SPAWNSEIS BSU SURVEY

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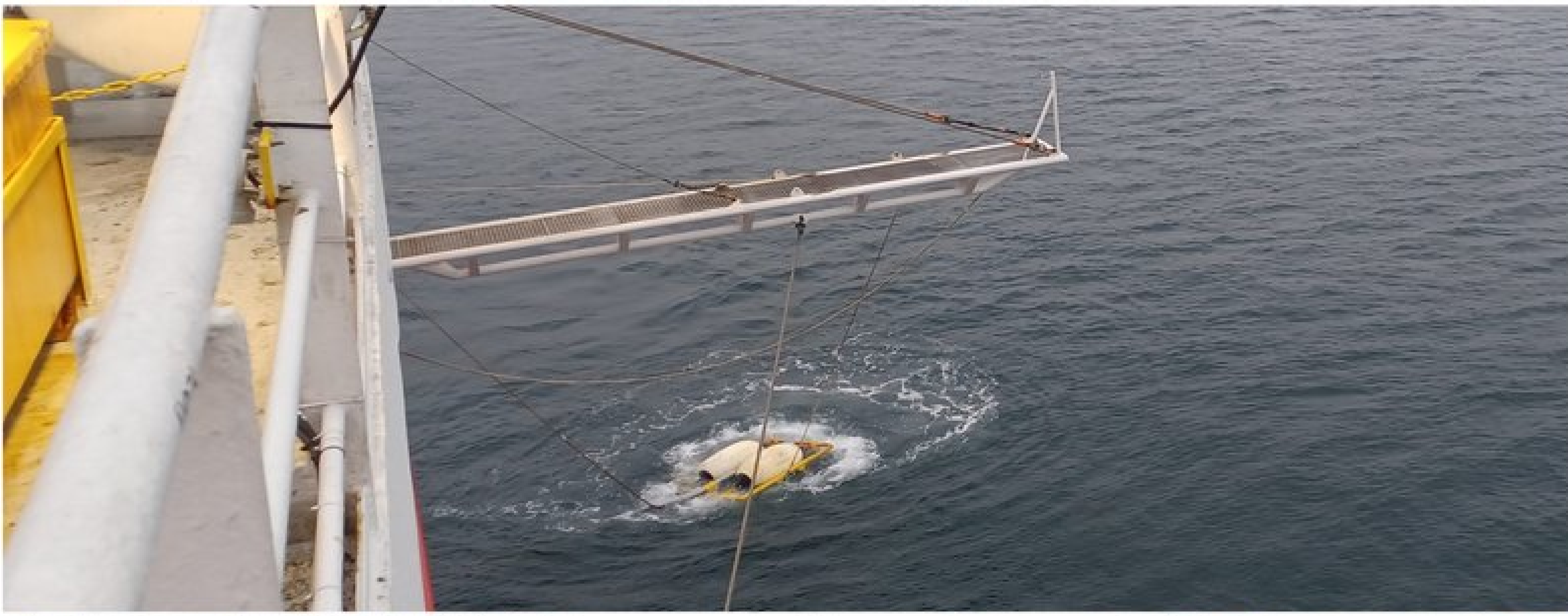

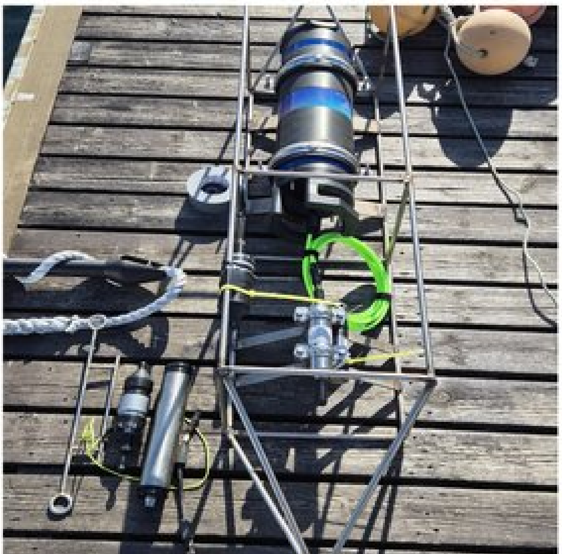

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Summary (English):

The purpose of this survey was to expose tagged cod to seismic airgun sounds. This is a follow up of previous exposure experiments documenting that spawning cod do not leave the area in response to airgun sound with sound exposure levels up to 145 dB re 1µPa²s. During the current survey, we conducted exposures in the same manner, but at a higher sound level. This cruise report describes the equipment, setup, and completed exposures in detail. Finally, the report presents the results from the sound measurements, as well as some preliminary results from the fish tags.

The cruise was carried out using the vessel “Fugro Meredian”, a seismic vessel operated by Fugro. The exposure was conducted using a block design consisting of: 1) Seismic 2) Vessel control and 3) Silent control. The order of these treatments was randomized, and each exposure lasted for 3 hours.

Prior to the survey, cod were tagged with acoustic telemetry tags, allowing for the tracking of the fish's movements in time and space to study behavioural changes related to the exposure.

A few days before start of the survey, hydrophones were deployed at four different locations in the bay to measure sound levels.

Analyses of data from the hydrophone closest to the seismic source (distance 175-370 m) show that sound exposure level (SEL) varied from 150.3 -151.5 dB re 1µPa2s. Hence, all exposures was more than 5 dB higher than in previous exposure experiments.

A total of 28 tagged fish was detected in the area dring the experimental period. Positioning and analyses of fish behaviour are still to be conducted, but a preliminary scan of the available data indicate that those fish present in the days before the survey started, remained in the area during the exposure period, indicating that the seismic survey did not abandon their habitat in response to the seismic exposure. Swimming depth and activity level had a high degree of individual variation, and need more in-depth analyses before any results can be given.

Summary (Norwegian):

Dette toktet hadde som formål å eksponere merket torsk for lyd fra luftkanon, og er en fortsettelse på tidligere forsøk hvor en har dokumentert at gytende torsk ikke forlater området i respons til lyd fra en luftkanon med lydeksponeringsnivå opp til 145 dB re 1µPa2s. På dette toktet har vi foretatt eksponering på samme måte, men med et høyere lydnivå.

Denne toktrapporten beskriver i detalj utstyr, oppsett og utført eksponering. Til sist i rapporten viser vi også resultater fra lydmålingene, samt noen foreløpige resultater fra fiskemerkene.

Toktet ble foretatt med fartøyet "Fugro Meredian", som er et seismikkfartøy operert av Fugro. Eksponeringen ble gjort som et blokkdesign bestående av 1) seismikk, 2) Fartøy kontroll og 3 stille kontroll, hvor rekkefølgen var randomisert. Hver eksponering varte i 3 timer.

Torsk var i forkant av toktet merket med akustiske telemetri merker som gjør at en kan spore fiskens bevegelser i tid og rom for å studere endringer i adferd relatert til eksponeringen.

Noen dager før toktstart ble det plassert ut hydrofoner på 4 ulike lokasjoner i bukten, som målte lydnivå.

Analyser av data fra hydrofonen nærmest den seismiske kilden (avstand 175–370 m) viser at lydeksponeringsnivået (sound exposure level, SEL) varierte fra 150.3 til 151.5 dB re 1µPa²s. Følgelig var alle eksponeringene mer enn 5 dB høyere enn i tidligere eksponeringseksperimenter med seismikk.

Totalt var det registert 28 merkede fisk i området i løpet av forsøksperioden. Posisjonering og analyser av fiskeatferd gjenstår å gjennomføre, men foreløpig visuell gjennomgang av rådata indikerer at fisken som var til stede i dagene før undersøkelsen startet, forble i området i eksponeringsperioden. Dette tyder på at den seismikk-eksponeringen ikke førte

til at de forlot habitatet i respons til eksponeringen. Svømmedybde og aktivitetsnivå varierte mye mellom ulike individer, og det er derfor vanskelig å gjøre noen samlede observasjoner om eventuelle endringer som følge av eksponeringen.

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1 - Background

In the SpawnSeis project, which started in 2018, we aimed at studying the effects of seismic airgun shooting on wild, free ranging, spawning cod. However, in recent years, the project has expanded to include other sources of anthropogenic sounds, as well as also other periods than just the spawning period. This is studied using an acoustic telemetry grid in Austevoll, Norway. This set up has proven to be a very good experimental site for studying the effect of anthropogenic sounds on spawning cod (McQueen et al., 2022, 2023, 2024). In the original design, a total of 30 acoustic receivers were placed in a grid on a cod spawning ground. Single receivers were also placed on northern and southern exit routes, as well as on three nearby spawning sites to document potential use of multiple sites during a season. Additionally, a curtain of three receivers has 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. Some of these receiver stations are no longer in use, due to receiver loss or decommissioning of some stations, but the main grid and gates across the exits are still in place. The receiver stations in use in 2025 are shown in Figure 1.

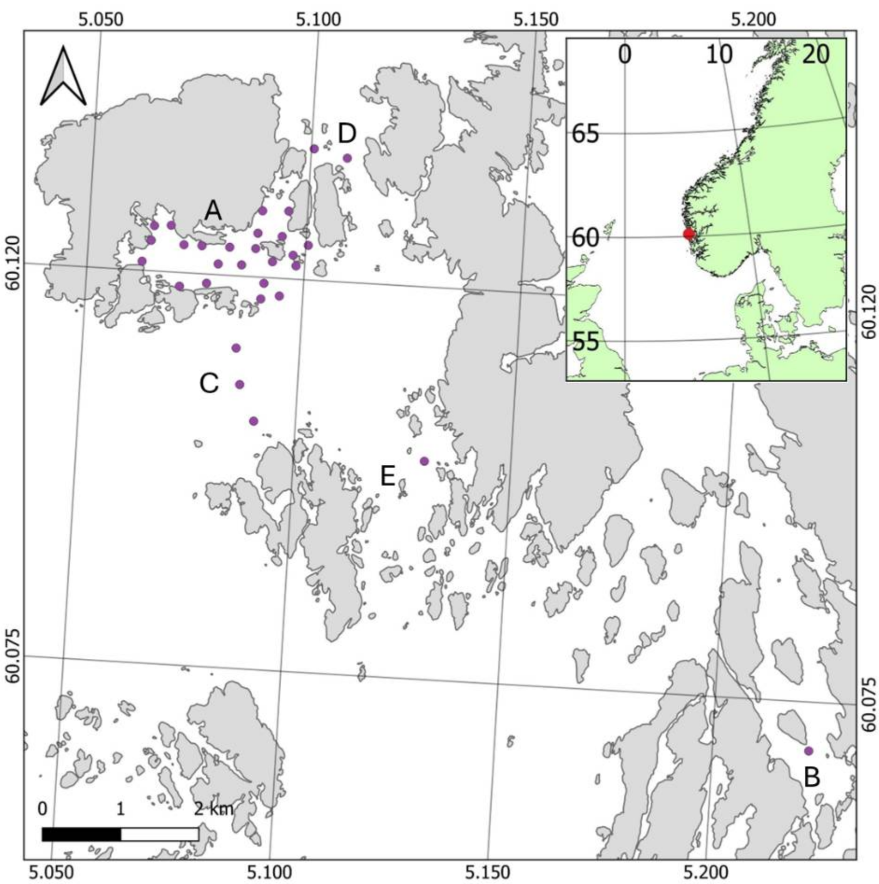

Figure 1. Overview of the telemetry receivers in the area (purple points). These are placed in the main exposure location in Bakkasund (A), and as curtains to control the western (C), northern (D) and southern (E) gateway from the main area as well as an additional spawning site in the area (B). The miniature insert picture shows the location of the research area in Austevoll as a red dot.

Every year, 50-60 cod have been tagged with acoustic transmitter tags. Tagging was performed in January in 2019, 2020, 2021, 2022 and 2024, in December 2022, and in April 2025. The movement of these fish can be tracked, vertically and horizontally. This allows us to study potential changes in behaviour such as vertical and horizontal avoidance, changes in home range and activity level in response to sound exposures. Two experiments with seismic air guns (Doksaeter Sivle *et al.*, 2021), one with a marine vibrator (Doksaeter Sivle *et al.*, 2022) and one with a sparker source (Sivle *et al.*, 2024) have been conducted in this bay and results have shown that air gun sound exposure levels up to 145 dB re 1 µPa^{2}s integrated over 10 s does not cause cod to move away from the area during the spawning period (McQueen et al., 2022) , and changes in behavior onsite are rather minor, but with seismic exposure resulting in somewhat deeper swimming (McQueen et al., 2023) . The marine vibrator exposure also did not cause fish to leave the test site, but changes in swimming depth and activity levels were observed during exposure (McQueen et al., 2024). Exposure to sparker source did not result in any significant changes in behavior (McQueen *et al.*, 2025) .

Most of the abovementioned experiments have been conducted during the spawning season. However, it has been proposed that the largest population-level effect of sound disturbance on fish could occur during feeding, as the sound disturbance may directly lead to higher energy expenditure and lower food intake (Soudijn *et al.*, 2020) . Further, to be able to test various sources, it must be done when these are available, which often are during the summer months. It is therefore crucial to have knowledge on the difference in response between summer/feeding period and winter/spawning period. To better understand this, we conducted a set of experiments in summer 2023/25 and winter 2024, where fish was exposed to noise from a research vessel as well as a 100 Hz continuous tone, assumed to simulate an operational offshore wind turbine.

Based on the results of the air gun experiments, IMR changed their advice to allow seismic operations closer to spawning areas than the 20 nmi buffer zone if the seismic company could document that the spawning areas are not exposed to sound exposure levels (SEL) exceeding those levels measured in that study; 145 dB re 1µPa^{2}s over 10 seconds (Sivle *et al.*, 2023). At this sound exposure level, spawning fish did not respond to the air gun in a way that is likely to affect the spawning at a population level. However, we do not know at what sound exposure level the fish start responding. It is therefore of interest to conduct similar tests, but with an increased sound exposure level, to better understand at what thresholds the fish start to respond.

The aim of the current study was to expose cod to higher sound exposure levels, aiming at levels that are representative of those experienced at close range to a typical site survey. Therefore, the exposure will be conducted with a real seismic vessel, as well as using a shot interval typically used in such surveys. This will allow testing the effect of both the seismic sound as well as to separate a potential response from that of the vessel sound itself.

2 - Methods

2.1.1 - Fish tagging

Adult cod were captured by local fishers using pots and gillnets, tagged with acoustic telemetry transmitters, and released (see McQueen et al., 2022, 2024 for details). The battery life of tags used is up to 766 days, meaning that surviving fish that stay in the area can be detected at the study site up to 2 years after tagging. A variety of tag types have been used since 2019 (from manufacturers Innovasea (2018-2024) and Thelma Biotel (2025)) All tags include acoustic transmitters, allowing triangulation of the fish's position, as well aspressure sensors that provide information on fish swimming depth. A subset of tags used have additionally included accelerometer sensors, used to infer fish activity levels. The tagging procedure is as follows: fish are anaesthetised prior to tagging. Tags are inserted through a 3 cm incision into the body cavity and closed by two absorbable sutures. Fish are observed until they are awake and appear to resume normal swimming behaviours. Thereafter, fish are released at a fixed position inside the bay. Thirty-eight cod were tagged on 07.04.2025 as part of this study: 12 females, 25 males and one uncertain (likely male). The average (±SD) length of tagged fish was 56 (± 8.7) cm, and average weight (±SD) was 1664 (± 714.7) g.

2.1.2 - Telemetry receivers

A total of 24 receivers are deployed in the bay to be able to monitor the movements of the tagged cod. Each of these are placed at a fixed position with a mooring. Each mooring has weights at the seafloor, then a rope that connects to a small underwater buoy. The receivers are attached to this rope, below the submerged buoy, so that the receivers are approx. 10 m from the surface (except for the receivers in very shallow water, which are closer to the surface). The submerged buoy is usually around 8 m from the surface. There is another rope which connects the mooring to a surface buoy. There is a bit of slack in the rope between the mooring and the surface buoy, to allow for changes in water level. Figure 2 show a sketch and photos to illustrate the setup.

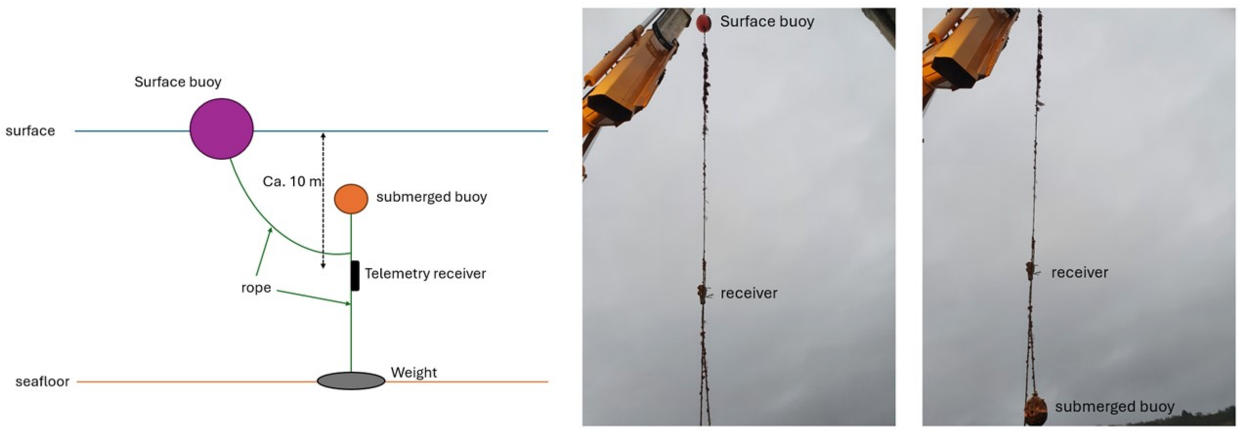

Figure 2 . Illustration (left) of the set up of the telemetry receivers and pictures (right) showing the system when retrieved form the water.

2.1.3 - Vessel

The vessel used was the 72.5 m long seismic vessel Fugro Meridian, operated by Fugro. This vessel is commonly used for site surveys in the North Sea, and hence a good representation of the vessel type associated with these types of operations. Note that for our experiment the vessel had to use the side propellers (dynamic positioning) to stay in one position which generates extra vessel noise.

2.1.4 - Seismic air gun

Seismic air gun transmission was conducted with an Input/Output Sleeve Gun-IB, with a volume of 10 in^3 (mini air gun). The gun was fired at a pressure of 2000 psi. The air gun was operated from the side of the ship, with two surface buoys and the air gun 1 m below the sea surface, with a pulse interval of 3 seconds.

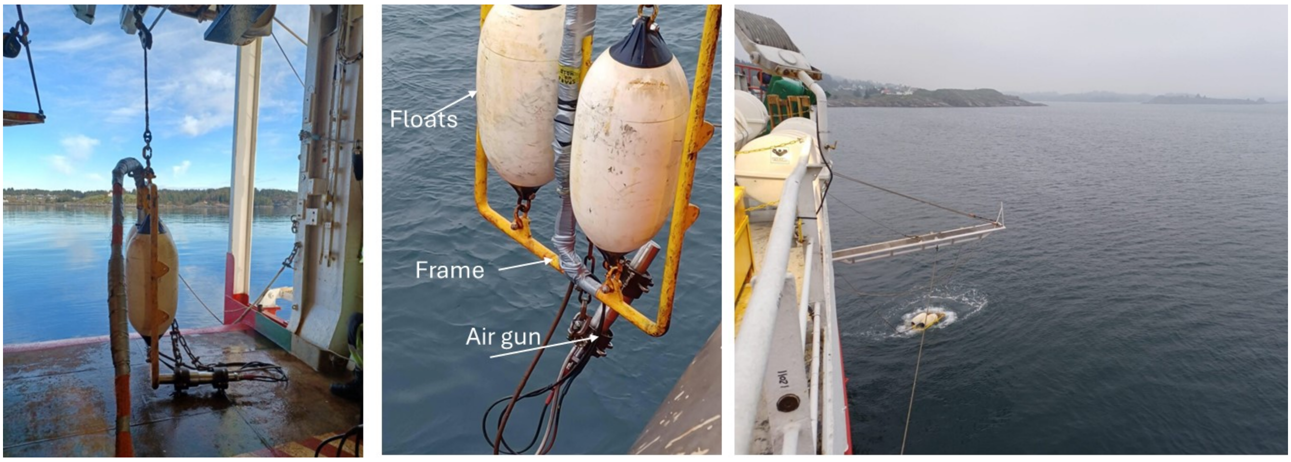

Figure 3. Seismic air gun and set up. The air gun was held at 1 m depth, held in place by a frame and surface floats. Left picture show set up on deck, middle picture while being deployed, and left picture during seismic shooting.

2.1.5 - Sound monitoring

Sound exposure in the bay was monitored by hydrophones placed at four different positions, covering different parts of the bay (Figure 7), monitoring sound exposure level experienced by the fish in the bay. Hydrophones were placed in the bay prior to the experiment start; 24.04.2025 by the small IMR vessel “Emmy Egedius” and retrieved 05.05.2025 by the IMR vessel “Svanhild”.

Five hydrophones were deployed at designated positions within the bay: inner, outer, centre, and side (Table 1). At the centre site, an IcListen and a SoundTrap were co-located (mounted in close proximity; see Figure 4) to enable instrument comparison. The two models have different lower frequency limit: the SoundTrap’s lower limit is 20 Hz, while the IcListen’s lower limit is 10 Hz. The sound pressure was recorded continuously during the employment and stored in 5-minute-long wav files.

The IcListen hydrophone had a large battery pack including 72 D-cell batteries. The battery pack and the hydrophone were connected with a cable and mounted in a large steel frame (Figure 5). The sound trap hydrophones had built in batteries of much smaller size and could therefore be attached directly to the rope (Figure 5). All hydrophone rigs were suspended in the same configuration using rope, buoys, and a 40–60 kg bottom weight resting on the seabed. Each hydrophone was suspended ~10 m above the bottom and supported by a subsurface (underwater) buoy attached to the mooring line approximately 5 m above the hydrophone. A surface buoy was tethered to the subsurface buoy with a loose sinking line; this arrangement decouples the hydrophone from surface wave motion. Sinking (nonbuoyant) rope was used for the moorings to prevent the line from floating at the surface, which was important because of local vessel traffic. This is similar to the suspension on the telemetry receivers (Figure 2), except that the surface buoy was attached to the submerged buoy and not below it.

Table 1. Overview of hydrophone deployments

Hydrophone type	Serial number	Sensitivity (dB re 1V/uPa)	lowest freq. (Hz)	highest freq. (Hz)	Location	hydrophone depth (m)	sample freq. (Hz)
Ocean Instruments, Sound Trap ST600STD	8717	-189.3	20	60000	inner	29	48000
Ocean Instruments, Sound Trap ST600STD	8714	-189.9	20	60000	outer	42	48000
Ocean Instruments, sound trap ST300HF	5779	-187.5	20	150000	side	43	48000
Ocean Sonics, IcListen HF	1758	-171	10	200000	center1	41	64000
Ocean Instruments, sound trap ST300HF	5513	-189	20	150000	center2	41	48000

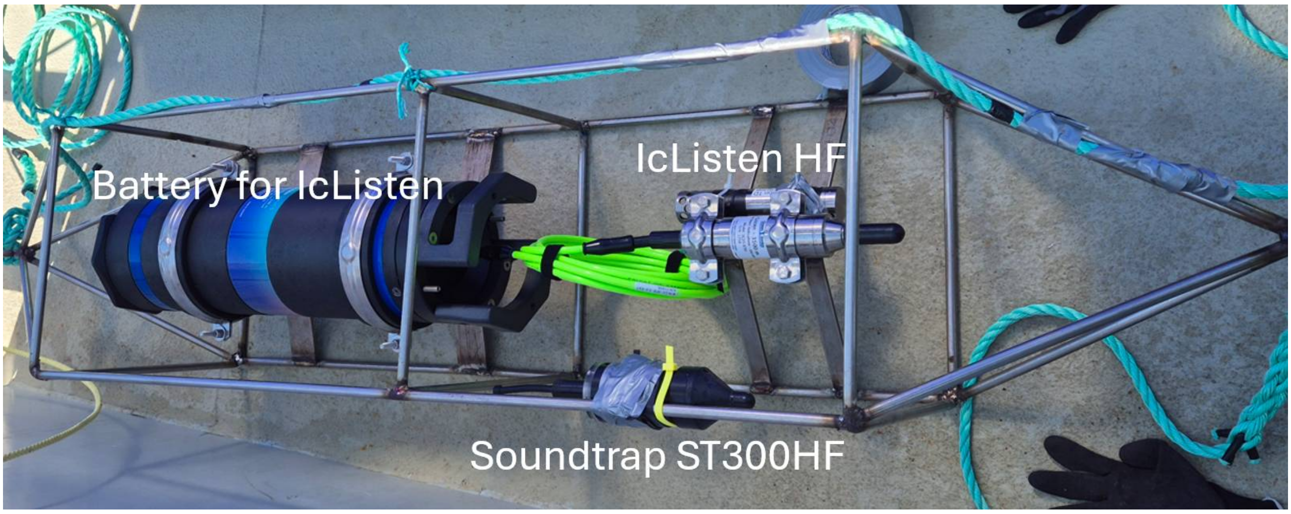

Figure 4. Hydrophone rig in the centre of the bay. The IcListen hydrophone required a large battery pack which was mounted in a steel frame. A sound trap hydrophone was also mounted on the frame. A depth logger (Starmon TD) is attached next to the IcListen hydrophone.

Figure 5. SoundTrap ST600STD and depth logger

2.1.6 - Hydrographic measurements

To be able to make sound speed profiles to better understand how sound is transmitted in the area, daily CTD casts were conducted.

CTD casts were done with the ships instrument; a Valeport Midas SVX2 Combined SVP/CTD (Figure 5).

Figure 6. The CTD instrument about to be deployed (left) and close up before being submerged (right).

2.1.7 - Vessel track

The position of the vessel throughout the experiment were synchronized with the ships single beam echosounder, giving the position as well as bottom depth every 3 seconds. The echosounder was of type Kongsberg EA600, with frequencies 38 kHz and 200 kHz. Grid coordinates are given in UTM zone 31N (ESPG 16031) projected coordinate system and the latitudes and longitudes are WGS 84.

2.1.8 - Experimental design

Originally the experiment aimed to follow the experimental set up used in the experiment with smaller air guns described in (Doksaeter Sivle et al., 2021) , using a “racetrack” outside the bay for the exposure, but this time using a larger air gun array. However, modelling of sound exposure in the area with the larger air gun array revealed that this resulted in sound exposure levels above the recommended threshold for potentially inducing behavioural exposure at nearby salmon farms. By reducing the source at the racetrack, the sound exposure inside the cod bay would however be too low for the experiment to gain much new knowledge. Therefore, it was decided to rather move the source vessel inside the bay, to increase the distance to the fish farms, and at the same time reducing the distance to the tagged cod. By moving the source from about 2 km from the main study area to inside the main part of it, sound levels at the cod will be higher. Therefore, the size of the source needed to be reduced to obtain a level similar as expected from a full-size source outside the bay. Based on sound propagation models and bathymetry in the area, we therefore calculated the anticipated sound exposure levels (SEL) at three positions in the bay, where we have had, and planned to have also in this experiment, hydrophones. Based on this, we decided to use a rather small air gun, the “mini-air gun” with a size of 10 cubic inches.

Inside the bay is rather shallow and with many receivers with surface buoys, making the area difficult to manoeuvre a large vessel in. We have considered anchoring up, but that was not possible due to the large vessel needing a 300 m clearance for this. Therefore, the vessel stayed stationary by using its Dynamic Positioning (DP) which includes use of side propellers. Two suggested positions for this are shown in Figure 7 , with the innermost position as the preferred option which was used. This figure also shows the locations of the telemetry receivers, as well as suggested positions of the hydrophones.

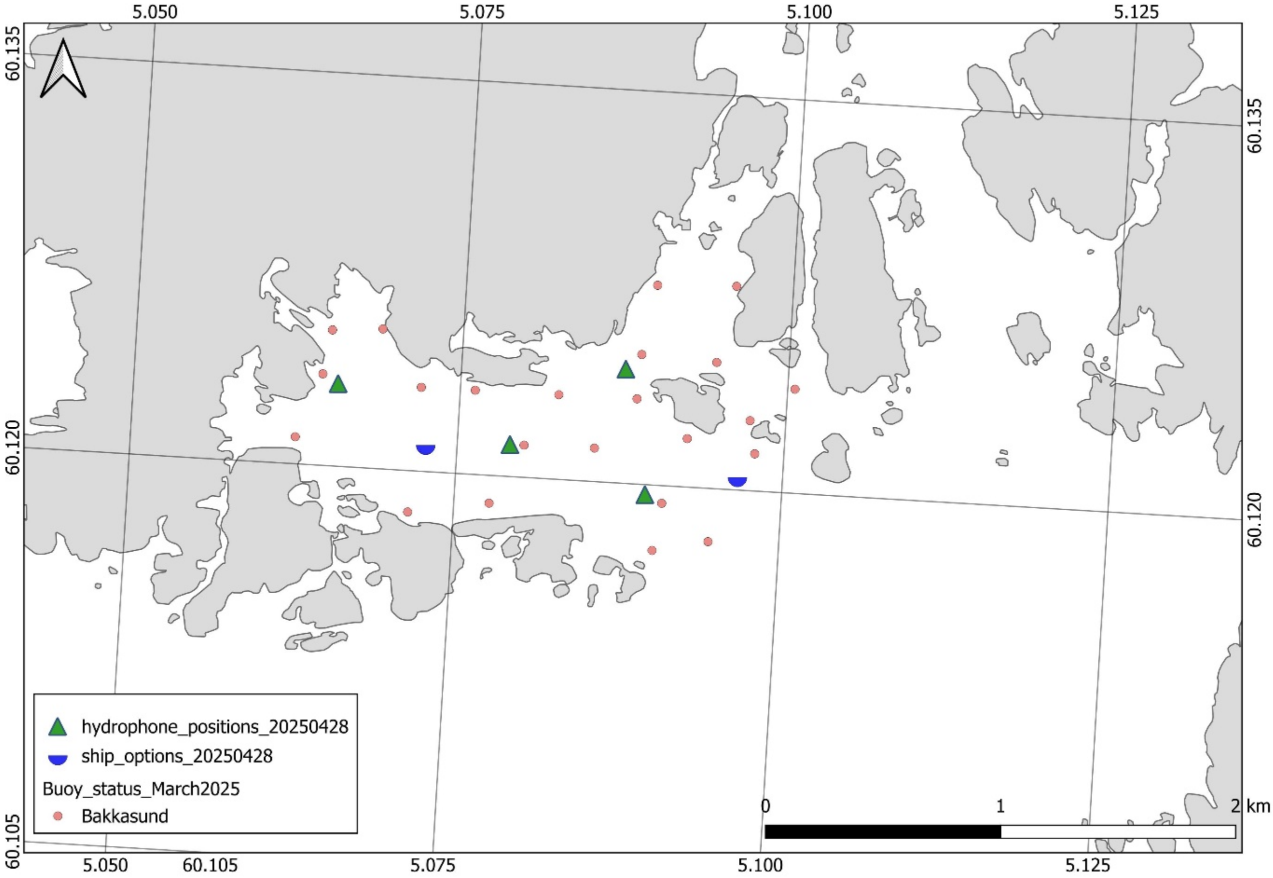

Figure 7. Map of the bay showing the positions of the telemetry receivers (red circles) and placement of hydrophones (green triangles). The hydrophone positions are located approximately 50 m from the telemetry receivers. Two alternative locations of the vessel to be positioned are shown as blue half circles. The preferred option is the one furthest into the bay which was used in this experiment.

Exposure was conducted as a block design, each block consisting of 3 exposure conditions:

- Seismic air gun transmission: Active air gun transmission (seismic) with the mini air gun with vessel running on DP. Other engines switched off as far as possible. Shot interval was 3 sec, as during a regular site survey.
- Vessel control: Vessel running on DP and everything else similar as during type 1), but without active shooting.
- Silent control: Vessel moves out of the area, and stays outside in an area where the sound from the vessel will not reach the bay.

Each exposure type last 3 hours. Order of the three exposure types within a block was randomized prior to the experiment.

2.2 - Results

2.2.1 - Daily operations

A summary of the activities each day are given in Table 2 .

Table 2. Summary of daily activities. All times are given in UTC.

Day	Description of activities	# Blocks, # CTDs
Tuesday April 29th 2025	Scientific crew embarked Kick-off meeting onboard Sail towards Bakkasund from Bergen at 16:00	0,0
Wednesday April 30th, 2025	Start operation around 04:00 by a survey around in the bay to locate a proper position for the vessel during exposure. Made CTD casts at all hydrophone locations and vessel location. Start operation.	2 blocks, 5 CTDS
Thursday May 1st 2025	Continue operation	2 blocks, 1 CTD
Friday May 2nd 2025	Continue operation	3 blocks, 1 CTD
Saturday May 3rd 2025	Continue operation	2 blocks, 1 CTD
Sunday May 4th 2025	Finish operation 04:35 Take CTD casts at vessel and all hydrophone positions Transit to Bergen, arrive 08:30.	1 block, 5 CTDs

Map of all the vessel track for each day, position of the ship during the different treatments for each block and the CTD positions are shown in Figure 8 .

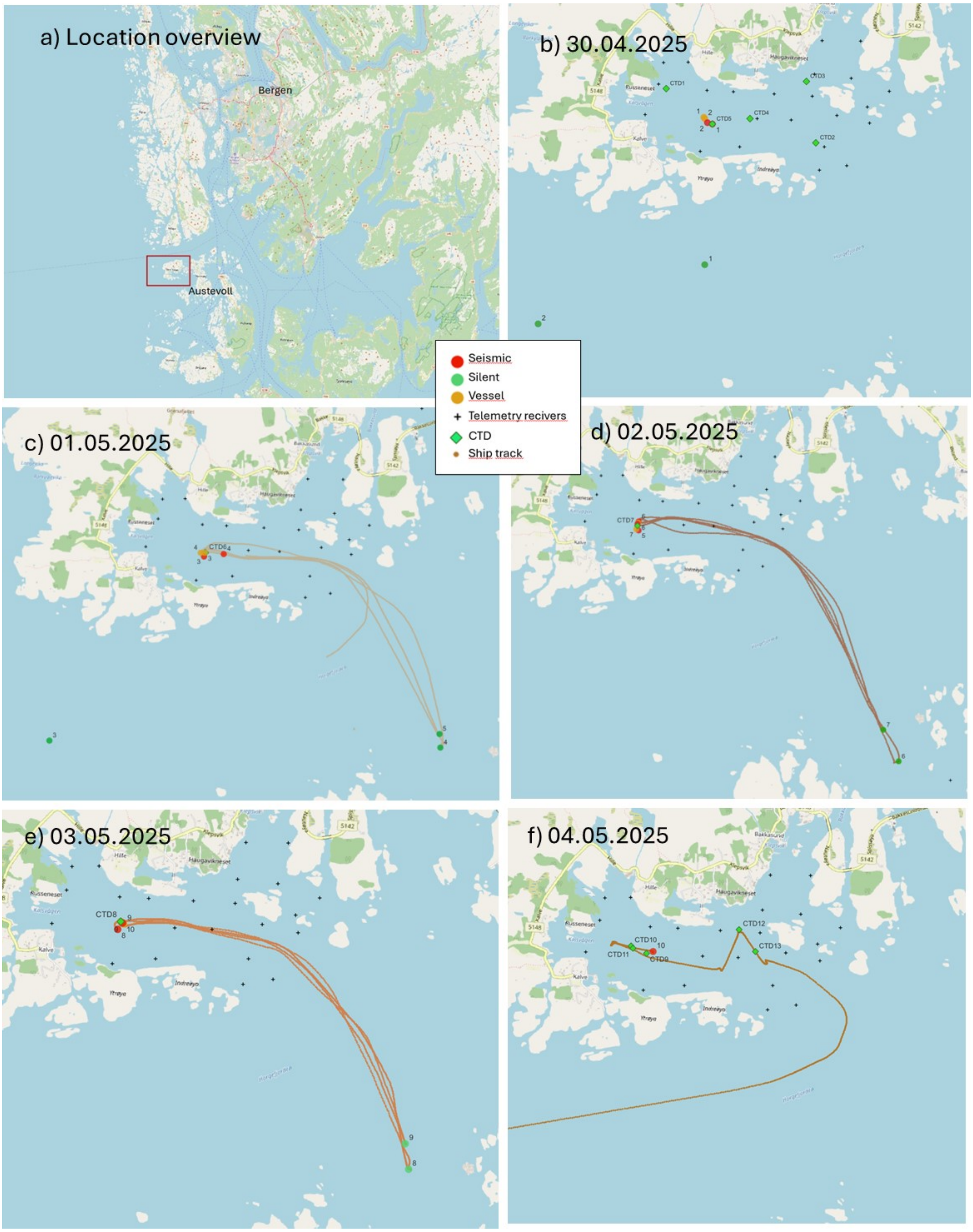

Figure 8. Map of daily activity for each of the survey days 30.April- 4.May 2025. a) show an overview of the location, with the red square indicating Bakkasund, the area within this square are the area shown in maps b-f. Position of vessel during all 3 treatments of those blocks conducted the day specified as red, orange and green dots for seismic, vessel control and silent control, respectively, with numbers next to them indicating the block number, as given in Table 3 . The ships track is shown in brown, and CTD stations marked as green diamonds. CTD names refer to those given in Table 4 . Ship track for 30.April and some parts of 1.May is missing.

2.2.2 - Final treatment schedule

A total of 10 blocks were conducted as planned. The final treatment schedule is shown in Table 3 .

Table 3. Final treatment schedule. Note that block 7 was moved to the end to save time.

Block	Run	Treatment	Date	Start time (UTC)	Stop time (UTC)	Lat	Lon
1	1	seismic	30.04.2025	06:39	09:39	60.1206	5.0732
1	2	silent	30.04.2025	10:00	13:00	60.1096	5.0733
1	3	vessel	30.04.2025	13:20	16:20	60.1211	5.071801
2	1	silent	30.04.2025	16:31	19:31	60.1042	5.0478
2	2	vessel	30.04.2025	19:51	22:51	60.121	5.071908
2	3	seismic	30.04.2025	22:53	01:53	60.12068	5.072387
3	1	seismic	01.05.2025	01:59	04:59	60.1205	5.0726
3	2	silent	01.05.2025	05:15	08:15	60.104	5.0481
3	3	vessel	01.05.2025	08:36	11:36	60.1208	5.0727
4	1	silent	01.05.2025	11:57	14:57	60.10538	5.114925
4	2	seismic	01.05.2025	15:25	18:25	60.1208	5.076
4	3	vessel	01.05.2025	18:26	21:26	60.12079	5.072067
5	1	silent	01.05.2025	21:41	00:41	60.10654	5.11462
5	2	vessel	02.05.2025	01:03	04:03	60.12091	5.071913
5	3	seismic	02.05.2025	04:04	07:04	60.1205	5.0722
6	1	seismic	02.05.2025	07:05	10:05	60.1213	5.0721
6	2	vessel	02.05.2025	10:06	13:06	60.12122	5.07205
6	3	silent	02.05.2025	13:14	16:14	60.1014	5.120702
7	1	vessel	02.05.2025	16:29	19:29	60.1206	5.0718
7	2	silent	02.05.2025	19:45	22:45	60.10411	5.117697
7	3	seismic	02.05.2025	23:07	02:07	60.12108	5.071933
8	1	seismic	03.05.2025	02:08	05:08	60.1209	5.072
8	2	silent	03.05.2025	05:20	08:20	60.105	5.1155
8	3	vessel	03.05.2025	08:35	11:35	60.12147	5.0724
9	1	silent	03.05.2025	11:47	14:47	60.10682	5.114838
9	2	vessel	03.05.2025	14:56	17:56	60.1213	5.0728
9	3	seismic	03.05.2025	18:03	21:03	60.12134	5.072567
10	1	vessel	03.05.2025	21:07	00:07	60.12135	5.072652
10	2	seismic	04.05.2025	00:09	03:09	60.12135	5.072652
10	3	silent	04.05.2025	04:40	07:40	on way to port	

2.2.3 - CTD casts

On the first day, CTD casts were done at all hydrophone positions. However, since the water masses are not expected to change much during the days, as well as between locations, the remaining days CTDs were done at the vessel position only. Overview of the CTD casts is given in Table 4 .

Table 4 . Overview of CTD casts done during the SpawnSeis BSU experiment.

Name	Date	Time (UTC)	Position	Comment
CTD1	30.04.2025	04:15	60.12315, 5.0656	outer bay hydrophone position
CTD2	30.04.2025	04:40	60.119616, 5.08956	mid bay hydrophone position
CTD3	30.04.2025	05:00	60.12435, 5.0875	side bay hydrophone position
CTD4	30.04.2025	05:30	60.121216, 5.07903	inner bay hydrophone position
CTD5	30.04.2025	05:45	60.1206, 5.0732	vessel position
CTD6	01.01.2025	08:36	60.1208, 5.0727	vessel position
CTD7	02.05.2025	03:19	60.12091, 5.071913	vessel position
CTD8	03.05.2025	08:40	60.121467, 5.0724	vessel position
CTD9	04.05.2025	03:25	60.1212, 5.0717	vessel position
CTD10	04.05.2025	03:38	60.1217, 5.0692	inner bay hydrophone position
CTD11	04.05.2025	03:55	60.1215, 5.0695	mid bay hydrophone position
CTD12	04.05.2025	04:09	60.1234, 5.0853	side bay hydrophone position
CTD13	04.05.2025	04:24	60.1218, 5.0879	outer bay hydrophone position

Sound speed profiles from the CTD casts for the hydrophone positions are shown in Figure 9 (30.04.2025) and Figure 10 (04.05.2025), and from the vessel position for all days in Figure 11 . CTD positions are shown in Figure 8 .

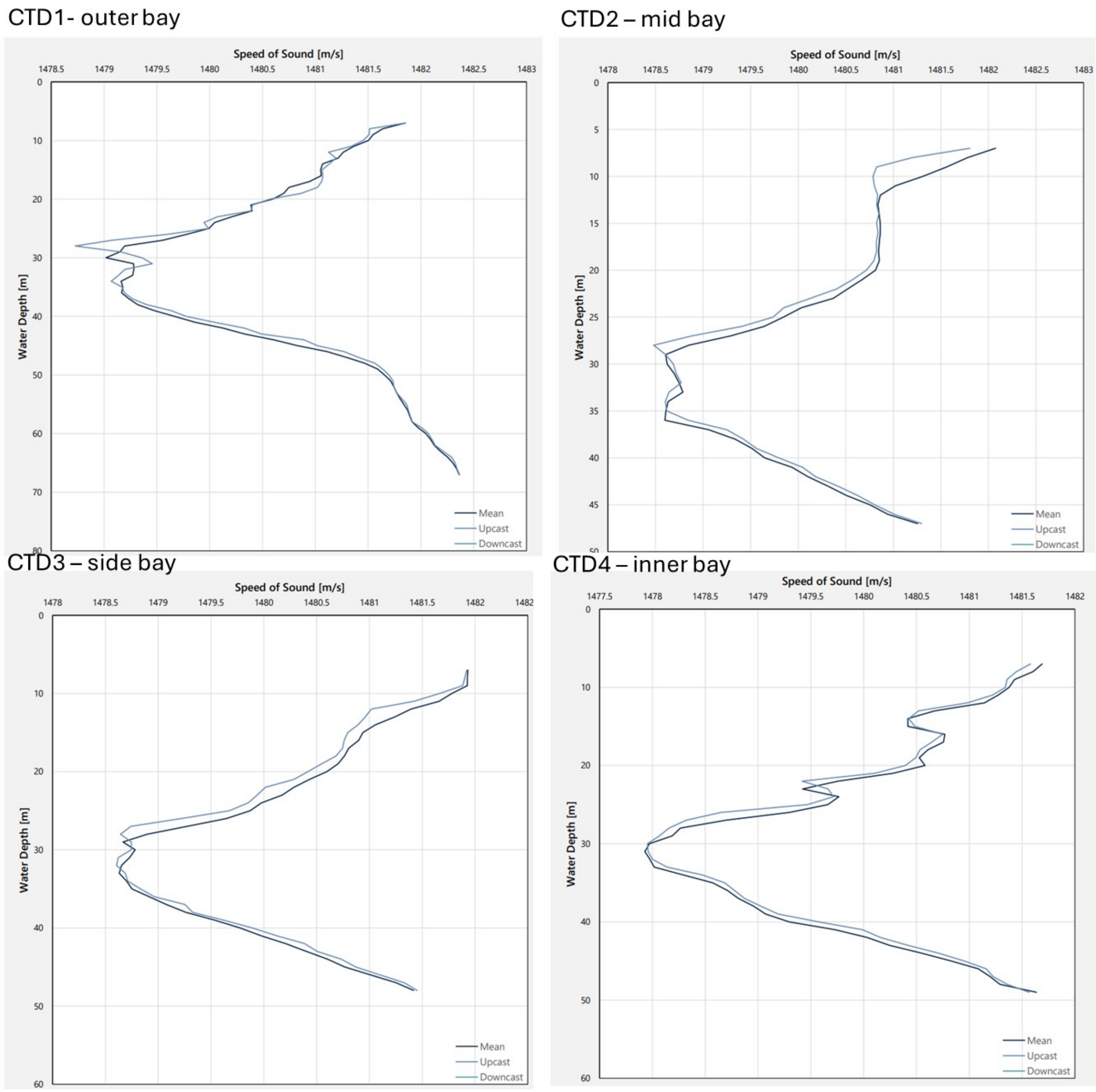

Figure 9. Sound velocity profiles for the 4 different hydrophone locations at 30.04.2025. Locations are shown in Figure 8.

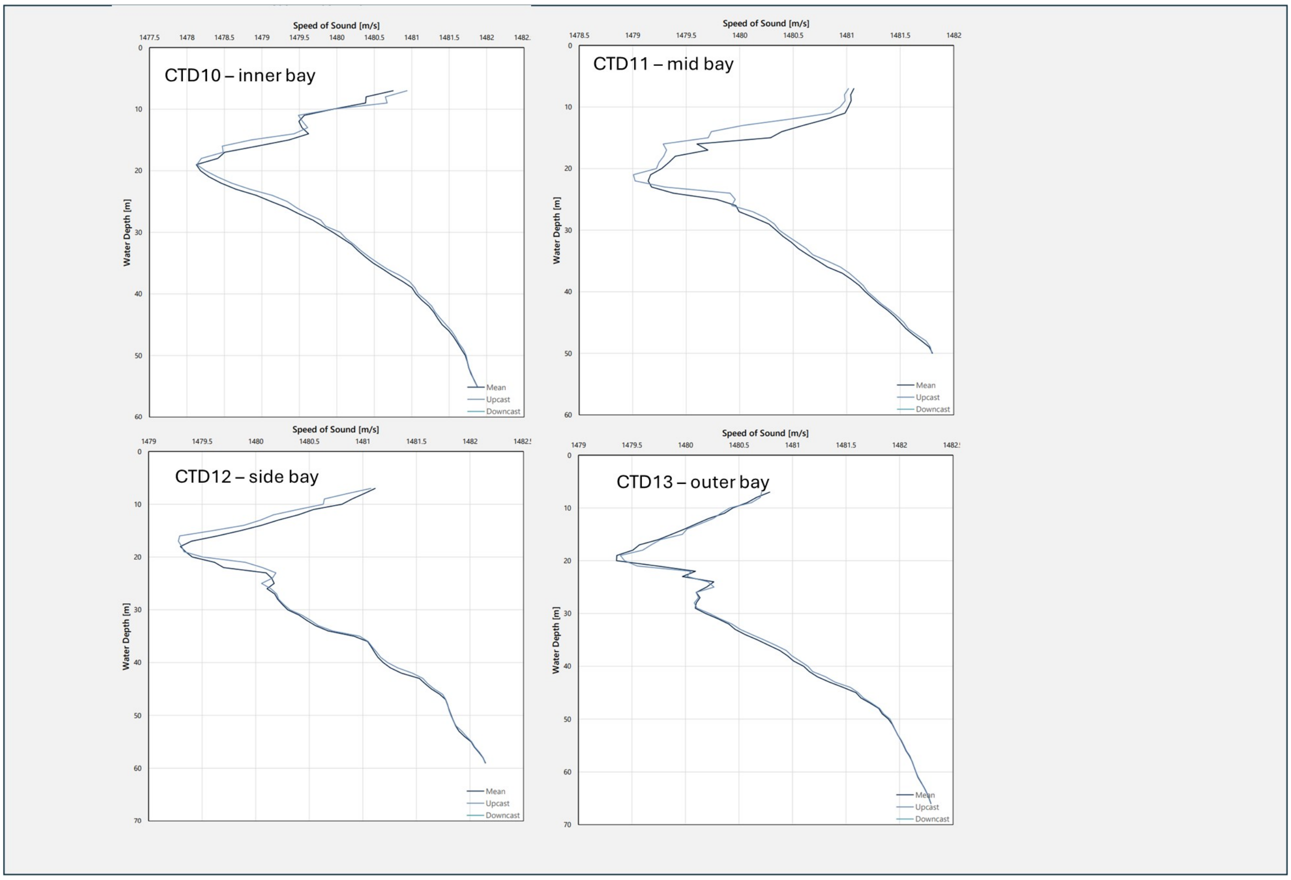

Figure 10. Sound speed profiles for all hydrophone positions from 04.05.2025. Locations are shown in Figure 8 ..

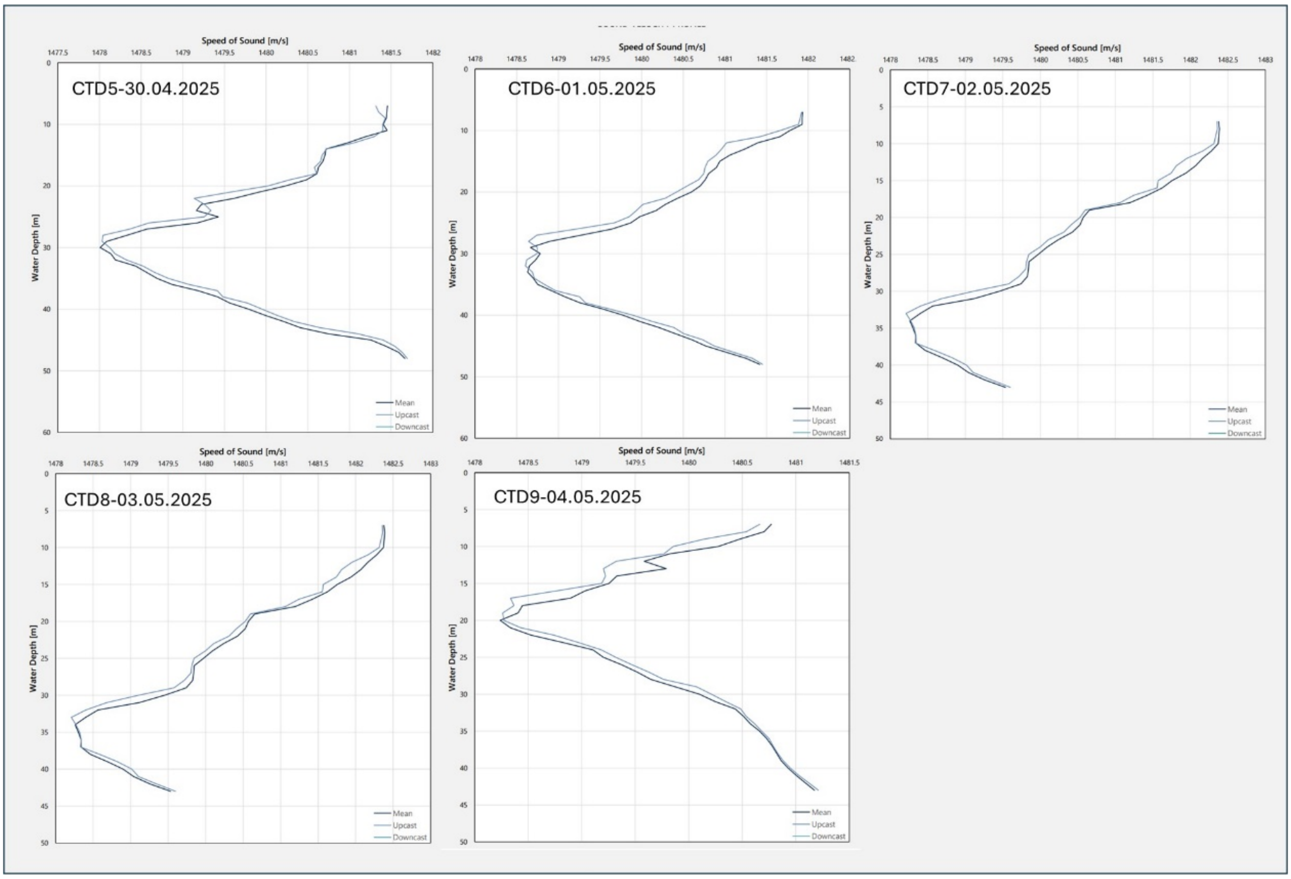

Figure 11. Sound velocity profiles from vessel position at the dates 30.04-2025 – 04.05.2025. Locations are shown in Figure 8 .

As can be seen from the profiles, the sound speed minimum was at around 30-35 m depth at all positions in the period 30.04 – 03.05, while the last day, 04.05, the sound speed minimum was shifted up to around 20 m at all positions. This is likely due to heavy winds in the last part of the day of 03.04, mixing the upper layers. The sound waves are always refracted towards the layer with minimum speed of sound which means that the depth of the sound speed minimum could have higher sound levels.

2.2.4 - Sound measurements

Position and time for the deployment and retrieval of the four hydrophone rigs are given in Table 5 .The distances between the hydrophones (deployment position) and the ship during the ten seismic exposure treatments were calculated using the "haversine method" (function "distHaversine" from R package "geosphere" (Hijmans, 2024)) (Table 6). The average distances between the ship during seismic exposure and the four hydrophones were as follows: 469 m to the inner bay hydrophone (H1), 943 m to the outer bay hydrophone (H2), 906 m to the side bay hydrophone (H3), and 351 m to the centre bay hydrophone (H4).

Table 5. Time and position for hydrophone deployments. Forgot to note the position and time for the side bay hydrophone on retrieval.

	Deployment			Retrieval		
Hydrophone name	**lat**	**lon**	**Time**	**lat**	**lon**	**Time**
inner bay hydrophone (H1)	60.123150	5.065633	20250424 12:20	60.123125	5.066019	20250505 11.58
outer bay hydrophone (H2)	60.119617	5.089567	20250424 13:15	60.119661	5.090122	20250505 11:16
side bay hydrophone (H3)	60.124350	5.08755	20250424 13:50	-	-	-

centre bay hydrophone (H4)	60.121217	5.079033	20250424 15:10	60.120986	5.079250	20250505 11:39

Table 6. Distances in metres calculated between the hydrophones and the ship during seismic exposure treatments.

Block	Distance to H1	Distance to H2	Distance to H3	Distance to H4
1	507	914	899	331
2	465	960	935	373
3	486	946	933	366
4	632	764	753	174
5	469	968	953	387
6	414	987	922	385
7	418	991	939	394
8	433	985	944	392
9	434	962	896	359
10	438	958	891	354

The sound recordings were analysed by use of Matlab. The data were bandpass filtered with a 3rd order Butterworth filter (5 – 1000 Hz) prior to the analyses. The data was converted to pascal by using the hydrophone sensitivity. The absolute peak sound pressure levels, $L_{p,\ 0\text{-}pk}$, and the sound exposure levels, $L_{E,p}$. (SEL) (ISO 18405:2017(E)) were estimated for every 10 seconds with 9 seconds overlap for each of the treatment periods.

The frequency content of the signals was also investigated for each treatment. An example (Figure 12)) from block 1 measured in the centre of the bay compares the energy spectral density of 1 second around a seismic pulse, 1 second before the pulse, 1 second of vessel noise, and 1 second of silent treatment. The energy spectral level of the silent period is about 50 dB below the vessel noise. For the airgun shot there is most energy below about 450 Hz, and highest levels between 100-150 Hz. There were no recordings of seismic signal without vessel noise.

The sound exposure level for a single shot including vessel noise was measured to 144 - 145 dB re 1 µPa^{2}s. Several repeated shots of the same level can be estimated as $145+10*\log_{10}(n)$, where n is the number of shots during the time interval of interest. For example, three repeated shots of the same level during 10 seconds will be $145+10*\log_{10}(3)=149.8$ dB re 1 uPa^{2}s. For our case with 3 seconds pulse interval, 10 seconds can include either 3 or 4 pulses, therefore the SEL for 10 seconds varies with about 1 dB (Figure 13) between different 10 s periods.

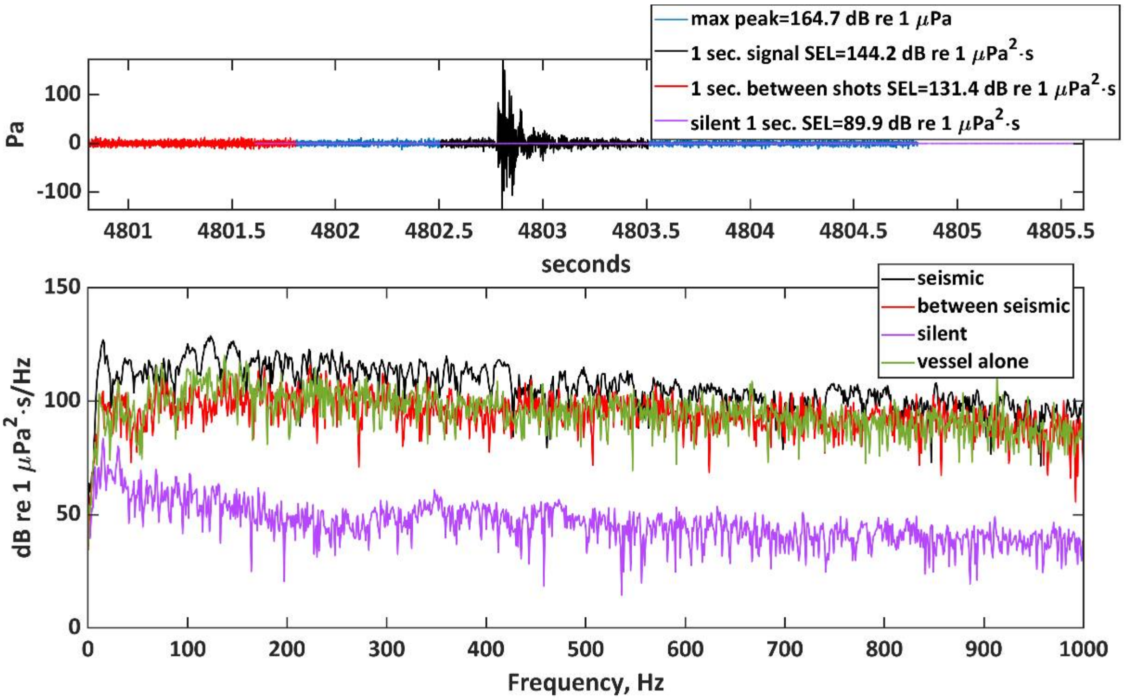

Figure 12. Example of a single seismic signal measured with the IcListen hydrophone in the centre of the bay. Zero to peak, SEL for the sigle shot, and SEL for a 1 second duration period before the shot is compared to the silent treatment (see figure legend). In the bottom panel the frequency content of the seismic signal (black1) relative to the period before (red), vessel noise alone (green), and silent with no vessel (purple) is shown. Most of the energy from the seismic is below 450 Hz with the highest levels between 100 – 150 Hz. The signal from the vessel dominates between the seismic signals. The signal from the vessel and vessel + seismic has much higher level than the silent for all measured frequencies, (up to over 20000 Hz). The broadband noise above 500 Hz is probably dominated by the vessel noise since the vessel noise alone shows a similar level.

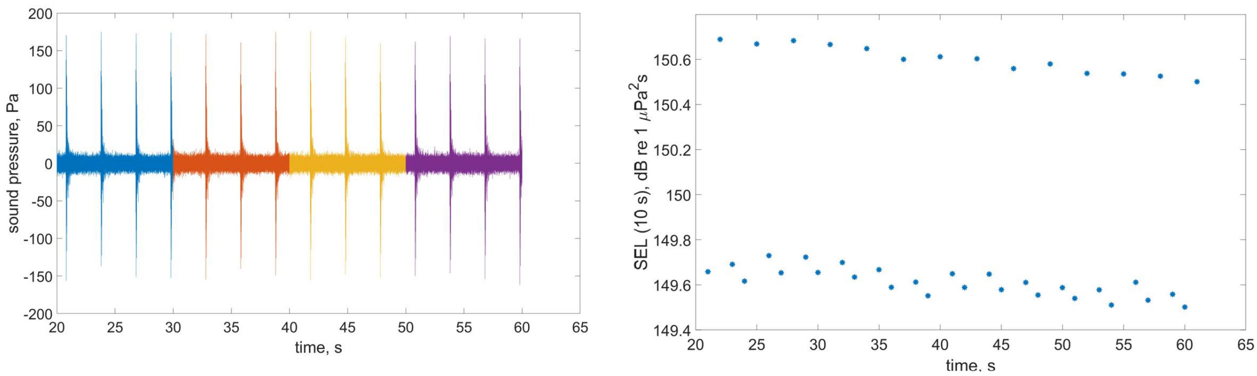

Figure 13. Zoom in on about 40 seconds of sound recording from the centre position. The different colours (left) marks 10 seconds intervals to illustrate that the pulse interval of 3 seconds results in 3 or 4 single seismic pulses pr 10 seconds. The SEL integrated over 10 seconds is affected by the the number of pulses resulting in about 1 dB difference if 3 or 4 pulses is included (right)

The mean estimated sound exposure levels integrated over 10 seconds for all the blocks and treatments are given in Table 7. The highest measured sound exposure levels were measured in the centre of the bay and ranged from 149.9 to 151.5 dB re 1 $\mu Pa^2 s$.

Examples of measured SEL for 10 seconds, with 9 seconds overlap, are shown in Figure 14 (block 1) and Figure 15 (block 5) for all treatment types and all positions. For the centre position the 10 s SEL for vessel noise is almost 144 dB re 1 µPa ^{2} s.

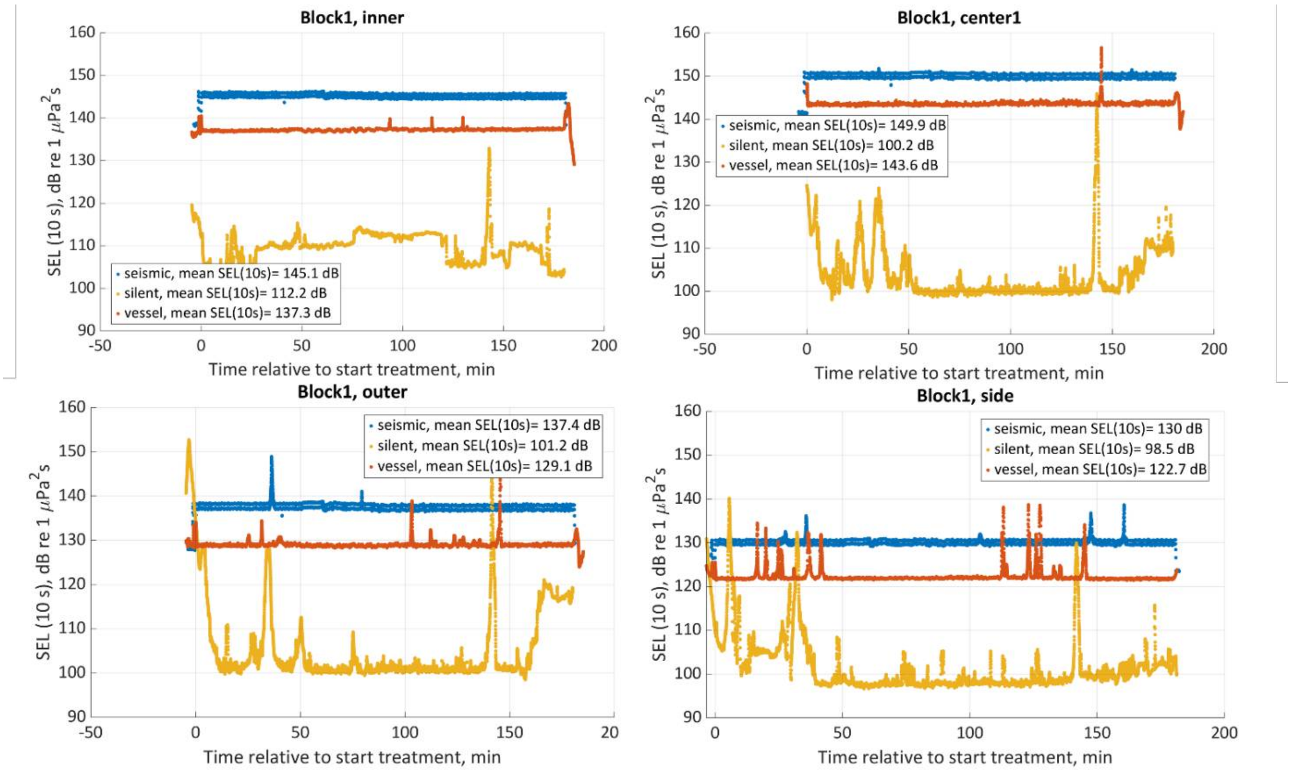

Figure 14. Block 1: Sound exposure levels (SEL) integrated over 10 seconds estimated for every 10 seconds (with 9 seconds overlap) for the duration of each treatment.

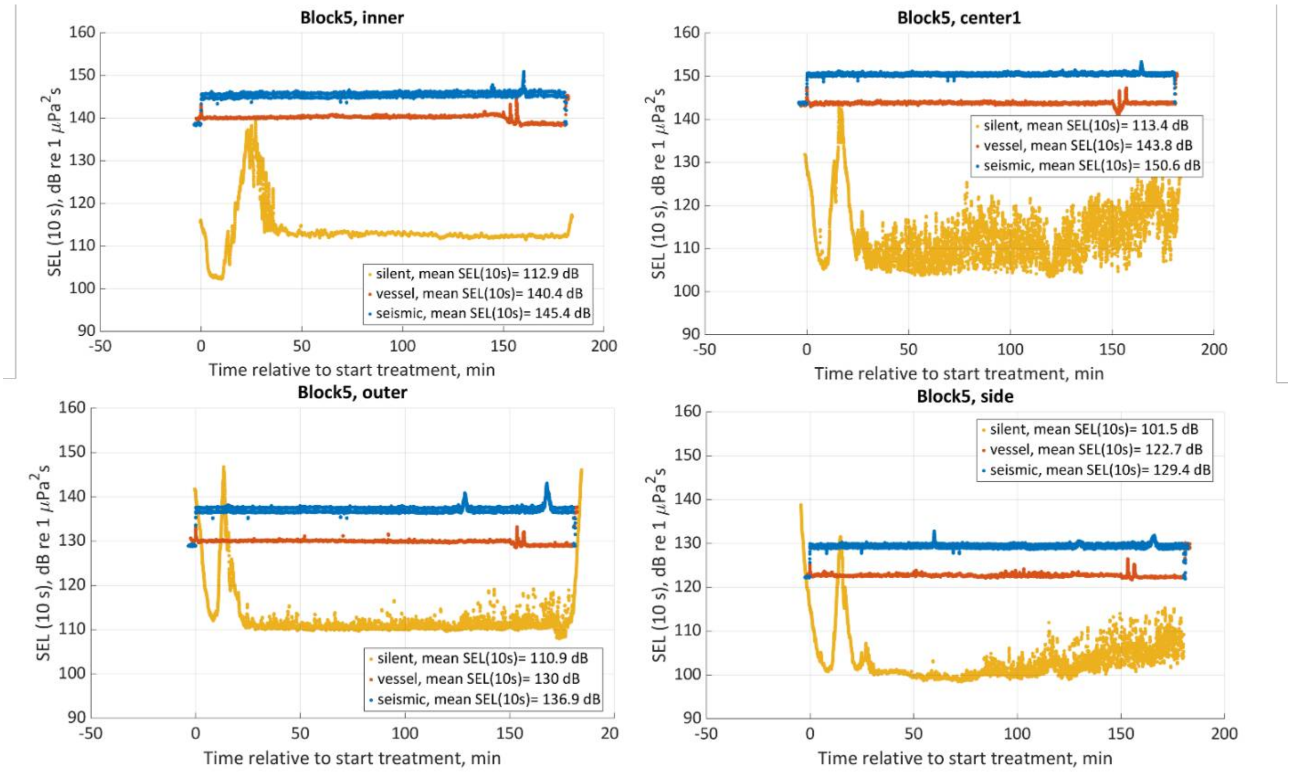

Figure 15 Block 5. Sound exposure levels (SEL) integrated over 10 seconds estimated for every 10 seconds (with 9 seconds overlap) for the duration of each treatment. The levels are a little different from Block 1, probably due to changes in the airgun position.

Table 7. SEL integrated over 10 seconds (dB re 1 μPa2s). Average values (averaged in linear domain) for 10 second periods within a time window of 1 hour in the middle of the treatment. Missing data are marked with NaN.

SEISMIC					
BlockNo	**inner_MeanSEL_dB**	**outer_MeanSEL_dB**	**side_MeanSEL_dB**	**center1_MeanSEL_dB**	**center2_MeanSEL_dB**
1	145.1	137.4	130	149.9	150.3
2	NaN	NaN	NaN	NaN	NaN
3	145.7	137.4	130.8	150	150.3
4	146.2	137.7	129.9	150.9	151.2
5	145.4	136.9	129.4	150.6	150.9
6	144.9	137	129.2	150.6	150.9
7	144.8	136.9	129.6	150.6	150.9
8	145	137	129.6	150.5	150.8
9	145.4	137	130.2	151.1	151.5
10	145.5	137.4	129.8	150.9	151.3
VESSEL					
BlockNo	**inner_MeanSEL_dB**	**outer_MeanSEL_dB**	**side_MeanSEL_dB**	**center1_MeanSEL_dB**	**center2_MeanSEL_dB**
1	137.3	129.1	122.7	143.6	144
2	139.3	129.4	122.3	144.2	144.6
3	139.2	130.8	125.5	143.5	143.9

4	140.4	130.4	123.8	143.2	143.6
5	140.4	130	122.7	143.8	144.1
6	137.3	129.2	121.8	143.7	144
7	137.8	129.4	122.6	143.4	143.8
8	140	131.2	126.5	145.1	145.4
9	NaN	NaN	NaN	NaN	NaN
10	139.3	131.4	128.3	145.1	145.6
SILENT					
BlockNo	**inner_MeanSEL_dB**	**outer_MeanSEL_dB**	**side_MeanSEL_dB**	**center1_MeanSEL_dB**	**center2_MeanSEL_dB**
1	112.2	101.2	98.5	100.2	100.9
2	106.4	97.9	99.8	94.7	98.6
3	106.5	112.8	109.8	117.9	110.1
4	107.1	111.3	104.7	117.6	109.5
5	112.9	110.9	101.5	113.4	106.9
6	119.5	118.2	115.2	120	119.1
7	107.7	107.7	103.7	107.9	106.9
8	111.4	106.1	97	101.8	101.6
9	127	118.2	120.2	122.1	NaN
10	105.3	113.3	114.2	119.3	110.4

In addition to the 10 s sound exposure levels which were used based on previous experiments where the pulse interval was 10 seconds, it is useful to also look at the sound exposure levels integrated over 1 hour and 3 hours. This comparison is also useful when comparing the results from this experiment with previous experiments. This experiment had higher 10 s SEL than previous experiments, but the SEL is even higher relative to previous experiments if we look at longer periods.

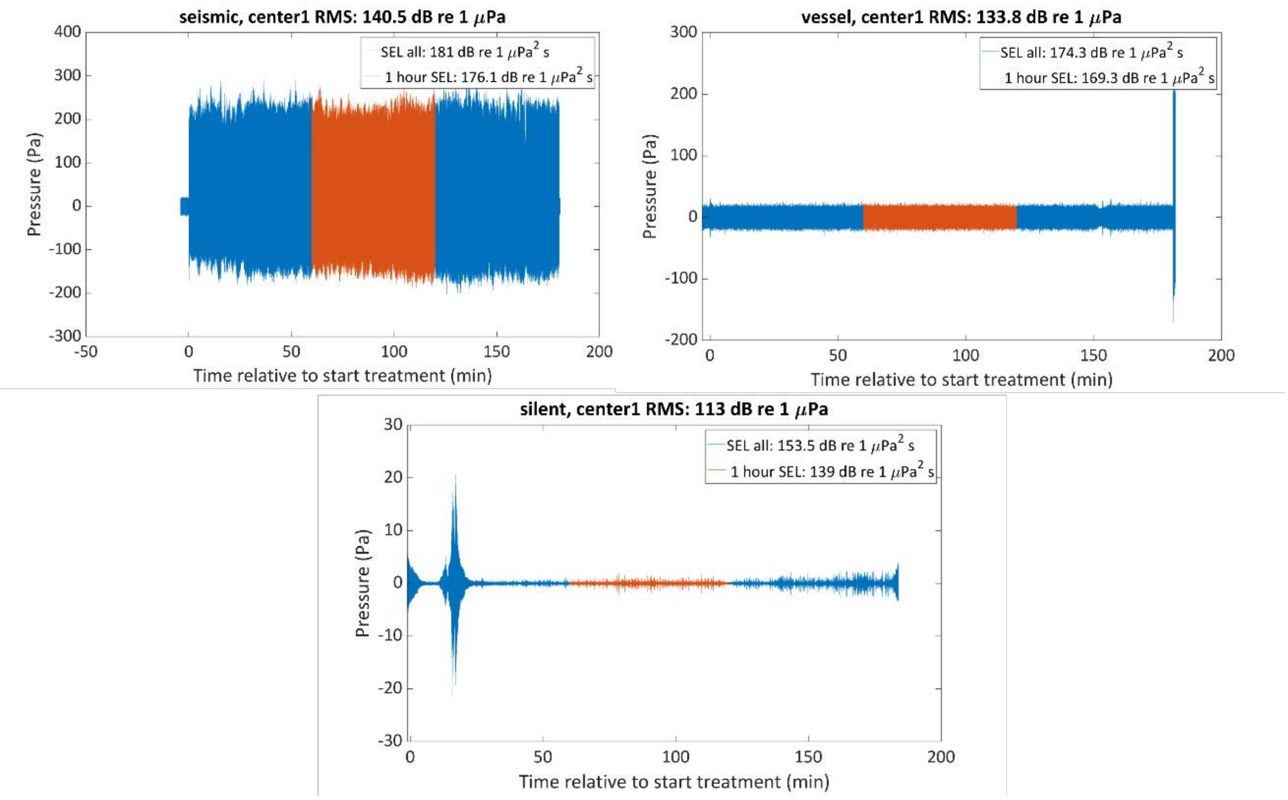

Figure 16. Example of the waveform of the recording for 3 hours of data for the three exposure types. The SEL for 1 hour (in the centre of the treatment marked in orange) is 176.1 dB re 1 µPa2s and 181 dB re 1 µPa2s for 3 hours of seismic exposure measured in the centre of the bay for Block 5.

The zero to peak sound pressure level is also of interest. Even if the SEL in this experiment is higher than previous experiments, this is due to the faster pulse repetition rate (3-4 pulses in 10 seconds). Examples of the absolute zero to peak pressure for the different treatments and positions are shown in Figure 17 and Figure 18 for Block 1 and Block 5, respectively. The mean zero to peak value measured in the centre position was 165.5 dB re 1 µPa for Block 1 and 167.4 dB re 1 µPa for Block 5.

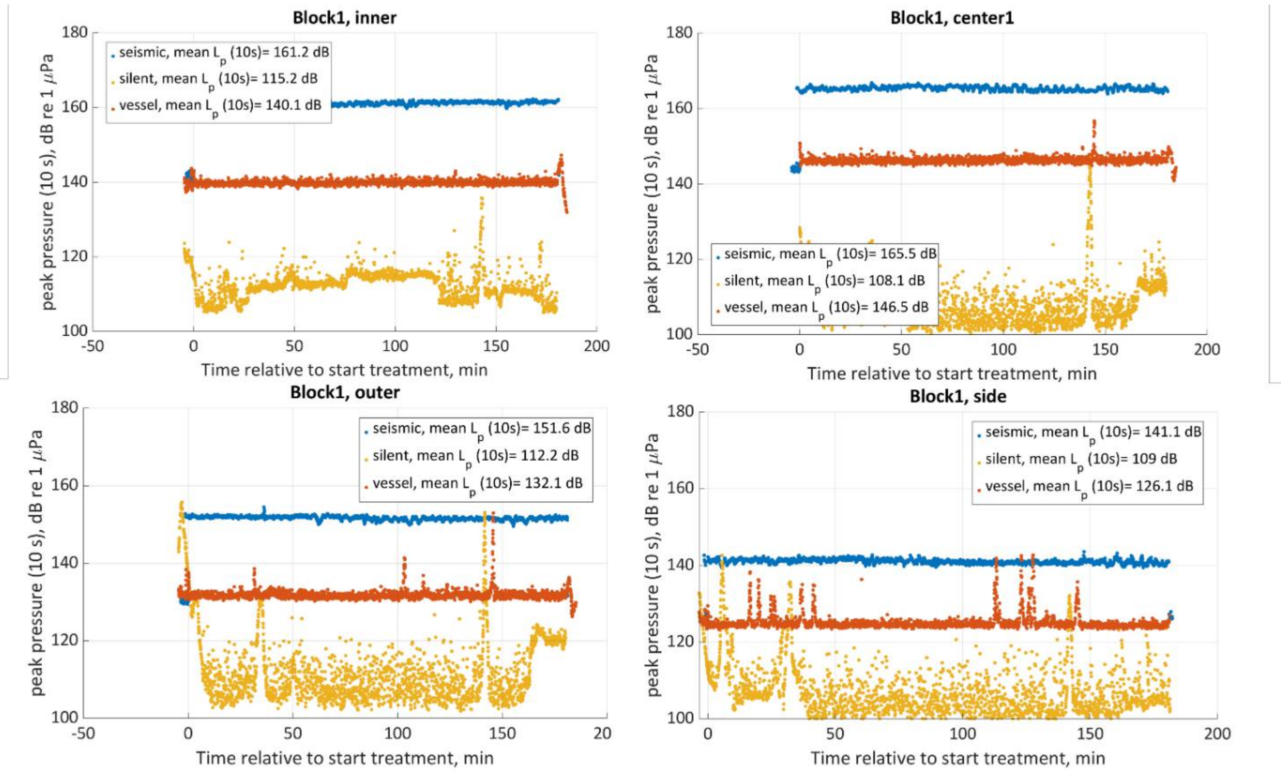

Figure 17. Block 1: Absolute zero to peak sound pressure level estimated as the maximum of the absolute value of the wave form forevery 10 s with 9 s overlap. This is shown for the inner, centre, outer and side position in the bay, for each treatment in Block 1.

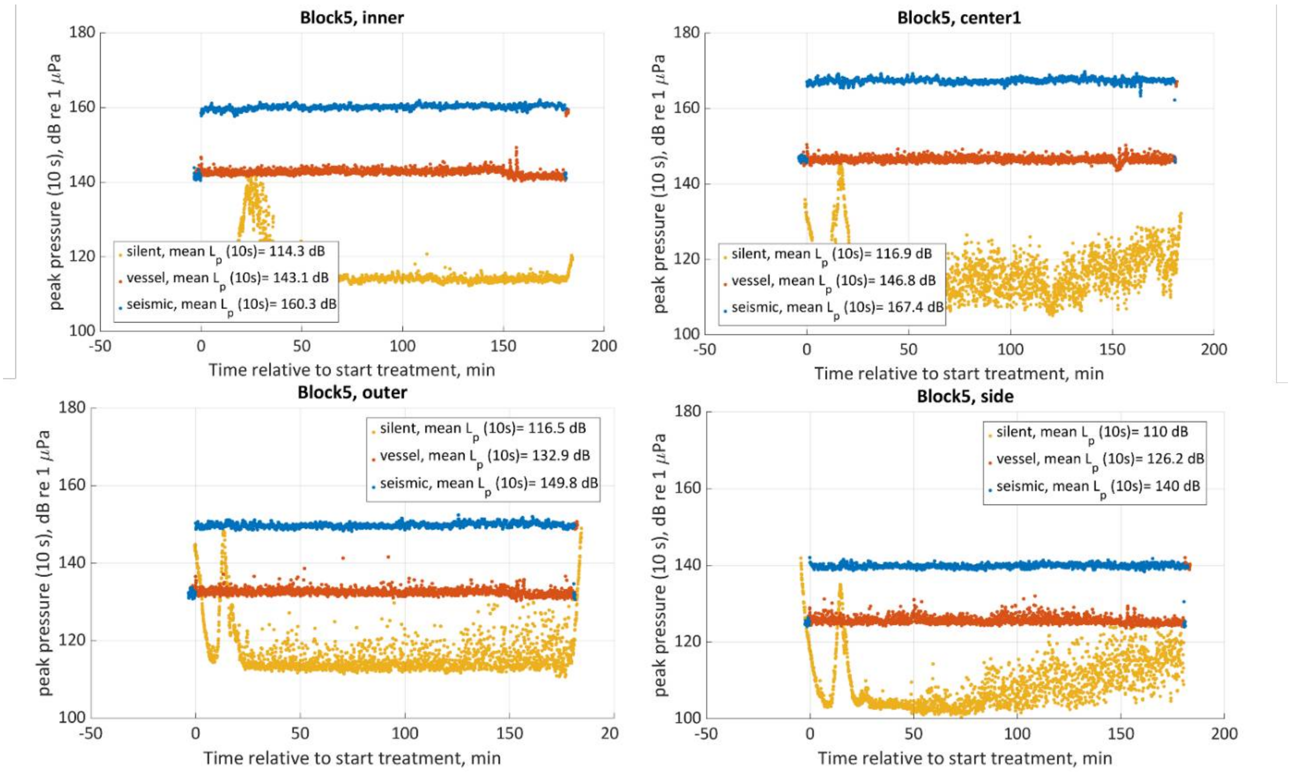

Figure 18. Block 5: Absolute zero to peak sound pressure level estimated as the maximum of the absolute value of the wave form for every 10 s with 9 s overlap. This is shown for the inner, centre, outer and side position in the bay, for each treatment in Block 5. The noise in the silent period can be local boat traffic in the bay.

2.2.5 - Fish behaviour

Data from the telemetry receivers was downloaded in September 2025. Fish positioning is yet to be calculated, but a preliminary overview of the data is shown here.

During the survey period, a total of 28 fish were detected in the area, 20 males and 8 females, with a mean length of 53 and 61 cm and mean weight 1.4 and 2 kg for males and females, respectively.

From visual inspection of the detection data, most of the tagged cod that were present in the telemetry grid in the days before the survey seem to stay in the general area throughout the survey period (Figure 20).

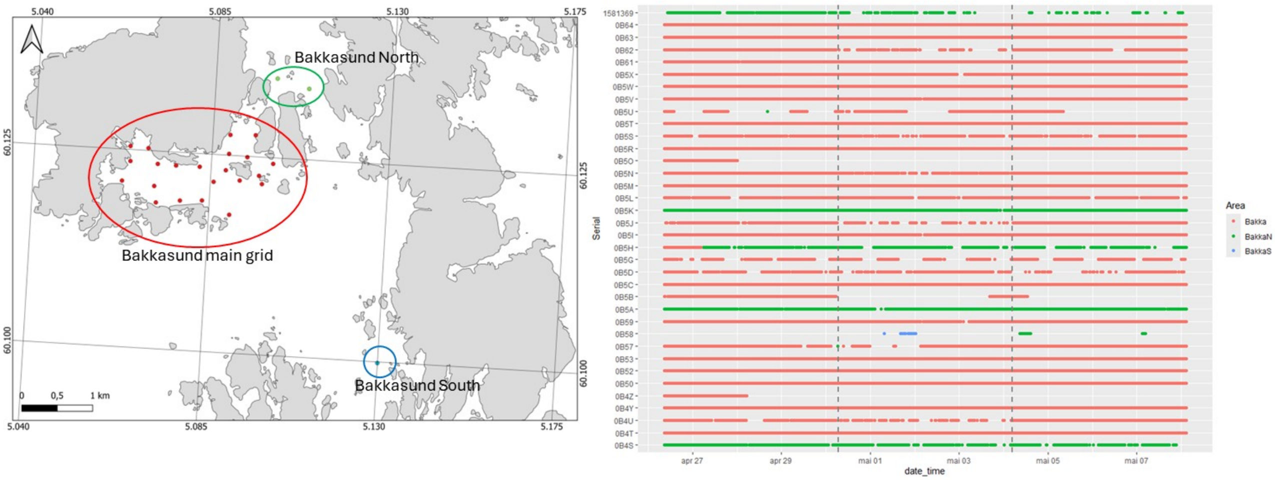

Figure 20. Map on the left shows the receivers downloaded in September 2025; from the main Bakkasund grid (red dots), the receivers in the north (green dots) and in the south (blue dot). Right plot show the detections of individual fish in a period 4 days before, 4 days during and 4 days after the survey, with. grey vertical dashed lines showing the survey period. The colours correspond to the areas in the map. Each row is a different tag ID, with

28 fish detected in Bakkasund during the survey period. Note we also have receivers in the west exit of the area, but these are not yet downloaded, planned for March 2026.

Swimming depth vas highly variable between the individual fish, with some performing clear diel vertical migrations, some with less systematic variations and some staying at the approximate same depth throughout the period (Figure 21).

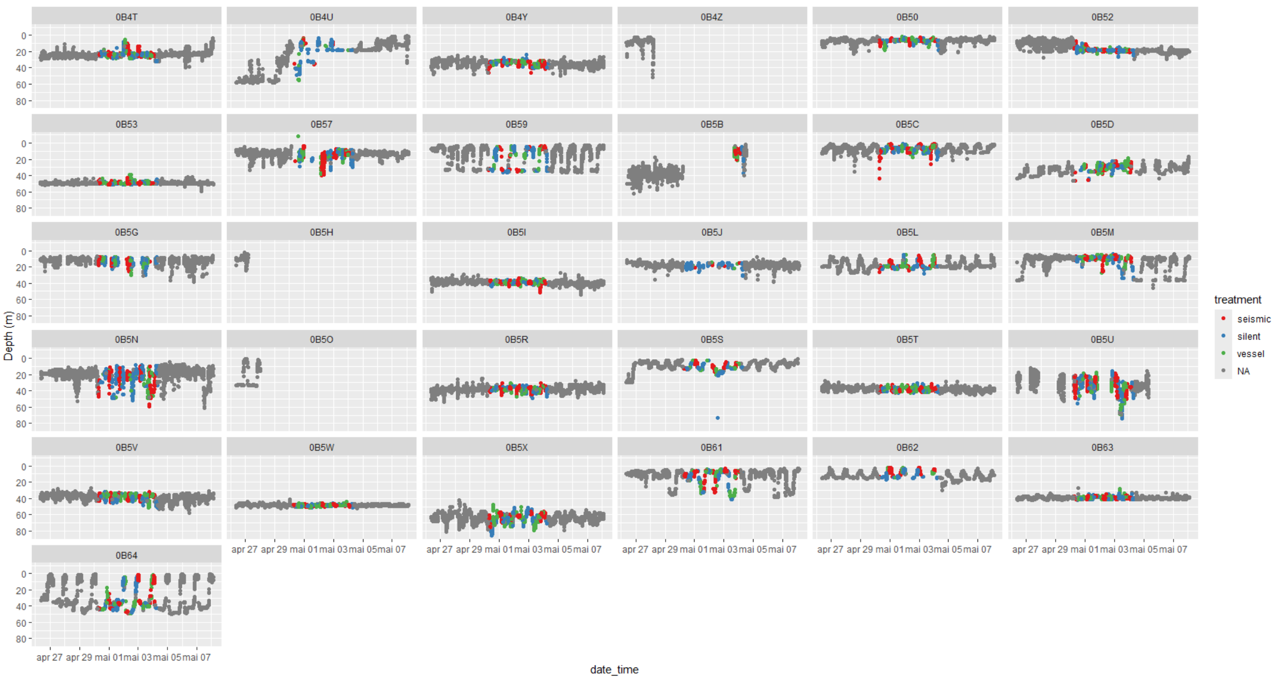

Figure 21. Swimming depth of individual fish present in the grid in the period comprising 4 days before, 4 days during and/or 4 days after the exposure survey. Grey dots are before/after the survey, coloured dots are the survey period, with different colours indicating the different treatments; seismic (red), vessel (green) and silent (blue).

Also activity level, expressed through acceleration varied among the individual fish (Figure 22).

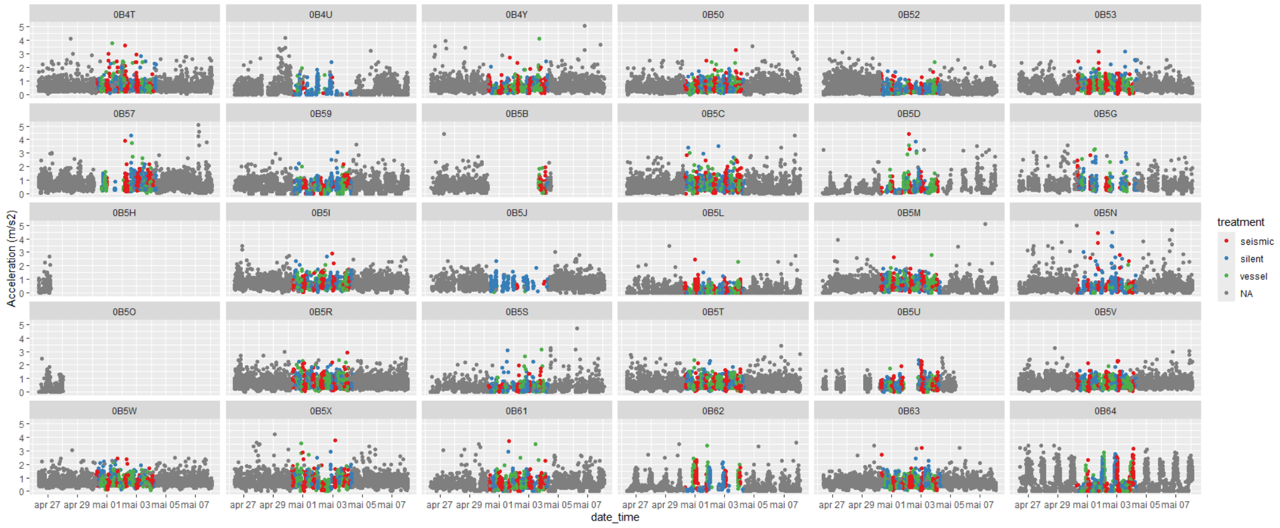

Figure 22. Accelerometer data for those fish present in the grid in the period comprising 4 days before, 4 days during and/or 4 days after the exposure survey. Grey dots are before/after the survey, coloured dots are the survey period, with different colours indicating the different treatments; seismic (red), vessel (green) and silent (blue).

Further analysis on fish behavioural metrics such as residency, swimming depth, home ranges and activity levels will be done by fitting statistical models similar as for previous exposure experiments (Mcqueen *et al.*, 2022; McQueen *et al.*, 2023).

3 - Data

Data are stored at the IMR storage at NMDC at the location \\ces.hi.no\nmdstorage\SCRATCH\SpawnSeis\Extention BSU\Survey\ and organized by the standard IMR survey structure (Table 8).

Table 8. Data catalogue structure

CRUISE_DOCUMENTS/CRUISE REPORT	This report
CRUISE_DOCUMENTS/CSR	Cruise summary report
CRUISE_LOG/ACTIVITY	Event log Word file with all daily activities logged Treatments.xls File with time for the blocks conducted
CRUISE_LOG/TRACK	Vessel position log Excel files, one for each day of the survey
EXPERIMENTS/HYDROPHONES	Sound files (wav), depth logger files
MULTIMEDIA_FILES	Images taken during the survey. Marked with name of crew members with ownership of the pictures/videos
PHYSICS/CTD_DATA	CTD casts All files marked with number (as in table 4), location and date.

3.1 - Permits

Permit to capture fish are given from the Directorate of Fisheries (ref 25/2684), and permit to tag fish and expose them to sound from Norwegian Food Safety Authority (Mattilsynet) (permit number id31177). Permit to conduct a scientific seismic survey are given from the Norwegian Offshore Directorate (Sokkeldirektoratet) (undersøkelsestillatelse 918 2025).

3.2 - Acknowledgements

This work has been financed in collaboration by IMR, Aker BP and Fugro. Tanks to Harald Fitje at the IMR workshop for making the frame for the hydrophone battery pack. Thanks to Børge Alfstad, Elin Sørhus and Glenn Sandtorv for helping with deployment and retrieval of hydrophone rigs, and Geir Pedersen for modelling the sound level in the cod bay in the planning phase. Thanks also to Eystein Kleppe for capturing the live cod that was tagged.

3.3 - References

Doksaeter Sivle, L., Olav Handegard, N., Kvadsheim, P., Nesse Forland, T., Wegge Ektvedt, K., Schuster, E., and McQueen, K. 2021. Cruise report SpawnSeis seismic exposure experiment on free ranging, spawning cod Cruise report for surveys 2020830 and 2021826.

Doksaeter Sivle, L., Nesse Forland, T., de Jong, K., McQueen, K., Schuster, E., Kvadsheim, P. H., Wegger Ektvedt, K., *et al.* 2022. SPAWNSEIS MV EXPOSURE EXPERIMENT-SURVEY REPORT IMR Survey number 2022812.

Hijmans R (2024). _geosphere: Spherical Trigonometry_. R package version 1.5-20, https://CRAN.R-project.org/package=geosphere

Mcqueen, K., Meager, J. J., Nyqvist, D., Skjæraasen, J. E., Olsen, E. M., Karlsen, Ø., Kvadsheim, P. H., *et al.* 2022. Spawning Atlantic cod (Gadus morhua L.) exposed to noise from seismic airguns do not abandon their spawning site. ICES Journal of Marine Science, 79. Oxford University Press.

McQueen, K., Skjæraasen, J. E., Nyqvist, D., Olsen, E. M., Karlsen, Ø., Meager, J. J., Kvadsheim, P. H., *et al.* 2023. Behavioural responses of wild, spawning Atlantic cod (Gadus morhua L.) to seismic airgun exposure. ICES Journal of Marine Science, 80: 1052–1065. Oxford University Press (OUP).

McQueen, K., Sivle, L. D., Khodabandeloo, B., Skjæraasen, J. E., Olsen, E. M., and Karlsen, Ø. 2025. Free-ranging Atlantic cod did not change their behaviour in response to a sparker seismic sound source. Marine Environmental Research, 210: 107254. https://www.sciencedirect.com/science/article/pii/S0141113625003113 (Accessed 4 September 2025).

Sivle, L. D., Forland, T. N., de Jong, K., Zhang, G., Kutti, T., Durif, C., Wehde, H., *et al.* 2023. Havforskningsinstituttets rådgivning for menneskeskapt støy i havet - Kunnskapsgrunnlag, vurderinger og råd for 2023. Rapport fra havforskningen, 1893–4536. Havforskningsinsituttet. https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-2023-2.

Sivle, L. D., McQueen, K., and Khodabandeloo, B. 2024. Survey report for testing a sparker sound source on cod behaviour (SpawnSeis Sparker). IMR Cruisereport, ISBN 1503-6294, 16 2024. Bergen. https://www.hi.no/hi/nettrapporter/toktrapport-en-2024-16.

Soudijn, F. H., van Kooten, T., Slabbekoorn, H., and de Roos, A. M. 2020. Population-level effects of acoustic disturbance in Atlantic cod: a size-structured analysis based on energy budgets. Proceedings of the Royal Society B, 287: 20200490. The Royal Society.

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