SONNE-Berichte

CLOCKS: Northern Cascadia: Extent of locked zone, prism deformation, slip-to-toe, and the edge of subduction

and

CASCADIA CO2: Seismic multi-parameter study at a possible site for CO2 storage in basalt in the Cascadia Basin utilizing shear wave events

(secondary user)

Cruise No. SO294

13.09. 2022 – 27.10. 2022,

Vancouver (Canada) – Port Hueneme (USA)

CLOCKS & CCO2

Dr. M. Riedel and all Cruise Participants

GEOMAR Helmholtz Centre for Ocean Research Kiel

2022

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1 Cruise Summary

1.1 Summary in English

Expedition SO294 served two scientific projects. The main program was designated towards the project CLOCKS: "Northern Cascadia: Extent of locked zone, prism deformation, slip-to-toe, and the edge of subduction". The Cascadia subduction zone extending from northern California to the northern tip of Vancouver Island, remains unbroken by a megathrust earthquake since January 26, 1700, which is known from Tsunami records in Japan. The megathrust fault on the subducting Juan de Fuca (JdF) Plate is believed to be fully locked based on previous studies. We address several open questions on the state of locking of the megathrust by long-term monitoring experiments: nine short-period ocean bottom seismometers (OBS) were deployed combined with six ocean bottom pressure (OBP) gauges and six broad-band seismometers (deployed in a small sub-grid) allowing analyses of very low-frequency earthquakes and tremors. A set of eleven short-period OBS were deployed north of the Nootka Fault zone separating the JdF and Explorer Plates. The deeper structure of the subducting JdF Plate and the overlying North American plate was the target of an amphibious Magnetotelluric (MT) experiment. Along a 2D profile from the deformation front to the shelf off Vancouver Island, marine MT data were recorded for a month. A landward extension of the profile across Vancouver Island was recorded by the University of Alberta in the summer of 2022. These data are being jointly analyzed to identify and quantify hydration and dehydration processes, which play a major role in controlling seismicity. In order to image faulting and identify potential slip-to-toe events where the megathrust may have ruptured all the way to the deformation front, we acquired seismic data across the fragmented deformation front at the central northern Cascadia margin. Seismic data were also collected in the Winona Basin (Explorer Plate) to address the extent of subduction off northern Vancouver Island. These experiments were complemented by acquisition of heat-probe data measuring heat-flux. This will improve the thermal model used to define the limits of the locked zone by estimating the 125°C (upper limit) and 350°C (lower limit) isotherms. To study the recurrence rate of megathrust earthquakes on the Explorer Plate, we collected twelve cores at four slope failures.

A secondary user project was added to SO294 to utilize the opportunity provided by the vessel operating off the West Coast of Canada. This project is a collaborative study between GEOMAR and Ocean Networks Canada (ONC) on potential CO_2 storage in marine basalt complexes called CASCADIA CO2 (CCO2). ONC leads a project that aims at CO_2 capture from the atmosphere and injection into oceanic crust in the Cascadia Basin, where boreholes from previous scientific drilling campaigns provided prior information on the physical properties of the basalt formations and overlying sediments. CCO2 studies the lateral variations of the basalt and its physical properties by the acquisition of seismic data on OBS optimized for the measurement of S-waves, a dataset yet missing in the assessments of the CO_2 storage potential of basalt. In total, 22 OBS were deployed along two perpendicular profiles receiving seismic signals from the G-Gun array.

Projects CLOCKS and CCO2 are accompanied by a mitigation program to protect marine mammals and other endangered species. Eight observers conducted continuous visual observations during daylight hours and 24h passive acoustic monitoring (PAM) during all seismic acquisition. An Infra-Red camera system was tested as identification tool for the presence of marine mammals.

1.2 Zusammenfassung

Die Expedition SO294 beinhaltet zwei Projekte. Das Hauptprogramm war das Projekt CLOCKS: "Der nördliche Cascadia Kontinentalrand: Ausdehnung der Bruchzone von Subduktions-Erdbeben, und Deformation des Akkretionskeils". Die Cascadia-Subduktionszone, die sich von Nordkalifornien bis zur Nordspitze von Vancouver Island erstreckt, wurde seit dem 26. Januar 1700 nicht mehr durch ein Erdbeben durchbrochen. Dies ist aus Tsunami-Aufzeichnungen in Japan bekannt. Die Bruchzone (Megathrust) auf der Juan de Fuca (JdF) Platte ist entlang des gesamten Cascadia Kontinentalrandes blockiert. CLOCKS befasst sich mit offene Fragen zum Zustand der Megathrust mittels seismischer Langzeitüberwachung: neun kurzperiodische Ozeanbodenseismometer (OBS) wurden zusammen mit sechs Ozeanbodendrucksensoren (OBP) eingesetzt und zusätzlich mit sechs Breitbandseismometer so in einem Raster aufgestellt, um Analysen zu niederfrequenten Erdbeben und Tremors durchzuführen. Nördlich der Nootka Störungszone, die die JdF und Explorer Platten trennt, wurden elf kurzperiodische OBS eingesetzt. Die tiefere Struktur der JdF Platte und der überlagernden nordamerikanischen Platte war das Ziel eines amphibischen magnetotellurischen (MT) Experiments. Entlang eines 2D Profils von der Deformationsfront bis auf den Schelf vor Vancouver Island wurden einen Monat lang MT-Daten aufgezeichnet. Im Sommer 2022 wurden weitere MT-Daten über Vancouver Island mit Landstationen der Universität von Alberta erfasst. Die Land- und marinen Datensätze werden gemeinsam ausgewertet um Hydrations- und Dehydrationsprozesse, die einen wesentlichen Einfluss auf die Seismizität der Subduktionszone haben, zu identifizieren und quantifizieren. Um Verwerfungen im Sediment oberhalb der ozeanischen Kruste abzubilden, die darauf hindeuten könnten ob die Megathrust bis zur Deformationsfront durchgebrochen ist, haben wir reflexions-seismische Daten im zentralen Teil des nördlichen Cascadia Kontinentalrandes erfasst. Zusätzlich wurden seismische Daten im Winona-Becken (Explorer-Platte) gesammelt, um das Ausmaß der Subduktion vor der nördlichen Vancouver Island zu untersuchen. Ergänzt wurden diese Experimente durch Wärmestrommessungen, die das thermische Modell verbessern, das zur Definition der Grenzen der blockierten Bruchzone verwendet wird (Isothermen von 125°C als Ober- und 350°C als Untergrenze). Zur Bestimmung der Wiederholungsrate von Megathrust-Erdbeben der Explorer-Platte haben wir zwölf Schwerelote an vier Hangrutschungen genommen.

SO294 wurde um ein Nebennutzerprojekt erweitert. Dabei handelt es sich um eine Studie von GEOMAR mit Ocean Networks Canada (ONC) zur potenziellen CO_2-Speicherung in marinem Basaltgestein: CASCADIA CO2 (CCO2). ONC leitet ein Projekt zur Abscheidung von CO_2 aus der Atmosphäre und Injektion in Basaltlagen der ozeanischen Kruste im Cascadia Becken. Bohrungen aus früheren wissenschaftlichen Kampagnen haben Informationen über die physikalischen Eigenschaften der Basaltformationen und der darüber liegenden Sedimentschichten geliefert. CCO2 untersucht die lateralen Variationen der Basaltformation und ihre physikalischen Eigenschaften durch die Erfassung seismischer Daten mit OBS, die für die Messung von S-Wellen optimiert aufgestellt wurden. Insgesamt wurden 22 OBS entlang zweier sich kreuzender Profile eingesetzt. Als seismische Signalquelle diente das G-Gun Array.

CLOCKS und CCO2 wurden von einem Programm zum Schutz von Meeressäugern und anderer gefährdeten Arten begleitet. Acht Beobachter:Innen führten tagsüber visuelle Beobachtungen sowie eine kontinuierliche passive akustische Überwachung (PAM) während aller seismischen Arbeiten durch. Eine Infrarot-Kamera, die rund um die Uhr in Betrieb war, wurde als zusätzliches Instrument zur Detektion von Meeressäugern eingesetzt.

2 Participants

2.1 Principal Investigators

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Bialas, Jörg, Dr.	GEOMAR

2.2 Scientific Party

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Kahler, Lisii Merit	Ocean Bottom Seismometers	GEOMAR
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MacTavish, Bruce	Marine Mammal Observer, visual	LGL
Warrior, Magena	Marine Mammal Observer, visual	LGL
Piercy, Meghan	Marine Mammal Observer, visual	LGL
Minicola, Ella	Marine Mammal Observer, visual	ONC

2.3 Participating Institutions

GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel
GSC Geological Survey of Canada - Pacific
JAMSTEC Japan Agency for Marine-Earth Science and Technology
ONC Ocean Networks Canada
Kobe University
University of Tokyo
Nippon Marine Enterprises
University of Alberta

3 Research Program

3.1 Description of the Work Area

3.1.1 CLOCKS

A great earthquake of magnitude M>8.5, comparable in size and impact to events that occurred off Sumatra (2004), Chile (2010), and Japan (2011), is expected to occur in the foreseeable future along the Cascadia subduction zone, which extends from Cape Mendocino, California, to the northern end of Vancouver Island, British Columbia (Fig. 3.1). Coastal evidence for past great Cascadia earthquakes was first reported by Atwater (1987), and the date of the most recent megathrust earthquake was determined by Satake et al. (1996) to be January 26, 1700, based on tsunami records in Japan. The recurrence rate of these events off Cascadia varies between 250 years to ~1000 years, defined using offshore turbidites that were deposited over the past 10,000 years off the coasts of Oregon, Washington, and Vancouver Island (e.g. Goldfinger et al., 2012). With dense urban centers such as Seattle, Vancouver, or Victoria, a megathrust earthquake coupled with a tsunami will have devastating impact on the region The Juan de Fuca Plate subducts underneath the North American Plate and convergence rate is on average 45 mm/year.

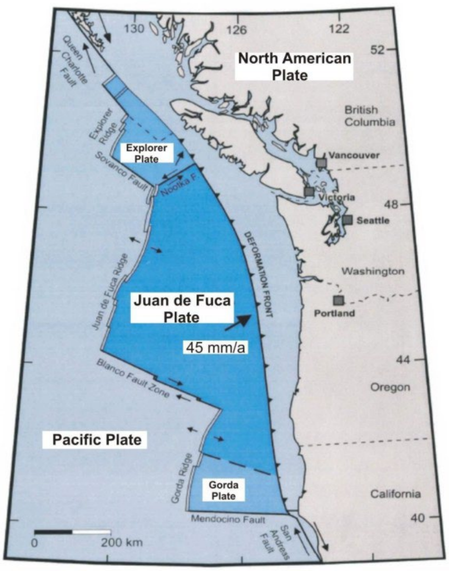

Fig. 3.1 Plate tectonic regime of the Cascadia subduction zone.

The maximum possible seaward limit of the rupture zone is the deformation front (DF) and co-seismic displacement all along to the toe of the prism ("slip-to-toe") has recently been documented during the 2011 Tohoku earthquake off Japan (e.g. Kodaira et al., 2012). The down-dip extent of seismogenic zones is often based on thermal models, using the 350ºC isotherm as the deepest possible extent for rocks to accumulate seismic strain. As depicted in the conceptual model by Saffer and Tobin (2011), the locked zone may exhibit transition zones at the upper and lower limit depending on temperature, physical properties of the subducting sediments, or fluid-pressure along the fault zone (Fig. 3.2). Very low frequency earthquakes (VLFE) may also occur at these transition zones but have yet not been recorded at Northern Cascadia.

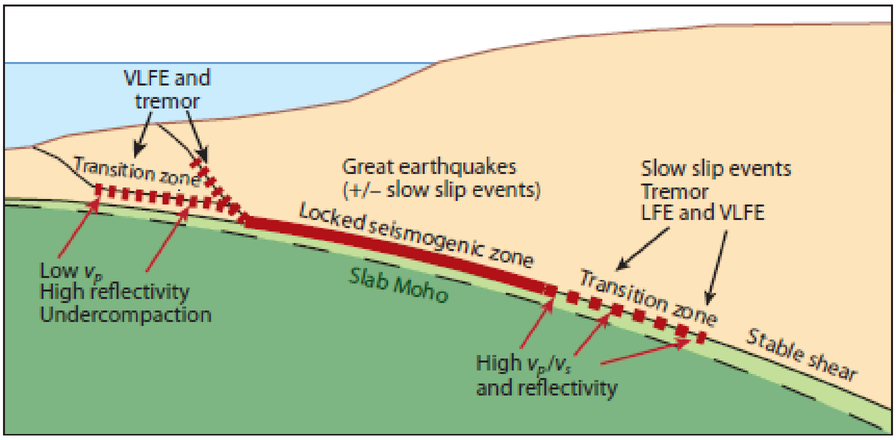

Fig. 3.2 Model of a locked zone with transitions at the upper and lower limit (from Saffer and Tobin, 2011).

For the study region of SO294 off central Vancouver Island, estimates of the limits of the locked zone between the DF and the 350°C isotherm are based on previous thermal models (e.g., Hyndman, 2013) and these limits are shown in Figure 3.3 together with regional seismicity from land-station data (2002-2015). Two marine long-term monitoring campaigns to study seismicity were conducted in 2010 and 2014 in collaboration between the Geological Survey of Canada and JAMSTEC (Riedel et al., 2014). Results suggest a low seismicity level across the prism (Obana et al., 2015). Expedition SO294-CLOCKS includes a continuation of this collaboration with JAMSTEC to study seismicity. JAMSTEC supports this effort with the deployment of 20 short-period OBS and six ocean bottom pressure gauges. Early work on the structure of the accretionary prism and crustal structure beneath Vancouver Island included seismic campaigns in 1985 and 1989, both acquiring multichannel seismic (MCS) data along several lines along the margin as well as onshore data acquisition as part of the LITHOPROBE projects (e.g. Hyndman, 1995).

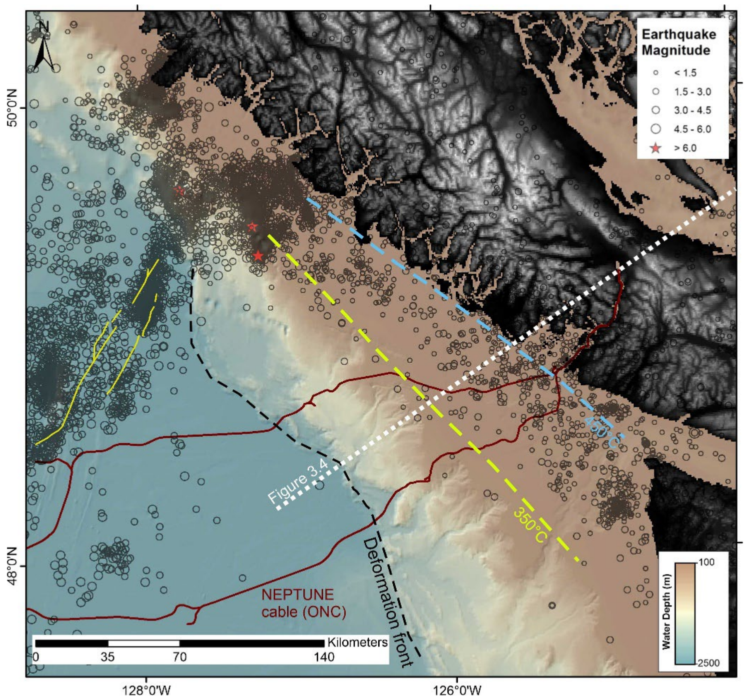

Fig. 3.3 Map of the northern Cascadia margin off Vancouver Island. Shown are estimates of extent of locked zone from deformation front (dashed black line) to the 350ºC isotherm (yellow) together with the 450ºC isotherm (blue). An interpreted transect (Fig. 3.4) is indicated by the white dotted line. Seismicity from the NRCan catalog (2002-2015) is shown as black circles (M>6: red stars).

Due to the complex nature of accreted terranes, imaging of the subducted plate proved difficult (Nedimović et al., 2003), especially beneath the shelf and most of Vancouver Island. A cross-section through the margin as shown in Figure 3.4 shows the main structural elements summarizing the results of previous studies. Wide-angle active-source seismic tomography to image the subducted slab was accomplished as part of the *Seismic Hazard in Puget Sound* (SHIPS) project in 1998 along southern Vancouver Island and the region around Seattle (e.g. Nedimović et al., 2003; Ramachandran et al., 2005).

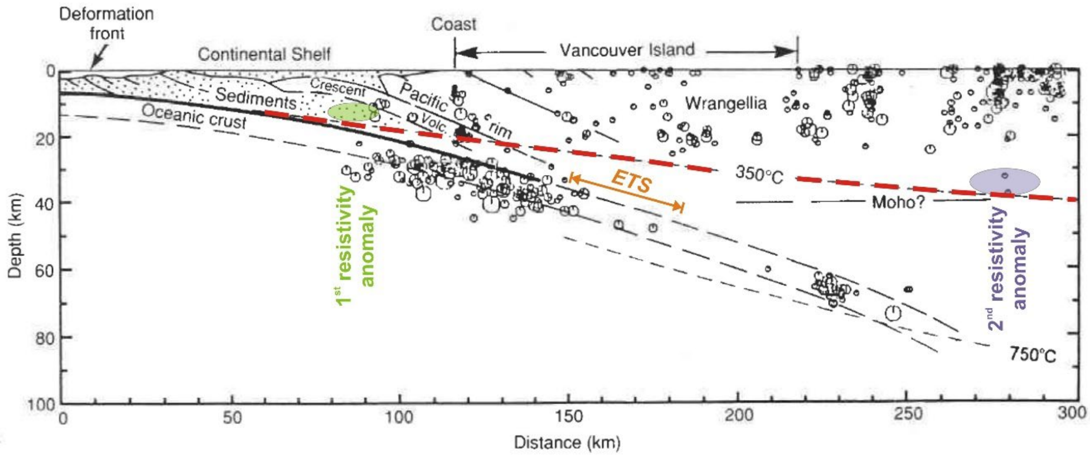

Fig. 3.4 Tectonic transect (after Hyndman, 1995) across the northern Cascadia margin (location see Fig. 3.2). Hypothesized location of two resistivity anomalies based on Worzewski et al., (2011) form the targets of the MT experiment. The 350° isotherm, and zone of episodic tremor and slip (ETS) are also shown.

3.1.2 CASCADIA CO2 (secondary user)

The project CASCADIA CO2 aims to contribute to pre-site surveys for a test injection of CO_2 into basalt formations in the Cascadia Basin, Canada. The Cascadia Basin is bounded on the west by the Juan de Fuca Ridge (JdFR) and on the east by the Cascadia Subduction Zone. The JdFR is formed by the 480 km long NNE trending mid-velocity spreading center between the Pacific Plate and the Juan de Fuca Plate (Nedimović et al., 2008). At its center, the JdFR is influenced by the Cobb hotspot, while the Endeavour segment to the north is influenced by the Heckle melt anomaly (Carbotte et al., 2008). The Heckle melt anomaly and the development of a broad plateau along the western flank of the JdFR in the Endeavour segment resulted in much thinner sediment cover than in the east (Carbotte et al., 2008). Along the eastern flank of the JdFR, features typical of the flanks of oceanic ridges in general are found in the Cascadia Basin: an extrusive igneous basement overlain by sediments that thicken with crustal age, and an abyssal hillslope bounded by high-grade faults that form linear structural trends subparallel to the spreading ridge (Davis et al., 1992; Goldberg et al., 2018). These features provide a promising environment for CO_2 storage in marine basalt because they may form natural boundaries for storage compartments. The nearly continuous sedimentary layer forms a low permeability barrier that seals off the permeable basalt reservoir from the overlying ocean.

Three scientific drilling expeditions, several site investigations, and deep crustal surveys have taken place in the region to date, making it one of the most extensively studied oceanic crustal sites in the world (e.g., Arnoux et al., 2019; Davis et al., 1997; Fisher et al., 2011; Fisher et al., 2005; Flueh et al., 1998; Goldberg et al., 2018; Qin et al., 2020). A 2D seismic survey was conducted as part of the ODP Leg 168 (Zühlsdorff et al., 2005). Seismic images across the boreholes show strong bedrock topography (Zühlsdorff et al., 2005). While sediments in the upper 100 m below the seafloor are nearly undisturbed, deeper sediment layers show a series of faults that coincide with basement topography. Sub-bottom profiler (PARASOUND) data recorded during the same survey show no continuation of faults toward the seafloor. The outcrops of Isita Bare, Mama Bare, Papa Bare, and Baby Bare surround the IODP boreholes and provide breaches in the sediments. The lowest reflection event in the data is caused by the top of the oceanic basement but no internal structure of the basement could be determined to date. In an earlier assessment of the potential for CO_2 injection within the offshore Canadian EEZ, Ferguson et al. (2018) provided a map of the distribution of basalt formations expected to provide a reservoir for CO_2 storage (Fig. 3.5). The CCO2 project is centered around the existing IODP boreholes and ONC infrastructure operated as part of the NEPTUNE underwater cabled observatory.

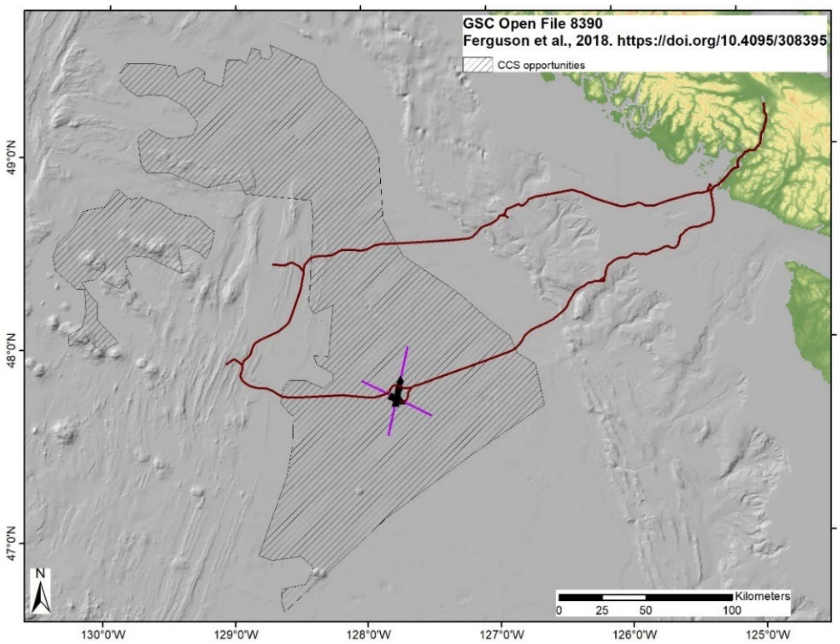

Fig. 3.5 Map showing the distribution of offshore basalt formations in the offshore EEZ of Canada deemed suitable for CO_2 injection (after Ferguson et al., 2018). The dark red line is the ONC network cable, OBS deployed for CCO2 are the black triangles and the two pink lines are the seismic profiles acquired.

3.2 Aims of the Cruise

3.2.1 CLOCKS

Earthquakes at subduction zones with magnitudes M>8.5 are among the most destructive earthquakes worldwide. The Cascadia subduction zone is one of the regions for which such an earthquake is expected in the near future. Currently, little is known about the behaviour of the Cascadia seismogenic zone or the tectonic structure along the deformation front off Vancouver Island. The transition to the Explorer Plate along the Nootka fault and the spatial delineation of subduction have not been mapped accurately to date. The focus of SO294 is to determine the delineation of the seismogenic zone, particularly the seaward limit. To do this, seismic reflection data will be used along with multibeam data to map the deformation structure and fragmentation of the deformation front. Thermal data will be combined with seismic methods to determine the temperature at the plate boundary and associated drainage processes. Magneto-Tellurik data will be acquired to determine the depth limit of this fault surface and fluid accumulations at the lower limit of the seismogenic zone. All of these data will help answer the question if during previous earthquakes the seismogenic zone has ruptured to the foot of the accretionary wedge, such as recognized after the 2011 Tohoku earthquake. The extent of Explorer Plate subduction north of the Nootka fault is currently poorly understood. Here, long-term earthquake monitoring as well as active-source 3D seismic tomography will be used to determine the location of the plate boundaries. In addition, an estimate of the earthquake rate at the Explorer Plate is obtained from sediment sampling at landslides. This would allow geohazards from such subduction earthquakes off Cascadia to be better constrained, and additionally an estimate of the tsunami hazard be determined. The investigation is based on intensive collaboration with the Geological Survey of Canada, University of Alberta, Japan Agency of Marine-Earth Science & Technology (JAMSTEC), and Ocean Networks Canada (ONC).

3.2.2 CASCADIA CO2 (secondary user)

In order to limit the global temperature increase to 1.5° C, the emission of 580 Gt of CO_2 needs to be avoided within the next 30 years. As adaption of society and economy will not be fast enough this amount of CO_2 needs to be taken out of the atmosphere and safely stored in the subsurface. The typical carbon storage application utilizes sandstone formations (depleted gas and oil reservoirs) where the CO_2 will be stored as a mobile cloud within the porosity of the host rock. In contrast, the new process of CO_2 storage in basalt formations will fix the carbon as a solid carbonate as the result of a mineralization process. First onshore trials (CarbFix, Wallula) showed that ~90% of the injected CO_2 was mineralized within two years. Marine basalt formations, far away from urban areas, offer large volumes of porous rock for this process. The project CASCADIA CO2 aims to contribute to pre-site surveys for a test injection of CO_2 into basalt formations of the Cascadia Basin. Beside velocity-depth models, lateral changes in porosity of the basalt will be determined. For this purpose, OBSs will be deployed, that record compressional and converted shear wave events. Along two orthogonal lines velocity-depth models will be developed for Vp and Vs. Undertaken over several years, fluid flow cross-hole tests between IODP wells have shown that there is a distinct anisotropy in the basalt layer (Fisher et al., 2014). This will be tested with the Vp and Vs models as well. In the following, new routines will be established to deduce the porosity distribution from the Vp to Vs ratios. The results will be made available for CO_2 injection modelling. These experiments lay ground for future investigations in volcanic provinces along the NW European continental margin offshore Norway.

3.3 Agenda of the Cruise

During SO294 several types of long-term monitoring instruments were deployed: nine short-period long-term OBS (JAMSTEC), six OBP (Kobe Univ., Tokyo Univ., JAMSTEC) and six broad-band long-term OBS (GEOMAR) were deployed on the central accretionary prism. An additional eleven short-period long-term OBS (JAMSTEC) were deployed north of the Nootka Fault in the Winona Basin region. These instruments will be recovered during upcoming expeditions lead by the GSC in 2023 (OBS) and 2024 (OBP).

A total of 54 short term OBS used for active-source seismic refraction analyses were used in three sub-regions of the study area: 22 OBS were deployed along two perpendicular profiles in the Cascadia Basin with the CCO2 project, 20 OBS were used along two parallel profiles in the Winona Basin, and 12 OBS were used in one profile across the central accretionary prism off Vancouver Island.

The seismic refraction experiments were run with a six G-Gun array with a combined volume of 2840 in^3 (84 L) and a total of 370 km of profile-length were acquired across the OBS. An additional 180 km were acquired on cross-lines not directly above the 2D OBS-profiles. High-resolution seismic reflection imaging was achieved using a single GI airgun (355 in^3, 6 L) and a MCS streamer consisting of 184 channels at 1.56 m spacing over a 290 m total active length. Reflection data were acquired in the Winona Basin (685 km) and across the deformation front of the central accretionary prism off Vancouver Island (425 km).

Heat-probe deployments to measure heat flux were done in the Winona Basin along the two main refraction profiles (total of 29 stations) and one short profile along seismic line P6004 on the northern end of the deformation front of central Vancouver Island (7 stations).

Gravity coring targeting four different sub marine slope failures was conducted in the Winona Basin. Twelve cores were taken, totaling 46.72 m of recovered sediment. Samples will be brought to the core-lab at the GSC in Sidney, BC for further analyses.

Along all cruise tracks, seafloor bathymetry was mapped with the EM122 and EM710 (< 800 m water depth) covering a total of 21,500 km^2. For processing the echosounder data and produce bathymetric maps, sound velocity of the ocean was measured at nine stations. Except during station work and during OBS recovery operations, sub bottom imaging was achieved using the PARASOUND system, totaling 5325 km of data. An overview of the entire cruise track from the port of Vancouver to Port Hueneme is given in Figure 3.6. A more detailed view of the cruise tacks in the study area combined with all stations visited is given in Figure 3.7.

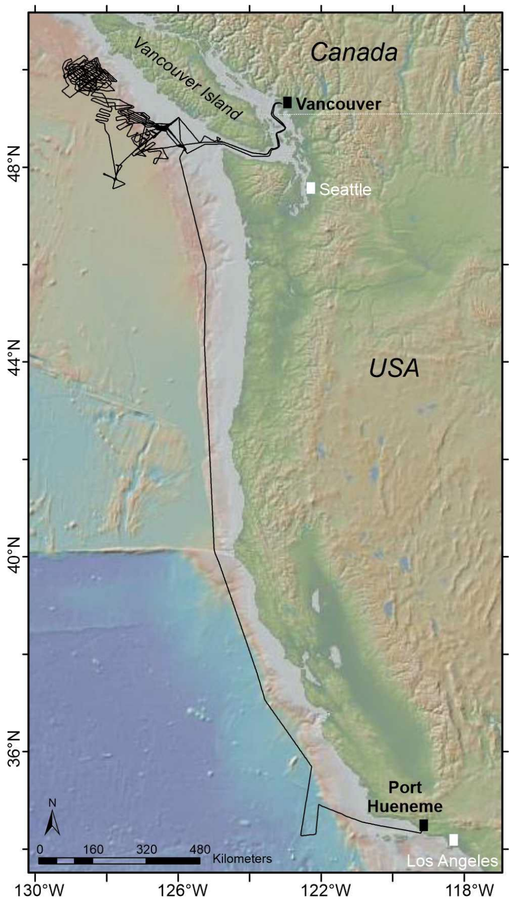

Fig. 3.6 Map of cruise track of SO294 from Vancouver to Port Hueneme (bathymetry: Ryan et al., 2009).

3.4 Mitigation measures

Prior to expedition SO294 two proposals were submitted by GEOMAR and collaborating agencies (GSC, ONC) to the Canadian authorities (Fisheries and Oceans Canada, DFO) outlining the proposed marine scientific studies including seismic and acoustic surveys along the Northern Cascadia Subduction Zone off Vancouver Island. DFO did review these proposals to assess the risks to species at risk (SAR) and to fish and fish habitat, including marine mammals. A detailed Letter of Advice (LoA) was provided to the research team on September 1, 2022, with specific mitigation measures which included the „Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment“. Overall, the proposed surveys were determined low risk. No Fisheries Act authorization or SAR permit was required because with the implementation of the mitigation measures outlined in the LoA, neither the death of fish (including marine mammals), the harmful alteration, disruption, or destruction of fish habitat or the potential for harm and harassment of aquatic SAR was expected.

In order to comply with the outlined rules and regulations, a team of eight specialists in marine mammal observation and the operation of a passive acoustic monitoring device were appointed for the duration of expedition SO294. Details on the procedures and mitigation measures implemented are given in Section 5.9 and all weekly reports to DFO are included in Section 11.3.

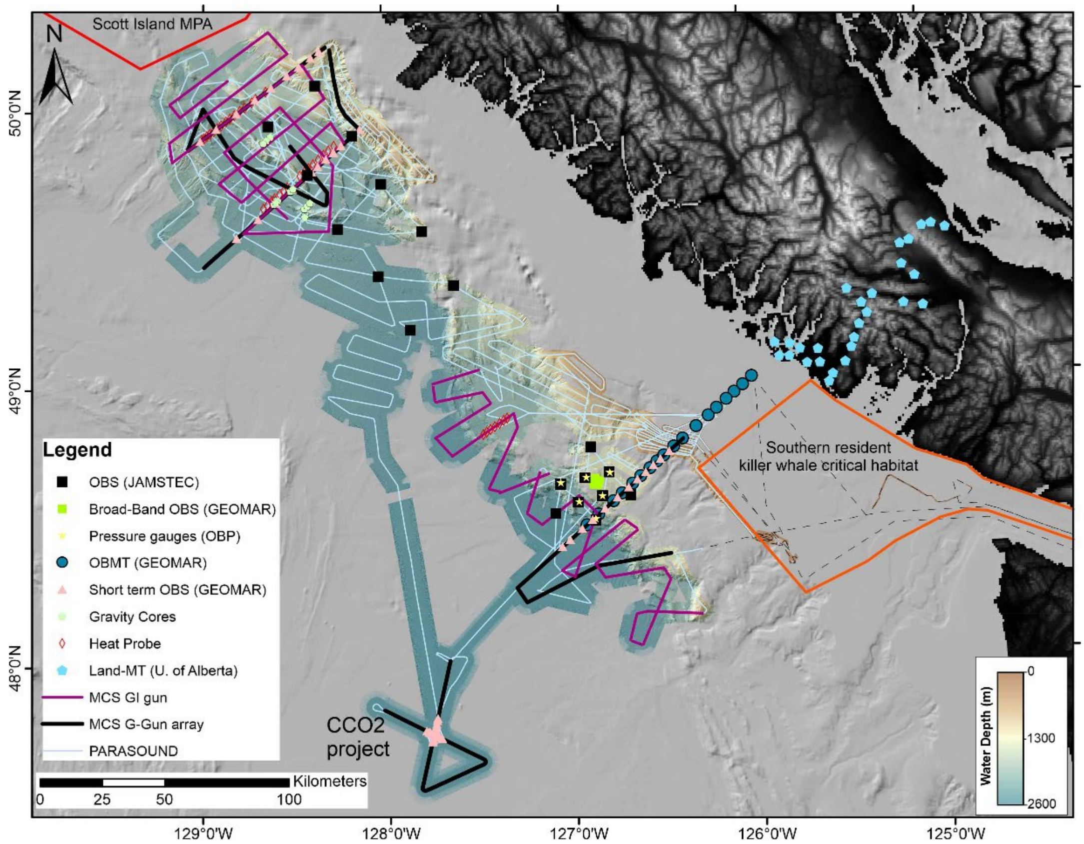

Fig. 3.7 Cruise track during SO294 with data acquisition and all instrumentation used, including land MT stations. Background bathymetry (Ryan et al., 2009) overlain by data from SO294 shown in color.

4 Narrative of the Cruise

Expedition SO294 started on September 12, 2022 in the port of Vancouver with the arrival of the main science team. Prior to the arrival of the main team, a group of six members from GEOMAR, two from JASCO, and two from LGL and Toyon prepared various components of the equipment to be used during SO294. Loading of JAMSTEC instruments (all pre-prepared at the GSC facilities in Sidney, BC) was conducted on September 11, 2022. The R/V SONNE departed from Vancouver on Tuesday, September 13, at 02:00 in the morning at the Pembina terminal in North Vancouver and started its journey to the region offshore Vancouver Island. On Tuesday, September 13 at 10:00, the pilot was dropped off Victoria and the R/V SONNE continued its way out of the Juan de Fuca Strait. Due to severe fog and low visibility, no proper marine mammal watch was possible that would have allowed a possible start of multibeam surveying during day-light hours around a region called Swiftsure Bank, known for abundant natural gas seepage. We therefore modified our plans and continued our way to the first site for testing the acoustic releasers. We arrived on station on Wednesday, September 14 at 00:45 at night. Three cages with releasers were prepared and the test went well and all releasers functioned well. After completion of the test we started our first multibeam and PARASOUND surveying while preparation of seismometers continued. We were then heading to the first deployment site for a long-term OBS and within one day we completed deploying 4 OBS, 3 OBPs, as well as 8 OBMT stations. After that, the R/V SONNE headed back to Vancouver to complete sludge discharge and bunker, loading of needed spares, as well as scientific equipment (broad-band seismometers) that could not be delivered in time for the initial departure. On our 2nd way out of the port of Vancouver back to the scientific study site, we had an opportunity to map gas flares across Swiftsure Bank. We successfully completed recording of data from 14:00 to 19:30 implementing the mandated mitigation measures including PAM. Deployments of the remaining OBMT stations started at midnight, September 18, and was followed by deploying the remaining OBS and OBP monitoring stations as well as all of the six broad-band seismometers.

Using the favorable weather conditions and other operational constraints, we headed out to the Cascadia Basin to complete the CCO2 Experiment first. We started with mapping a seamount (Mama Bare) and started a deployment sequence of 22 OBS across the study region. It was decided to limit OBS deployment to south of Mama Bare due to strong topographic changes along the intended profile. The G-Gun array was deployed, followed by our streamer and the PAM system. Use of the seismic sources started on 15:30 on September 21. The airgun array was ramped up to full strength over the course of 20 minutes. Two refraction seismic profiles were successfully completed. After recovery of all seismic gear, the OBS stations were recovered successfully, data copied from the recorders, and all units were gradually refurbished for the next intended deployment in the Winona Basin.

On September 22, 2022, we participated in the first Ship-2-Shore event with our collaborators ONC and GSC. Nearly 100 students from two schools from the West Coast of Vancouver Island participated. Two First Nations represented by the Nuu-Chah-Nulth Tribal council are within the region of the two schools, thus we were particularly happy to be able to participate in this online session as contribution to our outreach-program with the First Nations of Vancouver Island.

After completion of the CCO2 experiment, we headed north to the Explorer plate and added several tracks across the Nootka Fault zone to image the fault trace and mud volcanoes. At the end of this transit, we deployed the first of 11 long-term OBS to monitor seismicity on the Explorer Plate. Within the following two days, all OBS were deployed and multibeam mapping of the region was achieved in between instrument deployments.

Prior to deploying the OBS for an active-source seismic experiment, we took four cores at submarine slope failures with the aim to record small slump events that may be correlated to large subduction zone earthquakes. Despite increasing wind and wave heights, we successfully deployed all 20 short-term OBS, but could not immediately follow up with seismic data acquisition. We used the weather down time to complete multibeam mapping within the Winona Basin. Once weather had calmed, we deployed the airgun array, streamer, and PAM system and started our two seismic refraction profiles on the Explorer Plate and Winona Basin. The data collection with the airgun array took ~36 hours. We swapped the gun-array with a single GI gun to continue seismic operations and collected seismic reflection data for 4 days until Tuesday, October 4th.

Despite challenging wind conditions, we began the OBS recovery sequence on October 4th and all stations were successfully recovered by October 6th. We then spent three days alternating operations with heat flux measurements during night and gravity coring during day time. Overall, 29 heat flux measurements along the two main seismic refraction profiles were completed and we took 8 cores at three different slope failure deposits. In the evening of October 9th, we started our transit south to the central study region off Vancouver Island on the Juan de Fuca plate. We used the transit to fill gaps in the multibeam coverage and added a triangulation to define location of one of the long-term OBS, which had failed at the first time. During some deteriorating weather, we postponed the start of the seismic data acquisition and added instead more multibeam mapping and when wind and sea state allowed, we deployed the remaining twelve OBS along a seismic transect that follows the geometry of the OBMT profile. On Wednesday, October 12, we finally were able to deploy the single GI gun, streamer and PAM system and started our sequence of MCS data collection along and across the deformation front of the accretionary prism of the Juan de Fuca Plate. A total of 15 profiles imaging the fault-patterns of the fragmented deformation front were acquired. On Friday, October 14, we exchanged the GI gun with the G-Gun array and acquired seismic data for ~22 hours to complete the last refraction seismic experiment of SO294.

After recovery of all seismic gear, we started the OBMT station recovery on Saturday, October 15, at the shallowest and eastern-most portion of the transect. All MT and OBS gear along the transect was recovered by October 18. One OBMT station was not releasing itself from the seafloor but was recovered with the use of the ocean floor observing system (OFOS), for which we were granted special permission by the Canadian authorities within two days. After a final heat-probe transect across the deformation front we mapped the upper slope of Father Charles Canyon and added two survey regions for repeat pockmark imaging and habitat mapping in collaboration with the Canadian DFO and scientists from the CAU in Kiel.

On October 20, 2022, the official earthquake awareness and “shake-out” day, we participated in a 2nd Ship-2-Shore event in collaboration with the GSC and ONC. This time, five classes from two schools on Vancouver Island with 110 students attended simultaneously in the online session.

The remaining days of the cruise were used to also prepare to pack all gear, and switching the position of our containers on deck, which had to be done during calm sea state.

5 Preliminary Results

5.1 Underway Hydroacoustic

(I. Klaucke[1], K. Douglas[2], J. Kehew[3])

[1]GEOMAR

[2]GSC

[3]University of Ottawa

5.1.1 System Overview and Data Processing

RV SONNE is equipped with two hull-mounted multibeam echosounders from Kongsberg Maritime: the Simrad EM122 operating at 12 kHz and the Simrad EM710 operating between 40 and 100 kHz. During cruise SO294, the EM122 was used throughout the entire cruise to record bathymetric, backscatter and water column data, except for a dedicated shallow water survey during which only the EM710 was used. The EM710 was also used in addition to the EM122 at water depths shallower than 1000 meters, however not consistently. Data acquisition was set to high-density equidistant and multi-ping mode with the FM (chirp modulated) pulse enabled for both sounders. Swath width was reduced to 130° total swath in order to prioritize sounding density and quality over coverage, except for a few occasions when 140° swath was needed for wider coverage. The latter was consistent for shallow water surveys. In high-density equidistant mode, the EM122 produces 432 beams (400 beams for EM710), regardless of the swath width. Several sound velocity profiles were obtained using either a Valeport sound velocity probe or a Seabird CTD. Data quality was excellent even during suboptimal weather conditions. However, the simultaneous use of Parasound and EM710 resulted in interference and deteriorated data quality for the latter. The signal amplitude of the multibeam echosounders is also stored and preprocessed automatically by the Kongsberg acquisition software SIS. This preprocessing includes altitude processing and the application of time and angle varying gain functions.

5.1.2 EM122 & EM710

A total area of 21500 km² (which, for comparison corresponds to roughly 2/3 of the area of Vancouver Island) was mapped during the cruise (Fig. 5.1.1), resulting in almost the entire continental margin beyond the shelf-break off Vancouver Island, BC now being mapped. Data processing has been carried out onboard using QPS software (Qimera 2.8.4 for bathymetry and FMGT for backscatter data). Gridded surfaces in Qimera were then either exported directly as bag-files for use in ArcGIS, or edited soundings were exported as xyz-data for use with other software. The exported soundings were gridded with GMT using a near neighbor algorithm that requires 1 out of 4 filled sectors and uses a 60 m search radius for a 50 m grid cell size. An additional grid with a cell size of 25 m, a 30 m search radius was also calculated, as well as one grid that included soundings from previous expeditions. The backscatter data were processed applying radiometric corrections, angle-varying gain and anti-aliasing filters in order to produce a georeferenced mosaic. Processing of the bathymetric data (except for the dedicated shallow water surveys) was finished during SO294 and the data are fully available for post-cruise work for all participants.

The newly mapped area of the Winona Basin clearly shows NW-SE trending accretionary ridges that are subjected to mass failure, on both the basinward- and the landward-facing flanks (Fig. 5.1.2). The areas between the ridges are covered in sediment with a partially filled channel in the NW having transported sediment from the shelf to the basin and covering a well-defined transform fault. This channel winds around the accretionary ridges while the eastern part of the basin shows a canyon that has eroded deeply into and has cut through several ridges. This eastern canyon is probably fault-controlled, and the ridges on the lower slope also show intensive faulting.

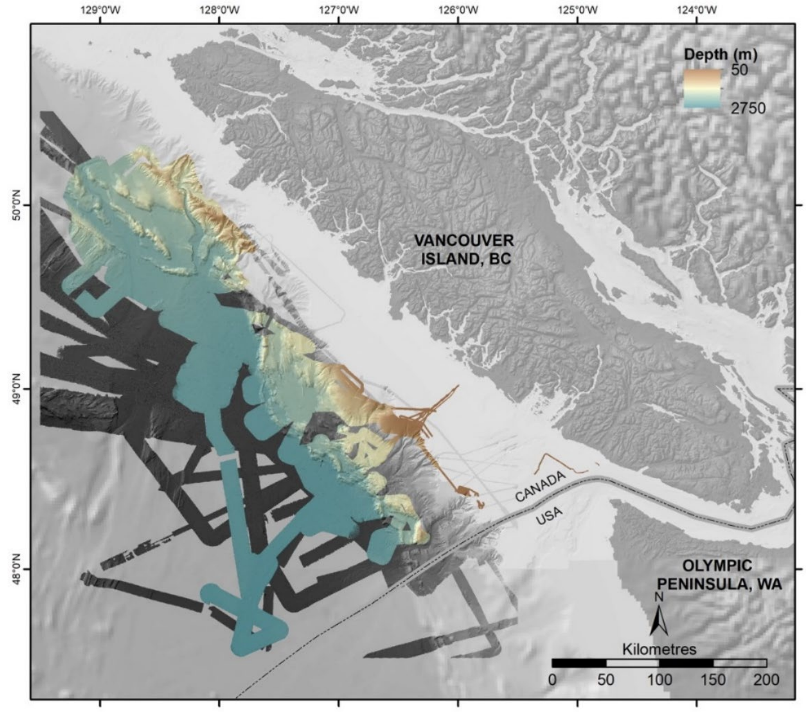

Fig. 5.1.1 Overview map of the total area covered by ship multibeam mapping during SO294 (color coded). The background shaded relief is a compilation from a variety of previous cruises and Ryan et al., 2009.

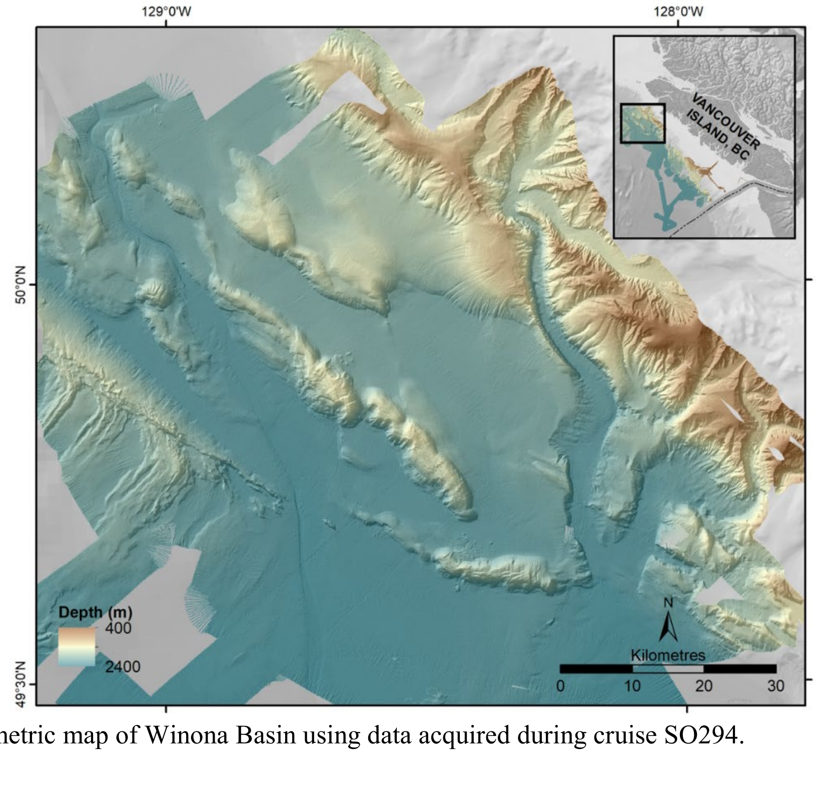

Fig. 5.1.2 Bathymetric map of Winona Basin using data acquired during cruise SO294.

5.1.3 Water column gas mapping

During the expedition, water column data were collected with the EM122 and EM710 sounders. The data were scanned for the occurrences of gas flares using the FMMidwater tool (Version 7.8.7). Of special note were gas flares mapped on Swiftsure Bank during the beginning of SO294, as well as in the Winona Basin. Post-cruise analyses will be undertaken to find all occurrences of gas flares and define their physical extent (projected seafloor location, height in the water column). Here, we show some of the most spectacular examples seen in the Winona Basin (Fig. 5.1.3). Abundant gas flares were seen in water depth of 500 – 700 m reaching nearly the sea surface (~40 m depth). These flares were also notably correlated to seafloor topography (Fig. 5.1.4).

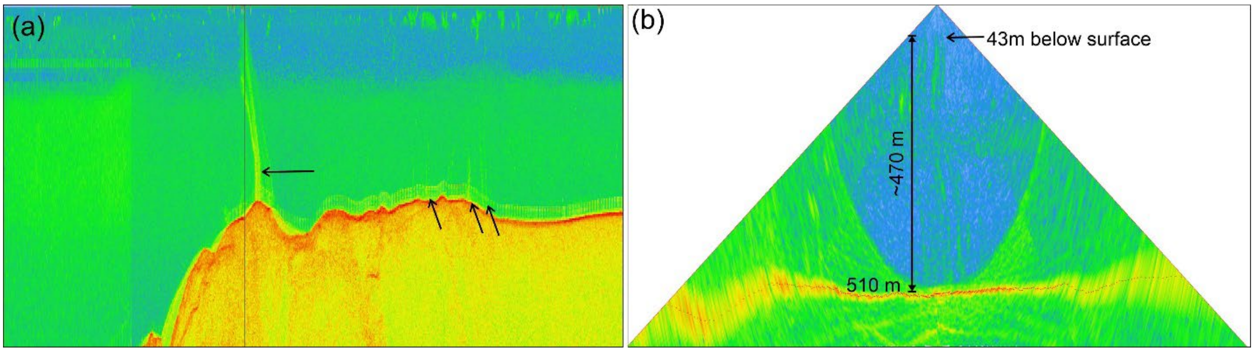

Fig. 5.1.3 Gas flare images from FMMidwater tool in Winona Basin (a) stack of line across flares (black arrows) and (b) fan-view of the largest flare, dubbed "blow-out" flare (location see Fig. 5.1.4).

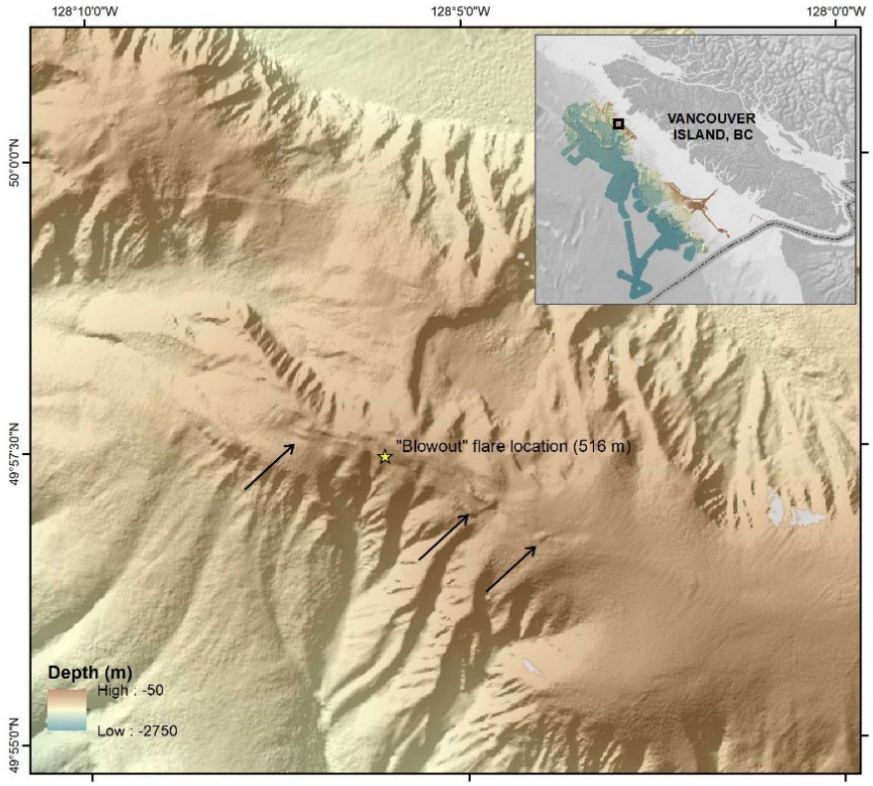

Fig. 5.1.4 Map showing location of "blow-out" gas flare and morphology (black arrows) correlated to other flares seen in the water column data.

5.1.4 PARASOUND

The PARASOUND echosounder installed on board the R/V SONNE utilizes the parametric effect based on the nonlinear relation of pressure and density during sonar wave propagation. Two high intensity acoustic waves with frequencies of 18-20 kHz (called primary high frequency, PHF) and 22-24 kHz were used to create a secondary high (40-42 kHz) and a secondary low (~4 kHz) frequency (referred to as SLF). While the SLF is used for the sub bottom profiling, the PHF can be used to image gas bubbles, plankton or fish in the water column. However, for the purpose of expedition SO294, we focus on the SLF for profiling, as the EM710 and EM122 multibeam systems are used for gas flare location detection. In total, 5958 km of generally high quality PARASOUND data were acquired continuously while along profiles or transits between stations, but not while the vessel was stationary (e.g. during coring or heat-probe measurements) or during OBS deployment, recovery, or triangulation. The PARASOUND data are revealing near-seafloor faulting and deformation. A seafloor-breaching strike-slip fault was identified ~25 km east of the deformation front and shows vertical offset of ~ 3 m (Fig. 5.1.5a). The frontal thrust-fault at the deformation front often breaches the seafloor as seen in the second example (Fig. 5.1.5b).

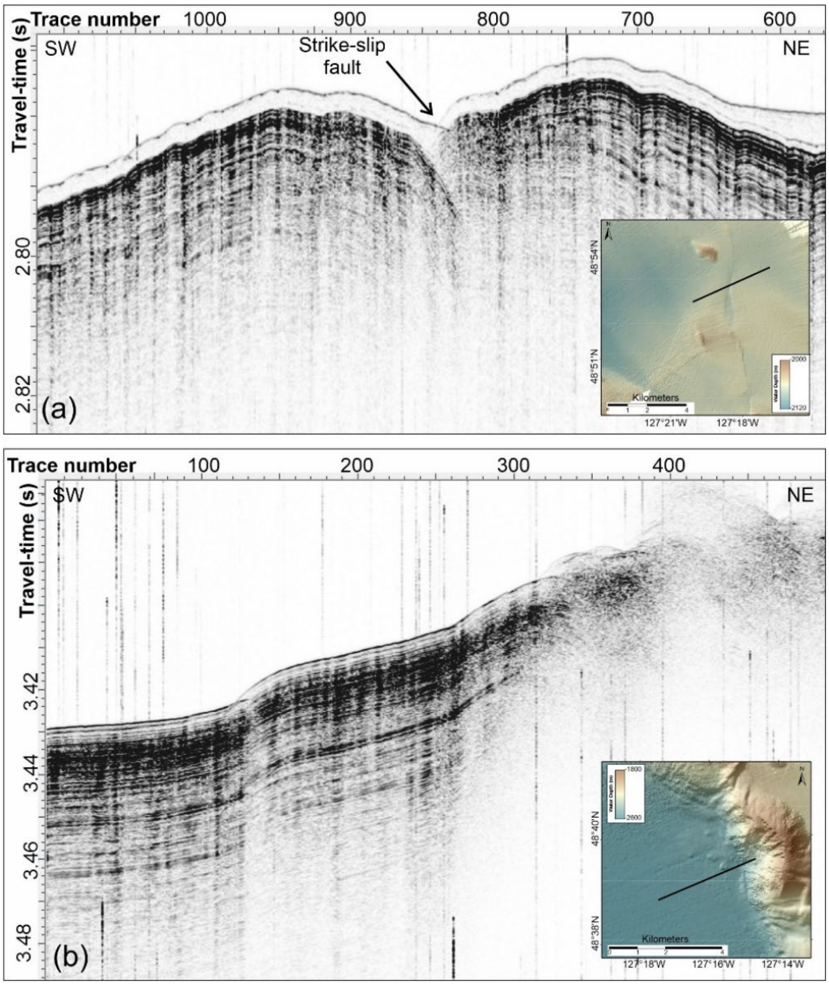

Fig. 5.1.5 Example of two PARASOUND profiles from (a) across a strike-slip fault, and (b) across the deformation front.

5.2 Long-term Ocean Bottom Monitoring equipment

5.2.1 Broad-band Seismometers by GEOMAR

(A. Jegen[1], J. Klein[1], M. Riedel[1], D. Lange[1])

[1]GEOMAR

In the subduction zone tectonic model and accretionary prism setup by Saffer and Tobin (2011), there could be tremor-like signals and very low frequency earthquakes (VLFE) occurring at the upper limit of the locked zone and within the transition zone to the deformation front. They can release a significant amount of the accumulated seismic strain without major shaking and may be similar to slow-slip events. A first attempt in detecting these signals at northern Cascadia did not succeed (McGuire and Collins, 2012) but may be related to a wide station spacing of > 10 km used. Therefore, we approached the topic of the VLFE by placing six broad-band seismometers within a closer grid and in a configuration to allow for analyses to detect wave-front propagation (Fig. 5.2.1). The technical design of the instruments used is that of the Ocean Bottom Seismometer *LOBSTER* (Long-term Ocean Bottom Seismometer for Tsunami and Earthquake Research) which is a design by K.U.M Umwelt- und Meerestechnik Kiel GmbH. The system is constructed to carry a hydrophone and seismometer, but the modular design of the front end allows adaptation to different seismometers and hydrophones or pressure sensors. During SO294 the sensors are HTI-01-PCA hydrophones from High Tech Inc. and Trillium compact OBS from Nanometrics and K.U.M. The three-component seismometer is housed in a titanium tube and is located between the anchor and the OBS frame which allows for optimal coupling with the seafloor. The recording device is a 6D6 recorder of K.U.M. Sampling of the seismic signal is at 100 Hz. As energy source Lithium batteries were used. The release transponder holds the anchor and drops the weight when an acoustic release command is sent. The anchor consists of 60 kg untreated steel. All OBS were deployed in the free fall mode. For recovery, the OBS is equipped with a flashlight, VHF radio beacon, flag and a swim-line. A total of six broad-band OBS equipped with Trillium seismometers were deployed during SO294 (Table 5.2.1) in an array pattern around the ONC node, that also hosts a buried broad-band seismometer. These six stations will be recovered during a cruise in 2023 using the Canadian Coast Guard Ship *John P. Tully* under the leadership of the GSC.

Table 5.2.1 Deployment information for broad-band OBS

Station	Name	Date / Time (UTC)	Latitude (N)	Longitude (W)	Depth (m)
SO294_36	BB1	09/19 / 02:29:39	48° 40.302’	126° 51.629’	1268
SO294_37	BB2	09/19 / 02:46:01	48° 39.679’	126° 50.301’	1288
SO294_38	BB3	09/19 / 03:02:27	48° 38.684’	126° 50.808’	1370
SO294_39	BB4	09/19 / 03:28:31	48° 39.444’	126° 51.571’	1348
SO294_40	BB5	09/19 / 03:49:14	48° 39.723’	126° 52.818’	1302
SO294_41	BB6	09/19 / 04:05:40	48° 38.801’	126° 52.407’	1360

5.2.2 Short-period Ocean Bottom Seismograph and Ocean Bottom Pressure Gauge

(K. Obana[1], T. Takahashi[1], T. Shirai[2])

[1]JAMSTEC

[2]NME

5.2.2.1 Overview

During expedition SO294, short-period ocean bottom seismographs (OBSs) and ocean bottom pressure gauges (OBPs) were deployed in two regions, Juan de Fuca and Explorer Plate region (Table 5.2.2). In the Juan de Fuca Plate region, six OBPs (OBP01 to 06) were deployed at 10 km station intervals forming equilateral triangles of side-lengths of 10 and 20 km. The OBSs (JSCS01 to 06) were deployed adjacent to each OBP, and in addition, three OBSs (JSCS07 to 09) were deployed surrounding the triangle array (Fig. 5.2.1). The triangle array collocates with the GEOMAR broad-band OBS array and one buried seismometer at the Clayoquot slope node of the NEPTUNE cabled observatory system operated by ONC. Although earthquakes and aseismic slow slip are known to be virtually absent on the shallow megathrust fault off Vancouver Island (Obana et al., 2015; McGuire et al., 2018), the combination of these instruments is expected to capture the seismic/aseismic events, including "rapid" aseismic slip recently discovered in the Izu-Ogasawara (Bonin) Trench (Fukao et al., 2021), if they occur. The OBSs will be recovered in 2023 after one year of observation and the OBPs in 2024 after two years of observation.

In the Explorer Plate region, eleven OBSs (JSCN01 to 11) were deployed from the Nootka Fault Zone in the south to offshore Brooks Peninsula in the north, with ~25 km station intervals (Figure 5.2.2). Combined analysis with Canadian National Seismograph Network stations would provide detail information of seismicity and crustal structure in the Explorer region. These OBSs will be recovered in 2023. The pre-cruise preparation of the instruments was conducted with Hajime Shiobara (Univ. Tokyo), Hiroko Sugioka (Kobe Univ.), and Takuya Maekawa (NME) under the collaboration with Geological Survey of Canada, Natural Resources Canada. The locations of the OBSs and OBPs on the seafloor were estimated by triangulation using slant range measurements between the vessel and the instruments on the seafloor.

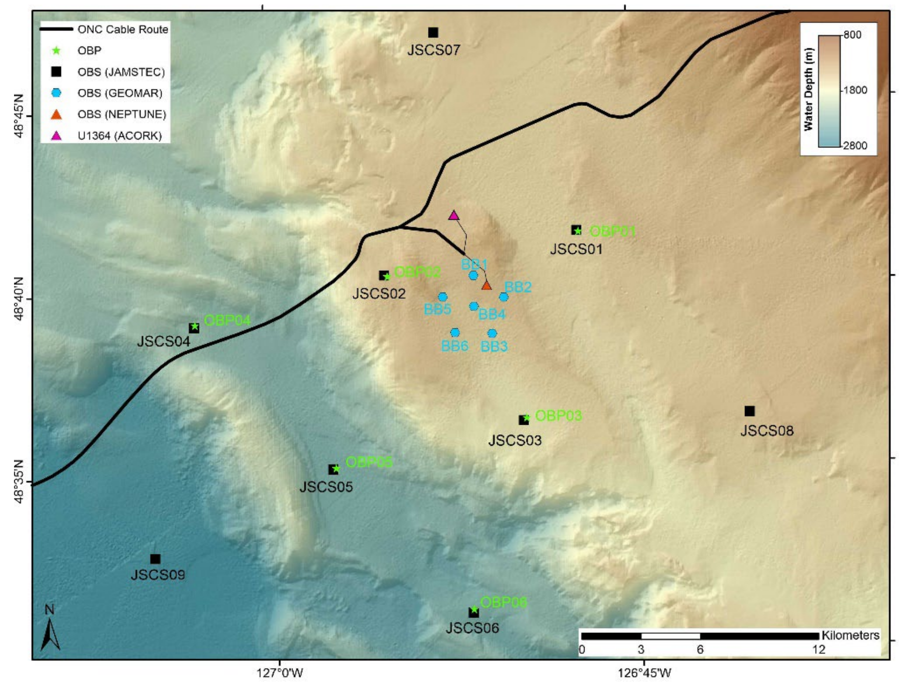

Fig. 5.2.1 Map showing deployment of long-term equipment around the observatory node "Clayoquot slope".

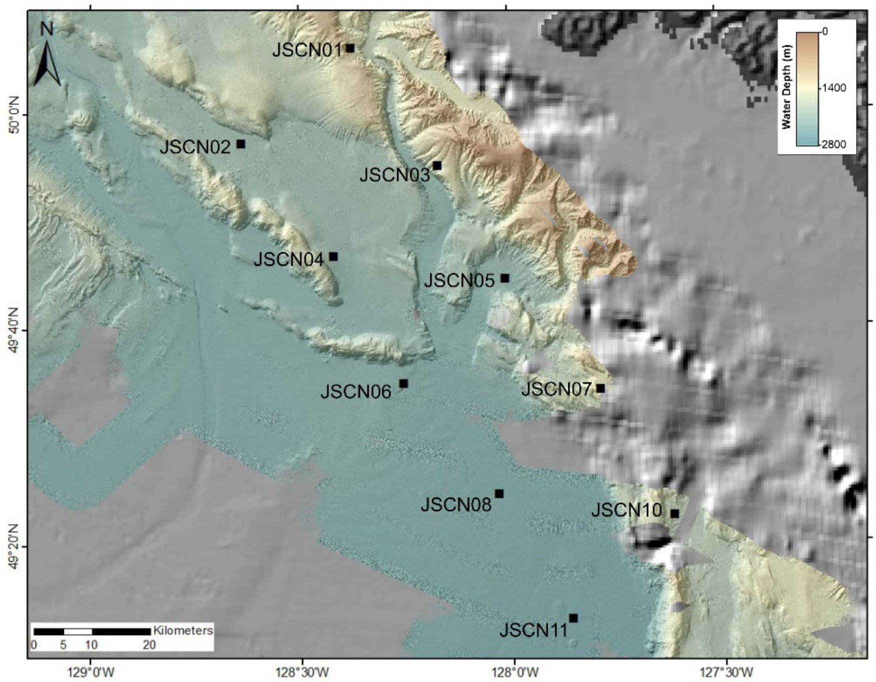

Fig. 5.2.2 Map showing deployment of long-term equipment (short-period OBS) in the Winona Basin.

5.2.2.2 Short-period Ocean-Bottom Seismometers

JAMSTEC deployed 20 OBSs in the CLOCKS survey area. The deployed OBSs are TOBS-24N (Tokyo Sokushin Co. Ltd., Tokyo, Japan). Each OBS is composed of a three-component 4.5 Hz geophone and a hydrophone. The yellow plastic sphere (Fig. 5.2.3) contains a pressure-resistant glass sphere to a depth up to 6,000 m. In the glass sphere, geophone, data logger, and batteries are installed. The hydrophone is attached to the outside of the sphere. The data recording period is approximately 10 months with a 100 Hz sampling rate.

Fig. 5.2.3 Photo of JAMSTEC short-period OBS.

5.2.2.3 Ocean-bottom pressure gauges

The Ocean-bottom pressure gauge (OBP) (Fig. 5.2.4), which was originally developed by Earthquake Research Institute, University of Tokyo (Shiobara et al., 2014), is a free-fall/pop-up type seafloor observation instrument equipped with an absolute pressure gauge (APG). The APG (Intelligent Depth Sensor, Model No. 8B7000-I-005, Paroscientific, Inc., Redmond, WA, US) used two quartz crystal resonators (one to convert analog force inputs generated by a Bourdon tube with digital outputs and the other to measure internal temperature to correct for its effect on resonant frequency), and it can measure absolute water pressure up to a depth of 7000 m (68.95 MPa) with a theoretical resolution of 1×10^{-9}. The sampling rate of the OBPs is set as 8 Hz, with an infinite impulse response (IIR) low-pass filter (2 Hz, -3 dB) included in the APG, which means the frequency range is from 2 Hz to DC. A titanium sphere housing with a diameter of 50 cm is used for the data logger, the acoustic transponder, and batteries. The OBPs deployed in this cruse are prepared for a two-year-long observation and will be recovered in 2024.

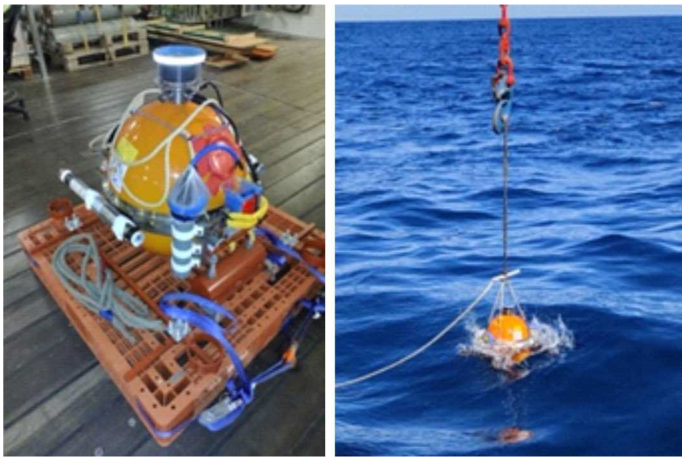

Fig. 5.2.4 Fully assembled OBP (left) and its deployment from R/V SONNE (right).

Table 5.2.2 Station and position list of long-term short period OBS and OBP

Station	Site No.	Gear	Deployment			Seafloor Position		
			Date, Time (UTC) YYYY/MM/DD hh:mm	Latitude [N]	Longitude [W]	Latitude [N]	Longitude [W]	Depth (m)
SO294_106	JSCN01	OBS	2022/9/25 22:39	50° 06.022’	128° 22.437’	50° 06.046’	128° 22.462’	1301
SO294_107	JSCN02	OBS	2022/9/26 01:10	49° 57.256’	128° 38.311’	49° 57.239’	128° 38.292’	2063
SO294_105	JSCN03	OBS	2022/9/25 19:26	49° 55.118’	128° 10.157’	49° 55.127’	128° 10.171’	1557
SO294_104	JSCN04	OBS	2022/9/25 15:38	49° 46.816’	128° 25.137’	49° 46.795’	128° 25.112’	2105
SO294_99	JSCN05	OBS	2022/9/24 19:21	49° 44.616’	128° 00.593’	49° 44.663’	128° 00.624’	2184
SO294_100	JSCN06	OBS	2022/9/24 22:51	49° 35.047’	128° 15.279’	49° 34.989’	128° 15.252’	2284
SO294_98	JSCN07	OBS	2022/9/24 15:37	49° 34.299’	127° 47.190’	49° 34.295’	127° 47.212’	1342
SO294_96	JSCN08	OBS	2022/9/24 02:41	49° 24.731’	128° 01.805’	49° 24.690’	128° 01.870’	2422
SO294_94	JSCN09	OBS	2022/9/23 20:48	49° 16.558’	127° 21.378’	49° 16.739’	127° 21.685’	1382
SO294_95	JSCN10	OBS	2022/9/23 23:39	49° 22.572’	127° 36.998’	49° 22.557’	127° 36.988’	1779
SO294_93	JSCN11	OBS	2022/9/23 15:23	49° 13.008’	127° 51.536’	49° 13.019’	127° 51.548’	2487
SO294_32	JSCS01	OBS	2022/9/18 19:20	48° 41.484’	126° 47.267’	48° 41.487’	126° 47.274’	1405
SO294_34	JSCS02	OBS	2022/9/19 00:11	48° 40.264’	126° 55.272’	48° 40.385’	126° 55.262’	1308
SO294_43	JSCS03	OBS	2022/9/19 19:09	48° 36.329’	126° 49.659’	48° 36.332’	126° 49.661’	1535
SO294_4	JSCS04	OBS	2022/9/14 23:13	48° 39.055’	127° 03.160’	48° 39.085’	127° 03.160’	2111
SO294_6	JSCS05	OBS	2022/9/15 02:11	48° 35.130’	126° 57.544’	48° 35.125’	126° 57.576’	2267
SO294_8	JSCS06	OBS	2022/9/15 04:52	48° 31.162’	126° 52.067’	48° 31.109’	126° 51.948’	2253
SO294_33	JSCS07	OBS	2022/9/18 21:57	48° 47.004’	126° 53.013’	48° 47.004’	126° 52.986’	1377
SO294_31	JSCS08	OBS	2022/9/18 16:38	48° 36.379’	126° 40.325’	48° 36.395’	126° 40.344’	1342
SO294_3	JSCS09	OBS	2022/9/14 21:00	48° 32.778’	127° 04.951’	48° 32.798’	127° 05.005’	2565
SO294_42	OBP01	OBP	2022/9/19 15:53	48° 41.551’	126° 47.148’	48° 41.457’	126° 47.208’	1403
SO294_35	OBP02	OBP	2022/9/19 00:30	48° 40.340’	126° 55.136’	48° 40.359’	126° 55.129’	1298
SO294_44	OBP03	OBP	2022/9/19 19:33	48° 36.384’	126° 49.549’	48° 36.401’	126° 49.534’	1534
SO294_5	OBP04	OBP	2022/9/14 23:57	48° 39.108’	127° 03.054’	48° 39.153’	127° 03.126’	2109
SO294_7	OBP05	OBP	2022/9/15 02:32	48° 35.177’	126° 57.452’	48° 35.155’	126° 57.446’	2263
SO294_9	OBP06	OBP	2022/9/15 05:06	48° 31.226’	126° 51.954’	48° 31.204’	126° 51.922’	2253

5.3 Ocean Bottom Magnetotelluric Equipment

(G. Franz[1], A. Haroon[1], A. Benevides[2])

[1]GEOMAR

[2]National Observatory Brazil

The electrical resistivity of the subsurface is very sensitive to the presence of fluid accumulations caused by dehydration processes within the subduction process due to the fact that electrical conduction in rocks is governed by ionic conduction within the fluid in the pore space. Since dehydration processes are linked to earthquake processes, electrical resistivity sections supply valuable information in the understanding of earthquake occurrences. An efficient methodology to image electrical resistivity variations down to a depth of 100 km is the magnetotelluric (MT) method. The MT method uses natural varying magnetic field variations as an electromagnetic source. Due to the plane wave characteristic of the natural source field, frequency dependent electrical impedance measurements consisting of the ratio of horizontal electric and magnetic field measurements, depend only on resistivity variations of the underlying seafloor.

5.3.1 Magnetotelluric Instrumentation

The remote ocean bottom electromagnetic receivers (OBEM) are placed stationary onto the seafloor. The receiver nodes are assembled on an instrument carrier consisting of a titanium frame on which syntactic foam elements are mounted to give the frame a positive buoyancy. This buoyancy is countered by a concrete anchor weight beneath the frame, which is held by a release (KUMquat K/MT562, K.U.M., Kiel) that can be opened via an acoustic impulse to recover the station after experiments. To facilitate recovery, the frames also hold a strobe flasher (NOVATECH ST400A), a radio beacon (NOVATECH RF700A1), a flag and a ~6 m long swim line attached with a float at the end. The frame holds a large titanium cylinder containing a battery pack and another smaller titanium cylinder containing the data logger and the receiver electronics (Magson GmbH, Berlin, 128GB microSD card). The logger records the natural variations of the Earth's electromagnetic field.

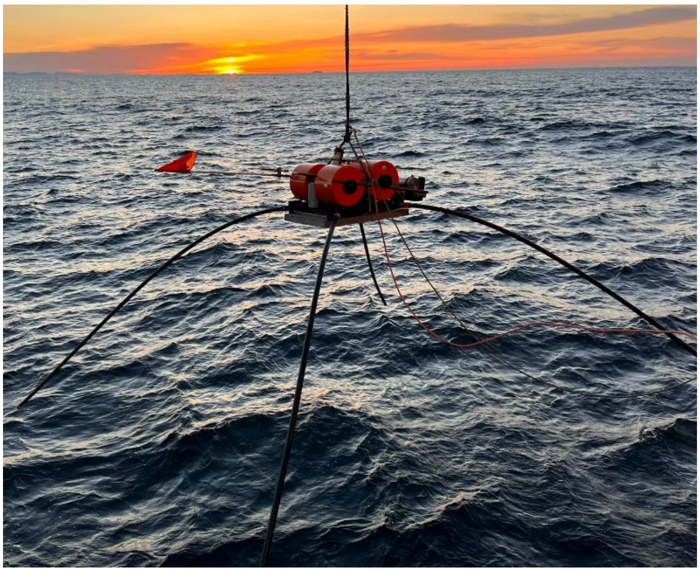

Fig. 5.3.1 OBEM receiver for Magnetotelluric measurements (Photo: T. Bartels).

The magnetic field is recorded with a 3-component (two orthogonal horizontal, one vertical component) fluxgate magnetometer with a precision of 10 pT/sqrt(Hz). Horizontal electric field variations are measured between two pairs of electrodes (non-polarizable Ag/Ag-Cl, CCS1PORT, Silvion), which are mounted within plastic tubes to form two orthogonal electrical dipoles (11.2 m length, Fig. 5.3.1). The logger also records tilt and temperature. Timing of measurements is kept by a temperature-controlled crystal clock (Seascan, SISMTB, drift < 500 ms/year), synchronized to a GPS prior to deployment and after recovery.

5.3.2 Marine Magnetotelluric Data Acquisition

To investigate the electrical resistivity structure of the northern Cascadia subduction zone, we deployed 18 OBEM receivers along a coast-perpendicular profile crossing the subduction zone forearc and continental shelf (see Fig. 3.7). All devices recorded with a sampling rate of 10 Hz. Instruments were deployed at distances between ~2 and 4.3 nautical miles (3.7 and 8 km), and in a range of ~2400 m to ~40 m water depth (see Table 6.1.1), with the aim to position stations close to the coastline, to facilitate integration with the onshore MT data acquired in the summer of 2022. On October 16th and 17th, we recovered 17 devices. Only station OBMT13 did not surface. The releaser gave a positive response, stating that the hook opened. However, the ranging data stayed constant and the instrument did not rise to the surface. On October 18th, with the help of the ship's crew, we were able to use the OFOS (Ocean Floor Observatory System) with attached camera, lights, and hooks to successfully recover OBMT13. Data acquisition on three stations (OBMT01, -02, -08) was not successful due to an early failure of the internal clocks leading to a failure in the recording software. OBMT06 recorded for ~8 days before shutting down. All other stations recorded for the entire deployment period and showed good data quality after preliminary inspection. An example of the measured fields is shown in Figure 5.3.2.

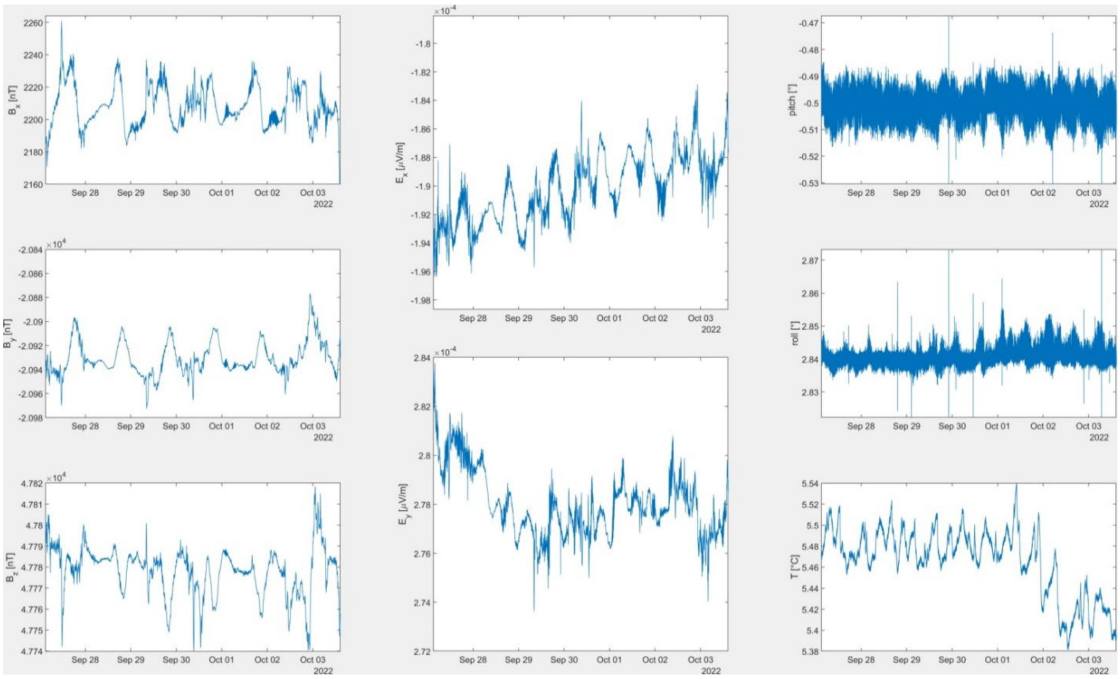

Fig. 5.3.2 Data example at station OBMT05 (~6 days). Shown are three components of the magnetic field (left column), horizontal electric fields (middle column), and tilt and temperature (right column).

5.4 Active-Source Ocean-Bottom-Seismometer Studies

(A. Jegen[1], J. Klein[1], M. Riedel[1])

[1]GEOMAR

The program of SO294 included three active-source OBS deployments. For the first deployment (P1000, CCO2), 22 OBS were deployed along two perpendicular lines (see section 5.8). The next OBS deployment was part of the CLOCKS project. Deployments were made along two parallel profiles with a total of 20 stations in the Winona Basin (P2000, Fig. 5.4.1). The final deployment with twelve stations coincided with the profile along the MT experiment (P3000). Locations of the individual OBS deployments are recorded in Table 6.1.1. However, loctions of the instruments on the seafloor are determined post-cruise using the direct arrival travel times during repositioning.

Two different OBS builds were used: the OBS2000 and the LOBSTER KUM OBS. These OBS systems record the emitted seismic wavefield by measuring both the acoustic pressure in the water column (HTI-01/04/90-PCA hydrophones; High Tech Inc.) and the local ground displacement (using a 4.5 Hz three-component seismometer, KUM, modified after Tim Owen, Cambridge).

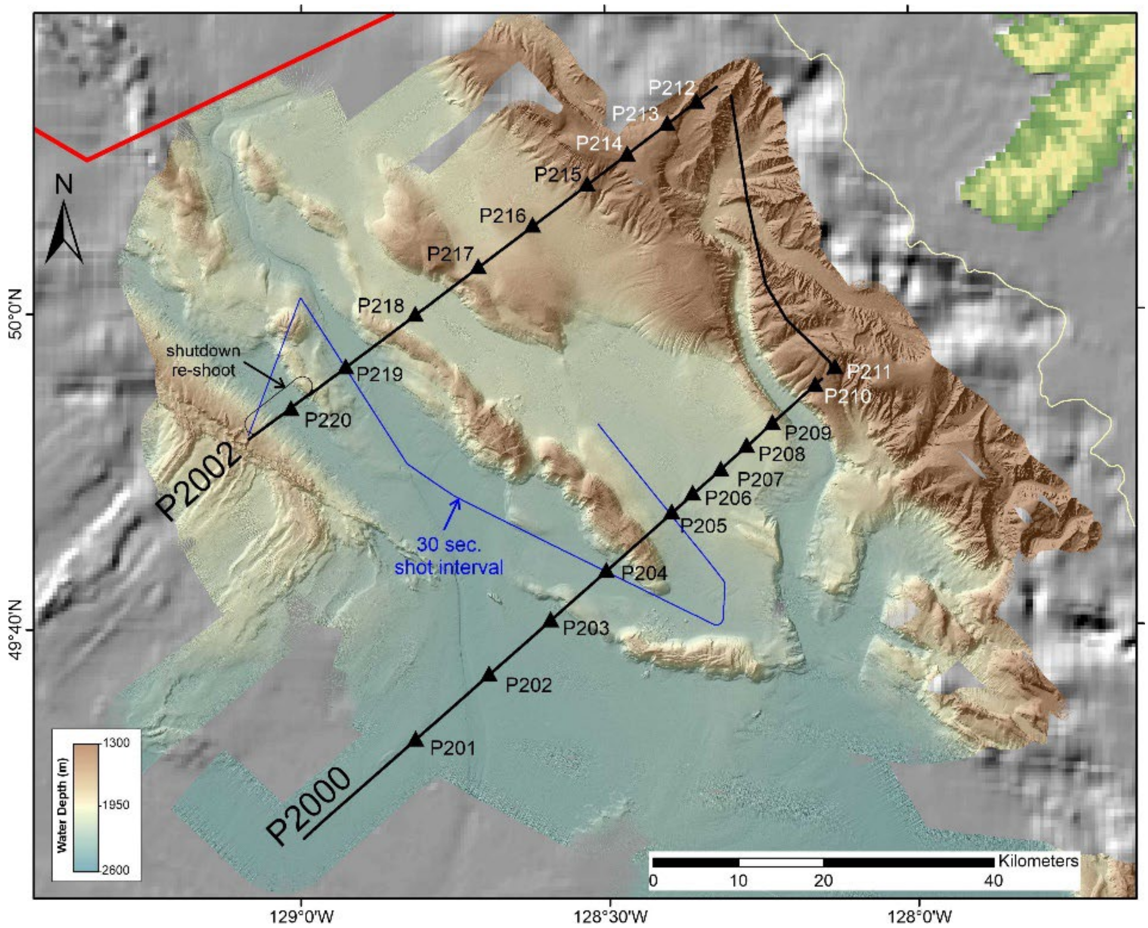

Fig. 5.4.1 Map of OBS stations (black triangles) and seismic lines of refraction experiment P2000. One re-shoot due to a shutdown occurred at the end of profile P2002. A cross-line was acquired with 30 second shot interval, whereas the main lines were acquired with a 60 second shot interval.

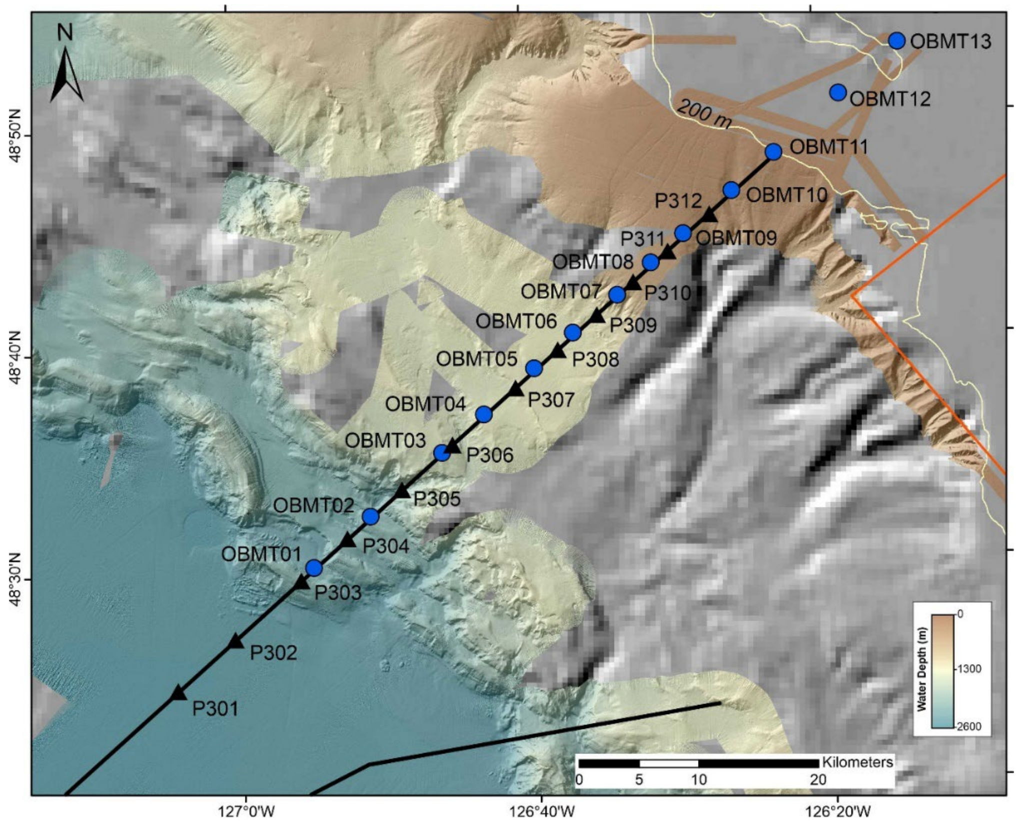

Fig. 5.4.2 Map of OBS deployment for the central seismic refraction experiment (survey P7000). The OBS (black triangles) are along the same line as the OBMT stations (blue circles).

GEOLOG data recorders were used, along with recorders by Sercel Marine Sources Division and Seismograph Services Inc. A reduced power source and an internal clock are required to power the recorder and generate an autonomous time signal. The recorder, power source, clock and the seismometer are encased in titanium tubes to protect them from the substantial ambient water pressure in depths up to 6000 m. Both OBS builds possess a flotation body made of synthetic foam, producing enough buoyancy to hold the OBS at the sea surface. The buoyancy of the OBS is counteracted by an anchor frame, which is attached to the bottom of the OBS before deployment and is released when the OBS is to be retrieved. The release is made possible by an acoustic transponder (K/MT562; KUM GmbH), which disconnects the OBS from the frame, causing the OBS to ascend to the sea surface, when a specific signal is emitted into the water column.After retrieval of the OBS to deck of the vessel, the pressure tubes holding the recorders are dismounted from the OBS. The recorders are connected to a GPS for clock synchronization and a time-drift between the times of deployment and retrieval is noted and applied to the data in post-processing. GPS-synchronization was made, data stored, and copied to disks in multiple formats. Several data examples were extracted and converted to shot records by applying the shot-time information of the G-Gun array (Fig. 5.4.1). An example from the OBS deployment in the Winona Basin show continuous direct arrivals, refracted P-wave- and converted S-wave arrivals (Fig. 5.4.1a). The station on the central profile (parallel to the MT transect) shows continuous P-wave refractions and a strong reflection from the top of the oceanic crust (Fig. 5.4.1.b).

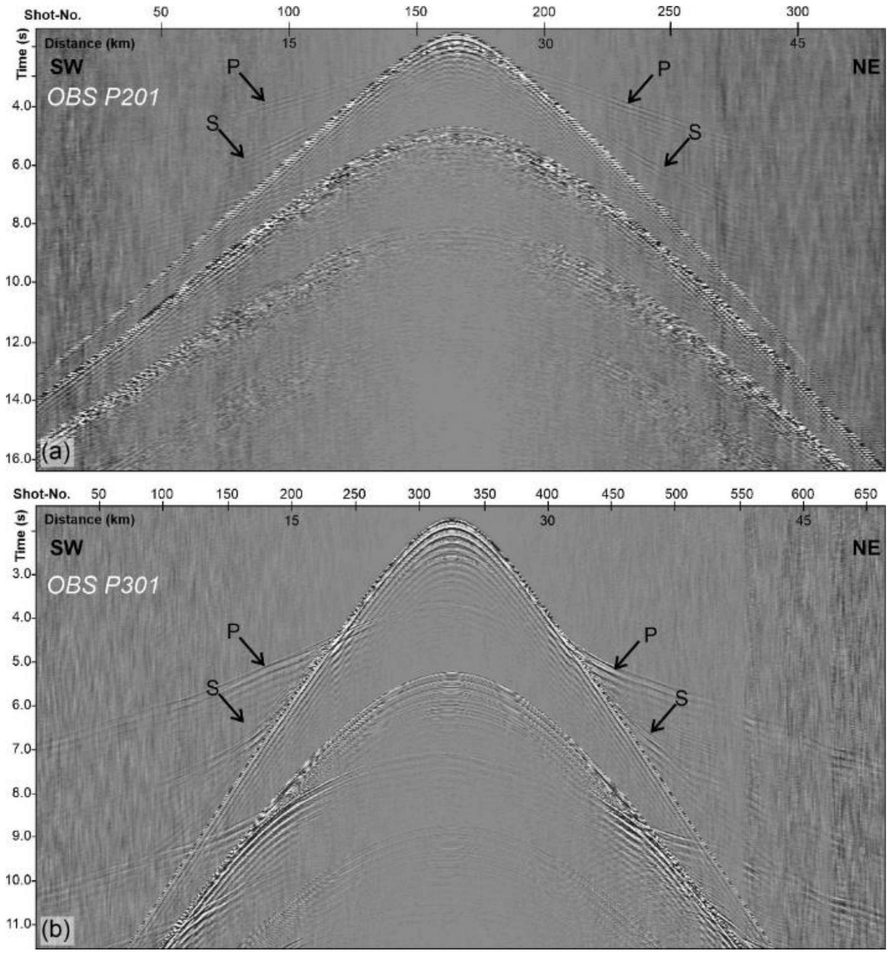

Fig. 5.4.3 Two examples of records from the hydrophone channel at station (a) OBS P201 in the Winona Basin and (b) OBS P301 along the central profile parallel to the MT stations. The records show continuous refracted P-wave arrivals and some converted S-wave arrivals.

5.5 Multichannel Seismic Imaging

(E. Klein[1], G. Wetzel[1], T. Bartles[1], L. Rohde[1], M. Riedel[1])

[1]GEOMAR

5.5.1 Overview

During SO294, a total of 1660 km of 2D multichannel seismic (MCS) reflection data were acquired, forming an extensive grid of lines in each of the three research areas (Fig. 5.5.1). The goal was to image the subsurface with a focus on the oceanic crust. In total, we shot seven surveys with two different acquisition geometries. P1000 was part of the secondary user project CCO2. Surverys P2000, P3000 and P7000 were part of OBS refraction measurements, while P4000, P5000 and P6000 were dedicated to high resolution streamer seismic acquisition. A list of all lines acquired is given in Table 6.2.1.

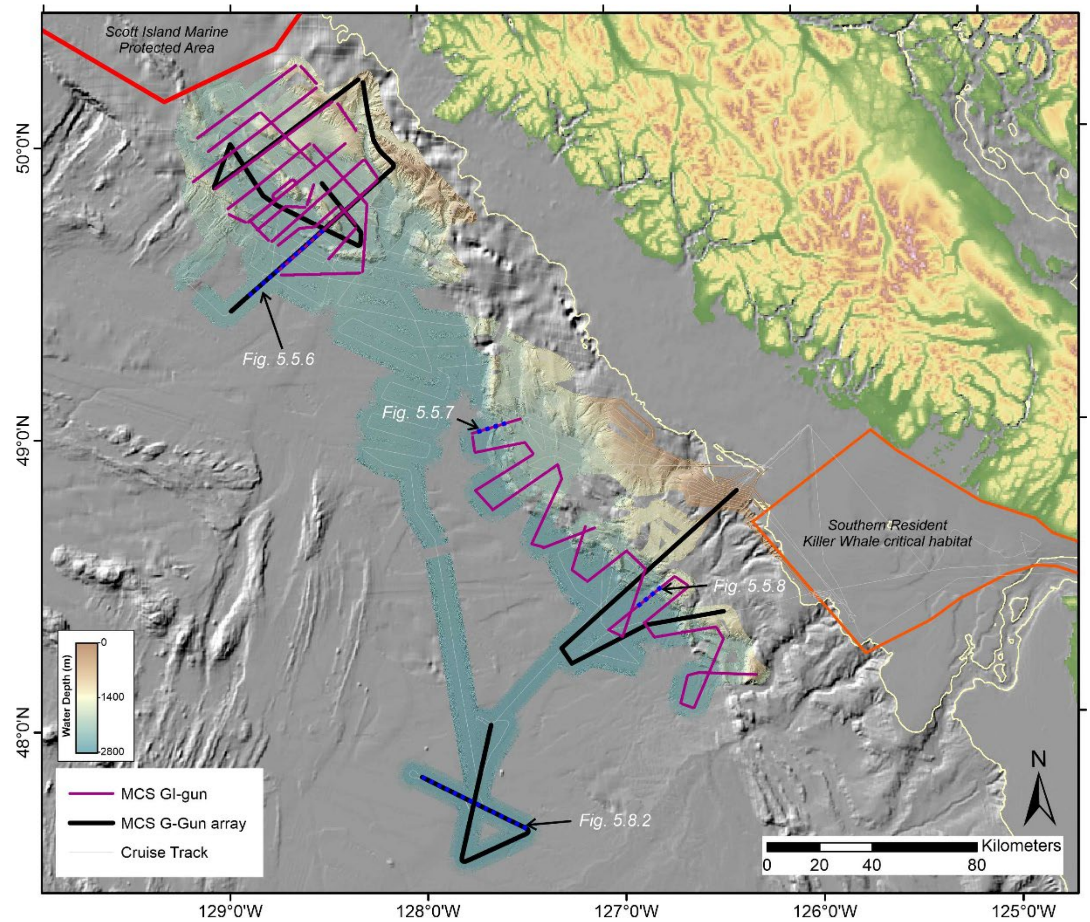

Fig 5.5.1 Map showing the location of MCS data acquired with the GI airgun and G-Gun array during SO294.

5.5.2 Streamer set-up

We used 23 active streamer sections each consisting of eight channels at a spacing of 1.5625 m (Geometrics GeoEel streamer segments, 12.5m). This resulted in 287.5 m of active streamer length. In Figures 5.5.2 and 5.5.3, the streamer set-up, deck geometries and gun settings for the 2D surveys are visualized. The receiver system consisted of a 40-m-long tow cable (from stern of the vessel), a 20-m-long stretch section, followed by 23 active streamer sections (7 oil-filled, 16 solid-state) and another stretch section, to reduce the drag noise of the tail-buoy at the end of the streamer. The active sections were connected to each other with analogue-to-digital (AD) converter modules, which communicate with the recording system in the lab via a TCP/IP protocol. A repeater connected the deck cable and the tow cable (lead-in). In the lab, the streamer power supply unit builds the connection between the recording system and the AD modules. It also handles the management of the streamer power supply.

For maintaining a constant streamer depth of 2 m (4 m for P7000), four bird Remote Units (RUs) were attached to the streamer during the survey. The birds communicate with the controller via coils embedded in the streamer and the information is forwarded via a twisted pair wire within the decks cable. Two RUs were directly attached to the stretch section and the 5th active section, respectively. The other two were attached to 1.56 m long bird sections added to the streamer between the active sections 13/14 and 19/20. As the bird sections do not contain hydrophones, the channel spacing are here increased to 3.125 m.

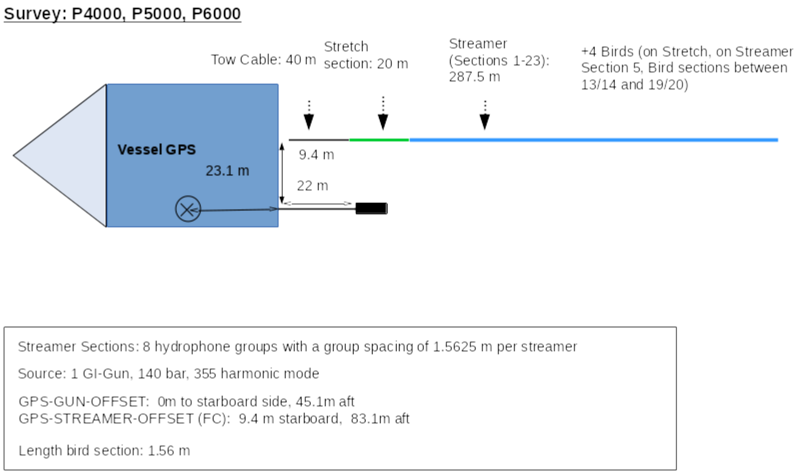

Fig. 5.5.2 Geometry of the seismic data acquisition using a single GI airgun and streamer.

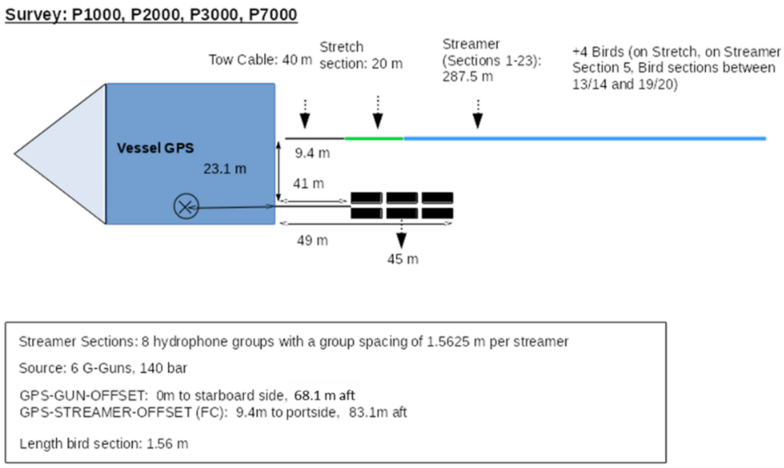

Fig. 5.5.3 Geometry of the seismic data acquisition using the G-gun array and streamer.

5.5.3 Seismic Sources

5.5.3.1 GI-Gun

For the high-resolution MCS surveys P4000, P5000, and P6000), a single GI-Gun was used as the seismic source. It was attached to a stringer by two steel chains of about 1 m length. The set-up was stabilized in a water depth of ~2 m by a large float, attached to the stringer. The gun was operated in Harmonic 355 mode (250 in³ generator and 105 in³ injector chamber) with a pressure of 140 bar. The injector pulse was triggered with a delay of 63 milliseconds after the generator. An unfiltered frequency spectrum is shown in Fig. 5.5.4a. Shot interval was 10 seconds, equivalent to ~25 m shot point distance at a survey speed of ~ 4 kn.

5.5.3.2 G-Gun array

The G-gun array used during SO294 consisted of six (6) G-Guns operated at a pressure of 140 bar. Two G-Guns each formed a cluster, and three clusters were towed together at a distance of 2.5 m to each other. The total length of the array is 8 m. Cluster 1 and 3 consisted of two 520 in^3 guns, and the middle cluster was made of two 380 in^3 guns. The total volume was 2840 in^3 (~46 L). The port-side deployment rail was used to deploy the array on the aft of the ship. During data acquisition, the array was towed 49 m behind the ship's stern, where the guns were towed 8 m below the sea surface. In order to achieve sufficient ray coverage while avoiding previous shot-noise and to allow receivers on land-stations to record the signals, the G-Gun array was used with a shot interval of 60 s, which translates to a shot point distance of 150 m at 4 kn speed. An unfiltered frequency spectrum is shown in Fig. 5.5.4b.

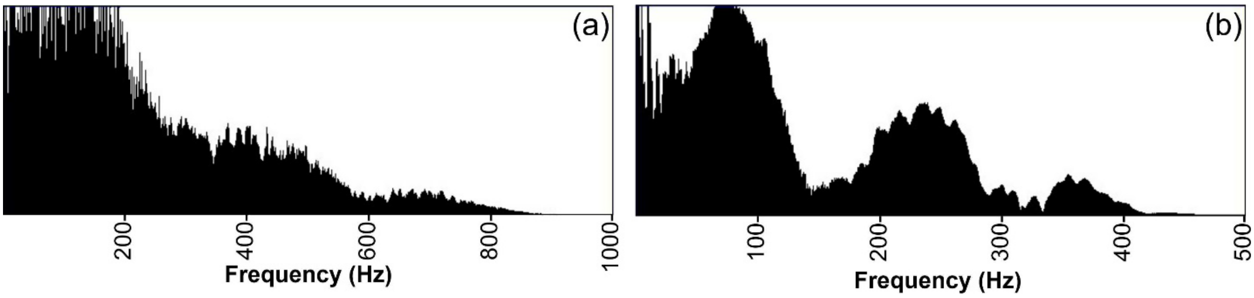

Fig. 5.5.4 (a) Frequency spectrum of the GI airgun. Frequencies up to 200 Hz (first notch) were generated. (b) Frequency spectrum of the G-Gun array. Frequencies up to 150 Hz (first notch) were generated.

5.5.4 Data Acquisition

The data was recorded with the Geometrics acquisition software. The recorded analogue signal was digitized with a sample rate of 1 millisecond for all G-Gun-Array surveys and 0.5 milliseconds for the GI-Gun surveys (Table 5.5.1). For each shot, a multiplexed SEG-D file was recorded, along with a log file, containing time information and shot number. During the survey, the Geometrics software allowed for a variety of displays for quality control, including shot gathers, a noise window and the frequency spectrum of each shot. On another computer, the vessels position, recorded by a separate GPS Antenna, was logged in RMC string.

Table 5.5.1 Data acquisition parameters for SO294

	P1000	P2000	P3000	P4000	P5000	P6000	P7000
Shot rate (s)	60	60	30	10	10	10	30
Record length (s)	12	12	12	8	8	8	12
Sample rate (ms)	1	1	1	0.5	0.5	0.5	1
Shot mode	G-Gun Array	G-Gun Array	G-Gun Array	GI Gun Harmonic 355	GI-Gun Harmonic 355	GI-Gun Harmonic 355	G-Gun Array
Streamer depth	2 m	2 m	2 m	2 m	2 m	2 m	4 m
Delay (ms)	55	55	55	150	150	150	55

5.5.5 On-Board Processing

A first processing of all seismic lines was done on board. The geometry configuration of the streamer and the delay of the sources was calculated. The data showed a delay of 55 ms for the G-Gun-Array and 150 ms for the GI-Gun. For binning, a grid size of 1.5625 m was chosen for the GI-Gun data and 6.25 m for the array. After analyzing the frequency spectrum and testing several filters, a bandpass filter with 15, 48, 650, 850 Hz was applied to all data (Fig. 5.5.5) though frequencies up to 500 Hz only are included for the G-gun data due to the lower sampling rate. The data were corrected for normal move out after common-mid-point (CMP) sorting, then stacked, and migrated with a 2D Stolt migration algorithm (up to 450 Hz). Normal moveout correction and migration were performed with a constant velocity of 1500 m/s. After migration, the sections were imported into Kingdom for verification of geometry and data quality and for a first interpretation of the geological structures imaged. Overall, data quality is superb and imaging of oceanic crust was achieved with the G-Gun array in the Winona Basin showing surprising strong variation in depth (Fig. 5.5.6). High-quality seismic images were also optained across the deformation front of the central margin off Vancouver Island showing a variation in frontal thrust vergence and deformation style (Figs. 5.5.7 and 5.5.8).

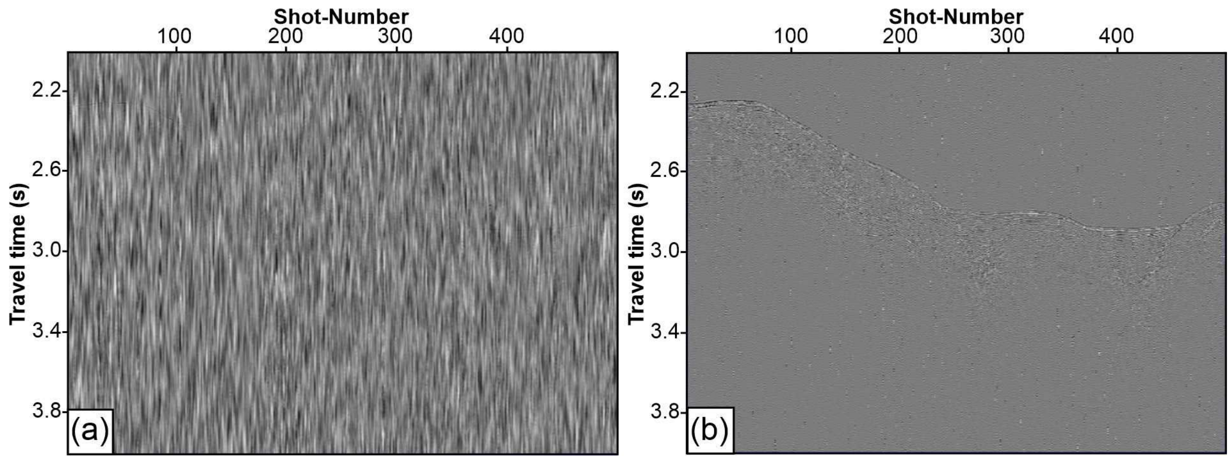

Fig. 5.5.5 Comparison of (a) raw seismic data and (b) band-pass filtered data.

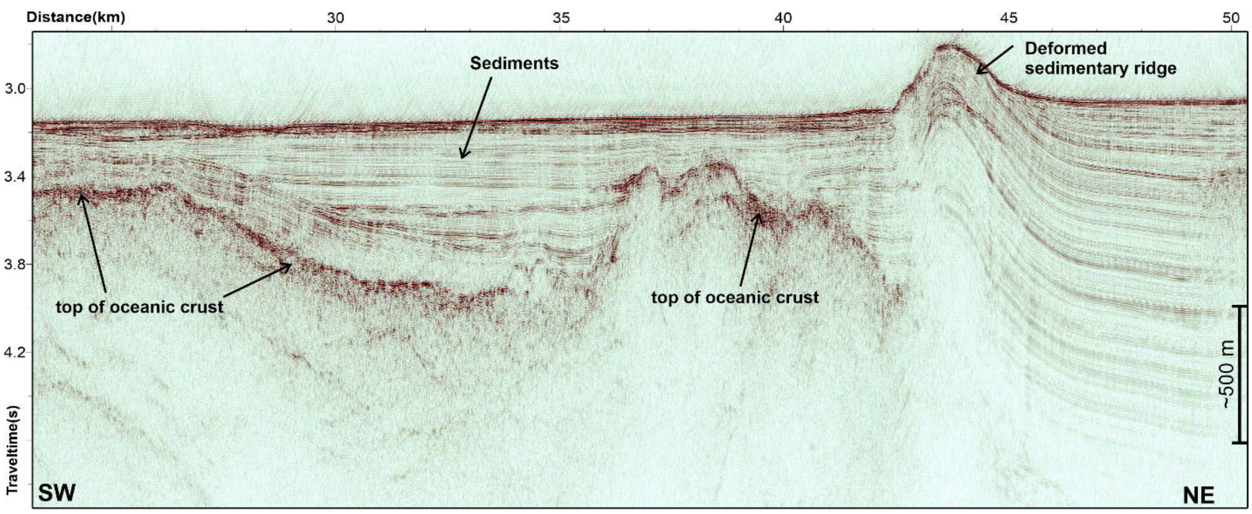

Fig. 5.5.6 Example of a seismic line from the Winona Basin acquired with the G-Gun array showing changing topography of the oceanic crust and a deformed sedimentary ridge (Location see Fig. 5.5.1).

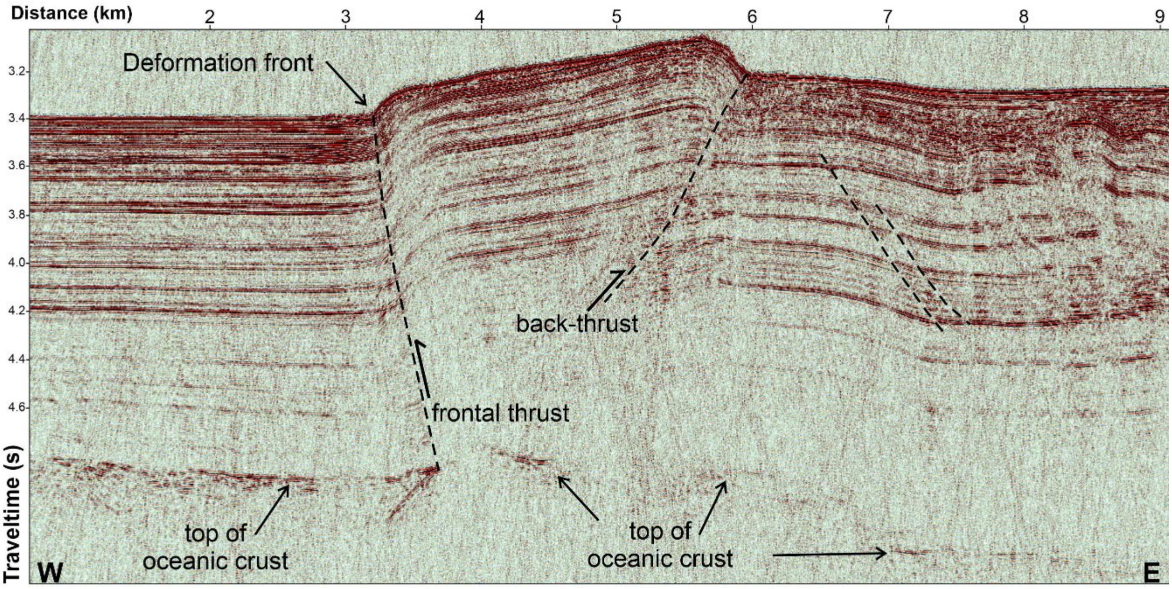

Fig. 5.5.7 Example of a seismic section at the northern part of the deformation front with strongly pronounced frontal thrust (Location see Fig. 5.5.1).

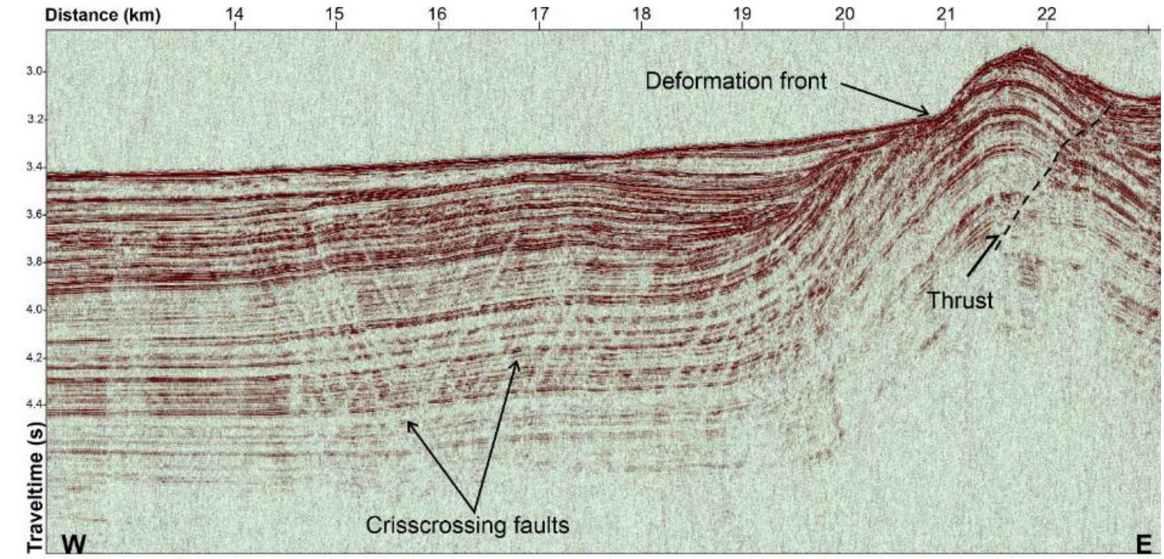

Fig. 5.5.8 Example of a seismic section with clearly pronounced, crisscrossing proto-faults, west of the deformation front. A seaward dipping thrust is visible at the eastern end of the seismic section (Location see Fig. 5.5.1).

5.6 Gravity Coring

(W. Schmitz[1], K. Douglas[2], M. Riedel[3], S. Kröger[3])

[1]University Hamburg

[2]GSC

[3]GEOMAR

A central question to the overall geohazard potential for subduction earthquakes of the Explorer Plate is the actual recurrence rate of these earthquakes, especially in comparison to the southern Juan de Fuca Plate where such rates have been well documented (Atwater, 1987; Hamilton et al., 2015). To date, only one study was made at one slope failure on the Explorer Plate (Riedel and Conway, 2015). In analogy to previous studies, we targeted four land-slides discovered in the new multibeam bathymetry data with gravity coring (Fig. 5.6.1). In total, we took twelve gravity cores with 46.72 m of sediment recovered (Table 6.3.1). The uppermost few meters of the sub-seafloor sediments were sampled with the gravity corer.

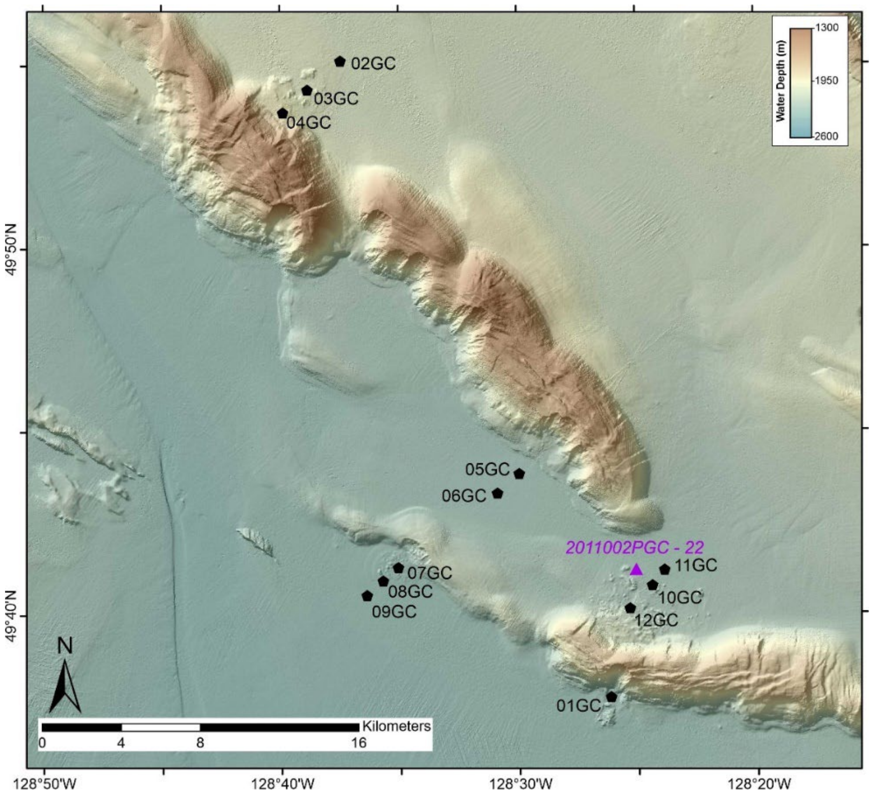

Fig. 5.6.1 Map showing four slope failures in the Winona Basin targeted during SO294 for gravity coring. One slide with 05GC and 06GC showed no debris on the seafloor, whereas all other failures showed visible exposed blocks of failed sediment on the seafloor. A piston core taken previously during expedition 201102PGC was taken without prior knowledge of the existence of the slope failure. The core was curated at the GSC-Pacific office in Sidney, BC, and will be re-analysed and included in our studies.

The cores were not processed onboard and only pore-water was extracted. After the end of the cruise, the core sections were brought by truck to the GSC core repository in Sidney, BC. There, the cores will be X-rayed, and whole-round magnetic susceptibility will be measured as a first indicator for the presence of mass transport deposits or turbidites within the cored sections. After additional physical property measurements using a multisensory core logger, splitting, core imaging and sediment description, sub-samples for ^{14}C dating will be taken to bracket events potentially linked to earthquakes and the results will be compared to the well-established record of subduction earthquakes of the Juan de Fuca Plate.

Each core was cut onboard into 1 m (max.) long sections on deck. Plastic caps were placed onto the core ends and the section was brought into the wet-lab for further processing. After labelling and cleaning of the outer surface of the sections, small holes were drilled into the liner (at the working half) and rhizones carefully inserted (Fig. 5.6.2). On average, the rhizones were collecting pore water for 12 hours. The pore water was transferred from the syringes attached to the rhizones to plastic vials. Sub-samples for chemical analyses were taken with pipettes. If sufficient pore-water was collected (> 4 ml), we took a 2 ml sub-sample for measurements of cations (Ca^{2+}, Mg^{2+}, K^{+}, etc.) and added 20 µl Nitric acid, and the sample was put into a fridge at 4°C. The remaining pore water (for measuring anions, $SO4^{2-}$, Cl^{-}, Br^{-}, etc.) was left in the original plastic vial and frozen at -20°C. Pore-water and rhizone sampling protocols are listed in Appendix 11.1 and 11.2.

Fig. 5.6.2 Image showing rhizone sampling at core section 1 of 01GC.

5.7 Heat Flow

(G. Wetzel[1], A. Haroon[1], M. Riedel[1])

[1]GEOMAR

5.7.1 Overview of measurements

In total, 29 heat flux measurements were completed in the Winona Basin along the two main seismic refraction profiles (Fig. 5.7.1). The measurements were almost all successful, but it was difficult to penetrate the sediment on two ridge structures. The probe could not penetrate deep enough into the sediment, so no heat flux data are available at these stations. However, this does not pose a problem to the overall interpretation of the temperature data, as we were able to identify the bottom simulating reflector (BSR) across these ridge structures in our MCS data. The BSR marks the lower boundary of the gas hydrate layer and is thus equivalent to an isotherm, and thus indirectly provides clues to the heat flux. A third heat-probe transect was made at the northern end of the deformation front of the Juan de Fuca Plate (Fig. 5.7.2) along the MCS line P6004. All stations and penetration information are listed in tables 6.4.1 – 6.4.4.

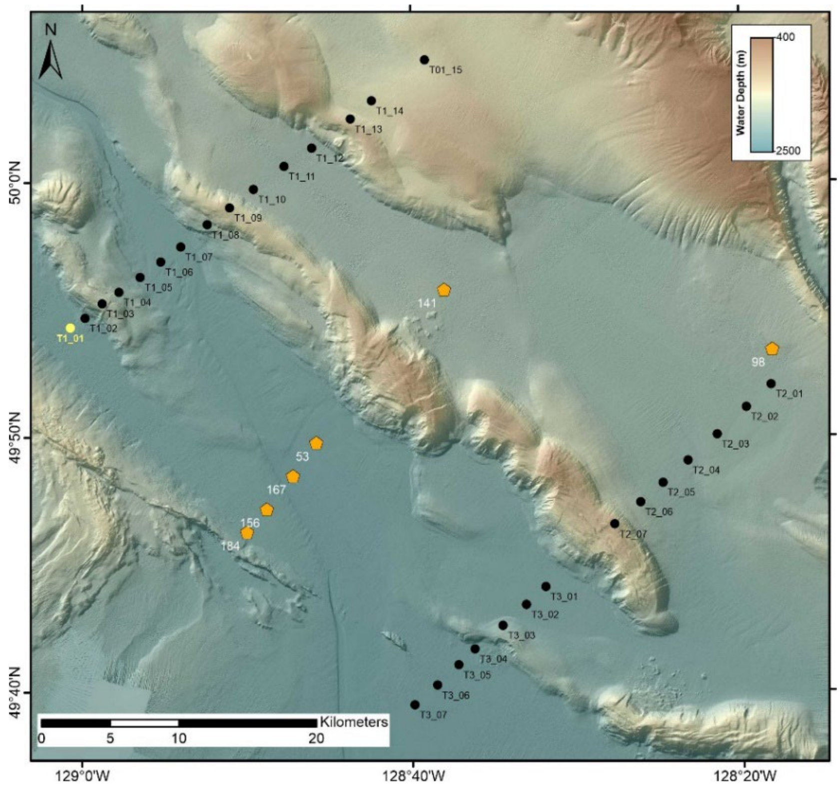

Fig. 5.7.1 Map showing heat-probe stations in the Winona Basin (black points). Stations form the international heat-flow database are also shown including thermal gradients (orange symbols). Results from Station T1_01 (highlighted by yellow symbol) are given in Figures 5.7.4 and 5.7.5.

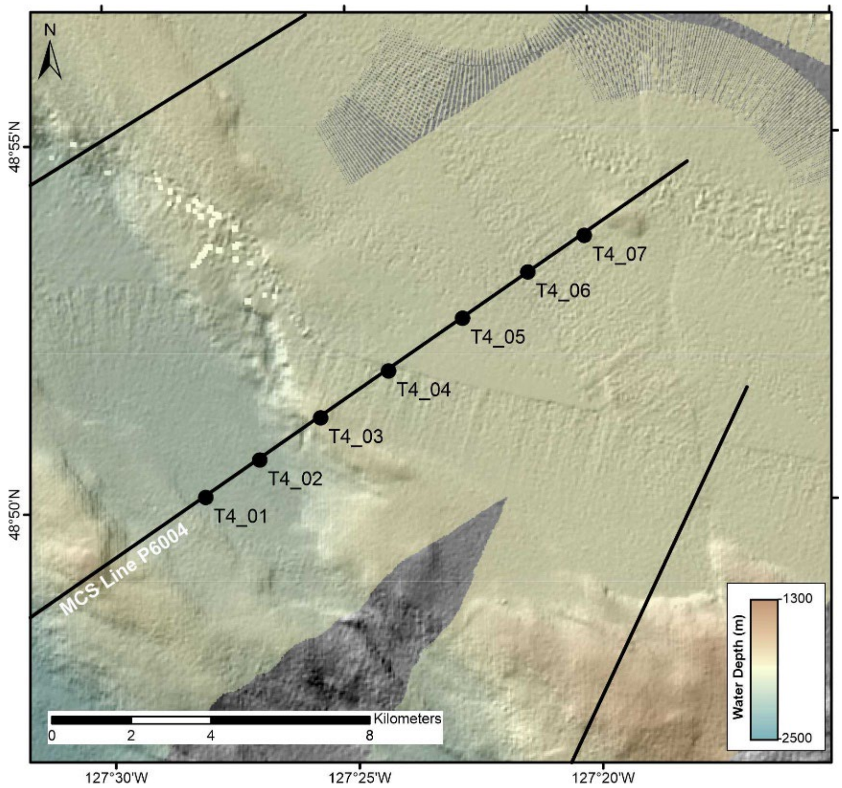

Fig. 5.7.2 Map showing heat-probe stations occupied across the northern portion of the deformation front along MCS profile P6004.

5.7.2 Methodology of heat-flux measurements

The principle of heat-probe measurements is as follows: the probe weighing ~1.5 tons consists of a topweight containing all electronics, and a 6 m long steel rod to which a temperature string of 22 individual thermal sensors is attached (Fig. 5.7.3). The probe is lowered from the ship by a winch-wire to the seafloor and penetrates by its own weight into the sediment. After penetration, frictional heating causes temperature to rise along the temperature string (Fig. 5.7.4). The temperature adjustment after the probe has fully penetrated into the sediments allows estimation of the in-situ temperature and thus the temperature gradient in the subsurface. After a 7-8-minute-long waiting period for the sensors to adjust to the prevailing ambient temperature in the subsurface, a controlled short thermal pulse is released and the temperature drop after this pulse is measured to calculate the thermal conductivity of the sediments (Fig. 5.7.5). Together with the temperature gradient, this is then used to determine heat flow.

Fig. 5.7.3 Deployment of the heat-probe (Photo: Sarah-Marie Kröger, GEOMAR).

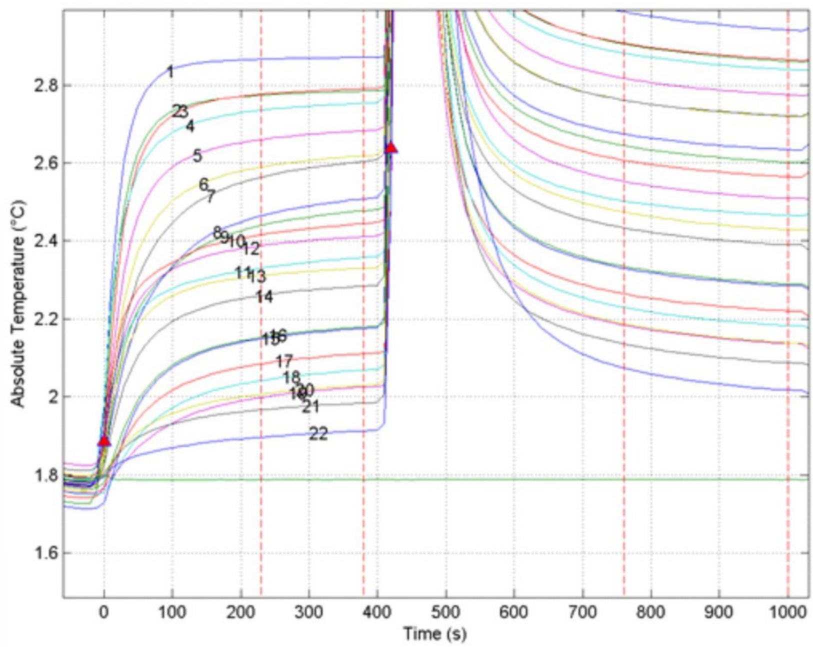

Fig. 5.7.4 Example of a raw temperature record prior to calibration of a heat-probe measurement at Station T1_01 (location see Fig. 5.7.1). Frictional heating is followed by adaptation of the sediments to in situ temperature in the subsurface, and the decline of temperature after a controlled heat pulse indicates thermal conductivity of the sediments.

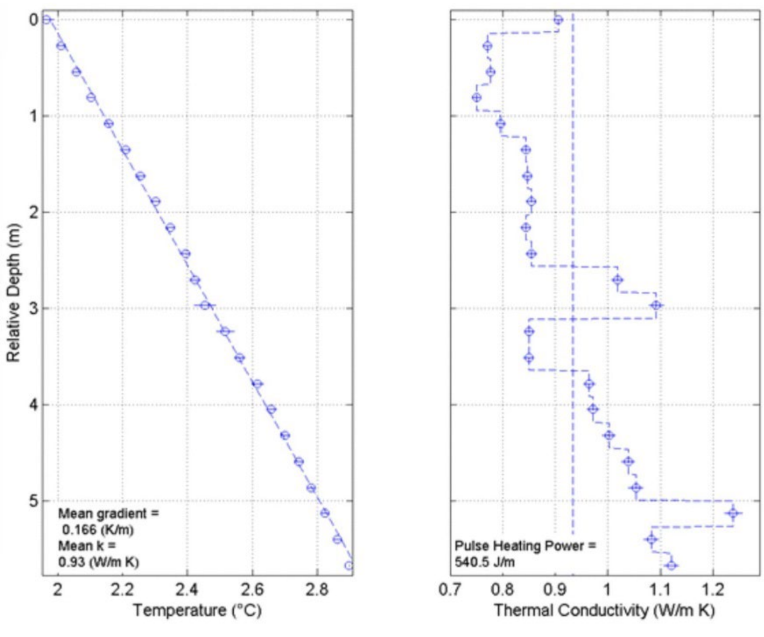

Fig. 5.7.5 Left: Temperature-depth profile at station T1_01 with calculated mean thermal gradient (~166°C/km). Right: Depth profile of the thermal conductivity of the sediment. Together, this yields a mean heat flux of ~154 mW/m^2.

5.8 CASCADIA CO2 (secondary user)

(J. Bialas[1], M. Riedel[1])

[1]GEOMAR

Due to favorable weather conditions and considering other technical constraints, we decided to start active seismic data acquisition with the CCO2 project. Upon approach to the study site, we first mapped the seafloor topography around Mama Bare seamount with modern multibeam bathymetry. Older maps had no optimal resolution to decide whether deployments of OBS are feasible. After processing of the new data, we decided to shorten the OBS layout to stations south of Mama Bare seamount to avoid complex topography and difficulties in interpreting refracted arrivals from the undulating topography of the oceanic crust, that outcrops at the seafloor. In total, 22 OBS were deployed along two perpendicular lines (Fig. 5.8.1). Due to the slow S-wave sound velocity converted shear waves will cover a much smaller subsurface volume than compressional waves. Therefore, OBS stations are irregularly spaced to allow for more optimal S-wave arrival detections within groups of instruments deployed at short distances. Using the G-gun array seismic data were acquired along the profiles and recorded on the OBS and streamer. Shot spacing was set to 1 minute (equivalent to a shot-point distance of 150 m), optimized for the OBS recordings. Streamer data though still provide important information on the topography of the oceanic crust (Fig. 5.8.2). From the 22 OBS deployed, 21 instruments recorded data. OBS 113 did not record any data due to a battery-failure that completely reset the recorder and re-formatted the flash-disk. n the other stations, strong continuous P- and S-wave arrivals were recognized (Fig. 5.8.3).

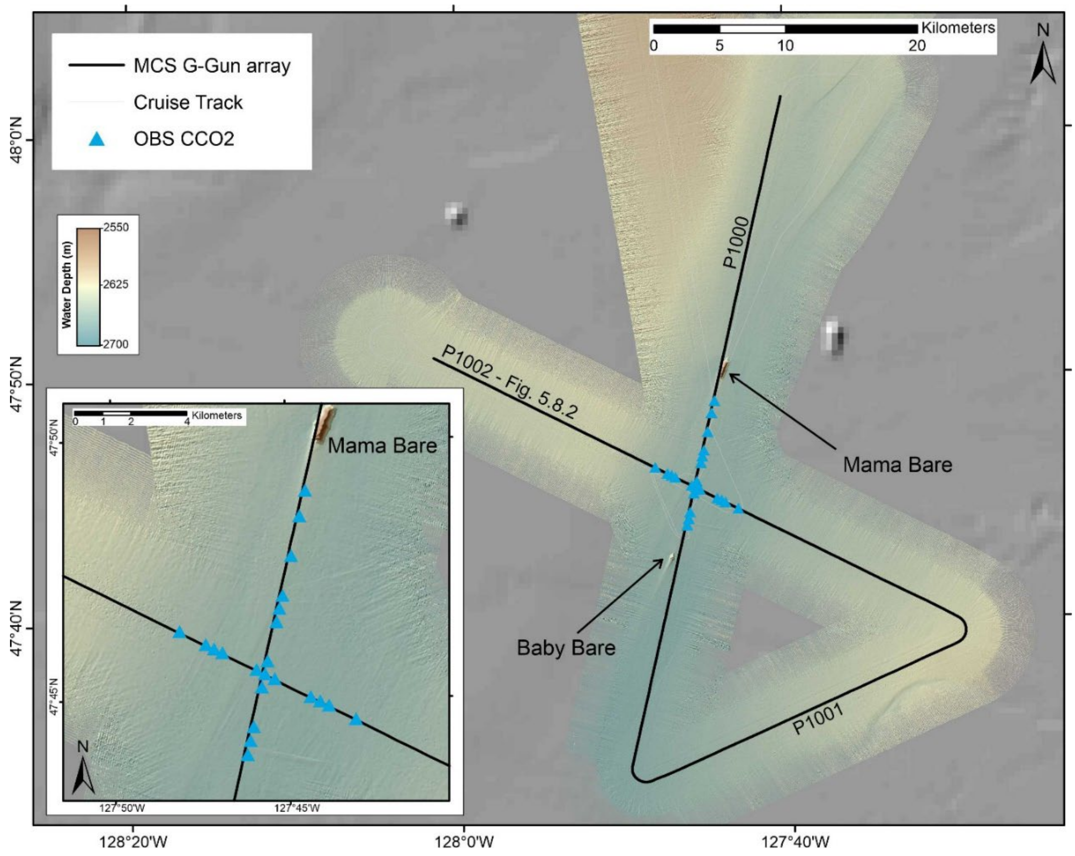

Fig. 5.8.1 Map showing OBS deployment layout and seismic lines acquired for the CCO2 Experiment.

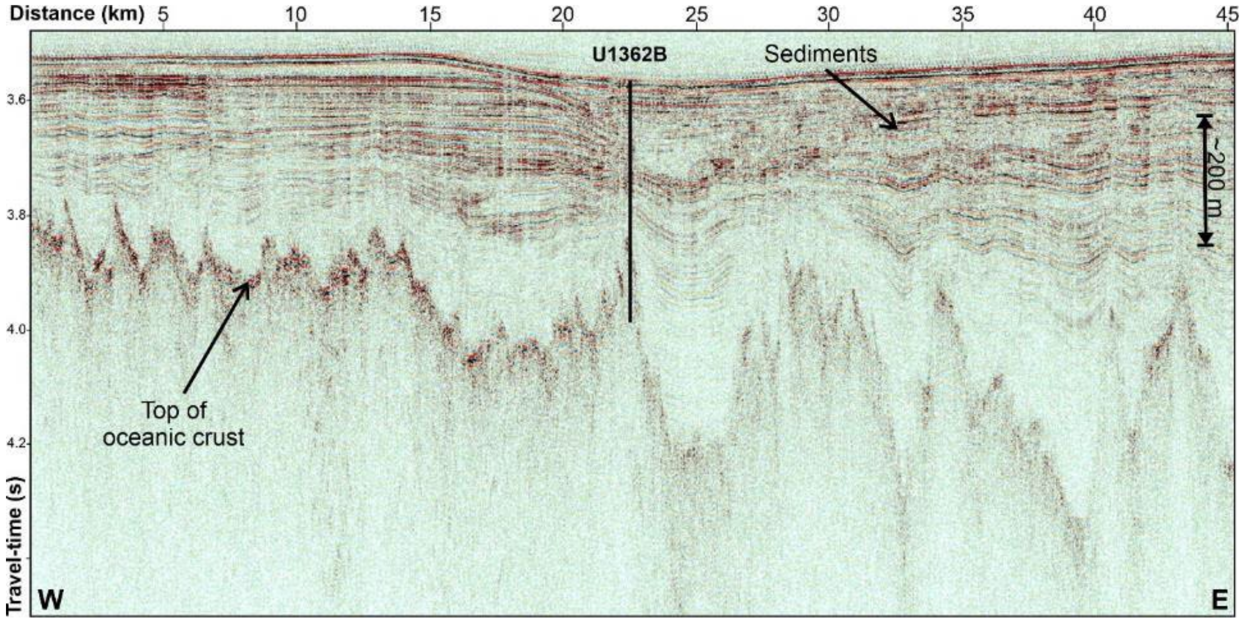

Fig. 5.8.2 Seismic reflection profile P1002 of the CCO2 study with sediment layers above the oceanic crust (Location see Fig. 5.8.1). Location of borehole U1362B (equipped with a CORK) is shown with aximum depth reached during drilling (Fisher et al., 2011).

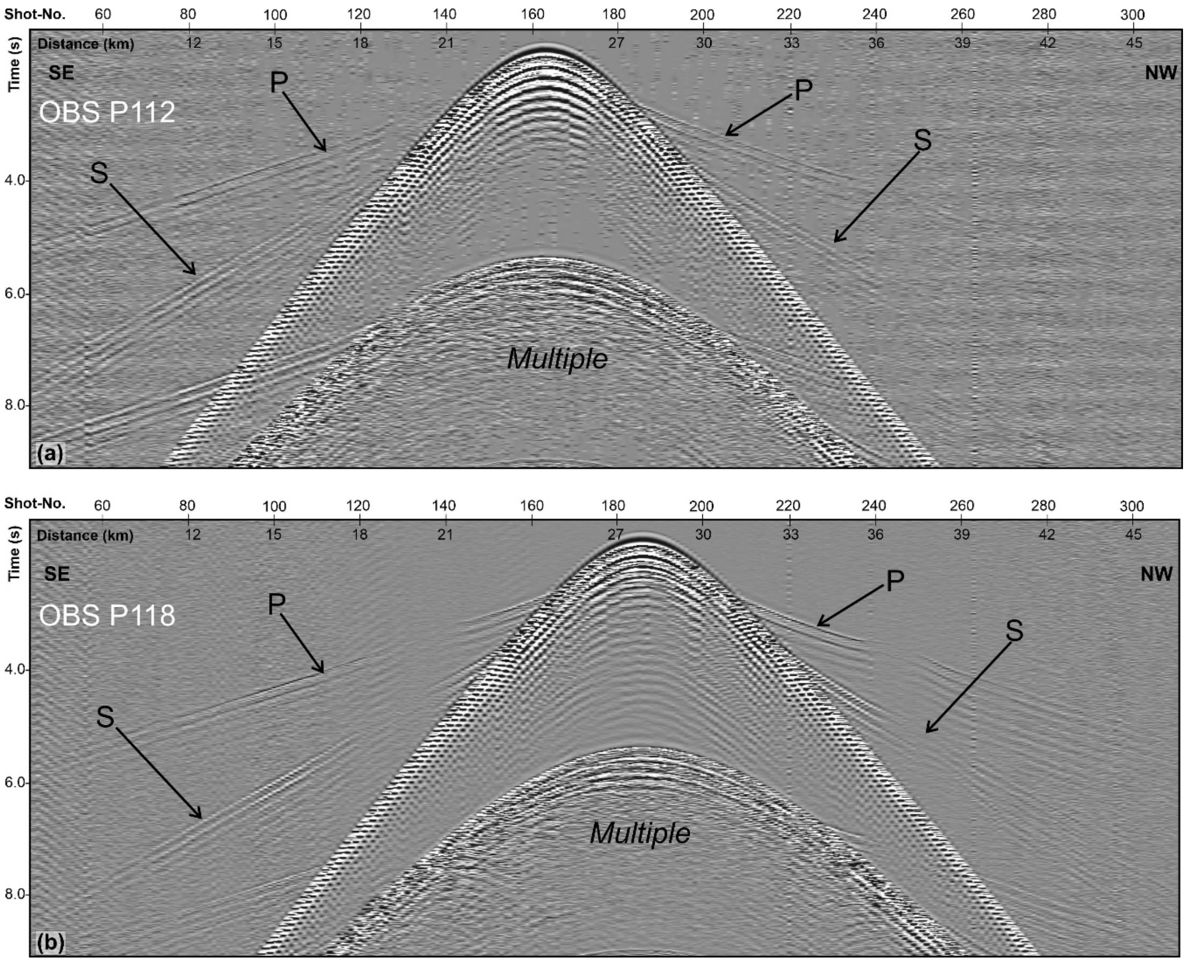

Fig. 5.8.3 Examples of OBS recordings from (a) OBS P112 and (b) OBS P118 of profile P1000 showing strong and continuous P- and S-wave arrivals.

5.9 Marine Mammal Monitoring and Mitigation Measures

(M. Holst[1], M. Warrior[1], M. Piercy[1], B. MacTavish[1], E, Minicola[1], A. Houeweling[2], L. MacKinnon[2], K Aubut Demers[2])

[1] LGL Environmental consultants

[2] JASCO Applied Sciences

The marine mammal monitoring team aboard R/V SONNE consisted of 4 marine mammal observers (MMO), 1 infrared camera operator, and 3 Passive Acoustic Monitoring (PAM) operators. The monitoring team was on board to implement monitoring and mitigation measures as recommended by DFO in the Letter of Advice (LoA) dated 1 September 2022 and the Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment.

During airgun operations, the monitoring and mitigation measures included: (1) using the smallest acoustic source possible to achieve the research goals; (2) conducting seismic surveys outside of Killer Whale critical habitat and outside of sensitive habitats with a setback that ensured that the estimated sound pressure level had diminished to ≤160 dB_{rms} re 1 μPa for the shortest distance to the boundary of these areas; (3) no seismic surveying in water <200 m deep, (4) combining various detections methods (visual observations with two MMOs and PAM) to increase the likelihood of detecting marine mammals; (5) PAM during all seismic operations; (6) visually monitoring the exclusion zone (EZ) of 1000 m for 60 minutes prior to initial start-up of the airgun(s); (7) ramping up the airgun array over a period of 20 minutes starting with the smallest airgun if no marine mammals were observed within the EZ during the 60 minute pre-start observation period, and no acoustic detections were made; (8) immediately shutting down the airgun(s) if a Killer Whale (all ecotypes), Northern Pacific Right Whale, whale with calf (any species) or aggregation of whales (any species) were detected at any distance; (9) shutting down the airgun(s) if a Sperm Whale or beaked whale were detected within an EZ of 1500 m, or other marine mammal/sea turtle were detected within an EZ of 1000 m; (10) waiting to start up the airgun(s) for 30 min after an animal was last seen in the EZ (60 min for deep divers) or not detected acoustically within the EZ any longer; and (11) for operations during poor visibility or at night, starting up the airgun(s) after the EZ was monitored for 30 minutes with no acoustic detections.

During bathymetric acoustic mapping using the multibeam in Killer Whale Critical Habitat, the mitigation measures included: (1) no bathymetric surveys at night; (2) combining various detections methods (visual observations with two MMOs and PAM) to increase the likelihood of detecting marine mammals; (3) visually monitoring the Killer Whale (all ecotypes) EZ of 1000 m for 30 minutes prior to initial start-up of the sounder; (4) immediately shutting down the sounder when a Killer Whale (all ecotypes) was detected within the EZ of 1000 m; (5) shutting down the sounder if other marine mammals/turtles, were detected within the EZ of 500 m; (6) following a shut down for a marine mammal within the EZ, the sounder was not started again for at least 30 min after the animal was last detected in the EZ or not detected acoustically within the EZ any longer. Similar mitigation measures were followed when using the sounders (multibeam and PARASOUND) outside of critical habitat, except that PAM did not take place, and acoustic mapping occurred during day and night.

In total, the MMOs conducted 436.5 hours of watches, including 102 hours during airgun operations, 18 hours during bathymetric mapping with the multibeam in Southern Resident Killer

Whale critical habitat, and 187 hours during acoustic mapping with the sounders outside of critical habitat; the rest of the watches occurred during periods without airgun operations or bathymetric mapping. Overall, the MMOs made 145 sightings totaling 1062 marine mammals during the cruise (Fig. 5.9.1). Thirty-four mitigation actions were implemented by the MMOs, including shut downs of the airgun(s) and sounders. PAM operators conducted 253 hours of monitoring, including 229 hours during seismic airgun operations and 24 hours during bathymetric mapping with the multibeam in critical habitat. Overall, PAM had 17 encounters totaling 6 species of marine mammals during the cruise. Four mitigation actions were implemented by PAM, including shutdowns of the airgun(s) and of the multibeam.

All detailed MMO and PAM logs are included as Appendix 11.3.

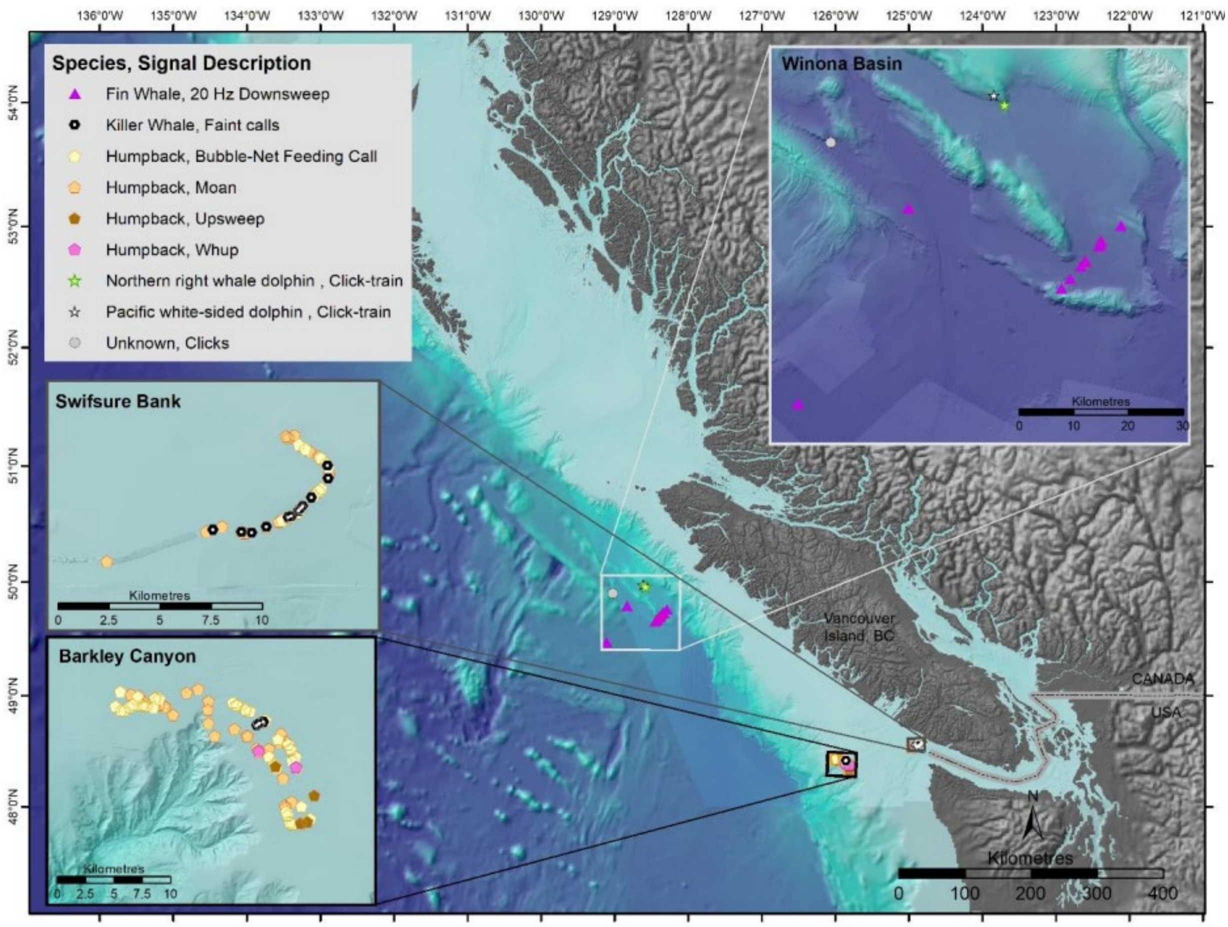

Fig. 5.9.1 Locations of marine mammal species and signal descriptions identified along cruise tracks from September 17 until October 21, 2022. Base map includes data from Ryan et al. (2009), Kung (2021), and SO294.

6 Station Lists SO294

6.1 Overall Station List

Table 6.1.1 List of all stations and events during SO294 in chronological order.

Station No.	Date/Time [UTC]	Gear	Latitude [N]	Longitude [W]	Remarks
SO294_0	2022/09/14 07:35:32	EM profiling	48° 16.298’	127° 11.507’	Transit
SO294_1	2022/09/14 07:36:20	Releaser Test	48° 16.296’	127° 11.507’	
SO294_2	2022/09/14 15:55:46	EM profiling	48° 16.249’	127° 11.521’	Transit
SO294_3	2022/09/14 21:00:23	JSCS09	48° 32.778’	127° 04.951’	Deploy and triangulation
SO294_4	2022/09/14 23:14:45	JSCS04	48° 39.056’	127° 03.160’	Deploy and triangulation
SO294_5	2022/09/14 23:57:48	OBP04	48° 39.108’	127° 03.054’	Deploy and triangulation
SO294_6	2022/09/15 02:11:35	JSCS05	48° 35.130’	126° 57.544’	Deploy and triangulation
SO294_7	2022/09/15 02:32:58	OBP05	48° 35.177’	126° 57.452’	Deploy and triangulation
SO294_8	2022/09/15 04:52:57	JSCS06	48° 31.162’	126° 52.067’	Deploy and triangulation
SO294_9	2022/09/15 05:06:16	OBP06	48° 31.226’	126° 51.954’	Deploy and triangulation
SO294_10	2022/09/15 07:55:47	OBMT01	48° 30.164’	126° 54.939’	Deployment
SO294_11	2022/09/15 08:45:20	OBMT02	48° 32.422’	126° 51.021’	Deployment
SO294_12	2022/09/15 09:31:03	OBMT03	48° 35.176’	126° 46.065’	Deployment
SO294_13	2022/09/15 10:11:57	OBMT04	48° 36.875’	126° 43.125’	Deployment
SO294_14	2022/09/15 10:50:23	OBMT05	48° 38.883’	126° 39.609’	Deployment
SO294_15	2022/09/15 11:28:13	OBMT06	48° 40.475’	126° 36.875’	Deployment
SO294_16	2022/09/15 12:01:31	OBMT07	48° 42.169’	126° 33.905’	Deployment
SO294_17	2022/09/15 12:37:02	OBMT08	48° 43.487’	126° 31.450’	Deployment
SO294_19	2022/09/17 21:31:53	EM 710 profiling	48° 33.298’	124° 51.414’	Inside critical habitat
SO294_20	2022/09/18 03:22:23	CTD / SVP	48° 30.161’	125° 24.140’	
SO294_21	2022/09/18 07:58:33	OBMT18	49° 01.224’	125° 59.495’	Deployment
SO294_22	2022/09/18 08:36:17	OBMT17	48° 59.531’	126° 02.477’	Deployment
SO294_23	2022/09/18 09:15:11	OBMT16	48° 57.979’	126° 05.374’	Deployment
SO294_24	2022/09/18 09:51:27	OBMT15	48° 56.492’	126° 08.076’	Deployment
SO294_25	2022/09/18 10:32:44	OBMT14	48° 54.655’	126° 11.353’	Deployment
SO294_26	2022/09/18 11:24:43	OBMT13	48° 53.142’	126° 14.117’	Deployment
SO294_27	2022/09/18 12:06:56	OBMT12	48° 50.898’	126° 18.250’	Deployment
SO294_28	2022/09/18 12:54:56	OBMT11	48° 48.312’	126° 22.788’	Deployment
SO294_29	2022/09/18 13:29:02	OBMT10	48° 46.623’	126° 25.771’	Deployment
SO294_30	2022/09/18 14:07:22	OBMT09	48° 44.803’	126° 29.160’	Deployment
SO294_31	2022/09/18 16:38:09	JSCS08	48° 36.379’	126° 40.325’	Deploy and triangulation
SO294_32	2022/09/18 19:20:19	JSCS01	48° 41.484’	126° 47.267’	Deploy and triangulation
SO294_33	2022/09/18 21:55:38	JSCS07	48° 47.001’	126° 53.000’	Deploy and triangulation
SO294_34	2022/09/19 00:12:15	JSCS02	48° 40.264’	126° 55.271’	Deploy and triangulation
SO294_35	2022/09/19 00:30:52	OBP02	48° 40.340’	126° 55.136’	Deploy and triangulation
SO294_36	2022/09/19 02:29:39	BB1	48° 40.302’	126° 51.629’	Deployment
SO294_37	2022/09/19 02:46:01	BB2	48° 39.679’	126° 50.301’	Deployment
SO294_38	2022/09/19 03:02:27	BB3	48° 38.684’	126° 50.808’	Deployment
SO294_39	2022/09/19 03:28:31	BB4	48° 39.444’	126° 51.571’	Deployment
SO294_40	2022/09/19 03:49:14	BB5	48° 39.723’	126° 52.818’	Deployment
SO294_41	2022/09/19 04:05:40	BB6	48° 38.801’	126° 52.407’	Deployment
SO294_42	2022/09/19 15:53:27	OBP01	48° 41.551’	126° 47.148’	Deploy and triangulation
SO294_43	2022/09/19 19:09:11	JSCS03	48° 36.328’	126° 49.658’	Deploy and triangulation
SO294_44	2022/09/19 19:33:32	OBP03	48° 36.384’	126° 49.549’	Deploy and triangulation
SO294_45	2022/09/19 21:19:09	EM profiling	48° 36.722’	126° 49.546’	Transit
SO294_46	2022/09/20 02:41:17	Streamer-Test	48° 01.210’	127° 40.584’	Transit
SO294_47	2022/09/20 06:14:15	OBS P101	47° 44.566’	127° 43.053’	Deployment, OBS CCO2_01
SO294_48	2022/09/20 06:27:41	OBS P102	47° 44.852’	127° 43.837’	Deployment, OBS CCO2_02
SO294_49	2022/09/20 06:37:38	OBS P103	47° 44.920’	127° 44.134’	Deployment, OBS CCO2_03
SO294_50	2022/09/20 06:47:32	OBS P101	47° 45.014’	127° 44.371’	Deployment, OBS CCO2_04
SO294_51	2022/09/20 07:14:42	OBS P105	47° 45.389’	127° 45.410’	Deployment, OBS CCO2_05
SO294_52	2022/09/20 07:24:34	OBS P106	47° 45.489’	127° 45.687’	Deployment, OBS CCO2_06
SO294_53	2022/09/20 07:51:06	OBS P107	47° 45.575’	127° 45.912’	Deployment, OBS CCO2_07
SO294_54	2022/09/20 08:08:48	OBS P108	47° 45.900’	127° 46.888’	Deployment, OBS CCO2_08
SO294_55	2022/09/20 08:15:40	OBS P109	47° 45.974’	127° 47.120’	Deployment, OBS CCO2_09
SO294_56	2022/09/20 08:20:56	OBS P110	47° 46.050’	127° 47.341’	Deployment, OBS CCO2_10
SO294_57	2022/09/20 08:33:33	OBS P111	47° 46.326’	127° 48.122’	Deployment, OBS CCO2_11
SO294_58	2022/09/20 12:10:40	OBS P112	47° 43.936’	127° 46.219’	Deployment, OBS CCO2_12
SO294_59	2022/09/20 12:20:32	OBS P113	47° 44.213’	127° 46.127’	Deployment, OBS CCO2_13
SO294_60	2022/09/20 12:28:26	OBS P114	47° 44.484’	127° 46.040’	Deployment, OBS CCO2_14
SO294_61	2022/09/20 12:45:06	OBS P115	47° 45.222’	127° 45.800’	Deployment, OBS CCO2_15
SO294_62	2022/09/20 13:00:44	OBS P116	47° 45.741’	127° 45.575’	Deployment, OBS CCO2_16

SO294_63	2022/09/20 13:16:00	OBS P117	47° 46.478’	127° 45.342’	Deployment, OBS CCO2_17
SO294_64	2022/09/20 13:24:22	OBS P118	47° 46.749’	127° 45.227’	Deployment, OBS CCO2_18
SO294_65	2022/09/20 16:21:09	OBS P119	47° 46.996’	127° 45.138’	Deployment, OBS CCO2_19
SO294_66	2022/09/20 16:52:04	OBS P120	47° 47.763’	127° 44.886’	Deployment, OBS CCO2_20
SO294_67	2022/09/20 17:21:38	OBS P121	47° 48.522’	127° 44.629’	Deployment, OBS CCO2_21
SO294_68	2022/09/20 17:40:39	OBS P122	47° 49.016’	127° 44.454’	Deployment, OBS CCO2_22
SO294_69	2022/09/20 20:03:37	Airgun array, streamer, PAM	47° 56.022’	127° 39.832’	Seismic survey P1000
SO294_70	2022/09/21 17:55:06	OBS P101	47° 44.487’	127° 43.191’	Recovery
SO294_71	2022/09/21 18:51:40	OBS P102	47° 44.511’	127° 43.053’	Recovery
SO294_72	2022/09/21 19:32:33	OBS P103	47° 44.672’	127° 43.758’	Recovery
SO294_73	2022/09/21 20:43:03	OBS P101	47° 44.820’	127° 44.046’	Recovery
SO294_74	2022/09/21 21:51:54	OBS P105	47° 44.917’	127° 44.385’	Recovery
SO294_75	2022/09/21 22:52:28	OBS P106	47° 45.272’	127° 45.466’	Recovery
SO294_76	2022/09/21 23:44:37	OBS P107	47° 45.412’	127° 45.704’	Recovery
SO294_77	2022/09/22 00:05:56	OBS P108	47° 45.418’	127° 45.719’	Recovery
SO294_78	2022/09/22 02:49:02	OBS P109	47° 45.508’	127° 45.895’	Recovery
SO294_79	2022/09/22 03:34:21	OBS P110	47° 45.914’	127° 47.137’	Recovery
SO294_80	2022/09/22 04:00:20	OBS P111	47° 45.975’	127° 47.365’	Recovery
SO294_81	2022/09/22 05:46:05	OBS P112	47° 43.608’	127° 46.182’	Recovery
SO294_82	2022/09/22 06:48:50	OBS P113	47° 43.830’	127° 46.143’	Recovery
SO294_83	2022/09/22 07:46:44	OBS P114	47° 44.147’	127° 46.073’	Recovery
SO294_84	2022/09/22 08:42:45	OBS P115	47° 44.404’	127° 46.019’	Recovery
SO294_85	2022/09/22 09:38:19	OBS P116	47° 45.126’	127° 45.817’	Recovery
SO294_86	2022/09/22 10:36:58	OBS P117	47° 45.628’	127° 45.627’	Recovery
SO294_87	2022/09/22 11:30:02	OBS P118	47° 46.397’	127° 45.429’	Recovery
SO294_88	2022/09/22 12:21:02	OBS P119	47° 46.674’	127° 45.225’	Recovery
SO294_89	2022/09/22 13:13:19	OBS P120	47° 46.977’	127° 45.088’	Recovery
SO294_90	2022/09/22 14:14:02	OBS P121	47° 47.752’	127° 44.825’	Recovery
SO294_91	2022/09/22 15:05:52	OBS P122	47° 48.486’	127° 44.626’	Recovery
SO294_92	2022/09/22 15:58:00	EM profiling	47° 49.000’	127° 44.435’	Transit
SO294_93	2022/09/23 15:32:42	JSCN11	49° 13.008’	127° 51.536’	Deploy and triangulation
SO294_94	2022/09/23 20:48:47	JSCN09	49° 16.558’	127° 21.378’	Deploy and triangulation
SO294_95	2022/09/23 23:39:45	JSCN10	49° 22.573’	127° 36.998’	Deploy and triangulation
SO294_96	2022/09/24 02:41:19	JSCN08	49° 24.731’	128° 01.805’	Deploy and triangulation
SO294_97	2022/09/24 04:41:05	EM profiling	49° 25.014’	128° 01.845’	Winona Basin
SO294_98	2022/09/24 15:37:15	JSCN07	49° 34.299’	127° 47.190’	Deploy and triangulation
SO294_99	2022/09/24 19:21:54	JSCN05	49° 44.616’	128° 00.593’	Deploy and triangulation
SO294_100	2022/09/24 22:50:48	JSCN06	49° 35.042’	128° 15.281’	Deploy and triangulation
SO294_101	2022/09/24 22:59:40	EM profiling	49° 34.925’	128° 15.083’	Winona Basin
SO294_102	2022/09/25 02:16:54	01GC	49° 37.723’	128° 26.168’	+ SVP
SO294_103	2022/09/25 04:06:33	Profiling	49° 37.691’	128° 26.199’	
SO294_104	2022/09/25 15:38:13	JSCN04	49° 46.816’	128° 25.137’	Deploy and triangulation
SO294_105	2022/09/25 19:25:15	JSCN03	49° 55.121’	128° 10.155’	Deploy and triangulation
SO294_106	2022/09/25 22:40:16	JSCN01	50° 06.021’	128° 22.437’	Deploy and triangulation
SO294_107	2022/09/26 01:10:58	JSCN02	49° 57.256’	128° 38.311’	Deploy and triangulation
SO294_108	2022/09/26 02:30:26	Profiling	49° 57.360’	128° 38.410’	
SO294_109	2022/09/26 15:56:17	02GC	49° 55.115’	128° 37.427’	
SO294_110	2022/09/26 17:58:47	03GC	49° 54.327’	128° 38.836’	+ SVP
SO294_111	2022/09/26 19:57:10	04GC	49° 53.730’	128° 39.934’	
SO294_112	2022/09/26 21:48:34	EM Profiling	49° 53.666’	128° 39.999’	
SO294_113	2022/09/27 17:27:28	OBS P201	49° 33.104’	128° 48.892’	Deployment, OBS_Ex_01
SO294_114	2022/09/27 18:16:27	OBS P202	49° 37.254’	128° 41.780’	Deployment, OBS_Ex_02
SO294_115	2022/09/27 19:01:33	OBS P203	49° 40.722’	128° 35.672’	Deployment, OBS_Ex_03
SO294_116	2022/09/27 19:38:06	OBS P204	49° 43.797’	128° 30.250’	Deployment, OBS_Ex_04
SO294_117	2022/09/27 20:21:25	OBS P205	49° 47.449’	128° 23.780’	Deployment, OBS_Ex_05
SO294_118	2022/09/27 20:41:17	OBS P206	49° 48.631’	128° 21.685’	Deployment, OBS_Ex_06
SO294_119	2022/09/27 21:02:07	OBS P207	49° 50.144’	128° 18.966’	Deployment, OBS_Ex_07
SO294_120	2022/09/27 21:27:18	OBS P208	49° 51.655’	128° 16.389’	Deployment, OBS_Ex_08
SO294_121	2022/09/27 21:46:23	OBS P209	49° 53.078’	128° 13.838’	Deployment, OBS_Ex_09
SO294_122	2022/09/27 22:14:33	OBS P210	49° 55.462’	128° 09.625’	Deployment, OBS_Ex_10
SO294_123	2022/09/27 22:31:34	OBS P211	49° 56.554’	128° 07.674’	Deployment, OBS_Ex_11
SO294_124	2022/09/28 00:51:33	OBS P212	50° 13.482’	128° 20.970’	Deployment, OBS_Ex_12
SO294_125	2022/09/28 01:13:11	OBS P213	50° 12.114’	128° 23.901’	Deployment, OBS_Ex_13
SO294_126	2022/09/28 01:41:52	OBS P214	50° 10.196’	128° 27.880’	Deployment, OBS_Ex_14
SO294_127	2022/09/28 02:09:10	OBS P215	50° 08.297’	128° 31.875’	Deployment, OBS_Ex_15
SO294_128	2022/09/28 02:43:03	OBS P216	50° 05.710’	128° 37.265’	Deployment, OBS_Ex_16
SO294_129	2022/09/28 03:22:36	OBS P217	50° 03.177’	128° 42.577’	Deployment, OBS_Ex_17
SO294_130	2022/09/28 04:08:04	OBS P218	50° 00.091’	128° 48.797’	Deployment, OBS_Ex_18
SO294_131	2022/09/28 04:55:43	OBS P219	49° 56.770’	128° 55.608’	Deployment, OBS_Ex_19
SO294_132	2022/09/28 05:31:00	OBS P220	49° 54.150’	129° 00.928’	Deployment, OBS_Ex_20
SO294_133	2022/09/28 05:40:02	EM Profiling	49° 53.601’	129° 01.515’	
SO294_135	2022/09/28 23:25:23	Airgun array	49° 33.379’	129° 14.653’	Seismic survey P2000/P3000

SO294_136	2022/09/30 21:13:24	GI airgun	49° 56.266’	128° 33.078’	Seismic survey P4000/P5000
SO294_137	2022/10/04 18:27:07	OBS P201	49° 33.546’	128° 49.376’	Recovery
SO294_138	2022/10/04 20:23:24	OBS P202	49° 37.635’	128° 42.242’	Recovery
SO294_139	2022/10/04 22:10:44	OBS P203	49° 41.121’	128° 36.083’	Recovery
SO294_140	2022/10/04 23:47:03	OBS P204	49° 44.204’	128° 30.373’	Recovery
SO294_141	2022/10/05 01:39:34	OBS P205	49° 47.757’	128° 23.823’	Recovery
SO294_142	2022/10/05 03:08:43	EM profiling	49° 47.086’	128° 18.781’	
SO294_143	2022/10/05 15:00:37	OBS P206	49° 48.790’	128° 21.185’	Recovery
SO294_144	2022/10/05 16:01:36	OBS P207	49° 48.398’	128° 21.132’	Recovery
SO294_145	2022/10/05 17:32:30	OBS P208	49° 51.967’	128° 15.979’	Recovery
SO294_146	2022/10/05 19:07:00	OBS P209	49° 53.418’	128° 13.329’	Recovery
SO294_147	2022/10/05 20:43:18	OBS P210	49° 55.552’	128° 10.052’	Recovery
SO294_148	2022/10/05 22:02:13	OBS P211	49° 56.600’	128° 08.094’	Recovery
SO294_149	2022/10/06 01:27:50	OBS P212	50° 13.414’	128° 20.832’	Recovery
SO294_150	2022/10/06 01:54:16	OBS P213	50° 13.477’	128° 20.852’	Recovery
SO294_151	2022/10/06 03:03:40	OBS P214	50° 10.030’	128° 27.578’	Recovery
SO294_152	2022/10/06 04:13:38	OBS P215	50° 08.083’	128° 31.327’	Recovery
SO294_153	2022/10/06 05:39:36	OBS P216	50° 05.268’	128° 36.772’	Recovery
SO294_154	2022/10/06 08:05:35	OBS P217	50° 02.819’	128° 42.520’	Recovery
SO294_155	2022/10/06 10:00:54	OBS P218	49° 59.767’	128° 48.777’	Recovery
SO294_156	2022/10/06 11:33:55	OBS P219	49° 56.623’	128° 55.443’	Recovery
SO294_157	2022/10/06 13:12:03	OBS P220	49° 53.987’	129° 00.802’	Recovery
SO294_158	2022/10/06 14:39:25	Heat-Probe	49° 54.306’	129° 00.608’	T1_01
SO294_159	2022/10/06 17:28:53	Heat-Probe	49° 54.686’	128° 59.840’	T1_02
SO294_160	2022/10/06 18:50:20	Heat-Probe	49° 55.270’	128° 58.774’	T1_03
SO294_161	2022/10/06 20:08:38	Heat-Probe	49° 55.715’	128° 57.653’	T1_04
SO294_162	2022/10/06 21:50:57	Heat-Probe	49° 56.262’	128° 56.467’	T1_05
SO294_163	2022/10/06 23:29:02	Heat-Probe	49° 56.881’	128° 55.223’	T1_06
SO294_164	2022/10/07 01:09:25	Heat-Probe	49° 57.522’	128° 53.934’	T1_07
SO294_165	2022/10/07 03:28:54	Heat-Probe	49° 58.354’	128° 52.388’	T1_08
SO294_166	2022/10/07 04:53:28	Heat-Probe	49° 59.030’	128° 51.025’	T1_09
SO294_167	2022/10/07 06:43:48	Heat-Probe	49° 59.747’	128° 49.564’	T1_10
SO294_168	2022/10/07 08:53:29	Heat-Probe	50° 00.646’	128° 47.698’	T1_11
SO294_169	2022/10/07 11:06:17	Heat-Probe	50° 01.347’	128° 46.022’	T1_12
SO294_170	2022/10/07 13:35:01	Heat-Probe	50° 02.482’	128° 43.657’	T1_13
SO294_171	2022/10/07 15:18:53	Heat-Probe	50° 03.203’	128° 42.367’	T1_14
SO294_172	2022/10/07 18:36:22	Heat-Probe	50° 04.803’	128° 39.125’	T1_15
SO294_173	2022/10/07 22:14:47	05GC	49° 43.830’	128° 29.961’	+ SVP
SO294_174	2022/10/08 00:39:21	06GC	49° 43.287’	128° 31.008’	
SO294_175	2022/10/08 04:00:34	Heat-Probe	49° 52.005’	128° 18.114’	T2_01
SO294_176	2022/10/08 06:32:50	Heat-Probe	49° 51.125’	128° 19.704’	T2_02
SO294_177	2022/10/08 08:42:02	Heat-Probe	49° 50.064’	128° 21.486’	T2_03
SO294_178	2022/10/08 10:47:37	Heat-Probe	49° 49.042’	128° 23.270’	T2_04
SO294_179	2022/10/08 12:28:11	Heat-Probe	49° 48.179’	128° 24.799’	T2_05
SO294_180	2022/10/08 14:14:43	Heat-Probe	49° 47.420’	128° 26.145’	T2_06
SO294_181	2022/10/08 16:01:30	Heat-Probe	49° 46.571’	128° 27.701’	T2_07
SO294_182	2022/10/08 18:10:51	07GC	49° 41.280’	128° 35.084’	
SO294_183	2022/10/08 20:18:56	08GC	49° 40.921’	128° 35.669’	
SO294_184	10/8/2022 22:17	09GC	49° 40.530’	128° 36.394’	
SO294_185	10/9/2022 1:50	Heat-Probe	49° 44.079’	128° 31.914’	T3_01
SO294_186	10/9/2022 4:04	Heat-Probe	49° 43.423’	128° 33.094’	T3_02
SO294_187	10/9/2022 5:57	Heat-Probe	49° 42.609’	128° 34.537’	T3_03
SO294_188	10/9/2022 8:15	Heat-Probe	49° 41.697’	128° 36.220’	T3_04
SO294_189	10/9/2022 9:46	Heat-Probe	49° 41.061’	128° 37.224’	T3_05
SO294_190	10/9/2022 11:25	Heat-Probe	49° 40.269’	128° 38.515’	T3_06
SO294_191	10/9/2022 13:14	Heat-Probe	49° 39.503’	128° 39.880’	T3_07
SO294_192	10/9/2022 17:20	10GC	49° 40.748’	128° 24.278’	
SO294_193	10/9/2022 19:13	11GC	49° 40.976’	128° 24.111’	
SO294_194	10/9/2022 21:10	12GC	49° 40.139’	128° 25.285’	
SO294_195	10/10/2022 18:02	JSCN09	49° 16.842’	127° 21.340’	Triangulation
SO294_196	10/11/2022 19:38	OBS P301	48° 24.805’	127° 04.382’	Deployment, OBS_C_01
SO294_197	10/11/2022 20:09	OBS P302	48° 27.069’	127° 00.415’	Deployment, OBS_C_02
SO294_198	10/11/2022 20:46	OBS P303	48° 29.651’	126° 55.865’	Deployment, OBS_C_03
SO294_199	10/11/2022 21:13	OBS P304	48° 31.500’	126° 52.645’	Deployment, OBS_C_04
SO294_200	10/11/2022 21:42	OBS P305	48° 33.616’	126° 48.832’	Deployment, OBS_C_05
SO294_201	10/11/2022 22:09	OBS P306	48° 35.580’	126° 45.317’	Deployment, OBS_C_06
SO294_202	10/11/2022 22:42	OBS P307	48° 38.090’	126° 40.948’	Deployment, OBS_C_07
SO294_203	10/11/2022 23:08	OBS P308	48° 39.726’	126° 37.981’	Deployment, OBS_C_08
SO294_204	10/11/2022 23:36	OBS P309	48° 41.256’	126° 35.293’	Deployment, OBS_C_09
SO294_205	10/12/2022 0:02	OBS P310	48° 42.683’	126° 32.715’	Deployment, OBS_C_10
SO294_206	10/12/2022 0:26	OBS P311	48° 44.019’	126° 30.310’	Deployment, OBS_C_11
SO294_207	10/12/2022 0:53	OBS P312	48° 45.649’	126° 27.403’	Deployment, OBS_C_12
SO294_208	10/12/2022 15:53	GI gun	48° 57.515’	127° 22.601’	Seismic survey P6000

SO294_209	10/14/2022 22:21	G-Gun array	48° 12.587’	126° 18.930’	Seismic survey P7000
SO294_210	10/16/2022 1:36	OBMT18	49° 01.147’	125° 59.762’	Recovery
SO294_211	10/16/2022 2:18	OBMT17	48° 59.513’	126° 02.666’	Recovery
SO294_212	10/16/2022 3:07	OBMT16	48° 57.759’	126° 05.784’	Recovery
SO294_213	10/16/2022 3:59	OBMT15	48° 56.356’	126° 08.289’	Recovery
SO294_214	10/16/2022 4:55	OBMT14	48° 54.501’	126° 11.551’	Recovery
SO294_215	10/16/2022 5:48	OBMT13	48° 53.028’	126° 14.392’	OBMT did not surface
SO294_216	10/16/2022 8:31	OBMT12	48° 51.011’	126° 18.754’	Recovery
SO294_217	10/16/2022 9:36	OBMT11	48° 48.388’	126° 23.215’	Recovery
SO294_218	10/16/2022 10:36	OBMT10	48° 46.767’	126° 26.212’	Recovery
SO294_219	10/16/2022 11:28	OBS P312	48° 45.783’	126° 27.749’	Recovery
SO294_220	10/16/2022 12:11	OBMT09	48° 44.879’	126° 29.487’	Recovery
SO294_221	10/16/2022 12:56	OBS P311	48° 44.171’	126° 30.551’	Recovery
SO294_222	10/16/2022 13:33	OBMT08	48° 43.620’	126° 31.742’	Recovery
SO294_223	10/16/2022 14:16	OBS P310	48° 42.819’	126° 32.904’	Recovery
SO294_224	10/16/2022 14:52	OBMT07	48° 42.192’	126° 33.988’	Recovery
SO294_225	10/16/2022 15:44	OBS P309	48° 41.634’	126° 35.524’	Recovery
SO294_226	10/16/2022 18:00	SVP / CTD	48° 45.108’	126° 47.516’	
SO294_227	10/16/2022 20:03	OBMT06	48° 40.761’	126° 37.043’	Recovery
SO294_228	10/16/2022 21:25	OBS P308	48° 40.060’	126° 38.190’	Recovery
SO294_229	10/16/2022 22:29	OBMT05	48° 39.237’	126° 39.886’	Recovery
SO294_230	10/16/2022 23:33	OBS P307	48° 38.368’	126° 41.186’	Recovery
SO294_231	10/17/2022 0:30	OBMT04	48° 37.024’	126° 43.277’	Recovery
SO294_232	10/17/2022 1:41	OBS P306	48° 35.785’	126° 45.550’	Recovery
SO294_233	10/17/2022 2:27	OBMT03	48° 35.268’	126° 46.208’	Recovery
SO294_234	10/17/2022 3:41	OBS P305	48° 33.926’	126° 49.182’	Recovery
SO294_235	10/17/2022 4:47	OBMT02	48° 32.624’	126° 51.313’	Recovery
SO294_236	10/17/2022 6:54	OBS P304	48° 31.664’	126° 52.862’	Recovery
SO294_237	10/17/2022 8:15	OBMT01	48° 30.412’	126° 55.419’	Recovery
SO294_238	10/17/2022 9:30	OBS P303	48° 30.273’	126° 54.834’	Recovery
SO294_239	10/17/2022 11:14	OBS P302	48° 27.196’	127° 00.616’	Recovery
SO294_240	10/17/2022 12:42	OBS P301	48° 24.976’	127° 04.614’	Recovery
SO294_241	10/17/2022 20:10	OBMT13	48° 53.257’	126° 14.600’	2nd attempt, not surfaced
SO294_242	10/18/2022 3:02	Heat-Probe	48° 50.223’	127° 28.045’	T4_01
SO294_243	10/18/2022 5:08	Heat-Probe	48° 50.706’	127° 26.843’	T4_02
SO294_244	10/18/2022 6:38	Heat-Probe	48° 51.253’	127° 25.617’	T4_03
SO294_245	10/18/2022 8:32	Heat-Probe	48° 51.878’	127° 24.182’	T4_04
SO294_246	10/18/2022 10:29	Heat-Probe	48° 52.581’	127° 22.636’	T4_05
SO294_247	10/18/2022 11:54	Heat-Probe	48° 53.165’	127° 21.330’	T4_06
SO294_248	10/18/2022 13:23	Heat-Probe	48° 53.645’	127° 20.147’	T4_07
SO294_249	10/18/2022 20:42	OBMT13	48° 53.069’	126° 14.051’	Recovery with OFOS
SO294_250	10/19/2022 15:10	CTD – SVP	48° 24.260’	125° 51.985’	
SO294_251	10/19/2022 15:40	PAM, EM	48° 24.264’	125° 52.080’	Inside critical habitat
SO294_252	10/20/2022 1:34	CTD – SVP	48° 26.046’	126° 00.056’	
SO294_253	10/20/2022 15:06	CTD – SVP	48° 21.510’	125° 47.316’	
SO294_254	10/20/2022 15:37	PAM, EM	48° 21.540’	125° 47.236’	Inside critical habitat

6.2 Seismic profiles

Table 6.2.1 Seismic Profile List (all times in UTC)

Station No. SO294_	Profile	Date 2022	Time SOL	Time EOL	Latitude SOL [N]	Longitude SOL [W]	Latitude EOL [N]	Longitude EOL [W]	FFN Start	FFN End	Remarks
69	P1000	20.09.	23:12	05:00	48°01.30’	127°40.20’	47°34.26’	127°49.71’	1108	1455	Gun Array, 60s
69	P1001	21.09.	05:20	08:15	47°33.54’	127°48.40’	47°39.01’	127°29.78’	1475	1651	Gun Array, 60s
69	P1002	21.09.	08:30	13:30	47°50.91’	128°01.52’	47°39.91’	127°29.73’	1665	1966	Gun Array, 60s
135	P2000	29.09.	02:41	13:15	49°26.25’	129°00.66’	49°55.85’	128°08.78’	3131	3765	Gun Array, 60s
135	P2001	29.09.	13:30	17:56	49°56.93’	128°08.20’	50°03.07’	128°14.71’	3780	4046	Gun Array, 60s
135	P2002	29.09.	18:15	05:30	50°14.28’	128°19.15’	49°52.10’	129°05.35’	4065	4740	Gun Array, 60s
135	P2002	29.09.	01:40	04:19	49°54.86’	128°59.41’	49°55.10’	128°59.08’	4197	4669	Gun Array, 60s
135	P3000	30.09.	05:47	07:45	49°52.73’	129°06.43’	50°01.00’	129°02.11’	5007	5244	Gun Array, 30s
135	P3001	30.09.	08:15	15:53	50°01.00’	128°59.96’	49°40.32’	128°19.81’	5304	6220	Gun Array, 30s
135	P3002	30.09.	16:45	20:00	49°43.06’	128° 18.72’	49°53.21’	128°31.09’	6323	6714	Gun Array, 30s
136	P4001	30.09.	22:24	00:52	49°59.88’	128°38.21’	50°07.48’	128°49.90’	7375	8604	GI Gun, 10 s
136	P4002	01.10.	01:02	04:11	50°07.52’	128°51.06’	49°59.70’	129°06.98’	8672	9805	GI Gun, 10 s
136	P4003	01.10.	05:13	10:55	50°02.51’	129°10.28’	50°17.36’	128°38.91’	10175	12226	GI Gun, 10 s
136	P4004	01.10.	11:12	12:13	50°16.96’	128°37.18’	50°14.01’	128°32.29’	12325	12696	GI Gun, 10 s
136	P4005	01.10.	12:28	19:47	50°12.68’	128°32.61’	49°53.36’	129°12.01’	12783	15420	GI Gun, 10 s
136	P4005	01.10.	15:21	16:05	50°04.50’	128°49.24’	50°02.56’	128°53.19’	13823	14090	shut down, no repeat
136	P4006	01.10.	21:45	04:38	49°52.03’	129°04.74’	50°09.88’	128°27.37’	16124	18604	GI Gun, 10 s
136	P4007	02.10.	04:50	06:51	50°09.83’	128° 26.13’	50°03.86’	128°19.84’	18678	19404	GI Gun, 10 s
136	P4008	02.10.	07:12	13:13	50°02.72’	128°20.59’	49°45.72’	128°53.08’	19540	21697	GI Gun, 10 s
136	P4008	02.10.	11:03	11:43	49°51.76’	128°41.54’	49°50.00’	128 44.89’	20915	21157	Gap, repeat P5018
136	P4008	02.10.	12:42	13:11	49°47.22”	128°50.24’	49°45.84’	128°52.87’	21511	21682	shut down, repeat P5018
136	P4009	02.10.	13:23	14:28	49°44.97'	128°53.15’	49°41.36’	128°47.84’	21757	22147	GI Gun, 10 s
136	P4010	02.10.	14:39	20:42	49°41.23’	128°45.80’	49°57.55’	128°18.10’	22212	24383	GI Gun, 10 s
136	P4011	02.10.	20:53	21:45	49°57.56’	128°16.84’	49°54.23’	128°13.33’	24455	24764	GI Gun, 10 s
136	P4012	02.10.	21:56	04:00	49°53.49’	128°13.47’	49°36.12’	128°43.13’	24834	27014	GI Gun, 10 s
136	P5013	03.10.	04:23	08:06	49°34.33’	128°43.67’	49°34.61’	128°19.01’	29087	30424	GI Gun, 10 s
136	P5014	03.10.	08:19	11:48	49°35.06’	128°18.19’	49°48.45’	128°16.66’	30502	31759	GI Gun, 10 s
136	P5014	03.10.	11:05	11:31	49°45.62’	128°16.98’	49°47.30’	128°16.79’	31498	31650	shut down, no repeat
136	P5015	03.10.	11:56	11:49	49°48.89’	128°16.87’	49°48,45’	128°16.66’	31803	31759	GI Gun, 10 s
136	P5015	03.10.	14:55	15:35	49°57.37’	128°28.47’	49°59.27’	128°31.12’	32882	33119	shut down, no repeat
136	P5016	03.10.	16:23	20:50	50°01.12’	128°34.862’	49°47.86’	129°00.86’	33407	35009	GI Gun, 10 s
136	P5017	03.10.	21:13	21:58	49°46.69’	129°00.260’	49°45.10’	128°55.06’	35142	35414	GI Gun, 10 s
136	P5018	03.10.	22:05	03:40	49°45.28’	128°54.085’	49°54.26’	128°36.86’	35458	37471	GI Gun, 10 s
136	P5018	04.10.	00:06	02:17	49°51.68’	128°41.82’	49°50.03’	128°44.92’	36184	36970	shut down, repeat
136	P5019	04.10.	04:18	05:11	49°52.70’	128°33.54’	49°48.64’	128°35.69’	37695	38021	GI Gun, 10 s
136	P5020	04.10.	05:22	06:10	49°48.19’	128°36.53’	49°48.38’	128°41.89’	38080	38368	GI Gun, 10 s
136	P5021	04.10.	06:17	07:55	49°48.27’	128°42.67’	49°43.47’	128°51.62’	38410	38996	GI Gun, 10 s
136	P5022	04.10.	08:10	09:00	49°42.49’	128°51.66’	49°40.47’	128°45.85’	39085	39385	GI Gun, 10 s
136	P5023	04.10.	09:09	12:12	49°40.47’	128°44.74’	49°48.16’	128°26.20’	39439	40537	GI Gun, 10 s
136	P5024	04.10.	12:24	13:19	49°48.13’	128°24.84’	49°44.59’	128°20.27’	40618	40939	GI Gun, 10 s
136	P5025	04.10.	13:30	15:30	49°43.78’	128°20.25’	49°37.47’	128°28.98’	41006	41661	GI Gun, 10 s
136	P5025	04.10.	13:35	15:30	49°43.47’	128°20.67’	49°37.47’	128°28.98’	41038	41545	shut down, no repeat
208	P6000	12.10.	17:03	17:37	49°01.43’	127°26.71’	49°03.78’	127°28.29’	43188	43382	GI Gun, 10 s
208	P6001	12.10.	17:48	20:17	49°04.16’	127°29.33’	49°01.50’	127°43.52’	43452	44343	GI Gun, 10 s
208	P6002	12.10.	21:21	23:30	48°57.62’	127°42.24’	48°59.15’	127°28.05’	44700	45506	GI Gun, 10 s
208	P6003	12.10.	00:11	02:49	48°56.49’	127°26.52‘	48°50.03‘	127°42.83’	45749	46702	GI Gun, 10 s

208	P6004	13.10.	04:10	07:25	48°45.92’	127°37.84‘	48°45.10’	127°19.20’	47187	48354	GI Gun, 10 s
208	P6005	13.10.	08:26	11:22	48°50.97’	127°17.31’	48°39.08’	127!26.15’	48717	49777	GI Gun, 10 s
208	P6006	13.10.	12:00	14:14	48°37.61’	127°22.89’	48°41.16’	127°08.16’	50003	50808	GI Gun, 10 s
208	P6007	13.10.	14:57	17:04	48°42.27’	127°09.66’	48°33.54’	127°14.04’	51067	51803	GI Gun, 10 s
208	P6008	13.10.	18:07	20:16	48°30.70’	127°09.15’	48°36.41’	126°57.37’	52206	52984	GI Gun, 10 s
208	P6009	13.10.	21:28	00:34	48°32.66’	126°51.78’	48°19.66’	126°58.85’	53417	54532	GI Gun, 10 s
208	P6010	14.10.	01:27	05:10	48°20.99’	127°02.33’	48°30.70’	126°43.51’	54848	56186	GI Gun, 10 s
208	P6011	14.10.	06:09	08:25	48°28.57’	126°38.98’	48°22.06’	126°51.70’	56541	57354	GI Gun, 10 s
208	P6012	14.10.	09:25	12:15	48°18.84’	126°48.70’	48°20.39’	126°31.13’	57715	58734	GI Gun, 10 s
208	P6013	14.10.	13:01	16:00	48°17.51’	126°28.54’	48°04.63’	126°37.40’	59015	60084	GI Gun, 10 s
208	P6014	14.10.	16:49	17:55	48°05.52’	126°41.61’	48°10.15’	126°39.75’	60361	60786	GI Gun, 10 s
208	P6015	14.10.	18:38	21:23	48°11.13’	126°35.61’	48°10.31’	126°18.28’	61035	62024	GI Gun, 10 s
209	P7000	15.10.	01:15	08:30	48°23.57’	126°27.76’	48°13.98’	127°14.10’	64716	65585	Gun Array, 30s
209	P7001	15.10.	09:33	16:50	48°17.25’	127°17.41’	48°37.84’	126°41.16’	65711	66586	Gun Array, 30s
209	P7002	15.10.	18:39	22:30	48°37.05’	126°42.42’	48°47.95’	126°23.27’	67141	67600	Down to five guns from FFN 67314

6.3 Gravity Coring

Table 6.3.1 Sample Station List of gravity cores taken

Station No.	Sample Station	Date 2022	Time [UTC]	Latitude [N]	Longitude [W]	Water Depth [m]	Pore water Y/N	Total length recovered [cm]	Number of sections
SO294_102	01GC	9/25	02:15	49° 37.69’	128° 26.12’	2305	Y	498	5
SO294_109	02GC	9/26	15:56	49° 55.07’	128° 37.46’	2041	Y	494	5
SO294_110	03GC	9/26	17:58	49° 54.28’	128° 38.85’	2036	N	145	2
SO294_111	04GC	9/26	19:57	49° 53.67’	128° 39.99’	1869	Y	300	3
SO294_173	05GC	10/07	22:14	49° 43.83’	128° 30.04’	2273	Y	506	5
SO294_174	06GC	10/08	00:39	49° 43.29’	128° 30.99’	2272	Y	449	5
SO294_182	07GC	10/08	18:10	49° 41.26’	128° 35.16’	2313	Y	252	4
SO294_183	08GC	10/08	20:18	49° 40.91’	128° 35.82’	2317	Y	500	5
SO294_184	09GC	10/08	22:17	49° 40.53’	128° 36.50’	2327	Y	500	5
SO294_192	10GC	10/09	17:20	49° 40.77’	128° 24.47’	2237	Y	367	4
SO294_193	11GC	10/09	19:13	49° 40.95’	128° 24.19’	2239	Y	500	5
SO294_194	12GC	10/09	21:10	49° 40.15’	128° 25.39’	2214	N	161	2

6.4 Heat-Probe station lists and protocols

Table 6.4.1 Deployment T1

Station-No.	Latitude (N)	Longitude (W)	Water Depth (m)	Time in [hh:mm:ss]	Time out [hh:mm:ss]	Wire out [m]	Pull-out (kN)	File
SO294_158	49° 54.519’	129° 00.620’	2289	15:46:40	16:03:20	2300	62	T1_01
SO294_159	49° 54.702’	128° 59.717’	2254	17:32:00	17:49:00	2262	54	T1_02
SO294_160	49° 55.253’	128° 58.723’	1875	18:54:30	19:13:19	1893	56	T1_03
SO294_161	49° 55.705’	128° 57.654’	2073	20:20:30	20:38:00	2075	64	T1_04
SO294_162	49° 56.302’	128° 56.391’	2230	22:05:50	22:24:00	2240	63	T1_05
SO294_163	49° 56.885’	128° 55.153’	2264	23:44:30	00:02:00	2275	62.5	T1_06
SO294_164	49° 57.496’	128° 53.920’	2272	01:24:00	01:40:30	2292	61.5	T1_07
SO294_165	49° 58.353’	128° 52.321’	1986	03:32:50	03:51:40	1994	64	T1_08
SO294_166	49° 59.006’	128° 50.970’	1643	05:00:15	05:16:50	1645	52	T1_09
SO294_167	49° 59.760’	128° 49.495’	2033	06:55:00	07:13:00	2047	56	T1_10
SO294_168	50° 00.655’	128° 47.623’	2066	09:18:33	09:36:04	2074	57	T1_11
SO294_169	50° 01.360’	128° 45.941’	2054	11:30:45	11:48:50	2070	58	T1_12
SO294_170	50° 02.494’	128° 43.599’	1654	13:50:00	14:06:30	1641	49	T1_13
SO294_171	50° 03.211’	128° 42.310’	1732	15:28:10	15:46:00	1734	54	T1_14
SO294_172	50° 04.815’	128° 39.044’	1724	18:40:00	18:57:00	1732	54	T1_15

Table 6.4.2 Deployment T2

Station-No.	Latitude (N)	Longitude (W)	Water Depth (m)	Time in [hh:mm:ss]	Time out [hh:mm:ss]	Wire out [m]	Pull-out (kN)	File
SO294_175	49° 52.018’	128° 18.102’	2073	04:44:55	05:03:00	2081	63	T2_01
SO294_176	49° 51.199’	128° 19.515’	2095	06:35:30	06:53:00	2117	63	T2_02
SO294_177	49° 50.108’	128° 21.332’	2106	08:44:00	09:01:30	2120	64	T2_03
SO294_178	49° 49.067’	128° 23.099’	2125	10:52:16	11:09:10	2142	59	T2_04
SO294_179	49° 48.192’	128° 24.691’	2130	12:43:45	13:01:00	2143	59	T2_05
SO294_180	49° 47.446’	128° 26.026’	2030	14:27:45	14:44:15	2050	65	T2_06
SO294_181	49° 46.481’	128° 27.764’	1530	16:21:30	16:31:45	n.a.	n.a.	T2_07

Table 6.4.3 Deployment T3

Station-No.	Latitude (N)	Longitude (W)	Water Depth (m)	Time in [hh:mm:ss]	Time out [hh:mm:ss]	Wire out [m]	Pull-out (kN)	File
SO294_185	49° 44.125’	128° 31.831’	2280	02:38:20	02:55:00	2291	63	T3_01
SO294_186	49° 43.450’	128° 32.969’	2277	04:19:00	04:35:45	2294	64	T3_02
SO294_187	49° 42.648’	128° 34.394’	2214	06:10:30	06:27:00	2220	61	T3_03
SO294_188	49° 41.717’	128° 36.082’	2324	08:19:00	08:39:00	2335	67	T3_04
SO294_189	49° 41.102’	128° 37.071’	2326	09:48:30	10:06:00	2347	65	T3_05
SO294_190	49° 40.282’	128° 38.415’	2330	11:40:54	11:57:27	2348	61	T3_06
SO294_191	49° 39.517’	128° 39.779’	2330	13:31:20	13:47:50	2348	63	T3_07

Table 6.4.4 Deployment T4

Station-No.	Latitude (N)	Longitude (W)	Water Depth (m)	Time in [hh:mm:ss]	Time out [hh:mm:ss]	Wire out [m]	Pull-out (kN)	File
SO294_242	48° 50.176’	127° 28.093’	2270	03:53:30	04:10:00	2286	54	T4_01
SO294_243	48° 50.669’	127° 26.950’	2286	05:23:20	05:40:00	2286	55	T4_02
SO294_244	48° 51.223’	127° 25.694’	2053	06:51:00	07:07:30	2069	62	T4_03
SO294_245	48° 51.885’	127° 24.181’	2092	08:36:00	08:53:20	2110	53	T4_04
SO294_246	48° 52.566’	127° 22.649’	2081	10:33:05	10:50:10	2098	47	T4_05
SO294_247	48° 53.182’	127° 21.269’	2083	12:09:30	12:27:00	2098	55	T4_06
SO294_248	48° 53.611’	127° 20.189’	2069	13:36:40	13:54:20	2087	58	T4_07

7 Data and Sample Storage and Availability

The metadata of the onboard DSHIP-System is collected made publicly available through the Kiel Data Management Team (KDMT), which provides an information and data archival system. This Ocean Science Information System (OSIS-Kiel) is accessible for all project participants and can be used to share and edit field information and to provide scientific data, as they become available. The central system OSIS is providing information on granted ship time with information on the scientific program and the general details down to the availability of data files from already concluded cruises. The transparency on the research activities is regarded as an invitation to external scientists to start communication on collaboration on behalf of the newly available data. The KDMT will take care as data curators to fulfill the here proposed data publication of the data in a World Data Center (e.g. PANGAEA) which will then provide long-term archival and access to the data. The data publication process will be based on the available files in OSIS and is therefore transparent to all reviewers and scientists. This cooperation with a world data center will make the data globally searchable, and links to the data owners will provide points of contact to project-external scientists. The seismic, bathymetric and hydro-acoustic raw data and video footage as well as processed seismic data will be archived on a dedicated server at GEOMAR, which is daily backed up and which holds all data since the founding days of GEOMAR. OSIS provides contact information for these large data files.
Availability of metadata in OSIS-Kiel (portal.geomar.de/osis): 2 weeks after the cruise
Availability of data in OSIS-Kiel (portal.geomar.de/osis): 6 months after the cruise
Availability of data in a WDC/PANGAEA (www.pangaea.de): 5 years after the cruise
All hydroacoustic data collected during SO294 are stored in facilities of GEOMAR Helmholtz Center for Ocean Research Kiel (responsible Dr. M. Riedel). Multibeam field data are stored at the bathymetric data center of the Bundesamt für Seeschiffahrt und Hydrografie (BSH).

Table 7.1 Overview of data availability

Type	**Database**	**Available**	**Free Access**	**Contact**
Ship‘s Metadata	BSH, OSIS-Kiel	November 2022	November 2022	info@pangaea.de
PARASOUND	GEOMAR	November 2022	November 2027	mriedel@geomar.de
Multibeam	BSH, PANGAEA	November 2022	November 2027	mriedel@geomar.de
OBS Data	GEOMAR	November 2022	November 2027	mriedel@geomar.de
MCS Data	GEOMAR	November 2022	November 2027	mriedel@geomar.de

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10 Abbreviations

APG	Absolute pressure gauge
BSR	Bottom Simulating Reflector
CAU	Christian Albrecht´s Universität Kiel / University Kiel
DF	Deformation front
DFO	Fisheries and Ocean Canada
EZ	Exclusion Zone
GI gun	Generator-Injector airgun
GPS	GlobalPositioning System
GSC	Geological Survey of Canada
GC	Gravity Core
JdF	Juan de Fuca
LOBSTER	Long-term Ocean Bottom Seismometer for Tsunami and Earthquake Research
MCS	Multichannel Seismic
MMO	Marine Mammal Observer
NTC	Nuu-Chah-Nulth Tribal council
NOB	National Observatory Brazil
OBEM	Ocean Bottom Electromagnetic receivers
OBMT	Ocean Bottom Magnetotelluric
OBS	Ocean Bottom Seismometer
OBP	Ocean Bottom Pressure sensor
OFOS	Ocean Floor Observatory System
ONC	Ocean Networks Canada
OSIS	Ocean Science Information System
PAM	Passive acoustic monitoring
PDT	Pacific Daylight time (local time used onboard)
RU	Remote Unit
VLFE	Very-low frequency earthquakes
VHF	Very-high frequency

11 Appendices

11.1 Gravity core rhizone sampling

Station SO294_102_01GC

Sample-No.	Core Section	Depth in section [cm]	Depth in core [cm bsf]	Date/Time Rhizone in	Date/Time Rhizone out	Pore-fluid recovered [ml]	Remarks
1	1	30	468	2022-09-24 22:10 PDT	2022-09-25 09:50 PDT	1.5	Replaced at 12:35
2	1	60	438	22:12	09:52	21	
3	1	90	408	22:14	09:54	22	
4	2	30	368	22:21	09:55	20	
5	2	58	340	22:21	-	-	Replaced at 08:30
6	2	90	308	22:21	10:00	5	
7	3	30	268	22:18	10:02	22	
8	3	60	238	22:22	10:03	22	
9	3	90	208	22:23	10:03	8	
10	4	30	168	22:24	-	-	
11	4	60	138	22:25	10:00	20	
12	4	90	108	22:24	10:00	1.5	
13	5	30	68	22:28	10:00	20	
14	5	60	38	22:28	10:00	21	
15	5	90	8	22:28	10:00	5	

Station SO294_109_02GC

Sample-No.	Core Section	Depth in section [cm]	Depth in core [cm bsf]	Date/Time Rhizone in	Date/Time Rhizone out	Pore-fluid recovered [ml]	Remarks
1	1	40	454	2022-09-26 16:30 PDT	2022-09-27 08:30 PDT	6	
2	1	80	414	16:30	08:30	21	
3	2	40	354	16:30	08:30	4	
4	2	80	314	16:30	08:30	20	
5	3	40	254	16:30	08:30	20	
6	3	80	214	16:30	08:30	22	
7	4	40	154	16:30	08:30	~1	Directly to ICP
8	4	80	114	16:30	08:30	6	Rhizone still in core
9	5	40	54	16:30	08:30	0.5	Directly to ICP
10	5	80	14	16:30	08:30	0	

Station SO294_111_04GC

Sample-No.	Core Section	Depth in section [cm]	Depth in core [cm bsf]	Date/Time Rhizone in	Date/Time Rhizone out	Pore-fluid recovered [ml]	Remarks
1	1	40	260	2022-09-26 17:00 PDT	2022-09-27 08:30 PDT	7	
2	1	80	220	17:00	08:35	5	
3	2	40	160	17:00	08:35	3	
4	2	80	120	17:00	08:35	20	
5	3	40	60	17:00	08:35	0.5	Directly to ICP
6	3	80	20	17:00	08:35	17	

Station SO294_173_05GC

Sample-No.	Core Section	Depth in section [cm]	Depth in core [cm bsf]	Date/Time Rhizone in	Date/Time Rhizone out	Pore-fluid recovered [ml]
1	1	30	476	2022-10-07 19:00 PDT	2022-10-08 07:50 PDT	22
2	1	60	446	19:00	07:50	18
3	1	90	416	19:00	07:55	20
4	2	30	376	19:00	08:00	11
5	2	60	346	19:00	08:00	9
6	2	90	316	19:00	08:00	21
7	3	30	276	19:00	08:05	21
8	3	60	246	19:00	08:05	22
9	3	90	216	19:00	08:05	22
10	4	30	176	19:00	08:10	14
11	4	60	146	19:00	08:10	22
12	4	90	116	19:00	08:10	14
13	5	30	76	19:00	08:05	22
14	5	60	46	19:00	08:05	22
15	5	90	16	19:00	08:05	22

Station SO294_174_06GC

Sample-No.	Core Section	Depth in section [cm]	Depth in core [cm bsf]	Date/Time Rhizone in	Date/Time Rhizone out	Pore-fluid recovered [ml]	Remarks
1	1	30	419	2022-10-07 20:45 PDT	2022-10-08 08:40 PDT	21	Section 1 is shorter: 89 cm
2	1	60	389	20:45	08:40	3	53 cm missing between Section 1 - 2
3	2	30	330	20:45	08:40	9	Section 2 is shorter: 58 cm
4	3	30	272	20:45	08:40	0	
5	3	60	242	20:45	08:42	7	
6	3	90	212	20:45	08:43	16	
7	4	30	172	20:45	08:40	0	
8	4	60	142	20:45	08:43	0	
9	4	90	112	20:45	08:44	13	
10	5	30	72	20:45	08:45	16	
11	5	60	42	20:45	08:45	21	
12	5	90	12	20:45	08:45	1	

Station SO294_182_07GC

Sample-No.	Core Section	Depth in section [cm]	Depth in core [cm bsf]	Date/Time Rhizone in	Date/Time Rhizone out	Pore-fluid recovered [ml]	Remarks
1	1	10	242	2022-10-08 14:02 PDT	2022-10-09 07:42 PDT	5	Section length ~ 22 cm
2	2	30	200	14:02	07:42	21	
3	2	60	170	14:02	07:42	1	Added direct to small vial
4	2	90	140	14:02	07:42	2	Added direct to small vial
5	3	30	100	14:02	07:42	17	
6	3	60	70	14:02	07:42	12	
7	3	90	40	14:02	07:42	20	
8	4	15	15	14:02	07:42	2	Section length: 30 cm

Station SO294_183_08GC

Sample-No.	Core Section	Depth in section [cm]	Depth in core [cm bsf]	Date/Time Rhizone in	Date/Time Rhizone out	Pore-fluid recovered [ml]
1	1	30	470	2022-10-08 16:27 PDT	2022-10-09 08:00 PDT	1
2	1	60	440	16:27	08:00	3
3	1	90	410	16:27	08:00	0
4	2	30	370	16:30	08:00	2
5	2	60	340	16:30	08:00	22
6	2	90	310	16:30	08:00	18
7	3	30	270	16:28	08:00	21
8	3	60	240	16:28	08:00	17
9	3	90	210	16:28	08:00	17
10	4	30	170	16:32	08:00	15
11	4	60	140	16:32	08:00	21
12	4	90	110	16:32	08:00	5
13	5	30	70	16:35	08:00	5
14	5	60	40	16:35	08:00	18
15	5	90	10	16:35	08:00	21

Station SO294_184_09GC

Sample-No.	Core Section	Depth in section [cm]	Depth in core [cm bsf]	Date/Time Rhizone in	Date/Time Rhizone out	Pore-fluid recovered [ml]
1	1	30	470	2022-10-08 18:45 PDT	2022-10-09 08:08 PDT	21
2	1	60	440	18:45	08:08	15
3	1	90	410	18:45	08:08	1
4	2	30	370	18:45	08:08	21
5	2	60	340	18:45	08:08	22
6	2	90	310	18:45	08:08	7
7	3	30	270	18:45	08:08	22
8	3	60	240	18:45	08:08	8
9	3	90	210	18:45	08:08	18
10	4	30	170	18:45	08:08	10
11	4	60	140	18:45	08:08	22
12	4	90	110	18:45	08:08	15
13	5	30	70	18:45	08:08	2
14	5	60	40	18:45	08:08	14
15	5	90	10	18:45	08:08	4

Station SO294_192_10GC

Sample-No.	Core Section	Depth in section [cm]	Depth in core [cm bsf]	Date/Time Rhizone in	Date/Time Rhizone out	Pore-fluid recovered [ml]
1	1	30	337	2022-10-09 13:20 PDT	2022-10-10 11:15 PDT	20
2	1	60	307	13:20	11:15	20
3	1	90	277	13:20	11:15	0
4	2	30	237	13:20	11:20	4
5	2	60	207	13:20	11:20	20
6	2	90	177	13:20	11:20	22
7	3	30	137	13:20	11:20	3
8	3	60	107	13:20	11:20	2
9	3	90	77	13:20	11:20	15
10	4	20	47	13:20	11:20	8
11	4	40	27	13:20	11:20	3

Station SO294_193_11GC

Sample-No.	Core Section	Depth in section [cm]	Depth in core [cm bsf]	Date/Time Rhizone in	Date/Time Rhizone out	Pore-fluid recovered [ml]
1	1	30	470	2022-10-09 16:30 PDT	2022-10-10 13:52 PDT	17
2	1	60	440	16:30	13:52	22
3	1	90	410	16:30	13:52	16
4	2	30	370	16:30	13:52	20
5	2	60	340	16:30	13:52	19
6	2	90	310	16:30	13:52	19
7	3	30	270	16:30	13:52	3
8	3	60	240	16:30	13:52	20
9	3	90	210	16:30	13:52	2
10	4	30	170	16:30	13:52	17
11	4	60	140	16:30	13:52	20
12	4	90	110	16:30	13:52	16
13	5	30	70	16:30	13:52	20
14	5	60	40	16:30	13:52	9
15	5	90	10	16:30	13:52	21

11.2 Pore-fluid sub-sampling

Station SO294_102_01GC

Sample-No.	Core section	Depth in section [cm]	Depth in core [cm bsf]	Pore fluid recovered [ml]	ICP-Sample [ml]	Acid added [µl]	Nutrient-sample [ml]
1	1	30	468	1.5	1.5	15	0
2	1	60	438	21	2	20	19
3	1	90	408	22	2	20	20
4	2	30	368	20	2	20	18
5	2	58	340	-	-	-	-
6	2	90	308	5	2	20	3
7	3	30	268	22	2	20	20
8	3	60	238	22	2	20	20
9	3	90	208	8	2	20	6
10	4	30	168	1	1	10	0
11	4	60	138	20	2	20	18
12	4	90	108	1.5	1.5	15	0
13	5	30	68	20	2	20	18
14	5	60	38	21	2	20	19
15	5	90	8	5	2	20	3

Station SO294_109_02GC

Sample-No.	Core section	Depth in section [cm]	Depth in core [cm bsf]	Pore fluid recovered [ml]	ICP-Sample [ml]	Acid added [µl]	Nutrient-sample [ml]
1	1	40	454	6	2	20	4
2	1	80	414	21	2	20	19
3	2	40	354	4	2	20	2
4	2	80	314	20	2	20	18
5	3	40	254	20	2	20	18
6	3	80	214	22	2	20	20
7	4	40	154	~1	~1	10	0
8	4	80	114	6	2	20	4
9	5	40	54	0.5	0.5	7	0
10	5	80	14	0	0	0	0

Station SO294_111_04GC

Sample-No.	Core section	Depth in section [cm]	Depth in core [cm bsf]	Pore fluid recovered [ml]	ICP-Sample [ml]	-Acid added [µl]	Nutrient-sample [ml]
1	1	40	260	7	2	20	5
2	1	80	220	5	2	20	3
3	2	40	160	3	1.5	15	1.5
4	2	80	120	20	2	20	18
5	3	40	60	0.5	0.5	7	0
6	3	80	20	17	2	20	15

Station SO294_173_05GC

Sample-No.	Core section	Depth in section [cm]	Depth in core [cm bsf]	Pore fluid recovered [ml]	ICP-Sample [ml]	Acid added [µl]	Nutrient-sample [ml]
1	1	30	476	22	2	20	20
2	1	60	446	18	2	20	16
3	1	90	416	20	2	20	18
4	2	30	376	11	2	20	9
5	2	60	346	9	2	20	7
6	2	90	316	21	2	20	19
7	3	30	276	21	2	20	19
8	3	60	246	22	2	20	20
9	3	90	216	22	2	20	20
10	4	30	176	14	2	20	12
11	4	60	146	22	2	20	20
12	4	90	116	14	2	20	12
13	5	30	76	22	2	20	20
14	5	60	46	22	2	20	20
15	5	90	16	22	2	20	20

Station SO294_174_06GC

Sample-No.	Core section	Depth in section [cm]	Depth in core [cm bsf]	Pore fluid recovered [ml]	ICP-Sample [ml]	Acid added [µl]	Nutrient-sample [ml]
1	1	30	419	21	2	20	19
2	1	60	389	3	2	20	0
3	1	90	330	9	2	20	7
4	2	30	272	0	-	-	-
5	2	60	242	7	2	20	5
6	2	90	212	16	2	20	14
7	3	30	172	0	-	-	-
8	3	60	142	0	-	-	-
9	3	90	112	13	2	20	11
10	4	30	72	16	2	20	14
11	4	60	42	21	2	20	19
12	4	90	12	1	1	10	0

Station SO294_182_07GC

Sample-No.	Core section	Depth in section [cm]	Depth in core [cm bsf]	Pore fluid recovered [ml]	ICP-Sample [ml]	Acid added [µl]	Nutrient-sample [ml]
1	1	10	242	5	2	20	3
2	2	30	200	21	2	20	19
3	2	60	170	1	1	10	0
4	2	90	140	2	2	20	0
5	3	30	100	17	2	20	15
6	3	60	70	12	2	20	10
7	3	90	40	20	2	20	18
8	4	15	15	2	2	20	0

Station SO294_183_08GC

Sample-No.	Core section	Depth in section [cm]	Depth in core [cm bsf]	Pore fluid recovered [ml]	ICP-Sample [ml]	Acid added [µl]	Nutrient-sample [ml]
1	1	30	470	1	1	10	0
2	1	60	440	3	2	20	1
3	1	90	410	0	0	0	0
4	2	30	370	2	1	10	1
5	2	60	340	22	2	20	20
6	2	90	310	18	2	20	16
7	3	30	270	21	2	20	19
8	3	60	240	17	2	20	15
9	3	90	210	17	2	20	15
10	4	30	170	15	2	20	13
11	4	60	140	21	2	20	19
12	4	90	110	5	2	20	3
13	5	30	70	5	2	20	3
14	5	60	40	18	2	20	16
15	5	90	10	21	2	20	19

Station SO294_184_09GC

Sample-No.	Core section	Depth in section [cm]	Depth in core [cm bsf]	Pore fluid recovered [ml]	ICP-Sample [ml]	Acid added [µl]	Nutrient-sample [ml]
1	1	30	470	21	2	20	19
2	1	60	440	15	2	20	13
3	1	90	410	1	1	10	0
4	2	30	370	21	2	20	19
5	2	60	340	22	2	20	20
6	2	90	310	7	2	20	5
7	3	30	270	22	2	20	20
8	3	60	240	8	2	20	6
9	3	90	210	18	2	20	16
10	4	30	170	10	2	20	8
11	4	60	140	22	2	20	20
12	4	90	110	15	2	20	13
13	5	30	70	2	1	10	1
14	5	60	40	14	2	20	12
15	5	90	10	4	2	20	2

Station SO294_192_10GC

Sample-No.	Core section	Depth in section [cm]	Depth in core [cm bsf]	Pore fluid recovered [ml]	ICP-Sample [ml]	Acid added [µl]	Nutrient-sample [ml]
1	1	30	337	20	2	20	18
2	1	60	307	20	2	20	18
3	1	90	277	0	0	0	0
4	2	30	237	4	2	20	2
5	2	60	207	20	2	20	18
6	2	90	177	22	2	20	20
7	3	30	137	3	1	10	2
8	3	60	107	2	1	10	0
9	3	90	77	15	2	20	13
10	4	20	47	8	2	20	6
11	4	40	27	3	1	10	2

Station SO294_193_11GC

Sample-No.	Core section	Depth in section [cm]	Depth in core [cm bsf]	Pore fluid recovered [ml]	ICP-Sample [ml]	Acid added [µl]	Nutrient-sample [ml]
1	1	30	470	17	2	20	15
2	1	60	440	22	2	20	20
3	1	90	410	16	2	20	14
4	2	30	370	20	2	20	18
5	2	60	340	19	2	20	17
6	2	90	310	19	2	20	17
7	3	30	270	3	1	10	2
8	3	60	240	20	2	20	18
9	3	90	210	2	1	10	1
10	4	30	170	17	2	20	15
11	4	60	140	20	2	20	18
12	4	90	110	16	2	20	14
13	5	30	70	20	2	20	18
14	5	60	40	9	2	20	7
15	5	90	10	21	2	20	19

11.3 Marine Mammal Observation reports

WEEK ONE REPORT

13-19 September 2022, R/V SONNE

CLOCKS (21-HPAC-00671) and CCO2 (21-HPAC-01202) Surveys

1.1. General Summary

R/V SONNE departed Vancouver on 13 September en route to the survey area. Bathymetric mapping with the multibeam and PARASOUND echosounders took place outside of critical habitat on 14-15 September. On the evening of 15 September, the vessel headed back into the port of Vancouver and arrived back in the study area the morning of 17 September. R/V SONNE travelled through Critical Killer Whale Habitat on 17 September, and bathymetric mapping with the multibeam was conducted for ~5.4 hours. Multibeam bathymetric mapping was also conducted on 18 and 19 September, but outside critical habitat. No airgun operations took place during Week 1. Marine mammal observer effort and sightings can be found on Pages 2-7 of this report, and passive acoustic monitoring effort and detections can be found on Pages 8-19.

1.1.1. Mitigation Measures

The following monitoring and mitigation measures were followed while conducting bathymetric mapping with the multibeam echosounder in Southern Resident Killer Whale Critical Habitat (and outside of Critical Habitat, when practicable) based on the recommendations outlined by DFO in the Letter of Advice dated 22 August 2022:

- Bathymetric mapping using multibeam echosounders and a PARASOUND sub-bottom profiler were the only activities conducted within the Swiftsure and La Perouse survey areas.
- The smallest acoustic source possible was used to achieve the research goals.
- To allow for the greatest detection of killer whales, bathymetric surveys only occurred during daylight hours and when weather conditions permitted visual observations of marine mammals.
- Bathymetric surveys were not conducted during periods of adverse weather.
- Combined enhanced visual observations with non-visual detection methods to increase the likelihood of detecting marine mammals.
- Monitored the established Killer Whale (all ecotypes) exclusion zone with a radius of 1000 m for 30 minutes prior to initial start-up of the echosounder or resumption of operations following a complete shutdown.
- Two experienced marine mammal observers made constant observations prior to and during the bathymetric surveys.
- Passive acoustic monitoring occurred during all surveys.
- An immediate and complete shutdown of the echosounders would have been implemented if a Killer Whale (all ecotypes) were to have been observed within an established exclusion zone with a minimum radius of 1000 m.

- For other observations of marine mammals and/or turtles, an immediate and complete shutdown of the echosounders was initiated when these animals were observed within an established exclusion zone with a radius of 500 m.
- When transiting through the two seasonal slowdown areas located near Swiftsure Bank, the vessel slowed down to a speed of 10 knots or less. The vessel reduced speed when it was within 1000 m of the nearest killer whale.

Other mitigation measures considered, when practicable, included:

- Keeping 400 m distance from killer whales in southern BC coastal waters
- Keeping 200 m distance from killer whales in BC, outside of the 400 m approach areas
- Keeping 200 m distance from all cetaceans when in resting position or with a calf
- Keeping 100 m away from all other cetaceans

1.2. Marine Mammal Visual Observations

During Week 1 (13-19 September 2022), the marine mammal observers on R/V SONNE conducted 61.8 hours of watches. No monitoring took place on 13 September. There were 0 hours of watches during airgun operations, 27.6 hours during periods of multibeam, and 34.2 hrs without airgun operations or multibeam mapping (Table 1). Overall, there were 46 sightings totaling 468 marine mammals in the survey area (Table 2). While in Southern Resident Killer Whale Critical Habitat on 17 September, 5.4 hours of watches were conducted during multibeam bathymetric surveys (Table 3). Mitigation actions were taken four times — twice the vessel's course was altered to avoid potential close passage to marine mammals, once the multibeam echosounder was turned off when marine mammals came within the 500-m exclusion zone, and start up of multibeam mapping was delayed one time for marine mammals within the 500-m exclusion zone (Table 4). A complete list of all marine mammal sightings during Week 1 is provided in Table 5. A photo of the killer whale sighting on 15 September is included as Figure 1.

Table 1. Marine mammal visual observations conducted during various vessel activities

Watches during Various Vessel Activities	Hours
Watches during airgun operations (ramp ups, test and line shooting)	0
Watches during bathymetric mapping with the multibeam and/or PARASOUND (no airguns)	27.6
Watches without sounders or airguns	34.2
Total Marine Mammal Observations	**61.8**

Table 2. Summary of marine mammal sightings during Week 1 (13-19 September 2022).

Species	# of Sightings	# of Individuals
Killer Whale	3	30
Dall's Porpoise	3	21
Harbour Porpoise	1	2
Pacific White-sided Dolphin	1	300
Sei Whale	1	1
Fin/Sei Whale	3	5
Humpback Whale	17	78
Unidentified baleen whale	7	10
Unidentified whale	2	2
Steller Sea Lion	4	14
Unidentified sea lion	2	3
Harbour Seal	1	1
Unidentified seal	1	1
Total	**46**	**468**

Table 3. Marine mammal observations conducted in Southern Resident Killer Whale Critical Habitat.

Observations in Critical Habitat	Hours
Watches during multibeam and other sounders	5.4
Watches without multibeam or other sounders	5.8
Total marine mammal observations in Critical Habitat	**11.2**

Table 4. Mitigation actions taken during Week 1.

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Vessel Activity	Mitigation Action
15-09-2022 16:00:49	**Killer whale**	25	48.58167	125.9507	Multi-beam	Altered course to avoid approaching closer than 400 m
17-09-2022 10:06:57	**Humpback whale**	20	48.5252	124.784	Multi-beam	Altered course to avoid close approach to a feeding congregation
17-09-2022 14:08:46	**Steller sea lion**	2	48.576	124.821	Multi-beam	Turned off multibeam when two Steller sea lions surfaced 300 m from vessel
17-09-2022 14:35:16	**Dall's porpoise**	5	48.5529	124.864	Multi-beam	Multibeam start up was delayed as animals surfaced within 300 m of vessel

No. = Number of individuals

Table 5. List of all marine mammal sightings during Week 1 (13-19 September 2022)

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Multibeam in Critical Habitat	Mitigation Action
14-09-2022 11:43:58	**Unidentified baleen whale**	1	48.2611	126.9853	no	none
14-09-2022 12:15:12	**Fin/sei whale**	3	48.39791	127.0947	no	none
14-09-2022 14:39:59	**Fin/sei whale**	1	48.54408	127.0885	no	none
14-09-2022 15:50:08	**Fin/sei whale**	1	48.62309	127.0588	no	none
14-09-2022 16:22:30	**Sei whale**	1	46.65065	127.0531	no	none
14-09-2022 18:35:06	**Unidentified baleen whale**	2	48.65445	127.0522	no	none
15-09-2022 07:33:47	**Humpback whale**	1	48.80153	126.3865	no	none
15-09-2022 08:09:38	**Humpback whale**	1	48.8364	126.3246	no	none
15-09-2022 11:21:34	**Unidentified baleen whale**	1	48.97894	126.9744	no	none
15-09-2022 11:32:14	**Humpback whale**	1	48.97484	125.9755	no	none
15-09-2022 14:06:00	**Humpback whale**	2	48.59259	125.9423	no	none
15-09-2022 14:24:04	**Unidentified baleen whale**	1	48.59165	125.9394	no	none
15-09-2022 14:34:57	**Unidentified baleen whale**	1	48.51456	125.9098	no	none
15-09-2022 14:41:18	**Humpback whale**	1	48.51443	125.9098	no	none

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Multibeam in Critical Habitat	Mitigation Action
15-09-2022 15:09:36	**Humpback whale**	8	48.58248	125.9518	no	none
15-09-2022 15:49:58	**Harbour porpoise**	2	48.31905	125.7835	no	none
15-09-2022 15:55:15	**Humpback whale**	1	48.3021	125.7736	no	none
15-09-2022 15:57:50	**Unidentified seal**	1	48.58167	125.9507	no	none
15-09-2022 16:00:49	**Killer whale**	25	48.58167	125.9507	no	Yes; see Table 4
15-09-2022 16:11:44	**Humpback whale**	5	48.58167	125.9607	no	none
15-09-2022 17:11:58	**Steller sea lion**	1	48.3504	125.5707	no	none
15-09-2022 17:55:59	**Unidentified sea lion**	2	48.38998	125.4677	no	none
15-09-2022 17:58:49	**Humpback whale**	5	48.23832	125.2696	no	none
15-09-2022 18:07:52	**Unidentified sea lion**	1	48.38169	125.5275	no	none
15-09-2022 18:37:22	**Dall's porpoise**	4	48.38169	125.5275	no	none
15-09-2022 18:42:35	**Humpback whale**	1	48.38169	125.5275	no	none
15-09-2022 18:54:22	**Unidentified baleen whale**	1	48.38169	125.5275	no	none
17-09-2022 08:52:07	**Humpback whale**	2	48.4804	124.607	no	none
17-09-2022 09:19:32	**Humpback whale**	2	48.5032	124.691	no	none
17-09-2022 09:47:42	**Killer whale**	1	48.5172	124.746	no	none
17-09-2022 10:06:57	**Humpback whale**	20	48.5252	124.784	no	yes; see Table 4
17-09-2022 10:12:36	**Killer whale**	4	48.5253	124.796	no	none
17-09-2022 10:24:34	**Steller sea lion**	9	48.5263	124.821	no	none
17-09-2022 11:44:10	**Dall's porpoise**	12	48.5898	124.913	no	none
17-09-2022 12:08:00	**Harbour seal**	1	48.576	124.821	no	none
17-09-2022 12:19:25	**Humpback whale**	25	48.6175	124.913	no	none
17-09-2022 14:01:00	**Steller sea lion**	2	48.5823	124.823	yes	none

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Multibeam in Critical Habitat	Mitigation Action
17-09-2022 14:08:46	**Steller sea lion**	2	48.576	124.821	yes	yes; see Table 4
17-09-2022 14:35:16	**Dall's porpoise**	5	48.5529	124.864	yes	yes; see Table 4
17-09-2022 15:11:53	**Humpback whale**	1	48.5408	124.943	yes	none
17-09-2022 15:49:10	**Humpback whale**	1	48.5457	125.023	yes	none
17-09-2022 18:57:29	**Unidentified baleen whale**	3	48.5689	125.324	yes	none
17-09-2022 19:25:29	**Humpback whale**	1	48.5347	125.351	yes	none
18-09-2022 12:19:03	**Pacific white-sided dolphin**	300	48.708	126.796	yes	none
18-09-2022 15:56:51	**Unidentified whale**	1	48.7798	126.888	yes	none
19-09-2022 09:11:51	**Unidentified whale**	1	48.6886	126.78	no	none

No. = Number of individuals

Figure 1. Killer whales photographed on 15 September 2022 (photo credit: Bruce Mactavish).

MARINE MAMMAL TEAM ON BOARD R/V SONNE

LGL Marine Mammal Observers	ONC Marine Mammal Observer
Meike Holst (Project Manager)	Ella Minicola
Bruce Mactavish (Lead)	
Magena Warrior	
Meghan Piercy	

1.3. PAM Field Logs

1.3.1. Multibeam in Southern Resident Killer Whale Critical Habitat

Vessel: RV SONNE	Exclusion zone: 500 m all other marine mammals, 1000m for Killer whale
Date (YY/MM/DD in UTC): 22/09/17	Number of PAM Operators: 3 (AH, LM, KAD) No rotation
Source Activity: Multibeam sounder	Total effort: 5 hours, 49 minutes and 6 seconds (Monitoring) and 2 hours (Deployment and Retrieval)
Hydrophone array depth: 30m	
PAM Array: two 2-element apertures (1 m hydrophone spacing) towed at 230 m and 330 m starboard aft of vessel stern	PAM Software: PAMlab V9.13.1 (JASCO Applied Sciences)

Data Code: Species=common name or species category (1=uncertain, 2=fairly certain, 3=confident); Signal Description=tonal or click or call type; Bearing=Ch1+2(top), Ch3+4(bottom/shaded); Complete entry 1) start of monitoring 2) marine mammal first spotted for PAM 3) any change in source activity

Table 6. Field log entries during PAM monitoring. Shaded rows indicate Channel 3+4.

Time (HH:MM:SS UTC)	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (eg. Pre-clear, ramp-up, snapshots taken)
20:41:37	-	-	- -	-	-	-	-	-	PAM started
20:43:49	205	1.46	110.4 	Unknown	Moan with harmonic (287 Hz)	Y	>500	N	-
20:44:25	144	2.20	117.9 -	Unknown	Moan with harmonics (405 Hz and 582 Hz)	Y	~500	N	Unknown moan, on edge of exclusion zone, another call to confirm travelling towards
20:45:31	-	-	-	-	-	-	-	-	PAM initial clear given; Multibeam started

Time (HH:MM:SS UTC)	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (eg. Pre-clear, ramp-up, snapshots taken)
			-						
20:45:44	110	2.41	116.0 -	Unknown	Moan with harmonic (292 Hz)	Y	>500	N	-
20:50:09	310	82 (0.77-call, 1 between calls)	101.3 -	Humpback (3)	Bubble-net feeding calls	Y	>500	N	Humpback feeding observed earlier in day, no bubble-netting seen at surface. Probably bubble-net feeding at depth
20:52:29	493	3.5	113.7 -	Humpback (3)	Moan (associated with feeding calls?)	Y	>500	N	-
20:52:41	140	2.18	119 -	Humpback (2)	Moan with harmonic (279 Hz)	Y	<500	N	Shut down if more humpback calls are confirmed <500m, no MMO sightings in exclusion zone
20:53:42	140	2.71	114	Humpback (2)	Moan with harmonic (278 Hz)	Y	>500	N	-
20:53:53	340	125 (1.07 per call, 1.16 between calls)	104.7	Humpback (3)	Bubble-net feeding calls	Y	>500	N	-
20:55:50	161	2.61	116.5	Humpback (2)	Moan with harmonic (384 Hz)	Y	>500	N	-
20:59:52	93	2.21	122.3	Humpback (2)	Harmonic with harmonic (273 Hz)	Y	<500	N	MMOs confirm no humpback sightings within 500m, previous moan >500m, PAM

Time (HH:MM:SS UTC)	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (eg. Pre-clear, ramp-up, snapshots taken)
			-						to call shut down if another loud moan detected
21:00:52	315	120 (1 per call, 1 between calls)	103.5 -	Humpback (3)	Bubble-net feeding calls (very faint feeding calls at 140 Hz, likely another feeding group in distance or low harmonic?)	Y	>500m	N	-
21:01:18	518	3.68	112.6 -	Humpback (3)	Moan associated with feeding	Y	>500	N	-
21:01:56	142	2.09	117.0 -	Humpback (3)	-	Y	>500	N	-
21:03:48	332	60 (1 per call, 1 between calls)	105.0 -	Humpback (3)	Bubble-net feeding calls (very faint feeding calls at 153 Hz, likely another feeding group in distance or low harmonic?)	Y	>500	N	-
21:04:32	1136	0.58	100.1 -	Killer whale (1)	Upsweep with harmonic (2179 Hz)	Y	<1000	N	Unknown faint whistle, need further calls for a shutdown, No MMO killer whale sightings

Time (HH:MM:SS UTC)	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (eg. Pre-clear, ramp-up, snapshots taken)
21:05:20	336	18 (1.18 per call, 1 between calls)	103 -	Humpback (3)	Bubble-net feeding calls (very faint feeding calls at 153 Hz, likely another feeding group in distance or low harmonic?)	Y	>500	N	-
21:07:01	517	2.63	113.6 -	Humpback (2)	Moan associated with feeding?	Y	>500	N	-
21:08:31	508	3	106.9 114.2	Humpback (2)	Moan associated with feeding?	Y	>500	N	-
21:08:46	-	-	- -	-	-	-	-	-	Shut down by MMOs due to sea lions; Not detected on PAM
21:09:08	1157	1.02	103.7 -	Killer whale (2)	-	Y	<1000	N	Possibly Biggs but very faint, Already shut down
21:13:00	321	36 (0.81 per call, 0.8 between calls)	102.9 -	Humpback (3)	Bubble-net feeding calls with faint lower harmonic (162 Hz)	Y	>500	N	-

Time (HH:MM:SS UTC)	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (eg. Pre-clear, ramp-up, snapshots taken)
21:14:44	338	60 (0.85 per call, 1 between calls)	104.4	Humpback (3)	Bubble-net feeding calls with faint lower harmonic (169 Hz)	Y	>500	N	-
21:14:54	129	2.33	121.6 -	Humpback (2)	Low Moan with harmonic (270 Hz) associated with feeding call?	Y	<500	N	Already shut down
21:15:47	527	3.01	111.4 -	Humpback (3)	Moan associated with feeding calls	Y	>500	N	-
21:15:56	88	2.54	130.4 -	Humpback (2)	Low Moan with harmonic (290 Hz) associated with feeding call?	Y	<500	N	Already shut down
21:16:28	240	16 (1 per call, 0.9 between calls)	102.1 -	Humpback (3)	Bubble-net feeding calls with faint lower harmonic (161 Hz)	Y	>500	N	-
21:17:37	1682	0.85	99.1 -	Killer whale (3)	Tonal whistle	Y	<1000	N	Already shut down

Time (HH:MM:SS UTC)	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (eg. Pre-clear, ramp-up, snapshots taken)
21:17:53	1305	NA	102.6 -	Killer whale (3)	Very faint whistles	Y	<1000	N	Already shut down
21:21:14	143	3	120.6 -	Humpback whale (2)	Low Moan	Y	<1000	N	Already shut down
21:21:39	5301	0.74	- 95.3	Killer whale (3)	Faint whistle	Y	<500	N	Already shut down, travelling away?
21:21:41	1554	0.74	- 96.2	Killer whale (3)	Faint whistle	Y	<500	N	Already shut down
21:21:58	516	3.81	- 121.7	Humpback whale (3)	Moan with harmonic (1050 Hz)	Y	<1000	N	Already shut down
21:22:01	5073	1.07	90.6 -	Killer whale (3)	Faint whistle	Y	>1000	N	Travelling away?
21:22:19	4066	1.5	- 92.9	Killer whale (3)	Faint whistle	Y	>1000	N	-
21:23:01	5019	0.76	- 87.9	Killer whale (3)	Faint whistle	Y	>1000	N	Travelling away?, Still no MMO sightings of Killer whale
21:23:12	141	2.66	- 115.8	Humpback (3)	Low moan with harmonic (282 Hz)	Y	>500	N	-
21:23:40	5146	1.40	- 90.7	Killer whale (3)	Faint whistle	Y	>1000	N	-

Time (HH:MM:SS UTC)	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (eg. Pre-clear, ramp-up, snapshots taken)
21:23:54	512	3.13	- 117	Humpback whale (3)	Moan	Y	>500	N	-
21:24:53	308	48 (1 per call, 1 between calls)	108.9 107.5	Humpback (3)	Bubble-net feeding calls with low harmonics (168 Hz)	Y	>500	N	-
21:26:00	328	23.52 (1 per call 1 between calls)	- 104.1	Humpback (3)	Bubble-net feeding calls with low harmonic (160 Hz)	Y	>500	N	-
21:26:50	2701	1.13	85.4 -	Killer whale (3) SRKW?	Possible S01 Echolocation in the background, not visible	Y	>1000	N	No MMO Sightings of Killer whale
21:27:05	467	1.78	110.5 -	Humpback whale (3)	Non-song tonal	Y	>500	N	-
21:27:22	304	84 (1 per call, 1 between calls)	- 100.1	Humpback (3)	Bubble-net feeding calls with low harmonic (147 Hz)	Y	>500	N	-
21:27:38	3780	0.93	- 91.8	Killer whale (3)	Faint whistles continuing for a couple minutes	Y	>1000	N	All calls checked for source level, only recorded if >91.8dB
21:27:58	140	1.99	-			Y	<500	N	Already shut down

Time (HH:MM:SS UTC)	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (eg. Pre-clear, ramp-up, snapshots taken)
			120.4	Humpback (3)	Low Moan with harmonic (279 Hz)				
21:29:34	533	4.7	121 118	Humpback (3)	Moan with harmonics	Y	<500	N	Already shut down
21:29:43	306	94 (1 per call, 1 per duration)	- 107	Humpback (3)	Bubble-net feeding calls with low harmonics (156 Hz)	Y	>500	N	-
21:30:22	537	4	- 118	Humpback (3)	Moan with harmonics	Y	<500	N	Already shut down
21:34:19	5326	1.09	- 93.3	Killer whale (3)	Whistle	Y	>1000	N	-
21:34:35	137	1.18	- 116.2	Humpback (3)	Low Moan	Y	>500	N	-
21:39:20	4000	0.71	99.7 97.8	Killer whale (3)	Whistle	Y	<1000	N	Already shut down
21:41:31	10000	0.56 ICI	- 111	Sperm whale (1)	Possible Sperm whale clicks?	Y	>500	N	-
21:46	-	-	-	-	-	-	-	-	Clear given by MMOs, Multibeam started
21:41:51	139	2.06	- 116.6	Humpback (3)	Low Moan with harmonic	Y	>500	N	-

Time (HH:MM:SS UTC)	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (eg. Pre-clear, ramp-up, snapshots taken)
21:42:40	6596	1.42	89.2 	Killer whale (3)	Faint Whistles	Y	>1000	N	No MMO Killer whale sightings
21:42:48	135	3	117.8 	Humpback (3)	Low Moan	Y	~500	N	No MMO sightings <500m
21:48:45	141	2	121 120	Humpback (3)	Low Moan	Y	<500	N	No MMO sightings <500m, One more loud humpback call and then PAM call shutdown
21:51:10	5000	0.71	 88.6	Killer whale (3)	Whistle	Y	>1000	N	-
21:53:58	517	-	 116	Humpback whale (3)	Moan	-	>500	N	-
22:22:31	506	-	111 111	Humpback (3)	Moan		>500	N	-
23:00	-	-	- -	-	-	-	-	-	Loud vessel noise, many ships around, No calls detected or MMO sightings
01:00	-	-	- -	-	-	-	-	-	No calls detected, or MMO sightings
02:30:43	-	-	-	-	-	-	-	-	Stop Multibeam, PAM and MMO finish

*Distance inferred from species Source Level (SL). See Table 7.

1.3.2. Species Source Levels

Sound Pressure Level calculated from Source Level

Table 7. Mean species source level and calculated Sound Pressure Level (SPL) at 500, 1000, and 1500m. Shaded boxes indicate exclusion zone per species required for mitigation during air gun activity. Attenuation calculations are based on 20*log10(range).

Species	Source level (mean dB)	SPL if within 500m of hydrophone (dB)	SPL if within 1000m of hydrophone (dB)	SPL if within 1500m of hydrophone (dB)
North Pacific right whale	177.0	123.0	117.0	113.5
Killer whale whistles	154.0	100.0	94.0	90.5
Killer whale clicks	193.0	139.0	133.0	129.5
Blue whale	181.3	127.3	121.3	117.8
Fin whale	183.5	129.5	123.5	120.0
Sei whale	176.5	122.5	116.5	113.0
Minke whale	170.0	116.0	110.0	106.5
Gray whale	157.0	103.0	97.0	93.5
Humpback whale	171.5	117.5	111.5	108
Delphinid whistles	158.0	104.0	98.0	94.5
Pilot whale whistles	154.0	100.0	94.0	90.5
Delphinid clicks	188.0	134.0	128.0	124.5
Porpoise/Kogia clicks	191.0	137.0	131.0	127.5
Sperm whale	186.0	132.0	126.0	122.5
Baird's beaked whale	*	*	*	*
Blainville's beaked whale	201.0	147.0	141.0	137.5
Cuvier's beaked whale	203.0	149.0	143.0	139.5
Hubb's beaked whale	*	*	*	*
Stejneger's beaked whale	*	*	*	*

*No data in the literature, refer to Cuvier's beaked whale.

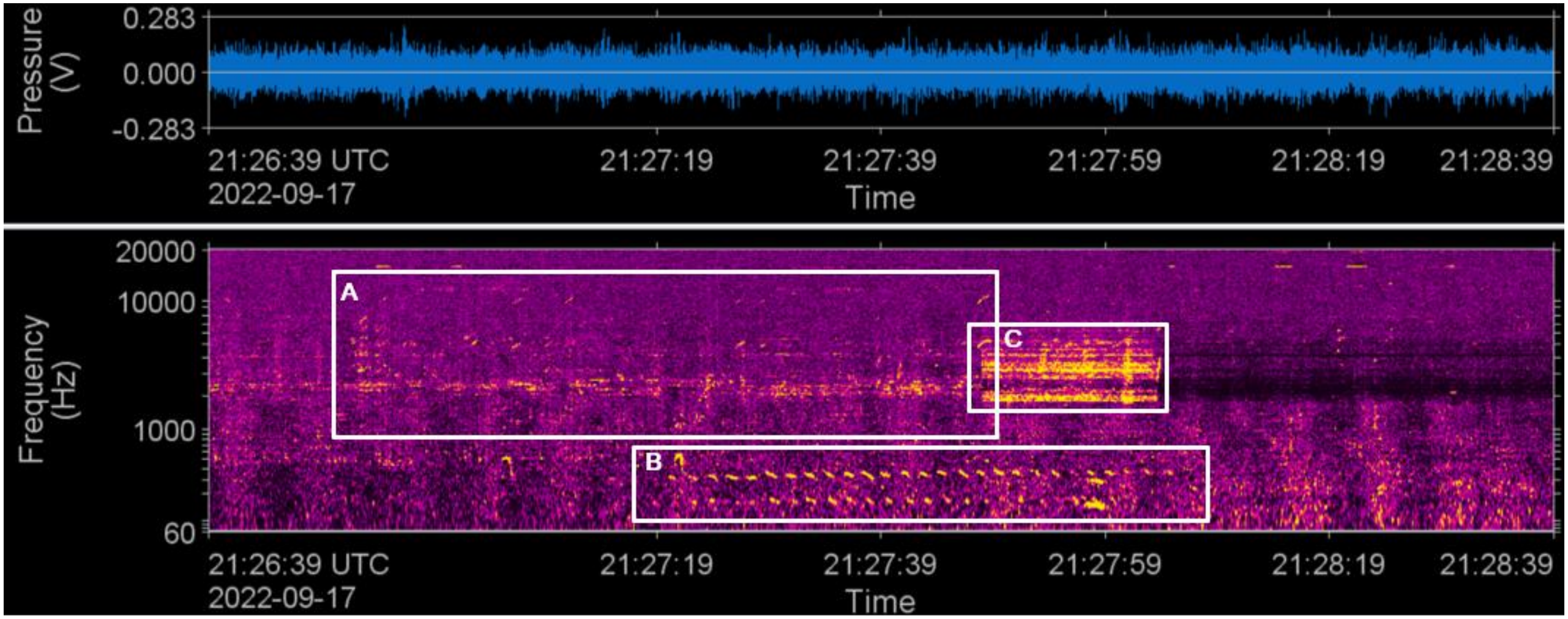

Figure 2. A waveform (above) and spectrogram (below; 2 Hz frequency resolution, 0.125s time window, 0.03125 s time step, Hamming window, normalized across-time), zoomed out in time (120 s duration), displaying faint killer whale calls (A), potential humpback bubble-net feeding (B), and noise from the ship turning (C).

WEEK TWO MARINE MAMMAL REPORT

20-26 September 2022, R/V SONNE

CLOCKS (21-HPAC-00671) and CCO2 (21-HPAC-01202) Surveys

1.1. General Summary

R/V SONNE started airgun operations at the CCO2 Survey Area during the afternoon of 20 Sept. Passive Acoustic Monitoring (PAM) took place before and during all airgun operations, and visual observations by marine mammal observers (MMOs) were conducted before and during all daytime airgun operations. Airgun operations with the 6-G gun array were conducted continuously from the afternoon of 20 Sept. to morning of 21 Sept., when airgun operations ceased. The CCO2 experiment concluded during Week 2, and R/V SONNE returned to the CLOCKS survey area. Bathymetric mapping with the multibeam and PARASOUND echosounders took place every day during Week 2, including during airgun operations, but no bathymetric mapping occurred within Southern Resident Critical Habitat. No marine mammals were seen or detected acoustically during airgun operations in the CCO2 Survey Area, and no airgun operations took place in the CLOCKS survey area during Week 2. MMO effort and sightings can be found on Pages 2-5 of this report, and PAM effort and detections can be found on Pages 6-8.

1.1.1. Mitigation Measures

The following monitoring and mitigation measures were followed while airgun operations were conducted, based on recommendations outlined by DFO in the Letter of Advice dated 22 August 2022:

- Use the smallest acoustic source (i.e., single airgun or airgun array) possible to achieve the research goals.
- Conduct seismic survey activities outside of designated SRKW Critical Habitat and outside of sensitive habitats (i.e., Scott Islands Marine National Wildlife Area, Pacific Offshore Area of Interest, or Checleset Bay Ecological Reserve) with a setback that ensures that the estimated sound pressure level has diminished to ≤160 dB_{rms} re 1 µPa for the shortest distance to the boundary of these areas.
- No seismic surveys are to occur in water <200 m deep.
- Combine enhanced visual observations (e.g., reticle and big-eye binoculars, night vision devices and digital cameras) with non-visual detection methods (e.g., infrared technology (FLIR) and passive acoustic monitoring) to increase the likelihood of detecting marine mammals during ramp up, Beaufort sea states >3, and during nighttime survey operations.
- Monitor the established exclusion zone with a radius of 1000 m for 60 minutes prior to initial start-up of the airgun array or resumption of operations following a complete shutdown to allow for the detection of deep diving animals.
- A minimum of two experienced marine mammal observers are to make constant observation, with redundancy of personnel of the vicinity of the survey vessel prior to and during operation of the single airgun or airgun array.

- Passive acoustic monitoring (PAM) is to occur during all seismic operations.
- Initiate an immediate and complete shutdown of the airgun array if a Killer Whale (all ecotypes), Northern Pacific Right Whale, whale with calf (any species) or aggregation of whales (any species) is observed.
- Initiate an immediate and complete shutdown of the airgun array if a Sperm Whale or a beaked whale (any species) is sighted within 1500 m of the airgun array.
- For other observations of marine mammals and/or turtles, initiate an immediate and complete shutdown of the airgun array if these animals are observed within an established exclusion zone with a radius of 1000 m.
- If no marine mammals are observed within the exclusion zone during the 60 minute pre-start observation period, ramp-up the airgun array over a period of 20 minutes starting with the smallest airgun.
- For operations during poor visibility or at night, ramp-up is not to begin until the exclusion zone has been monitored for a minimum of 30 minutes with no detections.

In addition, the following monitoring and mitigation measures were followed during bathymetric mapping using echosounders outside of Southern Resident Critical Habitat; these measures were adopted based on recommendations outlined by DFO in the Letter of Advice for acoustic mapping within Critical Habitat:

- Monitored an exclusion zone with a radius of 500 m for 30 minutes prior to initial start-up of the echosounder or resumption of operations following a complete shutdown.
- Two experienced marine mammal observers made constant observations prior to and during the bathymetric surveys.
- Implemented an immediate and complete shutdown of the echosounders when any marine mammal was observed within an established exclusion zone with a radius of 500 m.

Other mitigation measures considered, when practicable, included:

- Keeping 400 m distance from killer whales in southern BC coastal waters
- Keeping 200 m distance from killer whales in BC, outside of the 400 m approach areas
- Keeping 200 m distance from all cetaceans when in resting position or with a calf
- Keeping 100 m away from all other cetaceans

1.2. Marine Mammal Visual Observations

During Week 2 (20-26 September 2022), the MMOs on R/V SONNE conducted 89 hours of watches. There were 5.7 hours of watches during airgun operations with multibeam mapping and 46.0 hours during periods of multibeam mapping outside of critical habitat; the rest of the watches occurred during periods without airgun operations or bathymetric mapping (Table 1). Overall, there were 23 sightings totaling 49 marine mammals in the survey areas (Table 2). Mitigation actions were taken six times when the multibeam echosounder was turned off when marine mammals came within the 500-m exclusion zone (Table 3). A list of all marine mammal sightings during Week 2 is provided in Table 4.

Table 1. Marine mammal visual observations conducted during various vessel activities

Watches during Various Vessel Activities	Hours
Watches during airgun operations with sounders	5.7
Watches during bathymetric mapping with the multibeam and/or PARASOUND (no airguns)	46.0
Watches without airgun operations or sounders	37.3
Total Hours of Observations	**89.0**

Table 2. Summary of marine mammal sightings during Week 2.

Species	# of Sightings	# of Individuals
Dall's Porpoise	1	4
Northern Right Whale Dolphin	3	16
Fin Whale	10	20
Fin/Sei Whale	3	3
Humpback Whale	1	1
Unidentified Baleen Whale	2	2
Unidentified Whale	1	1
Unidentified Pinniped	1	1
Unidentified Marine Mammal	1	1
Total	**23**	**49**

able 3. Mitigation actions taken during Week 2

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Vessel Activity	Mitigation Action
22-09-2022 16:11:39	Unidentified Pinniped	1	48.6028	127.928	Sounders	Shut down sounders when a pinniped (likely sea lion) came within 500 m
23-09-2022 15:59:05	Fin Whale	3	49.3423	127.534	Sounders	Shut down sounders when one of three fin whales came within 500 m
24-09-2022 14:02:44	Fin Whale	1	49.7274	128.05	Sounders	Shut down sounders when a fin whale came within 500 m
24-09-2022 14:58:53	Fin Whale	1	49.6444	128.172	Sounders	Shut down sounders when fin whale came within 500 m
26-09-2022 17:00:33	Northern Right Whale Dolphin	6	49.9897	128.861	Sounders	Shut down sounders when a group of 6 northern right whale dolphins came within 500 m
26-09-2022 18:48:44	Northern Right Whale Dolphin	3	50.0865	128.693	Sounders	Shut down sounders when a group of 3 northern right whale dolphins came within 500 m

No. = Number of individuals

Table 4. List of all marine mammal sightings during Week 2.

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Airgun Operations	Mitigation Action
21-09-2022 16:32:56	Fin Whale	1	47.7552	127.7586	N	X
22-09-2022 16:11:39	Unidentified Pinniped	1	48.6028	127.9279	N	shut down sounders
22-09-2022 16:19:55	Northern Right Whale Dolphin	7	48.6193	127.932	N	X
22-09-2022 17:51:28	Unidentified Marine Mammal	1	48.7849	128.0446	N	X
23-09-2022 08:49:27	Unidentified Baleen Whale	1	49.2145	127.854	N	X
23-09-2022 09:19:31	Fin Whale	4	49.2147	127.8542	N	X
23-09-2022 09:39:05	Fin Whale	3	49.2235	127.8642	N	X
23-09-2022 10:52:11	Fin Whale	2	49.2481	127.9136	N	X
23-09-2022 11:13:29	Fin Whale	2	49.252	127.8453	N	X
23-09-2022 11:26:49	Fin/Sei Whale	1	49.2544	127.7999	N	X
23-09-2022 11:38:16	Fin Whale	1	49.2562	127.7584	N	X
23-09-2022 11:50:55	Fin Whale	2	49.2583	127.7134	N	X
23-09-2022 12:20:38	Unidentified Baleen Whale	1	49.2631	127.6075	N	X
23-09-2022 15:59:05	Fin Whale	3	49.3423	127.5336	N	shut down sounders
24-09-2022 07:53:22	Fin/Sei Whale	1	49.5692	127.8586	N	X
24-09-2022 14:02:44	Fin Whale	1	49.7274	128.0495	N	shut down sounders
24-09-2022 14:58:53	Fin Whale	1	49.6444	128.1722	N	shut down sounders
25-09-2022 11:09:24	Unidentified Whale	1	49.8437	128.3079	N	X
25-09-2022 15:56:19	Fin/Sei Whale	1	50.0963	128.3699	N	X
25-09-2022 17:14:32	Dall's Porpoise	4	50.0363	128.4933	N	X

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Airgun Operations	Mitigation Action
26-09-2022 10:15:10	Humpback Whale	1	49.918	128.6244	N	X
26-09-2022 17:00:33	Northern Right Whale Dolphin	6	49.9897	128.8605	N	shut down sounders
26-09-2022 18:48:44	Northern Right Whale Dolphin	3	50.0865	128.693	N	shut down sounders

No. = Number of individuals

MARINE MAMMAL TEAM ON BOARD R/V SONNE

LGL Marine Mammal Observers	ONC Marine Mammal Observer
Meike Holst (Project Manager)	Ella Minicola
Bruce Mactavish (Lead MMO)	
Magena Warrior	
Meghan Piercy	

1.3. PAM Field Logs

1.3.1. Cascadia CO_2 Seismic (G-gun array)

Vessel: RV SONNE	Exclusion zone: 1000m all other marine mammals, 1500m for Beaked and Sperm whales, shutdown for Killer whales and North Pacific Right whales
Date (YY/MM/DD in UTC): 22/09/20 – 22/09/21	Number of PAM Operators: 3 (AH, KLM, KAD)
Source Activity: 6 G-gun array (2840in^3)	Total effort: 16 hours, 55 minutes, and 31 seconds (Monitoring) and 2 hours (Deployment and Retrieval)
Hydrophone depth: 20m	
PAM Array: two 2-element apertures (1 m hydrophone spacing) towed at 200 m and 300 m starboard aft of vessel stern	PAM Software: PAMlab V9.13.1 (JASCO Applied Sciences)

Data Code: Species=common name or species category (1=uncertain, 2=fairly certain, 3=confident); Signal Description=tonal or click or call type; For SPL and Bearing=Ch1+2(top), Ch3+4(bottom/shaded); Complete entry 1) start of monitoring 2) marine mammal first spotted for PAM 3) any change in source activity

Table 5. Field log entries during PAM monitoring. Shaded rows indicate Channel 3+4.

Time (HH:MM:SS UTC)	PAM operator	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., pre-clear, ramp-up, snapshots taken)
22:13:44	AH	-	-	-	-	-	-	-	-	PAM started; No PAM 60 min preclear
				-						
22:28:20	AH	-	-	-	-	-	-	-	-	Airgun ramp up started, not detected on PAM
				-						
22:29	AH	-	-	-	-	-	-	-	-	First airgun shot, not detected on PAM
				-						

Time (HH:MM:SS UTC)	PAM operator	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., pre-clear, ramp-up, snapshots taken)
22:33:10		30-16776	0.12	- 154	-	Airgun pulse with 3 multipath arrivals (1st arrival SPL= 124 dB)	N	-	-	Airgun pulse detected on PAM
22:52:20		-	-	- - -	-	-	-	-	-	6 G airgun firing at 60 s. Ramp up complete. No calls detected.
03:00-07:00	KLM	-	-	- -	-	-	-	-	-	No detections recorded. Shift change.
07:00-11:00	KAD	-	-	- -	-	-	-	-	-	No detections recorded. Shift change.
11:00-15:00	AH	-	-	- -	-	-	-	-	-	No detections recorded.
15:15		-	-	- -	-	-	-	-	-	Airgun stopped. PAM finished.

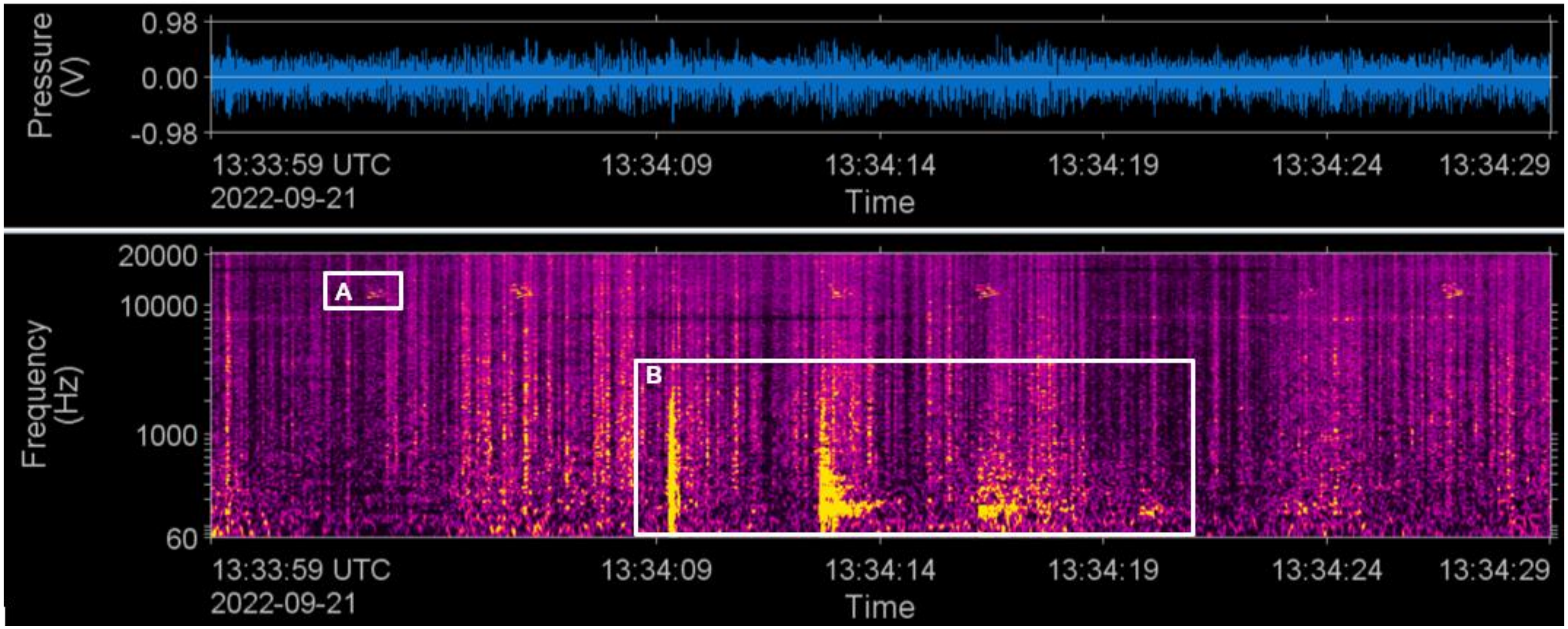

Figure 1. A waveform (above) and spectrogram (below; 2 Hz frequency resolution, 0.125s time window, 0.03125 s time step, Hamming window, normalized across-time), zoomed out in time (30 s duration), displaying a 6 G-gun shot with pressure signals (A), and the RV SONNE's depth sounder (B).

LGL LIMITED
environmental research associates

WEEK THREE MARINE MAMMAL REPORT

27 September-3 October 2022, R/V SONNE

CLOCKS CRUISE (21-HPAC-00671)

1.1. General Summary

R/V SONNE conducted activities within the CLOCKS Survey Area during Week 3. Airgun operations commenced the evening of 28 September. Passive Acoustic Monitoring (PAM) took place before and during all airgun operations, and visual observations by marine mammal observers (MMOs) were conducted before and during all daytime airgun operations. Airgun operations with the 6-G gun array were conducted from 28 September to 30 September at 1 pm. Airgun operations with a single GI gun commenced at 3:25 pm on 30 September and continued through 3 October 2022. Bathymetric mapping with the multibeam and PARASOUND echosounders took place every day during Week 3, including during airgun operations. No airgun operations or bathymetric mapping occurred within Southern Resident Critical Habitat. MMO effort and sightings can be found on Pages 2-6 of this report, and PAM effort and detections can be found on Pages 7-13.

1.1.1. Mitigation Measures

The following monitoring and mitigation measures were followed while airgun operations were conducted, based on recommendations outlined by DFO in the Letter of Advice dated 22 August 2022:

- Use the smallest acoustic source (i.e., single airgun or airgun array) possible to achieve the research goals.
- Conduct seismic survey activities outside of designated SRKW Critical Habitat and outside of sensitive habitats (i.e., Scott Islands Marine National Wildlife Area, Pacific Offshore Area of Interest, or Checleset Bay Ecological Reserve) with a setback that ensures that the estimated sound pressure level has diminished to ≤160 dB_{rms} re 1 µPa for the shortest distance to the boundary of these areas.
- No seismic surveys are to occur in water <200 m deep.
- Combine enhanced visual observations (e.g., reticle and big-eye binoculars, night vision devices and digital cameras) with non-visual detection methods (e.g., infrared technology (FLIR) and passive acoustic monitoring) to increase the likelihood of detecting marine mammals during ramp up, Beaufort sea states >3, and during nighttime survey operations.
- Monitor the established exclusion zone with a radius of 1000 m for 60 minutes prior to initial start-up of the airgun array or resumption of operations following a complete shutdown to allow for the detection of deep diving animals.
- A minimum of two experienced marine mammal observers are to make constant observation, with redundancy of personnel of the vicinity of the survey vessel prior to and during operation of the single airgun or airgun array.
- Passive acoustic monitoring (PAM) is to occur during all seismic operations.

- Initiate an immediate and complete shutdown of the airgun array if a Killer Whale (all ecotypes), Northern Pacific Right Whale, whale with calf (any species) or aggregation of whales (any species) is observed.
- Initiate an immediate and complete shutdown of the airgun array if a Sperm Whale or a beaked whale (any species) is sighted within 1500 m of the airgun array.
- For other observations of marine mammals and/or turtles, initiate an immediate and complete shutdown of the airgun array if these animals are observed within an established exclusion zone with a radius of 1000 m.
- If no marine mammals are observed within the exclusion zone during the 60 minute pre-start observation period, ramp-up the airgun array over a period of 20 minutes starting with the smallest airgun.
- For operations during poor visibility or at night, ramp-up is not to begin until the exclusion zone has been monitored for a minimum of 30 minutes with no detections.

In addition, the following monitoring and mitigation measures were followed during bathymetric mapping using echosounders outside of Southern Resident Critical Habitat; these measures were adopted based on recommendations outlined by DFO in the Letter of Advice for acoustic mapping within Critical Habitat:

- Monitored an exclusion zone with a radius of 500 m for 30 minutes prior to initial start-up of the echosounder or resumption of operations following a complete shutdown.
- Two experienced marine mammal observers made constant observations prior to and during the bathymetric surveys.
- Implemented an immediate and complete shutdown of the echosounders when any marine mammal was observed within an established exclusion zone with a radius of 500 m.

Other mitigation measures considered, when practicable, included:

- Keeping 400 m distance from killer whales in southern BC coastal waters
- Keeping 200 m distance from killer whales in BC, outside of the 400 m approach areas
- Keeping 200 m distance from all cetaceans when in resting position or with a calf
- Keeping 100 m away from all other cetaceans

1.2. Marine Mammal Visual Observations

During Week 3 (27 September-3 October 2022), the MMOs on R/V SONNE conducted 88.0 hours of watches. There were 57.0 hours of watches during airgun operations with bathymetric mapping, and 25.2 hours during periods of bathymetric mapping outside of critical habitat; the rest of the watches occurred during periods without airgun operations or bathymetric mapping (Table 1). Overall, there were 20 sightings totaling 75 marine mammals in the survey area (Table 2). Mitigation actions were taken 9 times — 7 times when the airgun(s) were shutdown when marine mammals came within the exclusion zone, and 2 times when the multibeam and other echosounders were turned off when marine mammals came within 500 m (Table 3). A list of all marine mammal sightings during Week 3 is provided in Table 4.

Table 1. Marine mammal visual observations conducted during various vessel activities

Watches during Various Vessel Activities	Hours
Watches during airgun operations with sounders	57.0
Watches during bathymetric mapping with the multibeam and/or PARASOUND (no airguns)	25.2
Watches without airgun operations or sounders	5.8
Total Hours of Observations	**88.0**

Table 2. Summary of marine mammal sightings during Week 3.

Species	# of Sightings	# of Individuals
Dall's Porpoise	1	6
Pacific White-sided/Northern Right Whale Dolphin*	1	48
Sperm Whale	1	1
Fin Whale	4	6
Fin/Sei Whale	2	2
Unidentified Baleen whale	8	8
Unidentified Whale	1	1
Steller Sea Lion	1	1
Unidentified Sea Lion	1	2
Total	**20**	**75**

*Mixed group consisting of 40 Pacific white-sided dolphins and 8 northern right whale dolphins.

Table 3. Mitigation actions taken during Week 3.

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Vessel Activity	Mitigation Action
28-09-2022 16:38:48	Fin Whale	2	49.5513	129.236	Multibeam and Parasound	Shutdown sounders when animals came within 500 m
29-09-2022 13:28:24	Unidentified Sea Lion	2	50.1368	128.531	6 G gun array + sounders	Shutdown airguns and sounders when animals entered the 1000-m exclusion zone
29-09-2022 18:41:02	Fin Whale	1	49.9142	128.991	6 G gun array + sounders	Shutdown airguns and sounders when animal entered the 1000-m exclusion zone
30-09-2022 08:59:33	Steller Sea Lion	1	49.6716	128.321	6 G gun array + sounders	Shutdown airguns and sounders when animal entered the 1000-m exclusion zone
30-09-2022 14:35:01	Mixed group of Pacific White-sided/Northern Right Whale Dolphin	40/8	49.9568	128.573	Multibeam and Parasound	Shutdown sounders when animals came within 500 m
01-10-2022 08:20:24	Fin/Sei Whale	1	50.0758	128.819	6 G gun array + sounders	Shutdown airguns and sounders when animal entered the 1000-m exclusion zone
01-10-2022 14:07:15	Fin Whale	1	49.8379	129.14	1 GI gun + sounders	Shutdown GI gun and sounders when animal entered the 1000-m exclusion zone
03-10-2022 07:55:44	Unidentified Baleen Whale	1	49.956	-128.475	1 GI gun + sounders	Shutdown GI gun and sounders when animal entered the 1000-m exclusion zone
03-10-2022 17:03:55	Sperm Whale	1	49.86	-128.699	1 GI gun + sounders	Shutdown GI gun and sounders when animal entered the 1500-m exclusion zone

No. = Number of individuals

Table 4. List of all marine mammal sightings during Week 3.

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Airgun Operations	Mitigation Action
28-09-2022 09:46:05	Dall's Porpoise	6	50.0943	129.118	No	X
28-09-2022 11:39:55	Unidentified Baleen Whale	1	50.1744	129.163	No	X
28-09-2022 13:44:36	Unidentified Baleen Whale	1	49.8801	129.176	No	X
28-09-2022 16:38:48	Fin Whale	2	49.5513	129.236	No	Shut down sounders
29-09-2022 13:28:24	Unidentified Sea Lion	2	50.1368	128.531	6 G gun array	Shut down airguns and sounders
29-09-2022 16:28:00	Unidentified Baleen Whale	1	50.0066	128.8	6 G gun array	X
29-09-2022 18:41:02	Fin Whale	1	49.9142	128.991	6 G gun array	Shut down airguns and sounders
30-09-2022 08:59:33	Steller Sea Lion	1	49.6716	128.321	6 G gun array	Shut down airguns and sounders
30-09-2022 14:35:01	Pacific white-sided/Northern Right Wale Dolphins*	40/8	49.9568	128.573	No	Shut down sounders
01-10-2022 08:20:24	Fin/Sei Whale	1	50.0758	128.819	1 GI gun	Shut down GI gun and sounders
01-10-2022 09:04:26	Unidentified Baleen Whale	1	50.0437	128.885	No	X
01-10-2022 14:07:15	Fin Whale	1	49.8379	129.14	1 GI gun	Shut down GI gun and sounders
01-10-2022 15:19:38	Fin/Sei Whale	1	49.8919	129.028	1 GI gun	X
01-10-2022 16:05:08	Unidentified Baleen Whale	1	49.9266	128.955	1 GI gun	X
02-10-2022 12:55:42	Unidentified Whale	1	49.9227	128.366	1 GI gun	X
02-10-2022 14:31:34	Fin Whale	2	49.9188	128.238	1 GI gun	X
03-10-2022 07:55:44	Unidentified Baleen Whale	1	49.956	128.475	1 GI gun	Shut down GI gun and sounders X
03-10-2022 12:08:59	Unidentified Baleen Whale	1	49.8782	128.854	1 GI gun	X
03-10-2022 16:20:56	Unidentified Baleen Whale	1	49.8213	128.773	1 GI gun	X
03-10-2022 17:03:55	Sperm Whale	1	49.86	128.699	1 GI gun	Shut down GI gun and sounders X

No. = Number of individuals. * For photo of northern right whale dolphin, see Figure 1.

Figure 1. Northern right whale dolphin photographed on 30 September 2022 (Photo credit: Bruce Mactavish)

MARINE MAMMAL TEAM ON BOARD R/V SONNE

LGL Marine Mammal Observers	ONC Marine Mammal Observer
Meike Holst (Project Manager)	Ella Minicola
Bruce Mactavish (Lead MMO)	
Magena Warrior	
Meghan Piercy	

1.3. PAM Field Logs

1.3.1. Winona Basin Seismic Profile (G-Gun array)

Vessel: RV SONNE	Exclusion zone: 1000m all other marine mammals, 1500m for Beaked and Sperm whales, shutdown for Killer whales and North Pacific Right whales
Date (YY/MM/DD in UTC): 22/09/29 – 22/09/30	Number of PAM Operators: 3 (AH, KLM, KAD)
Source Activity: 6 G-gun array (2840in^3) Hydrophone depth: 20m	Total effort: 43 hours, 49 minutes, and 33 seconds (Monitoring) and 1 hour (Deployment)
PAM Array: two 2-element apertures (1 m hydrophone spacing) towed at 200 m and 300 m starboard aft of vessel stern	PAM Software: PAMlab V9.13.1 (JASCO Applied Sciences)
Total number of detections: 2	Species detected: Fin whale and Unknown Odontocete

Data Code: Species=common name or species category (1=uncertain, 2=fairly certain, 3=confident); Signal Description=tonal or click or call type; SPL and Bearing=Ch1+2(top), Ch3+4(bottom/shaded); Complete entry 1) start of monitoring 2) marine mammal first spotted for PAM/MMO

Table 5. Field log entries during PAM monitoring. Light blue shaded rows indicate Channel 3+4. Grey shaded rows indicate no data applicable.

Date (YY/MM/DD)	Time (HH:MM:SS UTC)	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., pre-clear, ramp-up, snapshots taken)
22/09/29	00:48:10		-	-	-	-	-	-	-	-	-	PAM started
22/09/29	01:31:31	49°28.290’, 129°06.203’W	20	continuous	154.0 -	Fin whale (3)	Band of distant fin whales, no individual calls	Y	- -	>1000	N	Fin whales in distance, increased the frequency band. Only call shutdown if individual calls seen

Date (YY/MM/DD)	Time (HH:MM:SS UTC)	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., pre-clear, ramp-up, snapshots taken)
22/09/29	20:28:06		-	-	-	-	-	-	-	-	-	MMO shutdown for sea lions. Not detected on PAM.
22/09/30	01:40:50		-	-	-	-	-	-	-	-	-	MMO shutdown for Fin whale at 300m. No calls detected.
22/09/30	04:38:27	49°54.007', 129°01.287'W	64000	0.01	130 135	Unknown	Unknown Odontocete Click	Y	- -	>1500	N	Confirm more calls before call shutdown
22/09/30	15:59:18		-	-	-	-	-	-	-	-	-	MMO shut down for sea lion. No detections on PAM.
22/09/30	20:00:52		-	-	-	-	-	-	-	-	-	Airgun profile complete

*Distance inferred from species Source Level (SL). See Table .

1.3.2. Winona Basin Seismic Profile (Single GI-Gun)

Vessel: RV SONNE	Exclusion zone: 1000m all other marine mammals, 1500m for Beaked and Sperm whales, shutdown for Killer whales and North Pacific Right whales
Date (YY/MM/DD in UTC): 22/09/30 – 22/10/03	Number of PAM Operators: 3 (AH, KLM, KAD)
Source Activity: GI-gun Hydrophone depth: 20m	Total effort: 82 hours, 14 minutes, and 58 seconds (Monitoring)
PAM Array: two 2-element apertures (1 m hydrophone spacing) towed at 200 m and 300 m starboard aft of vessel stern	PAM Software: PAMlab V9.13.1 (JASCO Applied Sciences)
Total detections: 5	Species detected: Pacific white-sided dolphins and Fin whale

Data Code: Species=common name or species category (1=uncertain, 2=fairly certain, 3=confident); Signal Description=tonal or lick or call type; SPL and Bearing=Ch1+2(top), Ch3+4(bottom/shaded); Complete entry 1) start of monitoring 2) marine mammal first spotted for PAM/MMO

Table 6. Field log entries during PAM monitoring. Light blue shaded rows indicate Channel 3+4. Grey shaded rows indicate no data applicable.

Date (YY/MM/DD)	Time (HH:MM:SS UTC)	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., pre-clear, ramp-up, snapshots taken)
22/09/30	20:45:02	-	-	-	-	-	-	-	-	-	-	PAM started; Echosounder on
22/09/30	21:35:10	-	-	-	-	-	-	-	-	-	Y	MMO shut down for Pacific white-sided dolphins and northern right whale dolphins. No detections on PAM
22/09/30	21:38:32	48°36.408'N, 128°10.345'W	73666	0.00019	- 160.4	Pacific white-sided dolphin (3)	High frequency click-trains (0.07 inter-click interval)	Y	- -	<1000	N	No whistles or northern right whale dolphin vocalizations (too high frequency)

Date (YY/MM/DD)	Time (HH:MM:SS UTC)	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., pre-clear, ramp-up, snapshots taken)
22/10/01	15:21:12	-	-	-	-	-	-	-	-	-	-	MMO shut down for Fin whale. No detections on PAM
22/10/01	21:14:20	-	-	-	-	-	-	-	-	-	-	MMO shut down for Fin whale. No detections on PAM
22/10/02	12:24:06	48°47.555'N, 128°49.382'W	21	0.8	148 -	Fin whale (3)	20 Hz downsweep	N	257 -	<1000	N	Confirm a couple more fin calls to call shutdown
22/10/02	12:36:56	49°47.258'N, 128°50.129'W	19	0.5	146.1 -	Fin whale (3)	20 Hz downsweep	N	292	<1000	N	Confirm a couple more fin calls to call shutdown
22/10/02	12:39:57	49°46.958'N, 128°50.729'W	21.9	0.7	146.9 -	Fin whale (3)	20 Hz downsweep	Y	255	<1000	Y	Confirmed fin whale in exclusion zone. Shut down called by PAM.
22/10/03	10:57:30	49°45.688'N, 128°16.971'W	21.6	0.46	150.6 128.7	Fin whale (3)	20 Hz downsweep	Y	314 263	<1000	Y	Shut down called by PAM
22/10/03	14:55:40	-	-	-	-	-	-	-	-	-	-Y	MMO shutdown for unknown whale. No detections on PAM.

1.3.3. Spectrogram

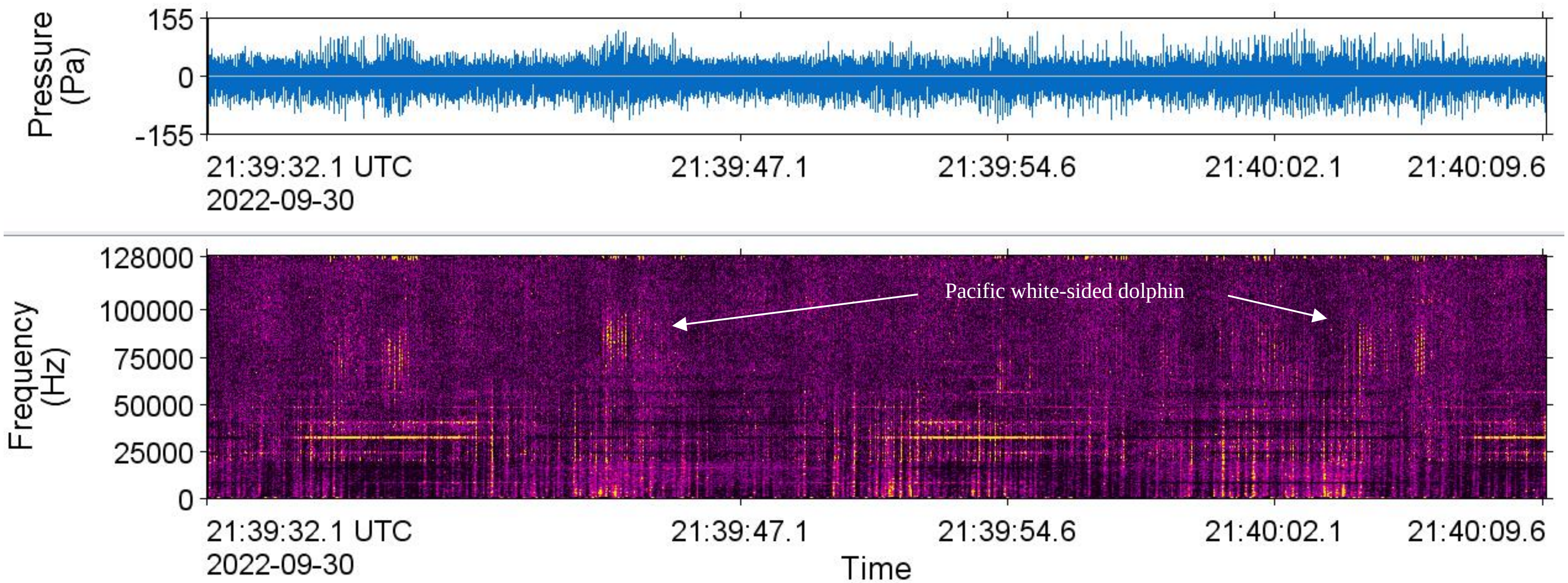

Figure 2. A waveform (above) and spectrogram (below; 0-60 Hz: 0.4 Hz frequency resolution, 2s time window, 0.5 s time step; 60 Hz-20 kHz: 2 Hz frequency resolution, 0.125s time window, 0.03125 s time step; 20-128 kHz: 2 Hz frequency resolution, 0.01s time window, 0.005 s time step, Hamming window, normalized across-time), zoomed out in time (44.4 s duration), displaying Pacific white-sided dolphin clicks.

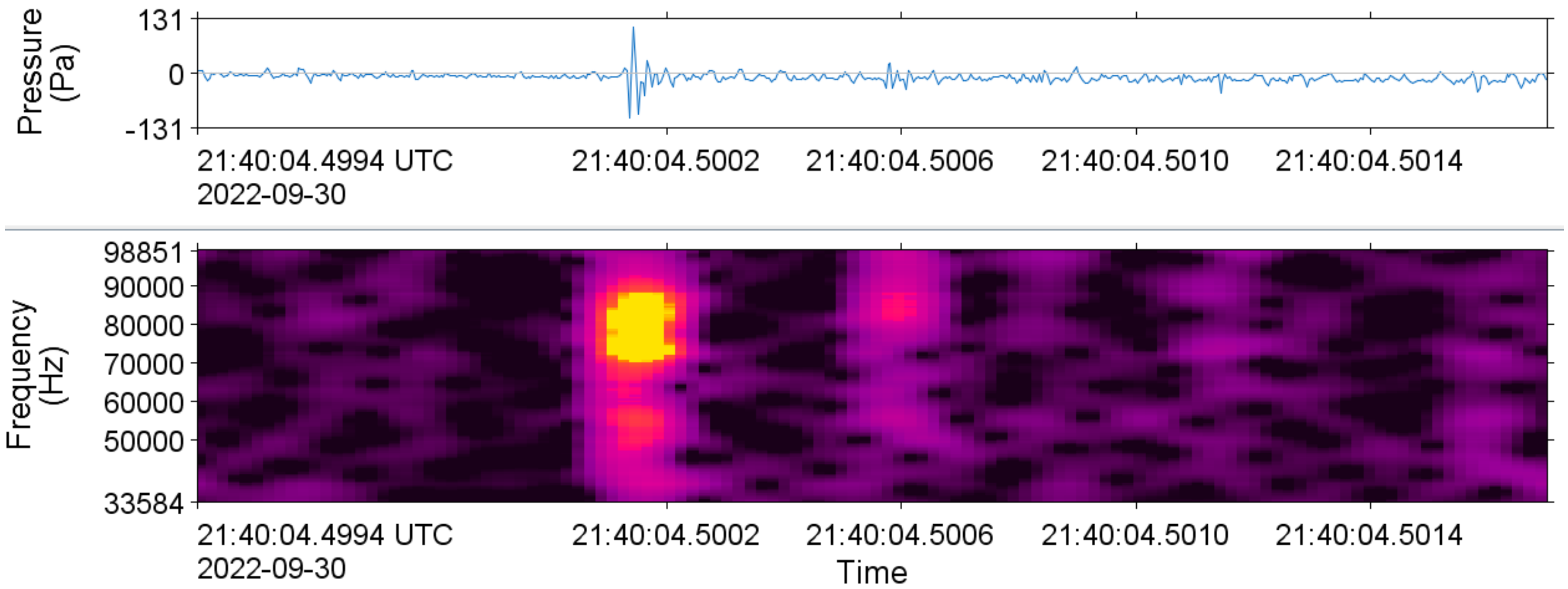

Figure 3. A waveform (above) and spectrogram (below; 512 Hz frequency resolution, 0.000226s time window, 0.00002 s time step; Hamming window, normalized across-time), zoomed in time (0.0023 s duration), displaying Pacific white-sided dolphin click.

1.4. Species Source Levels

1.4.1. Sound Pressure Level calculated from Source Level

Table 7. Mean species source level and calculated Sound Pressure Level (SPL) at 500, 1000, and 1500m. Shaded boxes indicate exclusion zone per species required for mitigation during air gun activity. Attenuation calculations are based on 20*log10(range).

Species	Source level (mean dB)	SPL if within 500m of hydrophone (dB)	SPL if within 1000m of hydrophone (dB)	SPL if within 1500m of hydrophone (dB)
Cetaceans				
North Pacific right whale	177.0	123.0	117.0	113.5
Killer whale whistles	154.0	100.0	94.0	90.5
Killer whale clicks	193.0	139.0	133.0	129.5
Blue whale	181.3	127.3	121.3	117.8
Fin whale	183.5	129.5	123.5	120.0
Sei whale	176.5	122.5	116.5	113.0
Minke whale	166.0	112.0	106.0	102.5
Gray whale	157.0	103.0	97.0	93.5
Humpback whale	171.5	117.5	111.5	108
Delphinid whistles	158.0	104.0	98.0	94.5
Pilot whale whistles	154.0	100.0	94.0	90.5
Delphinid clicks	188.0	134.0	128.0	124.5
Northern right whale dolphin clicks	157.5	103.5	97.5	94.0
Pacific white-sided dolphin clicks	170.0	116.0	110.0	106.4
Porpoise/Kogia clicks	191.0	137.0	131.0	127.5
Sperm whale	186.0	132.0	126.0	122.5
Baird's beaked whale	*	*	*	*
Blainville's beaked whale	201.0	147.0	141.0	137.5
Cuvier's beaked whale	203.0	149.0	143.0	139.5
Hubb's beaked whale	*	*	*	*
Steineger's beaked whale	*	*	*	*
Pinnipeds				
Harbour seal	144	90.0	84.0	80.5
Northern fur seal	**	**	**	**
Stellar sea lion	**	**	**	**

*No data in the literature, refer to Cuvier's beaked whale.

**No data in the literature, refer to Harbour seal

WEEK FOUR MARINE MAMMAL REPORT

4-10 October 2022, R/V SONNE

CLOCKS CRUISE (21-HPAC-00671)

1.1. General Summary

R/V SONNE conducted activities within the CLOCKS Survey Area during Week 4. Airgun operations with one GI gun took place on a single day (October 4) during Week 4; seismic acquisition for the week concluded at 8:19 am. Passive Acoustic Monitoring (PAM) occurred before and during all airgun operations, and visual observations by marine mammal observers (MMOs) were conducted before and during all daytime airgun operations and bathymetric surveys. Bathymetric mapping with the multibeam and PARASOUND echosounders took place every day during Week 4, including during airgun operations. No airgun operations or bathymetric mapping occurred within Southern Resident Critical Habitat. MMO effort and sightings can be found on Pages 3-4 of this report, and PAM effort and detections can be found on Pages 5-8.

1.1.1. Mitigation Measures

The following monitoring and mitigation measures were followed while airgun operations were conducted, based on recommendations outlined by DFO in the Letter of Advice dated 22 August 2022:

- Use the smallest acoustic source (i.e., single airgun or airgun array) possible to achieve the research goals.
- Conduct seismic survey activities outside of designated SRKW Critical Habitat and outside of sensitive habitats (i.e., Scott Islands Marine National Wildlife Area, Pacific Offshore Area of Interest, or Checleset Bay Ecological Reserve) with a setback that ensures that the estimated sound pressure level has diminished to ≤160 dB_{rms} re 1 µPa for the shortest distance to the boundary of these areas.
- No seismic surveys are to occur in water <200 m deep.
- Combine enhanced visual observations (e.g., reticle and big-eye binoculars, night vision devices and digital cameras) with non-visual detection methods (e.g., infrared technology (FLIR) and passive acoustic monitoring) to increase the likelihood of detecting marine mammals during ramp up, Beaufort sea states >3, and during nighttime survey operations.
- Monitor the established exclusion zone with a radius of 1000 m for 60 minutes prior to initial start-up of the airgun array or resumption of operations following a complete shutdown to allow for the detection of deep diving animals.
- A minimum of two experienced marine mammal observers are to make constant observation, with redundancy of personnel of the vicinity of the survey vessel prior to and during operation of the single airgun or airgun array.
- Passive acoustic monitoring (PAM) is to occur during all seismic operations.

- Initiate an immediate and complete shutdown of the airgun array if a Killer Whale (all ecotypes), Northern Pacific Right Whale, whale with calf (any species) or aggregation of whales (any species) is observed.
- Initiate an immediate and complete shutdown of the airgun array if a Sperm Whale or a beaked whale (any species) is sighted within 1500 m of the airgun array.
- For other observations of marine mammals and/or turtles, initiate an immediate and complete shutdown of the airgun array if these animals are observed within an established exclusion zone with a radius of 1000 m.
- If no marine mammals are observed within the exclusion zone during the 60 minute pre-start observation period, ramp-up the airgun array over a period of 20 minutes starting with the smallest airgun.
- For operations during poor visibility or at night, ramp-up is not to begin until the exclusion zone has been monitored for a minimum of 30 minutes with no detections.

In addition, the following monitoring and mitigation measures were followed during bathymetric mapping using echosounders outside of Southern Resident Critical Habitat; these measures were adopted based on recommendations outlined by DFO in the Letter of Advice for acoustic mapping within Critical Habitat:

- Monitored an exclusion zone with a radius of 500 m for 30 minutes prior to initial start-up of the echosounder or resumption of operations following a complete shutdown.
- Two experienced marine mammal observers made constant observations prior to and during the bathymetric surveys.
- Implemented an immediate and complete shutdown of the echosounders when any marine mammal was observed within an established exclusion zone with a radius of 500 m.

Other mitigation measures considered, when practicable, included:

- Keeping 400 m distance from killer whales in southern BC coastal waters
- Keeping 200 m distance from killer whales in BC, outside of the 400 m approach areas
- Keeping 200 m distance from all cetaceans when in resting position or with a calf
- Keeping 100 m away from all other cetaceans

1.2. Marine Mammal Visual Observations

During Week 4 (4-10 October 2022), the MMOs on R/V SONNE conducted 82.7 hours of watches. There were 0.4 hours of watches during airgun operations with bathymetric mapping, and 59.1 hours during periods of bathymetric mapping outside of critical habitat; the rest of the watches occurred during periods without airgun operations or bathymetric mapping (Table 1). Overall, there were 14 sightings totaling 25 marine mammals in the survey area (Table 2). One mitigation action had to be implemented by the MMOs during Week 4 (see Table 3). A list of all marine mammal sightings during Week 4 is provided in Table 4.

Table 1. Marine mammal visual observations conducted during various vessel activities during Week 4.

Watches during Various Vessel Activities	Hours
Watches during airgun operations with sounders	0.4
Watches during bathymetric mapping with the multibeam and/or PARASOUND (no airguns)	59.1
Watches without airgun operations or sounders	23.2
Total Hours of Observations	**82.7**

Table 2. Summary of marine mammal sightings during Week 4.

Species	# of Sightings	# of Individuals
Dall's Porpoise	1	4
Fin Whale	5	8
Fin/Sei Whale	1	2
Unidentified Baleen whale	2	2
Unidentified Whale	4	4
Pacific White-sided Dolphin	1	5
Total	**14**	**25**

Table 3. Mitigation actions taken during Week 4.

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Vessel Activity	Mitigation Action
10-10-2022 18:18:48	Pacific White-sided Dolphin	5	48.9252	127.104	Multibeam and Parasound	Shutdown sounders when animals came within 500 m

Table 4. List of all marine mammal sightings during Week 4.

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Airgun Operations	Mitigation Action
05-10-2022 07:49:54	Fin Whale	1	49.8124	128.339	No	No
05-10-2022 09:35:00	Unidentified Baleen Whale	1	49.8425	128.316	No	No
07-10-2022 07:52:51	Unidentified Whale	1	50.0498	128.713	No	No
07-10-2022 08:12:33	Unidentified Whale	1	50.0532	128.706	No	No
07-10-2022 08:38:26	Fin Whale	4	50.0543	128.704	No	No
07-10-2022 10:00:00	Fin Whale	1	50.0616	128.69	No	No
07-10-2022 11:01:49	Unidentified Baleen Whale	1	50.0768	128.658	No	No
07-10-2022 13:29:26	Fin/Sei whale	2	49.9845	128.61	No	No
07-10-2022 14:20:41	Fin Whale	1	49.8463	128.548	No	No
09-10-2022 16:58:46	Dall's Porpoise	4	49.8207	128.251	No	No
09-10-2022 17:10:21	Unidentified Whale	1	49.8456	128.224	No	No
09-10-2022 17:50:07	Unidentified Whale	1	49.93	128.131	No	No
10-10-2022 10:03:33	Fin Whale	1	49.2323	127.349	No	No
10-10-2022 18:18:48	Pacific White-sided Dolphin	5	48.9252	127.104	No	Yes

No. = Number of individuals.

MARINE MAMMAL TEAM ON BOARD R/V SONNE

LGL Marine Mammal Observers	ONC Marine Mammal Observer
Meike Holst (Project Manager)	Ella Minicola
Bruce Mactavish (Lead MMO)	
Magena Warrior	
Meghan Piercy	

1.3. PAM Field Logs

1.3.1. Winona Basin Seismic Profile (Single GI-Gun)

Vessel: RV SONNE	Exclusion zone: Shutdown for Killer whales and North Pacific Right whales, 1500m for Beaked and Sperm whales, and 1000m all other marine mammals
Date (YY/MM/DD in UTC): 22/10/04	Number of PAM Operators: 3 (AH, KLM, KAD)
Source Activity: GI-gun(335in^3)	Total effort: 15 hours, 19 minutes, and 30 seconds (Monitoring) and 1 hour (Retrieval)
Hydrophone depth: 30m	
PAM Array: two 2-element apertures (1 m hydrophone spacing) towed at 200 m and 300 m starboard aft of vessel stern	PAM Software: PAMlab V9.13.1 (JASCO Applied Sciences)
Total encounters: 2	Species detected: Fin whale

Data Code: Species=common name or species category (1=uncertain, 2=fairly certain, 3=confident); Signal Description=tonal or click or call type; SPL and Bearing=Ch1+2(top), Ch3+4(bottom/shaded); Complete entry 1) start of monitoring 2) marine mammal first spotted for PAM/MMO

Table 5. Field log entries during PAM monitoring. Light blue shaded rows indicate Channel 3+4. Grey shaded rows indicate no applicable data.

Date (YY/MM/DD)	Time (HH:MM:SS UTC)	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Distance calculated by beamformer (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
22/10/04	00:00:00	-	-	-	-	-	-	-	-	-	-	-	Continued from Week 3
22/10/04	00:03:00	-	-	-	-	-	-	-	-	-	-	Y	Sperm whale sighted by MMOs. Not detected on PAM.
22/10/04	13:24:20	49°44.220'N, 128°20.040'W	16.4	0.7	151.4** -	Fin whale (1)	A note	Y	241 -	<1000**	-	N	If fin song continues for multiple notes and continually <1000m call shutdown. Difficult to distinguish with low frequency vessel noise.
22/10/04	13:26:53	49°43.980'N, 128°20.100'W	29	0.5	152.2** -	Fin whale (1)	B note	Y	268 218	<1000**	400.9	N	
22/10/04	13:29:00	49°43.860'N, 128°20.160'W	23	0.5	150.8** -	Fin whale (2)	B note	Y	299 330	<1000**	257.3	N	
22/10/04	13:32:37	49°43.680'N, 128°20.400'W	16.2	0.5	156.2** -	Fin whale (2)	A note	Y	255 321	<1000**	446.8	N	
22/10/04	13:55:50	49°42.227'N, 128°22.433'W	23	0.5	152.3** -	Fin whale (2)	B note	Y	302 309	<1000**	906.8	Y	8 more detections since last recorded. FW shut down called.
22/10/04	13:59:35	49°42.180'N, 128°22.500'W	23	0.5	151.9** -	Fin whale (2)	B note	Y	314 234	<1000**	338.1	Y	Shut down
22/10/04	14:04:02	49°42.180'N,	16.1	0.5	155.2**	Fin whale (2)	A note	Y	277	<1000**	430.2	Y	Shut down

Date (YY/MM/DD)	Time (HH:MM:SS UTC)	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Distance calculated by beamformer (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
		128°22.500'W							253				
22/10/04	14:07:12	49°41.700'N, 128°23.160'W	21.8	0.5	152.8**	Fin whale (2)	B note	Y	273 279	<1000**	1040.9	Y	Shut down
22/10/04	14:26:57	49°40.500'N, 128°24.780'W	18.1	0.5	153.5**	Fin whale (2)	A note	N	257 282	<1000**	409.7	Y	20 more detections since last recorded.
22/10/04	14:43:00	49°39.540'N, 128°26.100'W	16.7	0.6	-	Fin whale (2)	A note	N	280 248	-	1190.2	Y	Cleared by PAM to restart airgun.
22/10/04	15:19:30	-	-	-		-	-	-		-	-	-	End of profile

*Distance inferred from species Source Level (SL). See Table

**SPL inaccurate for calculating distance due to loud low frequency vessel noise masking calls.

1.4. Species Source Levels

1.4.1. Sound Pressure Level calculated from Source Level

Table 6. Mean species source level and calculated Sound Pressure Level (SPL) at 500, 1000, and 1500m. Shaded boxes indicate exclusion zone per species required for mitigation during air gun activity. Attenuation calculations are based on 20*log10(range).

Species	Source level (mean dB)	SPL if within 500m of hydrophone (dB)	SPL if within 1000m of hydrophone (dB)	SPL if within 1500m of hydrophone (dB)
Cetaceans				
North Pacific right whale	177.0	123.0	117.0	113.5
Killer whale whistles	154.0	100.0	94.0	90.5
Killer whale clicks	193.0	139.0	133.0	129.5
Blue whale	181.3	127.3	121.3	117.8
Fin whale	183.5	129.5	123.5	120.0
Sei whale	176.5	122.5	116.5	113.0
Minke whale	166.0	112.0	106.0	102.5
Gray whale	157.0	103.0	97.0	93.5
Humpback whale	171.5	117.5	111.5	108
Delphinid whistles	158.0	104.0	98.0	94.5
Pilot whale whistles	154.0	100.0	94.0	90.5
Delphinid clicks	188.0	134.0	128.0	124.5
Northern right whale dolphin clicks	157.5	103.5	97.5	94.0
Pacific white-sided dolphin clicks	170.0	116.0	110.0	106.4
Porpoise/Kogia clicks	191.0	137.0	131.0	127.5
Sperm whale	186.0	132.0	126.0	122.5
Baird's beaked whale	*	*	*	*
Blainville's beaked whale	201.0	147.0	141.0	137.5
Cuvier's beaked whale	203.0	149.0	143.0	139.5
Hubb's beaked whale	*	*	*	*
Steineger's beaked whale	*	*	*	*
Pinnipeds				
Harbour seal	144	90.0	84.0	80.5
Northern fur seal	**	**	**	**
Stellar sea lion	**	**	**	**

*No data in the literature, refer to Cuvier's beaked whale.

**No data in the literature, refer to Harbour seal

WEEK FIVE MARINE MAMMAL REPORT

11-17 October 2022, R/V SONNE

CLOCKS CRUISE (21-HPAC-00671)

1.1. General Summary

R/V SONNE conducted activities within the CLOCKS Survey Area during Week 5. Airgun operations with one GI gun took place during October 12-14, and seismic operations with the 6 G gun array took place during October 14-15. Passive Acoustic Monitoring (PAM) occurred before and during all airgun operations, and visual observations by marine mammal observers (MMOs) were conducted before and during all daytime airgun operations and bathymetric surveys. Bathymetric mapping with the multibeam and PARASOUND echosounders took place every day during Week 5, including during airgun operations. No airgun operations or bathymetric mapping occurred within Southern Resident Critical Habitat. MMO effort and sightings can be found on Pages 2-5 of this report, and PAM effort and detections can be found on Pages 6-9.

1.1.1. Mitigation Measures

The following monitoring and mitigation measures were followed while airgun operations were conducted, based on recommendations outlined by DFO in the Letter of Advice dated 22 August 2022:

- Use the smallest acoustic source (i.e., single airgun or airgun array) possible to achieve the research goals.
- Conduct seismic survey activities outside of designated SRKW Critical Habitat and outside of sensitive habitats (i.e., Scott Islands Marine National Wildlife Area, Pacific Offshore Area of Interest, or Checleset Bay Ecological Reserve) with a setback that ensures that the estimated sound pressure level has diminished to ≤160 dB_{rms} re 1 µPa for the shortest distance to the boundary of these areas.
- No seismic surveys are to occur in water <200 m deep.
- Combine enhanced visual observations (e.g., reticle and big-eye binoculars, night vision devices and digital cameras) with non-visual detection methods (e.g., infrared technology (FLIR) and passive acoustic monitoring) to increase the likelihood of detecting marine mammals during ramp up, Beaufort sea states >3, and during nighttime survey operations.
- Monitor the established exclusion zone with a radius of 1000 m for 60 minutes prior to initial start-up of the airgun array or resumption of operations following a complete shutdown to allow for the detection of deep diving animals.
- A minimum of two experienced marine mammal observers are to make constant observation, with redundancy of personnel of the vicinity of the survey vessel prior to and during operation of the single airgun or airgun array.
- Passive acoustic monitoring (PAM) is to occur during all seismic operations.

- Initiate an immediate and complete shutdown of the airgun array if a Killer Whale (all ecotypes), Northern Pacific Right Whale, whale with calf (any species) or aggregation of whales (any species) is observed.
- Initiate an immediate and complete shutdown of the airgun array if a Sperm Whale or a beaked whale (any species) is sighted within 1500 m of the airgun array.
- For other observations of marine mammals and/or turtles, initiate an immediate and complete shutdown of the airgun array if these animals are observed within an established exclusion zone with a radius of 1000 m.
- If no marine mammals are observed within the exclusion zone during the 60 minute pre-start observation period, ramp-up the airgun array over a period of 20 minutes starting with the smallest airgun.
- For operations during poor visibility or at night, ramp-up is not to begin until the exclusion zone has been monitored for a minimum of 30 minutes with no detections.

In addition, the following monitoring and mitigation measures were followed during bathymetric mapping using echosounders outside of Southern Resident Critical Habitat; these measures were adopted based on recommendations outlined by DFO in the Letter of Advice for acoustic mapping within Critical Habitat:

- Monitored an exclusion zone with a radius of 500 m for 30 minutes prior to initial start-up of the echosounder or resumption of operations following a complete shutdown.
- Two experienced marine mammal observers made constant observations prior to and during the bathymetric surveys.
- Implemented an immediate and complete shutdown of the echosounders when any marine mammal was observed within an established exclusion zone with a radius of 500 m.

Other mitigation measures considered, when practicable, included:

- Keeping 400 m distance from killer whales in southern BC coastal waters
- Keeping 200 m distance from killer whales in BC, outside of the 400 m approach areas
- Keeping 200 m distance from all cetaceans when in resting position or with a calf
- Keeping 100 m away from all other cetaceans

1.2. Marine Mammal Visual Observations

During Week 5 (11-17 October 2022), the MMOs on R/V SONNE conducted 81.6 hours of watches. There were 28.3 hours of watches during airgun operations with the single GI gun, 10.7 hours of observations during seismic operations with the 6 G gun array, and 27.9 hours during periods of bathymetric mapping outside of critical habitat; the rest of the watches occurred during periods without airgun operations or bathymetric mapping (Table 1). Overall, there were 14 sightings totaling 395 marine mammals in the survey area (Table 2). Three mitigation actions had to be implemented by the MMOs during Week 5 – two shut downs of the sounders and one shut down of the airgun array (see Table 3). A list of all marine mammal sightings during Week 5 is provided in Table 4.

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Table 1. Marine mammal visual observations conducted during various vessel activities during Week 5.

Watches during Various Vessel Activities	Hours
Watches during airgun operations with one GI gun and sounders	28.3
Watches during airgun operations with the 6 G gun array and sounders	10.7
Watches during bathymetric mapping with the multibeam and/or PARASOUND (no airguns)	27.9
Watches without airgun operations or sounders	14.7
Total Hours of Observations	**81.6**

Table 2. Summary of marine mammal sightings during Week 5.

Species	# of Sightings	# of Individuals
Harbour Porpoise	1	4
Humpback Whale	2	2
Fin Whale	1	2
Unidentified Fin/Sei Whale	1	1
Unidentified Baleen Whale	3	3
Unidentified Whale	3	3
Pacific White-sided Dolphin	1	5
Pacific White-sided Dolphin/Northern Right Whale Dolphin*	2	375
Total	**14**	**395**

*Mixed groups consisted of 125+ northern right whale dolphins and 250+ Pacific white-sided dolphins; see Figure 1 for photo of northern right whale dolphins.

Table 3. Mitigation actions taken during Week 5.

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Vessel Activity	Mitigation Action
11-10-2022 07:58:58	Pacific White-Sided /Northern Right Whale Dolphins*	100/ 25	49.0601	127.0347	Sounders	Shutdown sounders when animals came within 500 m
15-10-2022 09:51:10	Unidentified Whale	1	48.6316	126.685	6 G gun array + sounders	Shutdown airguns + sounders when animal seen within 1000 m
17-10-2022 10:46:18	Pacific White-Sided/Northern Right Whale Dolphins*	150+/ 100+	48.7588	126.728	Sounders	Shutdown sounders when animals came within 500 m

*Mixed group; see Figure 1 for photo of northern right whale dolphins.

Table 4. List of all marine mammal sightings during Week 5.

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Airgun Operations	Mitigation Action
11-10-2022 07:58:58	Pacific White-Sided /Northern Right Whale Dolphins*	100/ 25	49.0601	127.0347	X	Yes, see Table 3
13-10-2022 09:28:52	Fin Whale	2	48.6003	127.213	Single GI gun + Sounders	-
13-10-2022 16:34:37	Unidentified Whale	1	48.3986	126.942	Single GI gun + Sounders	-
14-10-2022 09:19:20	Unidentified Baleen Whale	1	48.0722	126.652	Single GI gun + Sounders	-
15-10-2022 09:51:10	Unidentified Whale	1	48.6316	126.685	6 G gun array + sounders	Yes, see Table 3
15-10-2022 18:19:49	Harbour Porpoise	4	48.9935	126.026	X	-
16-10-2022 08:13:14	Pacific White-Sided Dolphins	5	48.704	126.568	X	-
16-10-2022 16:36:47	Unidentified Baleen Whale	1	48.6393	126.686	X	-
16-10-2022 16:36:47	Unidentified Baleen Whale	1	48.6347	126.681	X	-
17-10-2022 09:45:18	Unidentified Whale	1	48.6965	126.971	X	-
17-10-2022 10:46:18	Pacific White-Sided/Northern Right Whale Dolphins*	150+/ 100+	48.7588	126.728	X	Yes, see Table 3
17-10-2022 12:08:42	Humpback Whale	1	48.8375	126.421	X	-
17-10-2022 16:41:42	Humpback Whale	1	48.8976	126.741	X	-
17-10-2022 16:41:42	Fin/Sei whale	1	48.9029	126.933	X	-

No. = Number of individuals. *Mixed group; see Figure 1 for photo of northern right whale dolphins.

Figure 1. Northern right whale dolphins photographed on 17 October 2022 (Photo credit: Bruce Mactavish)

MARINE MAMMAL TEAM ON BOARD R/V SONNE

LGL Marine Mammal Observers	ONC Marine Mammal Observer
Meike Holst (Project Manager)	Ella Minicola
Bruce Mactavish (Lead MMO)	
Magena Warrior	
Meghan Piercy	

1.3. PAM Field Logs

1.3.1. Juan de Fuca Plate Seismic Profile (GI-gun and G-gun array)

Vessel: RV SONNE	Exclusion zone: Shutdown for killer whales or North Pacific right whales at any distance, 1500 m for beaked and sperm whales, and 1000 m all other marine mammals,
Date (YY/MM/DD in UTC): 22/10/12-22/10/15	Number of PAM Operators: 3 (AH, KLM, KAD)
Source Activity: GI-gun (355in^3) and 6G-gun array (2840in^3)	Total effort: 77 hours, 29 minutes, and 47 seconds (Monitoring) and 2 hours (Deployment and Retrieval)
Hydrophone depth: 30m	
PAM Array: two 2-element apertures (1 m hydrophone spacing) towed at 200 m and 300 m starboard aft of vessel stern	PAM Software: PAMlab V9.13.1 (JASCO Applied Sciences)
Total encounters: 0	Species detected: None

Data Code: Species=common name or species category (1=uncertain, 2=fairly certain, 3=confident); Signal Description=tonal or click or call type; SPL and Bearing=Ch1+2(top), Ch3+4(bottom/shaded); Complete entry 1) start of monitoring 2) marine mammal first spotted for PAM/MMO 3) any change in source activity

Table 5. Field log entries during PAM monitoring. Light blue shaded rows indicate Channel 3+4. Grey shaded rows indicate no applicable data.

Date (YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL (m)	Distance calculated by beamformer (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
22/10/12	17:00:25	AH	-	-	-	-	-	-	-	-	-	-	PAM started
	17:05:20		-	-	-	-	-	-	-	-	-	-	GI-gun first shot, every 10s
	18:10:14	KLM	13500-	0.11 (1.7	-	Teledyne	Ping	Y	-	-	-	N	R/V SONNE hull

Date (YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL (m)	Distance calculated by beamformer (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
			24000 (19000)	interval)	115.5-	PS70			-				mounted ParaSound-
22/10/12	18:23:41	KLM	58000	-	- -	Unknown	Monotone	N	- -	-	-	N	Unknown tone
22/10/14	00:42:48	AH	100-4000	-	- 124	Vessel noise	Propellor?	Y	- 342	-	-	N	Loud vessel, tankers on horizon
	21:23:50	KAD	-	-	-	-	-	-	-	-	-	Y	GI-gun off. MMO and PAM continue watch. EM122 still on
	22:52:20	AH	-	-	-	-	-	-	-	-	-	-	Ramp up started. First G-gun shot.
	23:00:00		-	-	-	-	-	-	-	-	-	-	Ramp up complete. Shooting 6 guns every 30 secs.
22/10/15	15:29:30	KLM	-	-	-	-	-	-	-	-	-	Y	Airgun stopped (mechanical issues)
	15:35:50		-	-	-	-	-	-	-	-	-	-	Airguns back on.
	16:50:00		-	-	-	-	-	-	-	-	-	Y	MMO shut down for unidentified marine mammal
	17:22:20		-	-	-	-	-	-	-	-	-	-	6G Gun Airgun ramp up. EM122 and PS70 on
	17:42:56		-	-	-	-	-	-	-	-	-	-	Ramp up complete

Date (YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL (m)	Distance calculated by beamformer (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
22/10/15	20:33:00	KAD	-	-	-	-	-	-	-	-	-	-	Multibeam EM710 turned on
	21:57:52		10000-14000 (11000)	0.1	- 134	Multibeam echosounder EM710	Ping	N	- -	-	-	N	1.1s intervals
	21:59:13		13500-24000 (20500)	0.1	- 121.9	Teledyne PS70	Ping	N	- -	-	-	N	1.8s intervals
	22:28:47	AH	-	-	-	-	-	-	-	-	-	Y	Profile complete. Guns off

1.4. Spectrogram

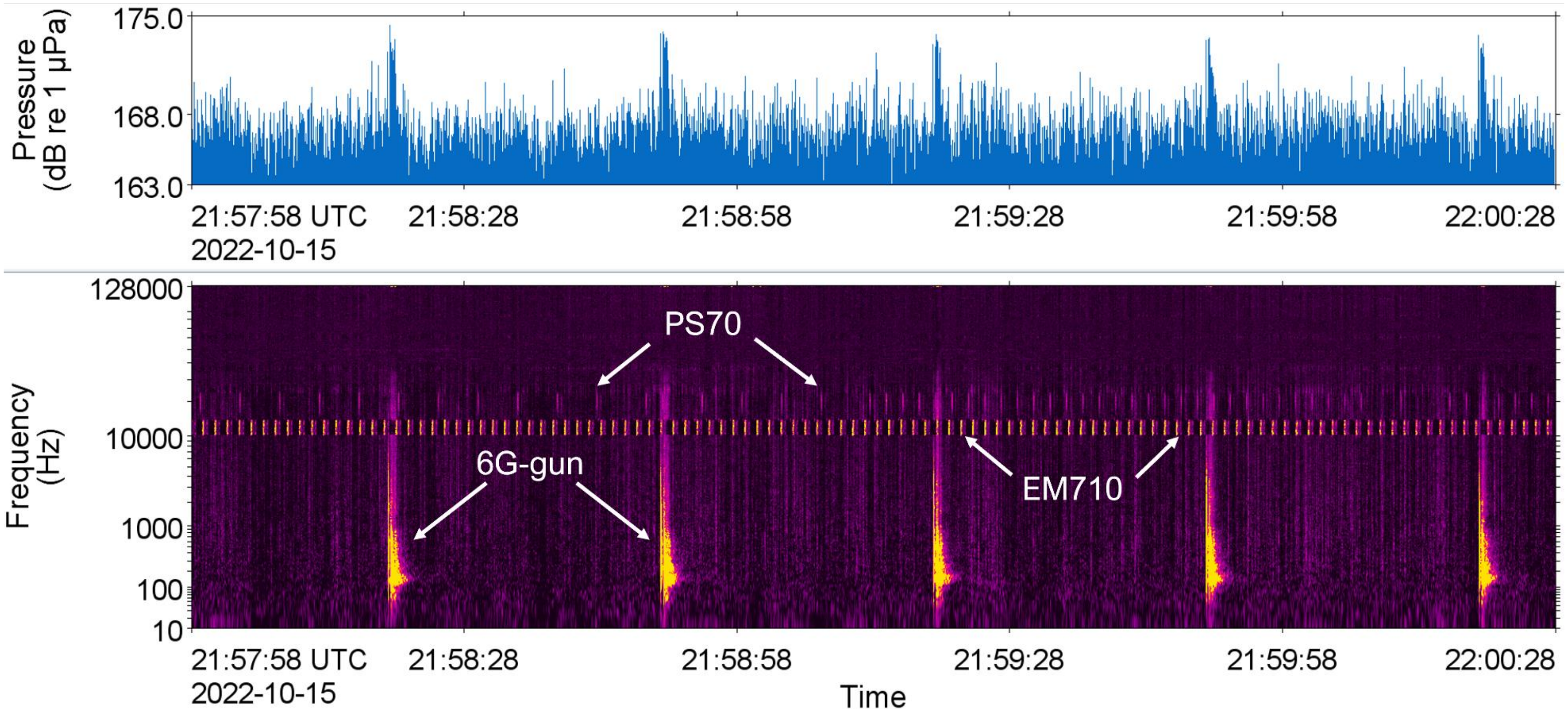

Figure 2. A waveform (above) and spectrogram (below; 2 Hz frequency resolution, 0.125s time window, 0.03125 s time step, Hamming window, normalized across-time), zoomed out in time (150 s duration), in log scale, displaying the 6 G-gun, Kongsberg multibeam echo sounder (EM710) and Teledyne ParaSound sub-bottom profiler (PS70) on 15 Oct 2022.

WEEK SIX MARINE MAMMAL REPORT

18-20 October 2022, R/V SONNE

CLOCKS CRUISE (21-HPAC-00671)

1.1. General Summary

R/V SONNE conducted activities within the CLOCKS Survey Area and within Killer Whale Critical Habitat during Week 6. The multibeam and PARASOUND echosounders were used outside of critical habitat on October 18 and within Killer Whale Critical Habitat on 19-20 October. The vessel departed Canadian waters on the evening of 20 October and marine mammal observations ended. No airgun operations took place during Week 6. Visual observations by marine mammal observers (MMOs) were conducted before and during all daytime acoustic bathymetric mapping within and outside of critical habitat; Passive Acoustic Monitoring (PAM) occurred only within critical habitat. MMO effort and sightings can be found on Pages 2-5 of this report, and PAM effort and detections can be found on Pages 6-26.

1.1.1. Mitigation Measures

The following monitoring and mitigation measures were followed while conducting bathymetric mapping with the multibeam echosounder in Killer Whale Critical Habitat (and outside of Critical Habitat, when practicable) based on the recommendations outlined by DFO in the Letter of Advice dated 22 August 2022:

- Bathymetric mapping using multibeam echosounders and a PARASOUND sub-bottom profiler were the only activities conducted within the Swiftsure and La Perouse survey areas.
- The smallest acoustic source possible was used to achieve the research goals.
- To allow for the greatest detection of killer whales, bathymetric surveys only occurred during daylight hours and when weather conditions permitted visual observations of marine mammals.
- Bathymetric surveys were not conducted during periods of adverse weather.
- Combined enhanced visual observations with non-visual detection methods to increase the likelihood of detecting marine mammals.
- Monitored the established Killer Whale (all ecotypes) exclusion zone with a radius of 1000 m for 30 minutes prior to initial start-up of the echosounder or resumption of operations following a complete shutdown.
- Two experienced marine mammal observers made constant observations prior to and during the bathymetric surveys.
- Passive acoustic monitoring occurred during all surveys.
- An immediate and complete shutdown of the echosounders would have been implemented if a Killer Whale (all ecotypes) were to have been observed within an established exclusion zone with a minimum radius of 1000 m.
- For other observations of marine mammals and/or turtles, an immediate and complete shutdown of the echosounders was initiated when these animals were observed within an established exclusion zone with a radius of 500 m.

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- When transiting through the two seasonal slowdown areas located near Swiftsure Bank, the vessel slowed down to a speed of 10 knots or less. The vessel reduced speed when it was within 1000 m of the nearest killer whale.

Other mitigation measures considered, when practicable, included:

- Keeping 400 m distance from killer whales in southern BC coastal waters
- Keeping 200 m distance from killer whales in BC, outside of the 400 m approach areas
- Keeping 200 m distance from all cetaceans when in resting position or with a calf
- Keeping 100 m away from all other cetaceans

1.2. Marine Mammal Visual Observations

During Week 6 (18-20 October 2022), the MMOs on R/V SONNE conducted 33.4 hours of watches. There were 12.5 hours of observations during periods of bathymetric mapping within Killer Whale Critical Habitat, and 6.6 hours of watches during periods of bathymetric mapping outside of critical habitat; the rest of the watches occurred during periods without bathymetric mapping (Table 1). Overall, there were 28 sightings totaling 60 marine mammals in the survey area (Table 2). Eleven mitigation actions had to be implemented by the MMOs during Week 6 (see Table 3). A list of all marine mammal sightings during Week 6 is provided in Table 4.

Table 1. Marine mammal visual observations conducted during various vessel activities during Week 6.

Watches during Various Vessel Activities	Hours
Watches during bathymetric mapping with the multibeam and/or PARASOUND (no airguns) inside Killer Whale Critical Habitat	12.5
Watches during bathymetric mapping with the multibeam and/or PARASOUND (no airguns) outside of Killer Whale Critical Habitat	6.6
Watches without airgun operations or sounders	14.3
Total Hours of Observations	**33.4**

Table 2. Summary of marine mammal sightings during Week 6.

Species	# of Sightings	# of Individuals
Humpback Whale	21	42
Unidentified Baleen Whale	2	2
Unidentified Whale	3	5
Killer Whale	1	10
Steller Sea Lion	1	1
Total	**28**	**60**

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environmental research associates

Table 3. Mitigation actions taken during Week 6.

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Vessel Activity	Mitigation Action
19-10-2022 13:58:00	Humpback Whale	1	48.4294	125.949	Multibeam in CH	Shutdown multibeam when animal came within 500 m
19-10-2022 16:19:05	Steller Sea Lion	1	48.4404	125.984	Multibeam in CH	Shutdown multibeam when animal came within 500 m
19-10-2022 16:20:43	Humpback Whale	1	48.4409	125.987	Multibeam in CH	Multibeam already shutdown; Extended shutdown time
19-10-2022 16:56:42^	Humpback Whale	1	48.4309	125.948	Multibeam in CH	One of six whales caused shutdown of multibeam when it came within 500 m
20-10-2022 09:48:34	Humpback Whale	1	48.3523	125.805	Multibeam in CH	Shutdown multibeam when PAM detected calls within 500 m
20-10-2022 10:25:03	Humpback Whale	2	48.3843	125.841	Multibeam in CH	Shutdown multibeam when animals came within 500 m
20-10-2022 10:56:51	Humpback Whale	2	48.4156	125.861	Multibeam in CH	Shutdown multibeam when animals came within 500 m
20-10-2022 10:58:32	Killer Whale*	10	48.4172	125.858	Multibeam in CH	Multibeam already shutdown; Extended shutdown time
20-10-2022 15:11:48^	Humpback Whale	1	48.408	125.832	Multibeam in CH	One of two whales caused shutdown of multibeam when it came within 500 m
20-10-2022 15:32:48	Humpback Whale	1	48.3818	125.808	Multibeam in CH	Multibeam already shutdown; Extended shutdown time
20-10-2022 16:29:20	Humpback Whale	2	48.3731	125.822	Multibeam in CH	Shutdown multibeam when animals came within 500 m
20-10-2022 17:29:57^	Humpback Whale	1	48.423	125.839	Multibeam in CH	One of three whales caused shutdown of multibeam when it came within 500 m

No. = Number of individuals. CH = Killer Whale Critical Habitat. ^Shutdown time different from initial sighting time.
*Transient killer whales as identified by acoustic detections (see photo, Fig. 1).

Table 4. List of all marine mammal sightings during Week 6.

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Multibeam in Critical Habitat+	Mitigation Action
18-10-2022 08:22:50	Unidentified Whale	2	48.903	127.427	No	-
19-10-2022 13:25:46	Humpback Whale	1	48.4387	125.919	Yes	-
19-10-2022 13:58:00	Humpback Whale	1	48.4294	125.949	Yes	Yes, see Table 3
19-10-2022 16:19:05	Steller Sea Lion	1	48.4404	125.984	Yes	Yes, see Table 3
19-10-2022 16:20:43	Humpback Whale	1	48.4409	125.987	Yes	Yes, see Table 3
19-10-2022 17:18:36^	Humpback Whale	6	48.4309	125.948	Yes	Yes, see Table 3

Date and Local Time	Species	No.	Latitude (°N)	Longitude (°W)	Multibeam in Critical Habitat+	Mitigation Action
19-10-2022 18:33:57	Unidentified Whale	1	48.4341	126.000	Yes	-
20-10-2022 08:46:00	Humpback Whale	2	48.3612	125.796	Yes	-
20-10-2022 09:01:52	Humpback Whale	7	48.3639	125.82	Yes	-
20-10-2022 09:32:41	Unidentified Whale	2	48.3399	125.802	Yes	-
20-10-2022 09:48:34	Humpback Whale	1	48.3523	125.805	Yes	Yes, see Table 3
20-10-2022 10:05:26	Humpback Whale	1	48.3657	125.824	Yes	-
20-10-2022 10:25:03	Humpback Whale	2	48.3843	125.841	Yes	Yes, see Table 3
20-10-2022 10:56:51	Humpback Whale	2	48.4156	125.861	Yes	Yes, see Table 3
20-10-2022 10:58:32	Killer Whale*	10	48.4172	125.858	Yes	Yes, see Table 3
20-10-2022 11:55:53	Humpback Whale	1	48.4124	125.869	Yes	-
20-10-2022 12:46:50	Humpback Whale	2	48.4277	125.941	Yes	-
20-10-2022 14:49:54^	Humpback Whale	2	48.408	125.832	Yes	Yes, see Table 3
20-10-2022 15:18:52	Unidentified Baleen Whale	1	48.3995	125.823	Yes	-
20-10-2022 15:27:25	Unidentified Baleen Whale	1	48.3885	125.813	Yes	-
20-10-2022 15:32:48	Humpback Whale	1	48.3818	125.808	Yes	Yes, see Table 3
20-10-2022 16:05:10	Humpback Whale	1	48.3531	125.804	Yes	-
20-10-2022 16:14:51	Humpback Whale	2	48.3609	125.812	Yes	-
20-10-2022 16:29:20	Humpback Whale	2	48.3731	125.822	Yes	Yes, see Table 3
20-10-2022 16:44:39	Humpback Whale	1	48.3872	125.835	Yes	-
20-10-2022 17:00:35	Humpback Whale	2	48.4004	125.847	Yes	-
20-10-2022 17:19:55	Humpback Whale	1	48.4181	125.855	Yes	-
20-10-2022 17:19:55^	Humpback Whale	3	48.423	125.839	Yes	Yes, see Table 3

No. = Number of individuals. ^Mitigation occurred after initial sighting time; see Table 3. *Transient killer whales as identified by acoustic detections (see photo, Fig. 1). +General vessel activity in the survey area; multibeam was not operational during all sightings due to numerous mitigation shut downs.

Figure 1. Killer whale photographed on 20 October 2022 in the Killer Whale Critical Habitat (Photo credit: April Houweling, JASCO)

MARINE MAMMAL TEAM ON BOARD R/V SONNE

LGL Marine Mammal Observers	ONC Marine Mammal Observer
Meike Holst (Project Manager)	Ella Minicola
Bruce Mactavish (Lead MMO)	
Magena Warrior	
Meghan Piercy	

1.3. PAM Field Logs

1.3.1. Barkley Canyon Multibeam Echosounder (EM710) in Southern Resident Killer Whale (SRKW) Critical Habitat, 19 to 20 October 2022

Vessel: RV SONNE	Exclusion zone: 1000 m for killer whales, 500 m all other marine mammals
Date (YY/MM/DD in UTC): 22/10/19 – 2022/10/20	Number of PAM Operators: 3 (AH, KLM, KAD); 1.5 hour rotation
Source Activity: Kongsberg EM 710 Multibeam	Total effort: 8 hours, 21minutes and 10 seconds (Monitoring) and 2 hours (Deployment and Retrieval)
Hydrophone depth: 30m	
PAM Array: two 2-element apertures (1 m hydrophone spacing) towed at 200 m and 300 m starboard aft of vessel stern	PAM Software: PAMlab V9.13.1 (JASCO Applied Sciences)
Total encounters: 3	Species detected: 1

Data Code: Species=common name or species category (1=uncertain, 2=fairly certain, 3=confident); Signal Description=tonal or click or call type; SPL and Bearing=Ch1+2(top), Ch3+4(bottom/shaded); Complete entry 1) start of monitoring 2) marine mammal first spotted for PAM/MMO 3) any change in source activity

Table 5. Field log entries during PAM monitoring. Light blue shaded rows indicate Channel 3+4. Grey shaded rows indicate no applicable data.

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shutdown (Y/N)	Comments (e.g. Pre-clear, ramp-up, snapshots taken)
22/10/19	16:04:00	AH	-	-	-	-	-	-	-	-	-	-	PAM started. 30-min preclear by PAM due to fog.
	16:34:00		-	-	-	-	-	-	-	-	-	-	PAM clear given.
	16:34:50		-	20500	0.1	- 133.1	ParasSound (PS70)	Ping	N	- -	-	N	Multibeam start. Masked by noise, only ParaSound visible on spectrogram.

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shutdown (Y/N)	Comments (e.g. Pre-clear, ramp-up, snapshots taken)
22/10/19	16:42:00	AH	48°24.709'N, 125°54.298'W	331	1.5	- 103.2	Humpback (1)	Faint moan	Y	- 268	>500	N	Not visible on ch1+2 due to noise
	17:53:47		48°26.729'N, 125°59.699'W	292	1 (1.13 interval between calls)	- 98.5	Humpback (2)	Bubble-net feeding calls	Y	- 281	>500	N	Not visible on ch1+2 due to noise
	17:54:49		48°26.751'N, 125°59.602'W	292	1.34	- 102.5	Humpback (2)	Bubble-net feeding calls	Y	- 265	>500	N	
	17:54:26		48°26.751'N, 125°59.602'W	532	0.8	- 96.6	Humpback (2)	Moan	Y	- 271	>500	N	
	18:04:03		48°26.639'N, 125°58.480'W	359	1.5	- 100.1	Humpback (2)	Bubble-net feeding calls	Y	- 273	>500	N	
	18:04:16		48°26.639'N, 125°58.480'W	379	0.7	- 98.6	Humpback (2)	Bubble-net feeding calls	Y	- 276	>500	N	
	18:04:54		48°26.632'N, 125°58.426'W	308	1.0	- 99.4	Humpback (2)	Bubble-net feeding calls	Y	- 274	>500	N	
	18:07:02		48°26.596'N, 125°58.163'W	276	0.7	- 97.6	Humpback (2)	Bubble-net feeding calls	Y	- 259	>500	N	

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shutdown (Y/N)	Comments (e.g. Pre-clear, ramp-up, snapshots taken)
22/10/19	21:00:00	KLM	-	-	-	-	-	-	-	-	-	Y	MMO shutdown for humpbacks. No calls detected. EM710 off.
	22:10:19		48°26.815'N, 125°56.208'W	389	0.5	- 98.9	Humpback (2)	Faint bubble-net feeding calls	Y	- 276	>500	N	Not visible on ch1+2 due to noise
	22:24:25		48°26.372'N, 125°54.642'W	342	0.9	- 102.5	Humpback (2)	Faint bubble-net feeding calls	Y	- 261	>500	N	
	22:24:35		48°26.372'N, 125°54.642'W	307	1.1	- 102.3	Humpback (2)	Faint bubble-net feeding calls	Y	- 275	>500	N	
	22:24:46		48°26.372'N, 125°54.642'W	328	1.1	102.6	Humpback (2)	Faint bubble-net feeding calls	Y	- 260	>500	N	

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shutdown (Y/N)	Comments (e.g. Pre-clear, ramp-up, snapshots taken)
22/10/19	22:30:46	AH	48°25.970'N 125°54.730'W	340	1.2	99.9	Humpback (2)	Faint bubble-net feeding calls	Y	- 256	>500	N	
	23:06:01		48°26.188'N, 125°57.740'W	396	0.7	- 100.5	Humpback (2)	Faint bubble-net feeding calls	Y	- 271	>500	N	Not visible on ch1+2 due to noise
	23:06:09		48°26.188'N, 125°57.741'W	345	1.0	- 98.2	Humpback (2)	Faint bubble-net feeding calls	Y	- 262	>500	N	
	23:06:18		48°26.188'N, 125°57.743'W	306	1.3	- 103.5	Humpback (2)	Faint bubble-net feeding calls	Y	- 219	>500	N	
	23:07:19		48°26.203'N, 125°57.828'W	271	0.7	- 104.3	Humpback (2)	Faint bubble-net feeding calls	Y	- 282	>500	N	
	23:11:27		48°26.277'N, 125°58.237'W	346	0.71	- 98.5	Humpback (2)	Faint bubble-net feeding calls	Y	- 259	>500	N	

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shutdown (Y/N)	Comments (e.g. Pre-clear, ramp-up, snapshots taken)
22/10/19	23:17:59	KAD	-	-	-	-	-	-	-	-	-	Y	Shutdown by MMOs for sea lion and humpback. No calls on PAM.
	23:21:44		48°26.465'N, 125°59.300'W	286	1.0	- 108.3	Humpback (2)	Faint bubble-net feeding calls	Y	- 271	>500	Y	Not visible on ch1+2 due to noise
	23:25:43		48°26.548'N, 125°59.739'W	307	1.2	- 110.9	Humpback (2)	Faint bubble-net feeding calls	Y	- 281	>500	Y	Not visible on ch1+2 due to noise
	23:31:50		48°26.838'N, 126°00.192'W	273	0.8	- 105.8	Humpback (2)	Faint bubble-net feeding calls	Y	- 275	>500	Y	
	23:39:33		48°26.999'N, 126°00.941'W	329	1.1	- 101.2	Humpback (2)	Faint bubble-net feeding calls	Y	- 326	>500	Y	Not visible on ch1+2 due to noise
	23:48:55		48°26.307'N, 126°01.326 W	330	1.0	- 103.4	Humpback (2)	Faint bubble-net feeding calls	Y	- 276	>500	Y	

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shutdown (Y/N)	Comments (e.g. Pre-clear, ramp-up, snapshots taken)
22/10/19	23:53:26		48°26.100'N, 126°00.947'W	338	0.8	- 98.5	Humpback (2)	Faint bubble-net feeding calls	Y	- 300	>500	N	Not visible on ch1+2 due to noise
22/10/19	23:55:48		48°26.101'N, 126°00.727'W	326	0.8	- 100.0	Humpback (2)	Faint bubble-net feeding calls	Y	- 268	>500	N	Not visible on ch1+2 due to noise
22/10/19	23:59:32		48°26.240'N, 126°00.348'W	338	1.1	- 105.4	Humpback (2)	Faint bubble-net feeding calls	Y	- -	>500	N	Not visible on ch1+2 due to noise
22/10/19	23:59:56		48°26.240'N, 126°00.348'W	167	0.9 (2.9 Intervals between calls)	- 106.5	Humpback (1)	Faint bubble-net feeding calls	Y	- 276	>500	N	Not visible on ch1+2 due to noise
22/10/19	23:59:58	KLM	48°26.250' N, 126°00.350'W	294	0.92	- 106.8	Humpback (2)	Faint bubble-net feeding calls	N	- 106.8	>500	N	Not visible on ch1+2 due to noise
22/10/20	00:02:28	KLM	48°26.354'N, 126°00.061'W	301	0.9	- 103.2	Humpback (2)	Faint bubble-net feeding calls	Y	- 103.2	>500	N	Not visible on ch1+2 due to noise

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annotation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shutdown (Y/N)	Comments (e.g. Pre-clear, ramp-up, snapshots taken)
22/10/20	00:07:54	KLM	48°26.307'N, 125°59.424'W	368	0.7	- 102.3	Humpback (2)	Faint bubble-net feeding calls	Y	- 252	>500	N	
	00:08:42		48°26.290'N, 125°59.306'W	321	0.9	- 102.0	Humpback (2)	Faint bubble-net feeding calls	Y	- 309.5	>500	N	
	00:10:13		48°26.274'N, 125°59.190'W	326	1.0	- 99.1	Humpback (2)	Faint bubble-net feeding calls	Y	- 271.8	>500	N	
	00:11:04		48°26.259'N, 125°59.075'W	300	0.7	- 98.4	Humpback (2)	Faint bubble-net feeding calls	Y	- 331.2	>500	N	
	00:14:54		48°26.183'N, 125°58.633'W	331	0.6	- 96.6	Humpback (2)	Faint bubble-net feeding calls	Y	- 260	>500	N	
	00:18:50		-	-	-	-	-	-	-	-	-	Y	MMOs shut down for humpback. EM710 off. Profile complete

*Distance inferred from species Source Level (SL). See Table 7.

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1.3.2. Barkley Canyon Multibeam Echosounder (EM710) in Southern Resident Killer Whale (SRKW) Critical Habitat, 20 to 21 October 2022

Vessel: RV SONNE	Exclusion zone: 1000 m for killer whales, 500 m all other marine mammals
Date (YY/MM/DD in UTC): 22/10/20 – 2022/10/21	Number of PAM Operators: 3 (AH, KLM, KAD); 1.5 hour rotation
Source Activity: Kongsberg EM 710 Multibeam	Total effort: 9 hours and 32 minutes (Monitoring) and 2 hours (Deployment and Retrieval)
Hydrophone depth: 30m	
PAM Array: two 2-element apertures (1 m hydrophone spacing) towed at 200 m and 300 m starboard aft of vessel stern	PAM Software: PAMlab V9.13.1 (JASCO Applied Sciences)
Total encounters: 6	Species detected: 2

Data Code: Species=common name or species category (1=uncertain, 2=fairly certain, 3=confident); Signal Description=tonal or click or call type; SPL and Bearing=Ch1+2(top), Ch3+4(bottom/shaded); Complete entry 1) start of monitoring 2) marine mammal first spotted for PAM 3) any change in source activity

Table 6. Field log entries during PAM monitoring. Light blue shaded rows indicate Channel 3+4. Grey shaded rows indicate no applicable data.

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annot-ation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
	16:01:00	AH	-	-	-	-	-	-	-	-	-	-	30 min MMO Clear, PAM start
	16:10:29		48°21.265'N,125°49.484'W	1086	4.5	- 101.9	Humpback (3)	Ascending moan	Y	- 272	>500	N	Not visible on ch1+2 due to noise
	16:14:32		48°21.165'N, 125°49.444'W	539	3.8	 110.0	Humpback (3)	Descending moan	N	- -	>500	N	Not visible on ch1+2 due to noise

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annot-ation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
22/10/20	16:14:44		48°20.966'N, 125°49.392'W	386	2.4	- 106.8	Humpback (3)	Bubble-net feeding	Y	- -	>500	N	Not visible on ch1+2 due to noise
	16:14:58		48°20.970' N, 125°49.395'W	324	1.0	- 110.0	Humpback (3)	Bubble-net feeding	Y	- -	>500	N	Not visible on ch1+2 due to noise
	16:17:24		48°20.798'N, 125°49.332'W	287	1.2	- 108.2	Humpback (3)	Bubble-net feeding	Y	327 246	>500	N	Not visible on ch1+2 due to noise
	16:22:13	AH	48°20.473'N, 125°49.209'W	417	1.4	107.0 104.9	Humpback (3)	Bubble-net feeding	Y	277 254	>500	N	Not visible on ch1+2 due to noise
	16:25:12		48°20.374'N, 125°49.030'W	355	1.6	110.4 112.4	Humpback (3)	Bubble-net feeding	Y	275 254	<500	Y	PAM shut down
	16:29:00		48°20.380'N, 125°48.483'W	339	1.3	- 108.1	Humpback (3)	Consecutive moans	Y	- 320	>500	N	PAM restart, calls left exclusion zone.
	16:29:40				0.6	111.5		Upsweep	Y	261	>500	N	

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annot-ation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
			48°20.385'N, 125°48.418'W	400-1800		109.7	Humpback (3)			327			Following consecutive moans. Onset of song? Only a couple minutes in duration
	16:34:01		48°20.444'N, 125°47.954'W	450-1500	-	- / 110.0	Humpback (3)	Upsweep	-	- / -	>500	N	Upsweeps end
22/10/20	16:37:09	AH	48°20.583'N, 125°47.733'W	398	1.7	- / 106.6	Humpback (3)	Faint bubble-net feeding	Y	- / 346	>500	Y	MMO shutdown for humpback
	16:56:52		48°21.439'N, 125°49.001'W	250	3.7	- / 106.5	Humpback (3)	Moan	Y	- / -	>500	Y	Not visible on ch1+2 due to noise
	17:25:00		-	-	-	-	-	-	-	-	-	Y	MMO shut down (2 humpbacks)
	17:39:02		48°23.852'N, 125°51.168'W	621	0.726	- / 102.8	Humpback (3)	Moan	Y	- / 202	>500	Y	Not visible on ch1+2 due to noise
	17:40:21			185	0.264	-		Whup	Y	-	<500	Y	

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annot-ation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
			48°23.905'N, 125°51.212'W			117.7	Humpback (3)			291			Already shutdown
	17:40:31		48°23.931'N, 125°51.233'W	237	0.842	- 109.0	Humpback (3)	Bubble-net feeding	Y	- 311	>500	Y	Not visible on ch1+2 due to noise
	17:42:22		48°24.032'N, 125°51.324'W	864	0.677	- 103.3	Humpback (3)	Moan	Y	- 234	>500	Y	Not visible on ch1+2 due to noise
	17:58:40		-	-	-	-	-	-	-	-	-	-	Killer whale – first visual observation by MMOs
	18:01:00		48°25.136'N, 125°51.253'W	1637	0.611	- 105.8	Killer whale (3)	Faint discrete call	Y	- 269	<1000	Y	Already shutdown
	18:02:27		48°25.189'N, 125°51.115'W	2037	0.578	- 109.5	Killer whale (3)	Faint discrete call	Y	- 272	<1000	Y	Already shutdown
22/10/20	18:03:06	KAD	48°25.208'N, 125°51.066'W	1872	0.578	- 109.3	Killer whale (3)	Faint discrete call	Y	- 268	<1000	Y	Already shutdown
	18:05:29		48°25.265'N, 125°50.780'W	2409	0.346	- 107.5	Killer whale (3)	Faint discrete call	Y	- 255	<1000	Y	Already shutdown
	18:19:10		48°24.435'N, 125°49.799'W	310	0.759	- 112.8	Humpback (3)	Bubble-net feeding	Y	- 266	<500	Y	Already shutdown

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annot-ation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
	18:20:42		48°24.317'N, 125°49.709'W	507	0.611	- 101.7	Humpback (3)	Moan	Y	- 254	>500	Y	Not visible on ch1+2 due to noise
	18:21:16		48°24.278'N, 125°49.693'W	527	1.93	- 106.5	Humpback (3)	Moan	Y	- -	>500	Y	Not visible on ch1+2 due to noise
	18:33:26		48°23.983'N, 125°50.467'W	439	0.957	- 101.5	Humpback (3)	Moan	Y	- 304	>500	Y	Not visible on ch1+2 due to noise
	18:51:50		48°24.628'N, 125°51.915'W	509	0.644	- 100.0	Humpback (3)	Moan	Y	- 253	>500	Y	Not visible on ch1+2 due to noise
22/10/20	18:53:43		48°24.669'N, 125°52.003'W	893	0.545	- 104.5	Humpback (3)	Moan	Y	- 299	>500	Y	Not visible on ch1+2 due to noise
	18:59:00		-	-	-	-	-	-	-	-	-	-	Clear from MMO
	19:04:26	KLM	48°24.993'N, 125°52.868'W	516	2.57	- 102.7	Humpback (3)	Moan	Y	- 346	>500	N	Not visible on ch1+2 due to noise
	19:24:32		48°25.335'N, 125°54.707'W	224	2.4	- 107.6	Humpback (1)	Faint Moan	Y	- 302	>500	N	Not visible on ch1+2 due to noise

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annot-ation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
	19:55:07		48°25.795'N, 125°57.228'W	643	0.6	- 104.6	Humpback (1)	Faint Moan	Y	- 204	>500	N	MMOs observing lobtailing
	21:16:30		48°26.972'N, 125°55.362'W	410	1.3	- 106.4	Humpback (1)	Faint Moan	Y	- 264	>500	N	Not visible on ch1+2 due to noise
	21:38:09		48°26.249'N, 125°52.898'W	389	1.0	- 106.1	Humpback (3)	Bubble-net feeding	Y	- 342	>500	N	Not visible on ch1+2 due to noise
	21:40:28		48°26.136'N, 125°52.634'W	430	0.9	- 105.6	Humpback (3)	Bubble-net feeding	Y	- 238	>500	N	Not visible on ch1+2 due to noise
22/10/20	21:40:56		48°26.137'N, 125°52.632'W	363	0.9	- 106.8	Humpback (3)	Bubble-net feeding	Y	- 234	>500	N	Not visible on ch1+2 due to noise
	21:46:17		48°25.916'N, 125°52.054'W	375	0.8	- 107.1	Humpback (3)	Bubble-net feeding	Y	- 246	>500	N	Not visible on ch1+2 due to noise
	21:46:36		48°25.900'N, 125°52.000'W	271	0.8	- 110.2	Humpback (3)	Bubble-net feeding	Y	- 270	>500	N	Not visible on ch1+2 due to noise
	21:49:05		48°25.825'N, 125°51.733'W	360	0.627	- 102.2	Humpback (3)	Bubble-net feeding	Y	- -	>500	N	Not visible on ch1+2 due to noise

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annot-ation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
	22:00:19		-48°25.360'N, 125°50.630'W	126	1.2	- 115.4	Humpback (1)	Faint moan	Y	- 292	<500	N	No other calls, not in 500m exclusion zone (MMOs)
	22:14:21		-	-	-	-	-	-	-	-	-	Y	MMO shutdown for humpbacks
	22:26:34		48°23.372'N, 125°48.838'W	364	1.5	- 102.3	Humpback (3)	Bubble-net feeding	Y	- -	>500	Y	Not visible on ch1+2 due to noise
	22:30:33	AH	48°23.070'N, 125°48.593'W	191	-	- 121.8	Humpback (3)	Whup	Y	- -	<500	Y	Onset of song? Only a couple minutes long
22/10/20	22:31:42		48°22.995'N, 125°48.531'W	333	1.1	- 105.9	Humpback (3)	Bubble-net feeding	Y	- -	>500	Y	Not visible on ch1+2 due to noise
	22:48:47		48°21.686'N, 125°47.354'W	853	0.6	- 109.5	Humpback (3)	Upsweep	Y	- -	>500	Y	Consecutive upsweeps
	23:05:39			392	1.1	-			Y	-	>500	Y	

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annot-ation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
			48°21.199'N, 125°48.305'W			105.8	Humpback (3)	Bubble-net feeding		-			Not visible on ch1+2 due to noise
	23:32:44		48°22.562'N, 125°49.532'W	484	0.99	- 108.8	Humpback (3)	Moan		- 330	>500	Y	With breaching impulse?
	23:38:50	KLM	-	-	-	-	-	-	-	-	-	Y	EM710 shutdown by MMOs for humpbacks
	23:41:38	KLM	48°23.053'N, 125°49.979'W	411	1.42	- 114.6	Humpback (3)	Moan	Y	- -	<500	Y	Onset of song? Already shutdown
22/10/20	23:42:48	KLM	48°23.138'N, 125°50.051'W	773	3.37	- 107.6	Humpback (1)	Upsweep	Y	- -	>500	Y	Onset of song? Only a couple minutes long
22/10/20	23:44:18	KLM	48°23.248'N, 125°50.144'W	414	1.52	- 106.2	Humpback (3)	Moans	Y	- -	>500	Y	Onset of song? Not visible on ch1+2 due to noise

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annot-ation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
	23:52:24		48°23.626'N, 125°50.485'W	357	1.49	- 104.4	Humpback (3)	Bubble-net feeding	Y	- 246	>500	Y	Not visible on ch1+2 due to noise
	23:53:05		48 23.650'N, 125°50.507'W	325	1.52	- 112.5	Humpback (3)	Bubble-net feeding	Y	- 243	<500	Y	Already shutdown
22/10/21	00:23:10		48°25.254'N, 125°50.969'W	450	0.99	- 101.9	Humpback (3)	Moan	Y	- 281	>500	N	Not visible on ch1+2 due to noise
	00:25:30		-	-	-	-	-	-	-	-	-	Y	Shutdown by MMOs for humpback
	00:38:52		48°24.687'N, 125°49.563'W	414	2.08	- 106.8	Humpback (3)	Moan	Y	- 236	>500	Y	Not visible on ch1+2 due to noise
	00:43:34		48°24.293'N, 125°49.191'W	350	1.45	- 108.3	Humpback (3)	Moan	Y	- 243	>500	Y	Not visible on ch1+2 due to noise
22/10/21	00:44:58	KLM	48°24.164'N, 125°49.081'W	338	1.06	- 112.0	Humpback (3)	Bubble-net feeding	Y	- 317	<500	Y	Already shutdown
	00:47:34		48°23.954'N, 125°48.917'W	397	1.35	- 105.5	Humpback (3)	Bubble net feeding	Y	- -	>500	Y	Not visible on ch1+2 due to noise

Date YY/MM/DD	Time (HH:MM:SS UTC)	PAM operator	Latitude, Longitude	Freq (Hz)	Duration (s)	SPL (dB)	Species (confidence)	Signal Description	Annot-ation (Y/N)	Bearing (°)	Distance calculated from SPL* (m)	Source Shut Down (Y/N)	Comments (e.g., Pre-clear, ramp-up, snapshots taken)
	00:48:34		48°23.915'N, 125°48.884'W	415	0.86	- / 109.4	Humpback (3)	Bubble-net feeding	Y	- / 203	>500	Y	Not visible on ch1+2 due to noise
	00:52:24		48°23.559N, 125°48.576'W	382	0.70	- / 108.5	Humpback (3)	Bubble-net feeding	Y	- / 334	>500	Y	Not visible on ch1+2 due to noise
	01:33:00		-	-	-	-	-	-	-	-	-	-	EM710 off, end of profile

*Distance inferred from species Source Level (SL). See Table 7.

1.4. Spectrograms

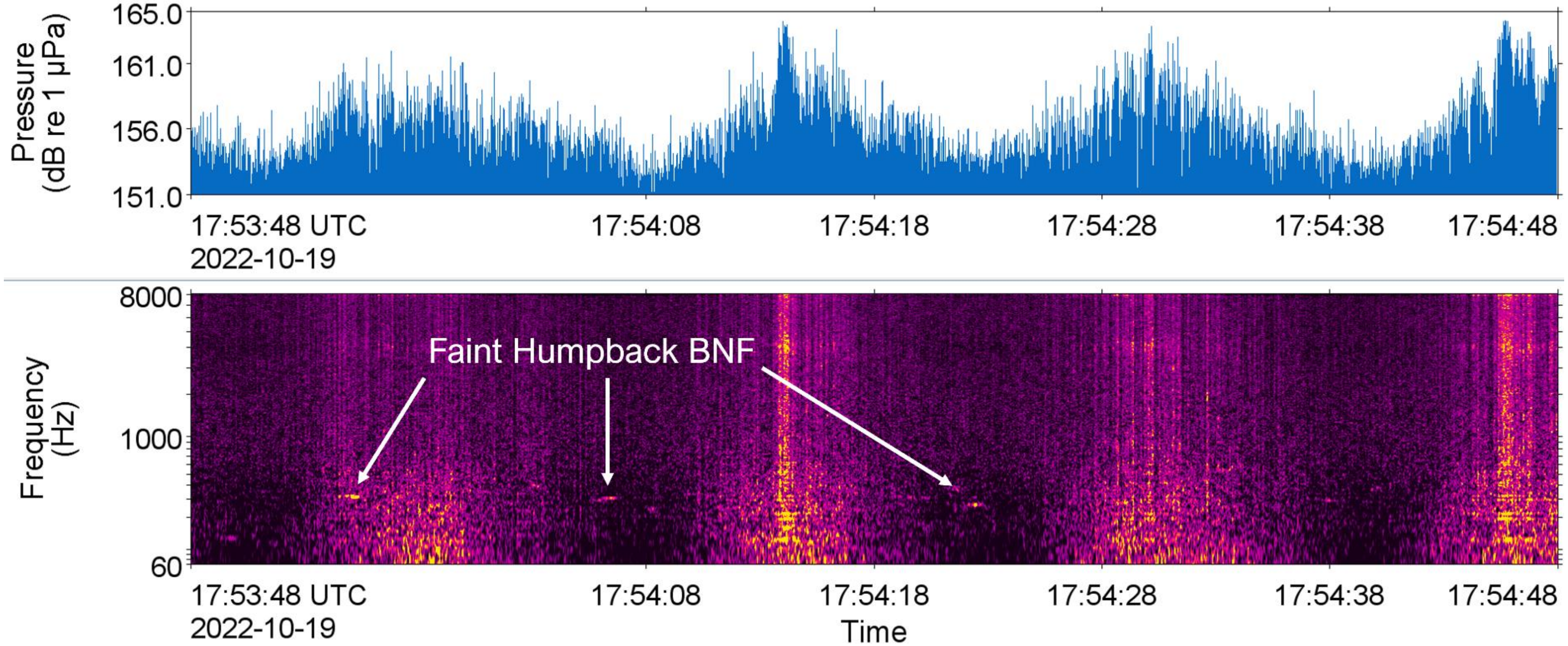

Figure 2. A waveform (above) and spectrogram (below; 2 Hz frequency resolution, 0.125 s time window, 0.03125 s time step, Hamming window, normalized across-time), 60 s, in log scale, displaying faint, potential humpback bubble-net feeding (BNF) calls and unknown vertical bands of noise on 19 October 2022.

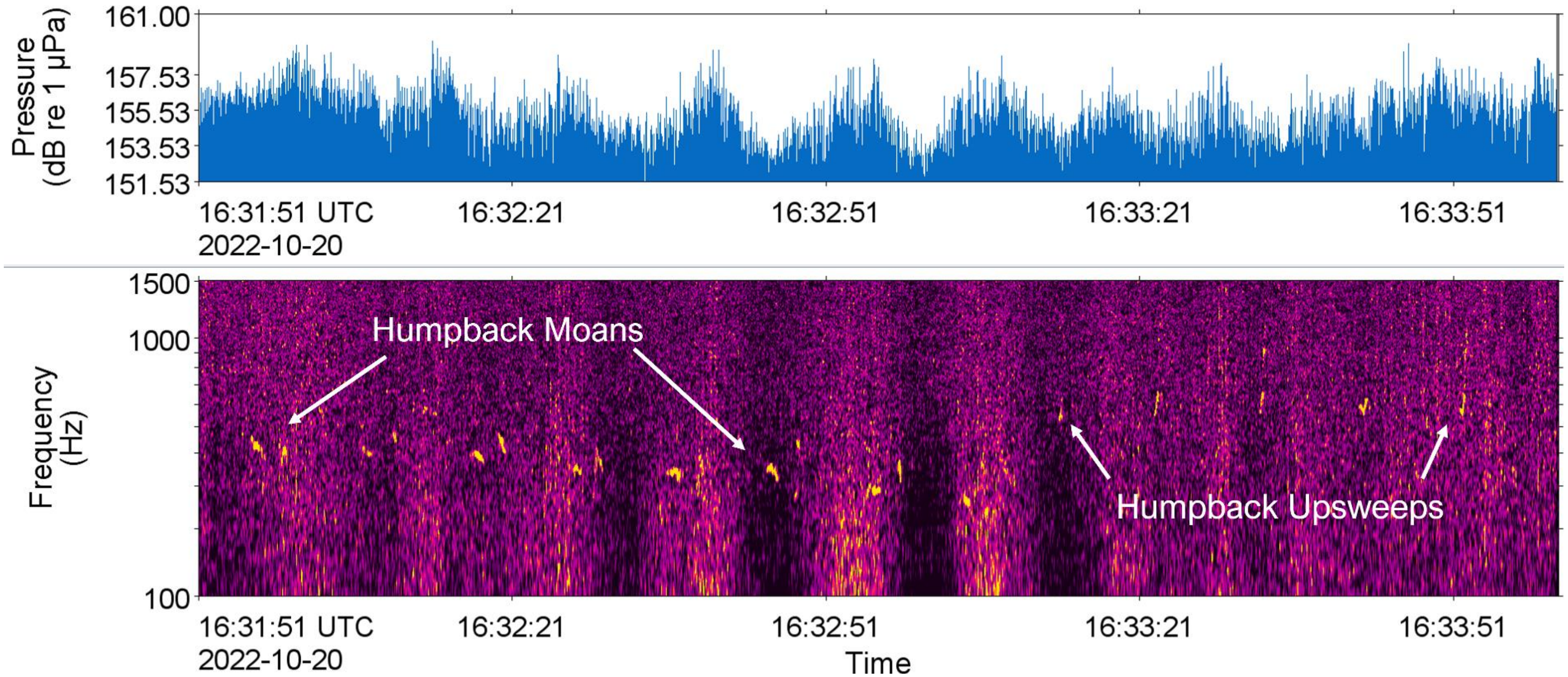

Figure 3. A waveform (above) and spectrogram (below; 2 Hz frequency resolution, 0.125 s time window, 0.03125 s time step, Hamming window, normalized across-time), 150 s duration, in log scale, displaying consecutive humpback moans and upsweeps on 20 October 2022.

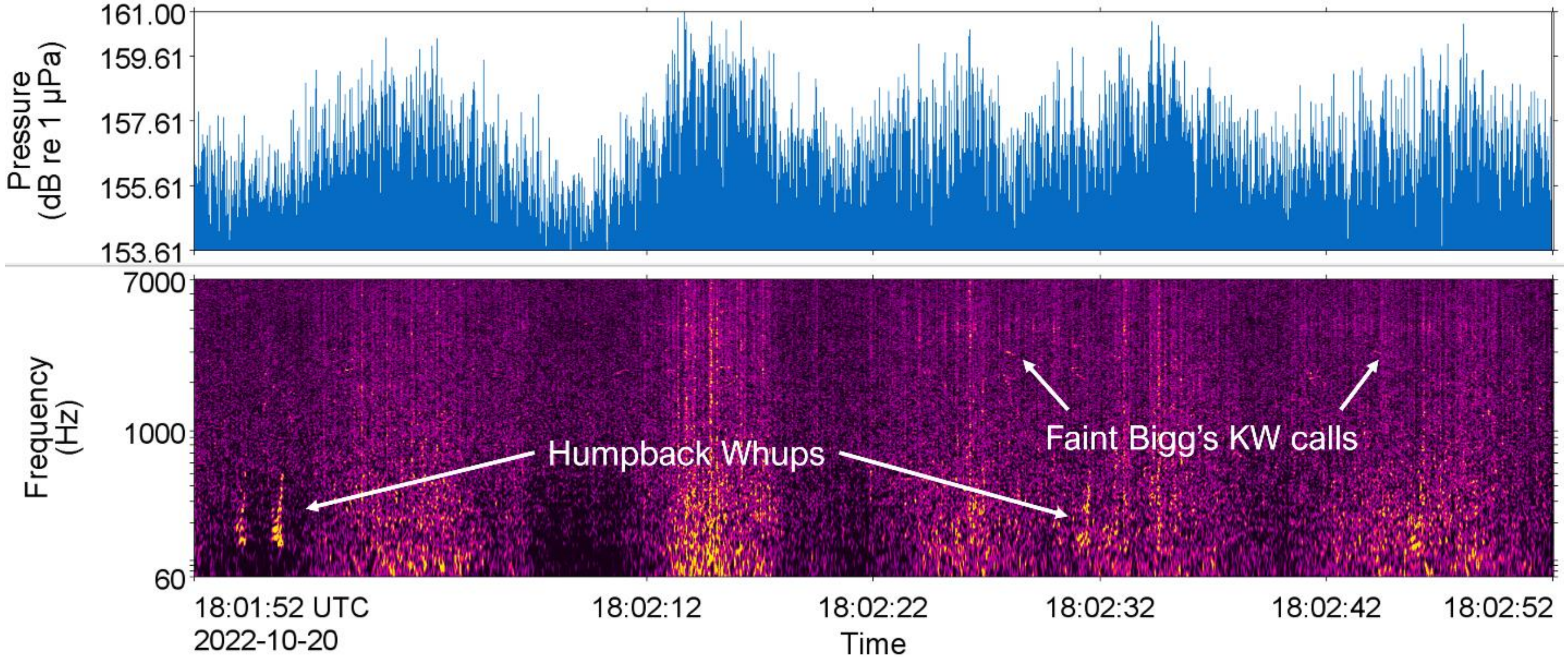

Figure 4. A waveform (above) and spectrogram (below; 2 Hz frequency resolution, 0.125 s time window, 0.03125 s time step, Hamming window, normalized across-time), 60 s duration, in log scale, displaying humpback whups, and faint Bigg's killer whale discrete calls on 20 October 2022.

1.5. Species Source Levels

1.5.1. Sound Pressure Level calculated from Source Level

Table 7. Mean species source level and calculated Sound Pressure Level (SPL) at 500, 1000, and 1500m. Shaded boxes indicate exclusion zone per species required for mitigation during air gun activity. Attenuation calculations are based on 20*log10(range).

Species	Source level (mean dB)	SPL if within 500m of hydrophone (dB)	SPL if within 1000m of hydrophone (dB)	SPL if within 1500m of hydrophone (dB)
Cetaceans				
North Pacific right whale	177.0	123.0	117.0	113.5
Killer whale whistles	154.0	100.0	94.0	90.5
Killer whale clicks	193.0	139.0	133.0	129.5
Blue whale	181.3	127.3	121.3	117.8
Fin whale	183.5	129.5	123.5	120.0
Sei whale	176.5	122.5	116.5	113.0
Minke whale	166.0	112.0	106.0	102.5
Gray whale	157.0	103.0	97.0	93.5
Humpback whale	171.5	117.5	111.5	108
Delphinid whistles	158.0	104.0	98.0	94.5
Pilot whale whistles	154.0	100.0	94.0	90.5
Delphinid clicks	188.0	134.0	128.0	124.5
Porpoise/Kogia clicks	191.0	137.0	131.0	127.5
Sperm whale	186.0	132.0	126.0	122.5
Baird’s beaked whale	*	*	*	*
Blainville’s beaked whale	201.0	147.0	141.0	137.5
Cuvier’s beaked whale	203.0	149.0	143.0	139.5
Hubb’s beaked whale	*	*	*	*
Steineger’s beaked whale	*	*	*	*
Pinnipeds				
Harbour seal	144	90.0	84.0	80.5
Northern fur seal	**	**	**	**
Stellar sea lion	**	**	**	**

*No data in the literature, refer to Cuvier’s beaked whale.

**No data in the literature, refer to Harbour seal