Pile Driving Sound Field Verification Plan

Submitted To:

National Marine Fisheries Service

Office of Protected Resources

Silver Spring, MD;

National Marine Fisheries Service

Greater Atlantic Regional Fisheries Office – Protected Resource Division

Gloucester, MA;

Bureau of Ocean and Energy Management

Washington D.C.; and,

Bureau of Safety and Environmental Enforcement

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Table of Contents

List of Tables

List of Figures

1 Introduction

This underwater noise measurement plan for sound field verification (SFV) is proposed in connection with the planned foundation installation activities for the Revolution Wind Farm (RWF) Project. This SFV Plan meets the requirements of the Revolution Wind ITR issued by NMFS on 20 October 2023, §217.274(c)(14)(i) through (14)(x), Endangered Species Act Section 7 Consultation BiOp issued by NMFS Greater Atlantic Fisheries Office (GARFO) 21 July 2023 [GARFO- 2022-03532], Section 11.3 Condition 2 and Condition 10(e), and the Construction and Operations Plan (COP) Record of Decision issued by BOEM 21 August 2023, Condition 5.4.5. Additional details on these conditions are included in Table 1. The SFV Plan describes the proposed SFV for the Project. The goal of the SFV measurements is to obtain a dataset that can be used to verify modeled sound levels submitted in the underwater noise assessment (COP Appendix P3; Kusel et al. 2023) and used as input to predict ranges to acoustic thresholds that may result in injury or behavioral disruption of marine mammals, sea turtles and/or fish near the construction site. The comparison of the measured levels to the model predictions can then be used to determine if adjustments to mitigation and monitoring protocols should be made.

In accordance with §217.274(c)(14)(x) of the ITR, this SFV Plan will be submitted to NMFS for review and approval at least 180 days prior to the planned start of pile driving. This SFV Plan describes how Revolution Wind will ensure that the first seven monopile (MP) installation sites selected for SFV are representative of the rest of the MP installation sites. This plan includes methodology for collecting, analyzing, and preparing SFV data for submission to NMFS. The plan also describes how the effectiveness of the noise abatement systems (NAS) will be evaluated based on the SFV results.

Table 1. Relevant Conditions from COP Approval, Final ITR, and BiOp.

Condition	Detail
Condition 5.4.5	The Lessee must submit, prepare, and implement a SFV Plan prior to pile driving and UXO detonation. The Lessee must submit a SFV Plan or Plans, if separate Pile Driving SFV Plans and UXO/MEC Plans are prepared, to BOEM, BSEE, NMFS OPR, and NMFS GARFO at least 180 days before impact pile driving or UXO detonation is planned to begin. NMFS GARFO will review the plan and provide comments within 45 days of receipt of the plan. NMFS GARFO's comments to BOEM, BSEE, and the Lessee will include a determination as to whether the plan is consistent with the requirements outlined in the BiOp and its ITS. If the plan is determined to be inconsistent with these requirements, the Lessee must resubmit a modified plan that addresses the identified issues at least 15 days before the start of the associated activity; at that time, BOEM, BSEE and NMFS will discuss a timeline for review of the modified plan to meet the Lessee's schedule to the maximum extent practicable. The Lessee must obtain BOEM's and BSEE's concurrence with this Plan prior to the start of pile driving or UXO detonation activities
ITR § 217.274 (c)(14)(x)	LOA Holder must submit a SFV Plan to NMFS Office of Protected Resources for review and approval at least 180 days prior to planned start of foundation installation activities and abide by the Plan if approved.
BiOp Terms & Conditions 10(e)	Monopile Installation and UXO/MEC Detonation. BOEM, BSEE, and/or Revolution Wind must submit this Plan (or Plans, if separate Pile Driving SFV Plans and UXO/MEC SFV Plans are prepared) to NMFS GARFO at least 180 calendar days before impact pile driving or UXO detonation is planned to begin. BOEM, BSEE, and Revolution Wind must obtain NMFS GARFO's concurrence with this Plan(s) prior to the start of pile driving or UXO detonation activities.
BiOp T&C 2(a)	Consistent with the measures incorporated into the proposed action, Revolution Wind must implement SFV on at least the first three monopiles installed. If any of the SFV measurements from any pile indicate that the distance to any isopleth of concern is larger than those modeled assuming 10 dB attenuation, before the next pile is installed Revolution Wind must follow the additional measures specified in BiOp T&C 2(a)(Ii– v).
BiOp T&C 2(b)	Revolution Wind will submit a noise attenuation system (NAS) inspection/performance report to NMFS GARFO within 72 hours of the performance test, which must occur prior to the first pile installation as well as any additional piles for which SFV is conducted (additional details included in section 3 and 4.2 of this Plan.

1.1 Sequence of Events for Pile Driving

The RWF will consist of 79 positions for the installation of 65 wind turbine generators (WTGs) connected by a network of Inter-Array Cables and up to two Offshore Substation (OSS) MP foundations connected by an OSS-Link Cable. WTGs will be situated in an approximate 1.15 mi (1 nm, 1.8 km) by 1.15 mi (1 nm, 1.8 km) grid, aligned with layouts proposed for other projects in the Rhode Island/Massachusetts Wind Energy Area (RI-MA WEA) and Massachusetts Wind Energy Area (MA WEA). The water depths in the Lease Area range from 24–50 m (78.7–164 ft).

Each WTG and OSS will be installed on MP foundations that will be driven using an impact hammer. The WTG MP foundations will have a maximum diameter of 7/12 m (23 - 39 ft), and the OSS MP foundations will have a maximum diameter of 7/15 m (23 - 49 ft). Installation of a single MP foundation is expected to require a maximum of 4 hours of active impact hammering, which can occur either in a continuous 4-hour interval or intermittently over a longer period of time. It is anticipated that a maximum of three WTG MP foundations can be driven into the seabed per day assuming 24-hour pile driving operation[1]. Installation of the OSS MP foundation will be similar to the WTG MP foundations; however, OSS MP foundations are larger in diameter and require a larger number of hammer strikes over a longer period. A noise abatement system (NAS) consisting of the simultaneous use of a double big bubble curtain and a Helmholtz resonator (AdBm) will be deployed during each pile driving event to reduce sounds propagated into the marine environment. Further details surrounding each system is described in Section 4 of the Pile Driving Monitoring Plan (PDMP).

The MPs will be driven into the seabed using a Menck 4400S hydraulic hammer, and the hammer will not exceed a maximum energy of 4,000 kJ during installation. The MP will be lifted with the main crane from the upending lane into the motion compensated pile gripper frame (MCPGF), positioned overhead the target installation location and lowered to self- penetration depth. Once the pile is stabbed and self-weight penetration is achieved the aim compressors are started up and AdBm will be lowered to the seabed from the pile gripper. After de-coupling the Pile Flange Lifting tool, the piling hammer will be lifted from deck and placed on the MP. The pile will be driven to the required depth. Once the target depth is reached the hammer will be retrieved, placed on deck and disconnected from the main crane.

The sequence of events from foundation transport to foundation installation is described further here. The MP foundations are transported by Heavy Transport Vessel (HTV) directly to the field. The MP foundations will be transferred from the HTV to the upend hinge on the Heavy Lift Vessel (HLV), synonymous to the Bokalift 2 (BL2), or intermediately stored in Cradles onboard the BL2. The bubble curtain vessel will deploy double bubble curtain rings before the HLV moves into MP installation position. At the same time Passive Acoustic Monitoring (PAM) for marine mammals and SFV acoustic measurement moorings will be deployed around the foundation and subsequent recording and monitoring will begin.

Pile initiation begins when the HLV moves into installation position and the MPs are upended using the Upend Hinge and transferred to the Motion Compensated Pile Gripper (MCPGF). The MCPGF horizontally restrains the pile and ensures installation within the required tolerances. The bubble curtain vessel connects to the rings and starts performing noise mitigation. After lowering the MP to self-weight penetration, the AdBm is lowered to the seabed including start-up of air compressors subsequently the hydraulic hammer (Menck 4400S) will be installed on the top of the MP. Once the MP is stabbed and self-weight penetration is achieved it is no longer technically feasible to safely reverse operations and the MP must be driven to its final penetration. Pile driving will only commence after the Lead PSO has confirmed that that clearance zone has been clear of all applicable visual or acoustic detections of marine mammals and sea turtles for at least 60 minutes prior to the start of the activity (As seen in the Revolution Wind PDMP Section 3.5.2).

The assumed hammer energy schedules[2] used in the acoustic modeling for installation of WTG and OSS foundation installation are included in Table 2 and Table 3. The hydraulic hammer is used to drive the MP to final penetration, initially with soft starts then with the required energy for installation (maximum of 4,000 kJ). The soft start will include a minimum of 20 minutes of 4–6 strikes/min at 10–20

[1] 24-hour pile driving operations are subject to NMFS' approval of the *Nighttime Monitoring Plan for Pile Driving*.
[2] Actual hammer logs may deviate from the numbers included in the hammer energy schedules (Table 2 and Table 3), likely using less of the total hammer energy shown.

percent of the maximum hammer energy. During piling, monitoring will be undertaken to detect marine mammals and sea turtles and if required, a shutdown will be initiated. After piling is completed the monitoring systems and DBBC will shut down and the support vessels will relocate them to the next location, where the cycle will restart.

Table 2. Hammer energy schedule for 7/12 WTG MP installation with a total strike count of 10,740 and total penetration depth of 50 m.

Energy level (kilojoule [kJ])	Strike count	Pile penetration (m)	Modeled strike rate (min^{-1})
1,000	1,705	0-6	50
2,000	3,590	6-24	
3,000	2,384	24-36	
4,000	3,061	36-50	

Table 3. Hammer energy schedule for 7/15 OSS MP installation with a total strike count of 11,563 and total penetration depth of 50 m.

Energy level (kilojoule [kJ])	Strike count	Pile penetration	Modeled strike rate (min^{-1})
1,000	954	0-5	50
2,000	2,944	5-17	
3,000	4,899	27-36	
4,000	2,766	36-50	

1.2 Potential Auditory Injury and Behavioral Harassment Acoustic Ranges

The SFV measurements are intended to determine if the modeled potential auditory injury and behavioral harassment ranges, which are the basis of the mitigation and monitoring zones stated in condition 5.11.5 of the COP Record of Decision (ROD) and ITR Table 29, accurately reflect the actual sound levels and propagation during foundation installations. For marine mammals, the potential auditory injury zone is defined as the distance within which Level A harassment (involving potential permanent threshold shift (PTS) or auditory injury), may occur. The mitigation and monitoring zones designed to prevent auditory injury are based on the modeled exposure ranges ($ER_{95\%}$) for the installation of one and three WTG MPs per day and one OSS MP per day which are provided in PDMP Table 4. These exposure ranges were calculated using computer simulation modeling of realistic animal movements and their potential interactions with the expected sound fields produced by pile driving as that cannot be directly measured in the field. However, the acoustic modeling also included the calculation of acoustic ranges to potential auditory injury and behavioral harassment thresholds which were used in the exposure modeling and can be measured in the field. Therefore, the comparisons described in this plan are focused on the modeled and measured acoustic ranges even though the mitigation and monitoring zones are based on the exposure ranges.

Acoustic modeling was completed at two different representative sites within the Project Area for WTG MP installation and two different sites for OSS installation. The modeled potential auditory injury per-pile SEL_{cum} (L_E) acoustic ranges for installation of a 7/12 m WTG MP and a 7/15 m OSS MP that were included in the ITR Application and associated modeling report (Kusel et al. 2021) are provided in Table 4 and Table 5 for summer and winter, respectively. During subsequent reviews of the 2021 modeling report, it was determined that the values shown in the relevant tables (Kusel et al. 2021 Appendix H.4.) as reflecting 0, 6, 10, and 15 dB of noise attenuation inadvertently reflected 2, 8, 12, and 17 dB of noise attenuation. The values were corrected in later versions of the acoustic modeling report to show the correct distances assuming 0, 6, 10, and 15 dB of noise attenuation (Table 6 and Table 7) (Kusel et al. 2024). Importantly, the correct sound fields associated with 10 dB of noise attenuation were used throughout the sound exposure modeling process and therefore the exposure ranges and take estimates remained unchanged between the revised modeling reports and the values included in the ITR application. This also means that the acoustic ranges assuming 10 dB of noise attenuation provided in subsequent modeling reports are directly linked to the exposure ranges used for determining mitigation measures (clearance/shutdown zones) and are therefore the values that should be used when comparing to the measured SFV results. The measured per-pile SEL_{cum} (L_E) acoustic ranges SFV results for each pile will be compared against the modeled ranges from the nearest modeling site (Table 6 and Table 7) to the pile installed. This means that the SFV measurements will provide a fair comparison between MP installations expected to produce threshold distances most similar to the modeled threshold distances from the nearest site.

To account for the likely minimum sound reduction resulting from NAS(s), the modeling included hypothetical broadband attenuation levels of 0, 6, 10, and 15 dB for all impact pile driving acoustic modeling. Additionally, the modeled acoustic ranges (including Level A (PTS) harassment (or potential auditory injury (PTS))) take into account the hearing abilities of marine mammals relative to the sounds produced by the modeled activity. Thus, the behavioral harassment (Level B) acoustic ranges provide a more realistic indication of the distances at which sounds perceived by the marine mammals within each hearing group (as shown below) might reach the established threshold. The modeled behavioral harassment ranges from Kusel et al. (2024) are provided in Table 8. These are the modeled values (assuming 10 dB noise attenuation) from both WTG and OSS modeling sites. The original modeling report (Kusel et al. 2021) included results from only one of the WTG sites (L024-114) which were the values shown in the ITR application. Results from only one site were provided because the ranges themselves are not used in the exposure modeling process or the establishment of mitigation zones that must be implemented. Instead, the 3-dimensional sound fields from which the ranges are calculated are used in the exposure modeling and the sound fields from site L024-002 were in fact used in the exposure modeling. Nonetheless, since the ranges to the marine mammal behavioral harassment threshold at WTG site L024-114 are shorter, using them for comparison to SFV results is a more conservative approach. Therefore, those distance are shown in Table 9 as the values that will be compared to WTG SFV results. For the OSS foundations, the acoustic modeling report (Kusel et al. 2021) included SPL_{rms} tables for OSS2 that listed the ranges to SPL_{rms} 160 dB re 1 μPa as 4,100 m (summer) and 4,698 m (winter). When recalculating the SPL tables with 10 dB attenuation to include sea turtle ranges, it was found that the ranges to SPL 160 dB re 1 μPa were reduced to 3,875 m (summer) and 4,122 m (winter) (Table 9). The reason for this decrease is that the tables in the acoustic modeling reports (Kusel et al. 2021, 2023) were inadvertently generated assuming only 8 dB of broadband noise attenuation instead of 10 dB noise attenuation. As with WTG monopiles (above), the SPL_{rms} ranges in the tables were not directly used in any calculation of exposure, so exposure estimates and take requests were not affected. The SPL_{rms} ranges from SFV measurements will be compared to the ranges in Table 9 which reflect 10 dB noise attenuation and correspond to the modeling results upon which the take estimates included in the ITR Application were based.

In order to facilitate comparisons among offshore wind projects and pile locations, agencies have required that operators model and measure sound levels at 750 m from piles. Sound level predictions at 750 m from the pile were made using ITAP's empirical model to forecast single-strike SEL. For WTG and OSS MP foundations, the greatest broadband single-strike SEL (dB re 1 μPa2·s) across the two modeling locations for each foundation type is 185 dB re 1 μPa2·s during both summer and winter assuming a maximum hammer energy of 4,000 kJ (Kusel 2023). These modeled received levels will be compared against the sound level measurements collected during SFV recorded at the 750 m distance from the pile (as shown in Figure 2). A further description of the sound level predictions can be found in COP Appendix P3 (Kusel 2023).

Table 4. Acoustic ranges to ($R_{95\%}$) to potential auditory injury cumulative sound exposure level (SEL_{cum}) thresholds for marine mammals, sea turtles, and fish from installation of a single 7/12 m WTG MP (10,740 strikes) and a single 7/15 m OSS MP (11,563 strikes) in the summer (May – November) using an IHC S-4000 hammer and assuming increasing levels of broadband noise attenuation (2, 8, 12, 17 dB) (Kusel et al. 2021).

		Range (km)															
	SEL_{cum} Threshold (dB re 1 µPa²)	WTG MP Foundation								OSS MP Foundation							
		Modeling Location L024-002				Modeling Location L024-114				OSS2				OSS1			
Hearing Group		**2**	**8**	**12**	**17**	**2**	**8**	**12**	**17**	**2**	**8**	**12**	**17**	**2**	**8**	**12**	**17**
Low-frequency	183	9.065	6.27	4.656	2.952	8.458	5.904	4.476	2.868	10.603	7.835	5.97	4.032	9.252	6.768	5.324	3.774
Mid-frequency	185	0.595	0.122	0.08	0.028	0.564	0.146	0.089	0.028	0.689	0.206	0.09	0.029	0.605	0.184	0.09	0.029
High-frequency	155	6.756	4.6	3.42	2.246	6.61	4.532	3.447	2.174	7.608	5.401	4.048	2.758	7.08	4.968	3.846	2.517
Phocid pinniped	185	2.985	1.471	0.81	0.3	3.03	1.601	0.844	0.326	3.81	2.058	1.154	0.582	3.542	1.983	1.141	0.604
Sea turtles	204	1.598	0.679	0.33	0.161	1.62	0.679	0.354	0.161	2.585	1.394	0.86	0.397	2.493	1.329	0.84	0.397
Atlantic sturgeon[1]	187	-	-	5.420	-	-	-	4.968	-	-	-	6.895	-	-	-	5.943	-

[1] The acoustic threshold ranges for fish assume installation of **two** 12 m WTG MPs in 12 hours.

Table 5. Acoustic ranges ($R_{95\%}$) to potential auditory injury cumulative sound exposure level (SEL_{cum}) thresholds for marine mammals, sea turtles, and fish from installation of a single 7/12 m MP WTG (10,740 strikes) and a single 7/15 m OSS MP (11,563 strikes) in the winter (December – April) using an IHC S-4000 hammer and assuming increasing levels of broadband noise attenuation (2, 8, 12, and 17 dB) (Kusel et al. 2021).

		Range (km)															
		WTG MP Foundation								OSS MP Foundation							
	SEL_{cum} Threshold (dB re 1 µPa²)	Modeling Location L024-002				Modeling Location L024-114				OSS2				OSS1			
Hearing Group		**2**	**8**	**12**	**17**	**2**	**8**	**12**	**17**	**2**	**8**	**12**	**17**	**2**	**8**	**12**	**17**
Low-frequency	183	24.415	13.061	8.663	4.847	28.108	12.369	8.109	4.768	28.983	16.273	11.121	6.646	31.061	13.98	9.489	5.948
Mid-frequency	185	0.511	0.206	0.089	0.028	0.594	0.184	0.102	0.028	0.72	0.253	0.119	0.063	0.754	0.241	0.142	0.064
High-frequency	155	13.885	7.94	5.246	2.709	14.363	8.028	5.404	3.226	16.353	9.437	6.475	3.706	15.856	8.88	5.941	3.36
Phocid pinniped	185	4.907	2.226	1.134	0.428	5.205	2.302	1.165	0.475	6.72	2.773	1.583	0.698	6.462	2.7	1.547	0.688
Sea turtles	204	2.261	0.955	0.494	0.201	2.35	0.988	0.512	0.224	3.484	1.767	1.054	0.491	3.284	1.715	1.024	0.477
Atlantic sturgeon[1]	187	-	-	8.717	-	-	-	7.997	-	-	-	10.940	-	-	-	9.275	-

[1] The acoustic threshold ranges for fish assume installation of **two** 12 m WTG MPs in 12 hours.

Table 6. Acoustic ranges ($R_{95\%}$) to potential auditory injury cumulative sound exposure level (SEL_{cum}) thresholds for marine mammals, sea turtles, and fish from installation of a single 7/12 m WTG MP (10,740 strikes) and a single 7/15 m OSS MP (11,563 strikes) in the summer (May – November) using an IHC S-4000 hammer and assuming various noise attenuation (Kusel et al. 2024). The 10 dB noise attenuation values will be used for comparison to SFV results.

Hearing Group	SEL_{cum} Threshold (dB re 1 µPa²)	Range (km)															
		WTG MP Foundation								OSS MP Foundation							
		Modeling Location L024-002				Modeling Location L024-114				OSS2				OSS1			
		0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency	183	9.978	7.087	5.358	3.544	9.304	6.655	5.061	3.377	9.116	6.329	4.702	2.933	7.925	5.569	4.258	2.857
Mid-frequency	185	0.636	0.146	0.085	0.06	0.599	0.189	0.102	0.028	0.372	0.127	0.063	0.029	0.526	0.122	0.063	0.029
High-frequency	155	7.374	5.200	3.918	2.687	7.128	5.049	3.780	2.600	6.458	4.38	3.238	2.013	6.010	4.114	3.044	1.978
Phocid pinniped	185	3.548	1.805	1.174	0.612	3.516	1.966	1.163	0.580	2.990	1.513	0.762	0.313	2.668	1.319	0.763	0.310
Sea turtles	204	3.104	1.523	0.860	0.372	2.979	1.594	0.868	0.394	2.741	1.440	0.856	0.389	2.604	1.362	0.835	0.388
Atlantic sturgeon	187	-	-	6.048	-	-	-	5.576	-	-	-	6.524	-	-	-	5.681	-

Table 7. Acoustic ranges ($R_{95\%}$) to potential auditory injury cumulative sound exposure level (SEL_{cum}) thresholds for marine mammals, sea turtles, and fish from installation of a single 7/12 m MP WTG (10,740 strikes) and a single 7/15 m OSS MP (11,563 strikes) in the winter (December – April) using an IHC S-4000 hammer and assuming various broadband noise attenuation (Kusel et al. 2024). The 10 dB noise attenuation values will be used for comparison to SFV results.

Hearing Group	SEL_{cum} Threshold (dB re 1 µPa²)	Range (km)															
		WTG MP Foundation								OSS MP Foundation							
		Modeling Location L024-002				Modeling Location L024-114				OSS2				OSS1			
		0	6	10	15	0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency	183	28.963	15.602	10.433	6.035	35.059	15.024	9.550	5.760	22.189	12.349	8.442	4.786	21.052	10.681	7.287	4.369
Mid-frequency	185	0.767	0.281	0.108	0.063	0.762	0.261	0.122	0.063	0.482	0.145	0.083	0.029	0.525	0.161	0.100	0.029
High-frequency	155	16.282	9.311	6.499	3.711	16.658	9.376	6.456	3.701	12.774	7.317	4.750	2.381	12.152	6.717	4.422	2.356
Phocid pinniped	185	6.828	2.634	1.451	0.591	6.672	2.648	1.480	0.617	4.554	1.921	0.95	0.424	4.385	1.831	0.996	0.401
Sea turtles	204	4.756	2.275	1.274	0.552	4.585	2.404	1.344	0.592	4.014	1.974	1.171	0.544	3.766	1.944	1.140	0.536
Atlantic sturgeon	187	-	-	10.144	-	-	-	9.180	-	-	-	10.564	-	-	-	8.980	-

Table 8. Acoustic ranges ($R_{95\%}$) to behavioral harassment sound pressure level (SPL_{rms}) thresholds for marine mammals, sea turtles, and fish for installation of 7/12 m WTG MPs and 7/15 m OSS MPs during the summer and winter seasons using an IHC S-4000 hammer and assuming 10 dB broadband noise attenuation (Kusel et al. 2024).

	WTG MP				OSS MP			
	Modeling Location L024-002		Modeling Location L024-114		OSS 1		OSS 2	
Species Group	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Marine Mammals	3.918	4.357	3.833	4.271	3.756	4.005	3.875	4.122
Sea Turtles	1.011	1.440	1.018	1.519	1.089	1.343	1.127	1.408
Atlantic sturgeon[1]	6.301	10.664	5.805	9.758	5.959	9.221	6.921	10.888

[1] Ranges for Atlantic sturgeon are physiological acoustic ranges and not a result of animal movement modeling.

Table 9. Acoustic ranges ($R_{95\%}$) to behavioral harassment sound pressure level (SPL_{rms}) thresholds for marine mammals, sea turtles, and fish for installation of 7/12 m WTG MPs and 7/15 m OSS MPs during the summer and winter seasons using an IHC S-4000 hammer and assuming 10 dB broadband noise attenuation. These values will be used for comparison to SFV results.

	WTG MP		OSS MP	
	Modeling Location L024-114		Modeling Location OSS2	
Species Group	Summer	Winter	Summer	Winter
Marine Mammals	3.833	4.271	3.875	4.122
Sea Turtles	1.018	1.519	1.127	1.408
Atlantic sturgeon[1]	5.805	9.758	6.921	10.888

[1] Ranges for Atlantic sturgeon are physiological acoustic ranges and not a result of animal movement modeling.

2 Measurement Plan

2.1 Summary

Thorough sound field verification measurements will be conducted on at least the first seven consecutive WTG MPs installed for the Revolution Wind Project (Table 10) until measured noise levels are at or below the modeled noise levels, assuming 10 dB noise attenuation, for the season in which pile driving occurs. The required total hammer energy to drive the pile to its final installation depth is the primary indicator of the drivability difficulty as well as the expected largest underwater acoustic impact. This parameter was chosen to assess which MPs are representative of the rest of the Project's MP installations. The results of the drivability assessment are confidential as they are part of Orsted's in-house core foundation design knowledge and are therefore not included within this Plan. The installation sequence is fixed for the first 54 MPs (52 WTG positions and 2 OSS MPs) (Table 10). Sequencing for the remaining 13 positions is indicative and subject to change and is therefore not shown in Table 10. Due to logistical constraints including manufacturing and load-out considerations, it was not possible to be fully flexible with the WTG MP installation sequence (Table 10), meaning that three of the first seven WTG MPs to be installed (foundations B12, B11, and B20 [pile numbers 2, 3, and 6]) are expected to require less hammer energy and are expected to have broadband SEL_{cum} values approximately 2 dB lower than the first WTG MP (foundation B47). Foundation locations B47, B08, B30, and B73 (pile numbers 1, 4, 5, and 7) are expected to be difficult to drive (requiring more hammer energy) while foundation locations B12, B11, and B20 (pile numbers 2, 3, and 6) are expected to be easy to drive (requiring less hammer energy). Piles two and three are expected to require ~30% less hammer energy than piles 4 and 5 which equates to ~1.5 dB cSEL less hammer energy. Pile one is expected to require ~15% less hammer energy than piles 4 and 5 which equates to ~0.7 dB cSEL less hammer energy. Pile 6 is expected to require ~45% less hammer energy than piles 4 and 5 which equates to ~2.6 dB cSEL less hammer energy. And pile 7 is expected to require ~10% more hammer energy than piles 4 and 5 which equates to ~0.4 dB cSEL more hammer energy. Therefore, of the first seven piles to be installed, four (pile numbers 1, 4, 5, and 7) are indicative/representative of the MPs with the expected largest underwater acoustic impact. Given all seven WTG MPs are of comparable sizes and installed using the same hammer, they may all be considered comparable acoustic waveguides (structures that vibrate and generate sound of the same nature). As such, these first seven WTG MPs can be considered as representative when cumulative sound exposure and the corresponding acoustic ranges are scaled according to the difference between required hammer energy for the three 'easy-driven' piles and the other piles being measured (as described above).

In addition to the Thorough SFV measurements conducted on the first seven piles (as described above), Abbreviated SFV will be conducted on all remaining piles (starting with pile 8 [B13], Table 10). Abbreviated SFV will be used to record sounds at a single distance of 750 m throughout the duration of all pile driving of each foundation installed throughout the Revolution Wind Project campaign.

SFV will not be conducted for OSS foundation installation (summer or winter). Revolution Wind believes conducting SFV on the first seven WTG MPs is indicative/representative of the expected largest underwater impact for all MPs (both WTG and OSS) to be installed for the Project. The underwater acoustic analysis and exposure modeling assumed WTG MP foundations supposed by a tapered MP foundation that is 8 m on top and 12 m diameter at the mudline (7/12 m) and each OSS supposed by a tapered 7 m (top) to 15 m (mudline) MP foundation (7/15). the modeled acoustic ranges to potential auditory injury (SEL_{cum}) thresholds for marine mammals, sea turtles, and fish from installation of a single

7/12 m WTG MP (Table 4) are larger than those modeled for installation of a single 7/15 m OSS MP (Table 5) for both summer and winter installation. Additionally, the final engineering design of the MP results in diameters of 9.5 – 10 m for WTG MPs and 10 m for OSS MPs. Therefore, the results of SFV conducted on the first seven WTG MPs (in which piles 2–7 have a diameter of 10 m while pile 1 has a diameter of 9.5 m) are indicative/representative of the OSS MPs to be installed for the Project. No impact pile driving (WTG and OSS installation) is planned for the months of December through April; however, installation in December may only occur, upon NMFS approval, in the case of unexpected delays. If WTG MP installation in December is conditionally approved by NMFS in the case of unexpected delays, Revolution Wind will conduct Thorough SFV for the first three WTG MPs following the requirements in LOA Condition 3(c)(14).

Additional measurements may be conducted for several subsequent installations until Revolution Wind collects sound pressure data that it deems are representative of maximum propagation potential (highest sound emission) at the installation location. If installation of larger WTG MPs or additional MPs that may produce louder sound fields than those previously measured (e.g., higher hammer energy, installation(s) in December), additional SFV measures will be conducted as described below in section 2.2. The equipment, methodology, placement, and analysis will be the same for all pile measurements for the installation of WTG MPs. Output results will include sound pressure level and frequency context. SFV measurements will be conducted on the first seven MPs (Figure 3) with sufficient equipment to ensure that a robust and representative dataset is gathered to verify the modeled sound levels.

One or more contractors will be responsible for measurements, instrumentation, and submission of interim and final reports to Revolution Wind. Responsibilities will include deployment, retrieval of equipment, raw data acquisition, initial processing of time pressure level quantities, and analysis of processed data to prepare interim and final reports for Revolution Wind who will then review and submit to the relevant authorities.

2.2 Instrumentation and Deployment

All measurements will be performed according to the ISO 18406:2017 standard. The foundation installation noise will be measured using omnidirectional hydrophones capable of measuring frequencies between 20 Hz and 20 kHz. The hydrophone systems will have a sensitivity appropriate for the expected sound levels from pile driving received at the nominal ranges throughout the installation of the pile. And the dynamic range of the measurement system will be sufficient such that the signals will avoid poor signal-to-noise ratios for low amplitude signals and avoid clipping, nonlinearity, and saturation for high amplitude signals at each hydrophone location. The hydrophone systems will record continuously from deployment to retrieval, including during breaks in any piling resulting from delays or shutdowns. The recording systems will be retrieved and redeployed between each pile driving event. Each recording system is comprised of two separate recording units. These recording units are not connected to a single recorder; therefore, they will both record all sound data, independently of one another, so that should one fail, there will be in-water back-up.

Table 10. Revolution Wind Installation Sequence.

REV MP Installation Sequence			REV MP Installation Sequence		
#	Pile Identifier	USCG	#	Pile Identifier	USCG
1	B47	AK12	35	B25	AH05
2	B12	AE11	36	B33	AJ05
3	B11	AE10	37	B31	AJ03
4	B08*	AE07	38	B35	AJ07
5	B30	AJ02	39	B28	AH08
6	B20	AG06	40	B36	AJ08
7	B73*	AN16	41	B37	AJ09
8	B13	AF05	42	B29	AH09
9	B07	AE06	43	B23	AG09
10	B70	AN13	44	B16	AF10
11	B58	AL21	45	B17	AF11
12	B67	AM21	46	B46	AK10
13	B79	AP16	47	B50	AL10
14	B78	AP15	48	B59	AM11
15	B77	AP14	49	B60	AM12
16	B76	AP13	50	B61	AM14
17	B10	AE09	51	B72	AN15
18	B09	AE08	52	B26	AH06
19	B38	AJ10	53	Z02	
20	B39	AJ11	54	Z01	
21	B40	AJ12	55	B18	AG04
22	B51	AL12	56	B19	AG05
23	B41	AJ13	57	B27	AH07
24	B42	AJ14	58	B69	AN12
25	B63	AM17	59	B43	AJ15
26	B64	AM18	60	B74	AP11
27	B65	AM19	61	B75	AP12
28	B66	AM20	62	B22	AG08
29	B57	AL20	63	B34	AJ06
30	B56	AL19	64	B32	AJ04
31	B55	AL18	65	B24	AH04
32	B71	AN14	66	B14	AF06
33	B68	AN11	67	B15	AF09
34	B21	AG07			

* Acoustic modeling was performed closest to piles B08 and B73

As per LOA condition 3(c)(14)(iv) all hydrophones used will have undergone a full system, traceable laboratory calibration conforming to International Electrotechnical Commission (IEC) 60565 or an equivalent standard procedure from a factory or accredited source to ensure the hydrophone receives accurate sound levels, at a date not to exceed 2 years before deployment. The hydrophone signals will be verified prior to each buoy deployment and recovery by means of a pistonphone calibrator on deck or similar method. All pistonphone tests will be recorded and saved. Additionally, all measurement equipment shall be periodically inspected prior to and after each deployment on deck. This encompasses, but is not limited to, ensuring cables are intact, battery level is sufficient, hydrophone and other components are not damaged etc. If the measurement system employs filters via hardware or software (e.g., high-pass, low-pass etc.), not already accounted for by the calibration, the filter performance (i.e., the filter's frequency response) will be reported (as described in section 4) and the data corrected before analysis. As per LOA condition 3 (c)(14)(v) Revolution Wind will be prepared with additional equipment, which exceeds the amount of equipment necessary to perform the measurements, such that technical issues can be mitigated before measurement. There will be a total of 9x compressors onboard (7x in use and 2x spares). The 7x compressors will provide at least 0.55 m3/ (min x m) airflow meeting the requirements of LOA Condition 3 (c)(8)(ii). No additional compressors will be deployed. Gardline has included additional steps to the pre-deployment checklists, including ensuring that the high pass filtering is not accidentally ticked in the recorder setting. An additional seven recording units were purchased so that if any recorders show issues, additional redundances are available within the field. All measurement positions will be fixed (stationary) throughout the duration of a single foundation installation. Each measurement position will consist of two hydrophones, one at approximately mid depth and the second at 2 m above the seafloor. Deployment will be made using a heavy weight as anchor to prevent equipment drifting (typically total ballast weight exceeding 100 kg) – as depicted in Figure 1. The deployment and retrieval position of each hydrophone will be recorded using hand-held GPS equipment, or an alternative precise method.

Revolution Wind will use a mooring design consisting of a single mooring line (no loops of any sort) designed to reduce the risk of potential entanglement or entrainment of listed species in accordance with PDC 6 of the Offshore Wind Site Assessment and Site Characterization Activities Programmatic Consultation. The mooring setup will use high modulus polyethylene (HMPE) rope given its strength, easy handling and rigidity. The HMPE mooring line will include a quick release (g-hooks) that can easily be cut by Project personnel in the unlikely event of entanglement, allowing the animal to be released easily. Revolution Wind will use the shortest practical line length for the relevant pile installation location's water depth. Hydrophone cables will be attached (at regular intervals) to the HMPE mooring line to prevent entrapping species inside while preventing cable strum (ensuring quality data). Hydrophone buoy deployment will take place from the SFV deployment vessel(s) which will have PSOs on board monitoring a 500 m zone surrounding the deployment location. Should any species be observed, operations will be stopped until the animal(s) have departed the 500 m zone surrounding the deployment location. Should a live or dead marine protected species become entangled, Revolution Wind will follow the relevant reporting protocols detailed in PDMP section 5.5 and the Offshore Wind Site Assessment and Site Characterization Activities Programmatic Consultation PDC 8 and provide any on-water assistance as requested.

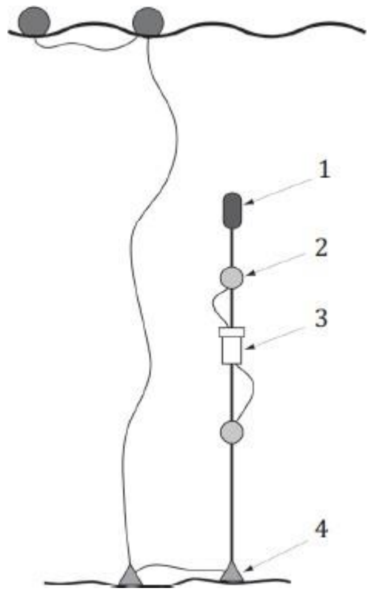

Figure 1. Conceptual design and layout of hydrophone deployment. 1 is the float, 2 is the hydrophone, 3 is the recorder and 4 is the bottom weight(s). From ISO18406:2017

2.3 Measurement Layout

The hydrophones used to conduct Thorough SFV will be placed at various distances from the installation location as depicted in Figure 3 and as amended where possible to reflect agency input and indicated by values in parentheses in the list below. The planned measurement configuration comprises at least five measurement locations consisting of:

- Two positions at 750 m distance from the installation location. The primary 750-m position will be in line, in the direction of lowest transmission loss (i.e., projected lowest transmission loss coefficient), with the measurement radial[3] such that the measurement radial has a complete set of four measurement locations as described in Figure 3. The secondary 750-m position will be placed at an azimuth 90 degrees from the measurement radial. (Positions 1-2 in); plus,
    - The 90-degree position will be selected based on what area around the pile SFV measurements are being taken from. Therefore, the position may be 90 degrees clockwise or 90 degrees counterclockwise from the main 750 m position.
- Single position at 1,500 m (or 2,000 m) distance along the same transect as one (basic) of the 750 m positions (Position 3 in Figure 3)
- Single position at 3,000 m (or 4,000 m) distance along the same transect as the basic 750 m and 1,500 m position (Position 4 in Figure 3)

[3] Measurement radials were chosen for each foundation considering local bathymetry ranging from the pile to the distance of the furthest measurement position (up to 10 km). The preferred directions are either along a constant water depth or towards deeper waters, if there is such variation in water depth within the first 10 km. As a result, most of the radials are located in the east-south quadrant.

- Single position at 10,000-12,000 m distance along the same transect as the basic 750 m, 1,500 m and 3,000 m position (Position 5 in Figure 3)

Placement of buoy positions 3 and 4 will be adjusted out to 2 km and 4 km, respectively for installation of piles 1, 5, and 6 (B47, B30, and B20). Exact placement (micro-siting) of buoy locations will be adjusted around avoidance areas such as UXOs and archaeological exclusion zones. Placement of buoy positions 3 and 4 for piles 2, 3, 4, and 7 will remain at the distances from the installation location as shown in Figure 2. The reason these buoy locations cannot be adjusted is because the SFV transect for these four piles fall outside of the APE; therefore, relocation would require additional survey and Qualified Marine Archaeologists sign off.

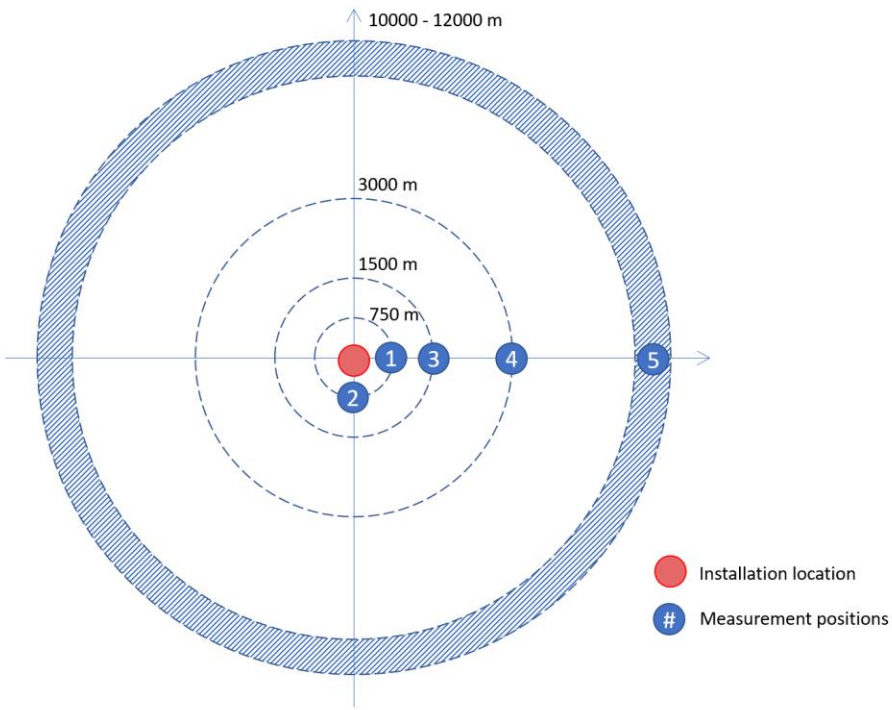

Figure 2. Proposed locations of hydrophone systems during Thorough SFV measurements.

The location of the WTG foundations where SFV measurements will be taken and the direction of the measurement transects are shown in Figure 3. Measurement transects were chosen for each foundation with the intention to capture low transmission losses considering local bathymetry, already surveyed and QMA cleared areas, and areas to avoid due to safety reasons (e.g. potential UXO presence). The local bathymetry ranging from the pile to the distance of the furthest measurement position (up to 10 km) was carefully considered. The preferred directions are either along a constant water depth or towards deeper waters, if there is such variation in water depth within the first 10 km. As a result, most of the transects are oriented towards the southeast quadrant. Given the Project's site and bathymetry and that the pile is a distributed acoustic line source, it is critical to avoid selecting transects towards very shallow waters where mode stripping could occur. Outside of that concern, the number of reflections of the acoustic beam from the seabed will be the primary mechanism that drives acoustic attenuation as no acoustic channels (such as SOFAR) are expected in these shallow waters. However, the number of reflections of the acoustic beam should play an insignificant role given the span of bathymetry in the area. For example, considering a pile installed at water depth of 40 m and comparing propagation along a transect of constant 40 m water depth vs. a transect that goes towards water depth of 50 m (a difference of 10 m which is much more than the difference of water depths for the proposed eastward transects at piles B11 and B12 compared to the alternative southwesterly transects from those piles), the number of reflections differs by a maximum of 25% which should translate to a maximum difference of 1 dB more attenuation. Furthermore, sound energy density (and therefore the corresponding sound levels) will decrease towards deeper waters, which will at least partially compensate for this attenuation difference. Additionally, the area for hydrophone placement along the southwest transects for piles 2 and 3 (B11 and B12) rather than the current transects in the eastern quadrat fall outside of the APE, and therefore would require additional survey and QMA sign off.

Abbreviated SFV measurements will be made using a single acoustic recorder, consisting of a near-bottom and mid-water hydrophone, placed approximately 750 m from the pile center.

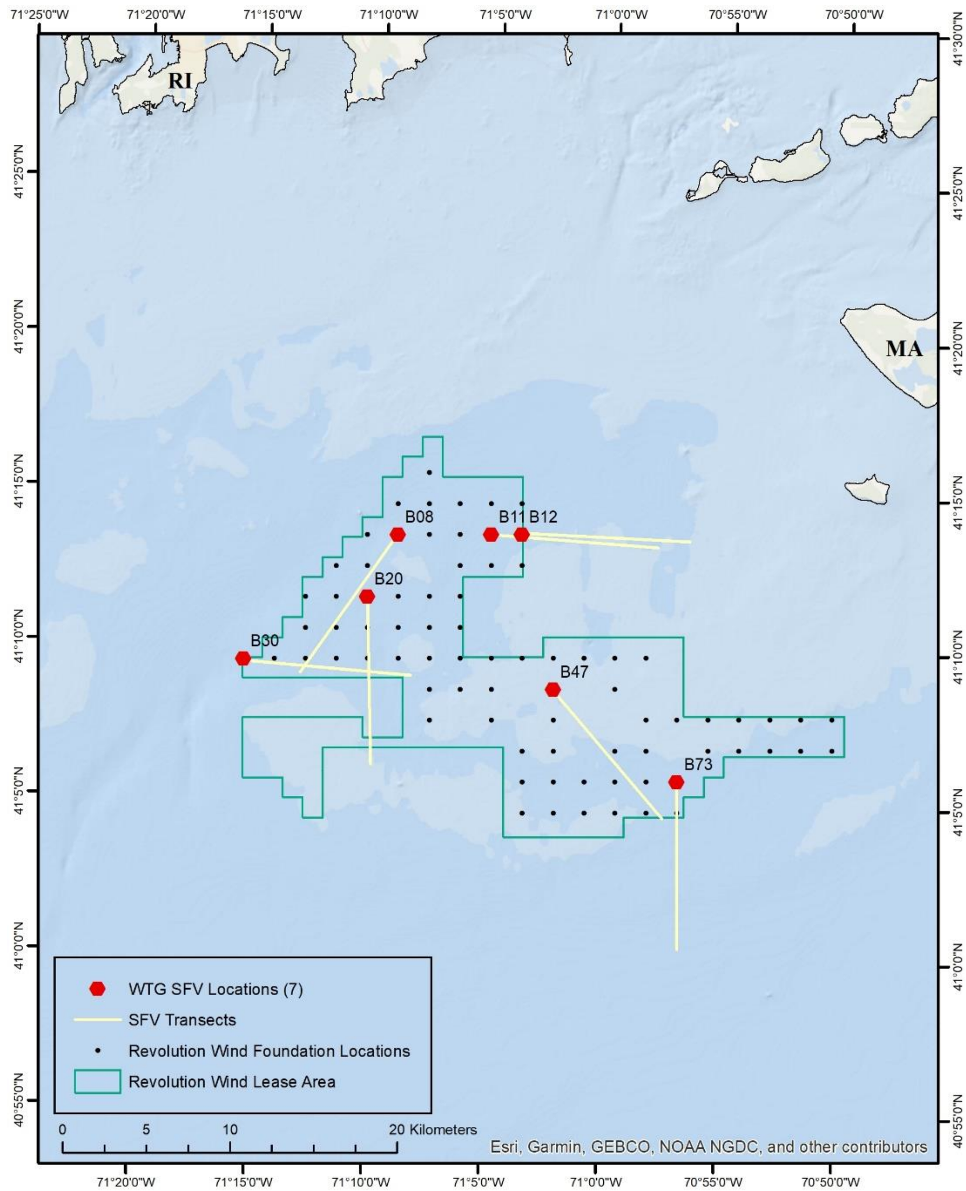

Figure 3. Map showing the WTG foundation locations where Thorough SFV measurements will be taken and the direction of the measurement radials along which acoustic recorders will be deployed.

Deployment and retrieval of each hydrophone will be conducted from a dedicated measurement vessel. Each position will be recorded using hand-held GPS equipment, or an alternative precise method. At the time of deployment, a conductivity, temperature, depth (CTD) cast will be conducted at each mooring position and the data reported and transmitted to the Revolution Wind analysis team including Boskalis, Gardline, JASCO, and Revolution Wind acoustics and marine mammal specialists. Sound levels from the main and secondary 750 m positions will be compared against one another. As long as the sound levels from the main and secondary (either clockwise or counterclockwise from the main transect) 750 m positions do not significantly differ from one another, the performance of the combined noise mitigation systems will be deemed comparable, which should be the case as directionality effect is expected for the effectiveness of both systems. The combined effectiveness of the AdBm system and the DBBC will be further assessed based on the post processed underwater noise data and compared to the noise prognosis prediction models by the Revolution Wind analysis team including Boskalis, the PSO provider, JASCO, Revolution Wind acoustics, and marine mammal specialists.

2.4 Analysis Method

All hydrophones will be retrieved by the measurement vessel after installation of each foundation. The acoustic reporting scientist will then process the recorded raw data (time series of pressure) using code in Python for pulse detection and analysis according to the ISO 18406:2017 standard. This process will be done for each hydrophone as the measurement buoys are being collected. In order to minimize any delay in evaluating the measured acoustic potential auditory injury and behavioral harassment ranges, once the raw data from each hydrophone is processed, it will be sent onshore via email following the file transfer protocol described below. The acoustic potential auditory injury and behavioral harassment ranges collected during SFV at the seven WTG hydrophone positions (shown in Figure 3) will be compared against the relevant modeled potential auditory injury and behavioral harassment ranges in Table 4 through Table 8 to determine if additional sound mitigation measures are necessary. Pre-piling and post-piling noise will be recorded 30 minutes prior to pile driving and post-piling. These noise levels will be included in the interim reports submitted to the agencies for each MP in which Thorough SFV measurements are conducted (Section 4.1).

A single SFV distribution email and file transfer protocol will be established prior to commencement of in-water foundation installation activities to ensure communication is complete after retrieval of the collected SFV data. The SFV provider’s data personnel will establish a streamlined format and extent of data delivery to reduce the follow-up work and data analysis. The streamlined protocol will identify the personnel required for delivery of the data, to reduce miscommunication or prevent delivery to incorrect personnel. The collected SFV data will be sent onshore with packages of data prioritized by recorder location. SFV measurements collected from hydrophones deployed at different locations along the primary transect (Figure 3) will be prioritized over collecting measurements at the same distance but in different directions (e.g., primary and secondary 750 m locations). Also, delivery of data from both the mid-water and bottom hydrophones at the same location will have lower priority compared to delivering data from two bottom hydrophones at two different locations (distances). The data from the 750 m location along the primary transect will always have the highest priority followed by other hydrophone locations along the primary transect while the second 750 m position will have the lowest priority across all deployment locations. All necessary contractor (including bubble curtain contractors) and Orsted personnel responsible for recovering, processing, and transmitting data to agencies will be included in the email distribution. The output of the analysis will include common acoustic metrics as specified below in Sections 3 and 4. The processed data will be subsequently transferred onshore via email with packages of data prioritized by location (as described above) and integrated into both the interim and final reports as described in Section 4 of this Plan.

3 Modification of Clearance and Shutdown Zones

Revolution Wind will conduct SFV to empirically determine the distances to the isopleths corresponding to potential auditory injury and behavioral harassment thresholds for comparison to the modeled (assuming 10 dB attenuation) potential auditory injury and behavioral harassment acoustic isopleths. To do this, Revolution Wind will calculate a sound propagation loss curve from in situ measurements at multiple distances from the MP, including at least one measurement location at 750 m from the MP, which will be used to determine the distances to the potential auditory injury and behavioral harassment thresholds. The propagation loss curve will allow the acoustic range (r) to the potential auditory injury and behavioral harassment thresholds to be calculated using the following damped geometrical spreading formula:

$$L_E(r) = L_E(r_1) - A\log_{10}\left(\frac{r}{r_1}\right) - \alpha(r - r_1)$$

where r_1 is the reference range in m, L_E is the sound exposure level or other sound level metric to be interpolated, A is the geometrical spreading coefficient in dB, and α is the absorption coefficient in dB/m. The values for A and α will be derived from the propagation loss curve fit to the measurement data using a least sum of squares regression method or other well accepted approach. A quality control review of the values A and α will ensure that estimates are within expected value ranges.

As long as the position of the outer-most recorder in the line of four recorders (Position 5, Figure 3) is farther than the distance to the largest threshold range, then the distances to thresholds will be interpolated from within the fit of the propagation loss curve rather than extrapolated beyond it. Extrapolation carries significantly more uncertainty than interpolation which is why Revolution Wind intends to deploy the furthest measurement position at the distance of 10 – 12 km to minimize the potential need for extrapolation. Frequency weighting will be applied to each 1/3 octave during the analysis phase before calculating ranges to frequency weighted thresholds. For verification of the distance to the behavioral harassment threshold, Revolution Wind will report the interpolated or extrapolated distance to the received SPL_{rms} of 160 dB, as well as the integration time of the SPL_{rms} calculation.

If any of the SFV measurements of the seven measured piles indicate distances to the isopleths corresponding to potential auditory injury and/or behavioral harassment thresholds are greater than the distances predicted by modeling assuming 10 dB attenuation, Revolution Wind will notify NMFS GARFO Protected Resources Division (NMFS GARFO – PRD), NMFS Office of Protected Resources (OPR), Bureau of Ocean and Energy Management (BOEM), and Bureau of Safety and Environmental Enforcement (BSEE) through TIMSWeb and at protectedspecies@bsee.gov via email. In this same email, Revolution Wind will communicate and confirm the noise mitigation adjustments that will be employed for installation of the next pile prior to beginning installation to ensure future piles do not exceed modeled distances to thresholds (assuming 10 dB attenuation). Additional measures may include improving the efficacy of the implemented noise attenuation technology through inspection and amendment of the DBBC layout, inspection of the nozzle hose and redrilling if needed, adjustment/increase of the air supply to the DBBC/ adjustment of air supply to the AdBm "filling small curtain" and/or modifying the piling schedule to reduce the sound source.

As per BiOp RPM 2(a)(ii), if any of the seven measured piles indicate that the distances to potential auditory injury thresholds for marine mammals, sea turtles, or fish are larger than the modeled distances (assuming 10 dB attenuation), NMFS may expand the relevant clearance and shutdown zones for the subsequent piles so that they are at least the size of the distances to those thresholds as indicated by the SFV measurements. And as per COP Condition 5.4.5 (a), if any of the seven measured piles indicate that distances to potential auditory injury and/or behavioral harassment thresholds for marine mammals, sea turtles, or fish are larger than the modeled distances (assuming 10 dB attenuation), additional SFV measurements will be conducted on the subsequent three MPs. In this case, and following BOEM, BSEE, or NMFS GARFOs review of the SFV interim reports for the first ten MPs (first seven and additional three), additional SFV measurements will be conducted should the SFV measurements continue to exceed the modeled results. These measurements would be in addition to the supplemental sound attenuation measures and/or adjustments to the relevant clearance and shutdown zones described above.

If modeled zones cannot be achieved through the described corrective actions and additional SFV measurements show continued exceedance of the modeled distances, discussions will be had with NMFS GARFO – PRD, NMFS OPR, BOEM, BSEE, and United States Army Corps of Engineers (USACE) to determine what additional mitigation measures can be implemented. Revolution Wind recognizes as per BiOp Section 7.1.3.1 (Sound Field Verification), in the event that noise attenuation measures and/or adjustments to pile driving cannot reduce the distances to less than those modeled, this may be considered new information that reveals effects of the action that may affected listed species in a manner or to an extent not previously considered and reinitiation of ESA consultation may be necessary (per BOEM or NMFS' request). If no additional measures are identified, pile installation will continue with implementation of the previously determined enhanced noise attenuation measures and any expanded clearance and shutdown zone sizes until SFV results for at least three additional foundations demonstrate that measured ranges to potential auditory injury or behavioral harassment isopleths meet or are less than those modeled assuming 10 dB of attenuation. Once the SFV results for at least three additional foundations indicate distances to isopleths corresponding to potential auditory injury and behavioral harassment thresholds are within the distances predicted by modeling assuming 10 dB attenuation, Revolution Wind will continue to implement the additional mitigation measures until NMFS grants approval to revert to the original clearance and shutdown zones or continue with the expanded clearance and shutdown zones with additional PSOs.

Revolution Wind will operate fully functional sound attenuation systems (e.g., ensure hose maintenance, pressure testing) that meet noise levels modeled, assuming 10 dB within five piles or else foundation installation activities will cease until NMFS and Revolution Wind can evaluate the situation and ensure future piles will not exceed noise levels modeled assuming 10 dB attenuation. The NAS will be optimized prior to each deployment using highly qualified NAS deployment and operational specialists. The construction contractor will submit a NAS inspection/performance report to Revolution Wind following an initial performance test conducted shortly after the NAS is fully operational and has been operating for at least 10 minutes; any corrections to the NAS to meet the performance standards will occur prior to pile driving. Revolution Wind will provide NMFS-OPR, NMFS-GARFO – PRD, and BSEE with a bubble curtain performance test and maintenance report to review within 72 hours after each pile using a bubble curtain is installed. Any repairs or alterations will be included in the interim report and sent to NMFS-OPR, NMFS GARFO – PRD, BOEM and BSEE (as described below in 4). The NAS will be assessed to evaluate potential measures that would improve efficacy. If these measures prove to be effective in improving the performance of the NAS, they will be implemented in the next use of the system.

If clearance and shutdown zones are expanded due to SFV results, monitoring of the revised zones will be achieved through a combined effort of PAM and visual observation. Based on the results of the SFV measurements, the PSO vessels will be placed at the outer limit of the revised clearance and shutdown zone(s). For every 1,500 m that a protected species clearance or shutdown zone is expanded, additional PSOs will be deployed from additional PSO vessels to ensure adequate coverage of the expanded clearance and/or shutdown zones In the event that the clearance or shutdown zone(s) are expanded, a proposed monitoring plan for the expanded zones describing the location of all PSOs will be submitted to NMFS GARFO – PRD for approval. The placement of real-time PAM devices will be adjusted to sufficiently cover any expanded clearance or shutdown zones (e.g., current buoys moved outwards). The total number of PAM stations and array configuration will depend on the size of the zone to be monitored, the amount of noise expected in the area, and the characteristics of the signals being monitored. Acoustic monitoring will extend out to the 10 km PAM monitoring zone. Depending on the extent of modified zone sizes, Orsted will be prepared to change the PAM configuration, including moving current buoys outwards or deploying additional buoys[4], to ensure adequate monitoring of the expanded zone(s).

If initial SFV measurements indicate distances to the isopleths corresponding to the potential auditory injury and behavioral harassment thresholds are less than the distances predicted by modeling assuming 10 dB attenuation, Revolution Wind may request a modification of the clearance and shutdown zones for impact pile driving. For a modification request to be considered by NMFS-OPR, Revolution Wind must have conducted SFV on at least seven foundations and ensure that subsequent foundations would be installed under conditions that are predicted to produce equal to or smaller harassment zones that those modeled assuming 10 dB of attenuation. The initial SFV will only be concluded once a full dataset is collected and deemed representative for the entire Revolution Project. If this dataset consistently shows measured acoustic ranges to be below the 10 dB modelled acoustic ranges and Revolution Wind continues to deploy and operate the impact hammer and NAS in the same manner, it is reasonable to expect the acoustic impact for the remainder of the installation sequence is comparable to the one measured at the start of SFV.

The modification request will contain the following information:

- Information regarding future foundation installations (e.g., water depth and predicted difficulty to drive);
- Confirmation that NASs and their maintenance will be left the same to allow an assessment of whether the distance to isopleths can reasonably be expected to remain shorter than originally modeled;
- Peak sound pressure level (PK), root-mean-square sound pressure level that contains 90% of the acoustic energy (SPL), integration time for SPL, and the unweighted single strike sound exposure level (SEL_{ss}) for all detected hammer strikes at the measurement positions. These metrics will be reported in format of scatter plots and spectrograms. Additionally, median, mean, maximum, minimum and 5-percentile exceedance will be reported for broadband values and 1/3 octave spectra of these pressure levels.
- Cumulative weighted SEL calculated from measurements at all measurement positions;
- Depth at the measurement and pile-driving locations;
- Description of sediment type at the pile-driving location;
- Hydrophone equipment and methods (i.e., recording device, bandwidth/sampling rate, distance from the pile where recordings were made; depth of recording device(s));
- Strike energy series required for installation of each pile (hammer logs);
- Maximal pile diameter for each monitored pile;

[4] Revolution Wind has a 100% redundancy of buoys so there exists contingency available to cover additional PAM requirements that may emerge depending on the extent of the increase.

- Local environmental conditions, such as wind speed and direction and current speed and direction, transmission loss data collected onsite (or the sound velocity profile), baseline pre- and post-activity ambient sound levels (broad-band and/or within frequencies of concern);
- Spatial configuration of the noise attenuation device(s) relative to the pile;
- The extents of the acoustic potential auditory injury and behavioral harassment zones for species or species groups;
- The range to the 150, 160, and 175 dB re 1 μPa SPL;
- A description of the noise attenuation devices and operational parameters (e.g., bubble flow rate, distance deployed from the pile, etc.) and any action taken to adjust noise attenuation devices.
- Acoustic ranges to relevant thresholds for each metric and corresponding estimated propagation loss curves
- Clipping information, if applicable.
- Ambient noise plot (using 5th percentile or similar), for each hydrophone;
- Discussion on differences between measured and modeled sound levels;
- Discussion how the above differences modify ranges to exposure potential auditory injury and behavioral harassment thresholds;
- Proposed modification of the clearance and shutdown zones for impact pile driving, and
- Details of how PSO vessels, PSO personnel, and PAM units will be reconfigured or redistributed to ensure relevant zones are sufficiently monitored.

4 Reporting

All reporting will be submitted to NMFS-OPR (itp.esch@noaa.gov); NMFS GARFO – PRD (nmfs.gar.incidental-take@noaa.gov); BOEM, (renewable_reporting@boem.gov); and BSEE via TIMSWeb with a notification email sent to BSEE through TIMSWeb and at protectedspecies@bsee.gov. Submittal requirements to BSEE will follow reporting requirements under JOINT NTL 2023 -N01 Appendix B.

4.1 Interim Reporting

Revolution Wind will provide initial results of each Thorough SFV measurements to BOEM (renewable_reporting@boem.gov), NMFS OPR (PR.ITP.MonitoringReports@noaa.gov), NMFS GARFO – PRD (nmfs.gar.incidental-take@noaa.gov), and USACE (cenae-r-@usace.army.mil) in an interim report for each of the first seven MPs as soon as they are available and prior to a subsequent foundation installation, but no later than 48 hours after each installation is complete (as described in ITR § 217.275 (g)(8) and BiOp T&C 10I(i)). If technical or other issues prevent submission within 48 hours, Revolution Wind will notify NMFS GARFO – PRD within that period with the reasons for delay and provide an anticipated schedule for submission of the interim report. The goal of the interim report is to provide rapid evaluation of the sound fields measured during piling compared to the modelled results (assuming 10 dB attenuation). Based on these comparisons, operations and agencies can ensure that the actual sound fields are not exceeding modelled threshold ranges. As much information as possible from multiple recorders (five at the absolute minimum from different distances from the foundation) will be included in the interim reports and the data will be provided in a standardized format with applicable reference values provided for comparison. In addition to being provided in the interim reporting template (Appendix A; Table B-1), the sound level statistics (of SEL, SPL, and PK) for each hydrophone will be provided as a spreadsheet or otherwise machine-readable format. As described above in section 2.1, three of the first seven piles are expected to require less hammer energy and, therefore, data from the installation of each of the first seven piles will be provided via an interim report (one submitted for each pile in which Thorough SFV measurements were conducted). The SFV measurement and analysis team will strive to include data from all hydrophones (at both depths at each location) in each interim report. The report will contain a meaningful comparison between the modelled and measured ranges based on a subset of measurement data from recorders prioritized as described in Section 2.4. SFV data collected from hydrophones deployed at different locations (Figure 3) along the primary transect will be prioritized over data from both hydrophones at a single location, as described in section 2.4. Interim results will be distributed to relevant Project personnel and contractors, including noise mitigation contractors, via internal communication channels no later than submission to BOEM and NMFS. The interim report will include the following:

- Summary of pile installation activities (pile identifier name, pile diameter, pile weight, pile length, water depth, sediment type, hammer type, total number of strikes, maximum single strike hammer energy, total installation time [start time and end time], duration of pile driving [pile driving plots/activity logs]);
- NAS deployments;
- Clipping information;
- Pre-piling and post-piling noise levels;
- Model-estimated acoustic ranges ($R_{95\%}$ SEL and $R_{95\%}$ SPL_{rms}) at 750 m from the foundation to compare with the real-world sound field measurements;
- Peak sound pressure level (SPL_{PK}), root-mean-square sound pressure level that contains 90% of the acoustic energy (SPL_{rms}), the unweighted single strike sound exposure level (SEL_{ss}), and the frequency-weighted cumulative SEL from measurements at all hydrophones for each hydrophone, including at least the maximum, arithmetic mean, minimum, median (L50) and L5 (95 percent exceedance) statistics for each metric;
- These metrics will be reported in format of scatter plots, spectrograms, and tabular form. Additionally median, mean, maximum, minimum and 5-percentile exceedance will be reported for broadband values and 1/3 octave spectra of these pressure levels;
- Conductivity, Temperature, Depth (CTD casts/sound velocity profiles of each hydrophone);
- Signal and kurtosis rise times;
- Estimated ranges to marine mammal, sea turtle, and fish potential auditory injury and behavioral harassment acoustic isopleths calculated using the maximum over-depth L5 (95% exceedance level, maximum of both hydrophones) of the associated metric;
- Comparison of modeled results assuming 10 dB attenuation against the measured marine mammal, sea turtle, and fish potential auditory injury and behavioral harassment acoustic isopleths;
- Estimated transmission loss coefficients (spreading and absorption);

- Local environmental conditions, such as wind speed and underwater sound speed profile;
- Location of the pile and hydrophone array in latitude/longitude;
- 1/3 octave band single strike SEL spectra;
- If filtering is applied, full filter characteristics will be reported;
- Hydrophone specifications (type, model, and sensitivity);
- The hydrophone signals will be verified prior to each buoy deployment and recovery by means of a pistonphone calibrator on deck or similar method. All pistonphone tests will be recorded and saved for inclusion in the interim report.
- If any in-situ calibration checks for hydrophones reveal a calibration drift greater than 0.75 dB, pistonphone calibration checks are inconclusive, or calibration checks are otherwise not effectively performed, Revolution Wind will indicate full details of the calibration produced results, and any associated issues.
- Any observations which are suspected to have significant impact on the results including but not limited to:
    - Observed noise mitigation system issues;
    - Obstructions along the measurement transect;
    - Technical issues with hydrophones or recording devices.

Reporting for Abbreviated SFV will use the same format and include most of the same content. However, since measurements will be taken at only a single distance, values that rely on calculations from a transmission loss model (such as ranges to acoustic thresholds) will not be reported.

4.2 NAS inspection/performance reporting

As per LOA condition 3(c)(8)(v) and BiOp T&C 2(a)(b), Revolution Wind will submit a NAS inspection/performance report to NMFS OPR (PR.ITP.MonitoringReports@noaa.gov) and NMFS GARFO – PRD (nmfs.gar.incidental-take@noaa.gov) within 72 hours following the performance test, which will occur to the first pile installation as well as any additional piles for which SFV is conducted. This report will be submitted as soon as possible as it is available, but no later than when the interim SFV report (as described in Section 4.1) is submitted for the respective pile. The contractor will provide the results of a performance test to Revolution Wind within 48 hours following the test. Any modifications to the attenuation device to meet the performance standards will occur before impact pile driving begins and maintenance or modifications are completed (as described in Section 3) and will be included within this report.

4.3 Final Reporting

A final report for the SFV of MP installations will be submitted to BOEM (renewable_reporting@boem.gov), NMFS OPR (PR.ITP.MonitoringReports@noaa.gov) and NMFS GARFO – PRD (nmfs.gar.incidental-take@noaa.gov) as soon as possible, but not later than 90 days following completion of impact pile driving of the five or more MPs for which SFV was carried out as per BiOp T&C 10 (e)(iii) and ITR § 217.275 (g)(9). The final report will include all details described above for the interim report, as well as the following:

- Peak sound pressure level (SPL_{pk}), the root-mean square sound pressure level that contains 90 percent of the acoustic energy (SPL_{rms}), the unweighted single strike sound exposure level (SEL_{ss}), the integration time for SPL_{rms}, the spectrum, and the frequency-weighted cumulative SEL from measurements at all hydrophones;
- At least the maximum, mean, median (L_{50}) and L_5 (95% exceedance) statistics for each metric;
- The SEL and SPL power spectral density and/or 1/3 octave band levels (or decidecade band levels) at the receiver locations;
- The sound levels will be reported in median, arithmetic mean (i.e., average in linear space), and L_5 (95% exceedance) (i.e., average in linear space) and in dB;
- Range of TL coefficients;
- Local environmental conditions (e.g., wind speed);
- Transmission loss data collected on-site (or the sound velocity profile);
- Baseline pre- and post-activity ambient sound levels (broadband and/or within frequencies of concern);
- Description of depth and sediment type, as documented in the Construction and Operations Plan (COP), at the recording and foundation installation locations;
- Extent of the measured acoustic potential auditory injury and behavioral harassment zone(s);
- Hammer energies required for pile installation and the number of strikes per pile;
- Hydrophone equipment and methods (i.e., recording device, bandwidth/sampling rate, distance from the pile where recordings were made);
- Depth of recording device(s);
- Description of the SFV measurement hardware and software, including software version used, calibration data, bandwidth capability and sensitivity of hydrophone(s), any filters used in hardware or software, any limitations with the equipment, and other relevant information;
- Spatial configuration of the noise attenuation device(s) relative to the pile;
- Description of the noise abatement system and operational parameters (e.g., bubble flow rate, distance deployed from the pile etc.), and any action taken to adjust the noise abatement system
- Discussion including any observations which are suspected to have a significant impact on the results including but not limited to:
    - Observed noise mitigation system issues;
    - Obstructions along the measurement transect; and,
    - Technical issues with hydrophones or recording devices.

Literature Cited

FHWG. 2008. Agreement in Principle for Interim Criteria for Injury to Fish from Pile Driving Activities. 12 Jun 2008 edition. Available at http://www.dot.ca.gov/hq/env/bio/files/fhwgcriteria_agree.pdf.

Finneran, J.J., E.E. Henderson, D.S. Houser, K. Jenkins, S. Kotecki, and J. Mulsow. 2017. Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III). Technical report by Space and Naval Warfare Systems Center Pacific (SSC Pacific). 183 p.

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McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, and J. Murdoch. 2000. Marine seismic surveys: a study of environmental implications. Australian Petroleum Production Exploration Association (APPEA) Journal 40(1):692-708. doi: 10.1071/AJ99048.

Indicative Underwater Sound Field Verification Interim Report – Revolution Wind

Underwater Sound Field Verification

Revolution Wind Interim Report: Pile XXXXXX

XX May 2024

Submitted to:

Orsted Wind Power North America, LLC

Authors:

Scientist 1
Scientist 2

P00XXXX-XX
Document XXXXXX
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Suggested citation:

Name 1, Name 2 and Name 3. 2024. *Underwater Sound Field Verification:Revolution Wind Interim Report: Pile XXXXXX*. Technical report by JASCO Applied Sciences for Revolution Wind, LLC.

Contents

Figures

Tables

1. Summary

1.1. Pile Location and Monitoring Summary

Pile XXXX is a tapered monopile with diameters ranging from X to XX m driven at the Revolution Wind lease area (OCS-A 0486). The pile was driven for X.XX hours between XX:XX – XX:XX Coordinate Universal Time (EDT) on XX May 2024 (Table 1). Noise Attenuation Systems (NAS) used during installation included an AdBm system deployed immediately adjacent to the pile and two big bubble curtains (double big bubble curtain), with one ring at approximately XX m and the second at approximately XX m from the pile.

Gardline performed sound field verification (SFV) measurements according to the ISO 18406:2017 standards. Four RSA-Porpoise subsea acoustic recorders (SARs) were deployed by Gardline on behalf of Revolution Wind to measure sound levels at ranges of 750 m to 10,000 m from the pile, along with an additional recorder at 750 m 90 degrees from the primary measurement radius (Figure 1 and Table 2). The stations were deployed toward deeper water of the pile at increasing ranges. Two hydrophones per system were deployed for analysis; one mounted 2 m above the seafloor and the other at the mid-water column depth.

Prior to piling two minutes of collected data were used to determine the ambient power spectral density (Appendix A). Table 2 shows the sound levels measured at each recorder during pile driving. No clipping was observed in the pulse detections during piling. Plots of the measured values, frequency distributions of decidecade-band single-strike sound exposure levels (SELss), and sound level statistics for the distribution of the measured data are presented in Appendix B.

Table 1. Summary of Pile XXXX activities, XX May 2024.

Date	2024-05-XX
Pile-Driving Activity	
Test pile identifier	
Pile diameter	
Pile weight	
Pile length	
Water depth	
Sediment Type	
Hammer type	
Total hammer strikes	
Total penetration:	
Pile Driving Start Time (hh:mm:ss)	
Pile Driving End Time (hh:mm:ss)	
Net duration of pile driving (hh:mm:ss)	
Maximum single strike energy	

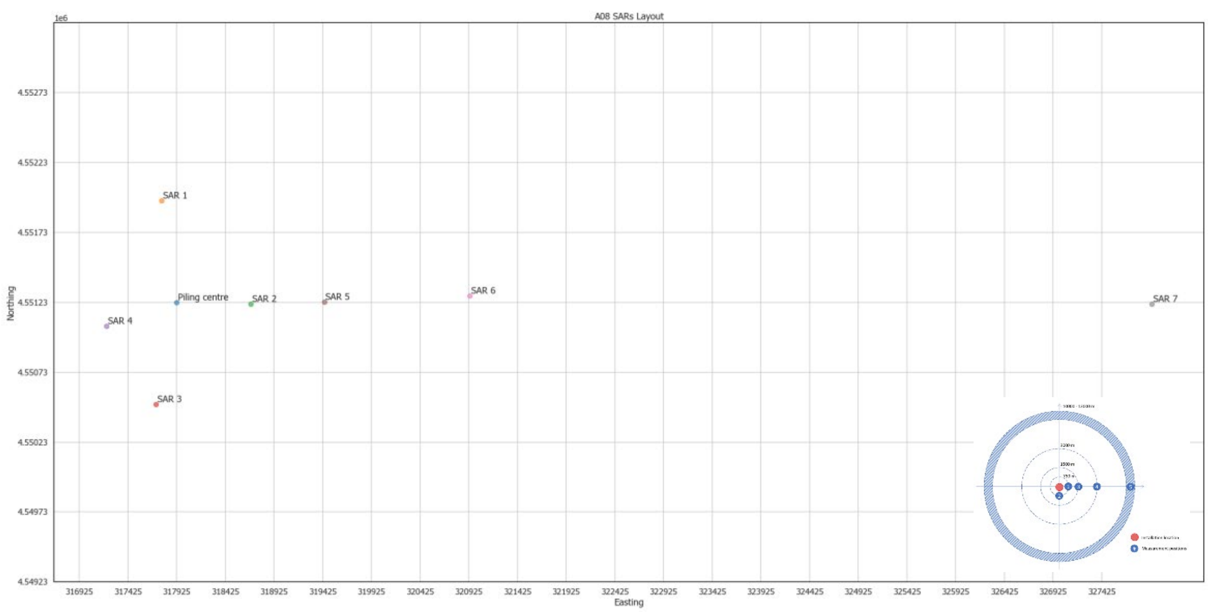

Figure 1. Nominal recorder deployment locations relative to the pile. Four measurement positions were deployed at increasing range toward deeper water from the pile XXXX.

Table 2. Summary of hydrophone locations and measured sound levels for Pile XXXX, XX May 2024. 0° is due North, and remaining angular measurements are degrees clockwise from North (E of N). The recording systems are deployed along a primary measurement radius at XXX degrees. The designation '750 @ 90°' refers to the recorder at 750 m at XXX degrees (90° relative to the primary measurement radius).

<table>
<tr><th>Location (nominal)</th><th>Measurement position # (refer to Figure 1)</th><th>Hydrophone Channel</th><th>Recorder ID</th><th>Distance from pile (m)</th><th>Water depth (m)</th><th>Impulses detected</th><th>Max rms SPL (dB re 1 µPa)</th><th>cSEL (dB re 1 µPa²·s)</th></tr>
<tr><td rowspan="2">750</td><td rowspan="2"></td><td>Bottom</td><td rowspan="2">SAR_X</td><td rowspan="2"></td><td rowspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>Mid-water</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">1500</td><td rowspan="2"></td><td>Bottom</td><td rowspan="2">SAR_X</td><td rowspan="2"></td><td rowspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>Mid-water</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">3000</td><td rowspan="2"></td><td>Bottom</td><td rowspan="2">SAR_X</td><td rowspan="2"></td><td rowspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>Mid-water</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">10000</td><td rowspan="2"></td><td>Bottom</td><td rowspan="2">SAR_X</td><td rowspan="2"></td><td rowspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>Mid-water</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">750 @ 90°</td><td rowspan="2"></td><td>Bottom</td><td rowspan="2">SAR_X</td><td rowspan="2"></td><td rowspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>Mid-water</td><td></td><td></td><td></td></tr>
</table>

Table 3. Ambient noise levels recorded at each station averaged over a 2-minute window preceding piling.All levels were recorded on the bottom-mounted hydrophone. The designation ‘750 @ 90°’ refers to the recorder at 750 m to the east of the pile putting it inline with the other recorders.

Location (nominal)	Measurement position # (refer to Figure 1)	Distance from pile (m)	Maximum spectral density (dB re 1μPa^{2}Hz^{-1})
750			
1500			
3000			
10000			
750 @ 90°			

1.2. Physiological and Behavioral Thresholds

The distances from pile driving to the noise levels that serve as the physiological and behavioral thresholds were extrapolated from a logarithmic regression fitted to the L5 values of the peak sound pressure level (PK), root-mean-square (rms) sound pressure level (SPL), as well as the cumulative sound exposure level (cSEL; sum of all single-strike SELs measured during the pile installation) of the received impulses on each recorder. The logarithmic regression was performed as a single function in the form of $A \cdot Log_{10}(r)$, where A is the attenuation coefficient, r is the distance from the source The decay coefficient α was not considered for these data due to variability in received levels between stations.

Due to propagation effects near the pile source, ranges less than 100 m, corresponding to about 3x the water depth, are not considered consistent with damped cylindrical spreading-type models and are shown for demonstration only. A minimum prediction range of 10 m has been applied. Predictions outside the measured data should be used with caution, as indicated by dashed lines in the regression plots.

The maximum of the bottom and mid-water hydrophones was used for the following regression ranges and coefficients.

Table 4. Estimated isopleth distances to the NMFS marine mammal physiological and behavioral thresholds. Expected ranges represent 10-dB attenuated ranges ($R_{95\%}$, in meters) for a 7/12 m diameter monopile during summer. The cSEL levels were calculated by summing all singe-strike SELs from each hammer strike.

Group	Level A: PK				Level A: cSEL		
	Threshold Level (dB re 1µPa)	Expected (m)	Measured (m) without absorption*	Threshold Level (dB re 1 µPa2·s)	Associated Modeling Location (L024-002 or L024-114)	Expected (m) (modeling location dependent)	Measured (m) without absorption*
LFC	219	<10		183			
MFC	230	<10		185			
HFC	202	178		155			
PPW	218	<10		183			
ST PTS	232	<10		204			
Large Fish	206	90		187			

*Ranges less than 100 m may not be consistent with damped cylindrical spreading-type models and are shown for demonstration only. A minimum prediction range of 10 m has been applied.

Table 5. Estimated isopleth distances for the NMFS behavioral thresholds.

		Level B: SPL		
Group	Threshold Level (dB re 1μPa)	Associated Modeling Location (L024-002 or L024-114)	Expected (m) (modeling location dependent)	Measured (m)
MM	160			
ST	175			
AS	150			

Table 6. Estimated curve fit coefficients for transmission loss with and without intrinsic attenuation.

Metric	A (dB/decade m) A·log(r)
PK (L5) (dB re 1 μPa)	
rms SPL (L5) (dB re 1 μPa)	
SELss (dB re 1 μPa2·s)	
SELss, LF (dB re 1 μPa2·s)	
SELss, MF (dB re 1 μPa2·s)	
SELss, HF (dB re 1 μPa2·s)	
SELss, PW (dB re 1 μPa2·s)	
SELss, TUW (dB re 1 μPa2·s)	
cSEL (dB re 1 μPa2·s)	
cSEL, LF (dB re 1 μPa2·s)	
cSEL, MF (dB re 1 μPa2·s)	
cSEL, HF (dB re 1 μPa2·s)	
cSE, PW (dB re 1 μPa2·s)	
cSEL, TUW (dB re 1 μPa2·s)	

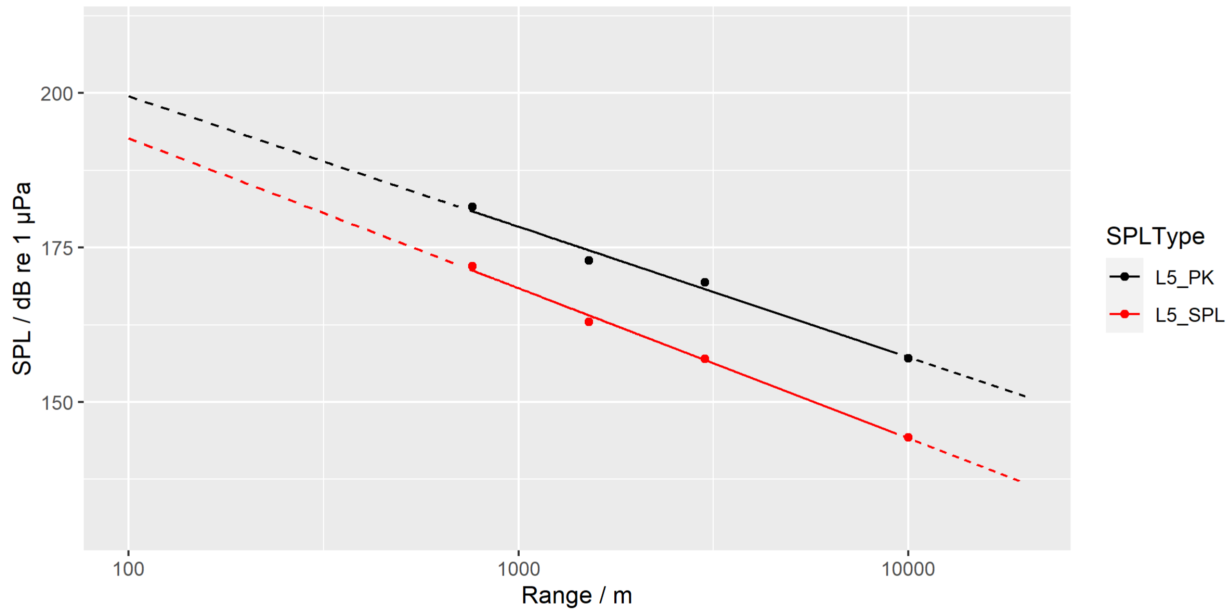

Figure 2. Regression without absorption based on L5 values of the PK and rms SPL during pile driving of XXXX on XX May 2024. PK and rms SPL are provided in instantaneous values. The regression fit uses the equations A $Log_{10}(r)+\alpha r$, where A is the transmission loss coefficient, α=0, and r is the range.

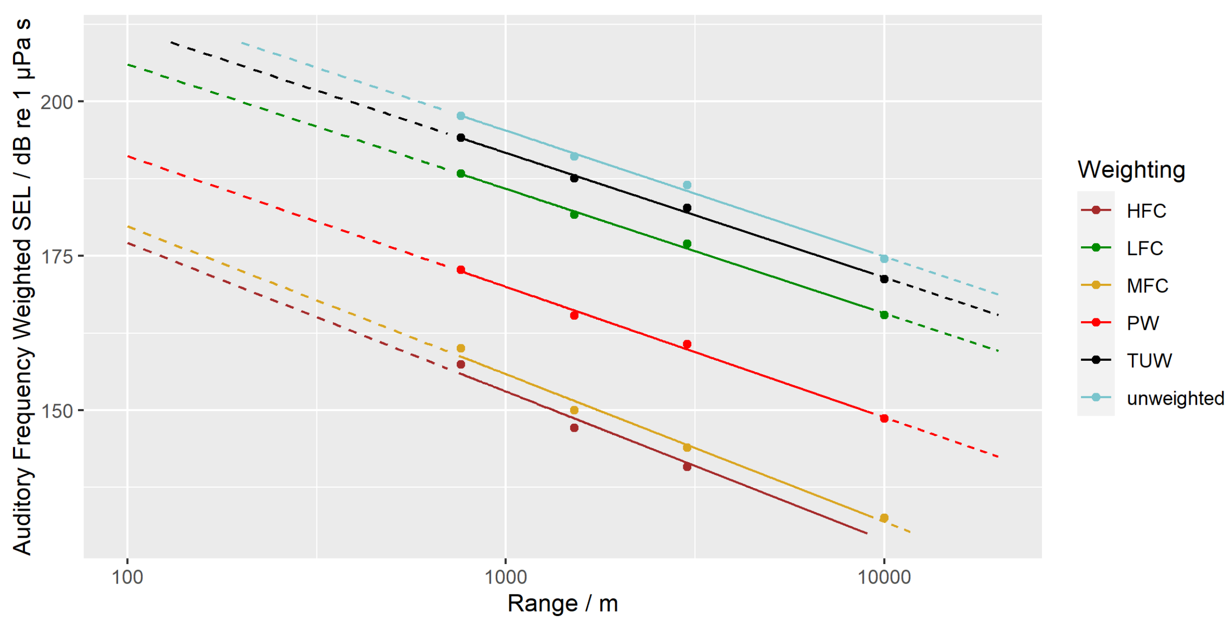

Figure 3. Regression without absorption based on the cSEL during pile driving of XXXX on XX May 2024. cSEL is provided as the hearing-weighted sum of the single-strike SEL (ssSEL) for all strikes and for each hearing group. The regression fit uses the equations A·$Log_{10}(r)+\alpha r$, where A is the transmission loss coefficient, α=0, and r is the range.

1.3. Observations

The impact hammer performed XXXX strikes and operated at a hammer energy up to XXXX kJ. Data were collected at the nominal recording locations (750, 1500, 3000, and 10000 m), and ranges to the regulatory (Level A and Level B) thresholds were determined for the different hearing groups by fitting the data with a spreading loss function without absorption.

TEXT DESCRIBING NOTABLE OBSERVATIONS HERE

1.3.1. Pulse Duration

Pulse duration was computed by Gardline for the window of detection for each strike. Pulse duration was used to compute the time-averaged root mean square (RMS) SPL,

$$SPL_{rms} = 20 * log10\left(\frac{1}{T}\sqrt{\int_T P(t)^2 dt}\right),$$

where T is the pulse duration from 5%-95% pulse energy, in seconds. As range from the pile increases, pulse duration is expected to increase due to geometric dispersion of the pulse energy. The pulse duration at the stations East of Pile XXXX are shown for the hydrophones in Figure 4. The pulse durations increase with range.

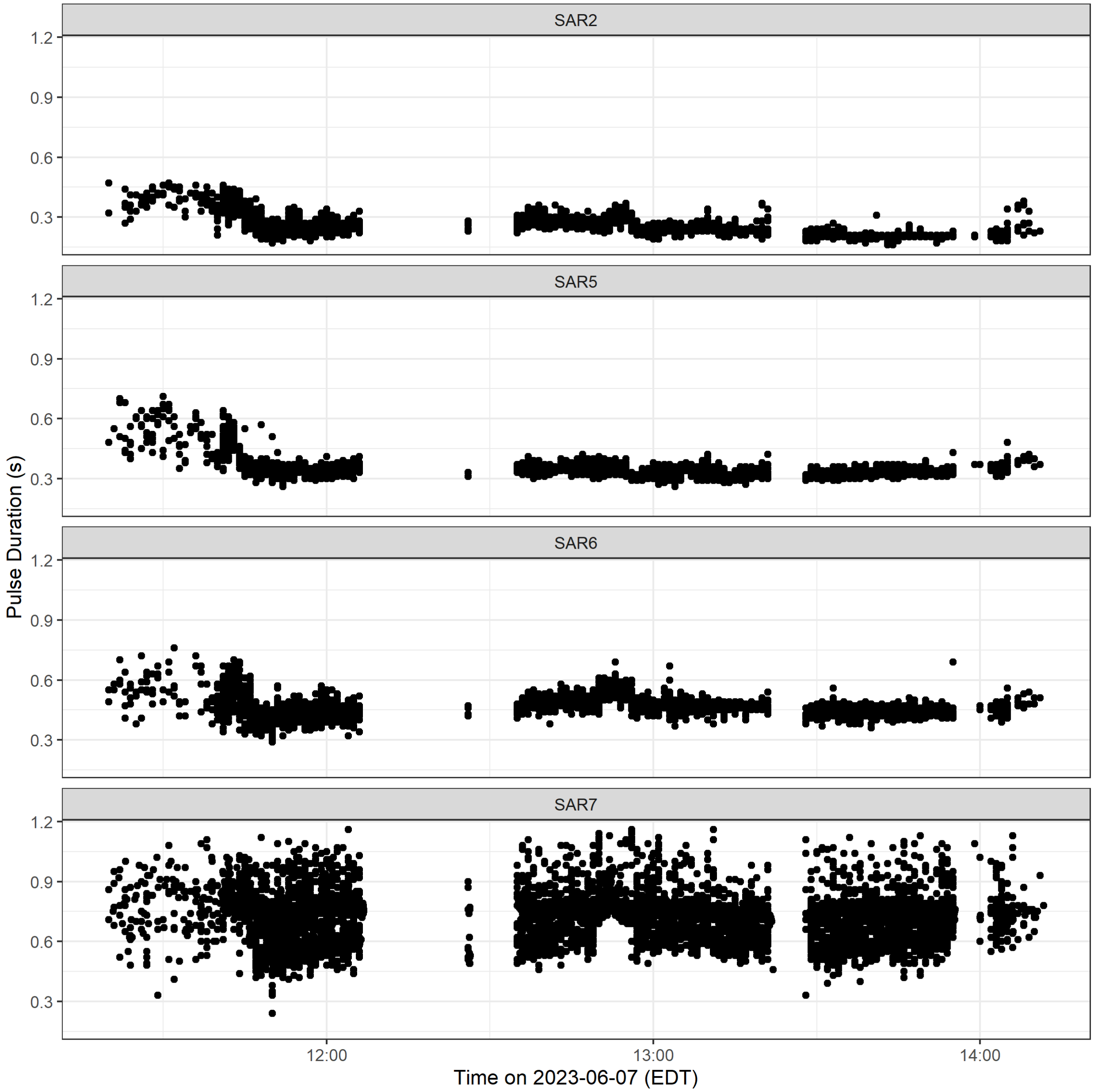

Figure 4. (EXAMPLE) Pulse duration, in seconds, of all detections on the bottom-mounted hydrophones at the stations SAR2, and SAR6, the mid-water hydrophone at SAR5, and both bottom-mounted and mid-water hydrophones at SAR7, with stations SAR 2, 5-7 located nominally at 750 m, 1500 m, 3000 m, and 10000 m to the East of A08.

1.3.1. Signal kurtosis

The kurtosis of the received signals was calculated at each of the recording locations (Figure 5).

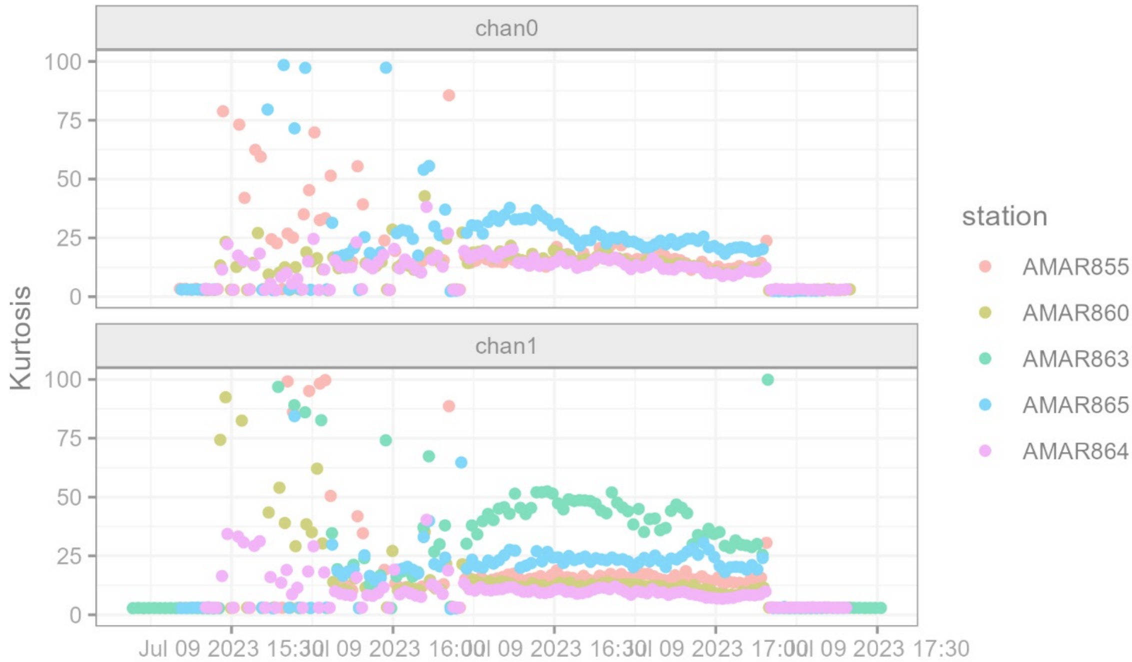

Figure 5. Signal kurtosis for each strike at each recording location.

1.3.2. Pulse rise time

The rise time of detected pulse was calculated at each of the recording locations (Figure 6).

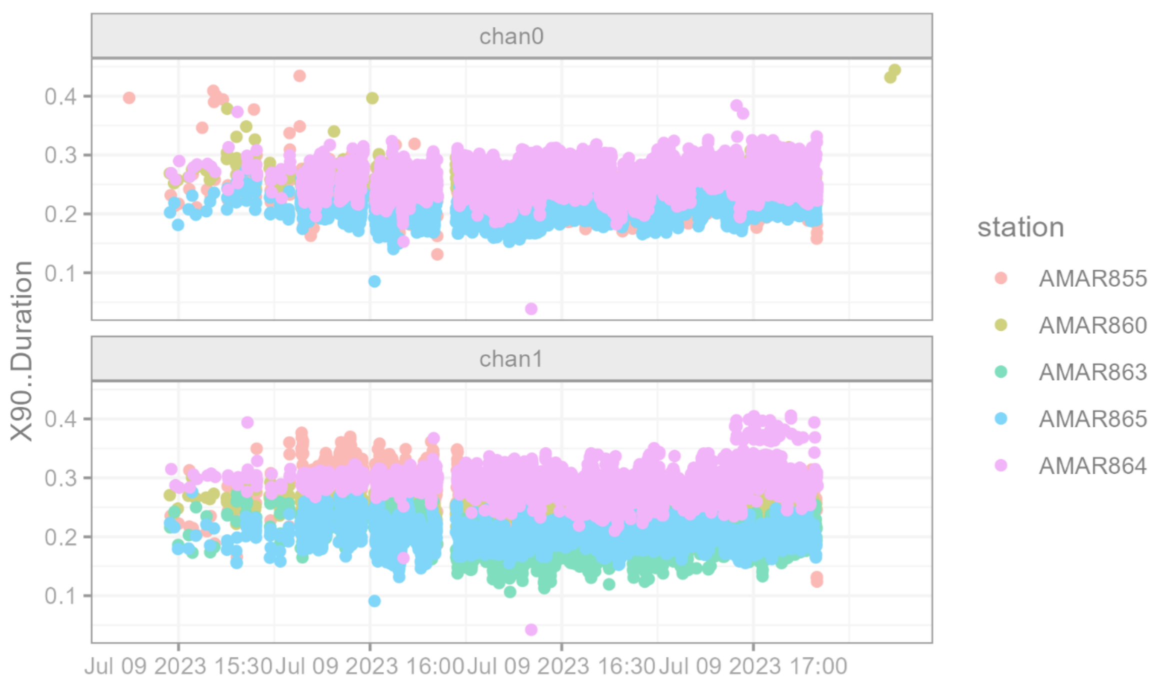

Figure 6. Pulse rise time for each strike at each recording location.

2. Pile Driving Logs (EXAMPLE)

Total number of strikes: 3786

Maximum per-strike energy: 3254 kJ

MHC 21 - Blowcount Curve - MENCK Kaltenkirchen
Boskalis - NEP
A08 - length 96.18 m - diameter 8 - 9.5 m - thickness 102 mm
penetration increment 0.20 m - total blows 3786 - final penetr. 33.70 m

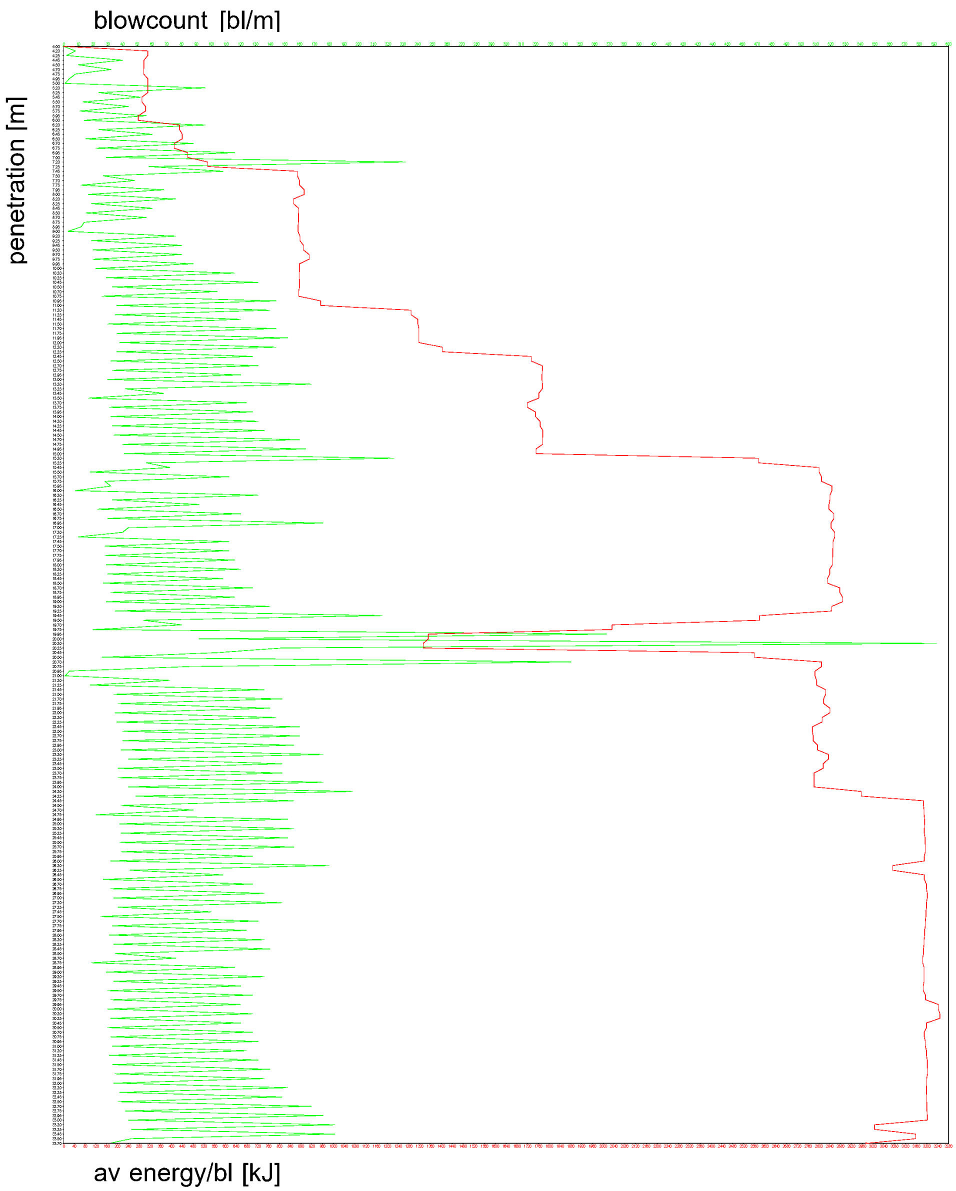

Figure 7. Penetration (m) as a function of blow count and energy (kJ) for the impact pile driving of Pile XXXX, XX May 2024.

3. Sound Velocity Profile

(EXAMPLE)

Figure 8 provides the measured speed of sound in water, based on a conductivity, temperature, depth (CTD) cast. Figure 9 provides the average sound speed velocity profile (SVP) derived from the CTD casts compared to historic data.

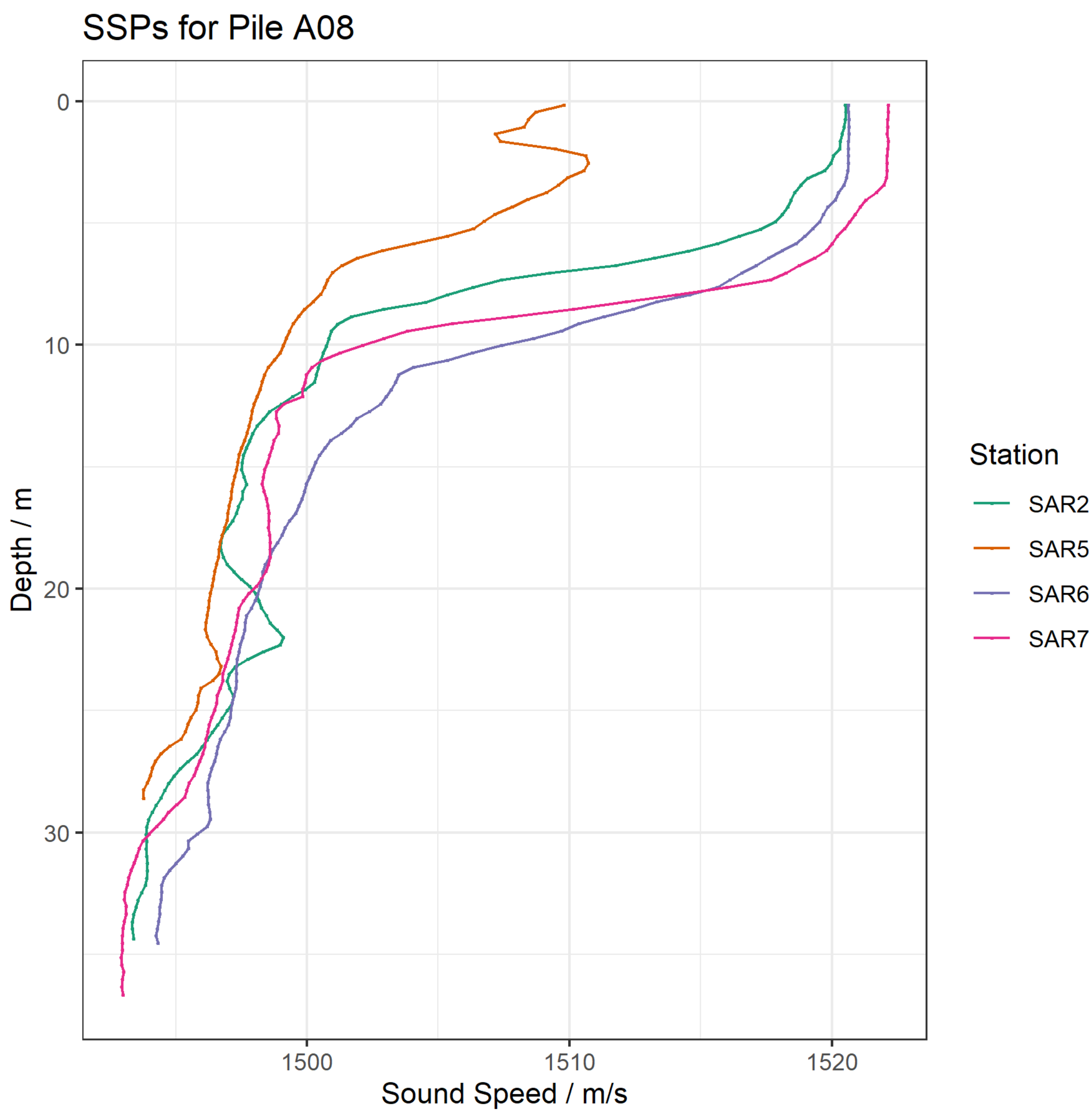

Figure 8. (EXAMPLE) CTD casts performed at the monitoring sites on XX May 2024.

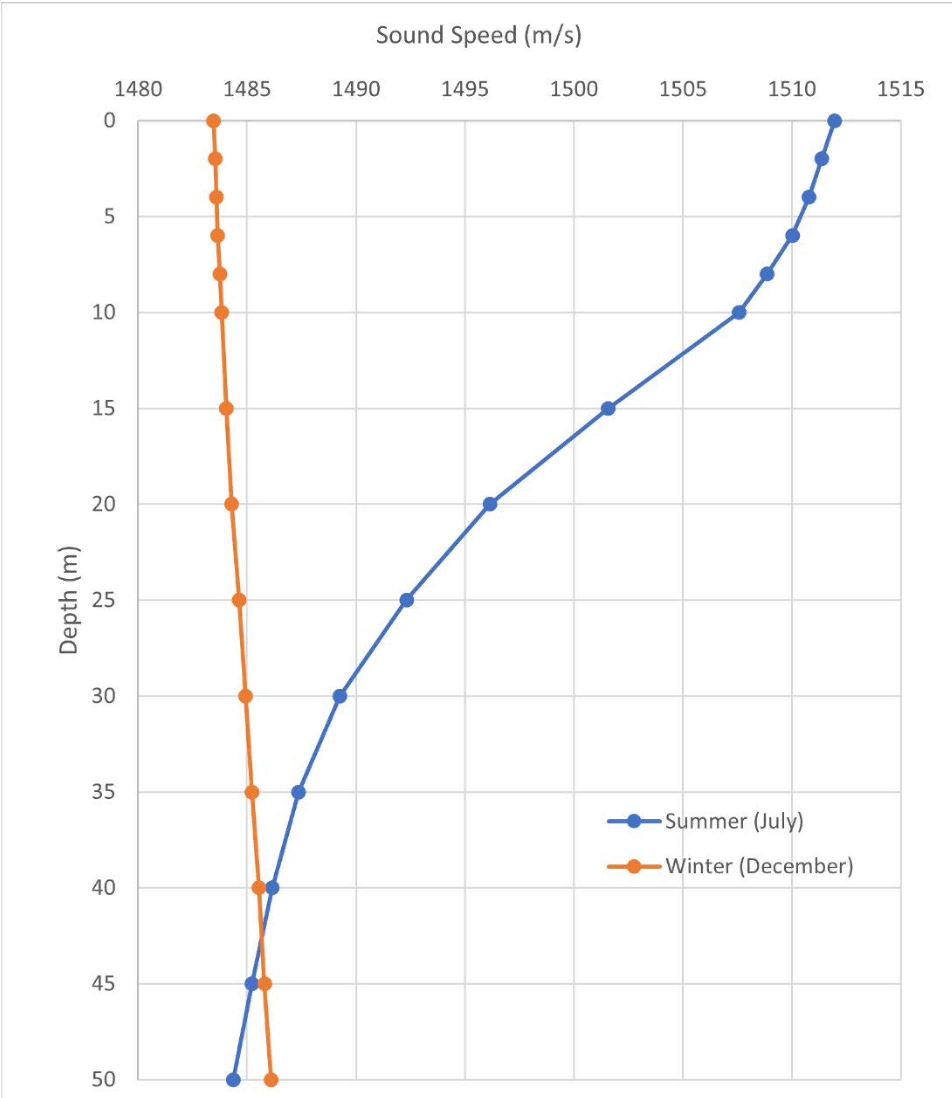

Figure 9. Average SVP derived from historic data (GDEM) for Summer and Winter at the modeled site.

4. Monitoring Equipment

Table 7 provides information about the monitoring equipment used on XX May 2024. Table 8 provides the locations of the hydrophone recorders. All hydrophones recorded 24-bit, single channel wav files at 48 kHz sample rate.

Table 7. Monitoring equipment for Pile XXXX, XX May 2024.

Equipment Used							
Acoustic Data Logger							
Model			Units Deployed				
Porpoise			4				
Hydrophone							
Station	Measurement position # (Figure 1)	Channel	Depth (m) (nominal)	Model	Sensitivity (dB re 1 V/µPa)	Pistonphone Calibrations Completed	Confirm High Pass Filtering Off
XXXX 750				*Porpoise*			
				Porpoise			
XXXX 1500				*Porpoise*			
				Porpoise			
XXXX 3000				*Porpoise*			
				Porpoise			
XXXX 10000				*Porpoise*			
				Porpoise			
XXXX 750 @ 90°				*Porpoise*			
				Porpoise			

Table 8. Locations and deployment times (EDT) of the hydrophone monitoring stations for Pile XXXX, XX May 2024.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Water depth (m)	Distance to pile (m)
XXXX 750					
XXXX 1500					
XXXX 3000					
XXXX 10000					
XXXX 750 @ 90°					

Appendix A. Ambient Measurements

Ambient sound levels calculated in a two minute window prior to commencement of pile driving.

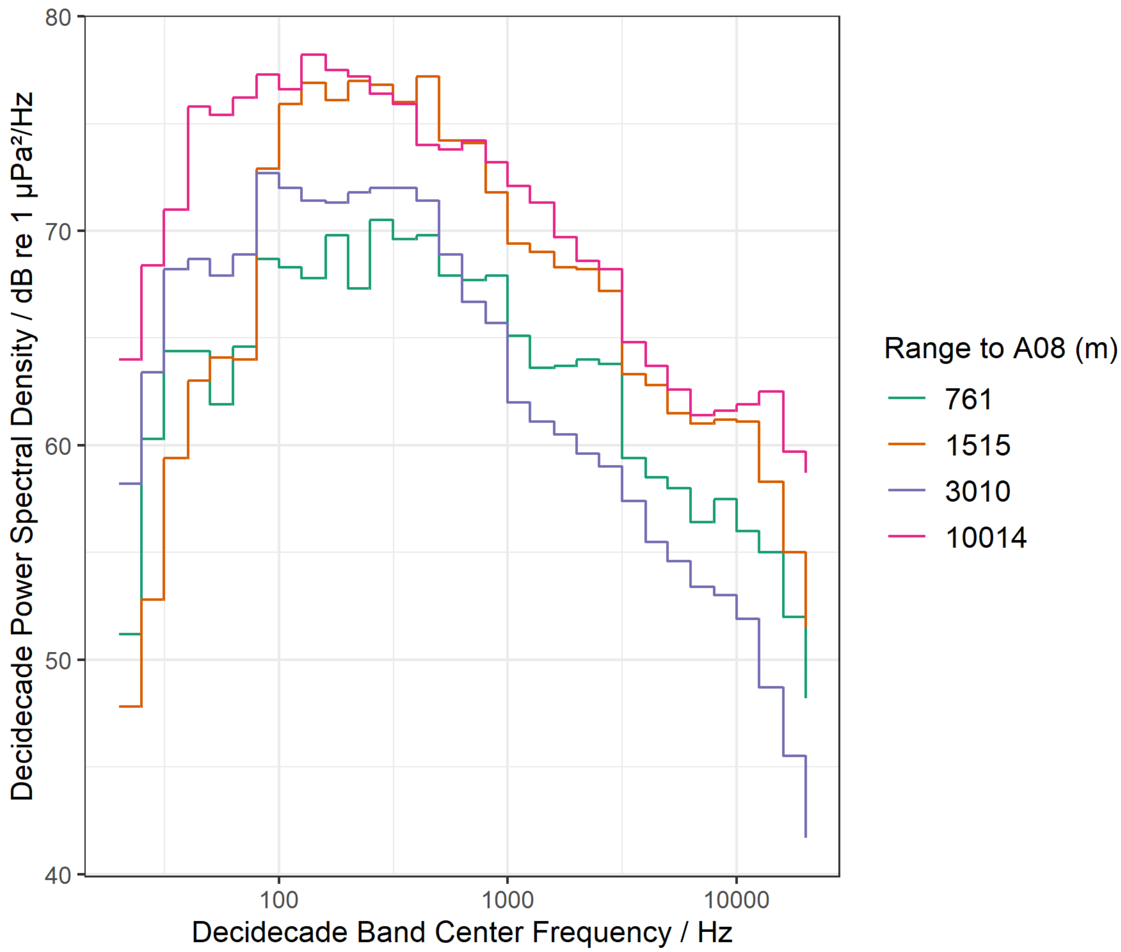

Figure 10. (EXAMPLE) Decidecade ambient noise power spectral density, averaged over a 2-minute period preceding piling. The level for each station is shown for the bottom channel.

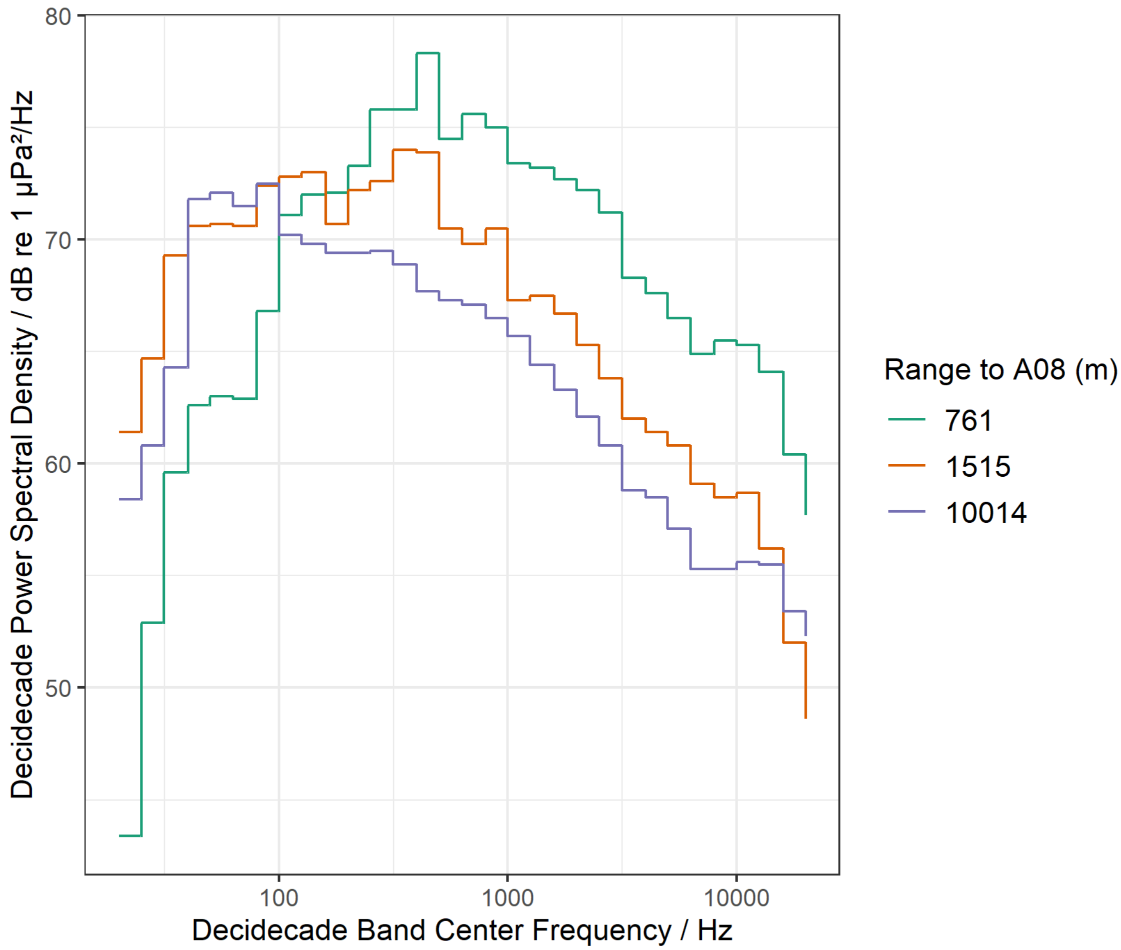

Figure 11. (EXAMPLE) Decidecade ambient noise power spectral density, averaged over a 2-minute period preceding piling. The level for each station is shown for the mid-water channel.

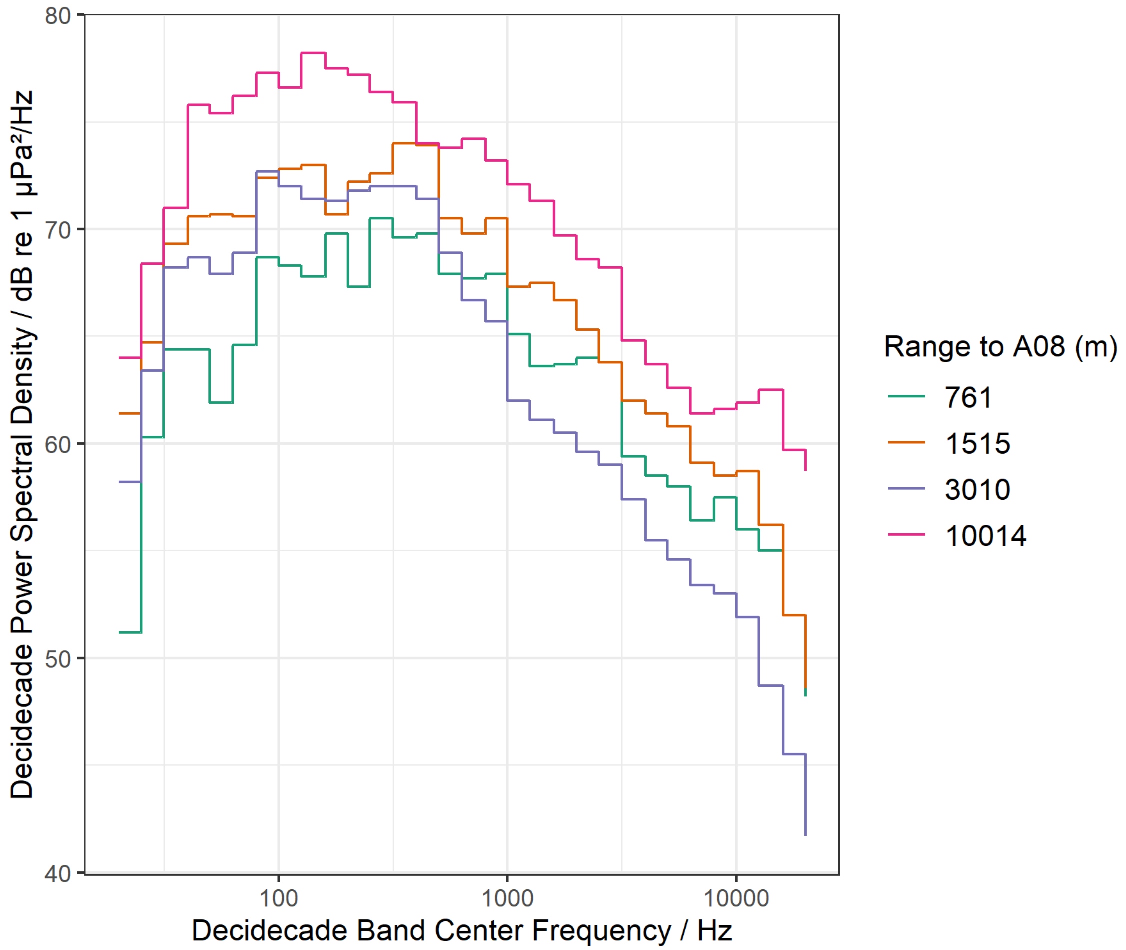

Figure 12. (EXAMPLE) Decidecade ambient noise power spectral density, averaged over a 2-minute period preceding piling. The level for each station is shown for the channel used in the regressions: the bottom hydrophone for the stations nominally at 750 m and 3000 m, the mid-water hydrophone for the station nominally at 1500 m, and the maximum over hydrophone at each center frequency for the station nominally at 10000 m.

Appendix B. Pile Driving Plots

(EXAMPLES)

B.1. Impact Pile-Driving Sound Levels at 750 m at 90°

B.1.1. Bottom-Mounted Hydrophone

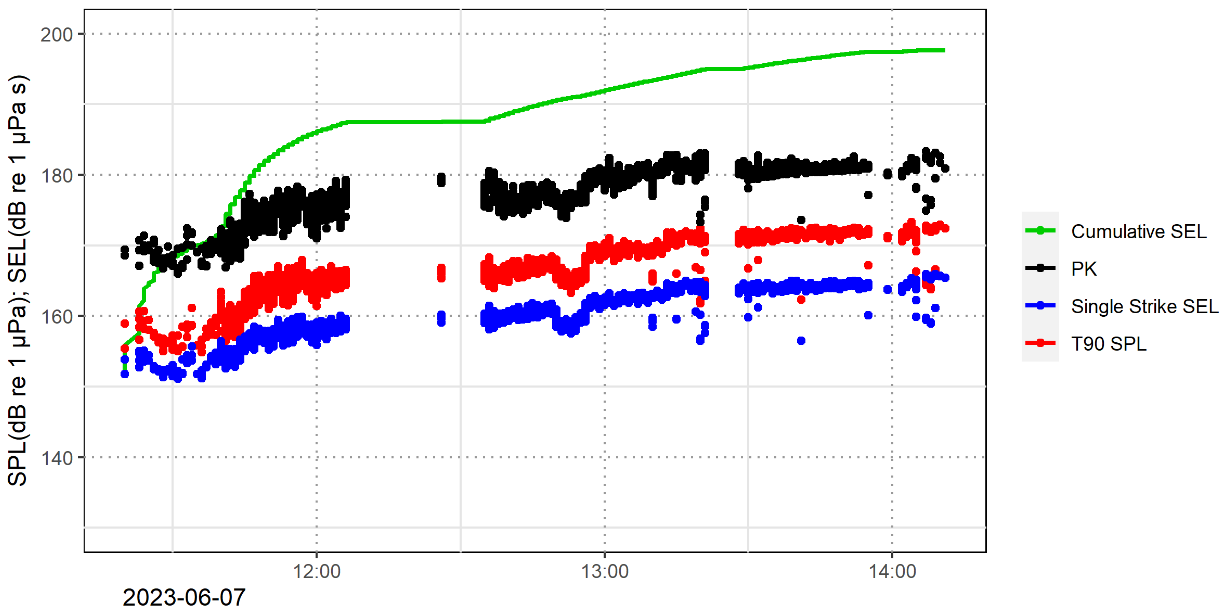

Figure B.1-1. Impact Pile Driving: PK, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of A08 measured 761 m from the pile at monitoring station SAR2. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

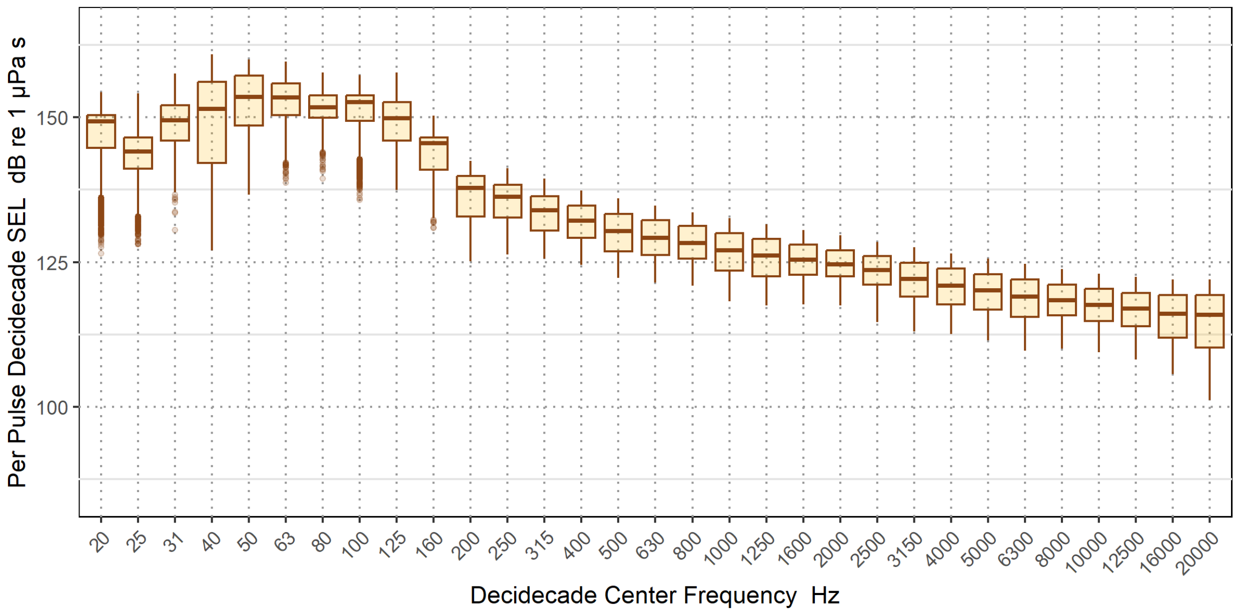

Figure B.1-2. Distribution of 1/3-octave-band SELss for the pile driving of A08 measured 761m from the pile at monitoring station SAR2.Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}).

B.1.2. Table of Sound Levels at 750 m at 90°

Table B-1. Sound levels for the pile driving of A08 measured 761 m from the pile at monitoring station SAR2.

Sound level statistic*	PK (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa²·s)
Bottom-Mounted Hydrophone			
L_{max}	183.3	173.3	165.9
L_5	181.6	172.0	164.6
L_{25}	180.7	171.2	163.9
L_{50}	178.9	168.1	161.4
L_{75}	175.7	165.1	158.5
L_{95}	170.9	159.6	154.8
L_{mean}	177.9	167.6	160.9

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the SPL or SEL exceeded by *n*% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

B.2. Impact Pile-Driving Sound Levels at 1500 m

B.2.1. Mid-Water Hydrophone

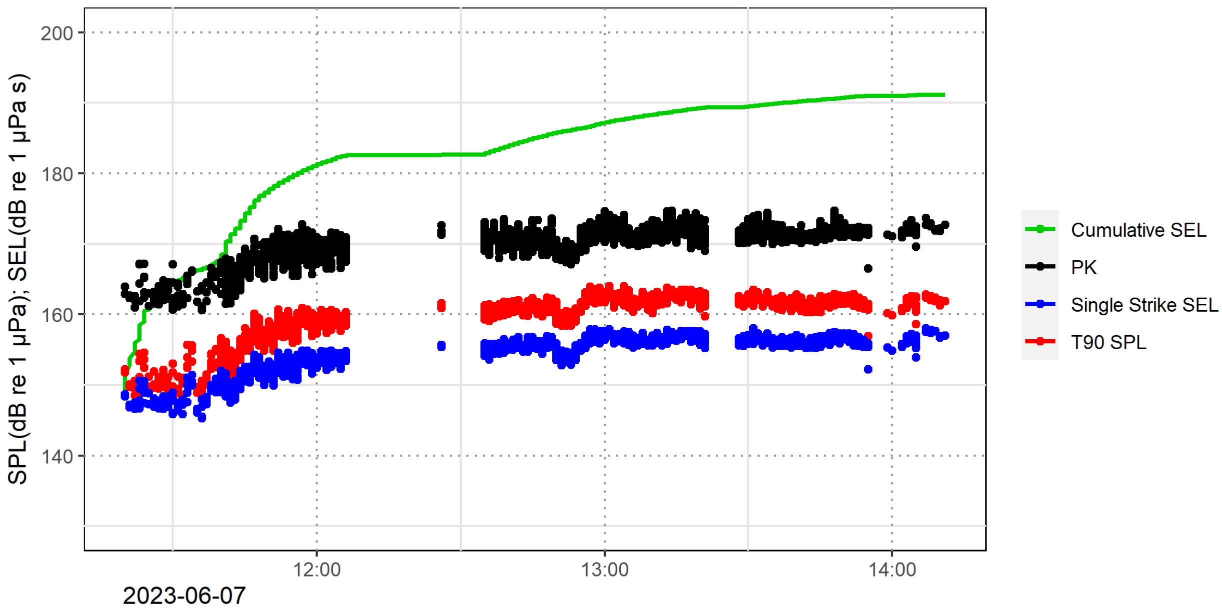

Figure B.2-3. Impact Pile Driving: PK, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of A08 measured 1515 m from the pile at monitoring station SAR5. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

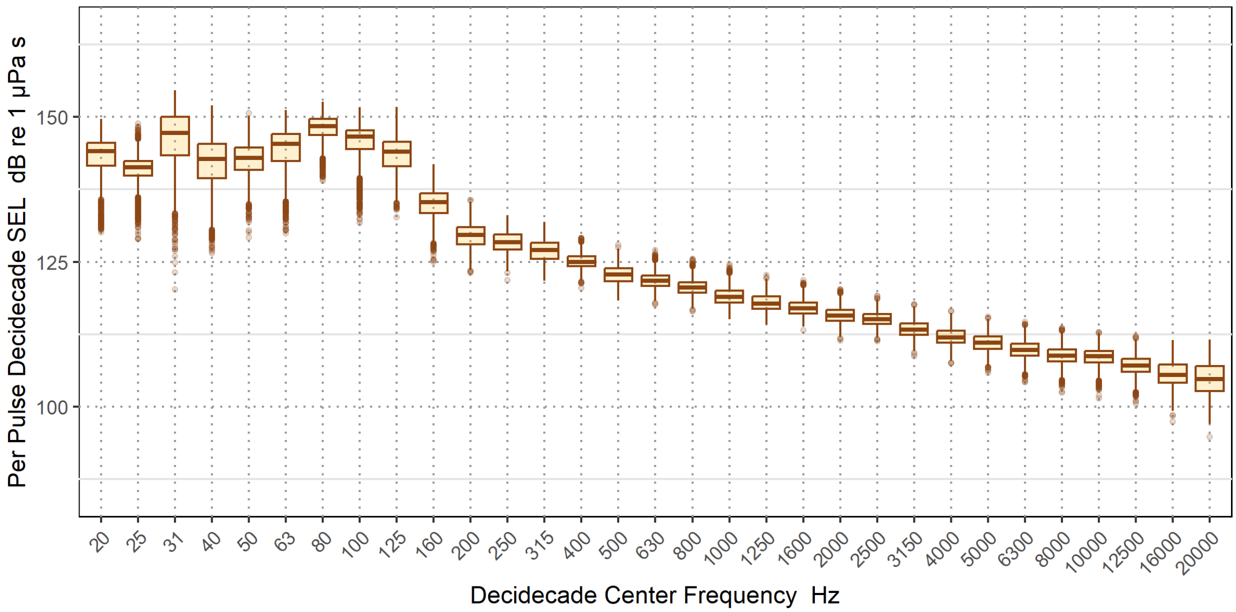

Figure B.2-4. Distribution of 1/3-octave-band SELss for the pile driving of A08 measured 1515 m from the pile at monitoring station SAR5. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

B.2.2. Table of Sound Levels at 1500 m

Table B-2. Sound levels for the pile driving of A08 measured 1515 m from the pile at monitoring station SAR5.

Sound level statistic*	PK (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa²·s)
Mid-Water Hydrophone			
L_{max}	174.7	164.0	158.0
L_5	172.9	163.0	157.2
L_{25}	171.6	162.0	156.5
L_{50}	170.8	161.2	155.8
L_{75}	169.0	159.2	153.7
L_{95}	165.6	154.1	149.9
L_{mean}	170.2	160.2	154.9

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (Ln) is the SPL or SEL exceeded by n% of the data. Lmax is the maximum recorded sound level. Lmean is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L50).

Impact Pile-Driving Sound Levels at 3000 m

B.3.1. Bottom-Mounted Hydrophone

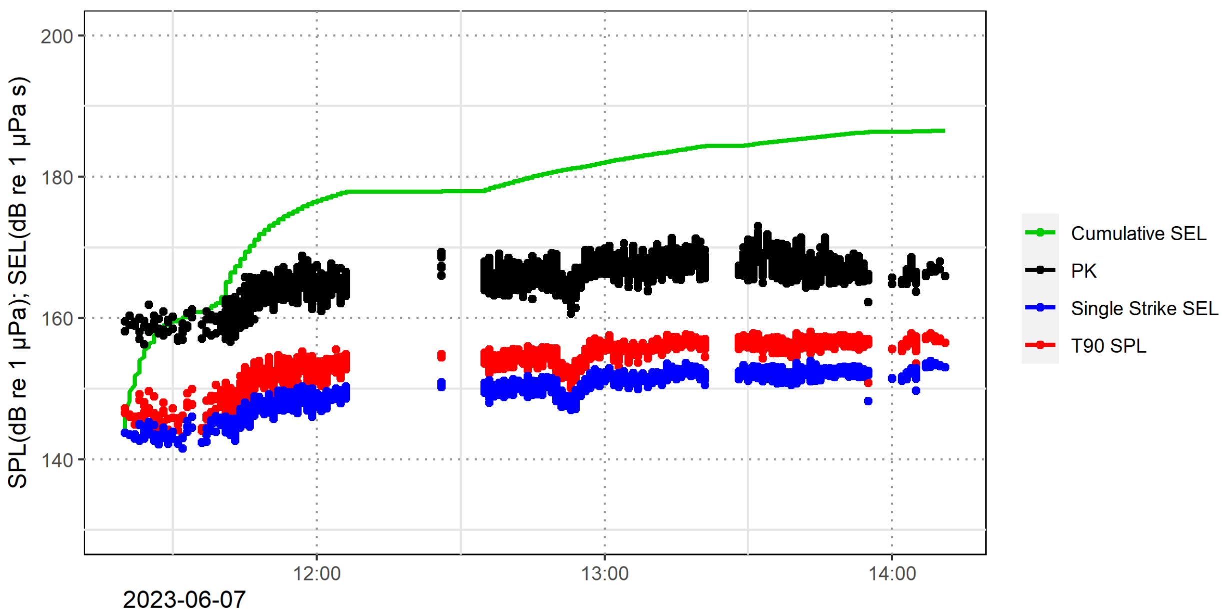

Figure B.3-5. Impact Pile Driving: PK, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of A08 measured 3010 m from the pile at monitoring station SAR6. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

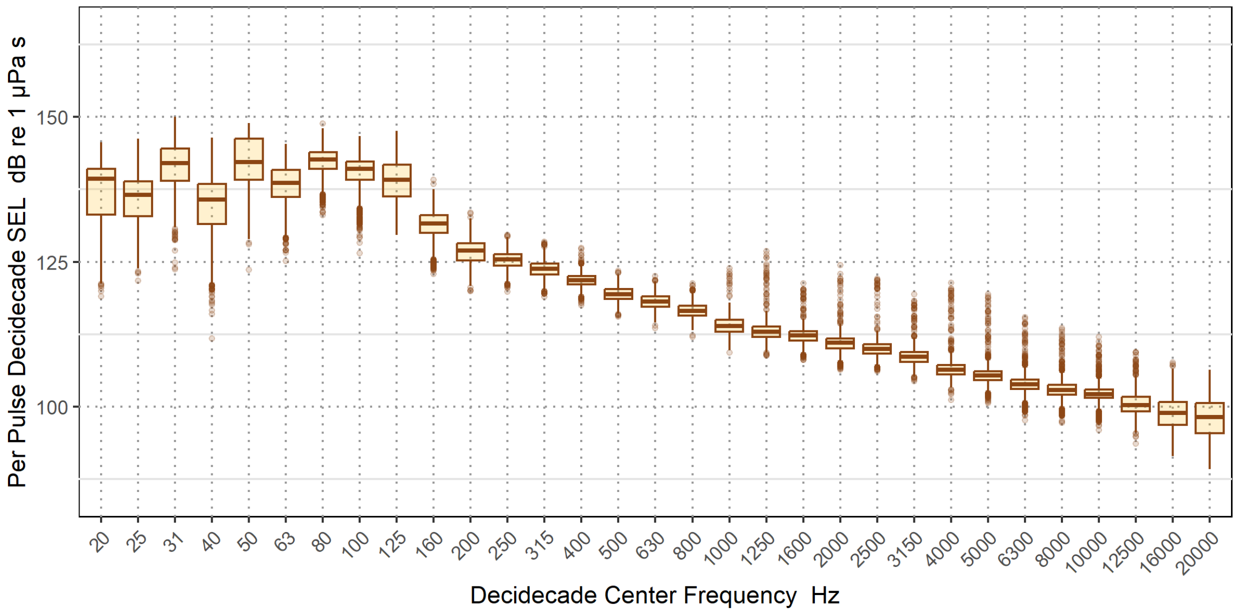

Figure B.3-6. Distribution of 1/3-octave-band SELss for the pile driving of A08 measured 3010 m from the pile at monitoring station SAR6. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

B.3.2. Table of Sound Levels at 3000 m

Table B-3. Sound levels for the pile driving of A08 measured 3010 m from the pile at monitoring station SAR6.

Sound level statistic*	PK (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
Bottom-Mounted Hydrophone			
L_{max}	173.0	158	153.9
L_5	169.4	157	152.7
L_{25}	167.6	156.3	152.1
L_{50}	166.2	155	150.8
L_{75}	164.6	152.9	148.7
L_{95}	160.3	148.5	145.3
L_{mean}	165.9	154.3	150.2

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (Ln) is the SPL or SEL exceeded by n% of the data. Lmax is the maximum recorded sound level. Lmean is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L50).

Impact Pile-Driving Sound Levels at 10000 m

B.4.1. Bottom-Mounted Hydrophone

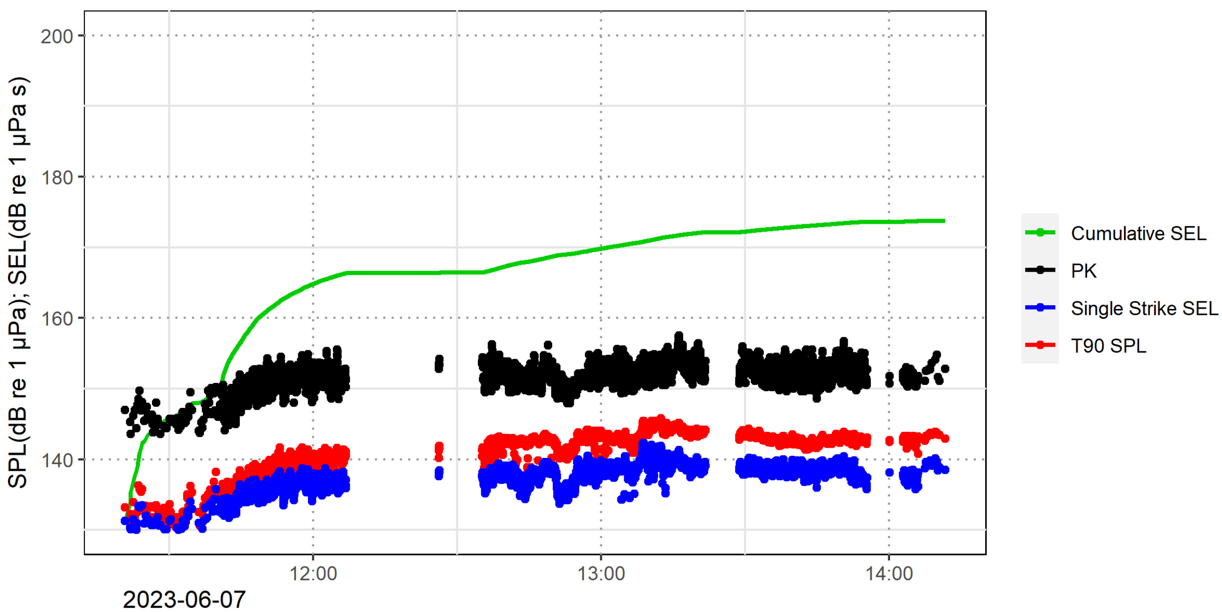

Figure B.4-7. Impact Pile Driving: PK, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of A08 measured 10014 m from the pile at monitoring station SAR7. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

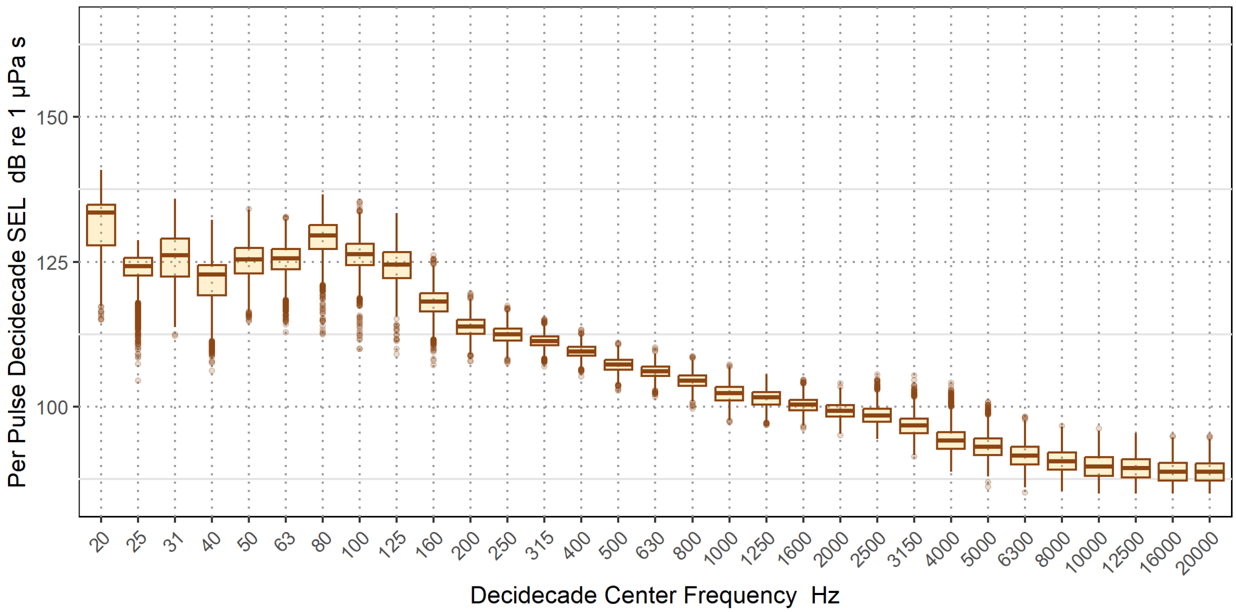

Figure B.4-8. Distribution of 1/3-octave-band SELss for the pile driving of A08 measured 10014 m the pile at monitoring station SAR7. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

B.4.2. Mid-Water Hydrophone

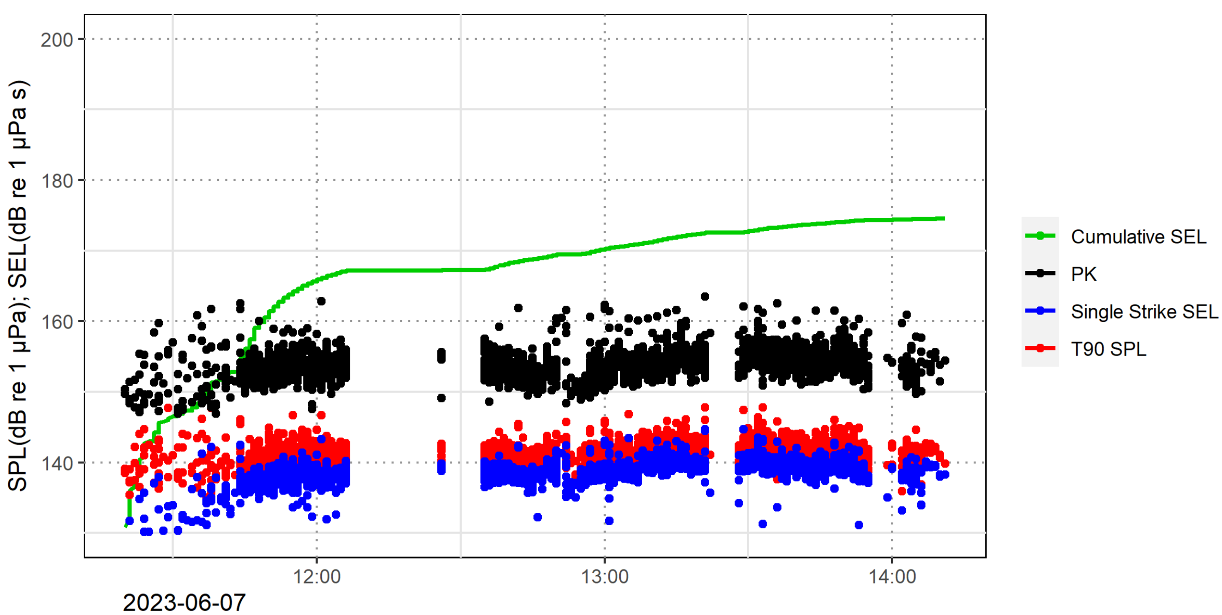

Figure B.4-9. Impact Pile Driving: PK, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of A08 measured 10014 m from the pile at location at monitoring station SAR7. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time. *The mid-water hydrophone at SAR7 was not functioning on June 19, 2023.

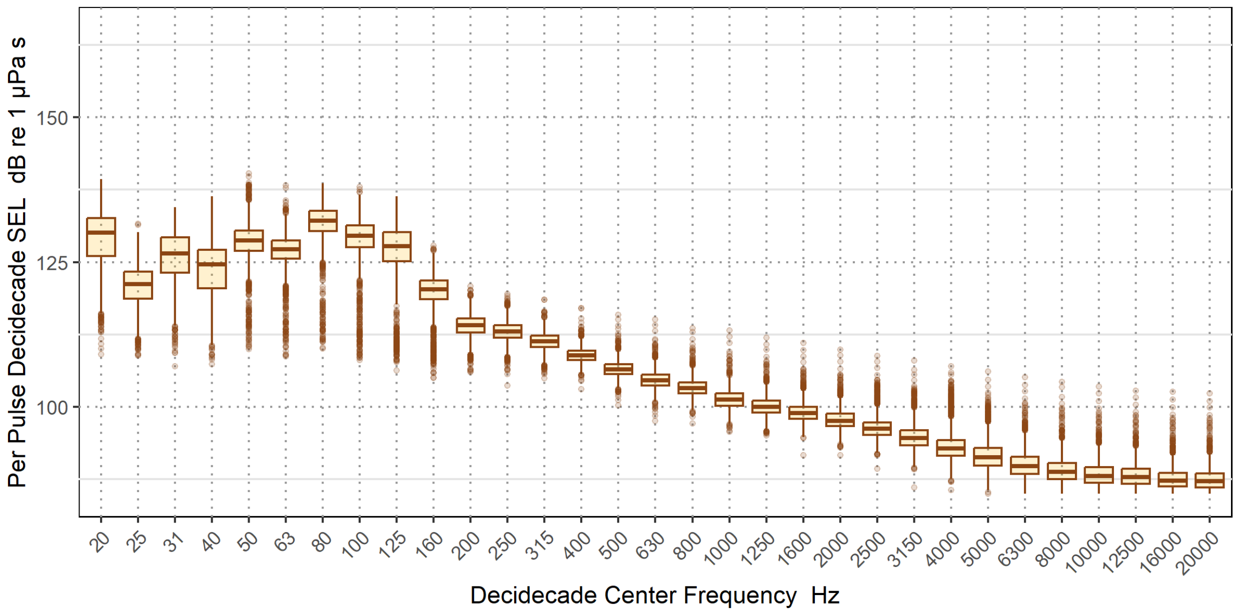

Figure B.4-10. Distribution of 1/3-octave-band SELss for the pile driving of A08 measured 10014 m from the pile at monitoring station SAR7. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). *The mid-water hydrophone at SAR7 was not functioning on June 19, 2023.

B.4.3. Table of Sound Levels at 10000 m

Table B-4. Sound levels for the pile driving of A08 measured 10014 m from the pile at monitoring station SAR7.

Sound level statistic*	PK (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
Bottom-Mounted Hydrophone			
L_{max}	157.5	145.8	142.3
L_5	154.5	144.3	140.0
L_{25}	152.9	143.1	138.8
L_{50}	151.8	142.5	137.9
L_{75}	150.6	140.3	136.5
L_{95}	148.4	136.0	134.0
L_{mean}	151.7	141.5	137.5
Mid-Water Hydrophone			
L_{max}	163.5	147.8	144.7
L_5	157.1	143.8	140.8
L_{25}	155.0	142.4	139.6
L_{50}	153.8	141.5	138.8
L_{75}	152.7	140.4	138.0
L_{95}	151.0	138.6	136.3
L_{mean}	153.9	141.4	138.6

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (Ln) is the SPL or SEL exceeded by n% of the data. Lmax is the maximum recorded sound level. Lmean is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L50).