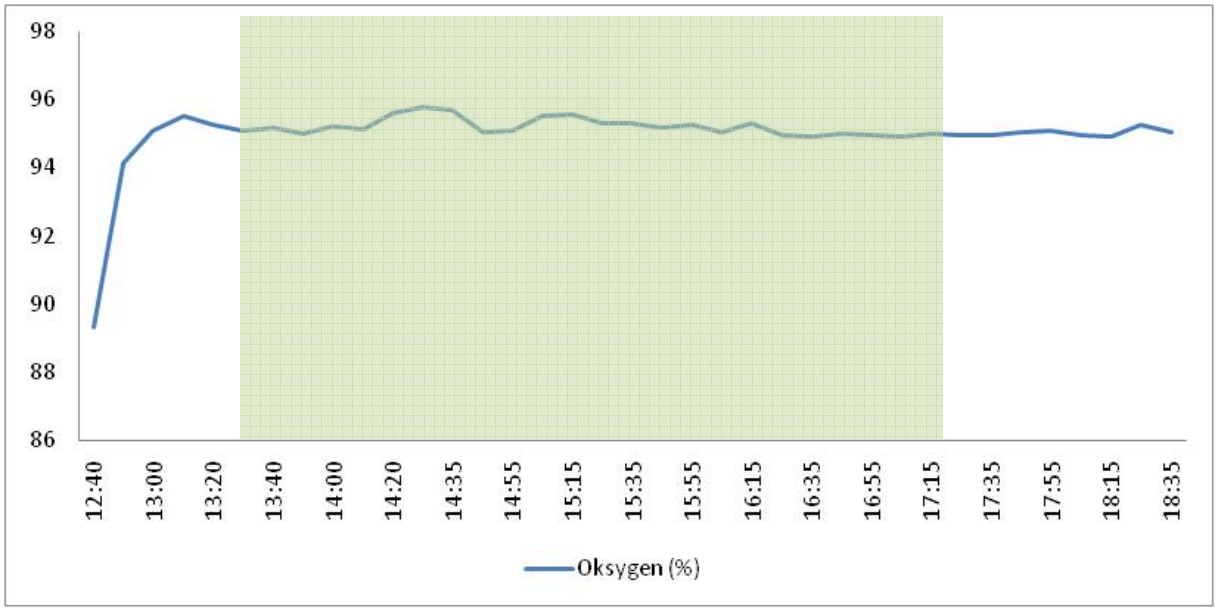

Figure 12 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. N water current direction (0-1°), water exiting fish cages away from measurement area.

13:30 – 13:37 sequence

Possible airgun sound signal detected during sequence (Figure 9). Not able to detect any behavioral changes in fish (Appendix 1 - Skotungneset 25.June 2009 - Snapshot sequence 1). Sound level recorded with reference hydrophone during shooting sequence is presented in Appendix 2 - Skotungneset 25.June - Airgun sequence 1 (13:30 – 13:37).

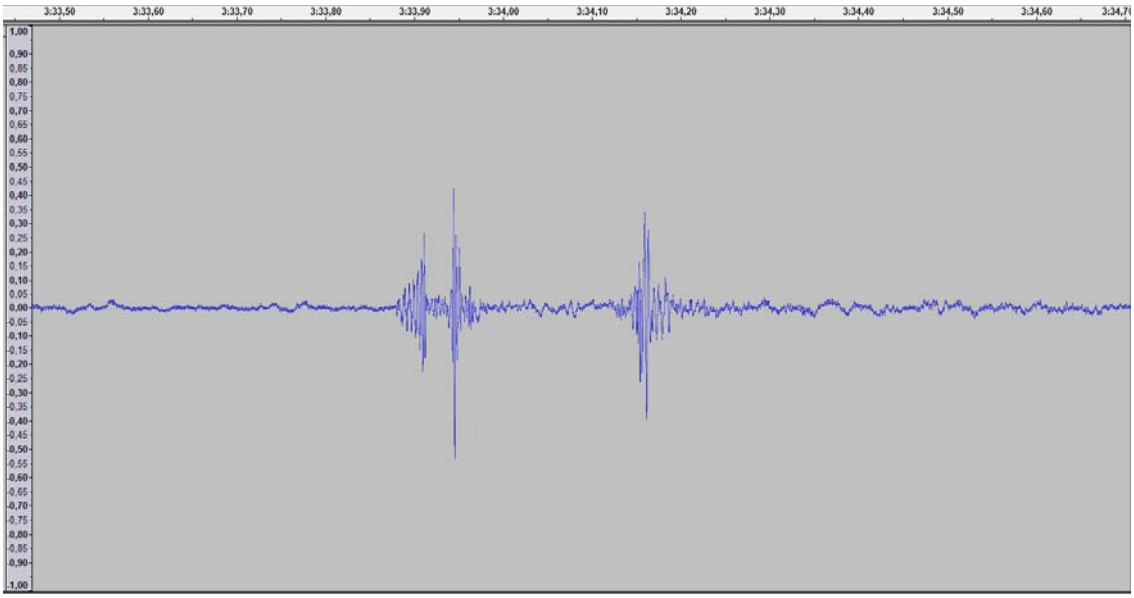

Figure 13 - Sound signals recorded just after start of 13:30 – 13:07 shooting sequence 25. June.

14:58 – 15:05 sequence

Airgun sound signals detected during sequence (Figure 14). Not able to detect any behavioral changes in fish (Appendix 1 – Skotungneset 25.June 2009 - Snapshot sequence 2). Sound level recorded with reference hydrophone during shooting sequence is presented in Appendix 2 – Skotungneset 25.June - Airgun sequence 2 (14:58 – 15:05).

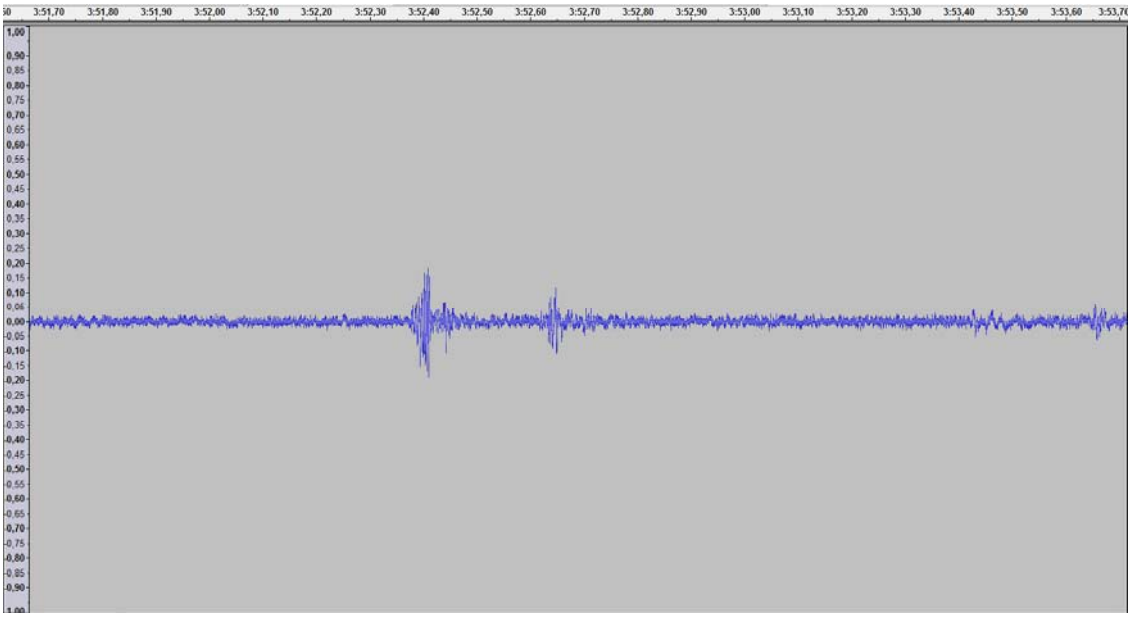

Figure 14 - Sound signals recorded just after start of 14:58 – 15:05 shooting sequence 25. June.

15:53 – 15:57, 16:01 – 16:05, 16:07 – 16:17 and 17:20 – 17:38 sequences

Similar or lower airgun output strength from source as previous sequences. No behavioural changes in the fish were observed during any of the sequences.

29. September 2009

Fish monitored at Skotungneset by Møreforsking during testing. Sound recorded with standard hydrophone and calibrated reference hydrophone. Times of discharges are shown in Table 4. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 15.

Table 4 - Signal log 29.September showing time of discharges

Time	No. Of shots	Gun-type	Volume	Pressure	Depth
15:07 – 15:17	20	G-Gun	250 Cu.in.	2000 psi	5 meters
15:31 – 15:41	20	G-Gun	250 Cu.in.	2000 psi	5 meters

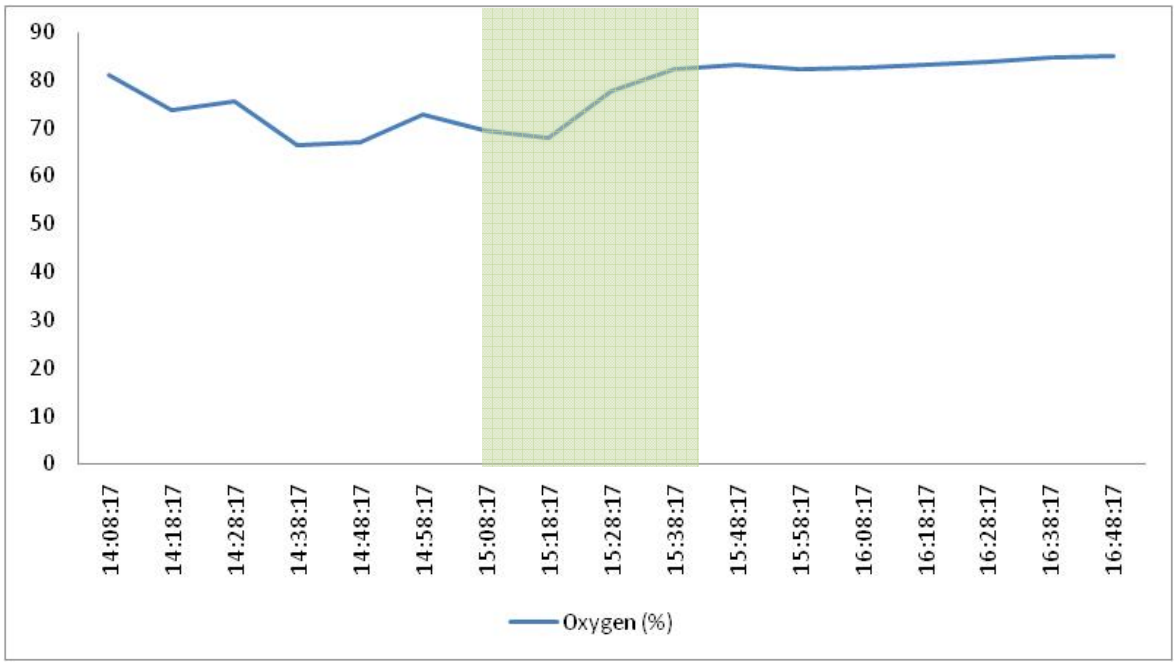

Figure 15 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. W-SW water current direction (238-247°), water exiting fish cages into measurement area.

15:07 – 15:17 sequence

Airgun sound signals detected during sequence (Figure 16). Not able to detect any behavioral changes in fish (Appendix 1 – Skotungneset 29.September 2009 - Snapshot sequence 1). Sound level recorded with reference hydrophone during shooting sequence is presented in Appendix 2 - Skotungneset 29.September - Airgun sequence 1 (15:07 – 15:17).

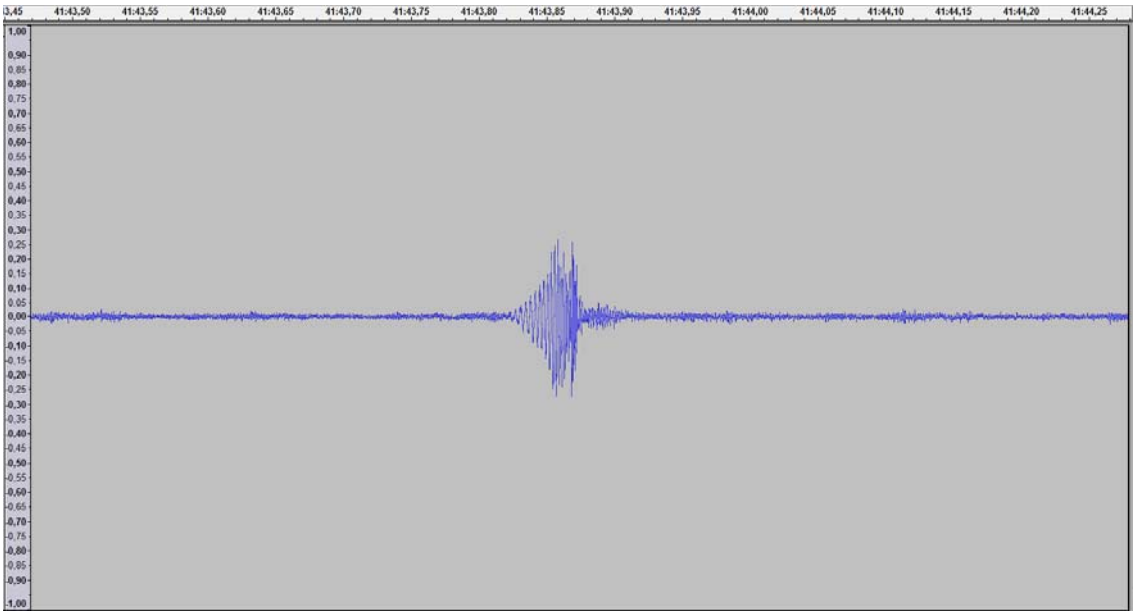

Figure 16 - Signal recorded just after start of 15:07 – 15:17 shooting sequence 29. September.

15:31 – 15:41 sequence

Same airgun output strength from source as previous sequence. No behavioural changes in the fish were observed during sequence.

30. September 2009

Fish monitored at Skotungneset by Møreforsking during testing. Sound recorded with standard hydrophone and calibrated reference hydrophone. Times of discharges are shown in Table 5. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 17.

Table 5 - Signal log 30.September showing time of discharges

Time	No. Of shots	Gun-type	Volume	Pressure	Depth
13:43 – 13:53	20	G-Gun	250 Cu.in.	2000 psi	5 meters
15:10 – 15:20	20	G-Gun	250 Cu.in.	2000 psi	5 meters
15:45 – 15:47	3	G-Gun	250 Cu.in.	2000 psi	5 meters

13:43 – 13:53 sequence

Airgun sound signals detected during sequence (Figure 18 and Figure 19). Not able to detect any behavioral changes in fish (Appendix 1 – Skotungneset 30.September 2009 - Snapshot sequence 1 and Appendix 1 – Skotungneset 30.September 2009 - Snapshot sequence 2). Sound level recorded with reference hydrophone during shooting sequence is presented in Appendix 2 - Skotungneset 30.September - Airgun sequence 1 (13:43 – 13:53).

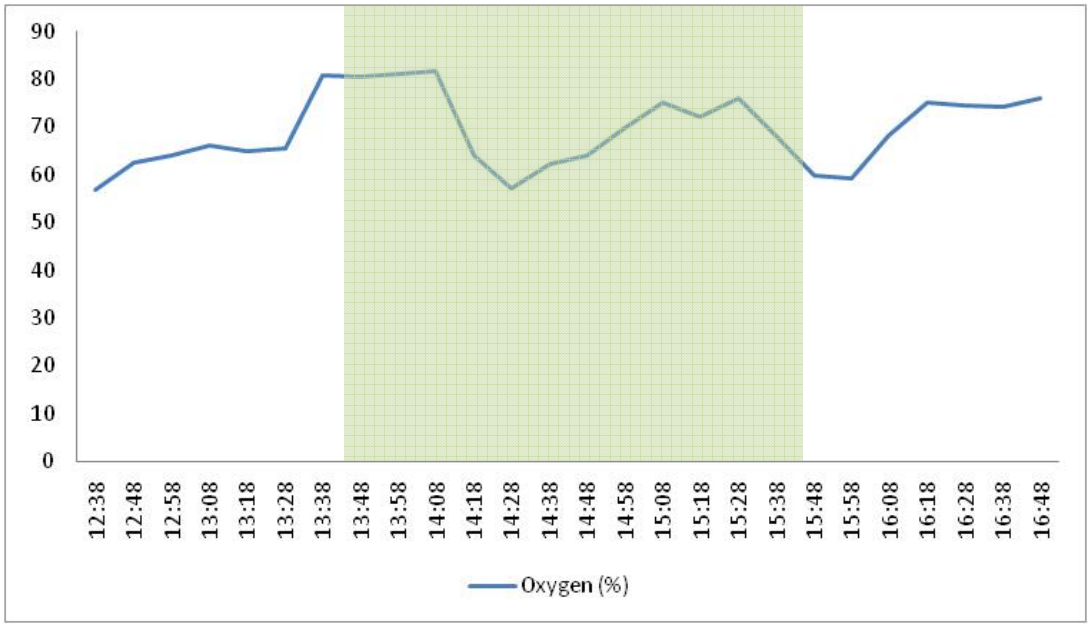

Figure 17 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. WSW-SSW water current direction (199-250°), water exiting fish cages into measurement area.

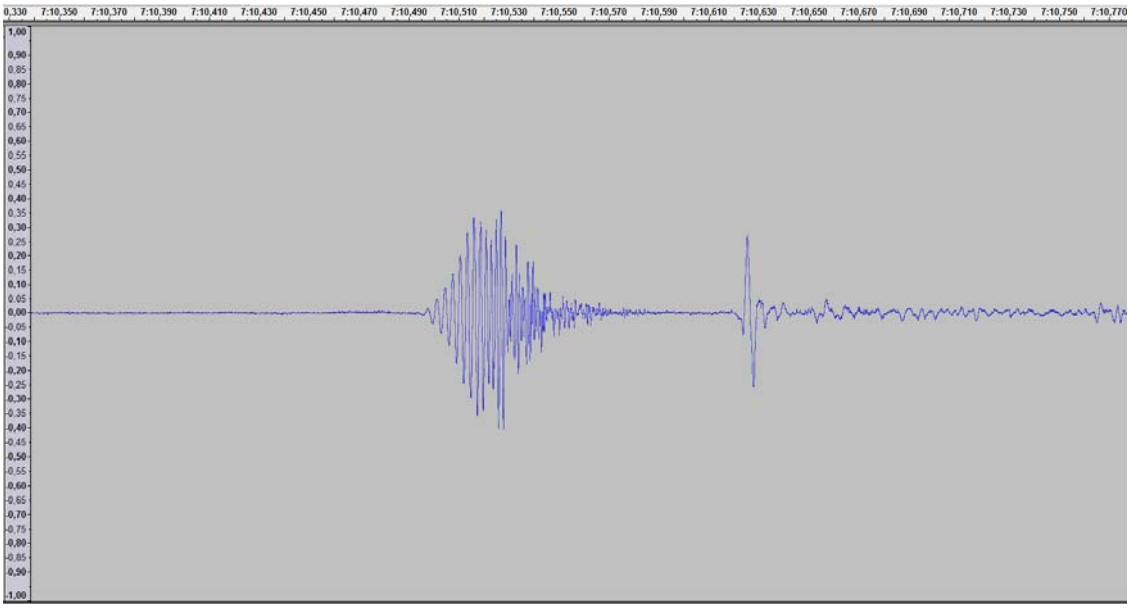

Figure 18 - Signal recorded after start of 13:43 – 13:53 shooting sequence 30. September

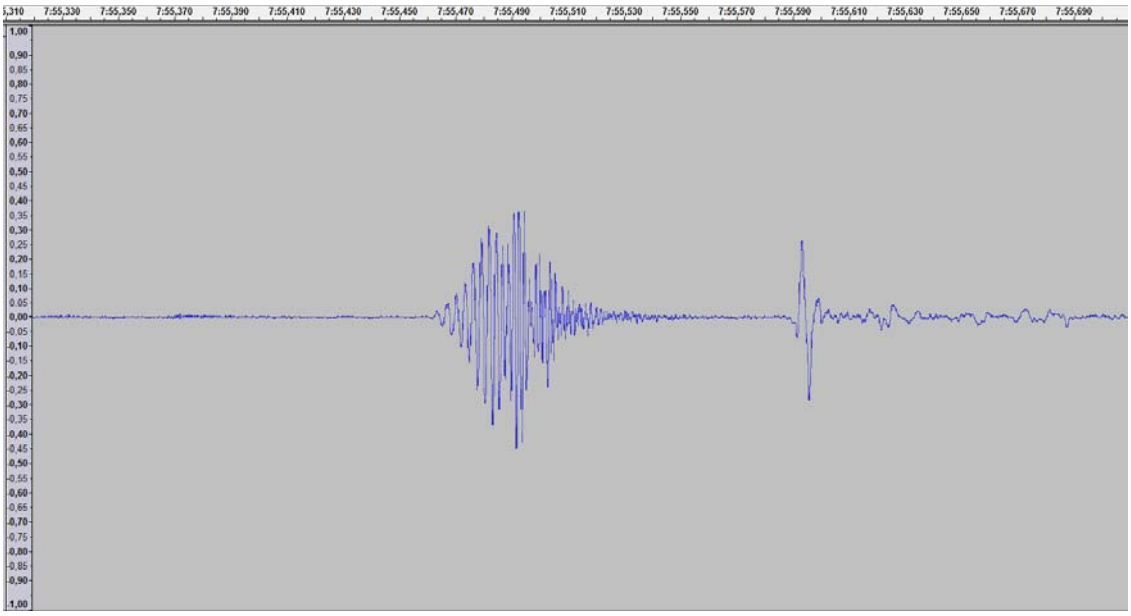

Figure 19 - Signal recorded after start of 15:07 – 15:17 shooting sequence 30. September

1. October 2009

Fish monitored at Skotungneset by Møreforsking during testing. Sound recorded with standard hydrophone and calibrated reference hydrophone. Times of discharges are shown in Table 6. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 20.

Table 6 - Signal log 1.October showing time of discharges

Time	No. Of shots	Gun-type	Volume	Pressure	Depth
11:00 – 11:05	3	G-Gun	250 Cu.in.	2000 psi	6 meters
11:20 – 11:34	37	G-Gun	250 Cu.in.	2000 psi	6 meters
11:45 – 12:23	44	G-Gun	250 Cu.in.	2000 psi	6 meters
12:25 – 12:28	3	G-Gun	250 Cu.in.	2000 psi	6 meters
14:06 – 14:45	44	G-Gun	250 Cu.in.	2000 psi	12 meters
14:51 – 15:30	44	G-Gun	250 Cu.in.	2000 psi	20 meters
15:55 – 16:32	44	G-Gun	250 Cu.in.	2000 psi	20 meters

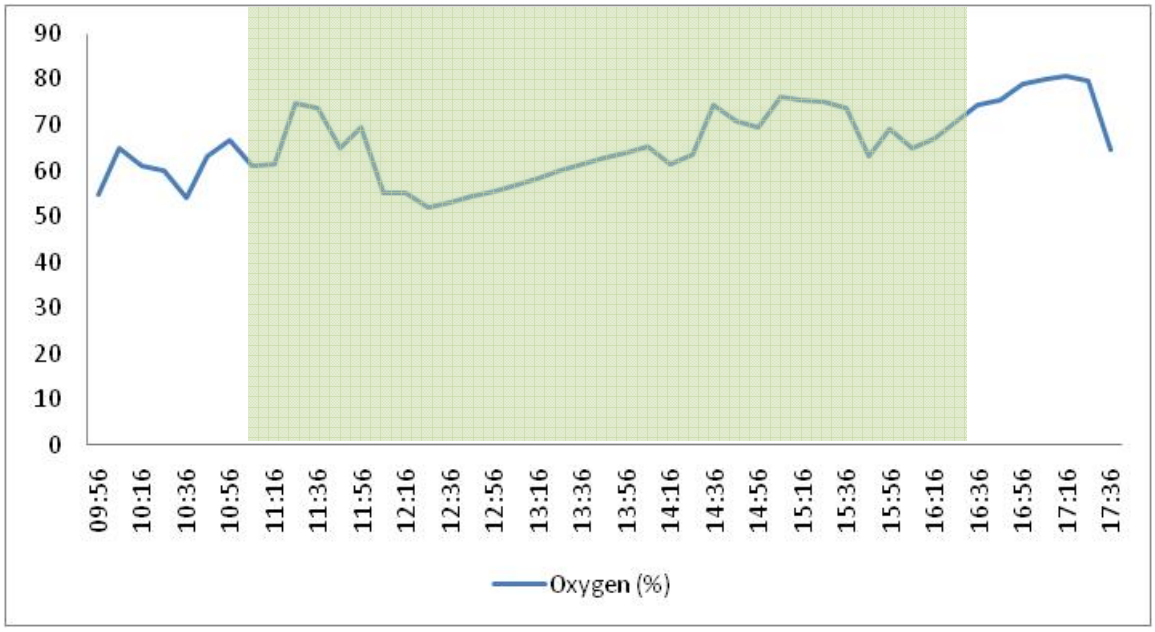

Figure 20 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. WSW-SSW water current direction (207-247°), water exiting fish cages into measurement area.

11: 00 – 11:05, 11:20 – 11:34, 11:45 – 12:23 and 12:25 – 12:28 sequences

Due to technical problems during monitoring no audio recordings were made during these sequences. However, no behavioral changes could be observed in the fish during monitoring.

14:06 – 14:45 and 14:51 – 15:30 sequences

Airgun sound signals detected during both sequences (Figure 21 and Figure 22). Not able to detect any behavioral changes in fish (Appendix 1 – Skotungneset 1.October 2009 - Snapshot sequence 1). Extract of sound level recorded with reference hydrophone during shooting sequence is presented in Appendix 2 - Skotungneset 1.October – Airgun sequence 5 (Extract) (14:06 – 14:45).

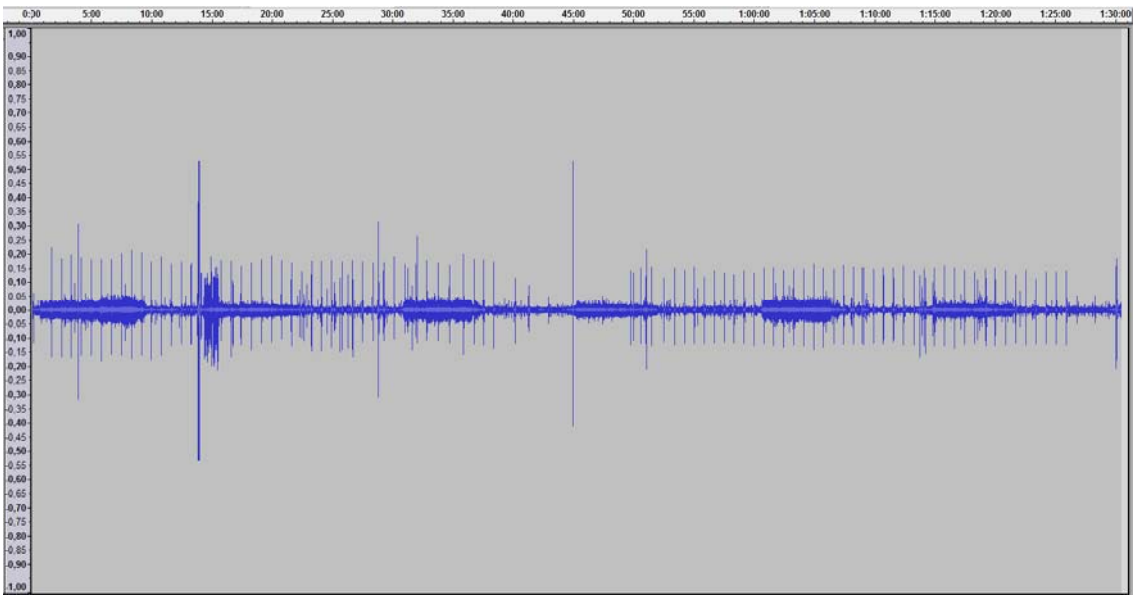

Figure 21 - Signals recorded during 14:06 – 14:45 and 14:51 – 15:30 sequences.

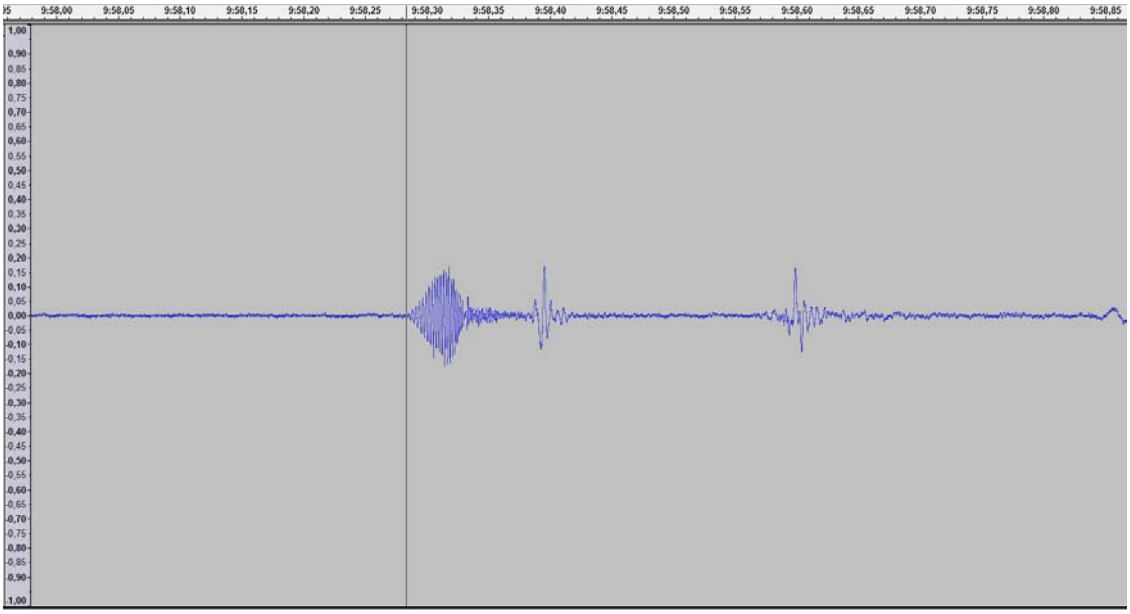

Figure 22 - Isolated signal from 14:06 – 14:45 sequence.

15:55 – 16:32 sequence

Same airgun output strength from source as during previous sequences. No behavioral changes in the fish were observed during sequence.

Overåneset

29. September 2009

Fish monitored at Overåneset by Møreforsking during testing. Sound recorded with standard hydrophone. Calibrated reference hydrophone not used as it was occupied at simultaneous monitoring at Skotungneset (See section 0). Times of discharges are shown in Table 7. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 23.

Table 7 – Signal log 29.September showing time of discharges

Time	No. Of shots	Gun-type	Volume	Pressure	Depth
15:07 – 15:17	20	G-Gun	250 Cu.in.	2000 psi	5 meters
15:31 – 15:41	20	G-Gun	250 Cu.in.	2000 psi	5 meters

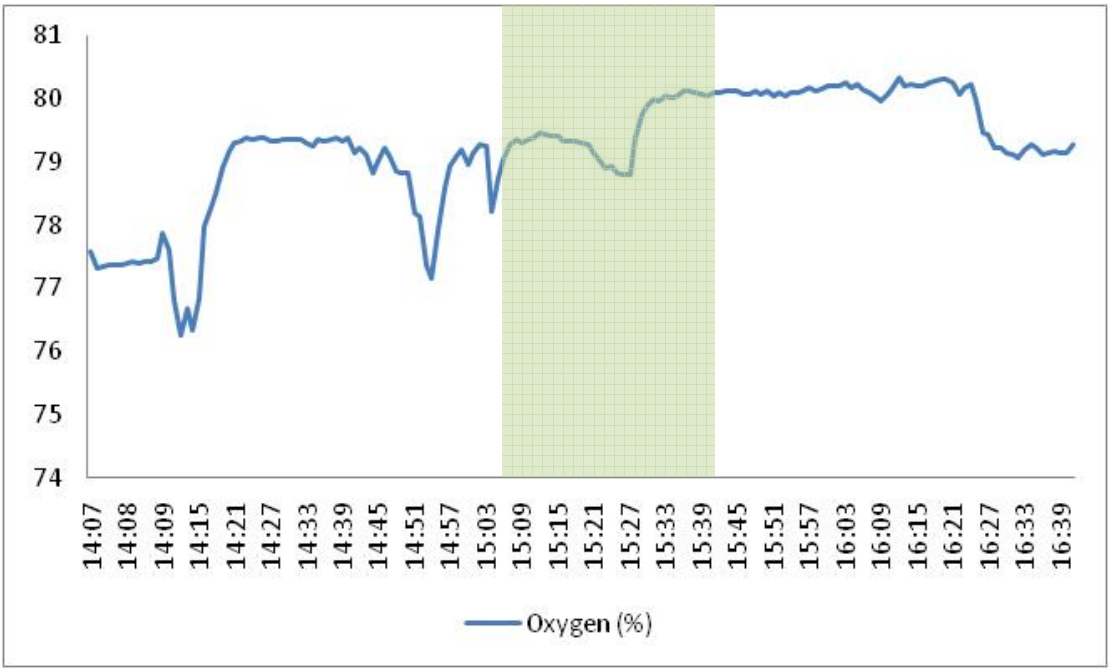

Figure 23 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. E-SE water current direction (98-124°), water exiting fish cages away from measurement area.

15:07 – 15:17 sequence

Airgun sound signals were detected during shooting sequence (Figure 24). During sequence the fish were aggregated around area of feeding and it was not possible to make any good snapshot sequences in relation to a given airgun signal. However no behavioral changes could be observed in fish by the observer.

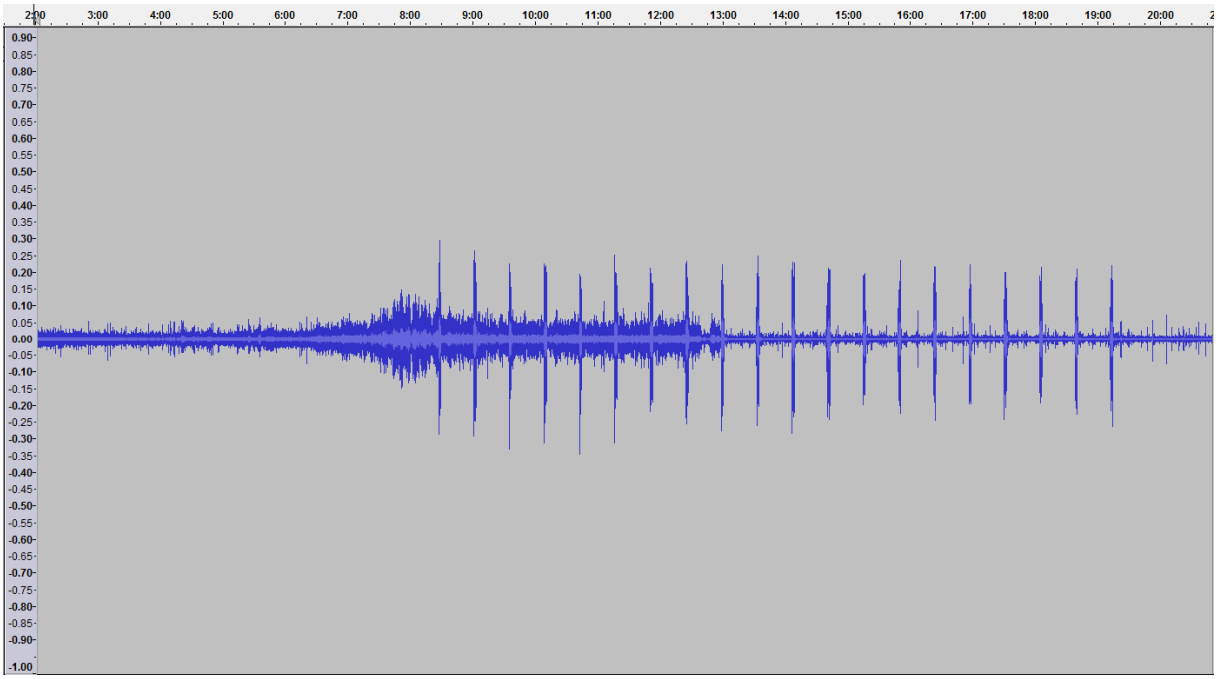

Figure 24 - Signals recorded during 15:07 – 15:17 sequence.

15:31 – 15:41 sequence

Same airgun output strength from source as previous sequence. No behavioral changes in the fish were observed during sequence.

2. October 2009

Fish monitored at Overåneset by Møreforsking during testing. Sound recorded with standard hydrophone and calibrated reference hydrophone. Times of discharges are shown in Table 8. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 25. Barge with seismic source located behind Overåneset and not in direct view of fish farm.

Table 8 - Signal log 2.October showing time of discharges

Time	No. Of shots	Gun-type	Volume	Pressure	Depth
14:52 – ? (calibration)	3	G-Gun	250 Cu.in.	1000 psi	4 meters
14:55 – 15:18	44	G-Gun	250 Cu.in.	1000 psi	25 meters
15:38 – 15:56	44	G-Gun	250 Cu.in.	500 psi	25 meters
16:00 – 16:27	44	G-Gun	250 Cu.in.	500 psi	3 meters
16:33 – 16:52	44	G-Gun	250 Cu.in.	1000 psi	3 meters
17:02 – 17:40	44	G-Gun	250 Cu.in.	2000 psi	3 meters

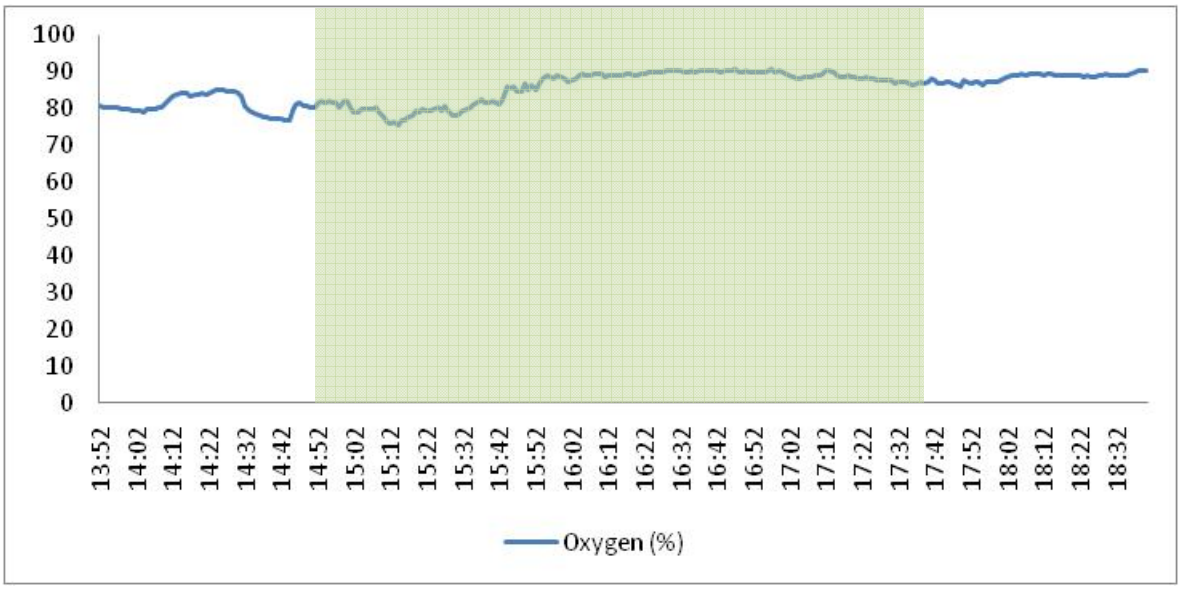

Figure 25 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. E-ESE water current direction (108-132°), water exiting fish cages away from measurement area.

14:52 – (Calibration)

Not able to isolate sound from airgun. No behavioral changes in fish observed.

14:55 – 15:18 sequence

Airgun sound signals detected during sequence (Figure 26). Not able to detect any behavioral changes in fish (Appendix 1 – Overåneset 2.October 2009 - Snapshot sequence 1)

Extract of sound level recorded with reference hydrophone during shooting sequence 14:55 – 14:18 is presented in Appendix 2 - Overåneset 2.October – Airgun sequence 2 (Extract) (14:55 – 15:18).

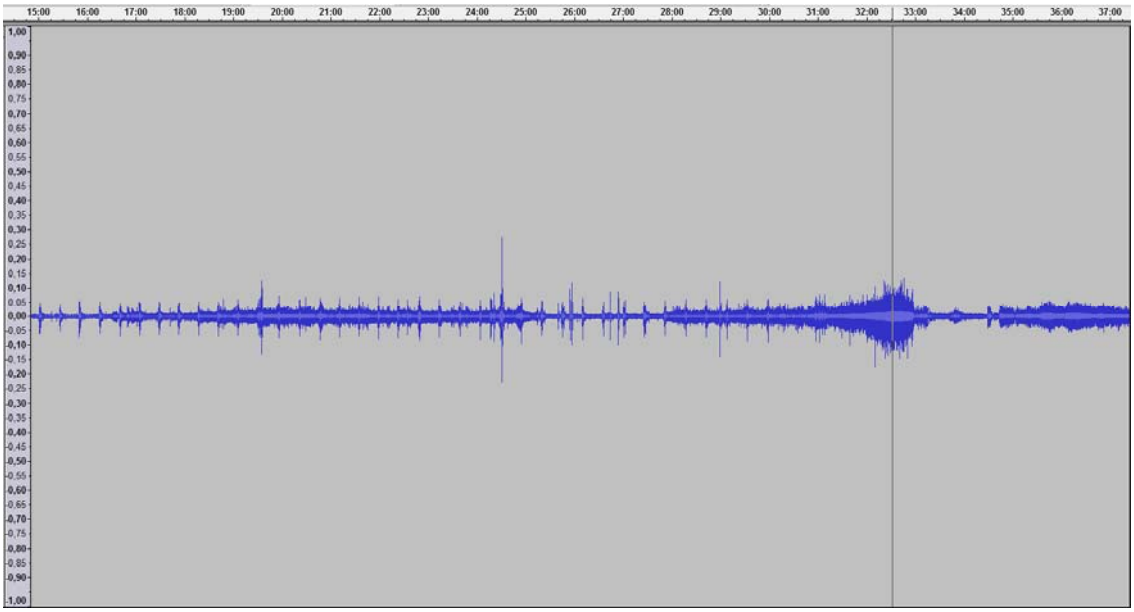

Figure 26 - Signals recorded during 14:55 – 15:18 sequence. Airgun signals are shown as sharp peaks. Smoother blue areas are sound from the ferry crossing the fjord between Stranda and Liabygda.

15:38 – 15:56, 16:00 – 16:27, 16:33 – 16-52 and 17:02 – 17:40 sequences

No behavioral changes observed in the fish.

20. October 2009

Fish monitored at Overåneset by Møreforsking during testing. Sound recorded with standard hydrophone. No reference hydrophone where used due to technical problems. Times of discharges are shown in Table 9. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 27.

Table 9 - Signal log 20.October showing time of discharges

Time	No. Of shots	Gun-type	Volume	Pressure	Depth
10:50 – 11:25	44	G-Gun	250 Cu.in.	2650 psi	5 meters
12:20 – 12:45	25	G-Gun	250 Cu.in.	2650 psi	5 meters
13:55 – 14:25	44	G-Gun	250 Cu.in.	1000 psi	2 meters
15:31 – 16:08	44	G-Gun	250 Cu.in.	1200 psi	2 meters
16:15 – 16:51	44	G-Gun	250 Cu.in.	1400 psi	2 meters
16:55 – 17:31	44	G-Gun	250 Cu.in.	1600 psi	2 meters

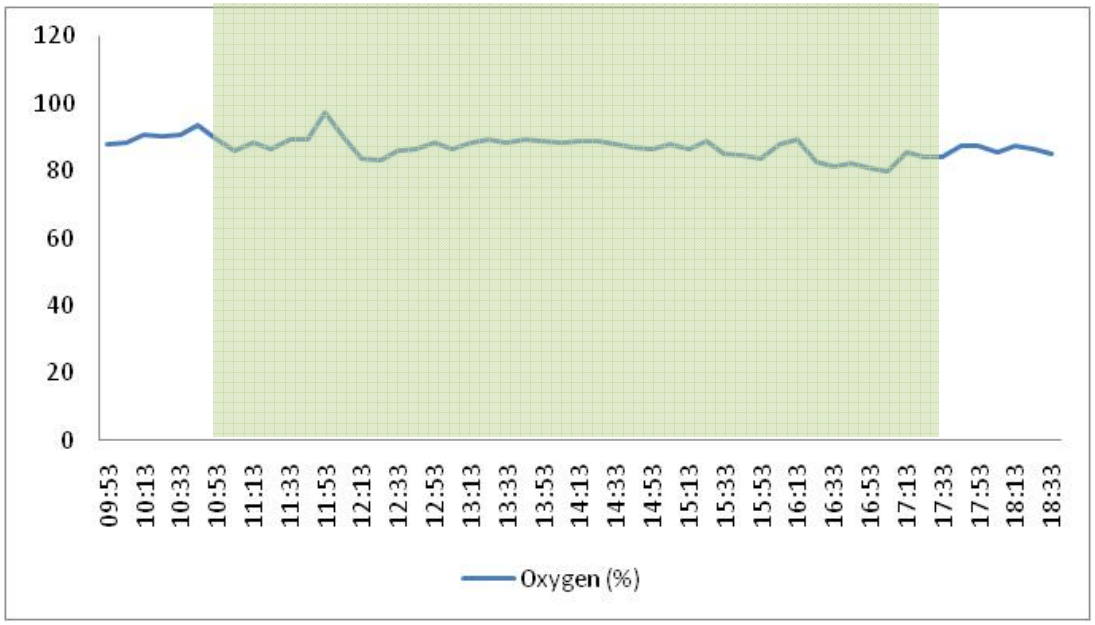

Figure 27 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. Varying current direction (E-W) (91-263°), water exiting fish cages in different directions.

10:50 – 11:25 and 12:20 – 12:45 sequence

Barge with seismic source went in and out of view behind Gravaneset. Weak airgun sound signals detected during both sequences (Figure 28 and Figure 29). Not able to detect any behavioral changes in fish either when barge was in view from fish farm (Appendix 1 –Overåneset 20.October 2009 - Snapshot sequence 1) or when barge was located out of view from fish farm (Appendix 1 – Overåneset 20.October 2009 - Snapshot sequence 2). Extract of sound level recorded with reference hydrophone during shooting sequence 10:50 – 11:25 is presented in Appendix 2 - Overåneset 20.October - Airgun sequence 1 (Extract) (10:50 – 11:25). Discharges cannot be identified from sound level measurements and could possibly be caused by electrical interference.

Figure 28 - Signals recorded during 10:50 – 11:25 sequence.

Figure 29 - Signals recorded during 12:20 – 12:45 sequence.

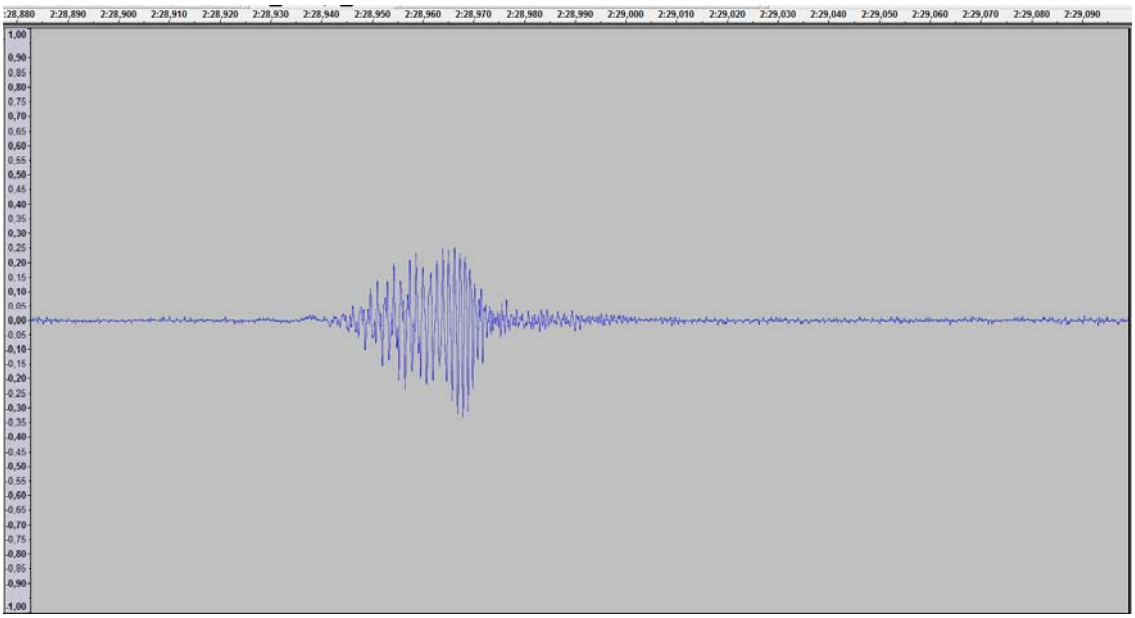

Figure 30 – Isolated sound signal from 10:50 – 11:25 sequence. Barge was in view from fish farm.

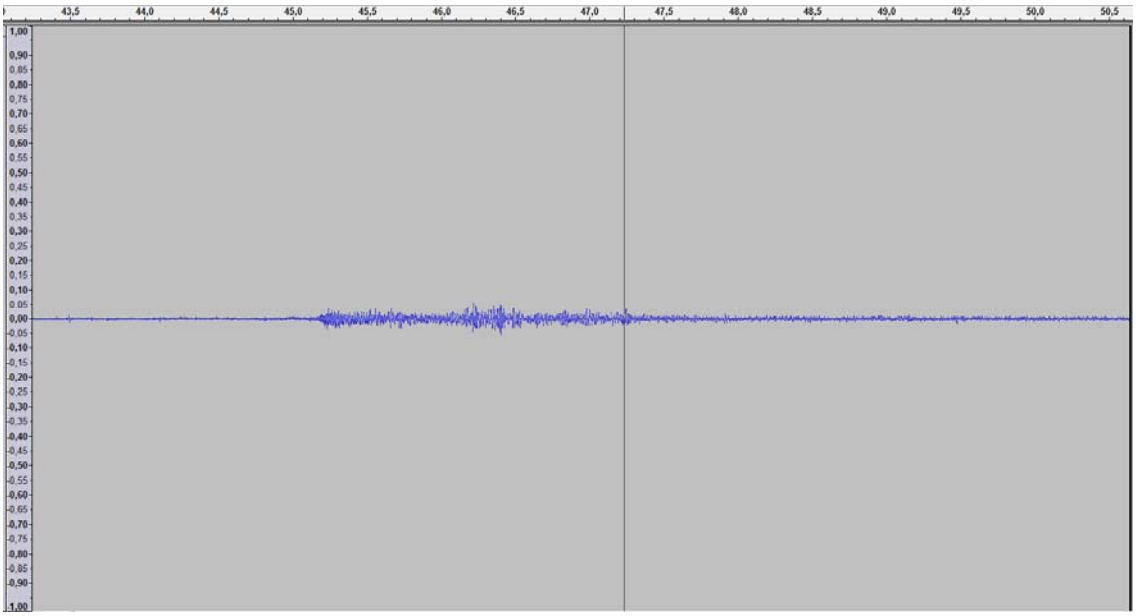

Figure 31 - Isolated sound signal from 12:20 – 12:45 sequence. Barge was located behind Gravaneset and not in view from fish farm.

13:55 – 14:25, 15:31 – 16:08, 16:15 – 16:51 and 16:55 – 17:31 sequences

Lower airgun output strength from source then previous sequences. No behavioral changes in the fish were observed during any of the sequences.

16. February 2010

Fish monitored at Overåneset by Møreforsking during testing. Sound recorded with standard hydrophone and calibrated reference hydrophone. Times of discharges are shown in Table 10. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 32.

Table 10 - Signal log 16.Ferbruary 2010 showing time of discharges

Time	No. Of shots	Gun-type	Volume	Pressure	Depth
13:07 – ? (Calibration)	3	G-Gun	150 Cu.in.	2500 psi	8 meters
13:11 – 13:35	30	G-Gun	150 Cu.in.	2500 psi	8 meters
13:59 – 14:23	30	G-Gun	150 Cu.in.	2500 psi	25 meters
15:04 – 15:28	30	G-Gun	150 Cu.in.	2500 psi	3 meters
16:17 – 16:41	30	G-Gun	150 Cu.in.	2500 psi	6 meters

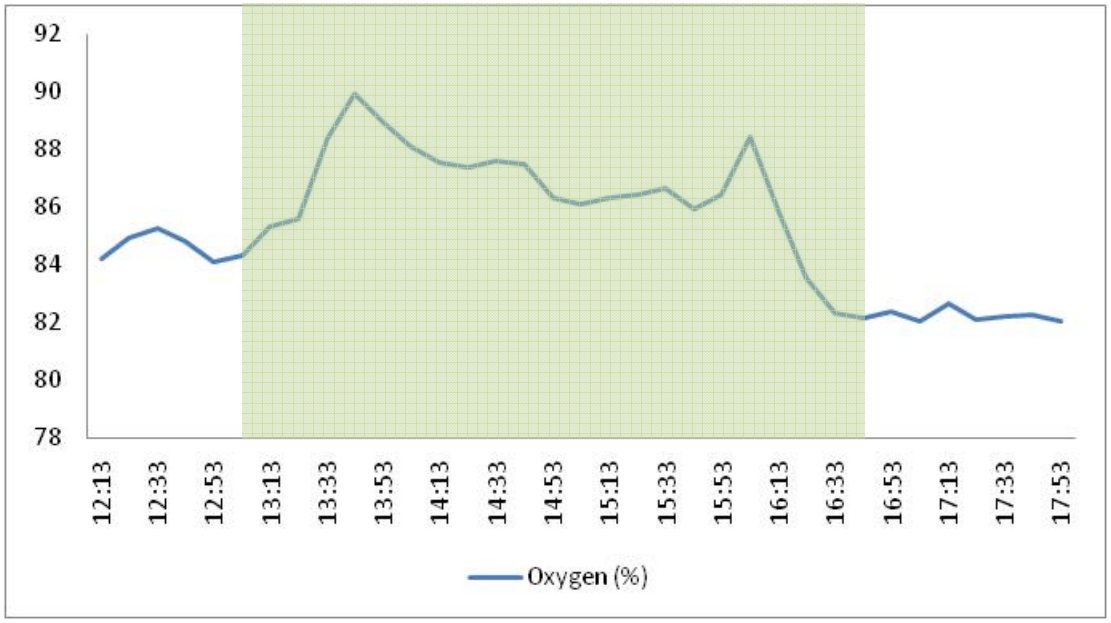

Figure 32 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. Direction of water current not available due to technical problems.

13:07 - ? (Calibration)

Same airgun output strength from source as following sequences. Look next section for observations. No behavioral changes in the fish were observed during sequence.

13:11 – 13:35 and 13:59 – 14:23 sequences

Airgun sound signals detected during both sequences (Figure 33 and Figure 34). Not able to detect any behavioral changes in fish during any of shooting sequences (Appendix 1 – Overåneset 16.February 2010 - Snapshot sequence 1 and Overåneset 16.February 2010 - Snapshot sequence 2). Extract of sound level recorded with reference hydrophone during shooting sequence 13:11 – 13:35 is presented in Appendix 2 -Overåneset 16.February 2010 - Airgun sequence 2 (Extract) (13:11 – 13:35).

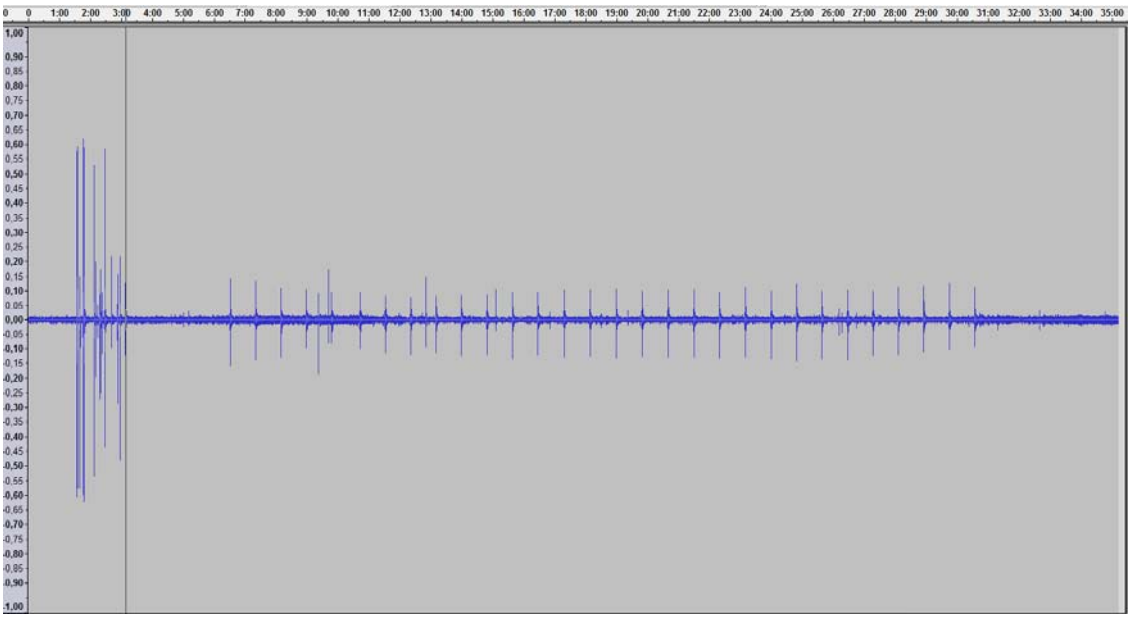

Figure 33 - Signals recorded during 13:11 – 13:35 sequence.

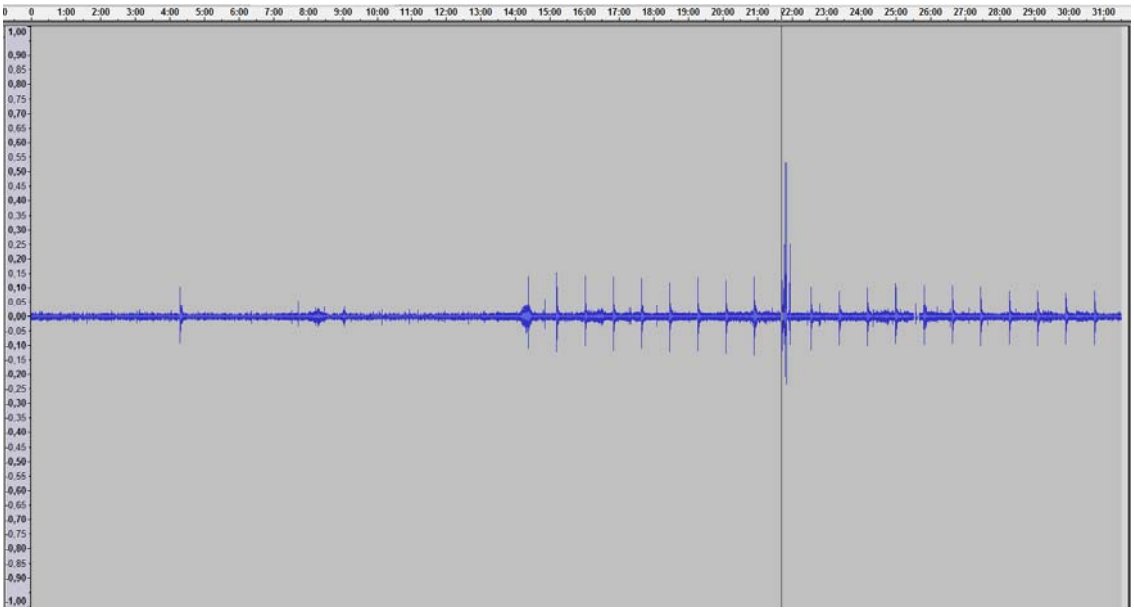

Figure 34 - Signals recorded during 13:59 – 14:23 sequence.

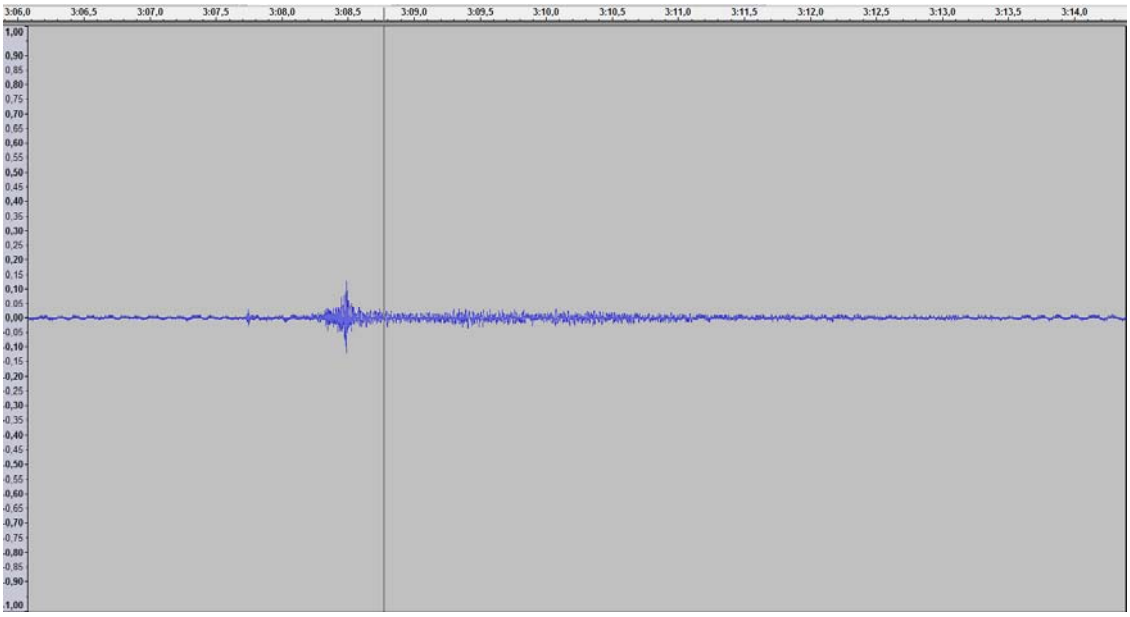

Figure 35 - Isolated sound signal from 13:11 – 13:35 sequence. Related images of fish in Snapshot sequence 14 in Appendix 1.

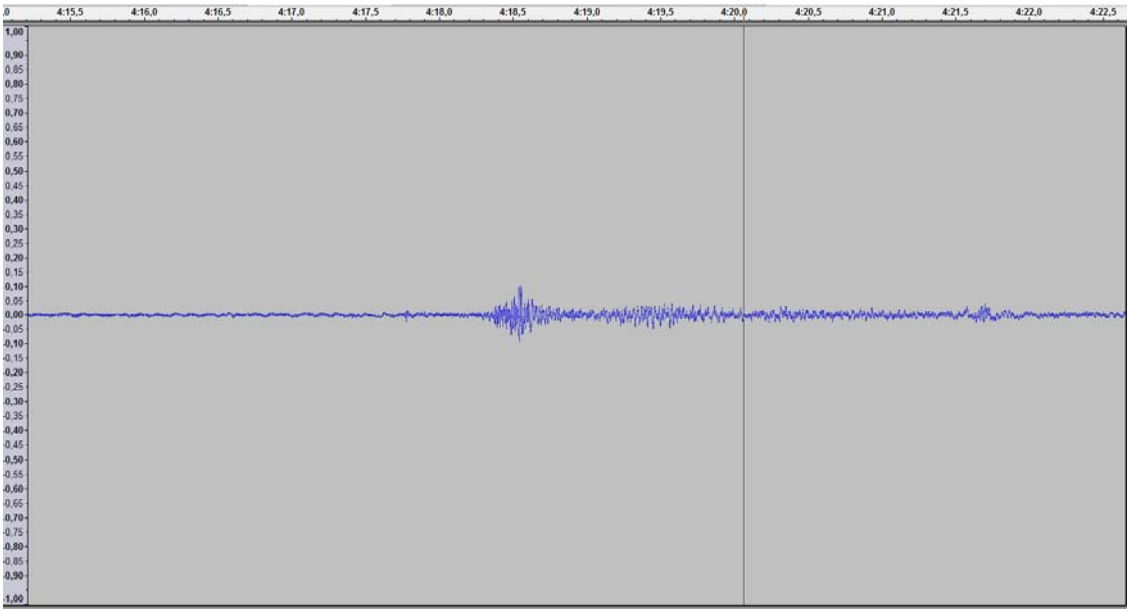

Figure 36 - Isolated sound signal from 13:59 – 14:23 sequence. Related images of fish in Snapshot sequence 15 in Appendix 1.

15:04 – 15:28 and 16:17 – 16:41 sequences

Same airgun output strength from source as previous sequences. No behavioral changes in the fish were observed.

10. March 2010

Fish monitored at Overåneset by Møreforsking during testing. Sound recorded with standard hydrophone and calibrated reference hydrophone. Times of discharges are shown in Table 11. Measured oxygen concentration in proximity of fish cage before, during and after testing is presented in Figure 37.

Table 11 - Signal log 10.March showing time of discharges

Time	No. Of shots	Gun-type	Volume	Pressure	Depth
11:50 – 12:10	30	G-Gun	2 X 250 Cu.in.	2000 psi	6 meters

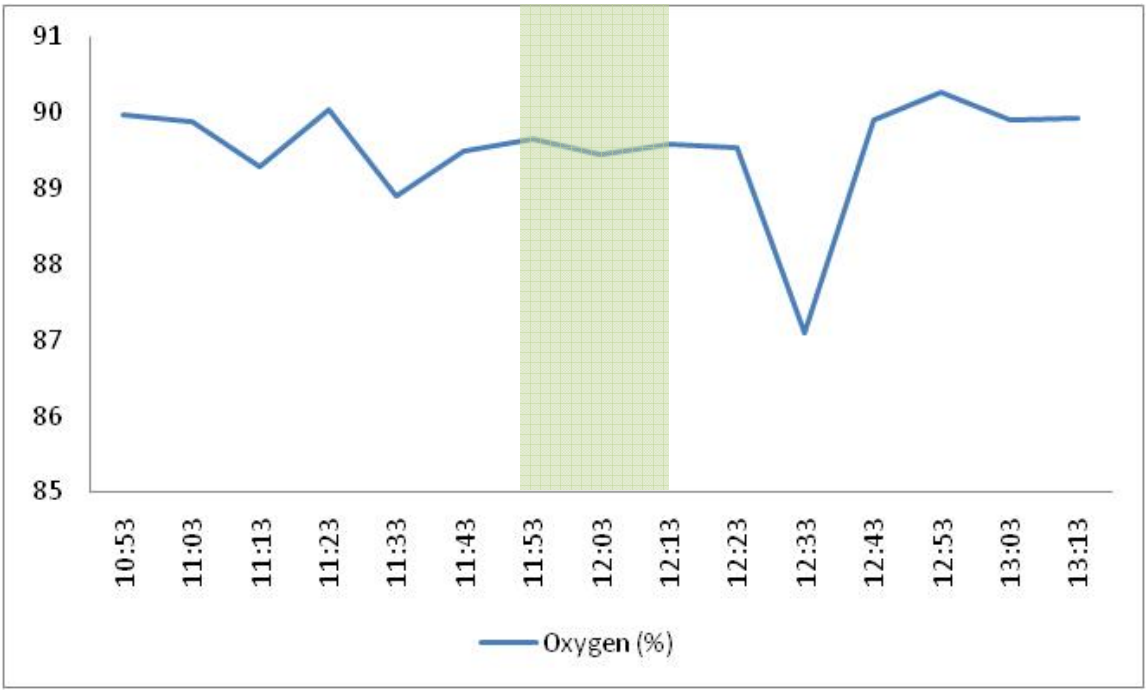

Figure 37 - Oxygen level measured in proximity of fish cage before, during and after testing. Green area shows period of testing. Direction of water current not available due to technical problems.

11:50 – 12:10 sequence

Airgun sound signals detected during sequence (Figure 38). Not able to detect any behavioral changes in fish (Appendix 1 – Overåneset 10.March 2010 - Snapshot sequence 1 and Overåneset 10.March 2010 - Snapshot sequence 2). Extract of sound level recorded with reference hydrophone during shooting sequence 10:50 – 11:25 is presented in Appendix 2 - Overåneset 10.March 2010 - Airgun sequence 1 (Extract) (11:50 – 12:10).

Figure 38 - Signals recorded during 13:59 – 14:23 sequence

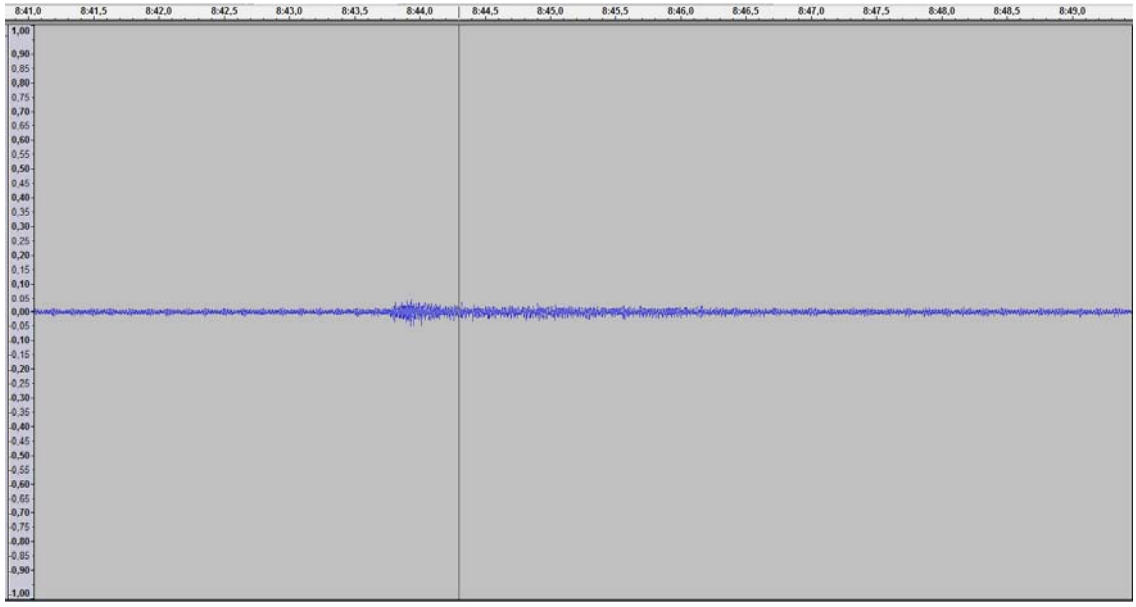

Figure 39 - Isolated sound signal from 11:50 – 12:10 sequence. Related images of fish in Snapshot sequence 16 in Appendix 1.

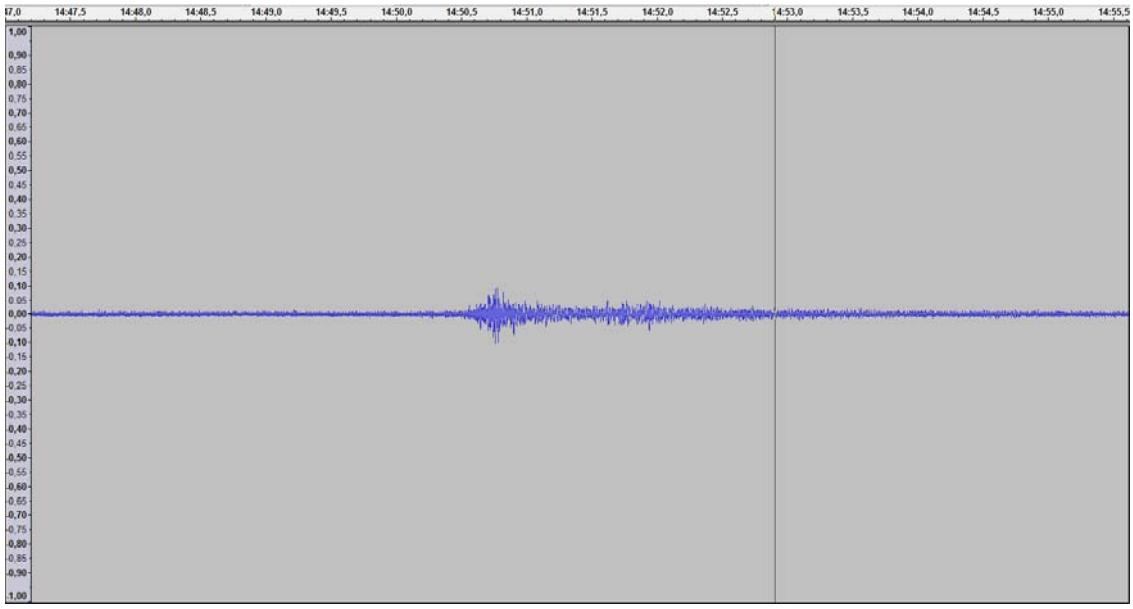

Figure 40 – Second isolated sound signal from 11:50 – 12:10 sequence. Related images of fish in Snapshot sequence 17 in Appendix 1.

4 CONCLUDING REMARKS

With the airgun output levels used and a distance to the fish farm of about 6-7 km it was not possible to observe any behavioral changes in the fish during periods of testing. This is similar to the results from previous monitoring conducted at by MM in Hjørundfjorden (Dyb, unpublished). During the period of monitoring other sources on and around the fish farm like boat traffic, forklift and daily work could generate significant sound levels (data not shown). From our observations these activities did not seem to cause any flight response in the fish unless high and sharp noises were produced. Oxygen levels measured in the water (after transition through fish cages) did not appear to change during periods of tests. Although it is not an optimal way of measuring physiological responses in the fish, it is reasonable to assume that with the biomass that was present in the cages a significant change in oxygen levels would occur if the fish were significantly stressed (Ellis *et al.* 2002, Wieser *et al.* 1985). As fish farmers did not report any differences in productivity compared to previous years this indicates that mortality, feed intake and growth of the fish were not affected. All combined, the results obtained thought this monitoring process suggest that the testing did not have any negative impacts on the farmed fish at the locations that were investigated.

5 REFERENCES

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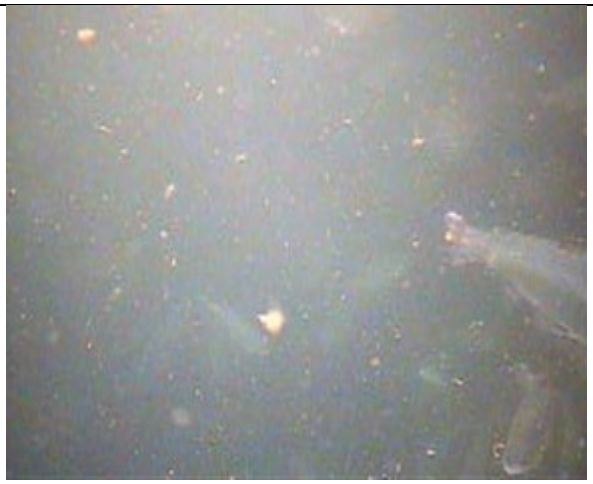
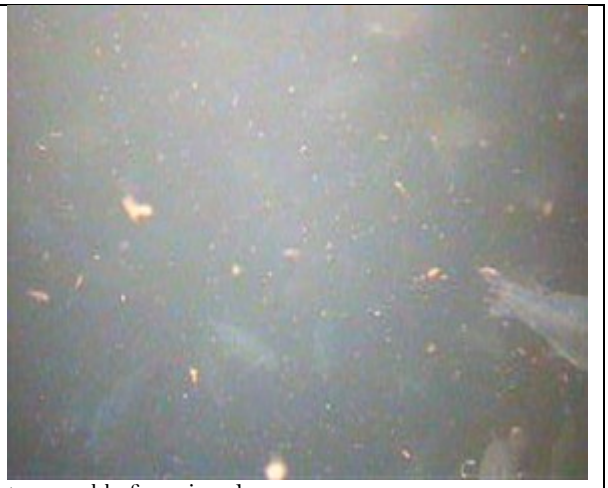
APPENDIX 1 – SNAPSHOTS OF FISH AT SPECIFIC POINTS DURING TESTING

Skotungneset 16.June 2009 - Snapshot sequence 1

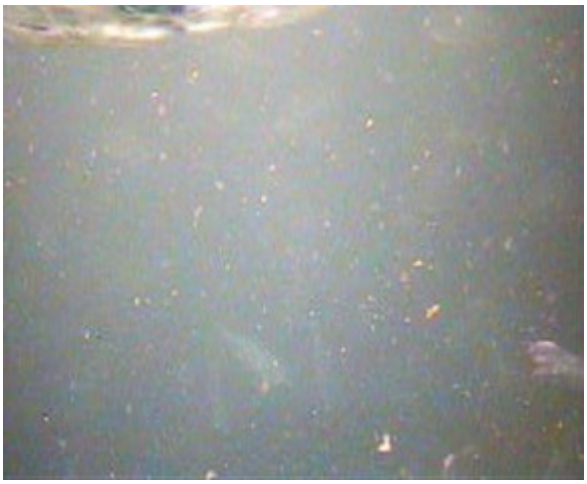
– Related to 16:00:00 signal



2 seconds before signal

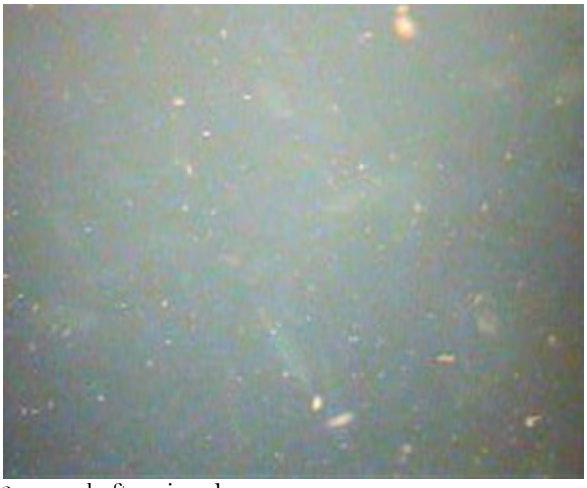


1 second before signal

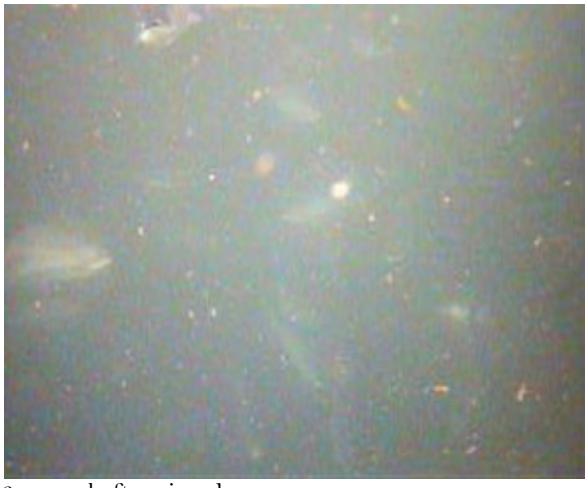


Signal recorded

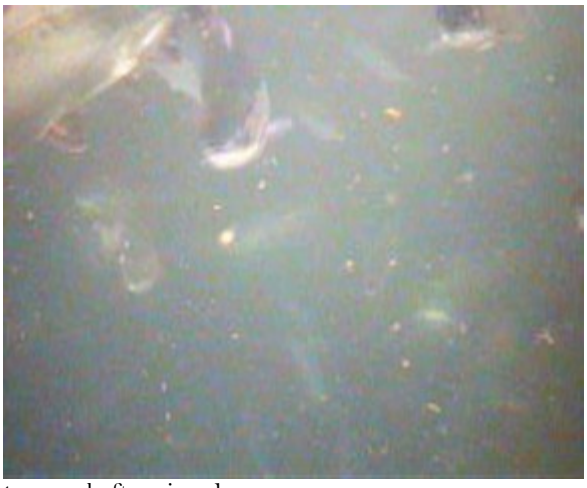
1 second after signal



2 second after signal



3 second after signal

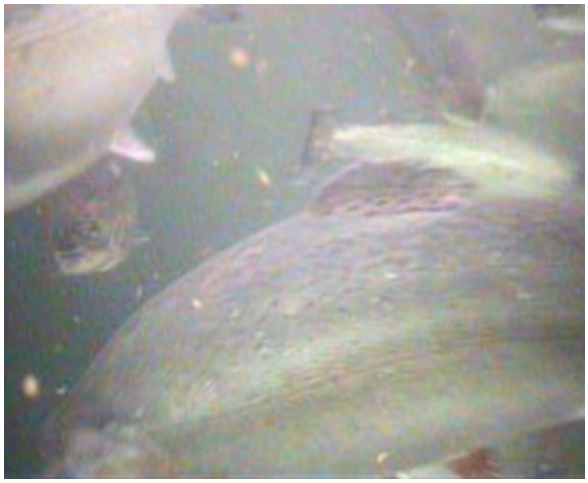

4 second after signal


5 second after signal


6 second after signal

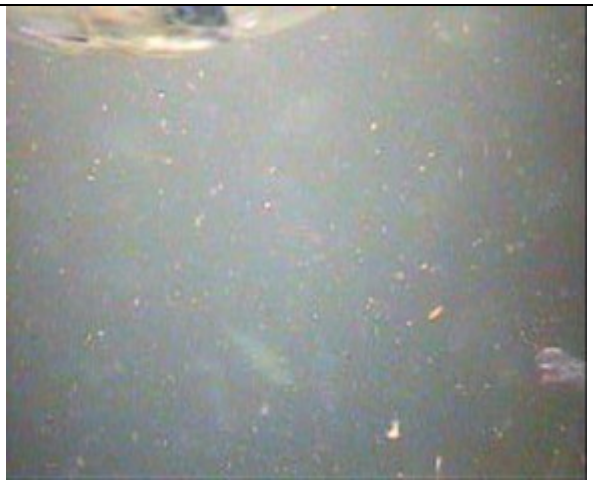

7 second after signal


8 second after signal


9 second after signal

Skotungneset 16.June 2009 - Snapshot sequence 2

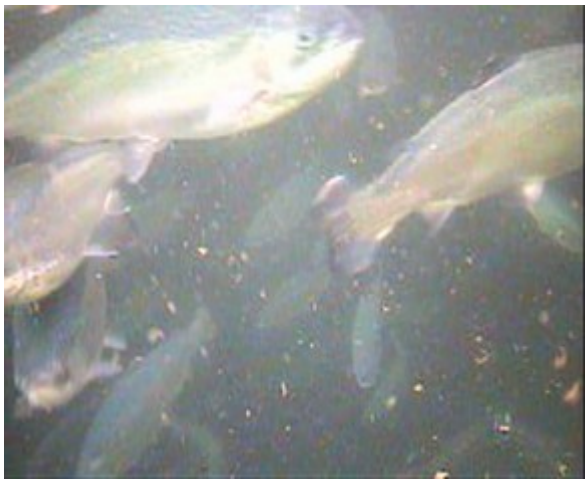
– Related to 16:01:00 signal



2 second before signal

1 second before signal

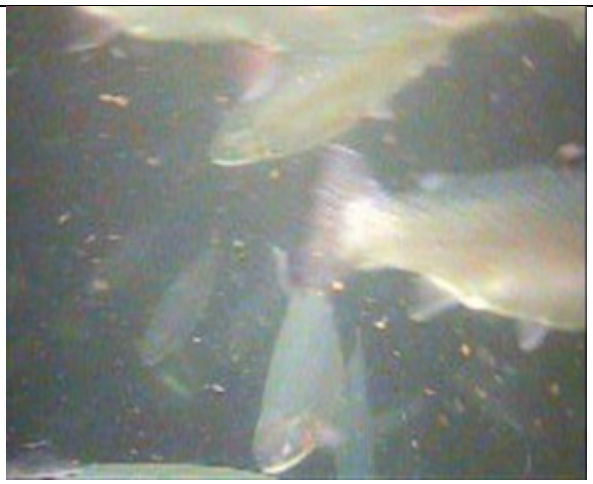
Signal recorded



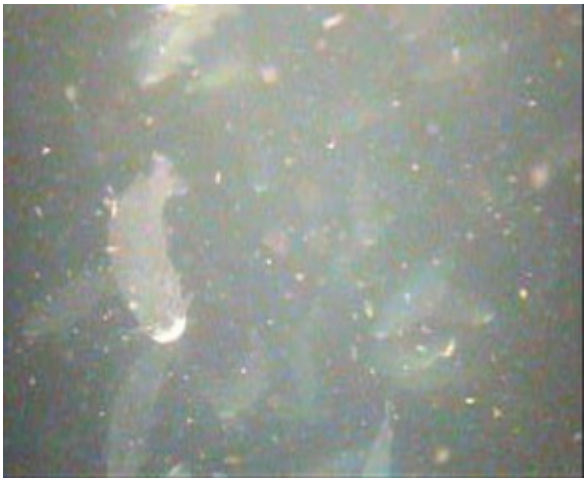
1 second after signal

2 second after signal

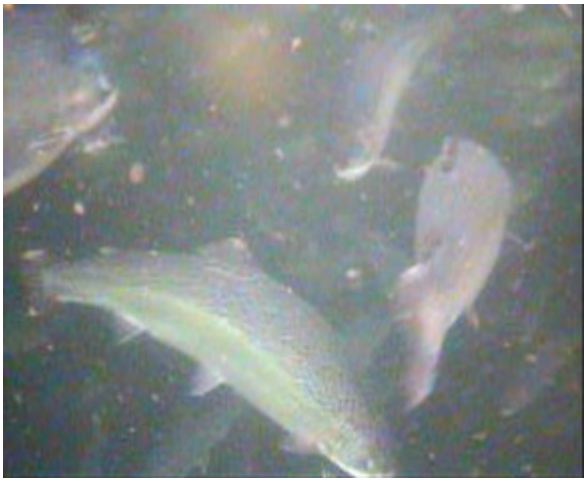
3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal

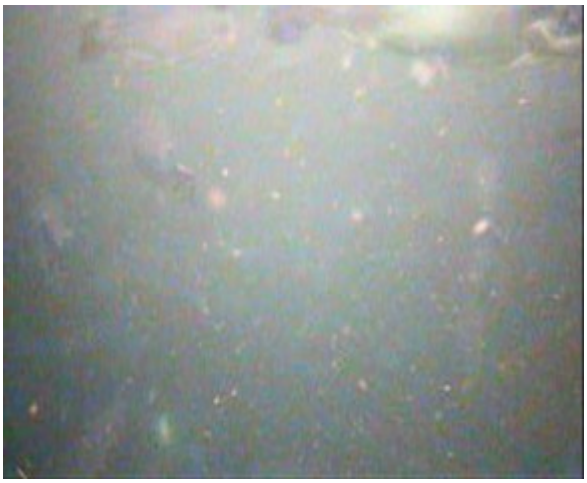

9 second after signal

Skotungneset 16.June 2009 - Snapshot sequence 3

– Related to 16:02:00 signal

2 second before signal

1 second before signal

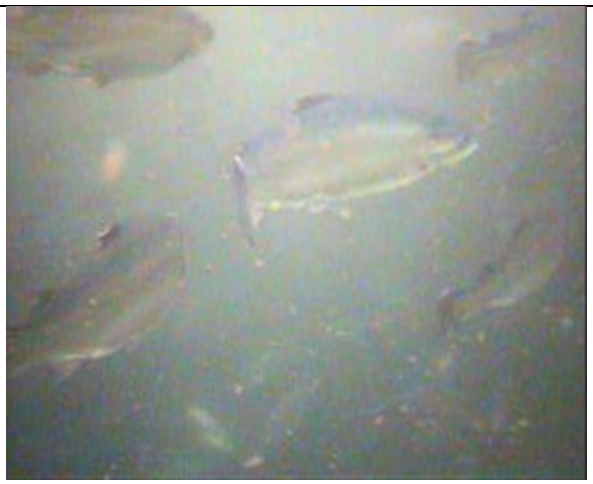


Signal recorded

1 second after signal

2 second after signal

3 second after signal

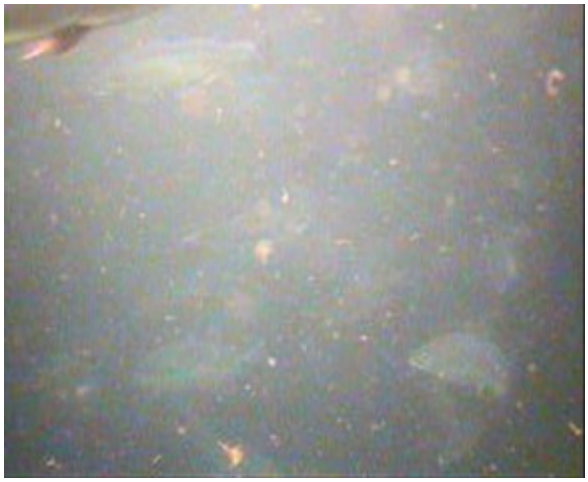

4 second after signal


5 second after signal


6 second after signal

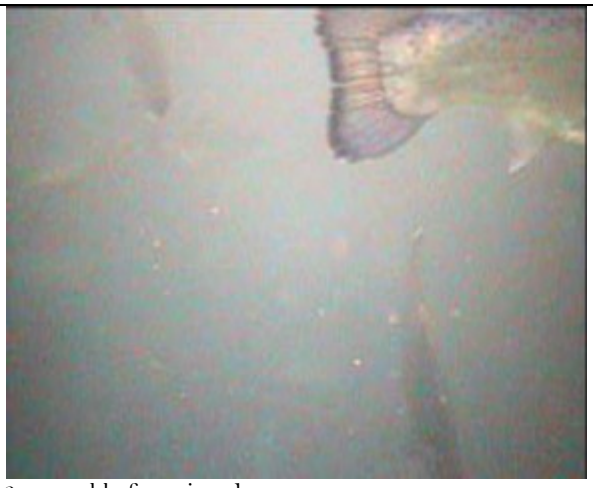

7 second after signal


8 second after signal

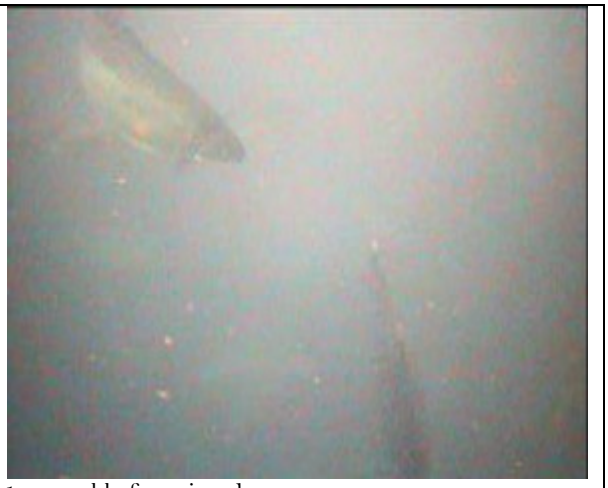

9 second after signal

Skotungneset 24.June 2009 - Snapshot sequence 1

– Related to recorded signal at start of 18:15 – 18:25 sequence (Figure 11)



2 second before signal

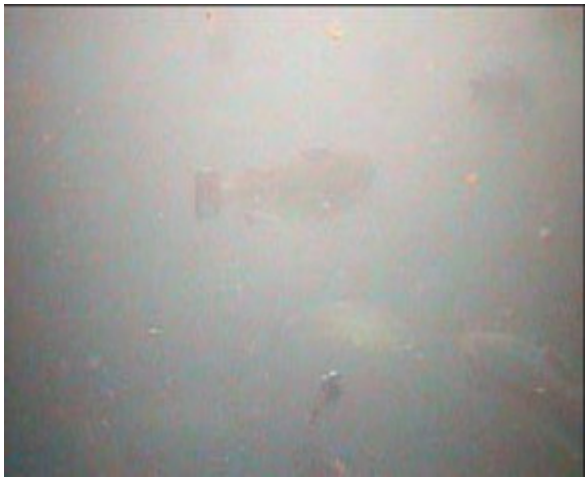


1 second before signal

Signal recorded

1 second after signal

2 second after signal



3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal


9 second after signal

Skotungneset 25.June 2009 - Snapshot sequence 1

– Related to recorded signal at start of 13:30 – 13:07 sequence (Figure 13)

2 second before signal

1 second before signal

Signal recorded

1 second after signal

2 second after signal

3 second after signal

4 second after signal

5 second after signal

6 second after signal

7 second after signal

8 second after signal

9 second after signal

Skotungneset 25.June 2009 - Snapshot sequence 2

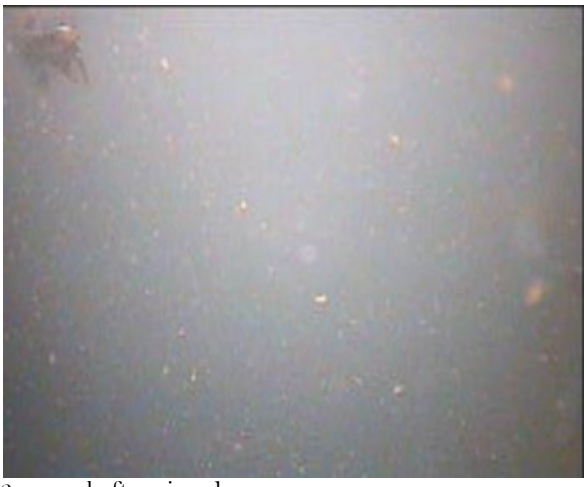
– Related to recorded signal at start of 14:58 – 15:05 sequence (Figure 14)

2 second before signal

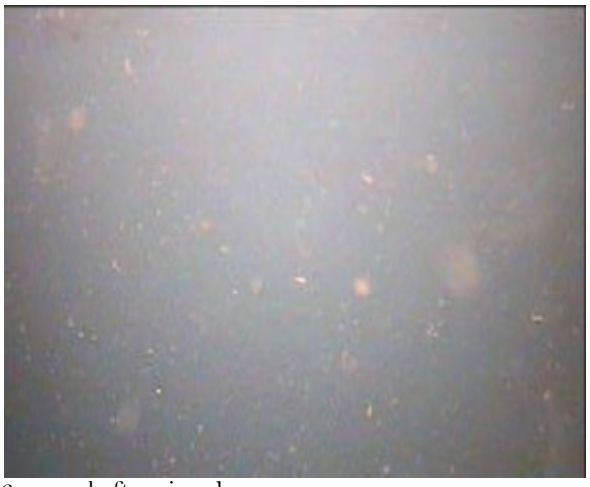
1 second before signal

Signal recorded

1 second after signal

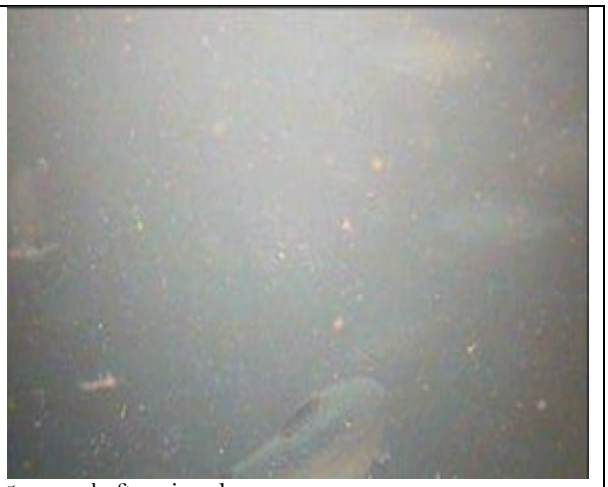


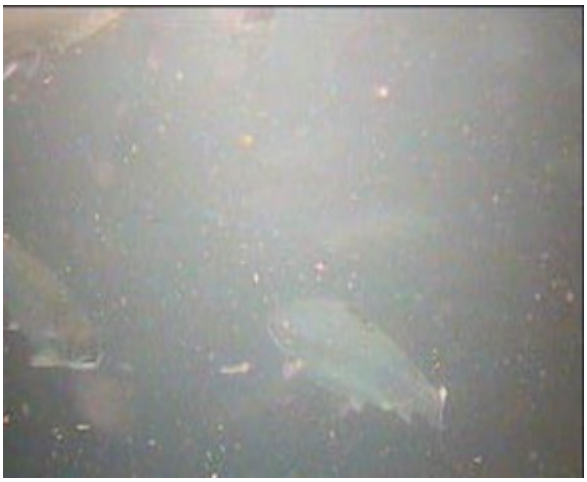
2 second after signal



3 second after signal

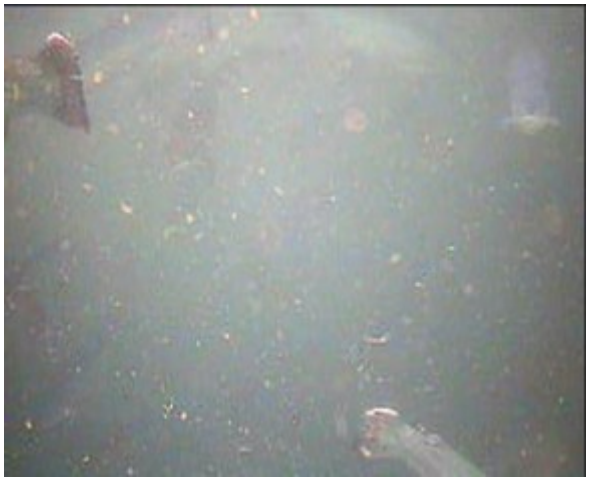

4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal


9 second after signal

Skotungneset 29.September 2009 - Snapshot sequence 1

– Related to recorded signal at start of 15:07 – 15:17 sequence (Figure 16)

2 second before signal

1 second before signal

Signal recorded

1 second after signal

2 second after signal

3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal


9 second after signal

Skotungneset 30.September 2009 - Snapshot sequence 1

– Related to recorded signal at start of 13:43 – 13:53 sequence (Figure 18)

2 second before signal

1 second before signal

Signal recorded

1 second after signal

2 second after signal

3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal


9 second after signal

Skotungneset 30.September 2009 - Snapshot sequence 2

– Related to recorded signal at start of 13:43 – 13:53 sequence (Figure 19)

2 second before signal

1 second before signal

Signal recorded

1 second after signal

2 second after signal

3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal


9 second after signal

Skotungneset 1.October 2009 - Snapshot sequence 1

– related to recorded signal within 14:06 – 14:45 sequence (Figure 22)

2 second before signal

1 second before signal

Signal recorded

1 second after signal

2 second after signal

3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal


9 second after signal

Overåneset 2.October 2009 - Snapshot sequence 1

– Related to recorded signal within 14:55 – 15:18 sequence

2 second before signal

1 second before signal

Signal recorded

1 second after signal

2 second after signal

3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal

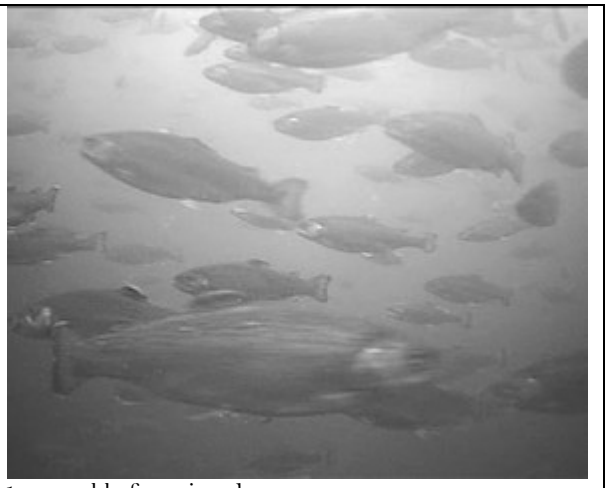

8 second after signal


9 second after signal

Overåneset 20.October 2009 - Snapshot sequence 1

- Related to recorded signal at start of 10:50 – 11:25 sequence (Figure 30)

2 second before signal



1 second before signal

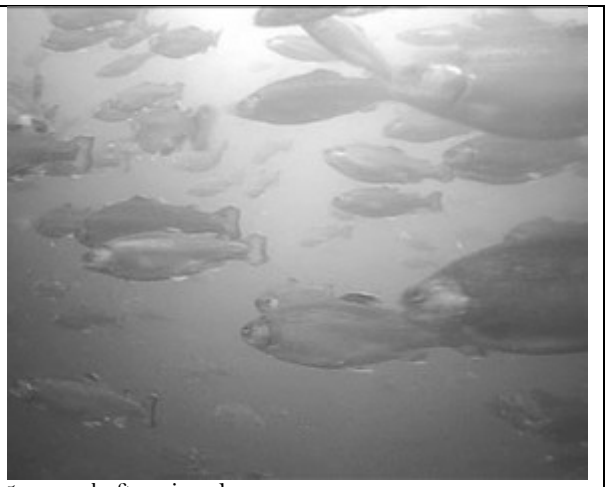
Signal recorded

1 second after signal

2 second after signal

3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal


9 second after signal

Overåneset 20.October 2009 - Snapshot sequence 2

– Related to recorded signal at start of 12:20 – 12:45 sequence (Figure 31)

2 second before signal

1 second before signal

Signal recorded

1 second after signal

2 second after signal

3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal


9 second after signal

Overåneset 16.February 2010 - Snapshot sequence 1

– Related to recorded signal at start of 13:11 – 13:35 sequence (Figure 35)

2 second before signal

1 second before signal

Signal recorded

1 second after signal

2 second after signal

3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal


9 second after signal

Overåneset 16.February 2010 - Snapshot sequence 2

– Related to recorded signal at start of 13:59 – 14:23 sequence (Figure 36)

2 second before signal

1 second before signal

Signal recorded

1 second after signal

2 second after signal

3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal


8 second after signal


9 second after signal

Overåneset 10.March 2010 - Snapshot sequence 1

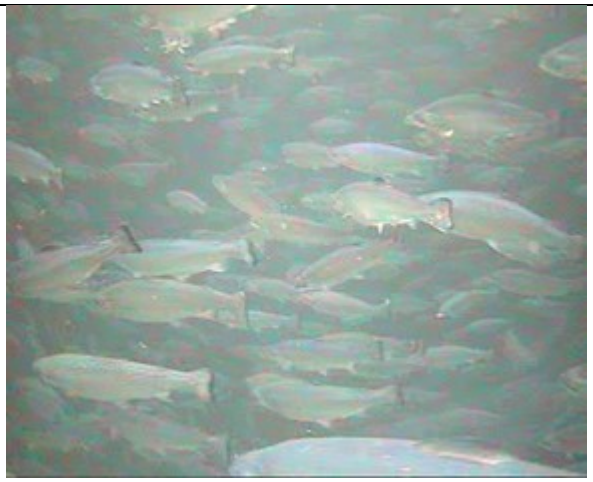
– Related to recorded signal at start of 11:50 – 12:10 sequence (Figure 39)

2 second before signal

1 second before signal

Signal recorded

1 second after signal



2 second after signal

3 second after signal

4 second after signal

5 second after signal

6 second after signal

7 second after signal

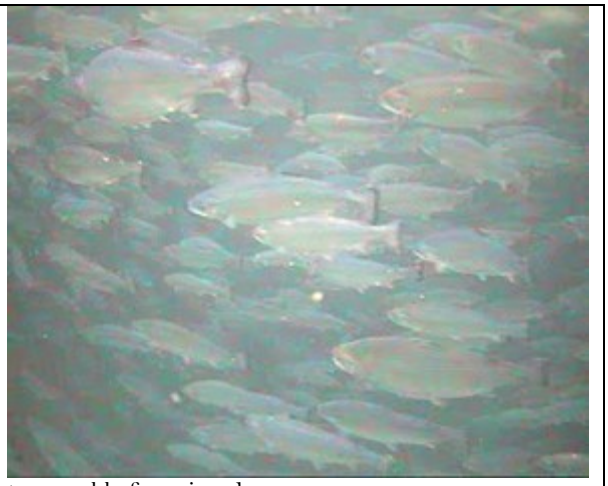
8 second after signal

9 second after signal

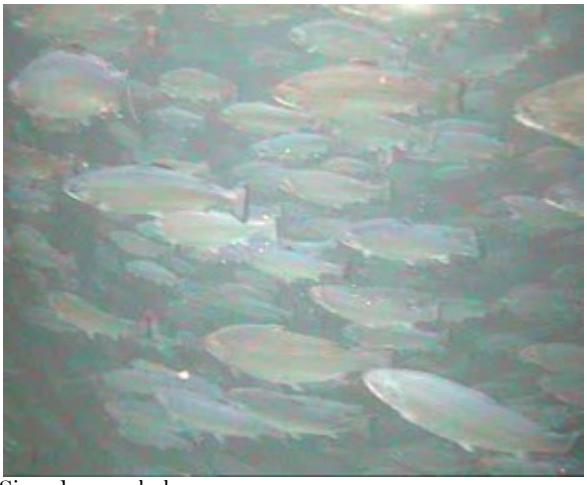
Overåneset 10.March 2010 - Snapshot sequence 2

– Related to recorded signal within 11:50 – 12:10 sequence (Figure 40)

2 second before signal



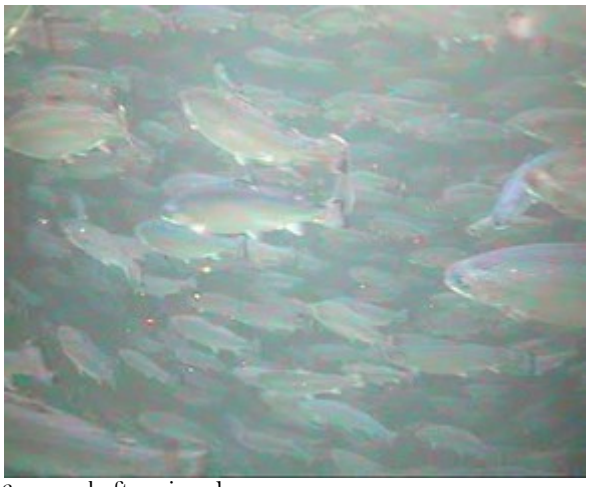
1 second before signal



Signal recorded

1 second after signal

2 second after signal



3 second after signal


4 second after signal


5 second after signal


6 second after signal


7 second after signal

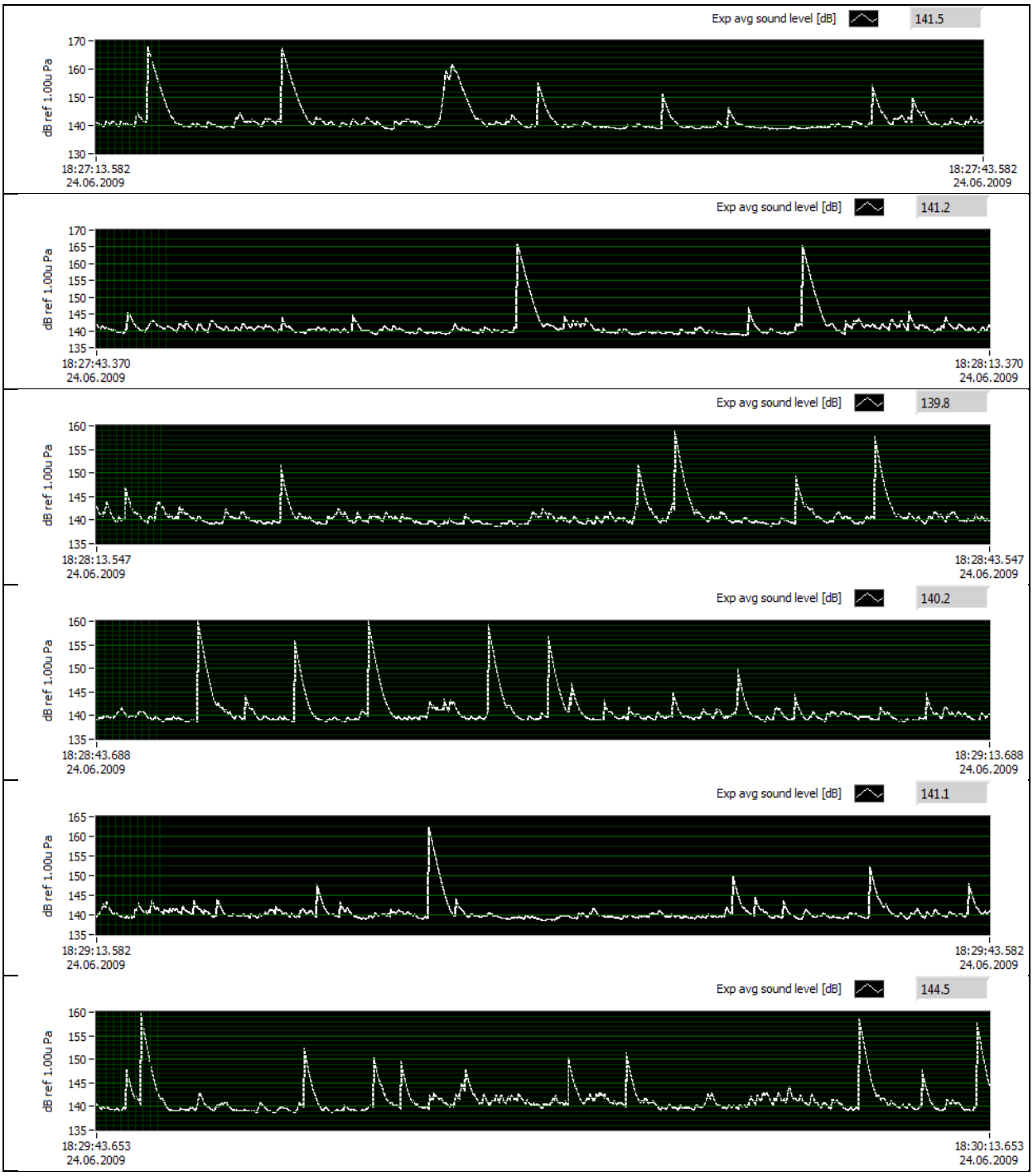

8 second after signal

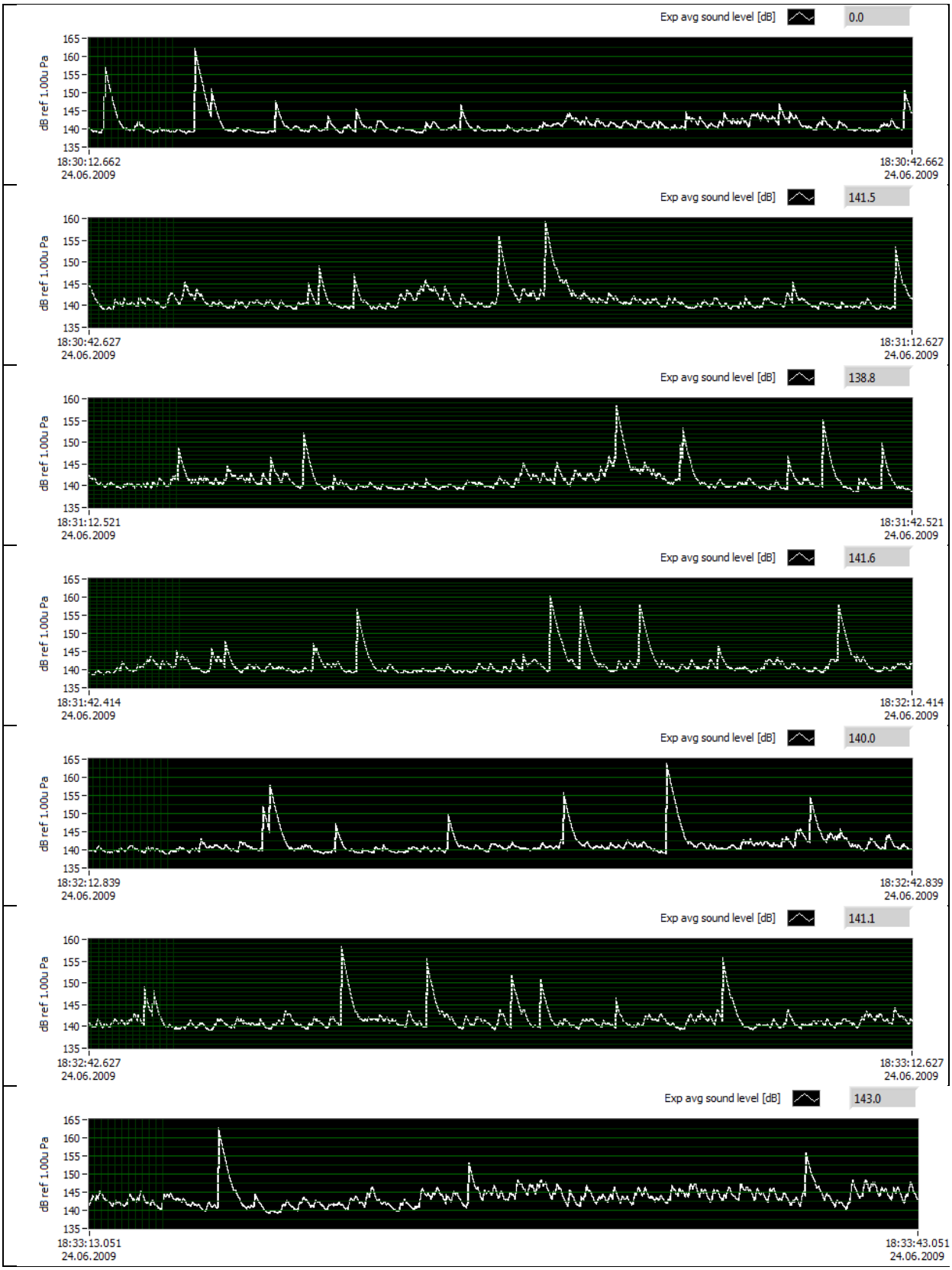

9 second after signal

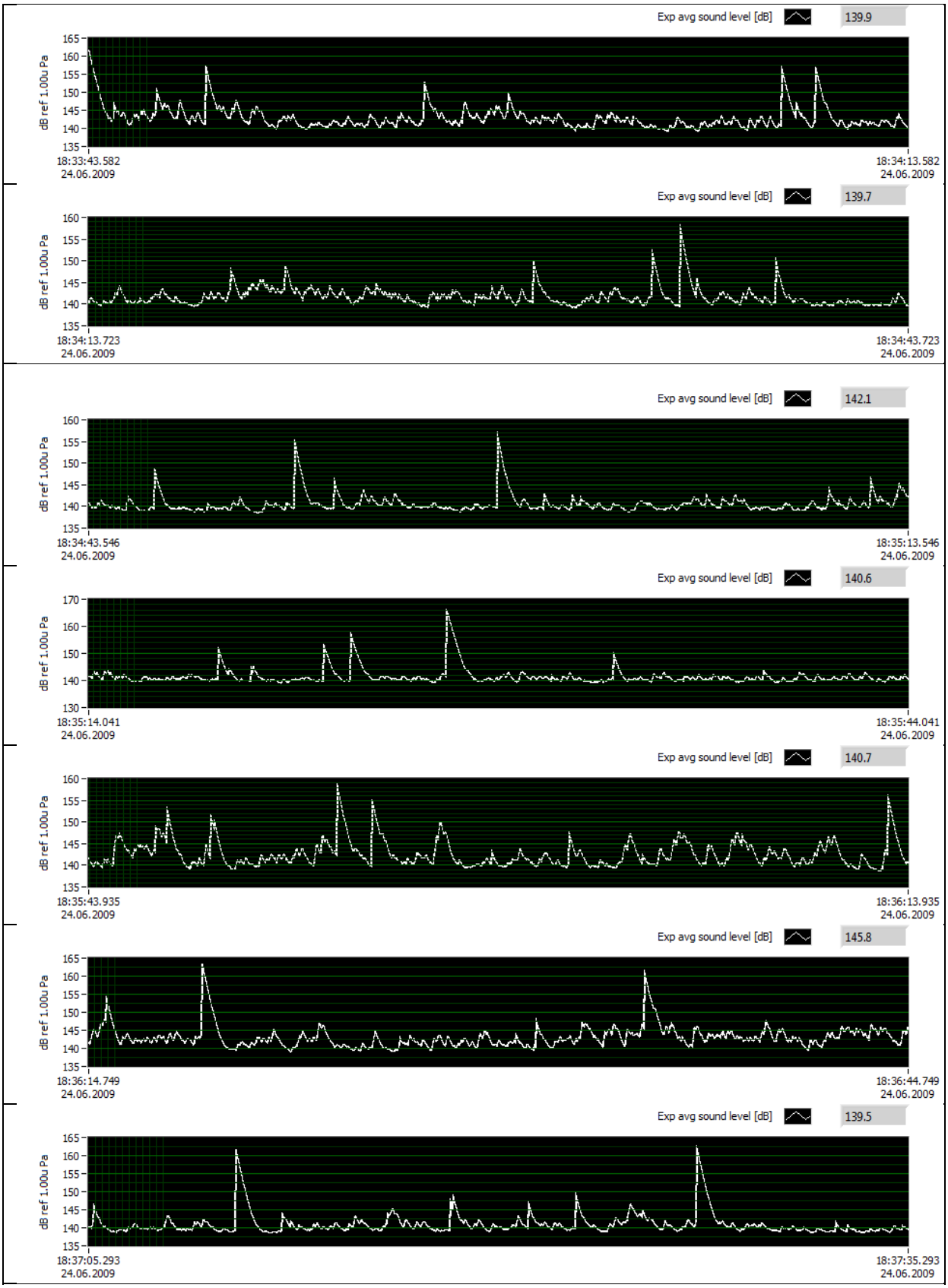
APPENDIX 2 –MEASURED SOUND DURING PERIODS OF TESTING.

Skotungneset 24.June - Airgun sequence 1 (18:15 – 18:25)

Comment: Timescale in figure do not correspond with given time in signal log (Table 2) due to unsynchronized clocks. (18:26:30 in figure = 18:15:10 on barge = time of first discharge). Start of log 43 seconds after first discharge due to corrupt log file. End of log: ~1 minute and 30 seconds after last discharge in sequence. Each graph show sound level during 30 second intervals

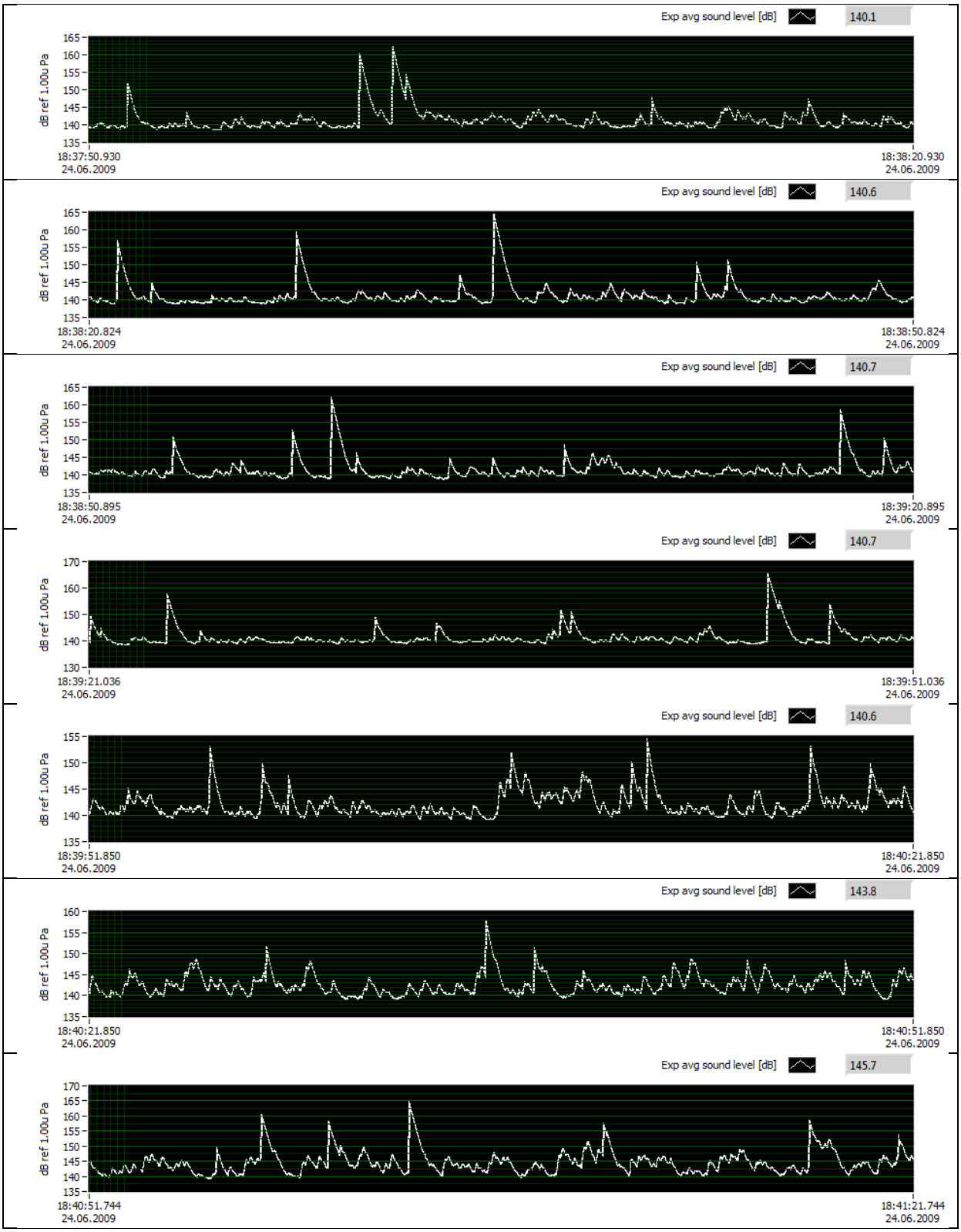


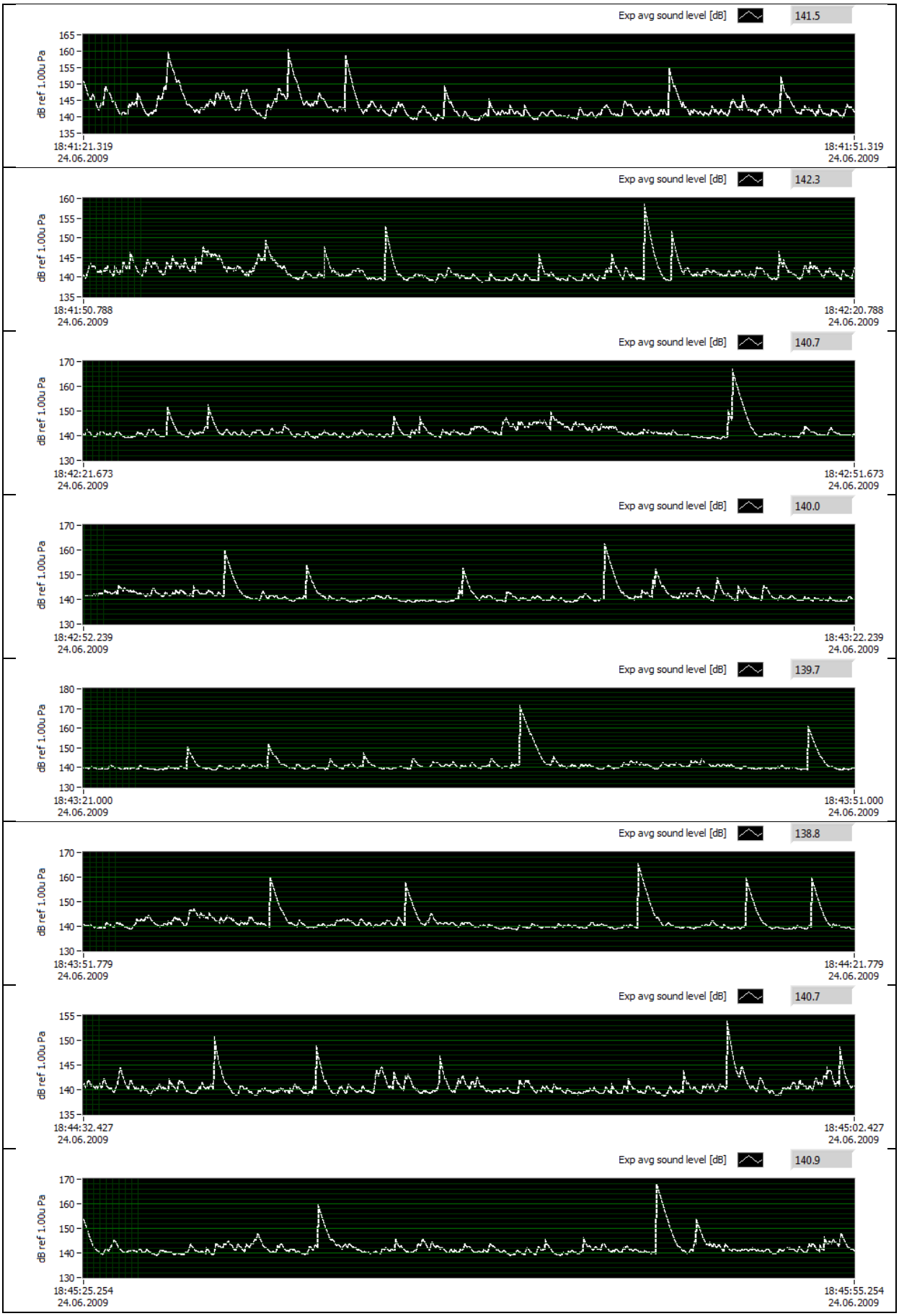

Exp avg sound level [dB]
0.0
dB ref 1.00u Pa
165
160
155
150
145
140
135
18:30:12.662
24.06.2009
18:30:42.662
24.06.2009
Exp avg sound level [dB]
141.5
dB ref 1.00u Pa
160
155
150
145
140
135
18:30:42.627
24.06.2009
18:31:12.627
24.06.2009
Exp avg sound level [dB]
138.8
dB ref 1.00u Pa
160
155
150
145
140
135
18:31:12.521
24.06.2009
18:31:42.521
24.06.2009
Exp avg sound level [dB]
141.6
dB ref 1.00u Pa
165
160
155
150
145
140
135
18:31:42.414
24.06.2009
18:32:12.414
24.06.2009
Exp avg sound level [dB]
140.0
dB ref 1.00u Pa
165
160
155
150
145
140
135
18:32:12.839
24.06.2009
18:32:42.839
24.06.2009
Exp avg sound level [dB]
141.1
dB ref 1.00u Pa
160
155
150
145
140
135
18:32:42.627
24.06.2009
18:33:12.627
24.06.2009
Exp avg sound level [dB]
143.0
dB ref 1.00u Pa
165
160
155
150
145
140
135
18:33:13.051
24.06.2009
18:33:43.051
24.06.2009

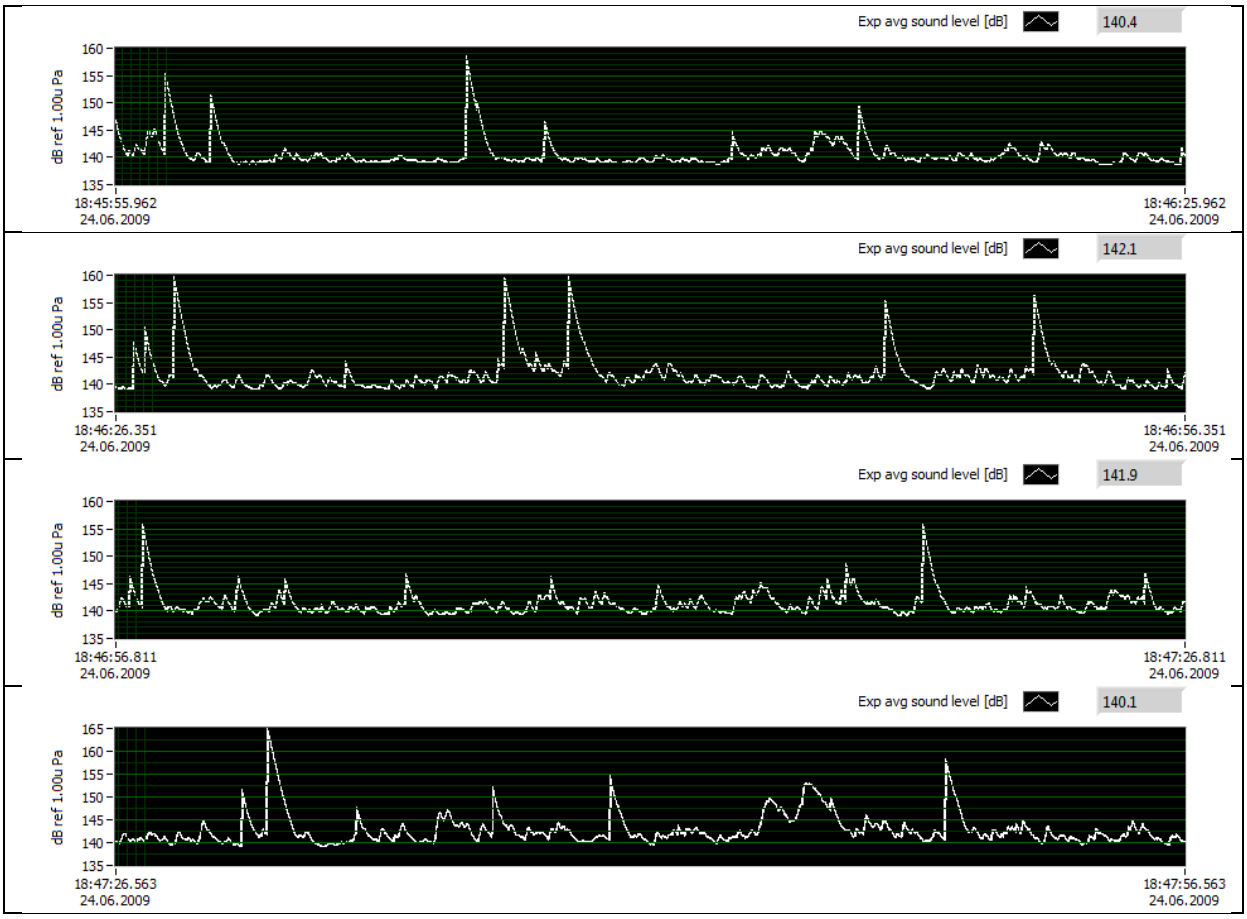

Exp avg sound level [dB]
139.9
dB ref 1.00u Pa
165
160
155
150
145
140
135
18:33:43.582
24.06.2009
18:34:13.582
24.06.2009
Exp avg sound level [dB]
139.7
dB ref 1.00u Pa
160
155
150
145
140
135
18:34:13.723
24.06.2009
18:34:43.723
24.06.2009
Exp avg sound level [dB]
142.1
dB ref 1.00u Pa
160
155
150
145
140
135
18:34:43.546
24.06.2009
18:35:13.546
24.06.2009
Exp avg sound level [dB]
140.6
dB ref 1.00u Pa
170
160
150
140
130
18:35:14.041
24.06.2009
18:35:44.041
24.06.2009
Exp avg sound level [dB]
140.7
dB ref 1.00u Pa
160
155
150
145
140
135
18:35:43.935
24.06.2009
18:36:13.935
24.06.2009
Exp avg sound level [dB]
145.8
dB ref 1.00u Pa
165
160
155
150
145
140
135
18:36:14.749
24.06.2009
18:36:44.749
24.06.2009
Exp avg sound level [dB]
139.5
dB ref 1.00u Pa
165
160
155
150
145
140
135
18:37:05.293
24.06.2009
18:37:35.293
24.06.2009

Skotungneset 24.June - Airgun sequence 2 (18:25 – 18:35)

Comment: Timescale in figure do not correspond with given time in signal log (Table 2) due to unsynchronized clocks. (18:38:12 in figure = 18:26:52 on barge = time of first discharge). End of log: 40 seconds after last discharge in sequence. Each graph show sound level during 30 second intervals.

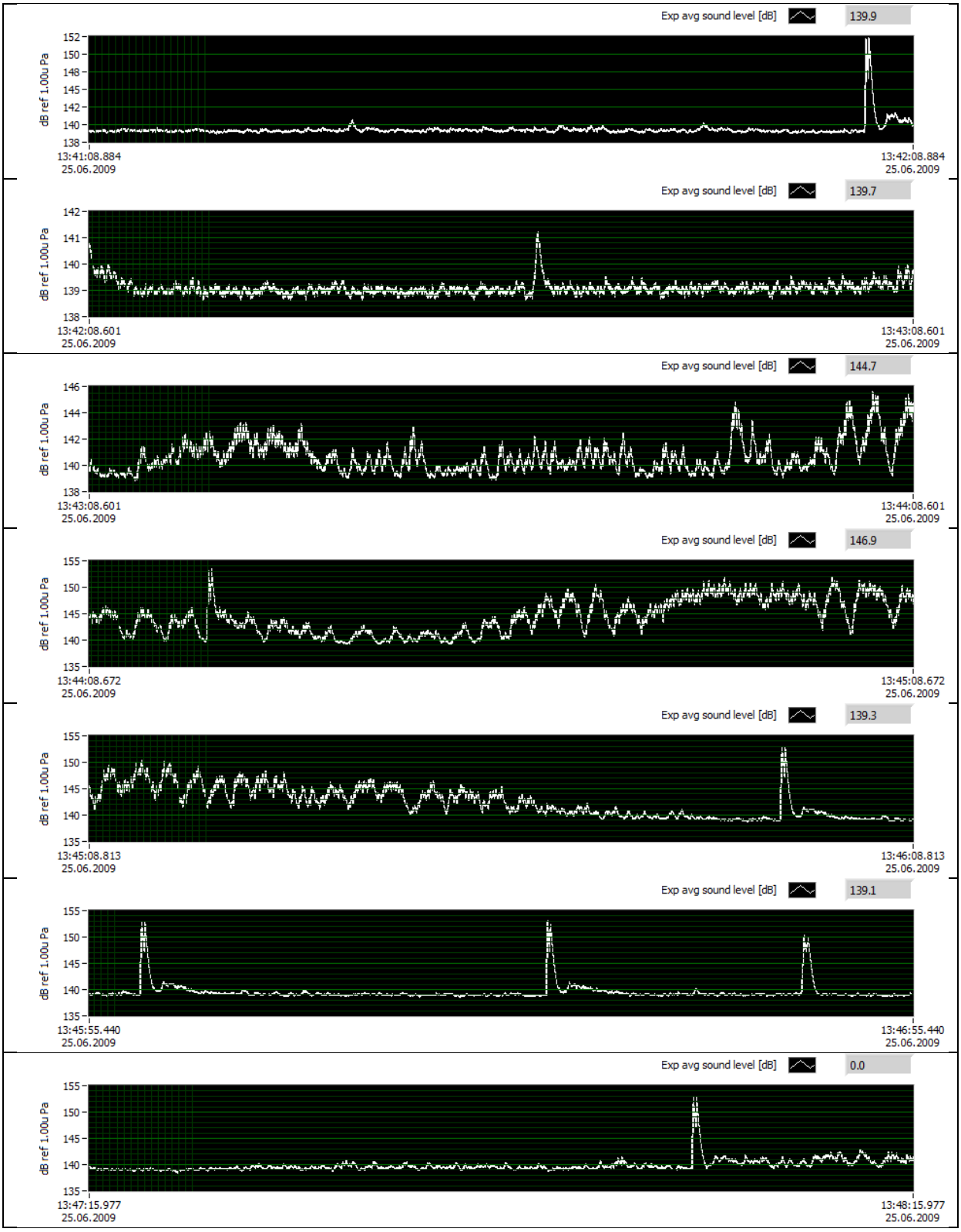


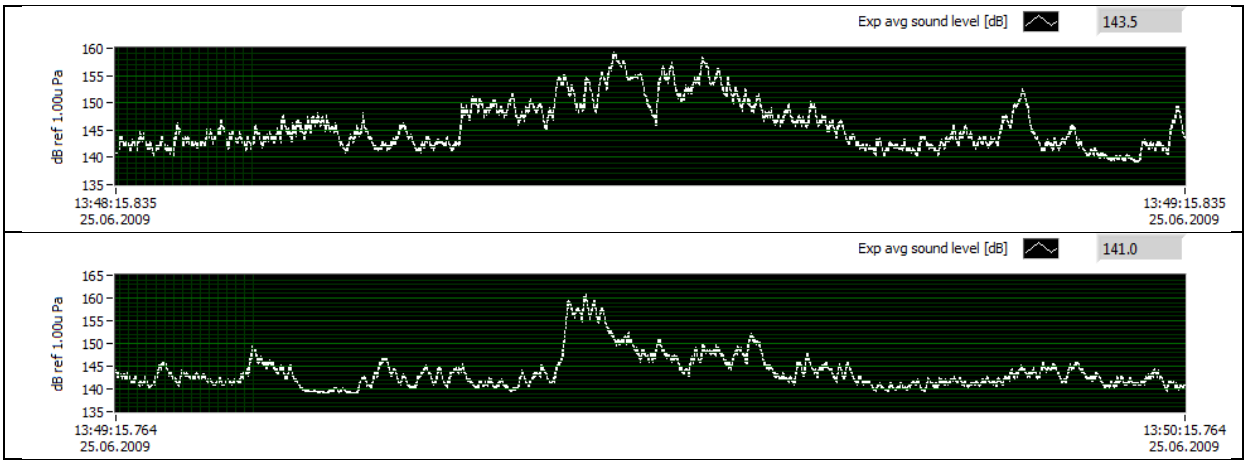

Exp avg sound level [dB]
141.5
dB ref 1.00u Pa
165
160
155
150
145
140
135
18:41:21.319
24.06.2009
18:41:51.319
24.06.2009
Exp avg sound level [dB]
142.3
dB ref 1.00u Pa
160
155
150
145
140
135
18:41:50.788
24.06.2009
18:42:20.788
24.06.2009
Exp avg sound level [dB]
140.7
dB ref 1.00u Pa
170
160
150
140
130
18:42:21.673
24.06.2009
18:42:51.673
24.06.2009
Exp avg sound level [dB]
140.0
dB ref 1.00u Pa
170
160
150
140
130
18:42:52.239
24.06.2009
18:43:22.239
24.06.2009
Exp avg sound level [dB]
139.7
dB ref 1.00u Pa
180
170
160
150
140
130
18:43:21.000
24.06.2009
18:43:51.000
24.06.2009
Exp avg sound level [dB]
138.8
dB ref 1.00u Pa
170
160
150
140
130
18:43:51.779
24.06.2009
18:44:21.779
24.06.2009
Exp avg sound level [dB]
140.7
dB ref 1.00u Pa
155
150
145
140
135
18:44:32.427
24.06.2009
18:45:02.427
24.06.2009
Exp avg sound level [dB]
140.9
dB ref 1.00u Pa
170
160
150
140
130
18:45:25.254
24.06.2009
18:45:55.254
24.06.2009


Exp avg sound level [dB]
140.4
dB ref 1.00u Pa
160
155
150
145
140
135
18:45:55.962
24.06.2009
18:46:25.962
24.06.2009
Exp avg sound level [dB]
142.1
dB ref 1.00u Pa
160
155
150
145
140
135
18:46:26.351
24.06.2009
18:46:56.351
24.06.2009
Exp avg sound level [dB]
141.9
dB ref 1.00u Pa
160
155
150
145
140
135
18:46:56.811
24.06.2009
18:47:26.811
24.06.2009
Exp avg sound level [dB]
140.1
dB ref 1.00u Pa
165
160
155
150
145
140
135
18:47:26.563
24.06.2009
18:47:56.563
24.06.2009

Skotungneset 25.June - Airgun sequence 1 (13:30 – 13:37)

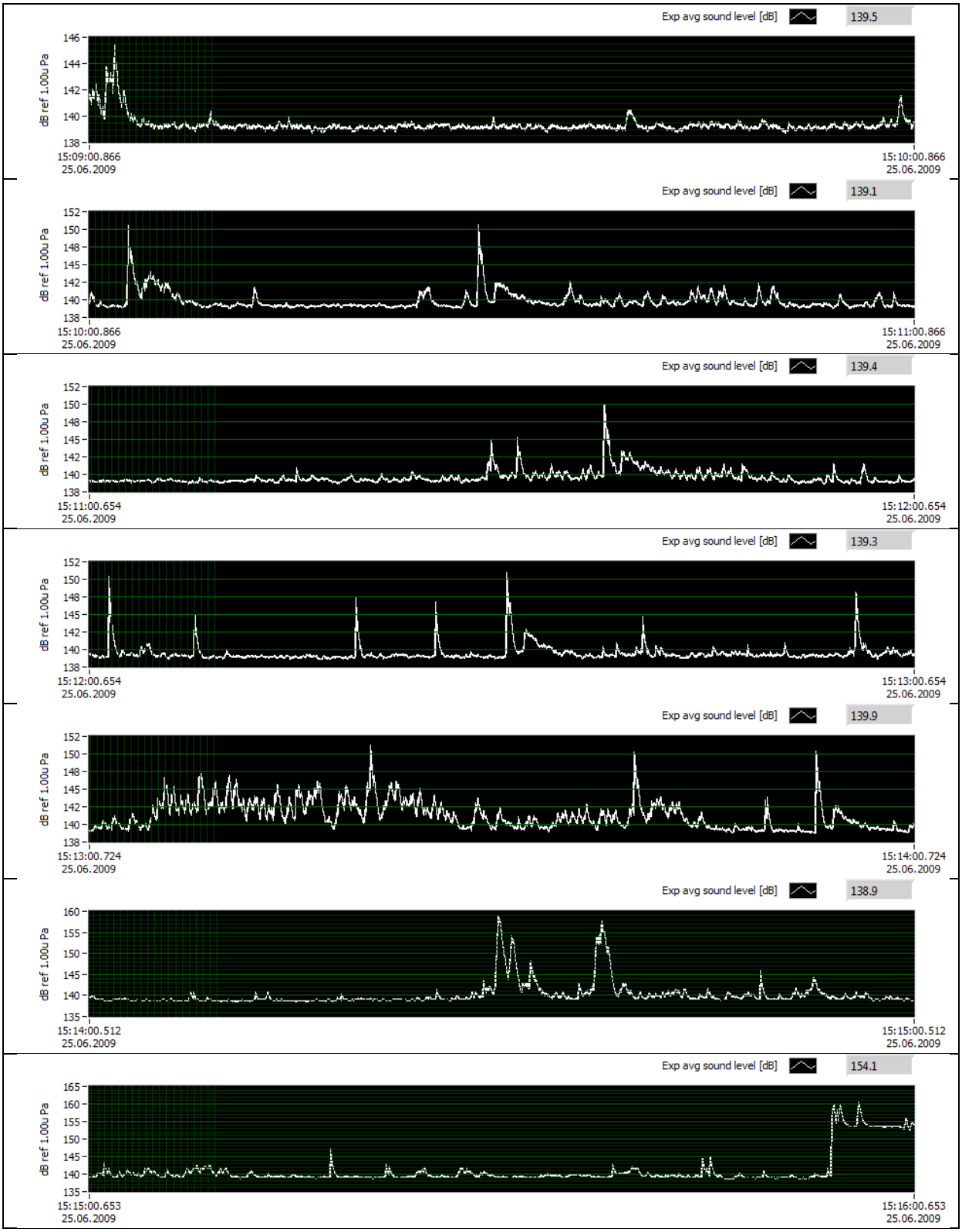
Comment: Timescale in figure do not correspond with given time in signal log (Table 3) due to unsynchronized clocks. (13:42:03 in figure = 13:30:43 on barge = time of first discharge). End of log: 1 minute and 10 seconds after last discharge in sequence. Each graph show sound level during 1 minute intervals.

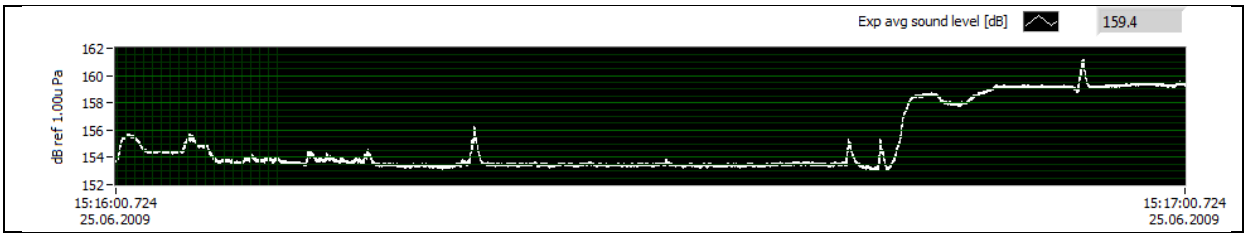



Exp avg sound level [dB]
143.5
dB ref 1.00u Pa
160
155
150
145
140
135
13:48:15.835
25.06.2009
13:49:15.835
25.06.2009
Exp avg sound level [dB]
141.0
dB ref 1.00u Pa
165
160
155
150
145
140
135
13:49:15.764
25.06.2009
13:50:15.764
25.06.2009

Skotungneset 25.June - Airgun sequence 2 (14:58 – 15:05)

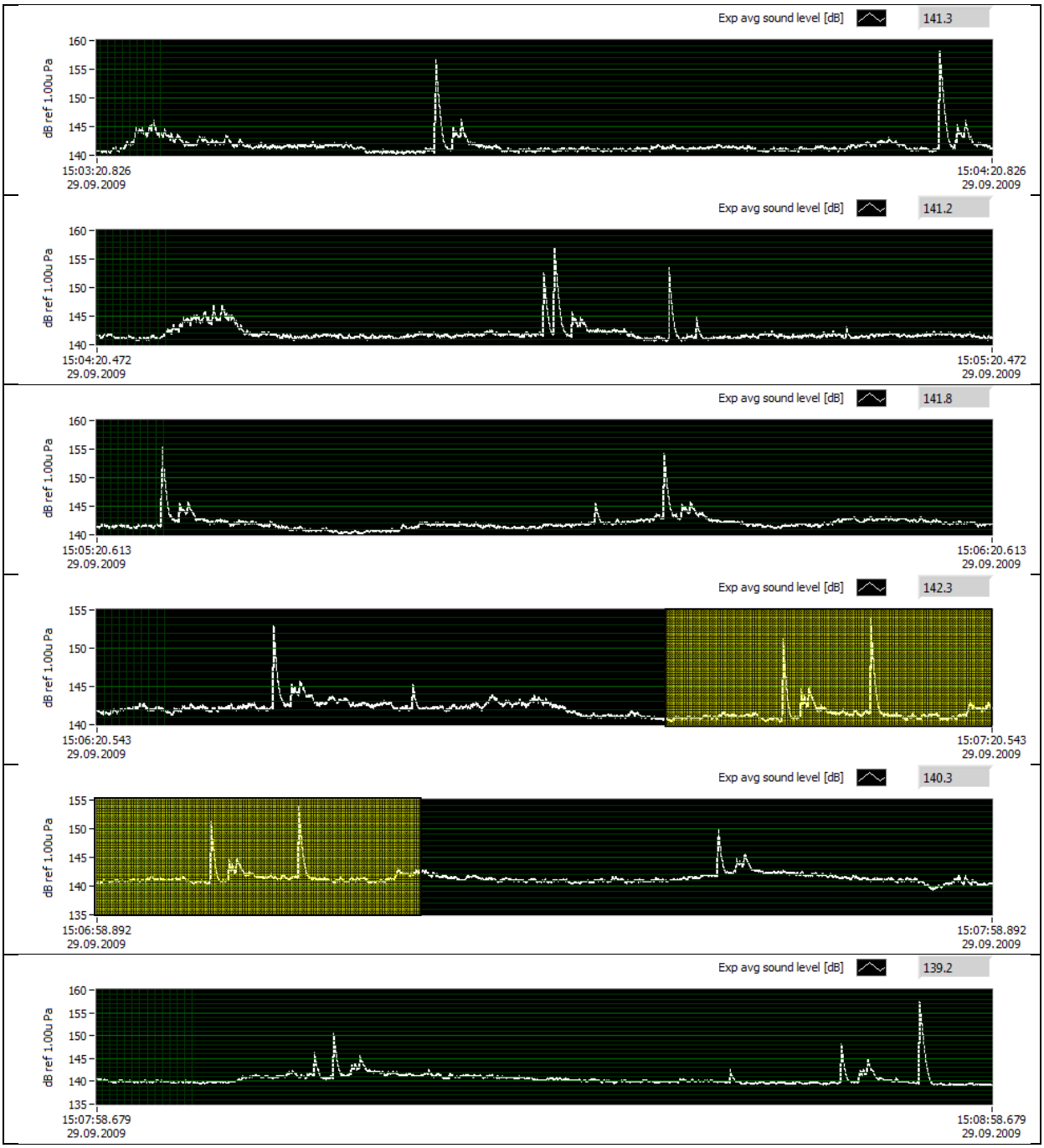
Comment: Timescale in figure do not correspond with given time in signal log (Table 3) due to unsynchronized clocks. (15:12:11 in figure = 15:00:51 on barge = time of first discharge). End of log: ~40 seconds after last discharge in sequence. Rise in sound level which can be observed around 15:16:45 was most probably caused by electrical interference once the automatic feeders were started at the fish farm. Each graph show sound level during 1 minute intervals

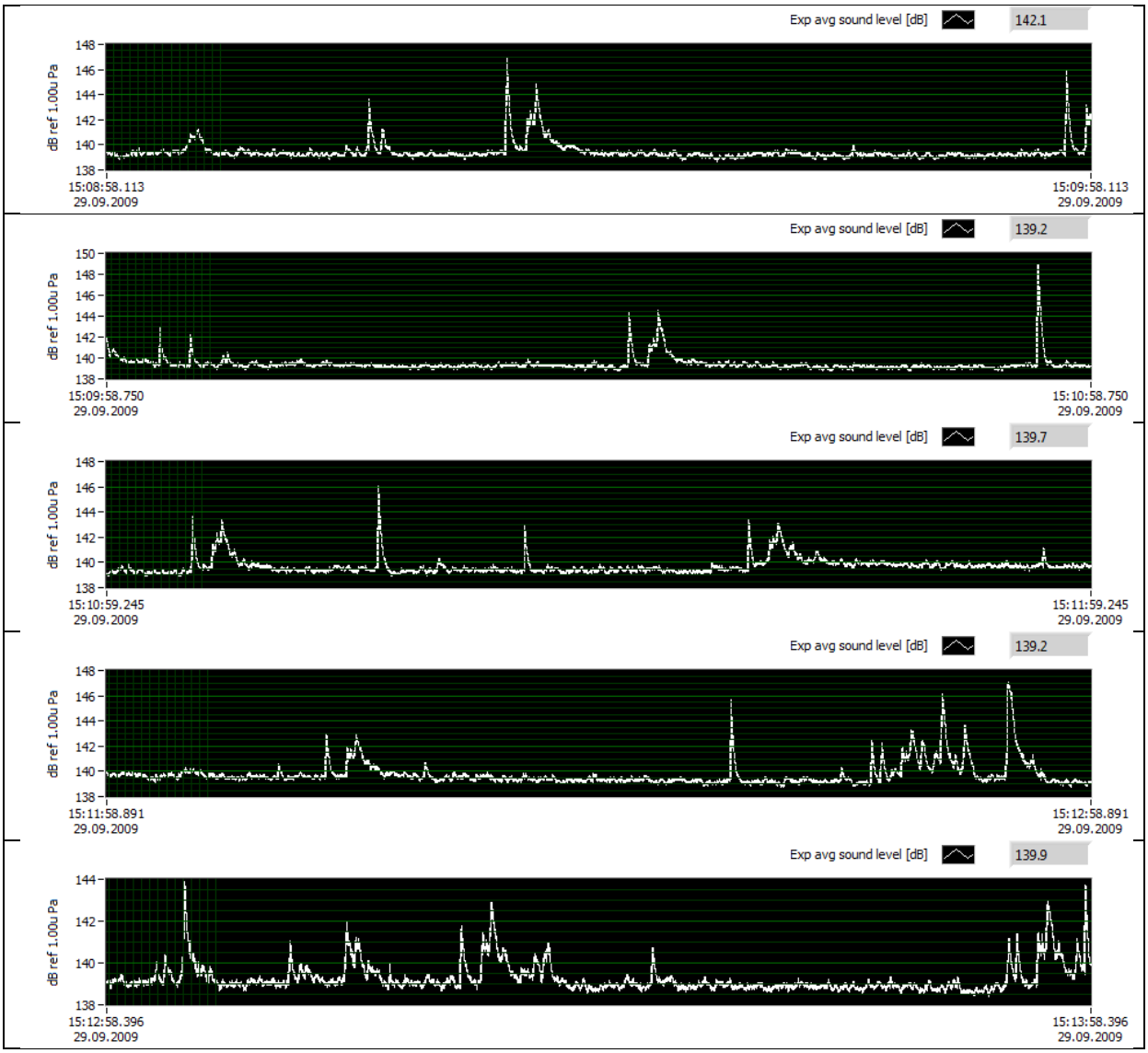



Exp avg sound level [dB]
159.4
dB ref 1.00u Pa
162
160
158
156
154
152
15:16:00.724
25.06.2009
15:17:00.724
25.06.2009

Skotungneset 29.September - Airgun sequence 1 (15:07 – 15:17)

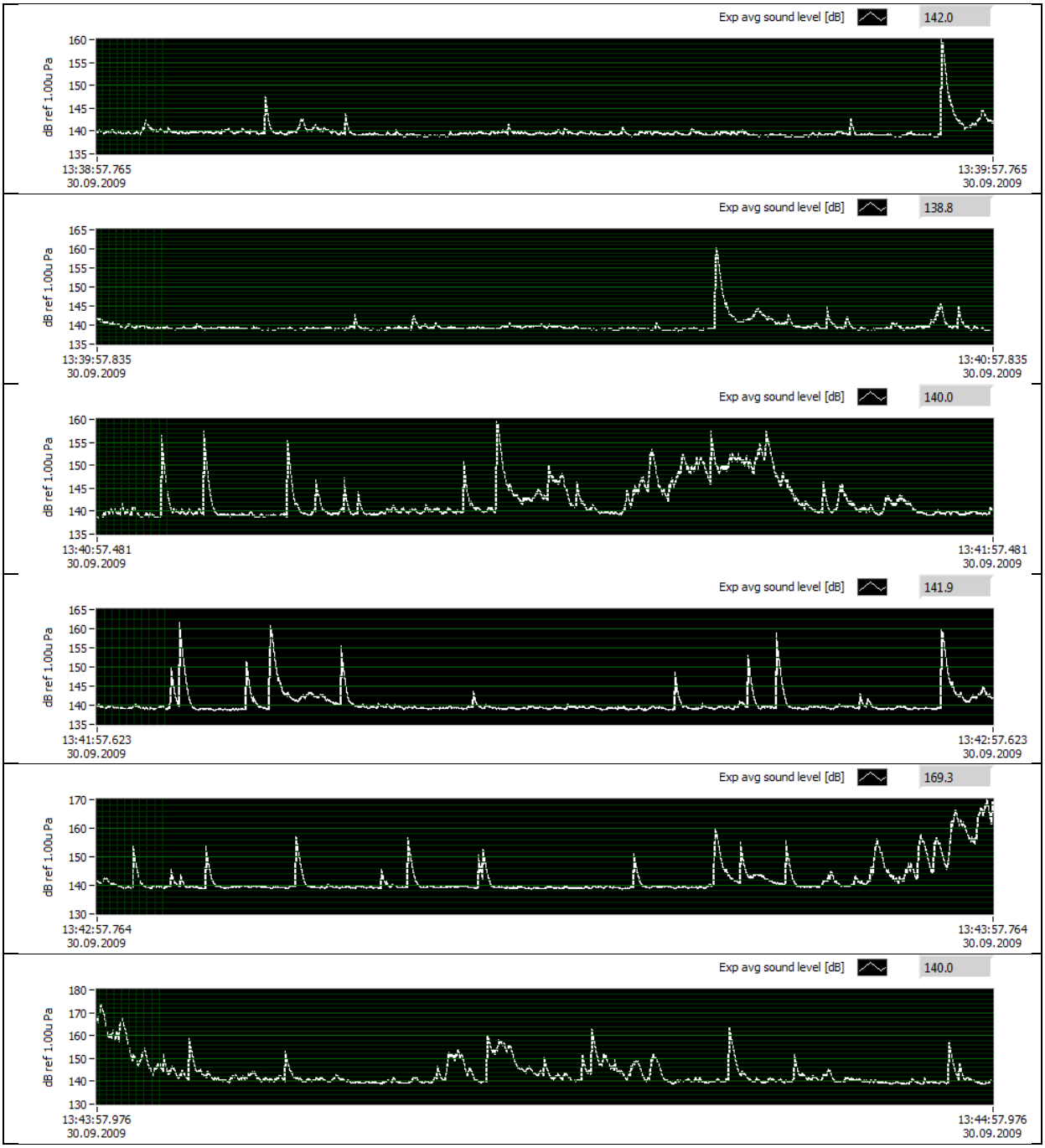
Comment: Timescale in figure do not correspond with given time in signal log (Table 4) due to unsynchronized clocks. (15:03:50 in figure = 15:07:00 on barge = time of first discharge.) (Yellow marking in figure show overlap in log). End of log: ~10 seconds after end of sequence. General high background noise as large boat was docking at fishfarm during testing. Each graph show sound level during 1 minute intervals

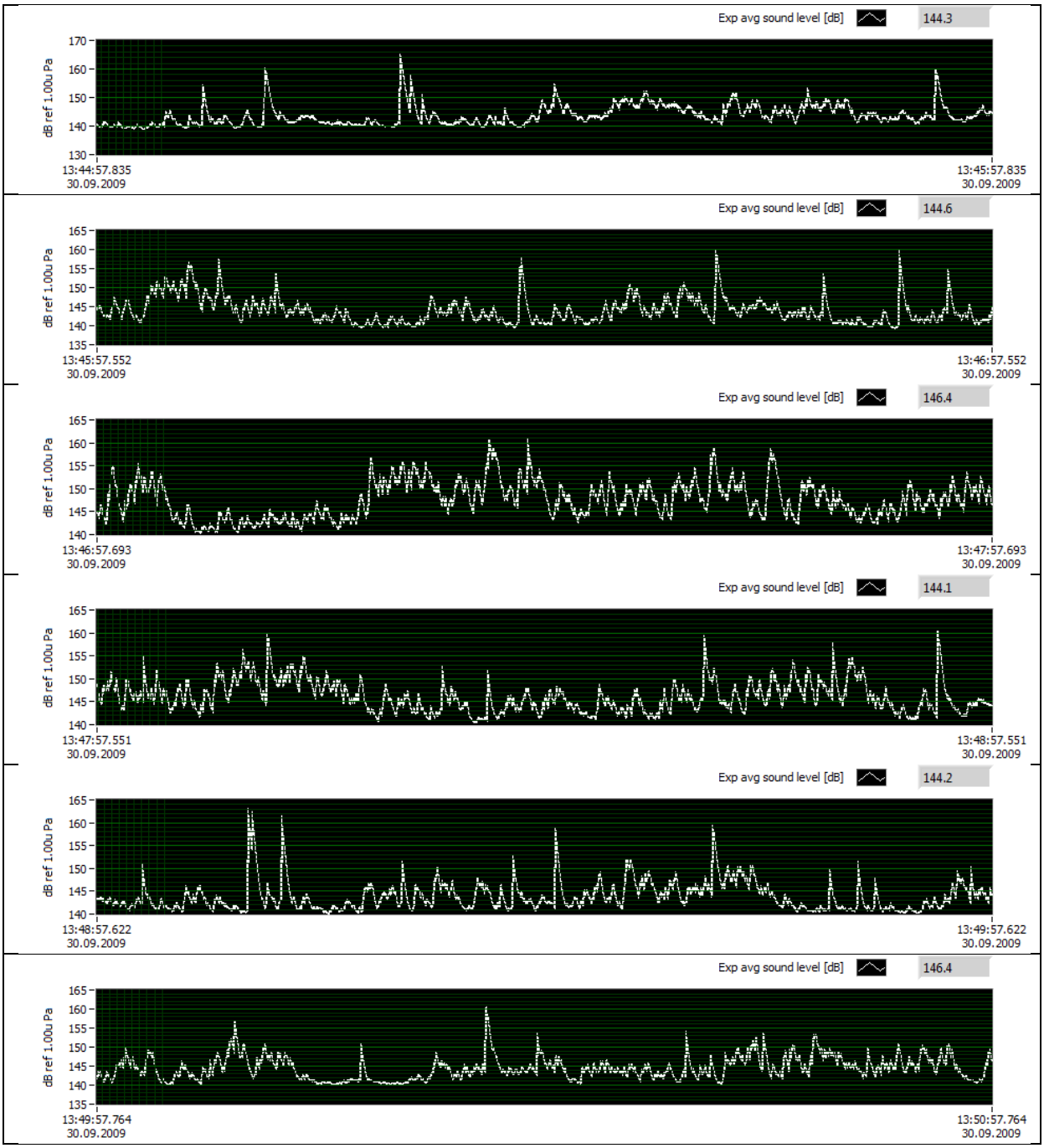



Exp avg sound level [dB]
142.1
dB ref 1.00u Pa
148
146
144
142
140
138
15:08:58.113
29.09.2009
15:09:58.113
29.09.2009
Exp avg sound level [dB]
139.2
dB ref 1.00u Pa
150
148
146
144
142
140
138
15:09:58.750
29.09.2009
15:10:58.750
29.09.2009
Exp avg sound level [dB]
139.7
dB ref 1.00u Pa
148
146
144
142
140
138
15:10:59.245
29.09.2009
15:11:59.245
29.09.2009
Exp avg sound level [dB]
139.2
dB ref 1.00u Pa
148
146
144
142
140
138
15:11:58.891
29.09.2009
15:12:58.891
29.09.2009
Exp avg sound level [dB]
139.9
dB ref 1.00u Pa
144
142
140
138
15:12:58.396
29.09.2009
15:13:58.396
29.09.2009

Skotungneset 30.September - Airgun sequence 1 (13:43 – 13:53)

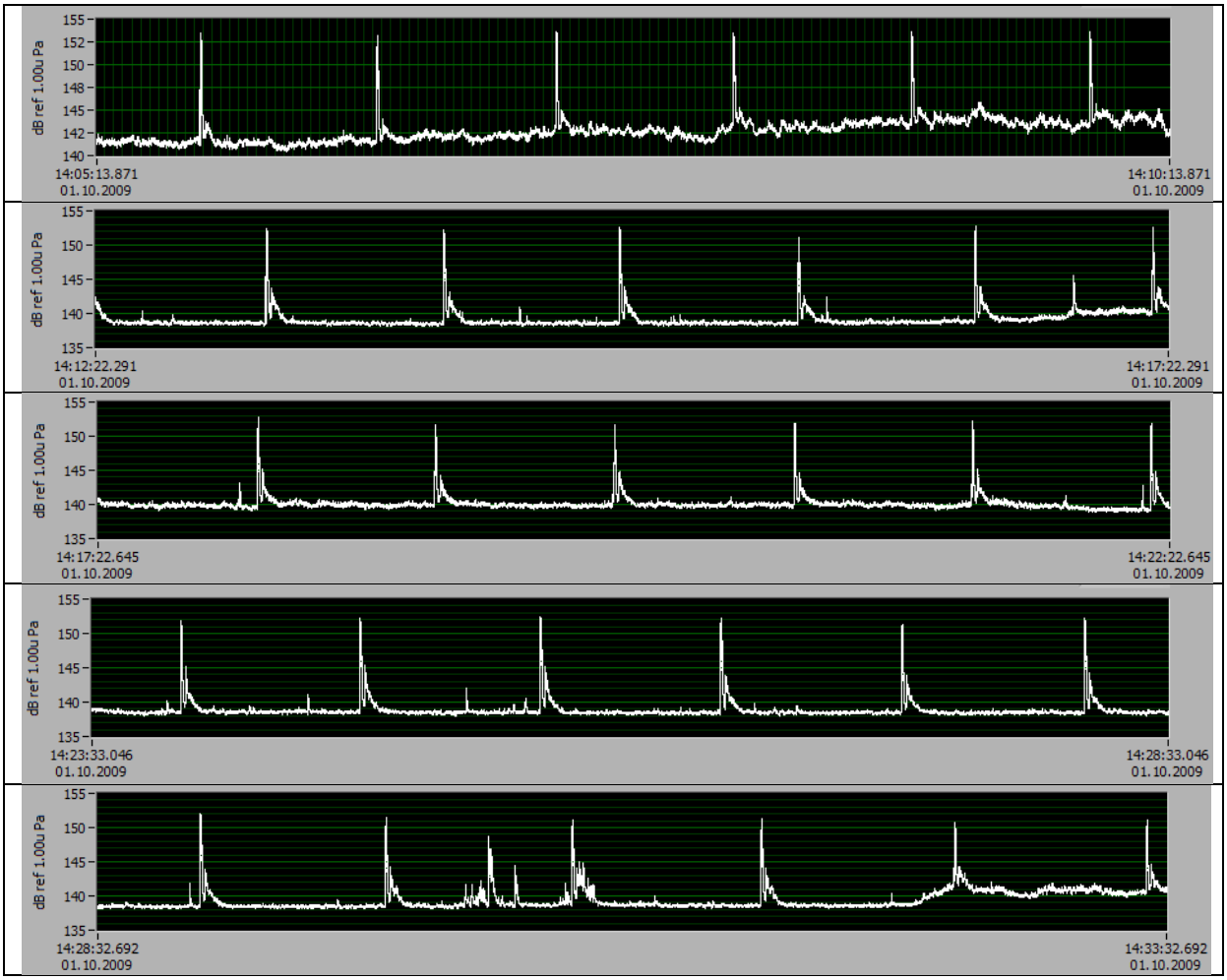
Comment: Timescale in figure do not correspond with given time in signal log (Table 4) due to unsynchronized clocks. (13:39:50 in figure = 13:43:00 on barge = time of first discharge.) End of log: ~1 minute after end of sequence. General high background noise in certain periods as hosing of nets at fish farm was conducted during testing. Each graph show sound level during 1 minute intervals




Exp avg sound level [dB]
144.3
dB ref 1.00u Pa
170
160
150
140
130
13:44:57.835
30.09.2009
13:45:57.835
30.09.2009
Exp avg sound level [dB]
144.6
dB ref 1.00u Pa
165
160
155
150
145
140
135
13:45:57.552
30.09.2009
13:46:57.552
30.09.2009
Exp avg sound level [dB]
146.4
dB ref 1.00u Pa
165
160
155
150
145
140
13:46:57.693
30.09.2009
13:47:57.693
30.09.2009
Exp avg sound level [dB]
144.1
dB ref 1.00u Pa
165
160
155
150
145
140
13:47:57.551
30.09.2009
13:48:57.551
30.09.2009
Exp avg sound level [dB]
144.2
dB ref 1.00u Pa
165
160
155
150
145
140
13:48:57.622
30.09.2009
13:49:57.622
30.09.2009
Exp avg sound level [dB]
146.4
dB ref 1.00u Pa
165
160
155
150
145
140
135
13:49:57.764
30.09.2009
13:50:57.764
30.09.2009

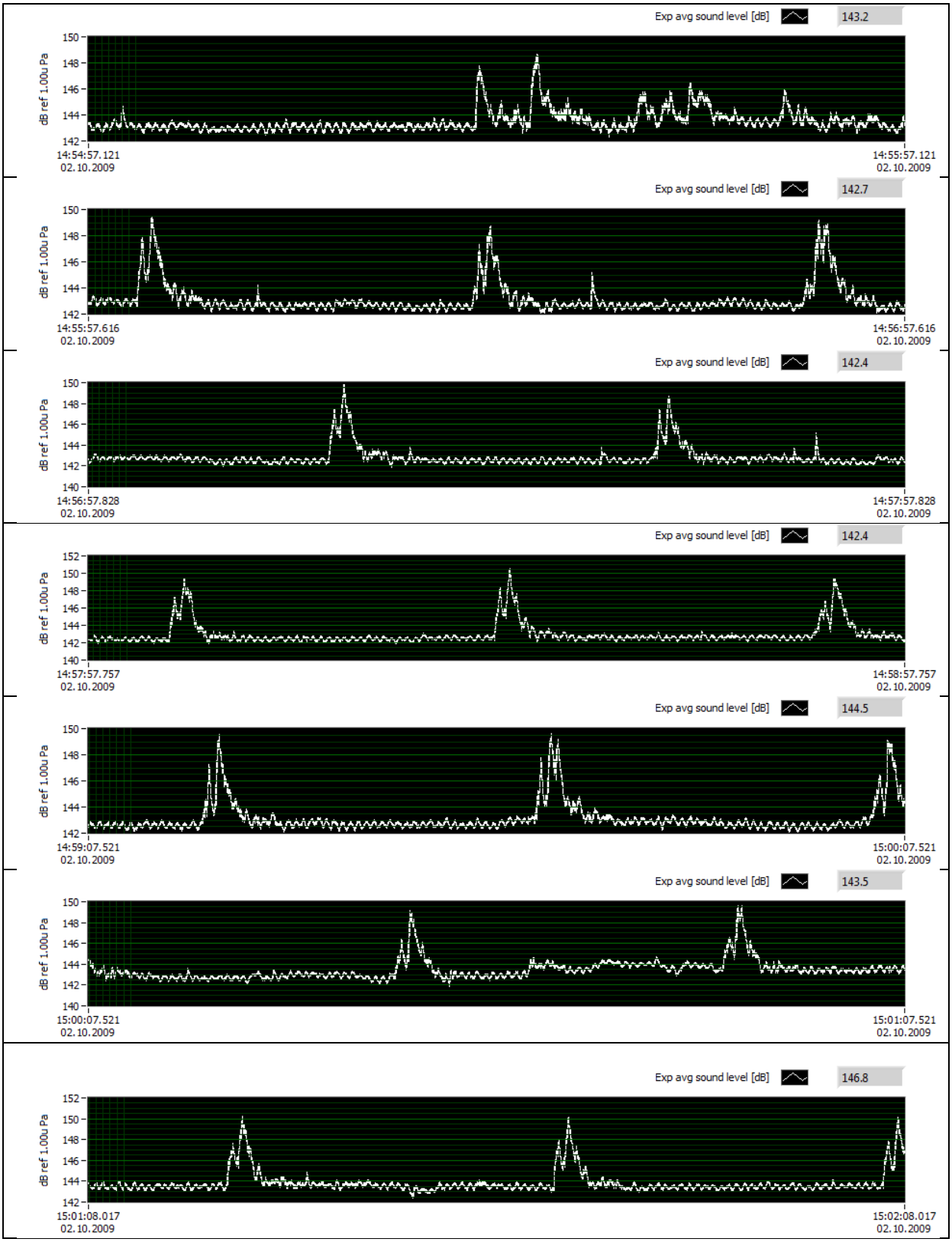
Skotungneset 1.October – Airgun sequence 5 (Extract) (14:06 – 14:45)

Comment: Figure show extract of sound level recorded during sequence. Each graph show sound level during 5 minute intervals.



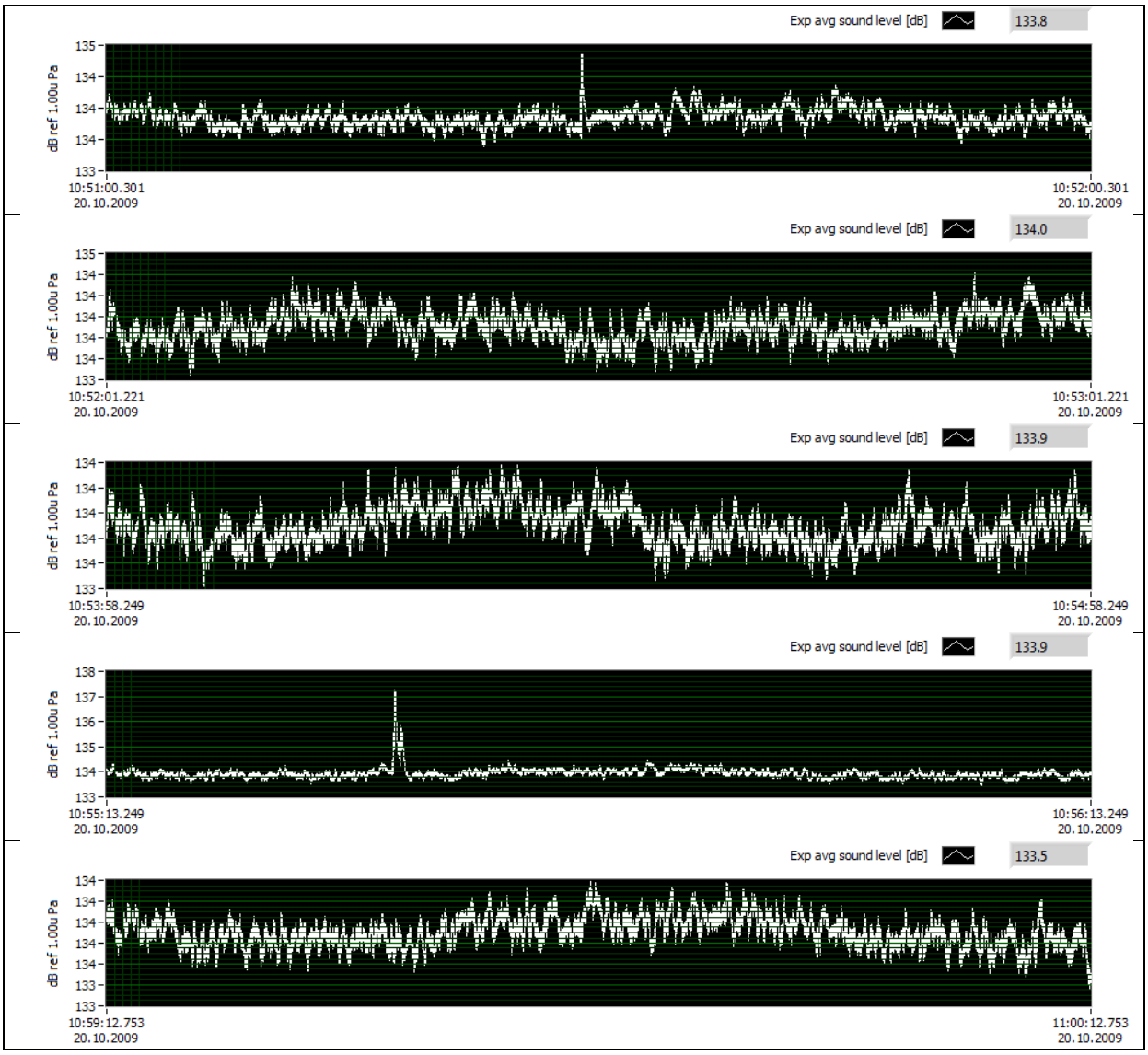
Overåneset 2.October – Airgun sequence 2 (Extract) (14:55 – 15:18)

Comment: Figure show extract of sound level recorded during sequence. Each graph show sound level during 1 minute intervals.



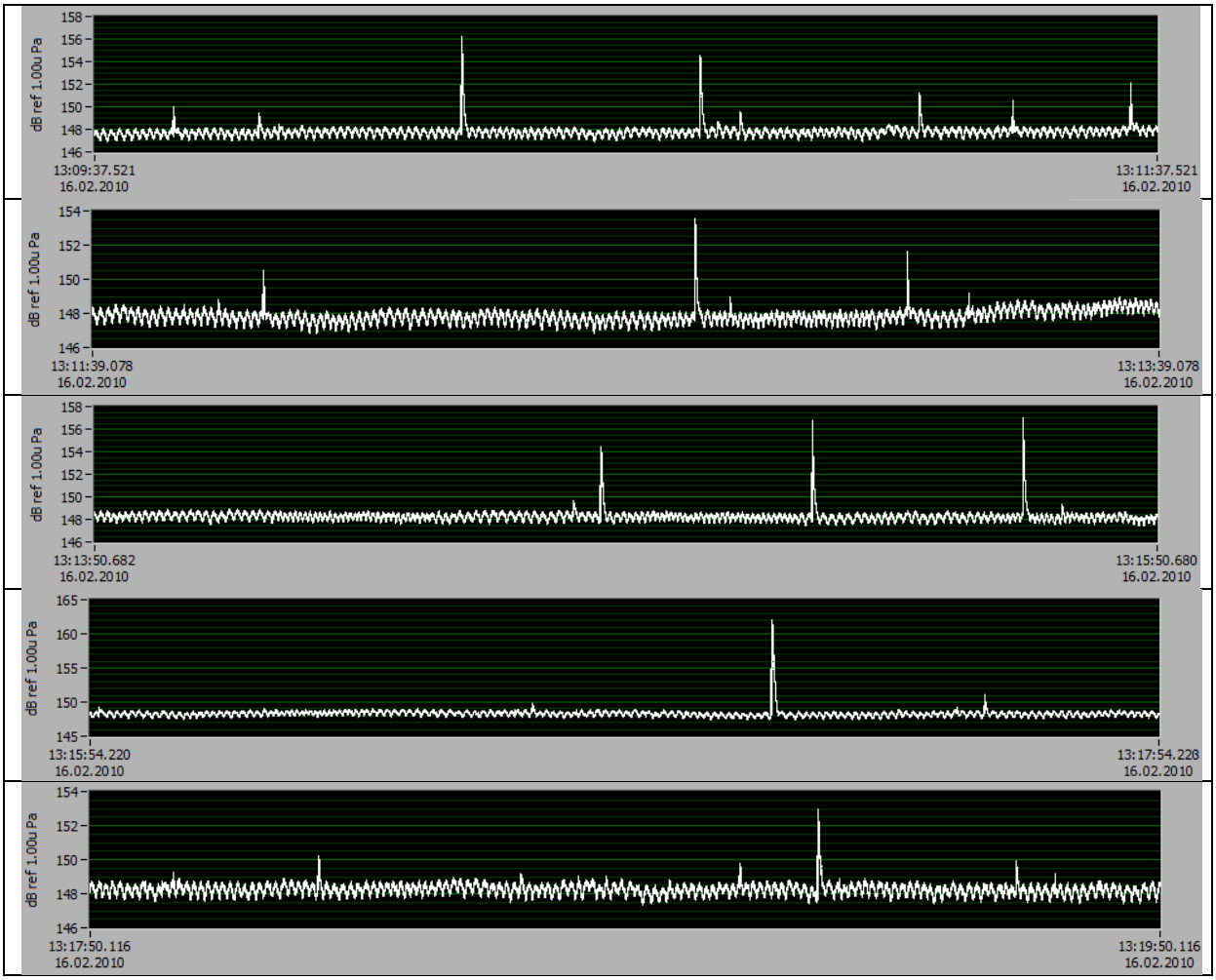
Overåneset 20.October - Airgun sequence 1 (Extract) (10:50 – 11:25)

Comment: Figure show extract of sound level recorded during sequence. No clear peaks can be observed. This could be caused by electrical interference. Each graph show sound level during 1 minute intervals.



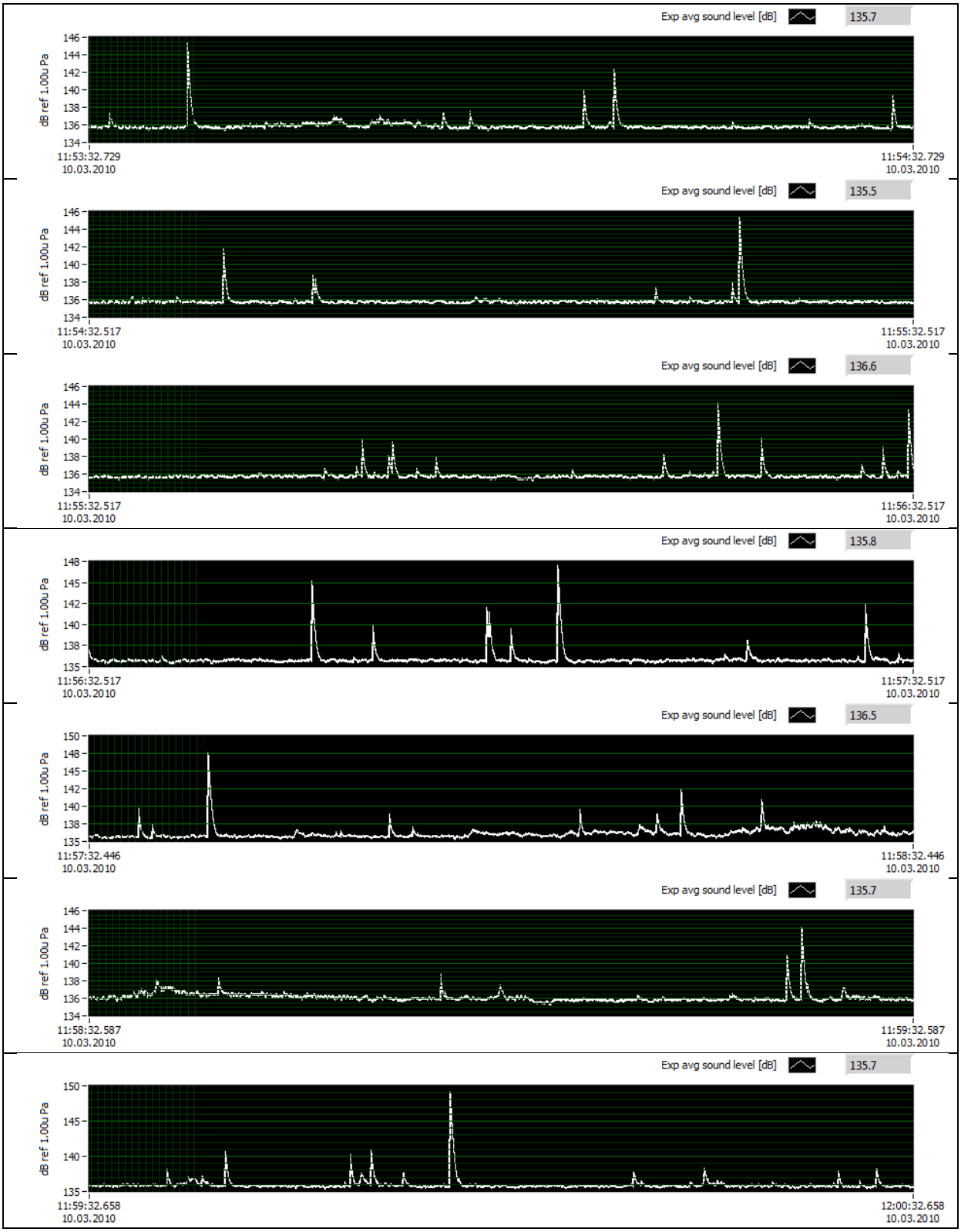
Overåneset 16.February 2010 - Airgun sequence 2 (Extract) (13:11 – 13:35)

Comment: Figure show extract of sound level recorded during sequence. Each graph show sound level during 2 minute intervals.



Overåneset 10.March 2010 - Airgun sequence 1 (Extract) (11:50 – 12:10)

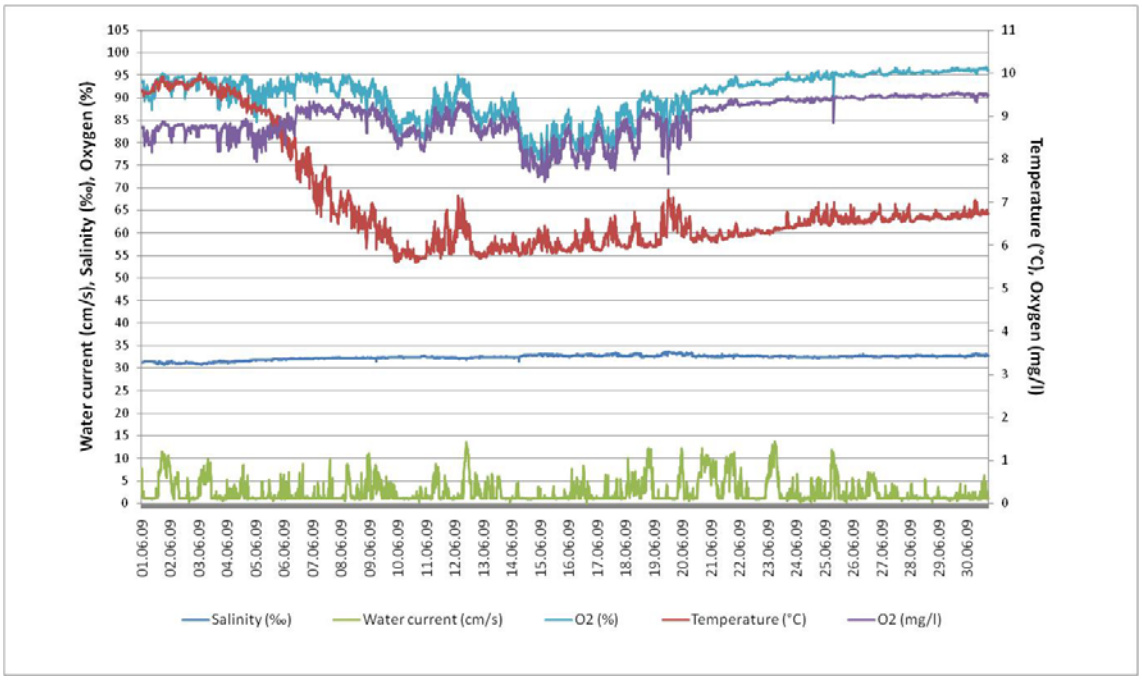
Comment: Figure show extract of sound level recorded during sequence. Each graph show sound level during 1 minute intervals.



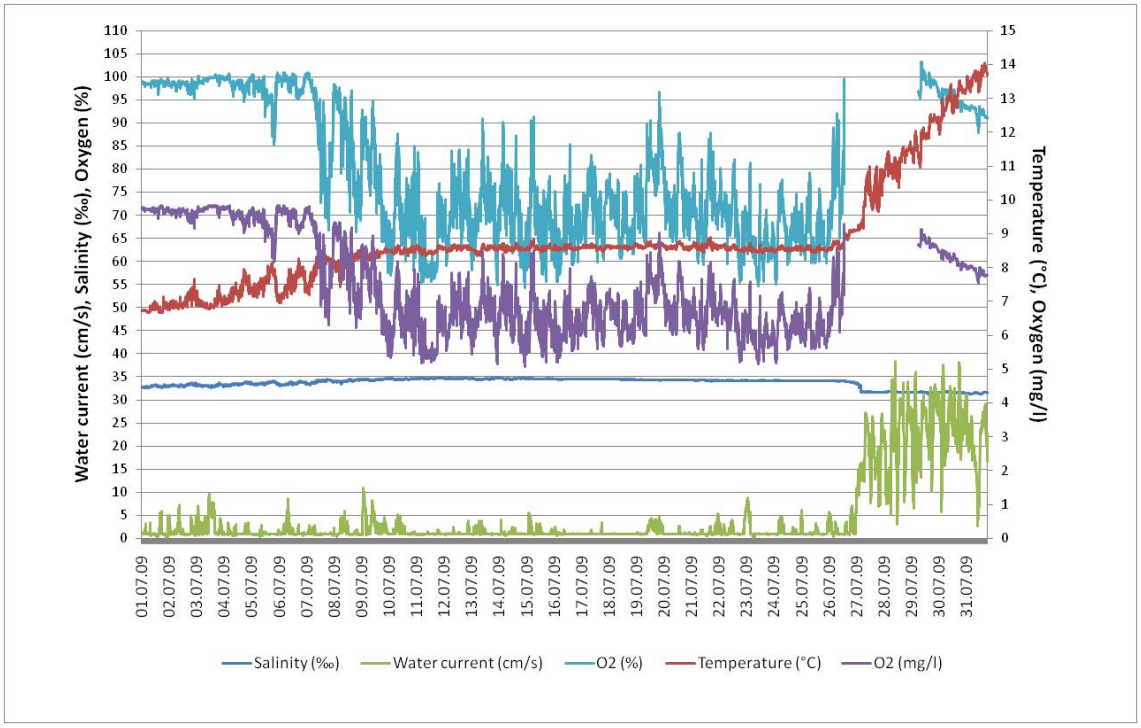
APPENDIX 3 – DATA FROM ENVIRONMENTAL MONITORING AT FISH FARMS

Skotungneset

June 2009

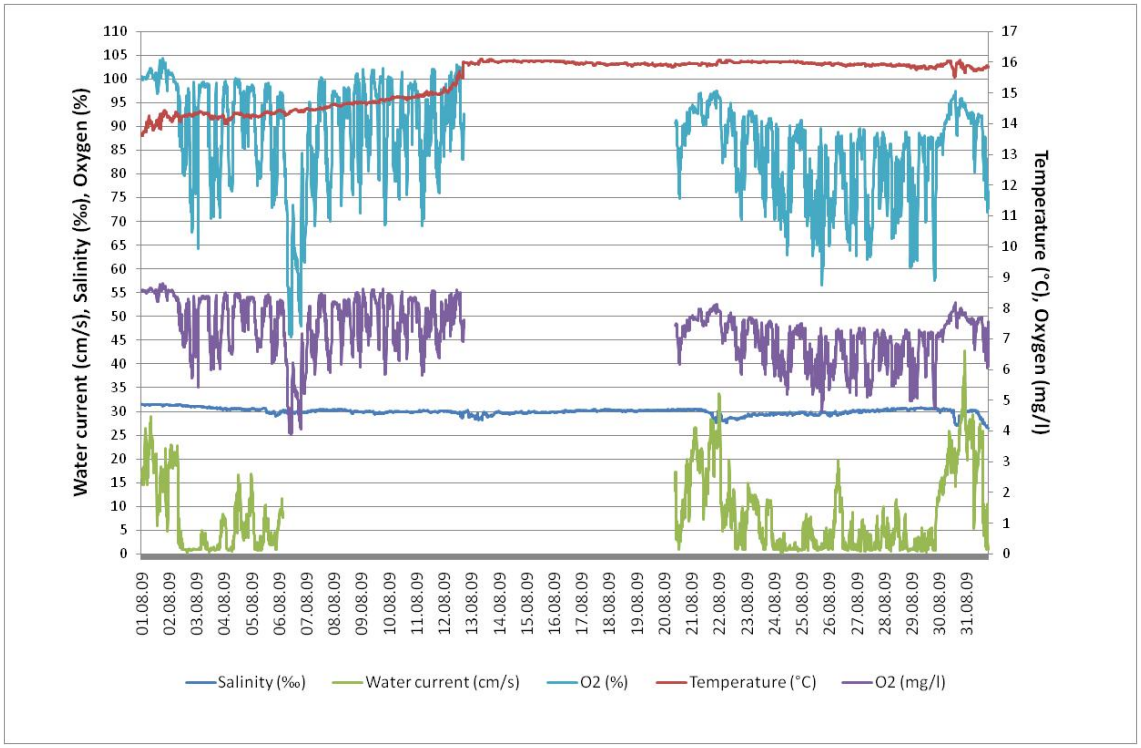


July 2009



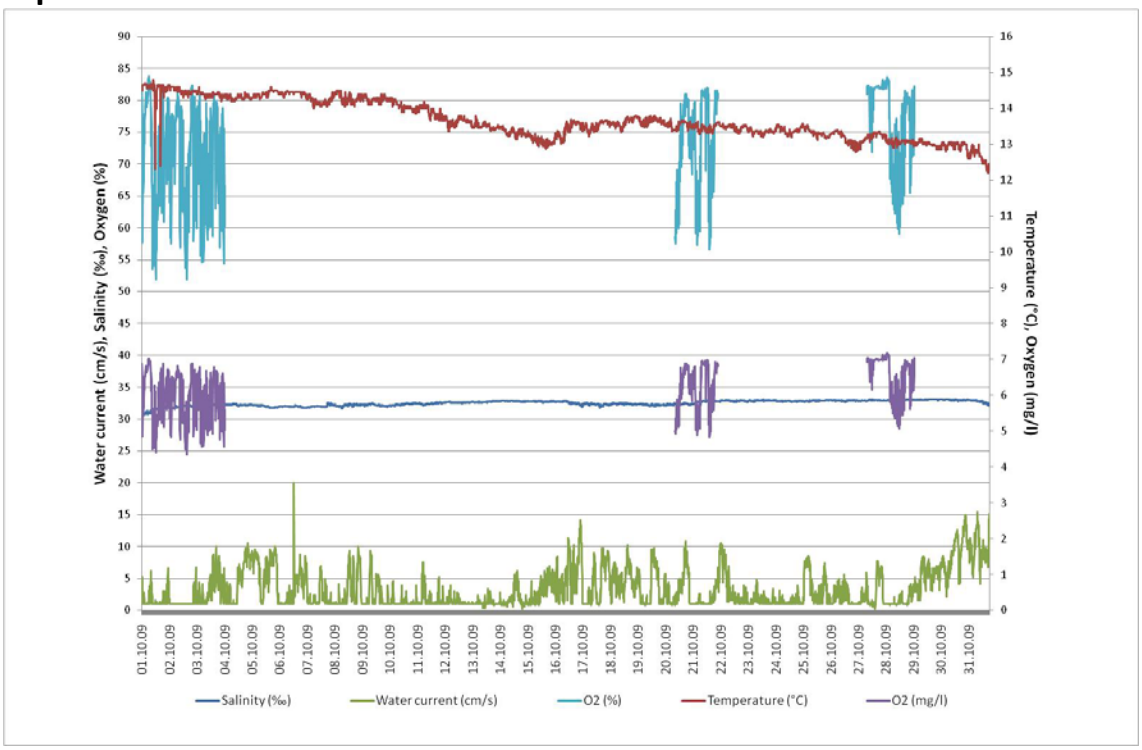
Missing data due to technical problems shown as gaps in figure.

August 2009



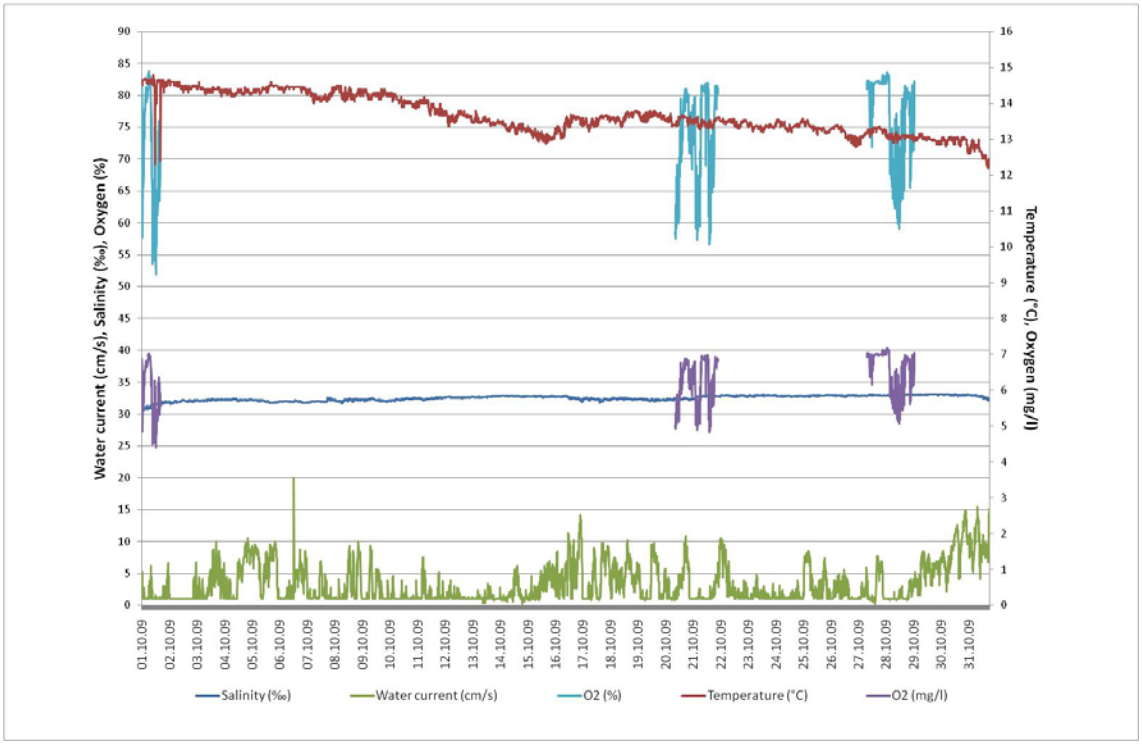
Missing data due to technical problems shown as gaps in figure.

September 2009



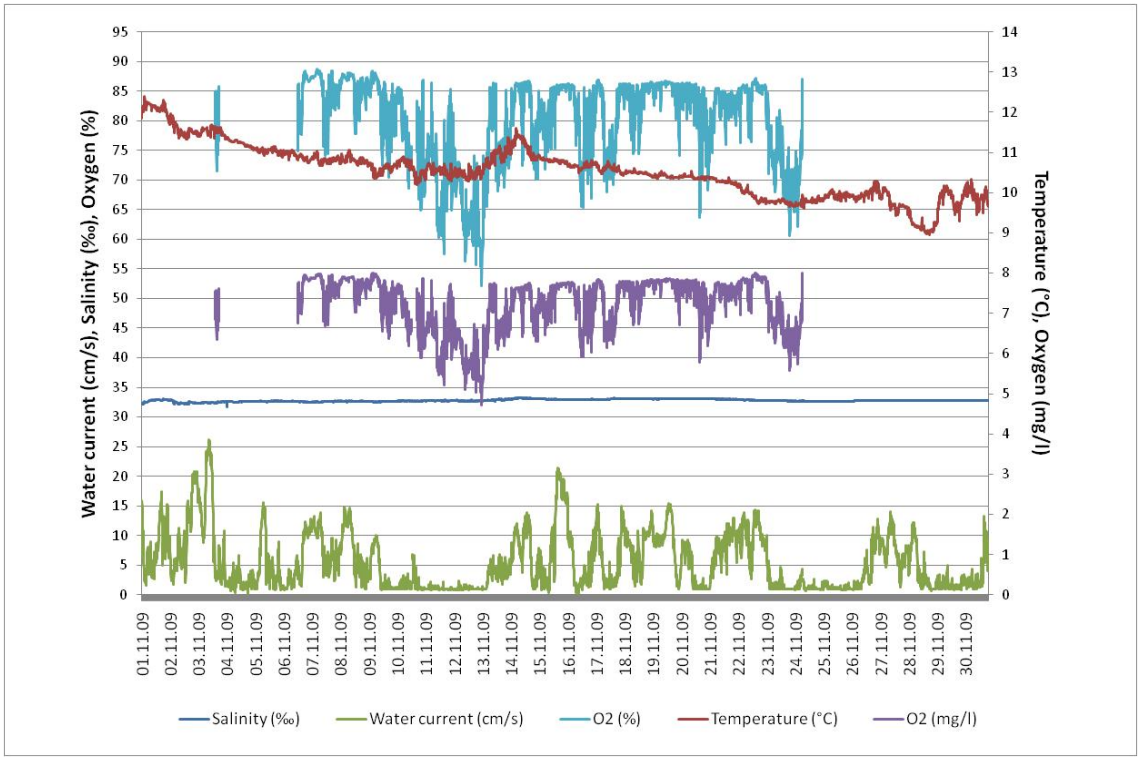
Missing data due to technical problems shown as gaps in figure.

October 2009



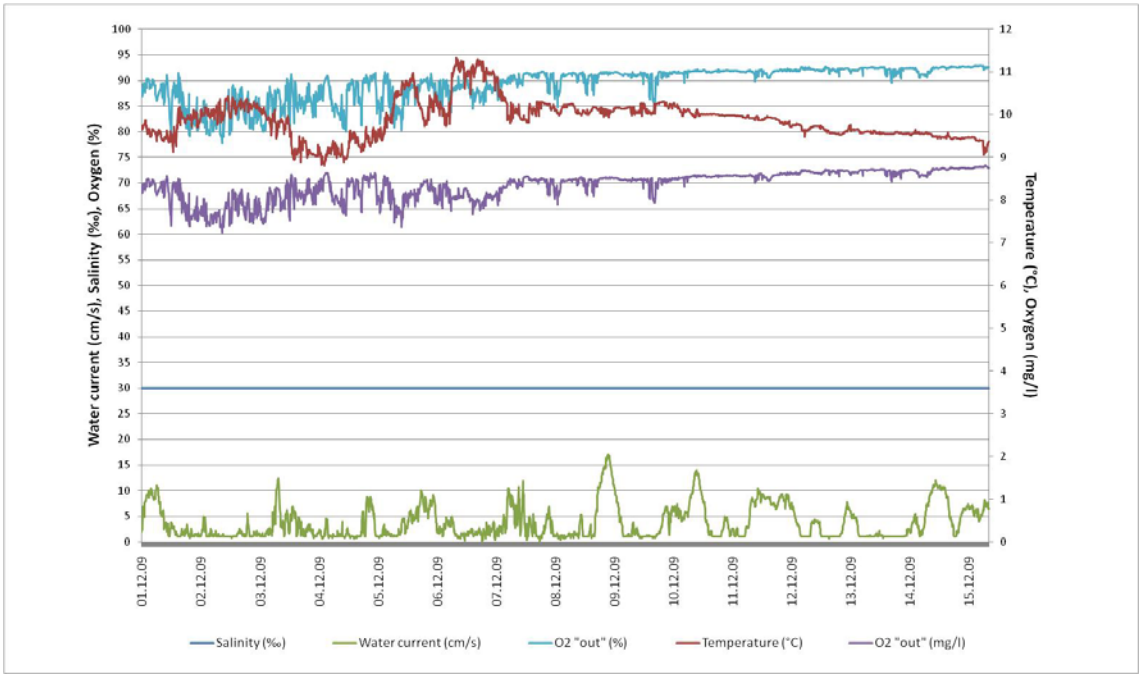
Missing data due to technical problems shown as gaps in figure.

November 2009



Missing data due to technical problems shown as gaps in figure.

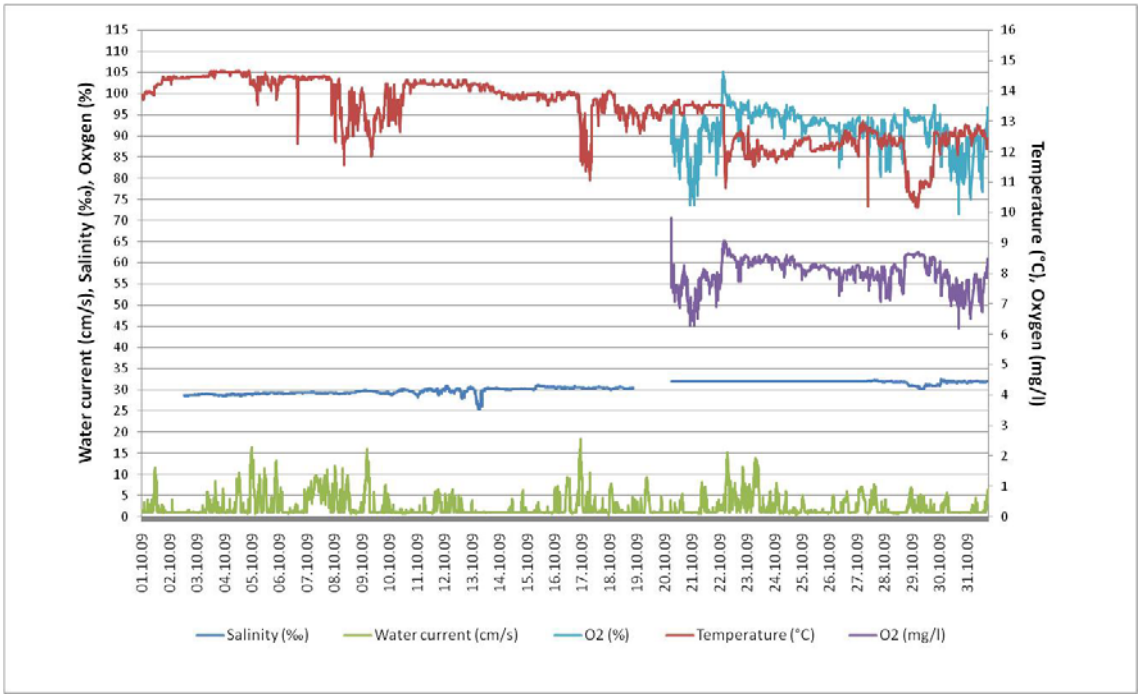
December 2009



Salinity not measured due to technical problems, set to 30‰ for calculation purposes.

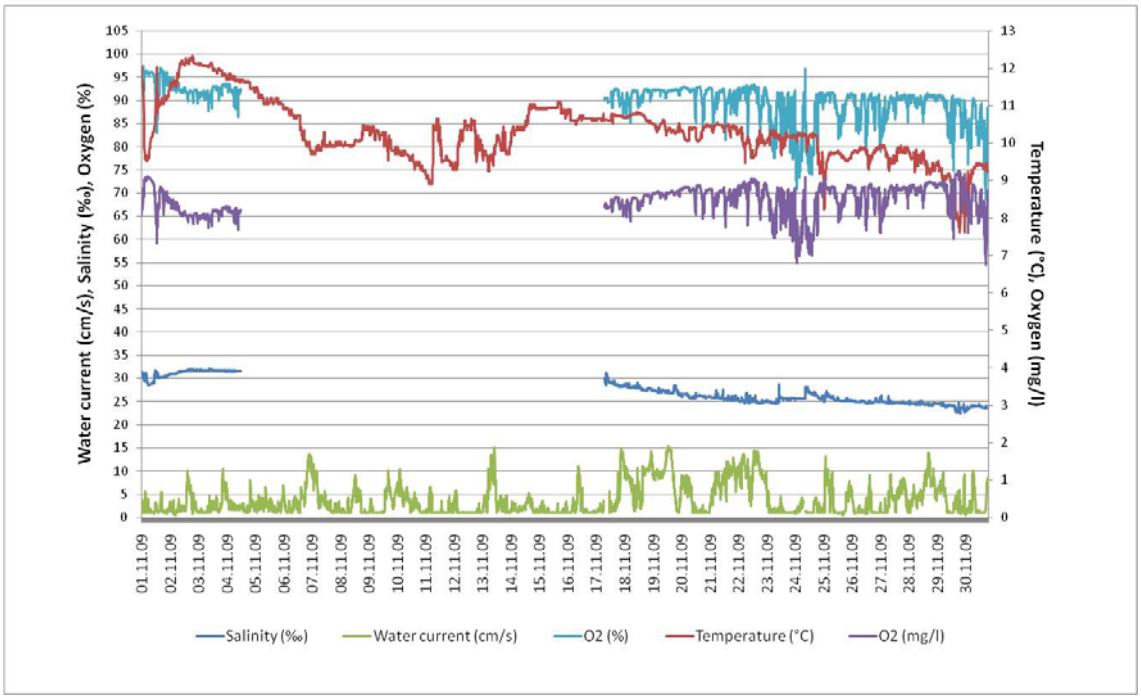
Overåneset

October 2009



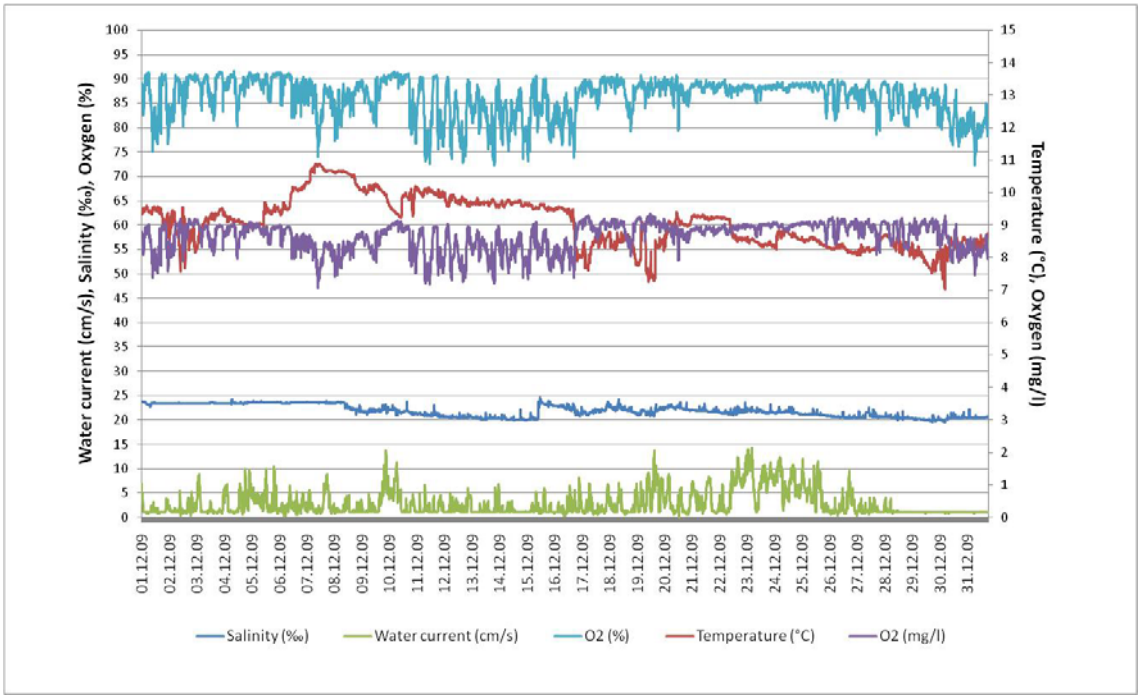
Missing data due to technical problems shown as gaps in figure.

November 2009

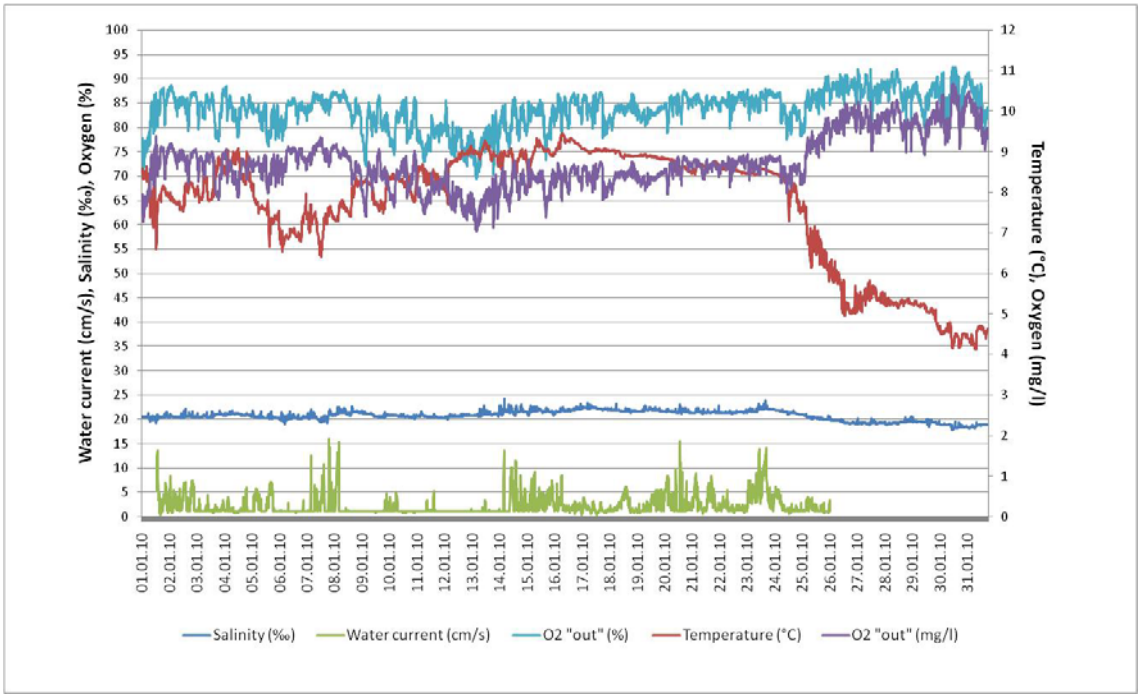


Missing data due to technical problems shown as gaps in figure.

December 2009

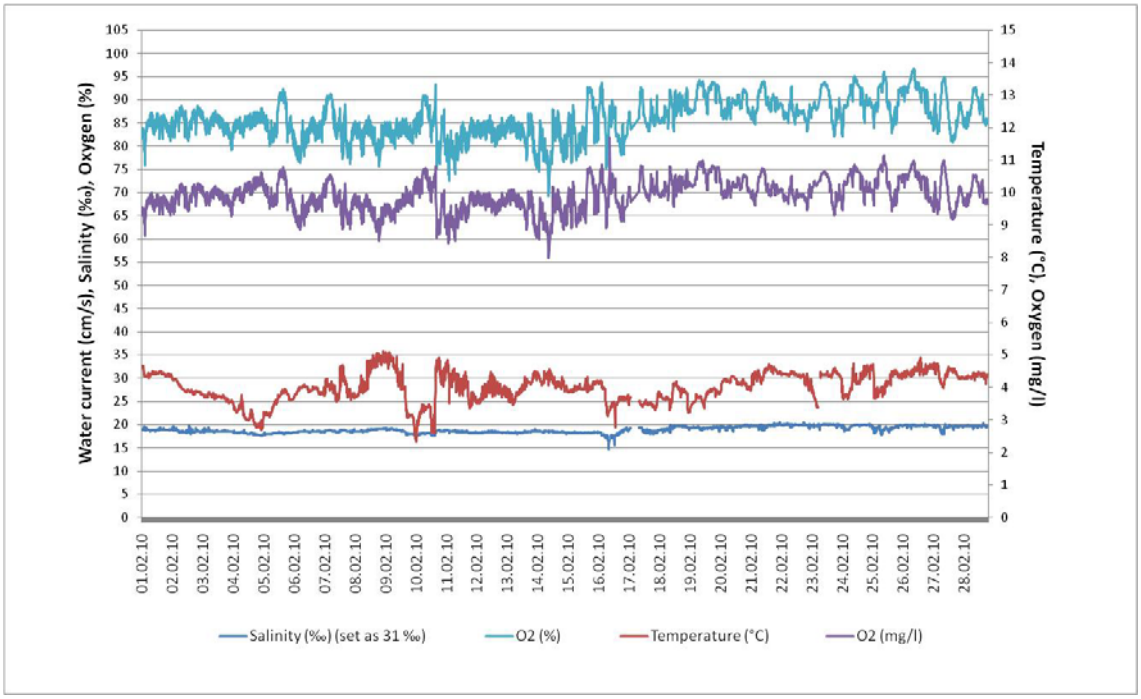


January 2010

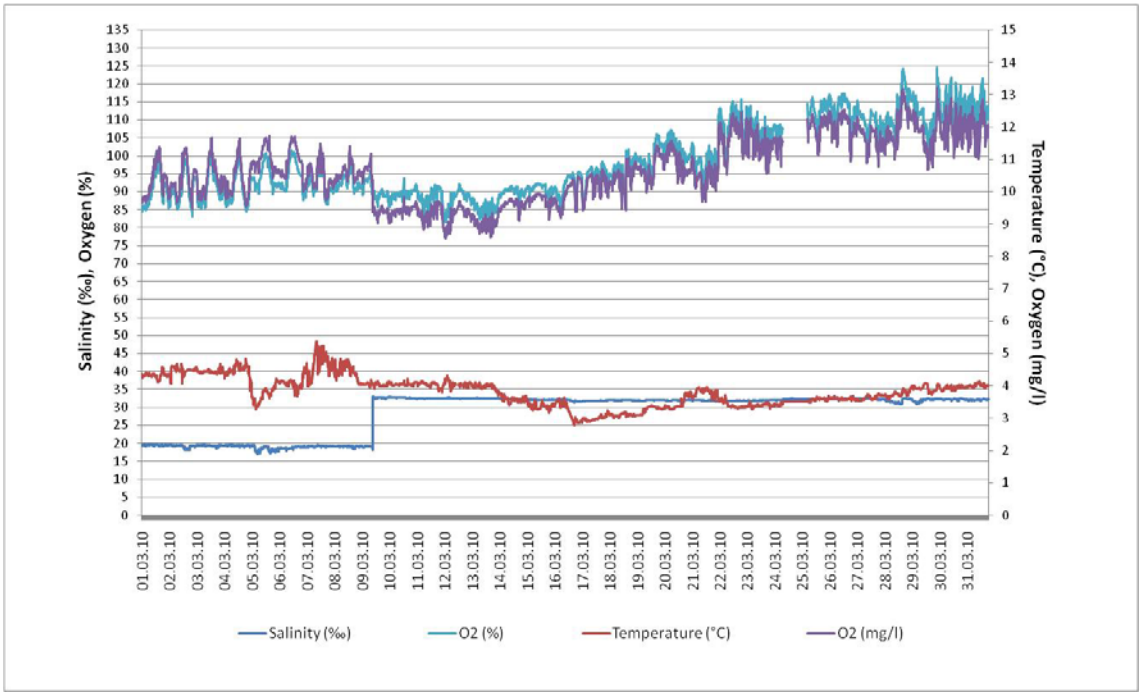


Missing data due to technical problems shown as gaps in figure.

February 2010

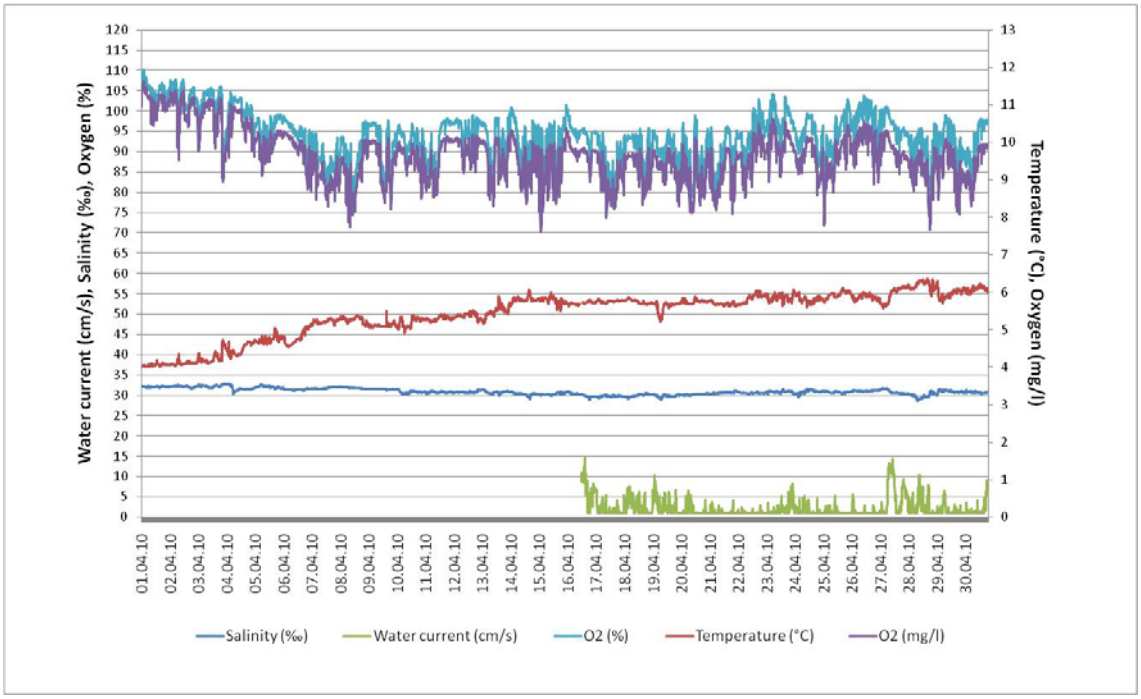


March 2010



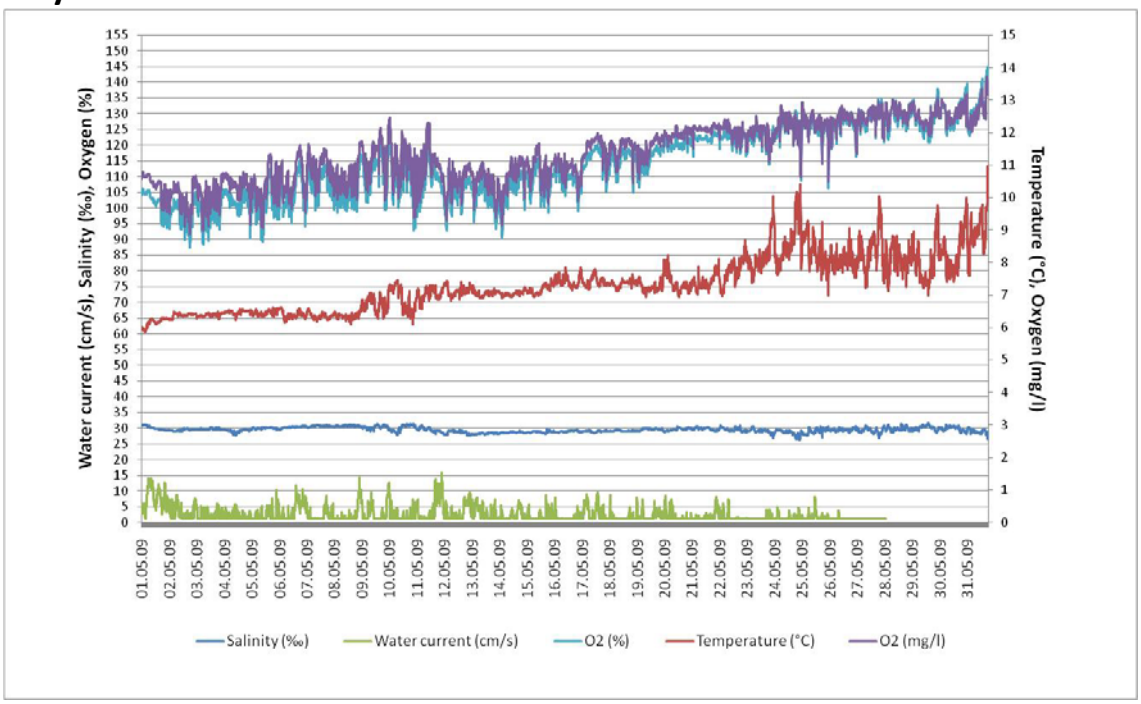
Rise in salinity caused by redeployment of monitoring station at greater depth. Oxygen levels above 100% most probably caused by photosynthesizing phytoplankton.

April 2010



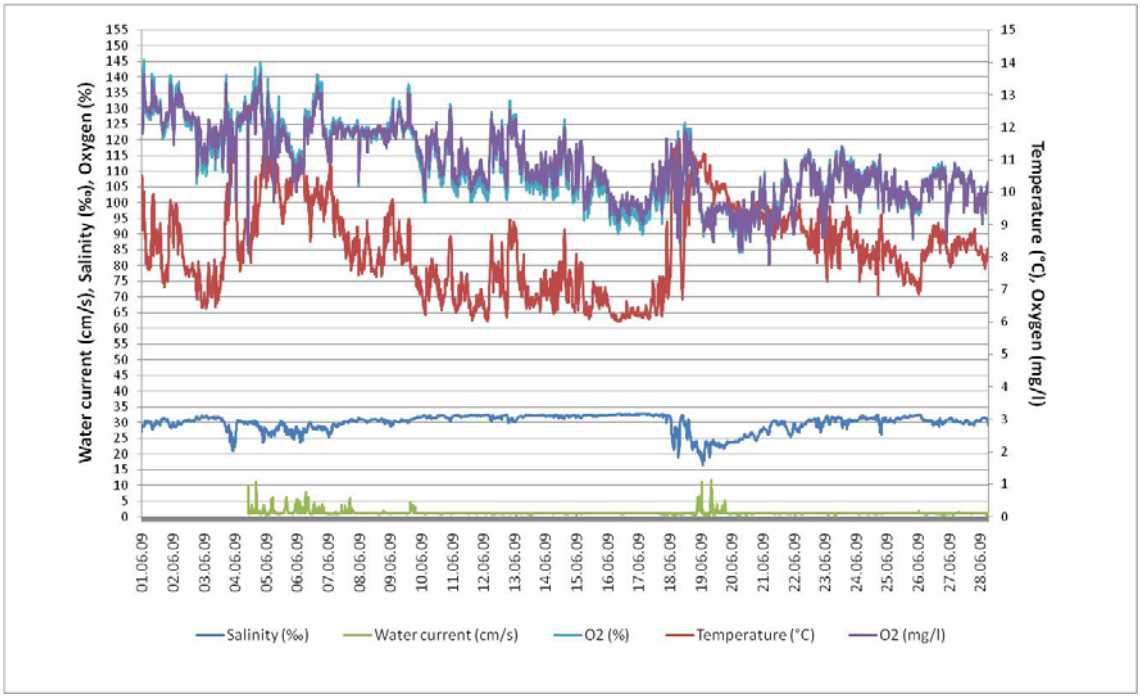
Missing data due to technical problems shown as gaps in figure.

May 2010



Missing data due to technical problems shown as gaps in figure. Oxygen levels above 100% most probably caused by photosynthesizing phytoplankton.

June 2010



Oxygen levels above 100% most probably caused by photosynthesizing phytoplankton.