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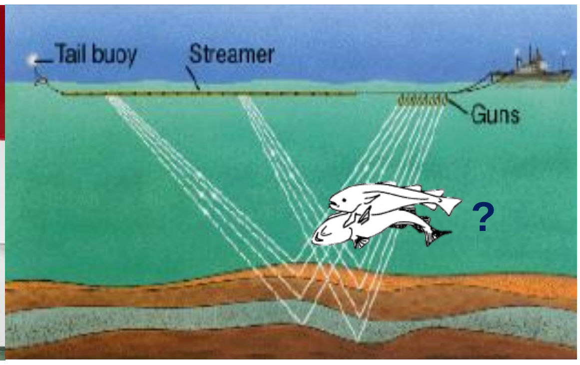
Cruise report

SpawnSeis seismic exposure experiment on free ranging, spawning cod



Cruise report for surveys 2020830 and 2021826

Lise Doksæter Sivle, Nils Olav Handegard, Petter Kvadsheim, Tonje Nesse Forland, Kari Wegge Ektvedt, Erik Schuster, Kate McQueen

Introduction

The objective of the SpawnSeis project is to study effects of seismic exposures on the behaviour of wild, free ranging, spawning cod using acoustic telemetry in Austevoll, Norway.

In autumn 2018, a total of 36 acoustic receivers were placed in two grids, on two separate cod spawning grounds. These act as one exposure area (30 receivers) and a smaller reference area (6 receivers) (fig. 1). Single receivers were also placed in northern and southern exit routes from the larger grid, as well as on three nearby spawning sites to document potential use of multiple sites during a season. Additionally, a curtain of three receivers have been deployed to cover the western exit route from the study area, and several single receivers were deployed north of the grid to increase detection coverage in this area. The first seismic survey was conducted in 2020, and the second survey in 2021 was conducted as similarly as possible to the first one.

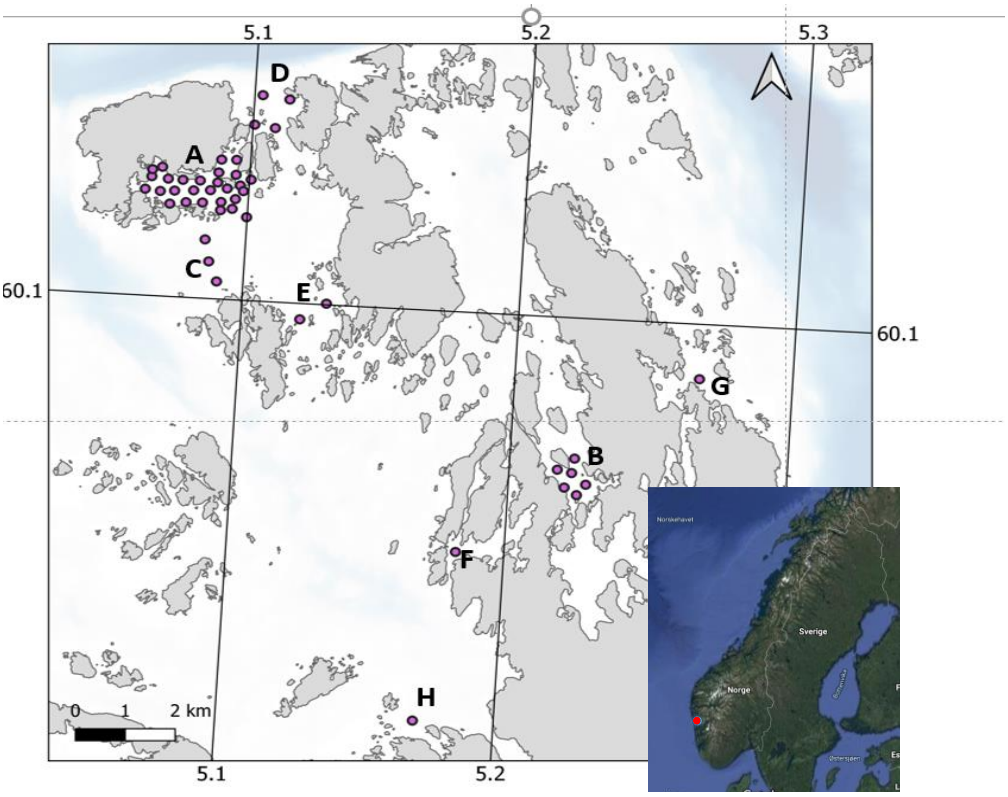


Figure 1. Overview of the telemetry receivers in the area. These are placed in the main exposure location in Bakkasund (A), the control area in Osen (B), as curtains to control the western (C), northern (D) and southern (E) gateway from the main area as well as 3 additional spawning sites in the area (F, G, H). The miniature insert picture shows the location of the research area in Austevoll as a red mark.

The objective of the two surveys covered in this report was to deploy airguns from the vessel, to expose the experimental area and to monitor the resulting noise patterns in the area where the cod are tagged. CTD stations were also taken in the area to characterise the propagation properties of the water column. The behavioural data will be downloaded from the listening buoys for the fish tags later and is not part of this report. The two surveys were conducted in two succeeding years; 2020 and 2021, both in mid-February, and followed the same experimental set-up.

Additionally, the survey was conducted in close collaboration with the ZoopSeis project, aiming to study mortality of zooplankton that occurs naturally in the area with and without seismic, as well as to study survival and non-lethal effects such as growth and development of cultivated copepods after exposure to seismic air gun shots.

During the exposure experiment in 2020, zooplankton samples were collected more or less opportunistically with plankton traps in the vicinity of the seismic shooting. Samples with and without shooting were taken to the lab, species were identified, and mortality rate for each species calculated. This was repeated in 2021, in addition to a more controlled experiment with cultivated zooplankton in small plastic bags at a fixed position. The cultivated copepods will be investigated in terms of growth and development, egg production, and egg hatching success in the following days after exposure and controls.

This sampling was done from a smaller vessel, and the description of that work is not covered in this report.

Materials, methods and results

Time period

The first survey was conducted between February 10th and February 14th 2020, and the second between February 14th and February 19th 2021. Timing of the survey was chosen to coincide with the spawning period of cod.

Vessel

The cruise was conducted using RV HU Sverdrup II for the exposure experiment (fig. 2). The vessel is 55 m length overall, has a maximum speed of 15 knots and has a crew of 7 in addition to a space for 15 scientific crew members.

Figure 2. H.U. Sverdrup II used for the seismic exposures.

A variety of scientists from the Norwegian Defense Research Agency (FFI), the Institute of Marine Research (IMR) and University of Bergen participated (UIB) in the surveys (table 1).

Table 1. Scientific crew for the two surveys

Scientific Crew 2020	Scientific crew 2021
Petter Kvadsheim (FFI)	Petter Kvadsheim (FFI)
Kari Ektvedt Wegger (FFI)	Kari Ektvedt Wegger (FFI)
Nils Olav Handagard (IMR)	Lise Doksæter Sivle (IMR)
Tonje Nesse Forland (IMR)	Nils Olav Handagard (IMR)
Erik Schuster (IMR)	Erik Schuster (IMR)
Franck Andersen (UIB)	Kate McQueen (IMR)
Jan Tore Øvredal (IMR)	

Seismic air gun system and vessel based hydrophones

The vessel has an airgun system installed consisting of an array with two 40 Cubic Inch HGS Sleeve Guns. The air guns are supplied with two Reavel-5417 compressors and the system is controlled by a Hot Shot fire control (Real Time Systems) (table 2). The air guns were fired at 110 bar pressure, with an expected nominal broadband peak pressure level of 223 dB re 1µPa·m. The operation of the array was monitored by a hull mounted TC4034 calibrated hydrophone with EC6081 amplifier (Teledyne).

During exposures the airgun array (2 times 40 Cubic Inch) was towed at 3 m depth at 2-3 knots speed. During active exposures guns were fired synchronously at 110 bar pressure every 10 s. UTC time and GPS position of every shot were recorded by the HotShot system. Levels and spectral content were recorded by the hull mounted hydrophone. The set-up of the system is shown in fig. 3 and fig. 4.

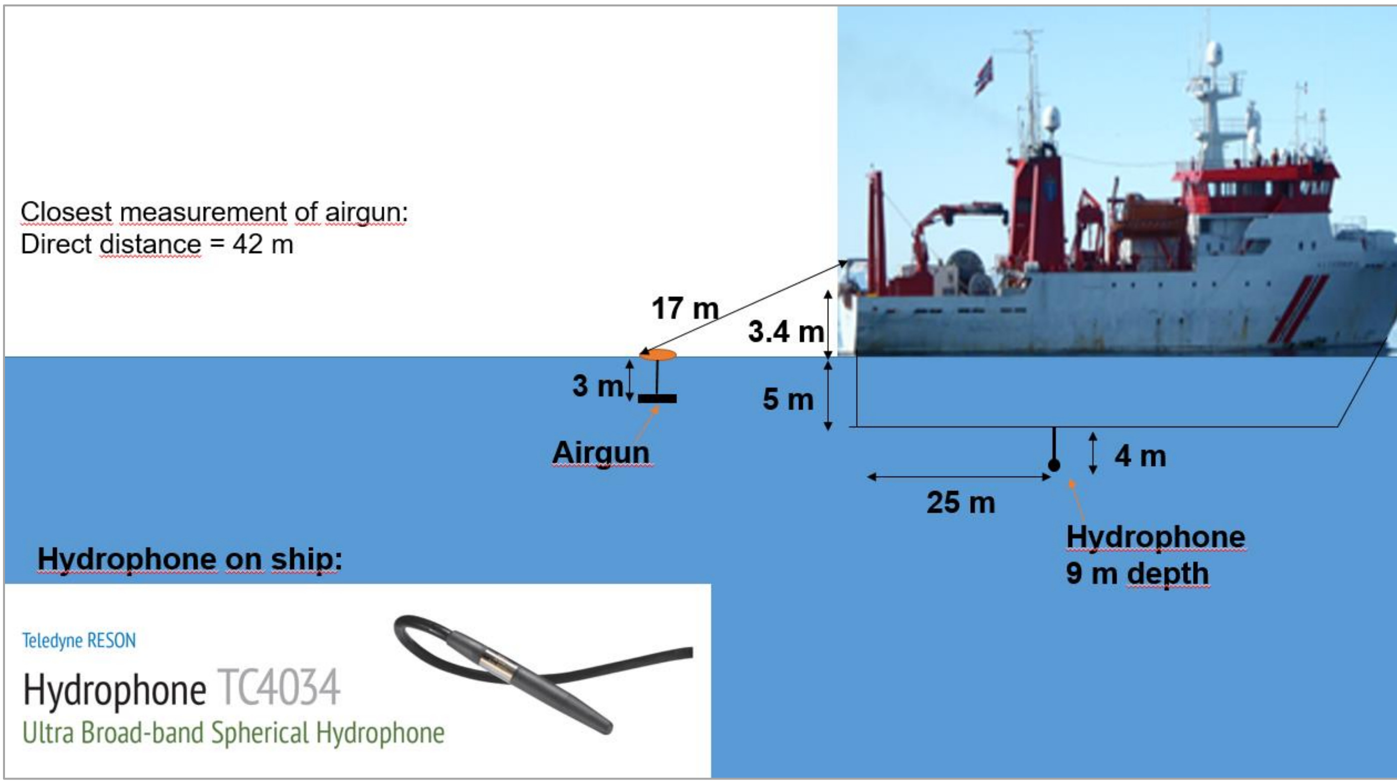


Figure 3. Air gun and hydrophone set up at H.U. Sverdrup.

Table 2. An overview of the vessel based systems.

System	Company	Instrument Name	Software version	Link
Vessel mounted Hydrophon	Teledyne Reson	TC4034		www.teledyne-reson.com
Preamplifier	Teledyne Reson	VP2000 voltage Preamplifier EC6081 mk2		www.teledynemarine.com/reson/
Sound card/ Audio system	RME	RME Fireface UC	RME Totalmix version 1.61	www.rme-audio.com
Recording system for sound card	Reaper		v 5.12/x64 rev ef 6009 (jan 21 2016)	www.reaper.fm
Source	Texas instrument/	Sleeve Gun (2* 40 cuin)		
Seismic source synkronizer system	Teledyne Real Time System	HotShot Rack monted version	Software versjon 3.002 Firmware 3.00	www.real-time-system
Compressor system for sleevgun	Gransow	CompAir Revell 5417		www.compair.com
System trigger	IXBlue	Delph	version 4,0,0,0	www.delph.ixblue.com
Shot loger	Made by FFI			
Eventlogger	Made by FFI			

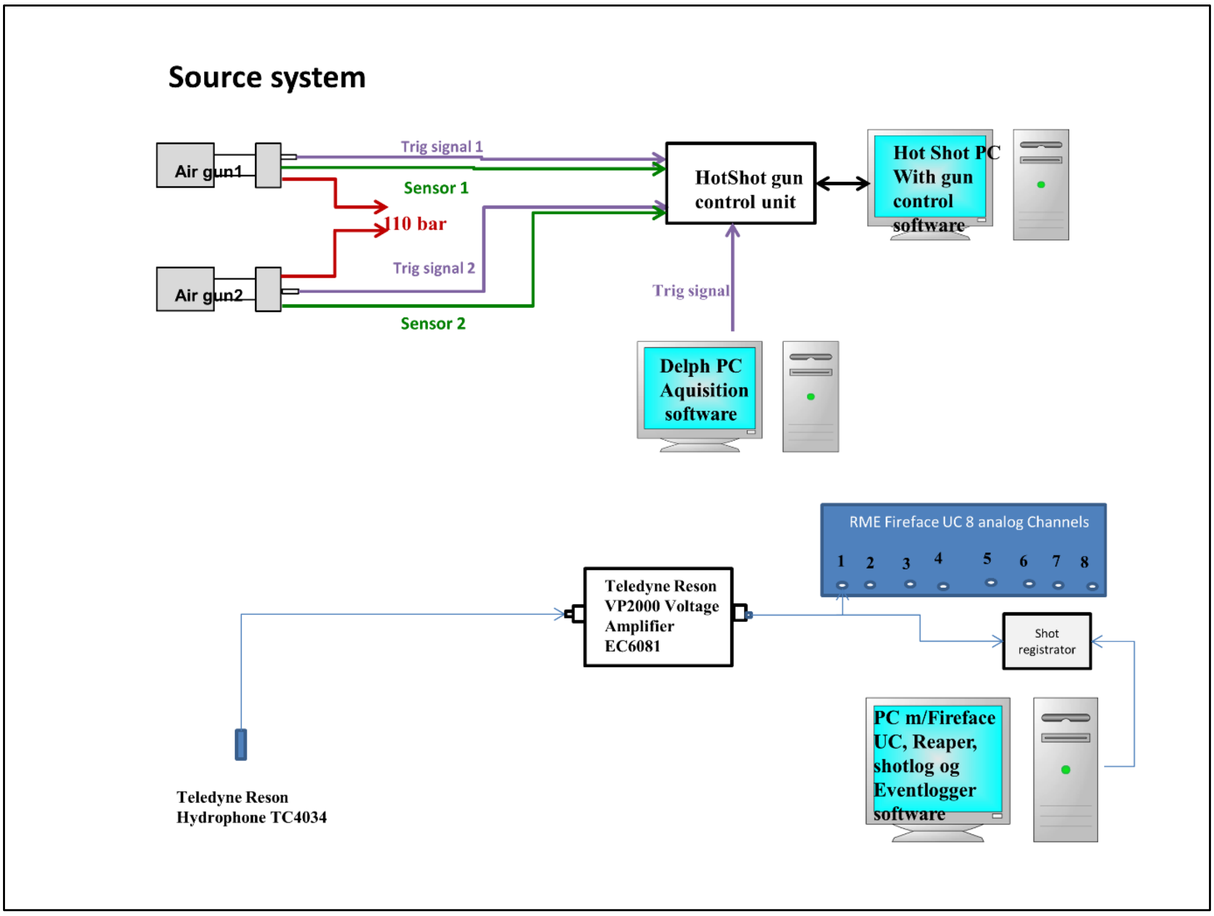


Figure 4. The exposure system and the vessel mounted hydrophone.

Exposure design

Three types of treatments were used:

- 3 hrs of active seismic exposure
- 3 hrs of boat control (ship doing the race track but no active seismic)
- 3 hrs of silent control (no ship in the area)

During the seismic exposure and boat control, the source vessel sailed a 3 nmi racetrack three times (fig. 5). Each treatment lasted 3 hours (tables 3 and 4). The source boat continued until the end of the 3-hour exposure session, and then switched to the next session according to table 3 and 4. During the boat control the source vessel sailed the same transect but without active transmission. During the pre-exposure silent control session, the source boat stayed more than 3nmi away from the spawning site. The order of the sessions is fully randomized within blocks of silent control, seismic exposure and boat control, allowing for testing the silent control as a "treatment". In 2020, a total of 9 blocks were conducted (table 3), while 10 blocks were conducted in 2021 (table 4).

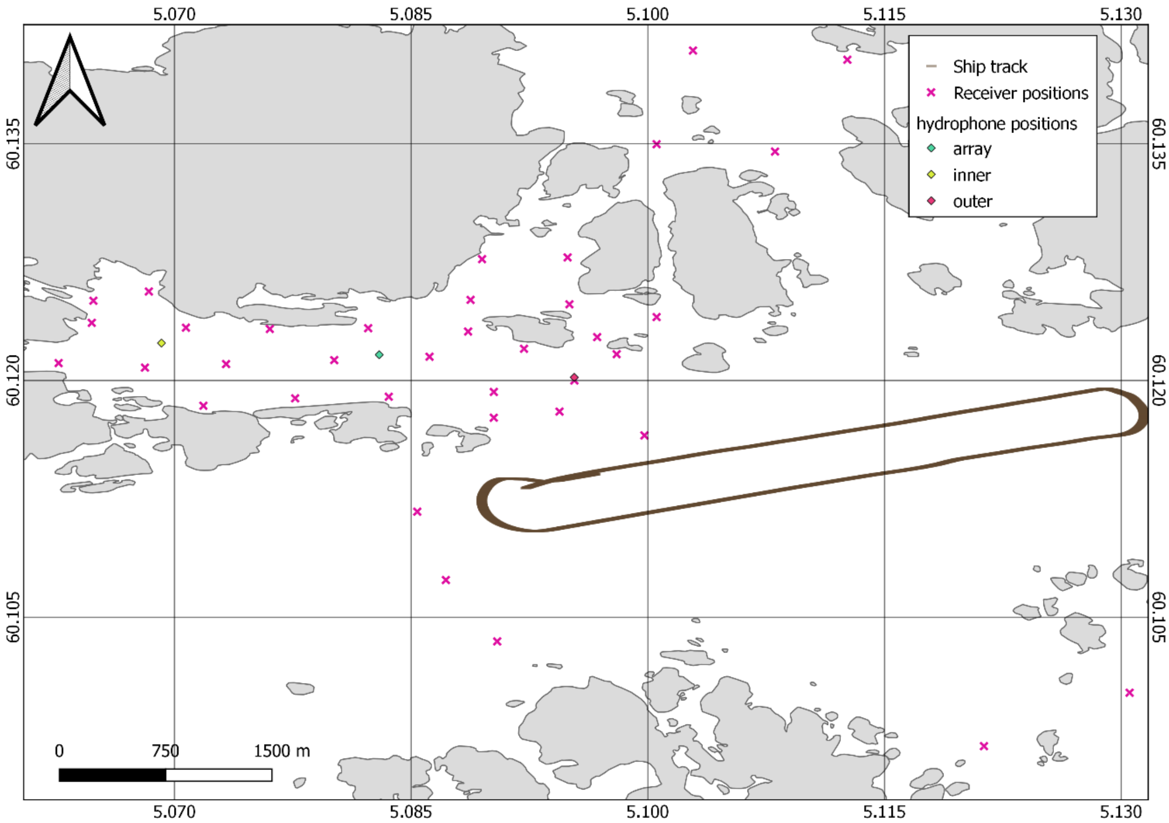


Figure 5. The 3nmi racetrack sailed by the source vessel (HUS) during the seismic and no-seismic exposure sessions. During silent control sessions HUS stayed in a holding area south of the exposure site sheltered from the cod spawning site. The hydrophone bottom rigs (inner and outer) and hydrophone arrays, as well as the Vemco receivers are also marked in the map.

Table 3. Executed exposures during the 2020 trial. All times are in UTC.

Number	**Treatment**	**Start**	**End**
0.1	Boat control	09.02.2020 22:50	10.02.2020 01:49
1.1	Seismic	10.02.2020 15:25	10.02.2020 18:24
1.2	Silent control	10.02.2020 19:08	10.02.2020 22:50
1.3	Boat control	10.02.2020 22:50	11.02.2020 01:49
2.1	Seismic	11.02.2020 01:49	11.02.2020 04:49
2.2	Boat control	11.02.2020 04:49	11.02.2020 07:50
2.3	Silent control	11.02.2020 07:50	11.02.2020 10:55
3.1	Boat control	11.02.2020 10:55	11.02.2020 13:55
3.2	Silent control	11.02.2020 13:55	11.02.2020 16:43
3.3	Seismic	11.02.2020 16:54	11.02.2020 19:55

4.1	Boat control	11.02.2020 19:55	11.02.2020 22:55
4.2	Seismic	11.02.2020 22:55	12.02.2020 01:55
4.3	Silent control	12.02.2020 02:31	12.02.2020 05:00
5.1	Silent control	12.02.2020 05:00	12.02.2020 07:57
5.2	Boat control	12.02.2020 07:57	12.02.2020 11:00
5.3	Seismic	12.02.2020 11:00	12.02.2020 14:00
6.1	Silent control	12.02.2020 17:30	12.02.2020 20:30
6.2	Seismic	12.02.2020 20:30	12.02.2020 23:30
6.3	Boat control	12.02.2020 23:30	13.02.2020 02:30
7.1	Boat control	13.02.2020 02:30	13.02.2020 05:30
7.2	Seismic	13.02.2020 05:31	13.02.2020 08:31
7.3	Silent control	13.02.2020 08:31	13.02.2020 11:31
8.1	Seismic	13.02.2020 12:40	13.02.2020 15:40
8.2	Boat control	13.02.2020 15:40	13.02.2020 18:40
8.3	Silent control	13.02.2020 18:40	13.02.2020 21:40
9.1	Silent control	13.02.2020 21:40	14.02.2020 00:40
9.2	Seismic	14.02.2020 00:40	14:02:2020 03:40
9.3	Boat control	14:02:2020 03:40	14:02:2020 06:41

Table 4. Executed exposures during the 2021 trial. All times are in UTC.

Number	Treatment	Start	End
0.1	Boat control	14.02.2021 22:43	15.02.2021 01:43
1.1	Seismic	15.02.2021 16:02	15.02.2021 19:02
1.2	Boat control	15.02.2021 19:02	15.02.2021 22:01
1.3	Silent control	15.02.2021 22:01	16.02.2021 01:05
2.1	Boat control	16.02.2021 01:05	16.02.2021 04:05
2.2	Silent control	16.02.2021 04:05	16.02.2021 07:05
2.3	Seismic	16.02.2021 07:05	16.02.2021 10:04
3.1	Silent control	16.02.2021 10:04	16.02.2021 13:05
3.2	Boat control	16.02.2021 13:08	16.02.2021 16:08
3.3	Seismic	16.02.2021 17:02	16.02.2021 20:02

4.1	Boat control	16.02.2021 20:02	16.02.2021 23:02
4.2	Seismic	16.02.2021 23:02	17.02.2021 02:03
4.3	Silent control	17.02.2021 02:03	17.02.2021 05:03
5.1	Seismic	17.02.2021 05:04	17.02.2021 08:04
5.2	Silent control	17.02.2021 08:04	17.02.2021 11:02
5.3	Boat control	17.02.2021 11:03	17.02.2021 14:03
6.1	Silent control	17.02.2021 14:03	17.02.2021 17:03
6.2	Seismic	17.02.2021 17:03	17.02.2021 20:12
6.3	Boat control	17.02.2021 20:02	17.02.2021 23:12
7.1	Seismic	17.02.2021 23:12	18.02.2021 02:12
7.2	Silent control	18.02.2021 02:12	19.02.2021 05:12
7.3	Boat control	18.02.2021 05:12	18.02.2021 08:12
8.1	Boat control	18.02.2021 08:12	18.02.2021 11:12
8.2	Seismic	18.02.2021 11:12	18.02.2021 14:12
8.3	Silent control	18.02.2021 14:30	18.02.2021 17:12
9.1	Seismic	18.02.2021 17:30	18.02.2021 20:30
9.2	Boat control	18.02.2021 20:30	18.02.2021 23:30
9.3	Silent control	18.02.2021 23:30	19.02.2021 02:31
10.1	Boat control	19.02.2021 02:31	19.02.2021 05:35
10.2	Seismic	19.02.2021 05:35	19.02.2021 08:35
10.3	Silent control	19.02.2021 08:35	19.02.2021 11:35

Hydrographic observations

A SAIV SD204 sonde was used to record conductivity, temperature and pressure data. Casts were taken at each site where we deployed the hydrophones, in addition to the central part of the vessel race track. Casts at these sites were taken repeatedly throughout the week in both years, as shown in tables 5 and 6. Fig. 6 shows the locations and overall results of the different stations for 2020. The similar plots for 2021 are shown in fig. 7.

Table 5. CTD casts for 2020.

STATION	DATE	TIME	NORTH	EAST	ECCO	cast	COMMENT
		UTC	Deg	Deg	DEPTH	depth	
HUS-01	10.02.2020	10:40					Empty cast
HUS-02	10.02.2020	11:16	60°7.34’	005°04.11’		60	Position of bottom mounted bouy 2, Kalsøyvika

HUS-03	10.02.2020	11:22	60°7.21’	005°05.74’		75	Position of bottom mounted bouy 1, Kalsøyvika
HUS-04	10.02.2020	18:56	60°6.93’	005°06.46’	78	70	Seismic racetrack
HUS-05	12.02.2020	2:34					Empty cast
HUS-06	12.02.2020	2:34	60°6.91’	005°06.48’	100	90	Seismic racetrack
HUS-07	12.02.2020	16:15	60°7.28’	005°05.07’		75	Position of floating vertical array
HUS-08	12.02.2020	16:32	60°7.34’	005°04.11’		60	Position of bottom mounted bouy 2, Kalsøyvika
HUS-09	12.02.2020	16:45	60°7.21’	005°05.74’		75	Position of bottom mounted bouy 1, Kalsøyvika
HUS-10	13.02.2020	12:34	60°7.03’	005°07.11’	108	100	Seismic racetrack
HUS-11	14.02.2020	06:58	60°7.03’	005°07.11’	102	90	Seismic racetrack
HUS-12	14.02.2020.	07:38	60°7.21’	005°05.74’		60	Position of bottom mounted bouy 1, Kalsøyvika
HUS-13	14.02.2020	07:45	60°7.28’	005°05.07’		75	Position of floating vertical array
HUS-14	14.02.2020	07:50	60°7.34’	005°04.11’		60	Position of bottom mounted bouy 2, Kalsøyvika

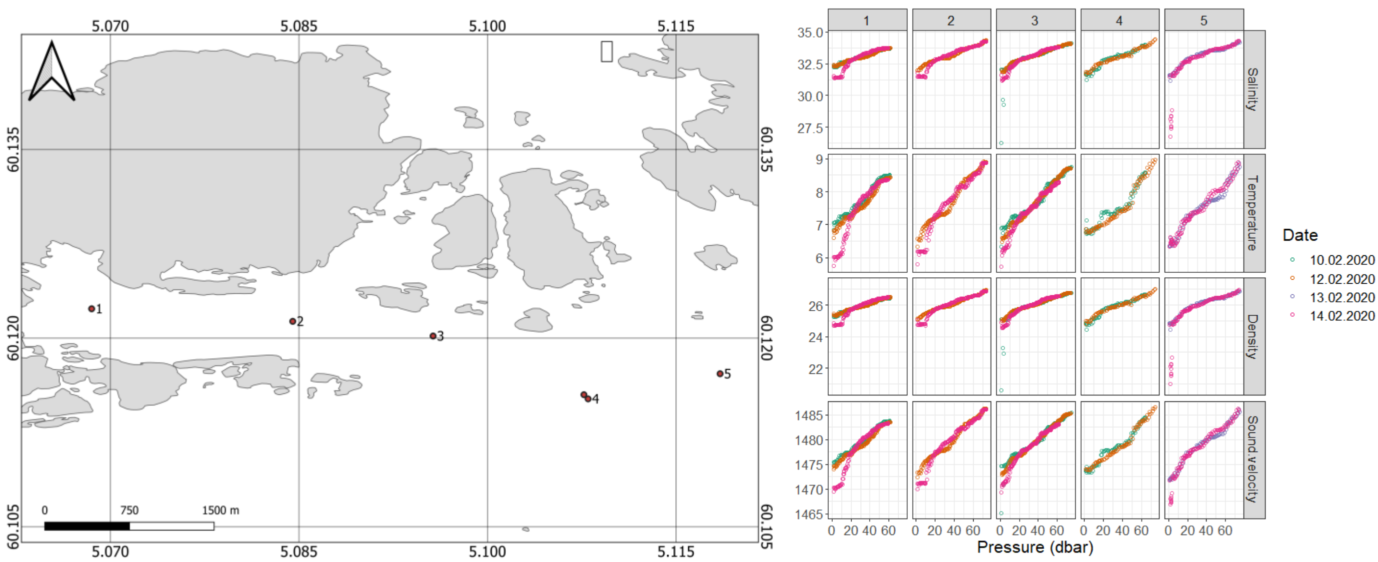


Figure 6. CTD casts for 2020. Casts are taken at the same five positions, but repeated throughout the week (details in table 5). Left: Locations of the CTD stations at positions of the inner (1) and outer (3) bottom hydrophone rigs, the hydrophone array in the middle of the bay (2) at the center of the racetrack (4) and outside the racetrack (5). Right: CTD profiles for the 5 locations, with different colors representing different sample days.

Table 6. CTD casts for 2021. Casts are taken in the same four positions, but repeated throughout the week.

Station number	Date	Time UTC	Latitude (N)	Longitude (E)	Cast depth	Comments

1	15.02.2021	12:59			45	Bottom mounted bouy west - inner cod bay, boat drifting off position
2	15.02.2021	13:03	60.1223	5.06848	55	Bottom mounted bouy west - inner cod bay, repeated
3	15.02.2021	13:10	60.1213	5.0845	70	Vertical floating array center of cod bay
4	15.02.2021	13:21			0	Empty cast
5	15.02.2021	13:22	60.1201	5.09567	70	Bottom mounted bouy east - outer cod bay
6	15.02.2021	13:47	60.1157	5.11015	50	Center of racetrack
7	16.02.2021	16:02	60.1223	5.06848	55	Bottom mounted bouy west - inner cod bay, repeated
8	16.02.2021	16:09	60.1213	5.0845	75	Vertical floating array center of cod bay
9	16.02.2021	16:14	60.1201	5.09567	70	Bottom mounted bouy east - outer cod bay
10	17.02.2021	11:54	60.1223	5.06848	55	Bottom mounted bouy west - inner cod bay, repeated
11	17.02.2021	12:02	60.1213	5.0845	75	Vertical floating array center of cod bay
12	17.02.2021	12:08	60.1201	5.09567	60	Bottom mounted bouy east - outer cod bay

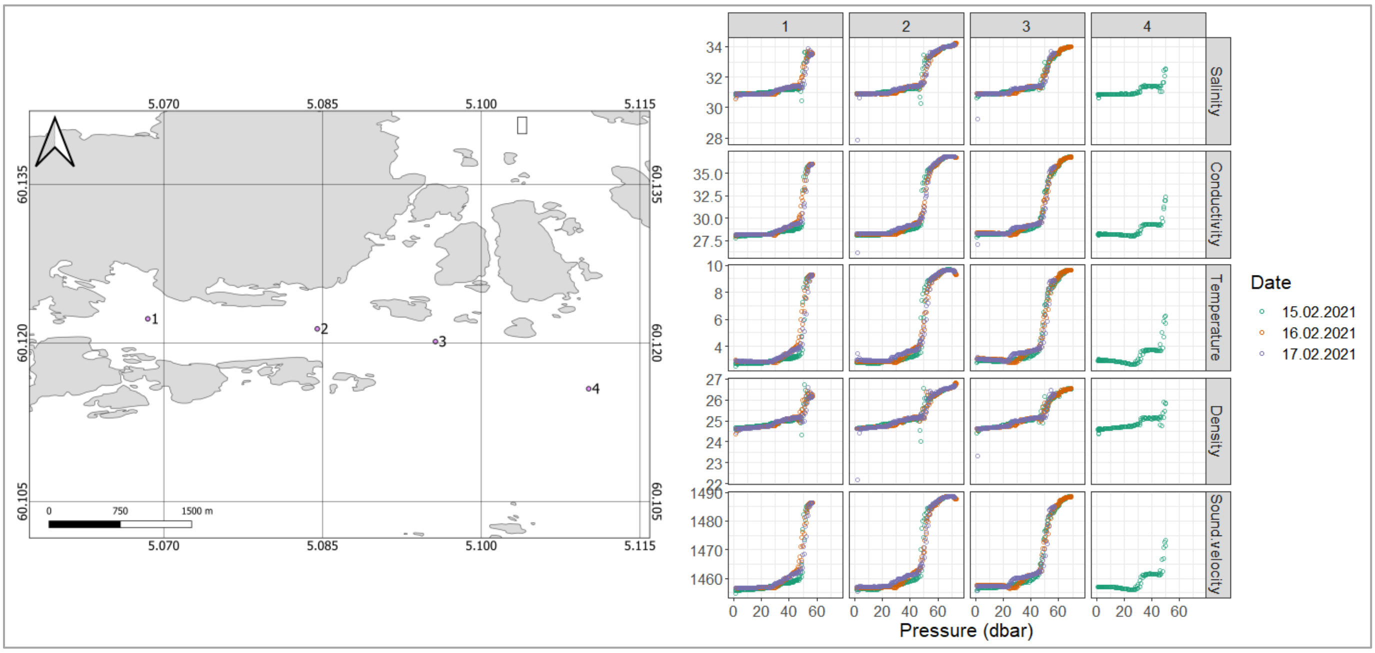


Figure 7. Left: Overview of the four CTD stations; Station 1 located in the inner part of the bay are sampled by casts 1, 7 and 10 (table 6), station 2 located in the centre of the bay are sampled by casts 3 and 8 (table 6), station 3 are located in the outer part of the bay are sampled by casts 5, 9 and 12 (table 6) and station 4, located in the center of the racetrack are sampled by cast 6. Right: CTD profiles for the 4 different stations. The different colors represent the different casts within each station.

Weather and tide information

Wind data was extracted from Yr (www.yr.no), referring to the average and maximum daily wind speeds recorded at the nearby Slåtterøy fyr observation station.

Tidal data was downloaded from the Norwegian Mapping Authority, Hydrographic Service. The water level observed at Bergen was multiplied by a factor of 0.83 and time adjusted by -15 minutes to estimate the water level in the Bakkasund grid.

In 2020, there was a storm in the study area during the exposure period. The maximum wind speed during the 2020 analysis period ranged from 7.7m/s to 24.3m/s, with average wind speed ranging from 2.9 to 17.5m/s (Norwegian Meteorological Institute and the Norwegian Broadcasting Corporation 2007-2021). In 2021, the weather conditions were calm but cold. The maximum wind speed ranged from 2.3m/s to 17.7m/s during the 2021 analysis period, with average wind speed ranging from 1.2 to 10.4 m/s (Norwegian Meteorological Institute and the Norwegian Broadcasting Corporation 2007-2021).

Hydrophone measurements

Hydrophones were used to observe the sound from the boat control, the seismic exposure and the background noise in the area. Recordings were conducted at several positions and depths (**Error! Reference source not found.**) throughout the experiments, and two different hydrophone sound recording systems were used in addition to ship based hydrophones. To avoid disturbing the fish unnecessarily, we used a small workboat to tow the hydrophones to the positions in the experimental site.

Tables 8 and 9 list the different hydrophones used in 2020 and 2021, respectively. Tables 10 and 11 list all the hydrophone deployments for 2020 and 2021, respectively.

Table 8. Hydrophones and calibrations for 2020.

Number	**Hydrophone**	**Type**	**SerialNumber**	**Sensitivity, dB re V/uPa**	**Frequency range, Hz**
H1	Bottom moored hydrophone No2	Naxys Ethernet Hydrophone, model 02345	002	-179	5 - 300 000
H2	Bottom moored hydrophone No3	Naxys Ethernet Hydrophone, model 02345	003	-179	5 - 300 000
H3	Sound trap	Ocean Instruments, sound trap 300 HF	5513	-176.3	20-60 000
H4	Vessel mounted hydrophone	reson TC4034		-218	1 - 470 000
H5	Vertical hydrophone array No4	Naxys Ethernet	004	-179	5 - 300 000

		Hydrophone, model 02345			
H6	Vertical hydrophone array No5	Naxys Ethernet Hydrophone, model 02345	005	-179	5 - 300 000
H7	icListen	Ocean Sonics, SC35-ETH icListen HF	1758	168.3	10 - 200 000

Table 9. Hydrophones and calibrations for 2021.

Number	**Hydrophone**	**Type**	**SerialNumber**	**Sensitivity, dB re V/uPa**	**Frequency range, Hz**
H1	Bottom moored hydrophone No4	Naxys Ethernet Hydrophone, model 02345	002	-179	5 - 300 000
H2	Bottom moored hydrophone No3	Naxys Ethernet Hydrophone, model 02345	004	-179	5 - 300 000
H3	Sound trap	Ocean Instruments, sound trap 300 HF	5513	-176.3	20-60 000
H4	Vessel mounted hydrophone	reson TC4034		-218	1 - 470 000
H5	Vertical hydrophone array Ch2	Naxys Ethernet Hydrophone, model 02345	019	-179	5 - 300 000
H6	Vertical hydrophone array Ch1	Naxys Ethernet Hydrophone, model 02345	005	-179	5 - 300 000

Table 10. Hydrophone deployment log for 2020 (more details in SpawnSeisHydrophoneDeploymentMetaData.xlsx).

DeplNumber	Hydrophone	StartTime	StopTime	LAT	LON	Comment
D1	Bottom moored hydrophone No2	10.02.2020 14:00	10.02:2020 19:45	60°07.21’	005°05.761’	Hydrophone on the shelf of the bay
D2	Bottom moored hydrophone No3	10.02.2020 14:00	12.02.2020 03:17	60°07.33’	005°04.109’	Hydrophone in the inner part of the bay
D3	Sound trap	10.02.2020 14:00	12.02.2020 14:00	60°07.33’	005°04.109’	Sound trap for vocalisations, inner part of the bay
D4	Vessel mounted hydrophone	12.02.2020 10:59	12.02.2020 14:17	NA		Vessel hydrophone data for exposure 5.3
D5	Vertical hydrophone array No4	12.02.2020 16:55	13.02.2020 14:51	60°07.238’	005°05.074’	Upper hydrophone in the array, center of the bay
D6	Vertical hydrophone array No5	12.02.2020 16:55	13.02.2020 14:52	60°07.238	05°074’	Lower hydrophone in the array, center of the bay
D7	Bottom moored hydrophone No3	13.02.2020 12:30	14.02.2020 07:00	60°07.337	05°04.109	Hydrophone in the inner part of the bay
D8	Sound trap	13.02.2020 12:30	14.02.2020 06:40	60°07.337	05°04.109	Sound trap for vocalisations, inner part of the bay
D9	IcListen	13.02.2020 12:30	13.02.2020 18:05	60°07.214	05°05.761	Replacing the bottom moored hydrophone No2 with IcListen, shelf of the bay
D10	Vessel mounted hydrophone	12.02.2020 20:30	12.02.2020 23:32	NA	NA	Vessel hydrophone data for exposure 6.2

D11	Vessel mounted hydrophone	13.02.2020 05:32	13.02.2020 08:39	NA	NA	Vessel hydrophone data for exposure 7.2
D12	Vessel mounted hydrophone	13.02.2020 12:38	13.02.2020 15:40	NA	NA	Vessel hydrophone data for exposure 8.1
D13	Vessel mounted hydrophone	14.02.2020 00:39	14.02.2020 03:41	NA	NA	Vessel hydrophone data for exposure 9.2

Table 11. Hydrophone deployment log for 2021. Details for "Hydrophone" can be found in table 9.

DeplNumber	Hydrophone	StartTime	StopTime	LATdeg	LONdeg	Comment
D14	H2	15.02.2020 14:00	16.02.2020 12:37	60° 7.298	5° 4.978	Hydrophone in the outer part of the bay
D15	H1	15.02.2021 14:00	16.02.2020 12:24	60° 7.212	5° 5.761	Hydrophone bottom inner part of bay. Sound trap mounted on same rig.
D16	H3	10.02.2020 12:00	16.02.2021 21:19	60° 7.212	5° 5.761	Sound trap for vocalisations, inner part of the bay
D17	H5	15.02.2021 14:00	16.02.2020 13:36	60° 7.342	5° 4.15	Upper hydrophone in the array, center of the bay
D18	H6	15.02.2021 14:00	16.02.2020 13:36	60° 7.342	5° 4.15	Lower hydrophone in the array, center of the bay
D19	H5	17.02.2020 12:00	18.02.2020 13:42	60° 7.216	5° 7.705	Hydrophone in outer part of the bay
D20	H1	17.02.2020 12:00	19.02.2020 14:35	60° 7.339	5° 4.095	Hydrophone in the inner part of the bay. Soundtrap on same rig
D21	H3	17.02.2021 14:00	17.02.2021 16:34	60° 7.337	5° 4.109	Sound trap for vocalisations, inner part of the bay, on hydrophone rig.
D22	H4	15.02.2021 16:02	15.02.2021 19:02	NA	NA	Vessel hydrophone data for exposure 1.1
D23	H4	16.02.2021 07:05	16.02.2021 10:04	NA	NA	Vessel hydrophone data for exposure 2.3
D24	H4	16.02.2021 17:02	16.02.2021 20:02	NA	NA	Vessel hydrophone data for exposure 3.3
D25	H4	16.02.2021 23:02	17.02.2021 02:03	NA	NA	Vessel hydrophone data for exposure 4.2

D26	H4	17.02.2021 05:04	17.02.2021 08:04	NA	NA	Vessel hydrophone data for exposure 5.1
D27	H4	17.02.2021 17:03	17.02.2021 20:12	NA	NA	Vessel hydrophone data for exposure 6.2
D28	H4	17.02.2021 23:12	18.02.2021 02:12	NA	NA	Vessel hydrophone data for exposure 7.1
D29	H4	18.02.2021 11:12	18.02.2021 14:12	NA	NA	Vessel hydrophone data for exposure 8.2
D27	H4	18.02.2021 17:30	18.02.2021 20:30	NA	NA	Vessel hydrophone data for exposure 9.1
D28	H4	19.02.2021 05:35	19.02.2021 08:35	NA	NA	Vessel hydrophone data for exposure 10.2

Drifting anti-heave surface buoy with vertical hydrophone array

A surface buoy system was used to record sound pressures at two different depths (fig. 8). To minimize vertical movements of the hydrophones due to waves, which is a source of noise, the buoy is designed with a long slim shape to allow the waves to climb on the buoy instead of moving it up and down. The buoy was kept upright by lead weights to ensure the string with the hydrophones was hanging straight down. The array was moored to the bottom by a separate rope with an anchor to avoid it to move, but without influencing the string with the hydrophones.

The buoy contained an UNO-2483G embedded computer with an internal flash drive for data-logging and instrumentation control. A GPS receiver enabled the buoy to be tracked and a radio Ethernet link allowed remote control and monitoring of the system from several nautical miles. The GPS position were logged for a shorter duration to document the exact location of the buoy.

Two Naxys 02345 Ethernet Hydrophones were attached to the buoy via cables along a string at depths of about 8 and 37 m. The sound pressure was recorded at 22 s intervals with 8 s pauses. The Naxys hydrophones are omni directional, with a frequency range of 5 Hz to 300 kHz, an element sensitivity of -211 dB re V/µPa A 48 kHz sampling rate was used. The hydrophone has an amplifier with an adjustable gain from 0 to 40 dB, and a 20 dB gain was used, except at the last deployment of the inner hydrophone, when 40 dB was used. Before deployment the hydrophones were calibrated using a Brüel & Kjær 4229 piston calibrator. RGB depth loggers was attached to each hydrophone to record their depths and vertical movements.

One of the bottom moored hydrophones failed in 2020 and was then replaced with the icListen (H7, table 8) for the last deployment.

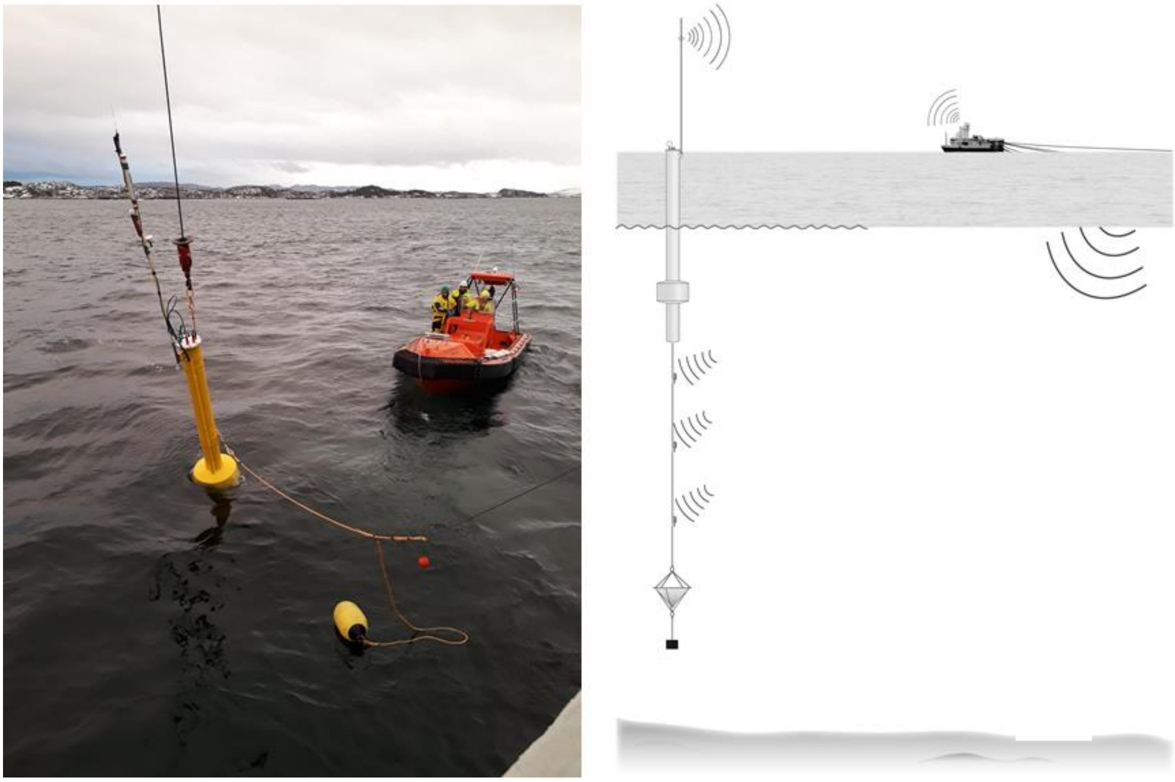


Figure 8. The hydrophone vertical array. Left: The surface part of the array visible above sea level. The array was towed by the HUS workboat into position, and moored to the bottom with heavy weights. Right: figure of how it looks when deployed. The figure shows 3 hydrophones at different depths, but in the current setting only two were used and the array was not drifting but fixed at one position.

Self-recording submersible hydrophone platform

Two submersible acoustic hydrophone platforms were used to record sound 8 m above bottom (fig. 9), at two locations during seismic shooting (tables 10 and 11). An underwater housing of anodized aluminium connected to a Naxys 02345 Ethernet hydrophone via an Ethernet cable was mounted in a steel frame. The frame was made buoyant with floats and was attached to weights (52kg) by an 8m rope. The underwater housing contained an Advantech PCM-3370F-JOA1 single-board computer for data logging and system control. The computer used a flash drive for data storage to avoid noise from the disk during logging. The electronics were powered by rechargeable A123 lithium-ion batteries with automatic low battery capacity shutdown circuitry, enabling the system to operate for about 30 hours. Logging interval, start time, gain and sampling frequency were configured via remote control software using a serial connection prior to deployment. Recorded sound data were downloaded to an external PC by disconnecting the hydrophone and using the Ethernet connection.

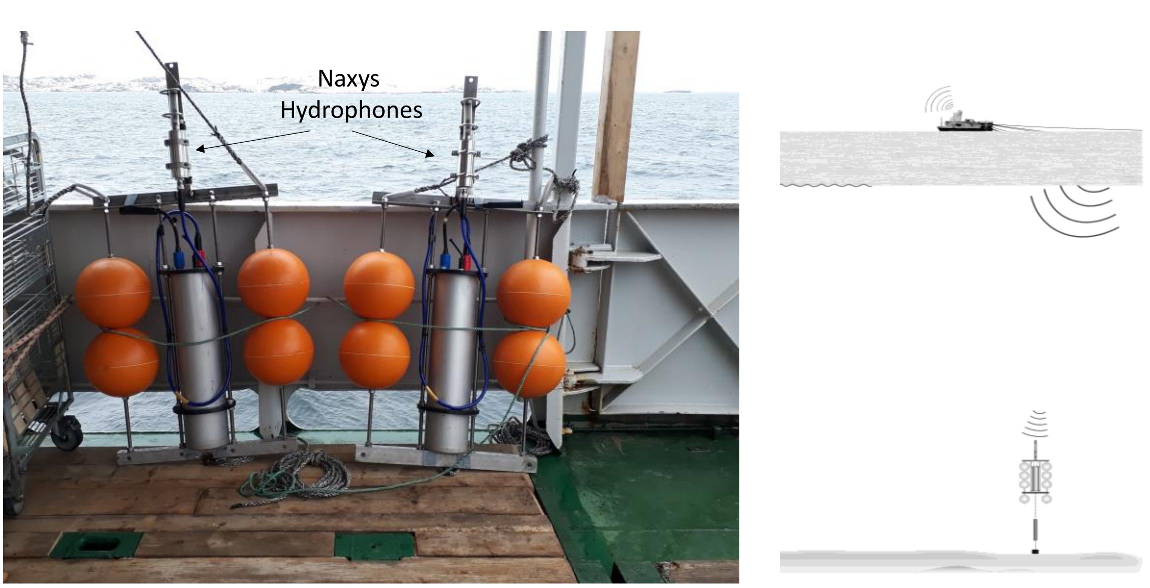


Figure 9. The two hydrophone platforms onboard HUS, ready to be deployed (left) and a figure of how it looks when deployed (right).

Sound trap 300 HF

A sound trap 300 HF hydrophone was placed in the area and was set to record cod vocalisations in the area (fig. 10). This was placed on the inner bottom hydrophone rig.

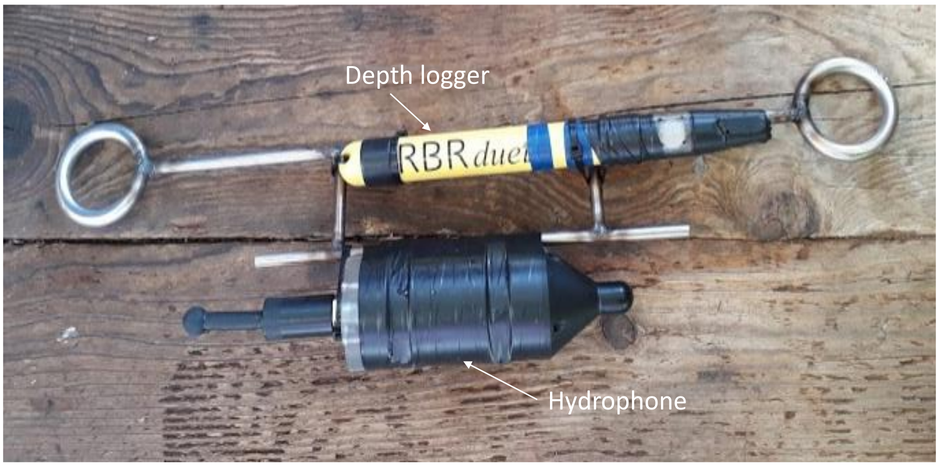


Figure 10. The sound trap hydrophone.

Sound recordings

Recordings from the hydrophones were used to calculate Sound Exposure Levels (SEL). The raw hydrophone data were bandpass filtered with a 6th order Butterworth filter with lower and upper cutoff at 10 Hz and 5 kHz, respectively. The filtered pressure data were squared and integrated over 1 second from the start of each pulse using trapezoid integration. Ten times the log10 of the integrated value results in the sound exposure level (SEL).

Below selected figures showing the sound exposure in the various parts of the bay are shown. Additional figures are shown in Appendix 1.

Sound measurements are not available for all blocks due to battery capacity. Available recordings, that are used in figures presented here and in Appendix 1, are shown in green in table 12.

Table 12. Green show hydrophone recordings used in the analyses described (only recordings for naxys hydrophones).

BlockNo	TreatmentNo	Number	Treatment	Start	End	inner	outer	center - upper	center - lower
0	1	0.1	Boat control	09.02.2020 22:50	10.02.2020 01:49				
1	1	1.1	Seismic	10.02.2020 15:25	10.02.2020 18:24				
1	2	1.2	Silent control	10.02.2020 19:08	10.02.2020 22:50				
1	3	1.3	Boat control	10.02.2020 22:50	11.02.2020 01:49				
2	1	2.1	Seismic	11.02.2020 01:49	11.02.2020 04:49				
2	2	2.2	Boat control	11.02.2020 04:49	11.02.2020 07:50				
2	3	2.3	Silent control	11.02.2020 07:50	11.02.2020 10:55				
3	1	3.1	Boat control	11.02.2020 10:55	11.02.2020 13:55				
3	2	3.2	Silent control	11.02.2020 13:55	11.02.2020 16:43				
3	3	3.3	Seismic	11.02.2020 16:54	11.02.2020 19:55				
4	1	4.1	Boat control	11.02.2020 19:55	11.02.2020 22:55				
4	2	4.2	Seismic	11.02.2020 22:55	12.02.2020 01:55				
4	3	4.3	Silent control	12.02.2020 02:31	12.02.2020 05:00				
5	1	5.1	Silent control	12.02.2020 05:00	12.02.2020 07:57				
5	2	5.2	Boat control	12.02.2020 07:57	12.02.2020 11:00				
5	3	5.3	Seismic	12.02.2020 11:00	12.02.2020 14:00				
6	1	6.1	Silent control	12.02.2020 17:30	12.02.2020 20:30				
6	2	6.2	Seismic	12.02.2020 20:30	12.02.2020 23:30				
6	3	6.3	Boat control	12.02.2020 23:30	13.02.2020 02:30				
7	1	7.1	Boat control	13.02.2020 02:30	13.02.2020 05:30				
7	2	7.2	Seismic	13.02.2020 05:31	13.02.2020 08:31				
7	3	7.3	Silent control	13.02.2020 08:31	13.02.2020 11:31				
8	1	8.1	Seismic	13.02.2020 12:40	13.02.2020 15:40				
8	2	8.2	Boat control	13.02.2020 15:40	13.02.2020 18:40				
8	3	8.3	Silent control	13.02.2020 18:40	13.02.2020 21:40				
9	1	9.1	Silent control	13.02.2020 21:40	14.02.2020 00:40				
9	2	9.2	Seismic	14.02.2020 00:40	14.02.2020 03:40				
9	3	9.3	Boat control	14.02.2020 03:40	14.02.2020 06:41				
10	1	0.1	Boat control	14.02.2021 22:43	15.02.2021 01:43				
11	1	1.1	Seismic	15.02.2021 16:02	15.02.2021 19:02				
11	2	1.2	Boat control	15.02.2021 19:02	15.02.2021 22:01				
11	3	1.3	Silent control	15.02.2021 22:01	16.02.2021 01:05				
12	1	2.1	Boat control	16.02.2021 01:05	16.02.2021 04:05				
12	2	2.2	Silent control	16.02.2021 04:05	16.02.2021 07:05				
12	3	2.3	Seismic	16.02.2021 07:05	16.02.2021 10:04				
13	1	3.1	Silent control	16.02.2021 10:04	16.02.2021 13:05				
13	2	3.2	Boat control	16.02.2021 13:08	16.02.2021 16:08				
13	3	3.3	Seismic	16.02.2021 17:02	16.02.2021 20:02				
14	1	4.1	Boat control	16.02.2021 20:02	16.02.2021 23:02				
14	2	4.2	Seismic	16.02.2021 23:02	17.02.2021 02:03				
14	3	4.3	Silent control	17.02.2021 02:03	17.02.2021 05:03				
15	1	5.1	Seismic	17.02.2021 05:04	17.02.2021 08:04				
15	2	5.2	Silent control	17.02.2021 08:04	17.02.2021 11:02				
15	3	5.3	Boat control	17.02.2021 11:03	17.02.2021 14:03				
16	1	6.1	Silent control	17.02.2021 14:03	17.02.2021 17:03				
16	2	6.2	Seismic	17.02.2021 17:03	17.02.2021 20:12				
16	3	6.3	Boat control	17.02.2021 20:02	17.02.2021 23:12				
17	1	7.1	Seismic	17.02.2021 23:12	18.02.2021 02:12				
17	2	7.2	Silent control	18.02.2021 02:12	19.02.2021 05:12				
17	3	7.3	Boat control	18.02.2021 05:12	18.02.2021 08:12				
18	1	8.1	Boat control	18.02.2021 08:12	18.02.2021 11:12				
18	2	8.2	Seismic	18.02.2021 11:12	18.02.2021 14:12				
18	3	8.3	Silent control	18.02.2021 14:30	18.02.2021 17:12				
19	1	9.1	Seismic	18.02.2021 17:30	18.02.2021 20:30				
19	2	9.2	Boat control	18.02.2021 20:30	18.02.2021 23:30				
19	3	9.3	Silent control	18.02.2021 23:30	19.02.2021 02:31				
20	1	10.1	Boat control	19.02.2021 02:31	19.02.2021 05:35				
20	2	10.2	Seismic	19.02.2021 05:35	19.02.2021 08:35				
20	3	10.3	Silent control	19.02.2021 08:35	19.02.2021 08:35				

Sound varies along the racetrack as the distance between sound source and hydrophone varies along the track (fig. 11). At the outer hydrophone, SEL of the seismic recordings varies from around 120 to 147 dB re1µPa^{2}s, while at the inner hydrophone SEL of the seismic signal varies from around 115 to 130 dB re1µPa^{2}s. The seismic signals seem to be relatively similar between the two years. The control sounds (silent and boat) are however quite a lot stronger in 2020 than in 2021 (fig. 11). This may be due to a slightly different placement of the hydrophone in the two years, and/or that the weather was quite different with more wind in 2020 that may have increased the ambient noise.

For both years, the seismic signals are significantly stronger than the ambient noise both in the inner and the outer part of the bay. In the inner bay, the noise due to the ship (boat control) are at similar level as the ambient sound (silent control) in both years.

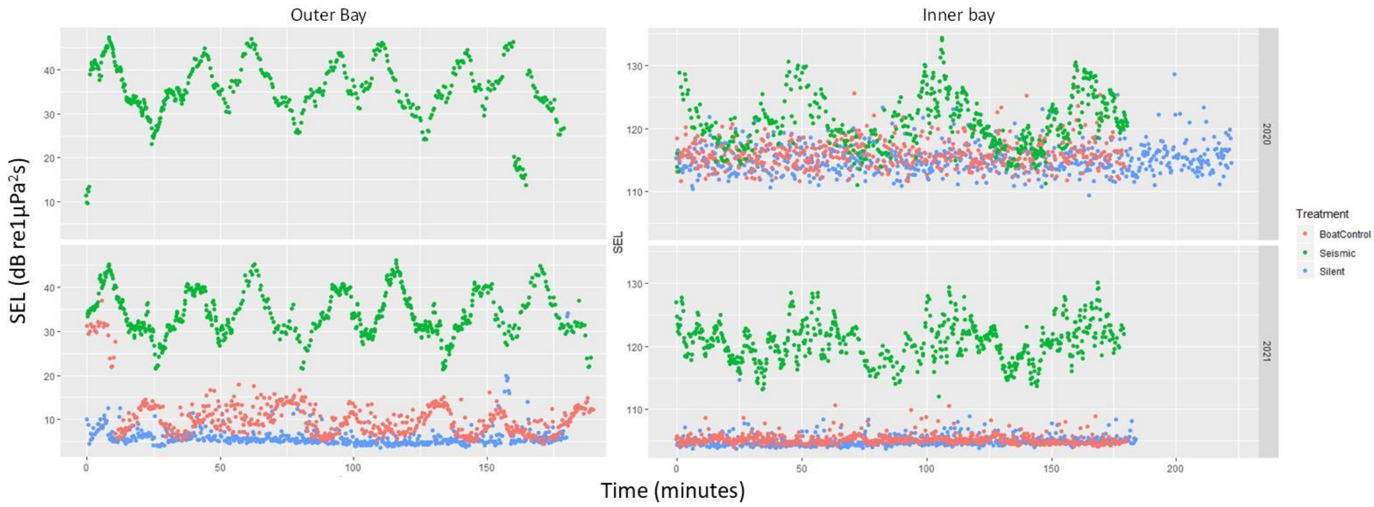


Figure 11. SEL for the three different treatments (seismic, silent, boat control) for the two years for the outer (left) and inner (right) hydrophone. For the outer bay, data for control runs (boat, silent) are not available. The figures are based on the data from the blocks indicated in green in table 13. All pulses are not included because only 22 of 30 seconds was recorded. Pulses in the centre of the recording was selected.

The spectral analysis show that most of the energy of the seismic lies in the frequency range 0-200 Hz (fig. 12, upper level), as expected, but there is also energy at higher frequencies. The background noise dominates the lower frequencies (0-20 Hz) (fig. 12, middle and lower level).

Similar spectral levels are recorded at the outer hydrophone (fig. 13). Here, the seismic signal stand out from the ambient noise very clear (fig.13, upper level), as expected due to the placement of this hydrophone closer to the source. Unfortunately, we miss recordings for the boat and silent control for this hydrophone in 2020, due to hydrophone failure after few hours of recording.

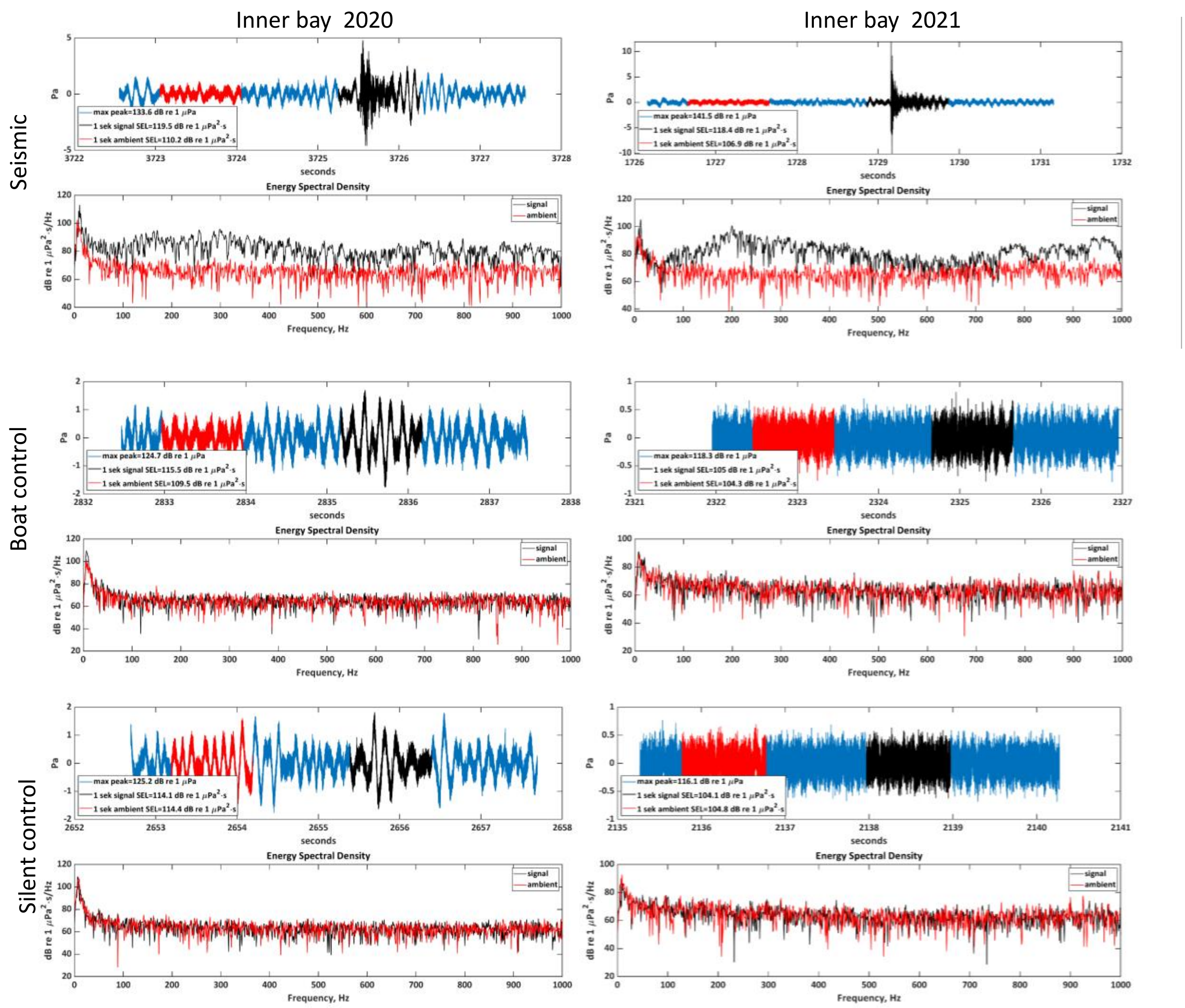


Figure 12. Examples of some selected pulses from where the frequency of the pulse and of the background noise is analysed for the inner bay hydrophone. The upper level shows a seismic pulse in black, as well as a similar interval of the background noise in red. Below in the spectral level of the seismic pulse and the background noise. In the inner part of the bay there is many reverberations due to reflection of the seismic pulse. This also affect the background noise between the pulse. Examples form 2020 are from block 2, of calculated values for the two bottom mounted hydrophones in the inner and outer part of the bay for 2020 and 2021.

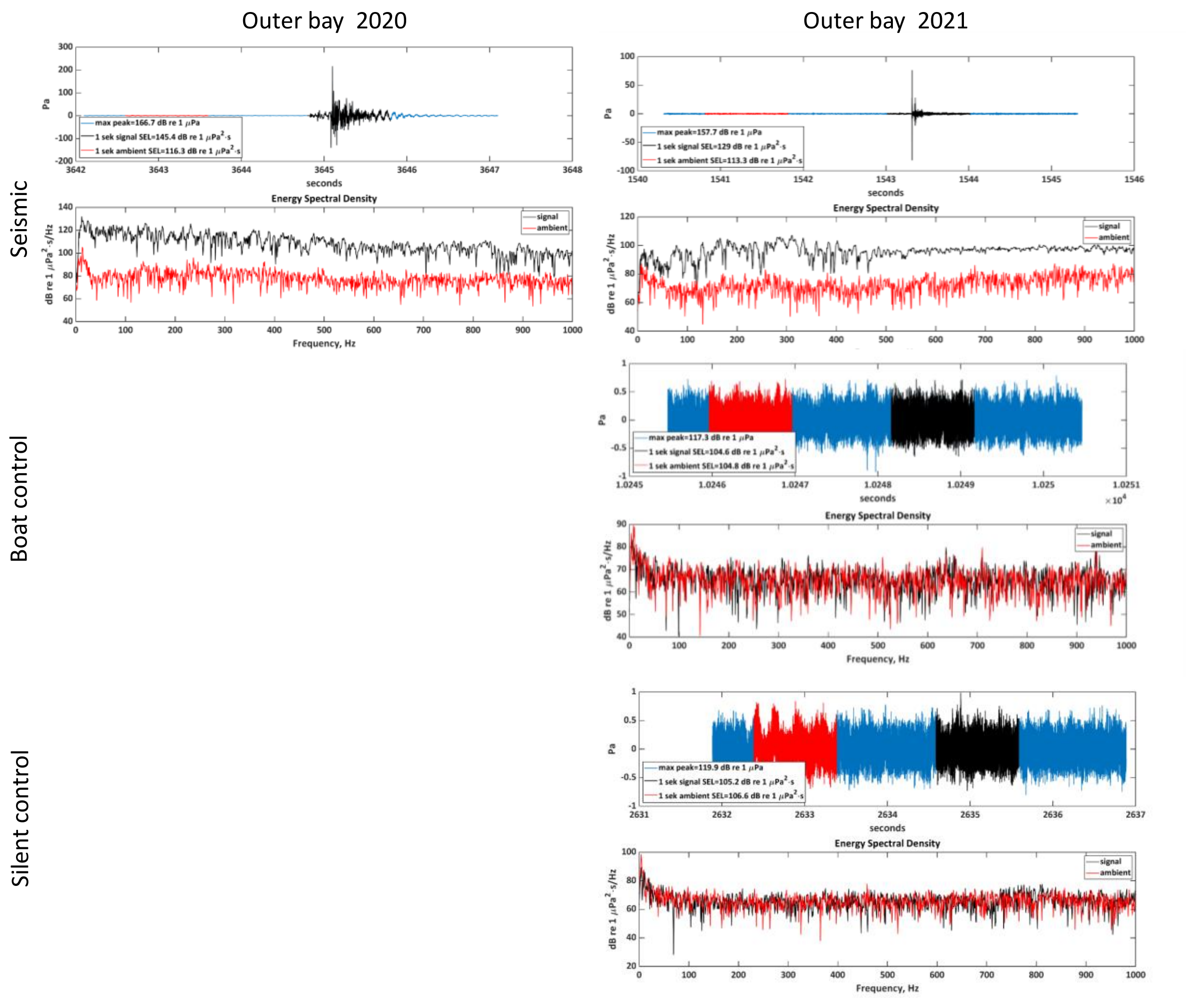


Figure 13. Examples of some selected pulses from where the frequency of the pulse and of the background noise is analysed for the outer bay hydrophone. The upper level shows a seismic pulse in black, as well as a similar interval of the background noise in red. Below in the spectral level of the seismic pulse and the background noise. In the inner part of the bay there is many reverberations due to reflection of the seismic pulse. This also affect the background noise between the pulse. Examples form 2020 are from block 2, but only for the treatment seismic, as the hydrophone stopped working after this, and therefore no data are available for the other two treatments. For 2021, examples are from block 11.

Recordings from the vertical array show that the sound level is higher in the upper part of the water column (fig. 14). This is likely due to this hydrophone being at approximately similar depth as the sound source. The background noise is higher between the shots probably due to reflections of the sound traveling around before dying out.

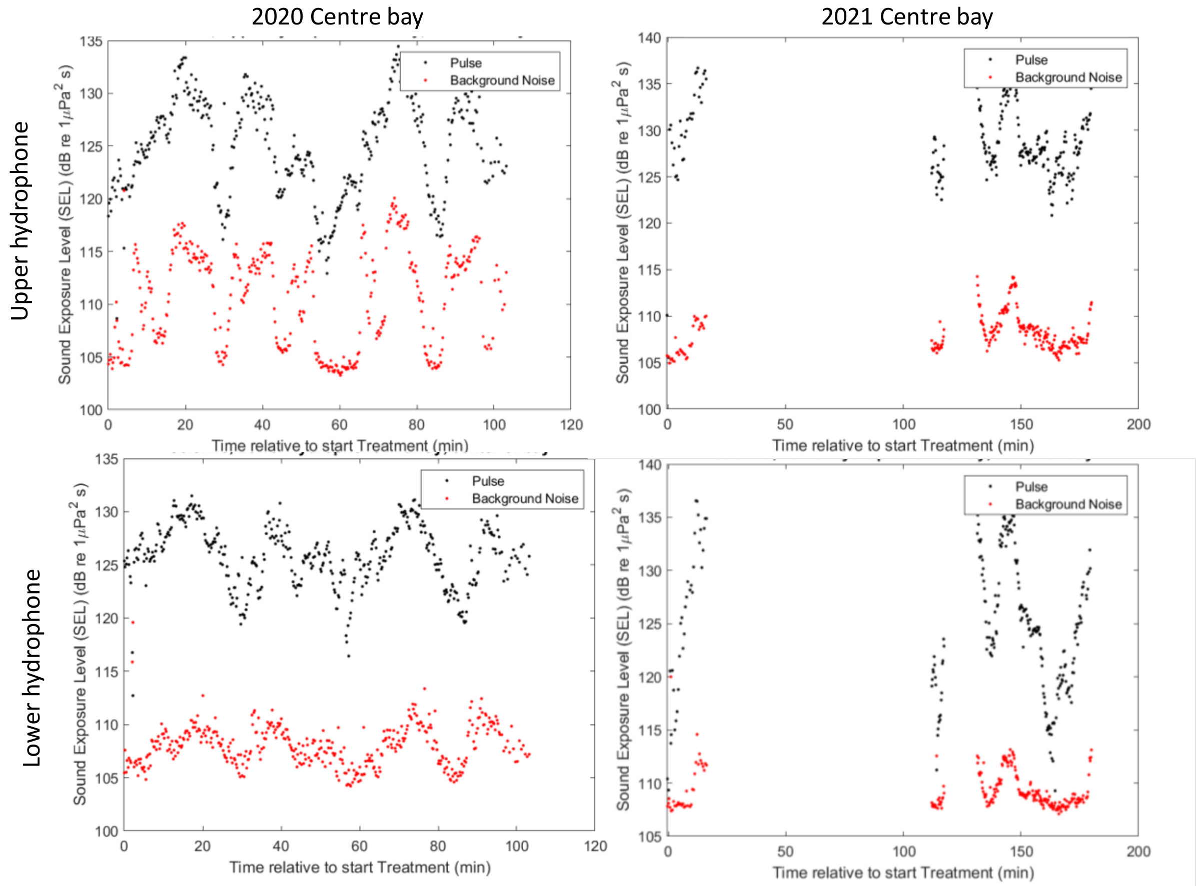


Figure 14. Sound Exposure Levels for The vertical hydrophone array in the centre of the bay, with two hydrophones at different depths at the same location; one at 8 m (upper hydrophone) and one at 37 m (lower hydrophone). The example for 2020 are from block 2 and for 2021 from block 11. For 2021, some of the data are missing due to this hydrophone being somewhat unstable in its recording, causing such datagaps.

The SEL measured with the array (fig. 14) are at levels between the inner and outer, as expected at its location in the center of the bay. However, the spectral plot show that the frequency distribution is somewhat different at this location, with energy spread more at higher frequencies; up to about 1 kHz during both years (fig. 15).

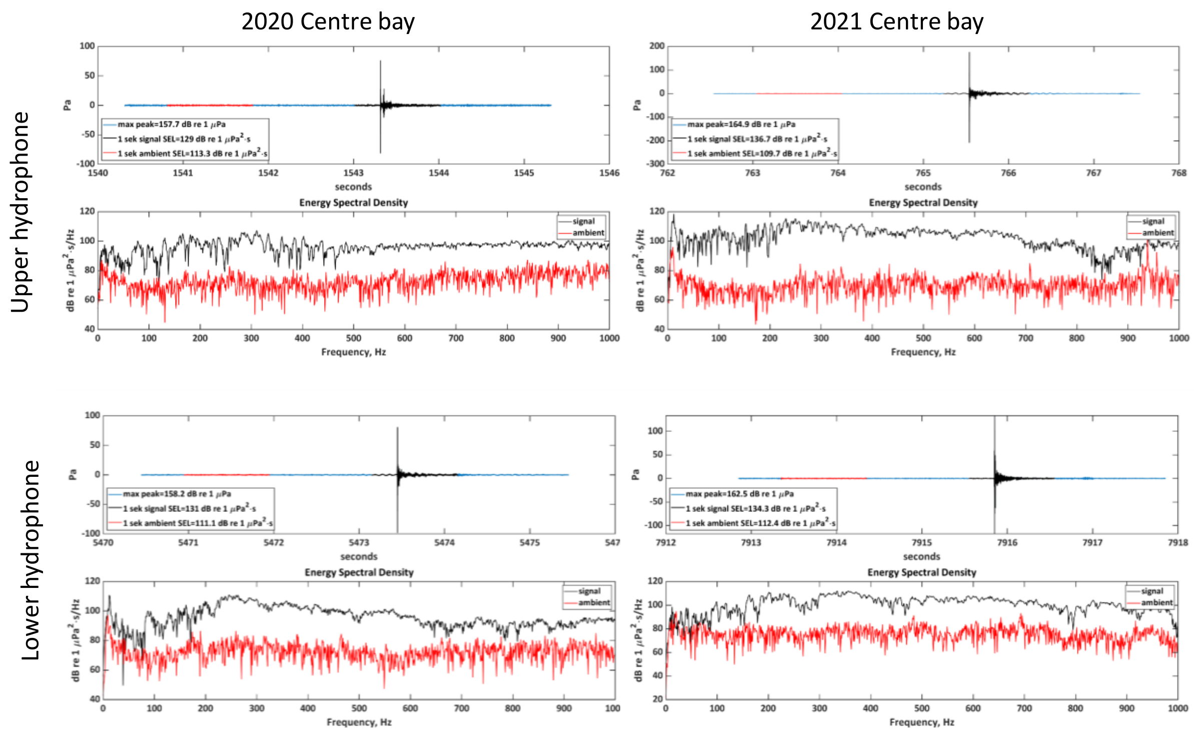


Figure 15. Examples of some selected pulses from where the frequency of the pulse and of the background noise is analysed for the vertical array hydrophones. The upper level of each plot shows a seismic pulse in black, as well as a similar interval of the background noise in red. Below in the spectral level of the seismic pulse and the background noise. Data from 2020 are from block 2, and for 2021 from block 11.

As shown in fig. 16, loud sounds can also occur that is not due to the seismic exposure. In this example, the frequency content is however quite different from the seismic. It does however show that the fish in this study are subject to loud sounds regularly.

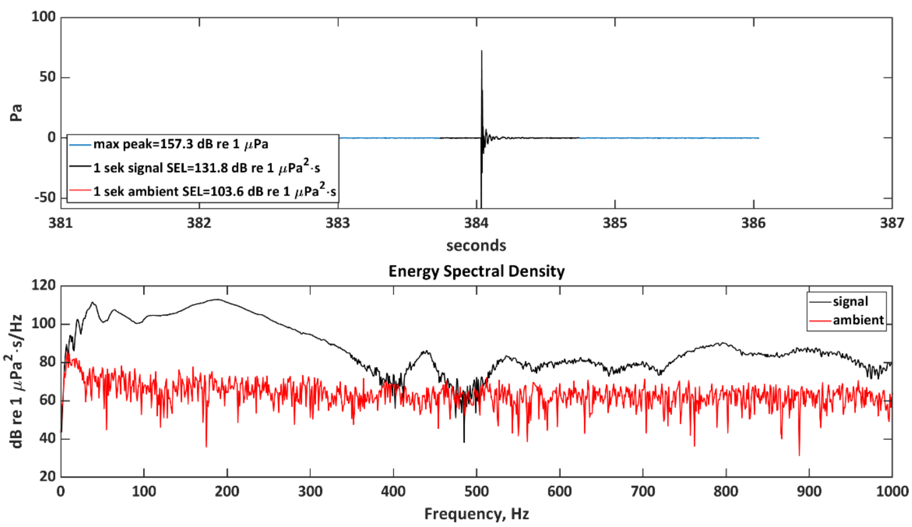


Figure 16. Example that also loud sounds can occur that is not seismic. This is a recording from the upper hydrophone at the array during block 2 in 2020 during the silent run. The frequency content of this pulse is however quite different from seismic.

Data organisation

The data organisation follows the IMR data organisation structure. The data referred to above are placed in its respective subfolder shown in table 13. The data are stored at an IMR server, and can be accessed by employees at IMR from the following paths:

For 2020 data:

\\ces.hi.no\nmdstorage\SCRATCH\S2021826_PH.U.SVERDRUP II[1007]

For 2021 data

\\ces.hi.no\nmdstorage\SCRATCH\S2020830 _PH.U. SVERDRUP II[1007]

Table 13. Organization of data files for 2020

CRUISE_DOCUMENTS\CRUISE_REPORT	The cruise report folder (this document).
CRUISE_DOCUMENTS\CSR	The cruise summary report.
CRUISE_LOG\ACTIVITY	EventLogger_ALL EVENTS.csv The FFI event log. Excel file with time and position of manually recorded events (e.g. start and stop of runs), hourly weather reports, and seismic shots (duplicated from shot-log). treatments.xlsx Clean file with treatment, start and stop times. Shotlog (directory) Directory with one csv file per seismic exposures, e.g. ShotLog_2020.02.14_003903.csv, containing the time for each individual air gun emission. Positions and screenshots.doc File with screenshots from ships navigation system during experiments, and list of important positions (seismic racetrack and buoy positions).
CRUISE_LOG\TRACK	Custom track log. The position of the vessel every second throughout trial (one directory and several files per day). Txt-format. The file Spawnseis-2020.xlsx is the position log in one file.
EXPERIMENTS\HYDROPHONES	The hydrophone recordings. Each hydrophone deployment and calibration is placed in a subfolder and refers to the deployment number (**Error! Reference source not found.**) and hydrophone (**Error! Reference source not found.**). The calibration folders and deployment follows “C<calibration>_<hydrophone>” and “D<deploymentNumber>_<hydrophone>”, respectively.

	Each calibration folder contains a sub folder for each gain setting where the wav files are placed, whereas the deployment folder contains the wav files for each deployment.
MULTIMEDIA_FILES\IMAGES	Images taken from the survey.
MULTIMEDIA_FILES\VIDEOS	Videos taken from the survey.
PHYSICS\CTD_DATA	CTD_LOGG_Spawnseis_2020.xls Excel file with time, position and depth of casts. SpawnseisCTD.SD2 and .txt CTD data in .SD2 and txt format, respectively, with all casts.

Permits

This experiment was conducted with permission to capture cod, given by the Norwegian Directorate of Fisheries (Fiskeridirektoratet) with permit numbers and for 19/12108, 19/14024 and 21/231 for the years 2020 and 2021, respectively.

Permission to tag cod and conduct exposure experiment was given by the Norwegian Food Safety Authority (Mattilsynet) with permit numbers FOTS ID 18034 for 2019-2020 and FOOTS ID 26019 for 2021.

Permission to use seismic was given by the Norwegian Petroleum Directorate (Oljedirektoratet) given as undersøkelsestillatelse 772/200 and 777/200 for 2020 and 2021, respectively.