Store Middelgrund Monopile Removal: How Far Can Sound Emissions from Decommissioning Impact on the Harbour Porpoise?

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Contents

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Abstract

The first large scale decommissioning projects of offshore wind farms are planned in Europe in the coming 5 years. The underwater sound generated during the decommissioning phase of offshore wind farms remains poorly understood due to the limited number of such projects conducted to date. Nevertheless, activities associated with decommissioning have the potential to impact marine life. This study is the first to present acoustic effect ranges from decommissioning activities associated with the removal of a 1.8 m diameter monopile by abrasive cutting and assessing their potential impact on the harbour porpoise.

Two JASCO Multi-Channel Acoustic Recorders, equipped with two hydrophones, were deployed for ~10 days in November 2024. The potential impact ranges on relevant marine fauna calculated for three key operations were studied: jacking-up of the vessel, dredging down-the-hole and cutting. The permanent threshold shift onset threshold was never exceeded by any of the operations. Both dredging and cutting exceeded the VHF weighted temporary threshold shift (TTS, L_E = 153 dB re 1 μPa^2 s according to Southall et al. (2019) and 161 dB re 1 μPa^2 s according to the National Marine Fisheries Service (NMFS).

Keywords

Decommissioning · Harbour porpoise · Impact · Acoustic effect ranges · Cutting · Dredging · Jacking-up · Offshore wind farm

Introduction

The decommissioning of the Store Middelgrund met mast was planned after the Swedish government rejected the application for building an Offshore Wind Farm (OWF) at the site. The met mast was in the Danish Exclusive Economic Zone (EEZ) on the border with Sweden.

Considering that the first large-scale decommissioning projects are expected to take place in Europe in the next few years, it is necessary to evaluate whether sound emissions from these activities may pose a risk to marine life, particularly marine mammals.

While many technical solutions for monopile removal are under development, only a few have been tested at sea. Currently, abrasive cutting, i.e., the method used for this project, appears the most technically viable for offshore operations.

The decommissioning operation at Store Middelgrund consisted of removing the met mast tower and then cutting the foundation using a dedicated jet cutting tool proprietary to ZITON and deployed from the vessel *WIND PIONEER*. The cutting operation required a first phase of dredging inside the monopile foundation and then inserting the cutting tool within the pile and cutting in sections at approximately 1 m below the soil surface. JASCO was requested to monitor the full cutting operation, including the dredging.

Decommissioning activities have several pathways for impact on marine life (Stranddorf et al. 2024); yet these are poorly understood. The current study aimed at characterizing the underwater sound emissions for the operation of removal of the monopile foundation of a met mast to determine the potential acoustic effect ranges on the harbour porpoise (*Phocoena phocoena*), the only cetacean commonly reported in the Kattegat area.

Methods

The removal of the 1.8-m diameter monopile foundation at Stora Middelgrund involved the following operations:

- Jacking up: The jack-up vessel arrived on site and was positioned securely using its four legs. The jack-up process lasted approximately 1 hour.
- Dredging: The soil inside the monopile was removed by injecting high-pressure water (approximately 2000 bar) to loosen the material. The resulting slurry was then extracted, allowing access to the required cutting depth below the seabed. The overall operation took around 8 hours spread over several days.
- Cutting: A custom-built ZITON tool (Fig. 1) was deployed to perform internal cutting approximately 1 m below the seabed, using water jet technology. The cutting duration was approximately 5 hours during a single day.

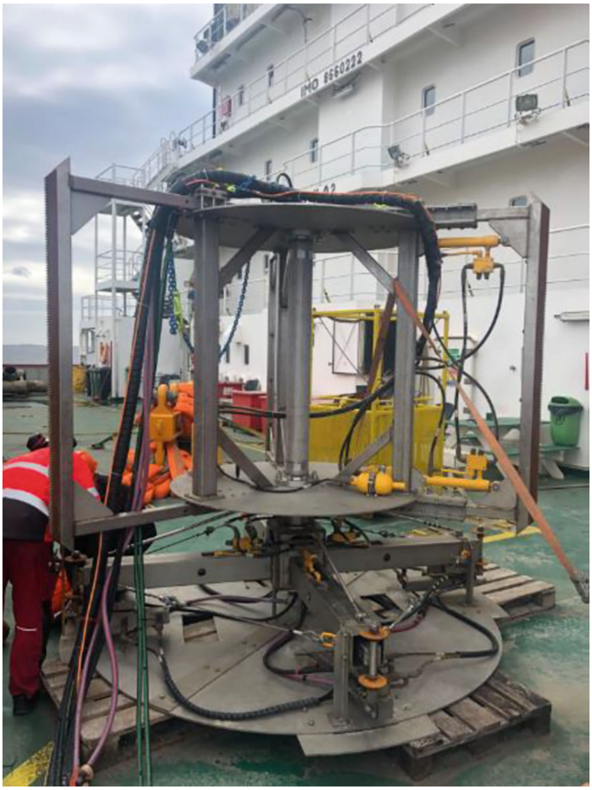

Fig. 1 Pictures of the ZITON custom cutting tool

Following the cutting operation, the cut pile was lifted onboard for transport and disposal onshore.

Data Collection

Underwater sound throughout the operation was recorded with two JASCO Autonomous Multichannel Acoustic Recorders—Generation 4 (AMAR G4s; see Fig. 2) in acetal housings. Each AMAR was fitted with two M36 omnidirectional hydrophones (GeoSpectrum Technologies Inc., with −165 and −200 ± 3 dB re 1 V/μPa sensitivity). The recorders were positioned 750 and 250 m from the met mast. One hydrophone was attached near the seabed, at a height of approximately 0.5 m from the seafloor and the other at approximately 3 m from the seafloor. The AMARs recorded continuously throughout the entire operation, from 19 November to 1 December 2024, at a sampling rate of 512 kHz, covering a recording bandwidth of 10 Hz to 256 kHz.

Data Analysis

All acoustic data were processed using JASCO's PAMlab software, which performed automated analyses of total ocean noise, anthropogenic sound sources, and harbour porpoise vocalizations.

Detection of harbour porpoise vocalizations was conducted using a combination of automated detector-classifiers and manual review by experienced JASCO analysts, ensuring robust identification of acoustic signals attributed to the species.

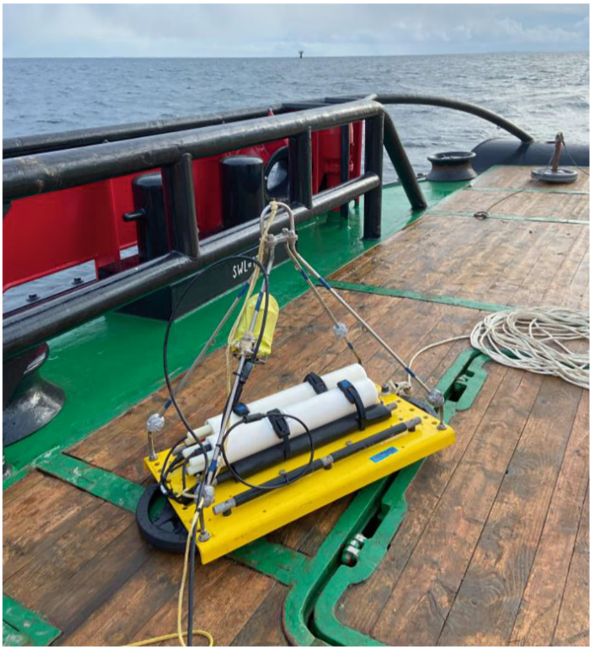

Fig. 2 The Autonomous Multichannel Acoustic Recorder Generation 4 ACE (AMAR G4; JASCO, white tube) used to measure underwater sound fitted on a baseplate ready for deployment on deck. The hydrophone 0.5 m from the seabed is inside the yellow flow shield in the photo. The hydrophone 3 m from the seabed is out of view, attached to the yellow line at the bottom left of the photo

Table 1 Relevant thresholds for harbour porpoises considered in this study. Note that the weighting curves applied to sound levels differ between the NMFS (2024) and Southall et al. (2019) assessment criteria. *PTS* Permanent Threshold Shift, *TTS* Temporary Threshold Shift

	NMFS (2024)	Southall et al. (2019)
Changes in hearing sensitivity	Weighted SEL24h ($L_{E,W,24h}$; dB re 1 μPa^2·s)	
PTS	181	173
TTS	161	153

Two assessment criteria were applied in this study, as the question of which acoustic exposure levels may injure marine mammals remains an active area of research at the time of the study. The most recent criteria available to the scientific community that are accepted by European Regulators are Southall et al. (2019) for marine mammals. Southall et al. (2019) are also the reference criteria included in the Danish guideline (2023). In 2024, the United States National Marine Fisheries Service (2024) published a new guideline on this topic; results according to these criteria were therefore also presented as best scientific knowledge to date. Both frameworks address changes in hearing sensitivity, temporary threshold shifts (TTS) and permanent threshold shifts (PTS). According to these classifications, harbour porpoises are categorized as very-high-frequency (VHF) cetaceans. The noise sources associated with the decommissioning activities—including jacking-up, dredging, and cutting—are classified as continuous noise sources. The criteria and relevant thresholds used in this study are summarized in Table 1.

Results

The activities associated with the decommissioning: jacking, dredging, and cutting, can be identified as temporary increases in sound levels at intermediate frequencies (100–10,000 Hz), visible as orange-red patches in the spectrogram (Fig. 3).

The PTS at 750 m was not exceeded by any of the operations. However, during dredging, the TTS threshold was exceeded at 750 m, according to both the Southall et al. (2019) and NMFS (2024) methodologies (Fig. 4).

The acoustic effect ranges were calculated by estimating the propagation loss on site using the smoothed semi-coherent image method described in Yubero et al. (2025). The PTS threshold was exceeded for dredging at a distance of 30 m for harbour porpoises, based on the Southall et al. (2019) criteria (Table 2). TTS thresholds were exceeded across all activities, ranging from 120 m for cutting to 2.6 km for dredging. Notably, the Southall et al. (2019) criteria yielded longer impact ranges for porpoises compared to the NMFS (2024) guidelines.

Harbour porpoise echolocation clicks (Fig. 5) were recorded at both monitoring stations throughout the deployment period. Detection numbers varied between stations and from day to day. Overall, during the day (daylight hours) more acoustic activity was recorded further from the source at 750 m compared to 250 m. While at 750 m detections occurred every day, independently of the time of day, at 250 m absence of acoustic activity is noted on some days.

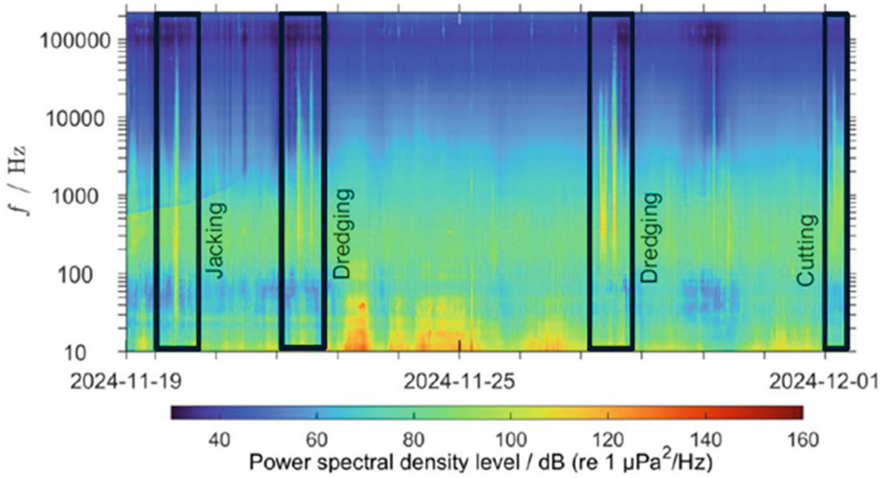

Fig. 3 Full deployment overview: black boxes indicate the days on which the decommissioning activities described took place

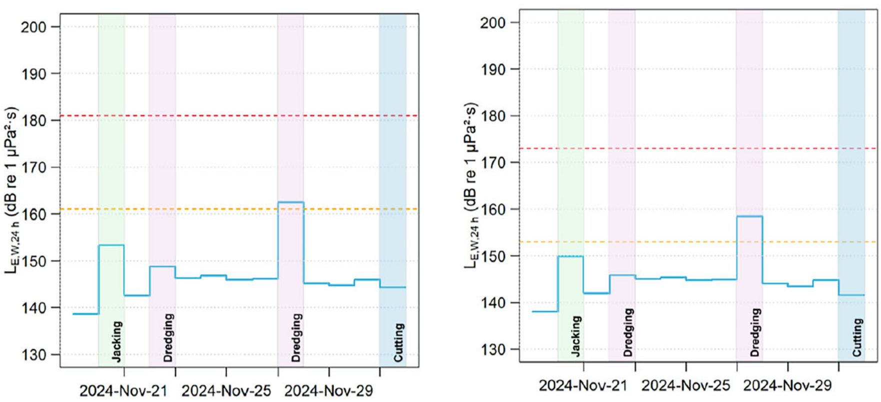

Fig. 4 Porpoise weighted daily sound exposure level (SEL) according to NMFS (2024) and Southall et al. (2019) weightings (left and right plots) for the 750 m station. The horizontal dashed lines represent the TTS (orange) and PTS (red) thresholds

Discussion

This study is among the first to investigate the acoustic impact of decommissioning a monopile steel foundation (1.8 m diameter) on harbour porpoises. The results indicate that PTS thresholds were not exceeded at a distance of 750 m from the source for any of the operations, regardless of the assessment criteria applied. However, modelling revealed that PTS thresholds were exceeded in close proximity to the source, ranging from 15 to 30 m depending on the acoustic criteria used.

Table 2 Distances at which TTS and PTS thresholds per criteria were expected to be exceeded. The character '–' indicates the threshold was not exceeded

Activity	Duration (h)	NMFS (2024)		Southall et al. (2019)	
		TTS	PTS	TTS	PTS
		Distance (m)			
Jacking up	1	125	–	360	10
Dredging	3	45	–	140	5
Dredging	5	1040	15	2610	30
Cutting	5	35	–	120	5

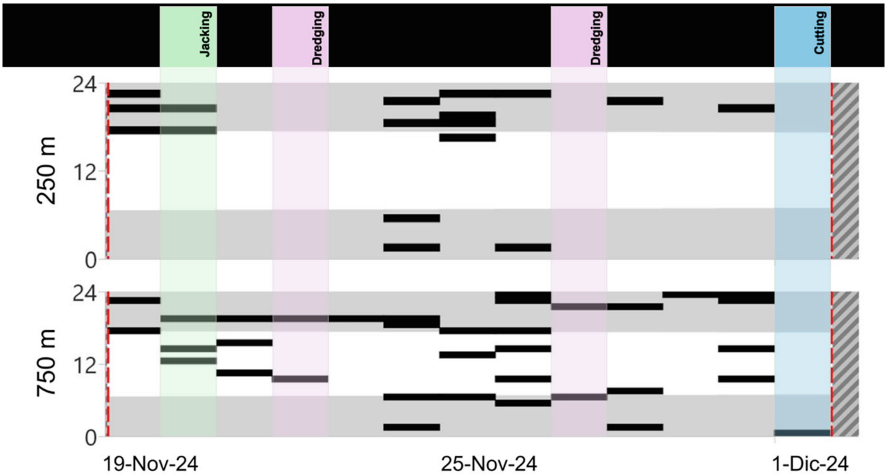

Fig. 5 Daily presence of harbour porpoise based on acoustic detections at 250 and 750 m from the source. The black boxes represent at least one acoustic detection in the respective 1 h-block (y-axis) for each day. Grey shading indicates nighttime (before sunrise/after sunset)

TTS thresholds were exceeded across all activities, with impact ranges varying from 120 m for cutting to 2.6 km for dredging when applying the Southall et al. (2019) criteria. The NMFS (2024) criteria yielded shorter impact ranges, less than half of those estimated using Southall et al. (2019). These differences highlight the importance of exercising caution when comparing studies that apply different criteria, due to changes in weighting functions and threshold levels.

It is important to note that the calculated impact ranges may be overestimated for two key reasons: (1) the exposure model assumes a static receiver position over a 24-hour period, and (2) the method used to estimate acoustic effect ranges carries greater uncertainty above 20 kHz, particularly at longer distances, as it does not account for sound attenuation.

Effective mitigation strategies could include visual and/or acoustic monitoring for the presence of marine mammals prior to initiating operations, ensuring clearance of a predefined safety zone. Additionally, assessments of such operations should incorporate realistic exposure durations over a 24-hour period.

Porpoise detections at 750 m from the source were higher than those reported by Khyn and Tougaard (2021) during monitoring campaigns in 2015 and 2019. However, due to the short duration of the current monitoring effort and the absence of long-term baseline data, no definitive conclusions can be drawn regarding the significance of this observation. Similarly, the observed decrease in acoustic activity following the first day of dredging cannot be conclusively attributed to the decommissioning activities (e.g., vessel presence or elevated sound levels), as other factors such as changes in prey availability may also have played a role.

Competing Interest Declaration The author(s) has no competing interests to declare that are relevant to the content of this manuscript.

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