Use of Fibre Optic Cables for Monitoring Continuous Low-Frequency Underwater Noise

A Pilot Study on Distributed Acoustic Sensing (DAS)

Scientific note from DCE – Danish Centre for Environment and Energy

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Data Sheet

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Front page photo: Fabienne Mannherz, a container ship and ferry line off the Danish coast

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Preface

The Danish Environmental Protection Agency (Miljøstyrelsen) is responsible for implementing the EU Marine Strategy Framework Directive through the national monitoring program (NOVANA). Descriptor 11 of the directive concerns underwater noise, requiring member states to implement monitoring activities that provide necessary data for assessment of the degree to which Good Environmental Status (GES) has been achieved in their marine waters. Currently, in Denmark monitoring is done using acoustic recorders deployed at select stations in Danish marine areas, combined with spatio-temporal modelling of anthropogenic noise.

The Danish Environmental Protection Agency commissioned this pilot study to investigate the potential of using seabed fibre-optic cables to monitor continuous low-frequency underwater noise using Distributed Acoustic Sensing (DAS) technology, based on promising preliminary studies (e.g. Landrø et al., 2022). This request was motivated by the potential for DAS as a cost-effective monitoring method because it would utilise existing seabed fibre cables to measure environmental noise.

The project was planned with GEUS, the Institute of Geological Survey in Denmark and Greenland, as a close collaborator to facilitate access to expertise and equipment related to DAS technology. In autumn 2024, GEUS conducted measurements on a newly laid fibre optic cable between Rønne and Sassnitz, Germany, with the interrogator placed in Rønne, and the proposal sought to co-locate acoustic recording stations for a first comparison of the two techniques and ideally, to facilitate a calibration that would inform the capabilities of utilising DAS for soundscape monitoring in Danish waters.

The present report describes the results of this pilot study and thus reports on the prospects and challenges in using DAS technology as a supplement, or replacement, of the existing monitoring based on sound recorders deployed on the seafloor.

The Danish Environmental Protection Agency were presented with an earlier draft of this report. Their comments and the changes made in the final report to address these comments can be found in the associated commentary sheet (see Data Sheet).

Summary

Distributed Acoustic Sensing (DAS), where existing marine fibre-optic telecommunication cables are used to record sound, has sparked discussions and inquiry into its potential for soundscape monitoring.

This pilot study investigates the potential of using DAS technology for continuous low-frequency noise monitoring in Danish waters as a cost-effective alternative to sound recorders. We present the collection and analysis of a dataset from the DAS-enabled fibre-optic cable between Rønne and Sassnitz (DAS interrogator operated by GEUS) with collocated acoustic recorders, including the detection and comparison of ship passages with both techniques.

Over approximately 17 days in autumn 2024, data were collected using both measurement techniques. Decidecade levels were calculated for the entire dataset, and a custom vessel detector was used to identify vessel passages and qualify them with AIS data.

Despite shared traits, the measurement approaches differ significantly, in that sound recorders measure the sound pressure in the water column above the fibre cable, whereas the DAS system measures the (minute) mechanical deformation of the optic fibre caused by the mechanical vibration in the seabed caused by the sound wave in the water above.

While parallel vessel detections in both acoustic and DAS data support the prospect of applying DAS technology in soundscape monitoring, this pilot study highlights the challenges that must be overcome before DAS systems on sea-bed cables should be considered part of the regular ship noise monitoring as part of the Danish obligations regarding the EU Marine Strategy Framework Directive, specifically GES criterion D11C2.

A key step towards the successful utilisation of DAS data is the calibration of a cable's sensitivity and self-noise across frequency for absolute measurements, and of its detection probability for vessel detection. The results of the pilot study have highlighted several significant obstacles to achieving this. Defining and conducting a sophisticated calibration of the Rønne-Sassnitz cable to investigate the feasibility and reliability of monitoring long-term noise trends for continuous low-frequency noise was beyond the scope of this explorative study. Nevertheless, the data and expertise gained during the project provide a solid foundation for the work required and the potential challenges. The study also identified an alternative approach to a performance assessment and application for noise monitoring of radiated underwater noise from vessels, by establishing an understanding of the cable's detection probability. Coupling ship detections with computational methods, such as machine learning for ship-feature characterisation and noise modelling, could provide valuable enhancements to noise models that rely solely on AIS data, given the potential of non-AIS ship detections. Efforts in this direction may benefit from technological and research initiatives to implement DAS for infrastructure integrity and maritime surveillance.

Table 0.1. Comparison of key characteristics of DAS systems and traditional sound recorders of particular relevance for long-term monitoring of ship noise.

	DAS	Sound recorder
Sensitivity	Self-noise limited above 10-20 Hz	Limited by ambient noise up to at least 500 Hz
Frequency range	Current systems in practice limited to 500 Hz	Usable to beyond 100 kHz, but self-noise limited at higher frequencies
Calibration	No simple way to convert to absolute sound pressures	Absolute levels attainable within 1-2 dB
Data management	Real-time processing required, but not yet available	Continuous recordings for several months possible, with subsequent off-line processing
Flexibility	Location of cable is fixed, and cable length and cable characteristics have major influence on what performance can be achieved	Location of recording stations can be changed from deployment to deployment
Investment	Interrogator is expensive, but one-time investment. Cable paid by the owner.	Low investment in instruments for a single station
Running costs	Low. Data collection and setup can be done remotely.	High, requires regular visits with ship/boat.

To conclude: DAS technology holds potential for contributing to monitoring of underwater noise, but at present, it cannot contribute in a meaningful way to the Danish underwater noise monitoring. A range of issues are apparent and listed below. Solutions to these issues are currently not available.

- The most important open issue is whether it is possible to convert DAS data into sound pressure levels, as required by the current monitoring, and if so, if it can be done with sufficient accuracy.
- It is questionable whether the large investment in interrogators and development of analysis tools will make DAS-based monitoring economically competitive compared to present-day monitoring with sound recorders.
- DAS technology on existing fibre cables could contribute additional data on levels of ship traffic in selected locations in Danish waters, especially the Belts and Straits.
- It remains to be studied if such DAS data constitutes added value compared to AIS-based modelling, justifying the additional costs.

1 Introduction

1.1 Background

Underwater noise from anthropogenic activities such as ships, offshore infrastructure construction and operation, seabed and sub-seabed surveys, sonars, echosounders etc., is well recognised as a pressure factor on the marine environment (European Commission, 2008; Hildebrand, 2009; Tyack et al., 2015). Central for the management of anthropogenic noise is accurate measurements and mapping of underwater noise. The EU Marine Strategy Framework Directive (European Commission, 2008) tasks EU member states with monitoring spatial distribution, temporal extent, and sound pressure levels of continuous anthropogenic underwater noise (criterion D11C2, European Commission, 2017), further detailed in advisory documents from expert groups (Sigray et al., 2021; TG-Noise, 2022), research projects (Crawford et al., 2018; Verfuß et al., 2015) and monitoring manuals (HELCOM, 2021; Tougaard, 2019). All methodologies for quantifying and assessing underwater noise at regional/ocean basin level ultimately rely on accurate, calibrated measurements of underwater sound for characterisation of the individual sound sources and accurate calibration of sound propagation models. So far, the only reliable methodology for such measurements is to measure sound pressure using hydrophones deployed in the water column.

The Danish Environmental Protection Agency (Miljøstyrelsen) seeks to explore alternative and/or supplementary monitoring and assessment approaches for the low-frequency noise from shipping.

Recent studies have suggested the potential of utilising marine fibre optic telecommunication cables for detecting and tracking vessels via the so-called Distributed Acoustic Sensing (DAS) technology (Landrø et al., 2022; Paap et al., 2025; Thiem et al., 2022), including prospects of using these detections for soundscape monitoring (Landrø et al., 2022). In this report, the potential for monitoring low-frequency noise in Danish waters using DAS technology was evaluated through a small pilot project, in which recordings from a DAS system on a subsea cable in the Baltic Sea were compared with conventional recordings from hydrophones in the water column above the fibre cable.

1.2 Introduction to Distributed Acoustic Sensing (DAS) in the Marine Environment

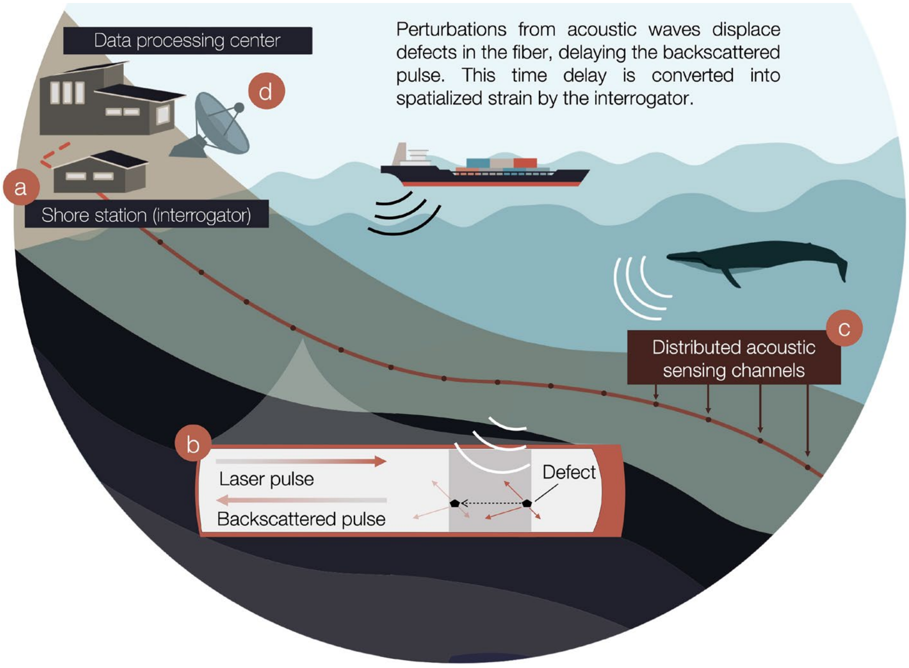

Figure 1.1. Visualisation of Distributed acoustic sensing (DAS) for low-frequency sound monitoring.
(a) An interrogator unit is connected to one shore-side end of an existing fibre optic telecommunication cable to enable it for DAS. (b) It sends laser pulses that are backscattered by structural anomalies in the cable while simultaneously, these defects are phase-shifted under the effect of external pressure waves. (c) The interrogator calculates time delays of the backscattered response at regu-larly spaced intervals along the fiber (channels). Time delays are averaged over the gauge length and converted into longitudinal strain waveforms analogous to acoustic pressure. (d) DAS two-dimensional data can be streamed in near-real-time to a remote data processing centre. (Figure and modified description source: Bouffaut et al. (2022).

Over 1.2 million km of fibre-optic cables have been placed in the world's oceans to facilitate the global telecommunication network (Landrø et al., 2022). Of these, many fibres within these cables remain unused, so-called dark fibres. These unused fibres present an opportunity to utilise existing telecommunication infrastructure to monitor low-frequency acoustic events over large distances with high temporal resolution.

DAS technology functions by attaching an optoelectronic instrument, called an interrogator unit, to one end of a fibre-optic cable. The interrogator sends a laser pulse into one end of the DAS-enabled fibre cable and then detects optical interference (backscattering) of this light beam due to density inhomogeneities in the fibre glass along pre-defined points along the fibre (called nodes or channels). External signals such as seismic or acoustic pressure waves cause strain on the cable. This strain leads to phase shifts in the backscattered laser light, that are captured by the interrogator and then used to re-create the seismic or acoustic signal (Figure 1.1). Thus, an acoustic wave in the water column, such as from a passing ship, will cause a small physical deformation of the fibre, measurable by the interrogator as variations in the backscattering of the transmitted light pulses. The physical entity measured by the interrogator is therefore not sound pressure per se, but the strain the acoustic wave inflicts on the fibre.

As the time between transmitting a pulse and reception of the backscatter from a particular distorted part of the fibre is determined by the distance from the interrogator and the speed of light in the fibre, this distance can be found by measuring the delay before reception of the backscatter signals. Many successive signals reflected from successive points on the cable at increasing distance can be analysed, effectively creating a long array of virtual detectors (nodes) along the cable, hence the name distributed acoustic sensing. The number of nodes, their physical separation and the recording bandwidth of the system are all interlinked parameters and ultimately sets the limitations of the system.

1.3 Current State of Knowledge & Technology

Several studies have evaluated the potential for utilising DAS-enabled fibre optic cables for maritime surveillance and infrastructure security by assessing the detection and trajectory of vessels (Rivet et al., 2021; Thiem et al., 2023; Shao et al., 2025; Paap et al., 2025). Rivet et al. (2021) demonstrate the feasibility and reliability of detecting and tracking an AIS-identified tanker in both shallow (85 m) and deep waters (2 000 m). Thiem et al. (2023) were able to detect and localise both AIS and non-AIS vessels with DAS.

Selected studies have explored further application scenarios for marine soundscape monitoring. Landrø et al. (2022) identified marine mammals, storms, earthquakes and vessels using DAS, concluding with a high potential for global near-continuous and real-time marine observation scenarios. Wilcock et al. (2023) recorded whales and ships with a DAS cable to explore future research opportunities. The authors demonstrate the capabilities but also list several limitations and uncertainties when it comes to ship detections. Further studies report the monitoring capabilities of baleen whales with DAS (Bouffaut et al., 2022; Horne et al., 2025), with Horne et al. (2025) coincidentally tracking a large container vessel and suggesting identification of a behavioural response. The same study notes that most of the AIS-vessels in proximity to the cable were not detected.

While many studies explore the detection and tracking capabilities of DAS for monitoring anthropogenic, biological and geological events, only a few investigate approaches to analyse, characterise and quantify sound sources such as passing vessels. Rivet et al. (2021) report on the measurement and distinguishing of ship-source noise in 100 Hz signals by applying a model of the acoustic features based on AIS data. Likewise, Landrø et al. (2022) suggest the potential of characterising ship sound signatures by augmentation of AIS data. Working with seismic airguns, Matsumoto et al. (2021) report that DAS technology yields comparable measurements of short-duration and broadband acoustic signals with co-located ocean bottom seismometer hydrophones.

1.3.1 Potential Use in D11C2 Monitoring

DAS technology remains largely exploratory at present and while the technology has potential applications for noise monitoring some criteria must be fulfilled before it can be used in the context of the national noise monitoring program.

Sufficient Bandwidth

Vessels generate sound of much larger bandwidth than most interrogator systems are capable of recording. There is a trade-off between sampling rate and usable length of the sampled fibre cable, due to the increase in data volume with both sample rate and cable length (number of nodes). Most studies have used sampling rates below 1 kHz, yielding a usable bandwidth of less than 500 Hz, with a few studies reporting experiments with up to 2 kHz sampling rates. Ship noise has peak energy in the bands below a few hundred Hz (MacGillivray & de Jong, 2021), but a significant amount of energy above natural ambient noise is present at higher frequencies, well beyond 50 kHz (Hermannsen et al., 2014). Small cetaceans, such as harbour porpoise, which is of particular importance for Danish waters, have very poor hearing at frequencies below 1 kHz and are known to respond predominantly to the components of the ship noise at higher frequencies (Dyndo et al., 2015; Tougaard, 2025). A DAS-based monitoring with the present limitations on bandwidth is therefore incapable of measuring the parts of the noise responsible for disturbance and masking of porpoises. As the ship noise spectra are very stereotypical in shape, however, this limitation can be overcome by using proxy indicator bands at lower frequencies, where the ships are detectable by the DAS system. Such proxy bands are used in other contexts as well, such as modelling of soundscapes in connection to assessment of good environmental status (see for example Klauson et al., 2024 for modelling for the HELCOM HOLAS 3 assessment, where bands of 125 Hz and 500 Hz were used). Nevertheless, higher bandwidth may be required to provide more information and hence better performance of detection, characterisation and quantification of sound measurements from DAS recordings (Rivet et al., 2021; Wilcock et al., 2023).

Ability to handle Data Volume

DAS technology generates very large amounts of data (multiple terabytes per day, depending on sampling rate and how many nodes are sampled). Continuous monitoring is therefore not possible over the extended periods required in the noise monitoring (months) without developing efficient data reduction strategies that can operate on the real-time data stream. Such systems are not available at present, but must involve techniques to detect relevant signals in real time and store only the information from relevant frequency bands and node distances (Horne et al., 2025; Lindsey & Martin, 2021; Wilcock et al., 2023).

Stability of Sensitivity

Reliable monitoring, as well as characterising and quantifying sound sources and levels, requires that measurements are obtained with calibrated equipment. For sound recorders with hydrophones, there are standard procedures available for such absolute calibration (e.g. Crawford et al., 2018), but as the DAS technology does not measure sound pressure per se, the recordings must be compared to synoptic measurements with calibrated hydrophones (Rivet et al., 2021; Wilcock et al., 2023). This is lacking in most DAS studies (Harmon et al., 2025; Horne et al., 2025; Lindsey & Martin, 2021; Paap et al., 2025; Rivet et al., 2021)

Sufficiently low Self-noise

In order for DAS measurements to provide the same information as hydrophone-based recorders can it is a requirement that the absolute sensitivity of the sensor system is at least as high as the hydrophones. Modern hydrophones are typically so sensitive at low frequencies that they are limited by the natural ambient noise whereas DAS systems seem to have a fairly high self-noise floor, whereby they are limited by self-noise rather than ambient noise and therefore will be unable to detect the lowest levels of sound in the environment.

The unique nature of DAS technology and data, with its high computational demands and often secluded data storage requirements, currently limits further research and development across different scientific fields. There is an urgent need for knowledge, experience and skill attraction from diverse scientific disciplines to investigate and develop technology towards the wider application of DAS (Lindsey & Martin, 2021).

1.4 Differences between DAS and Sound Recording

Measurements obtained with hydrophone-based sound recorders in the water column and measurements from DAS-enabled optic fibre cables in the seafloor cannot be compared directly, as they each measure entirely different properties of the sound field – properties that cannot be expected to correlate in a simple way.

1.4.1 Acoustic Recordings vs. Strain Measurement

A hydrophone converts a received sound pressure in the water column into a voltage signal with a proportionality factor constant for the particular hydrophone and expressed as the sensitivity. After appropriate amplification this voltage can be converted (sampled) into a digital signal by an analogue-to-digital converter. A single hydrophone at low frequencies (more precisely with a size much smaller than the wavelength of the sound waves) is omnidirectional, meaning that it is equally sensitive to sound from all directions and no directional information can be derived from the recorded signal.

With DAS technology on the other hand, the fibre cable compresses or extends in response to mechanical deformation of the sediment (strain) caused by the fluctuations in the sound field. This (minute) deformation of the fibre cable alters the refraction of the laser light pulses measured by the interrogator as small fluctuations in the time delays of the backscattered laser light.

1.4.2 Frequency Range

Typically, bioacoustic studies cover a broad frequency range from ~10 Hz to ~200 kHz, corresponding to the range in which most animals use acoustic signalling (Bradbury & Vehrencamp, 1998). Most studies of geophysics investigate much lower frequencies, from signals below 1 Hz to ~200 Hz, corresponding to the range in which seismic and climatic events are usually detected. Most important, the upper frequency limit is set by equipment restrictions and therefore not easy to overcome.

1.4.3 Spatial Resolution

Normal hydrophones are omnidirectional (equally sensitive from all directions of incidence) for low frequencies, which precludes localisation or tracking of sound sources with a single hydrophone. To track acoustic sources, multiple hydrophones are deployed separately to form an array, of which each hydrophone constitutes a separate channel.

DAS technology is inherently multichannel, where signals from different parts of the fibre (distance from the interrogator along the cable) can be separated in recordings due to the different delays in arrival times of the reflections back to the interrogator. This effectively constitutes an array of virtual recorders along the length of the cable, referred to as channels or nodes. Recordings from a single channel along the cable is referred to as a track or trace. The multichannel nature of DAS makes it ideal for acoustic localisation of the source of the sound and recordings can be obtained from a very large number of channels along many kilometres of cable, currently 100 km or more. This allows for very precise positioning of the sound source and as long as the source remains detectable by the DAS system, it can be tracked continuously. This ability to localize and track ships and other acoustic sources very accurately is the single-most important advantage of DAS over other technologies.

1.5 Data Handling

Working with acoustic recordings vs. DAS data requires different approaches to how data are collected, stored and processed.

1.5.1 Data Acquisition

Collecting acoustic data generally involves the deployment and recovery of recording equipment. Depending on the size, mooring and release systems, and deployment locations, different sized vessels may be required for their deployment.

DAS data differs considerably in the methods of deployment and data retrieval. Once an interrogator system has been connected to an existing fibre-optic cable, data collection can be configured, started, and stopped via remote access.

1.5.2 Location Specificity

Location details are essential for calibrating and comparing sound pressure levels between co-located recording stations and DAS-enabled fibre cables. For acoustic recorder deployments, the exact location is known to the scale of a matter of meters by the researchers in charge of the deployment and the authorities who issue relevant permits for the deployment of such equipment.

For DAS data, the positions of telecommunication cables are usually marked on navigational charts, but the exact positions must be obtained from the owner of the cable.

1.5.3 Data Types

Acoustic recordings are either stored in the recorder as uncompressed audio files, typically *Waveform Audio File Format* (.wav), or in formats involving a lossless data compression (*.sud files, Johnson et al., 2013). In any case, a recording consists of a series of measurements of the voltage output from the hydrophone (which can be converted into acoustic pressure by means of the sensitivity parameter obtained by calibration) sampled at regular intervals, referred to as the sample rate.

DAS data on the other had consists of many parallel recordings of the signal amplitude in separate channels, all sampled simultaneously and stored in a hierarchical data format known as HDF5. It is a binary file format designed for storing and organising large amounts of numerical or scientific data, as it enables storing datasets in a structured, file-system-like manner. Hence, any metadata or attributes are included within the file and can be read separately.

1.5.4 Data Volume & Storage

Acoustic recordings generate data volumes in direct proportion to recording duration, sample rate and number of channels (typically 1 for noise monitoring purposes) and also depend on the dynamic range (12 bit in older or cheaper systems, 16 bit in most systems, 24 bit in special applications). Due to the wide frequency range that is usually covered with acoustic recorders, data sets such as the one for this study are of considerable size, between 500 GB (2 months continuous at 48 kHz sampling rate, 16 bit) and 4 TB (2.5 months of 384 kHz sampling rate, 16 bit) for each recording station. The acoustic dataset collected for this study comprises approximately 1.5 TB of data.

DAS technology uses much lower sample rates but do so over a very large number of recording channels and can generate datasets of multiple terabytes per day, depending on the sampling rate and cable length. The data stored for the 17 days in this study comprises 14.5 TB. The interrogator settings used for this study generate approx. 2 TB of data per day. Multiple studies have highlighted that the volume of data generated poses a significant challenge for the wide-scale implementation of DAS data, especially when real-time streaming is feasible. Sustainable long-term implementation of DAS for noise monitoring will require an investment in a data storage solution. Alternatively, other studies have suggested that automated signal detection could allow for the reduction of data storage requirements by storing only data with positive detections (Wilcock et al., 2023). This could be relevant for the detection of discrete vessel passages. However, for the monitoring of continuous noise sources, a workflow including automated data analysis could reduce the necessity for storing the full 2 TB per day.

2 Data Collection & Methods

To conduct an initial assessment of the feasibility of using a Danish optic fibre telecommunication cable for monitoring human-made continuous low-frequency noise, DCE/Ecoscience deployed three acoustic recording stations near the DAS-enabled telecommunication cable between Bornholm/Rønne, Denmark and Sassnitz, Germany. **Figure 2.1** shows the approximate location of the cable

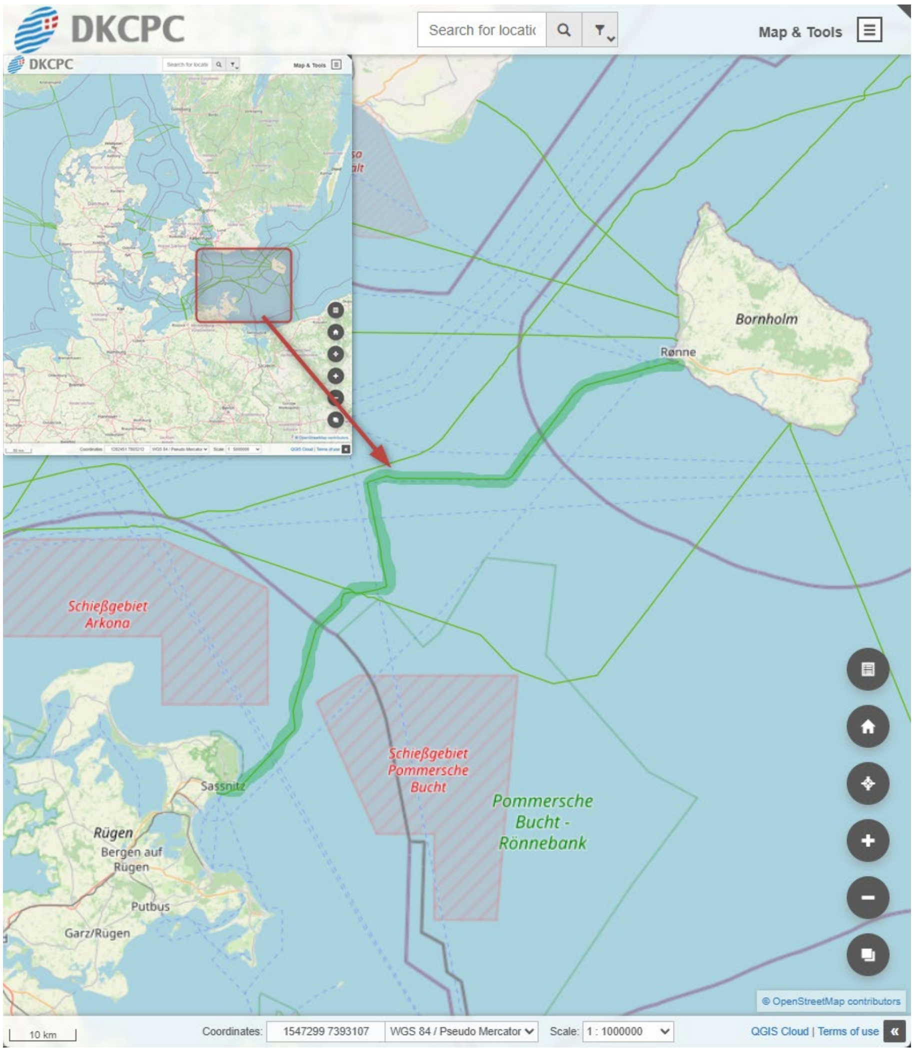

Figure 2.1. Study Area. The red arrow indicates the approximate position of the DAS-enabled fibre cable. Map & cable layer: QGIS, DKCPC cable awareness map (https://qgis-cloud.com/exjure/DKCPC_CableAwarenessMap/?=&=&l=Telecom%2CPower&bl=mapnik&t=DKCPC_CableAwarenessMap&)

2.1 Acoustic Recordings

2.1.1 Data Collection

In late summer 2024, three SoundTrap ST300 (Ocean Instruments, NZ) acoustic recorders with external battery packs were deployed off the coast of Bornholm within 100 m of the telecommunication cable (Figure 2.2).

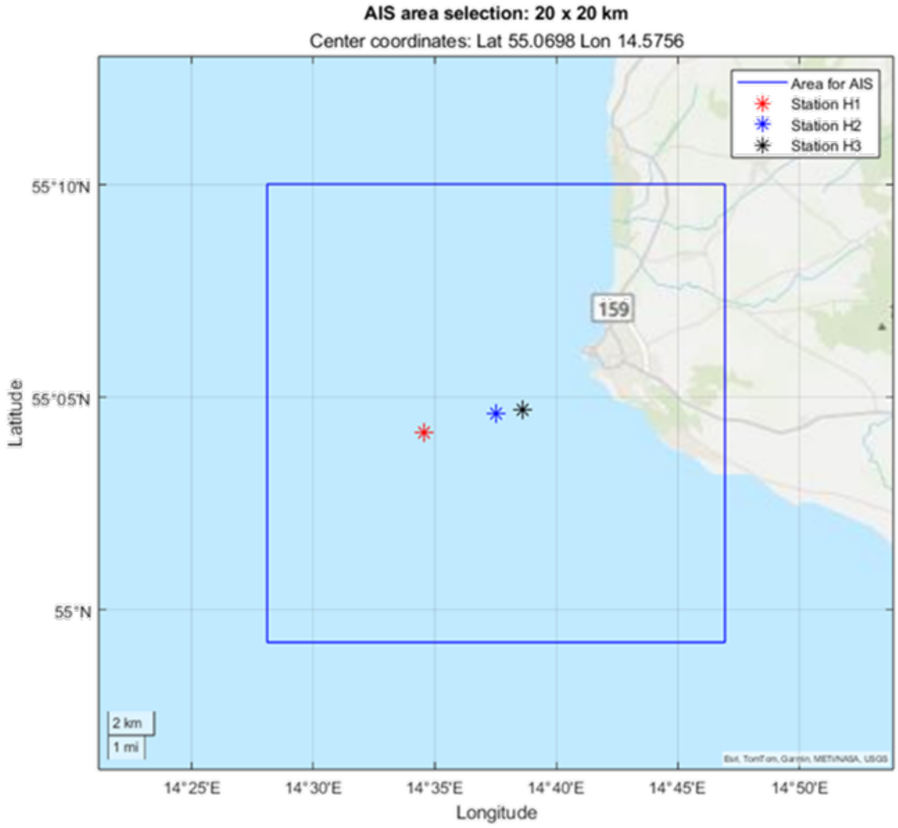

Figure 2.2. Location of recording stations. The blue square indicates the area considered for acquiring AIS data on the presence of ships.

The SoundTraps were calibrated using a pistonphone at 250 Hz with clip levels of 175.0, 175.3 and 175.6 dB re 1 µPa (respectively, recording stations H1, H2 and H3). The three stations recorded continuously from 26th July at a sampling rate of 48 kHz until the 26th / 28th September 2024 (see Table 1 for deployment and station details). Due to the built-in high-pass filter of the ST300, the usable frequency range for the recorders used in this study is approximately 20 Hz – 20 kHz. The stations were moored with biodegradable ballast bags and retrieved using acoustic releases. They were deployed and subsequently recovered with the AU's research vessel, *R/V Aurora*. During the first recovery attempt, only two of the three acoustic releases functioned, and the third station had to be recovered later using a Remote Operated Vehicle (ROV). Recording timeframes are limited by battery life, data storage capacity within the recorder, and the recording settings (such as duty cycling and sampling rate). For this study, the three recorders sampled continuously for ~2 months with a sampling rate of 48 kHz. Other SoundTrap models currently used in Danish waters allow for up to 2.5 months of continuous recordings with sampling rates of 384 kHz.

Table 2.1. Overview of recording stations. [Exact depth will be added in final version]

Station	Start date	Stop date	Latitude	Longitude	Depth
H1	26. 7. 2024	28. 9. 2024	55.070°N	14.576°E	30-40 m
H2	26. 7. 2024	26. 9. 2024	55.077°N	14.625°E	30-40 m
H3	26. 7. 2024	26. 9. 2024	55.078°N	14.644°E	30-40 m

2.1.2 Data Analysis

Data was processed using custom scripts in MATLAB (Mathworks, USA). Sound pressure levels per frequency band were calculated with 1-second resolution, resulting in 34 decidecade bands from 10 Hz to 20 kHz. Bands were used to run a custom-written vessel passage detection algorithm that identified the acoustic peak of a potential vessel passage. The potential passages were validated using AIS data from https://www.soefartsstyrelsen.dk/ (Figure 2.2). Diagnostic parameters used by the detector comprised a peak noise detection threshold 20 dB above the daily mean received levels (RL), a vessel range threshold of 600 m, and a minimum distance to other vessels of three times greater than the Closest Point of Approach (CPA) of the vessel passage in question.

2.2 DAS Data

2.2.1 Data Collection

Figure 2.3. The DAS interrogator unit at GEUS in Copenhagen.

The DAS data were collected by the Geological Survey of Denmark and Greenland (GEUS), which operates the DAS interrogator unit on the Bornholm cable. The ground station, an Alcatel Submarine Networks OptoDAS interrogator, is hosted at GEUS in Copenhagen (**Figure 2.3**). The interrogator can run continuously 24 hours per day, 7 days a week. The system has a 77 TB disk system in which it can store data without offload. The Bornholm cable serves as a DAS array along its entire cable length of ~120 km. The exact position of the seabed cable was provided by GlobalConnect, who owns the cable.

Data was acquired with 10 m channel spacing, 40 m gauge length, and a sampling frequency of f_s = 500 Hz, providing ~250 Hz of bandwidth, including coverage of frequencies below 1 Hz. With these settings, the interrogator can store approximately 30 days of DAS data on the interrogator storage. GEUS transmits the data of interest from the interrogator to their internal servers via a Nordunet fiber cable.

For this pilot study, GEUS collected data for several hours each day on 17 days spread across August and September 2024. The timeframe for the acoustic deployments for this study was chosen in parallel with a data acquisition period that GEUS had already planned for autumn 2024.

2.2.2 Data Analysis

Analysis was carried out by means of custom-written scripts provided by GEUS. These used Xdas, a Python framework designed to analyse DAS data (Trabattoni et al., 2025). Due to the vast amount of data and exploratory nature of this study, selected DAS recordings were analysed. Recordings were selected based on the most qualified and closest or loudest vessel passages observed in the acoustic data, assuring a selection of different vessel types and distances.

Data were truncated to the nodes ± 3 km around the closest point on the cable to the recording station that detected the vessel passage, with a duration ± 5 minutes from time of closest approach (CPA) of the vessel. These subset data were plotted in the time-distance domain to look for visual patterns of the passage detection. Subsequently, the acoustic strain-time and time-frequency plots were created for all instances in which a passage was identified.

3 Descriptive Results

The exploratory nature of this pilot project and the small amount of data collected preclude an in-depth quantitative analysis of the results. Instead, a qualitative overview of the results is presented, which nevertheless allows for preliminary conclusions to be drawn.

3.1 Detection & Comparison of Ship Passages

3.1.1 Ship Detection in Acoustic Dataset

For the 17 days of available DAS data, 56 unique qualified and AIS-identified vessel passages were identified in the acoustic recording dataset across the three stations, with 14 passages detected by two of the three stations. Six passages were detected on the outermost SoundTrap H1, 29 were detected at H2, and 37 were detected at H3, which was located closest to the port in Rønne.

The next sections showcase three examples of vessel passages first detected on the acoustic recordings and then identified within the DAS data. The location for the examples is all from the Soundtrap station H3. Three passages are named A, B and C with the details shown in Table 3.1.

Table 3.1. Overview of ship passage examples.

Passage	Date/Time (UTC)	Ship Type	Ship Size	CPA*
A	02-Sept-2024 04:38	Offshore Supply	152 m	92 m
B	15-Aug-2024 15:57	Passenger Ro-Ro (Ferry)	121 m	341 m
C	18-Aug-2024 16:18	Passenger (Cruise)	294 m	510 m

**Closest point of approach to H3 recording station*

3.1.2 Vessel Detection in Time-Frequency Visualisation

Spectrograms provide a visual representation of a signal's frequencies over time, using the horizontal axis for time, the vertical axis for frequency, and colour or brightness to indicate signal strength (amplitude).

All three spectrograms from the acoustic recordings show a clear broadband acoustic signature around the closest point of approach, ranging from ~50 Hz up to and beyond 10 kHz. The DAS data spectrogram from ship passage A (Figure 3.1, plot b) shows peak in the frequencies between 10 – 40 Hz, while the ship passages B and C (Figure 3.1, plots d and f) has peak energy at very low frequencies, down to 10 mHz, but still detectable energy above 100 Hz.

3.1.3 Waveforms of the Detected Signal

A signal's waveform is a graphical representation of its changes over time, showing in this case how sound pressure or strain varies. The horizontal axis represents time, and the vertical axis represents the amplitude.

The waveforms of both the SoundTrap recordings and the DAS data (Figure 3.2) show clear amplitude peaks for all three ship passages. However, the acoustic recordings observed elevated amplitudes for several minutes compared to the relatively short peak in the DAS observations.

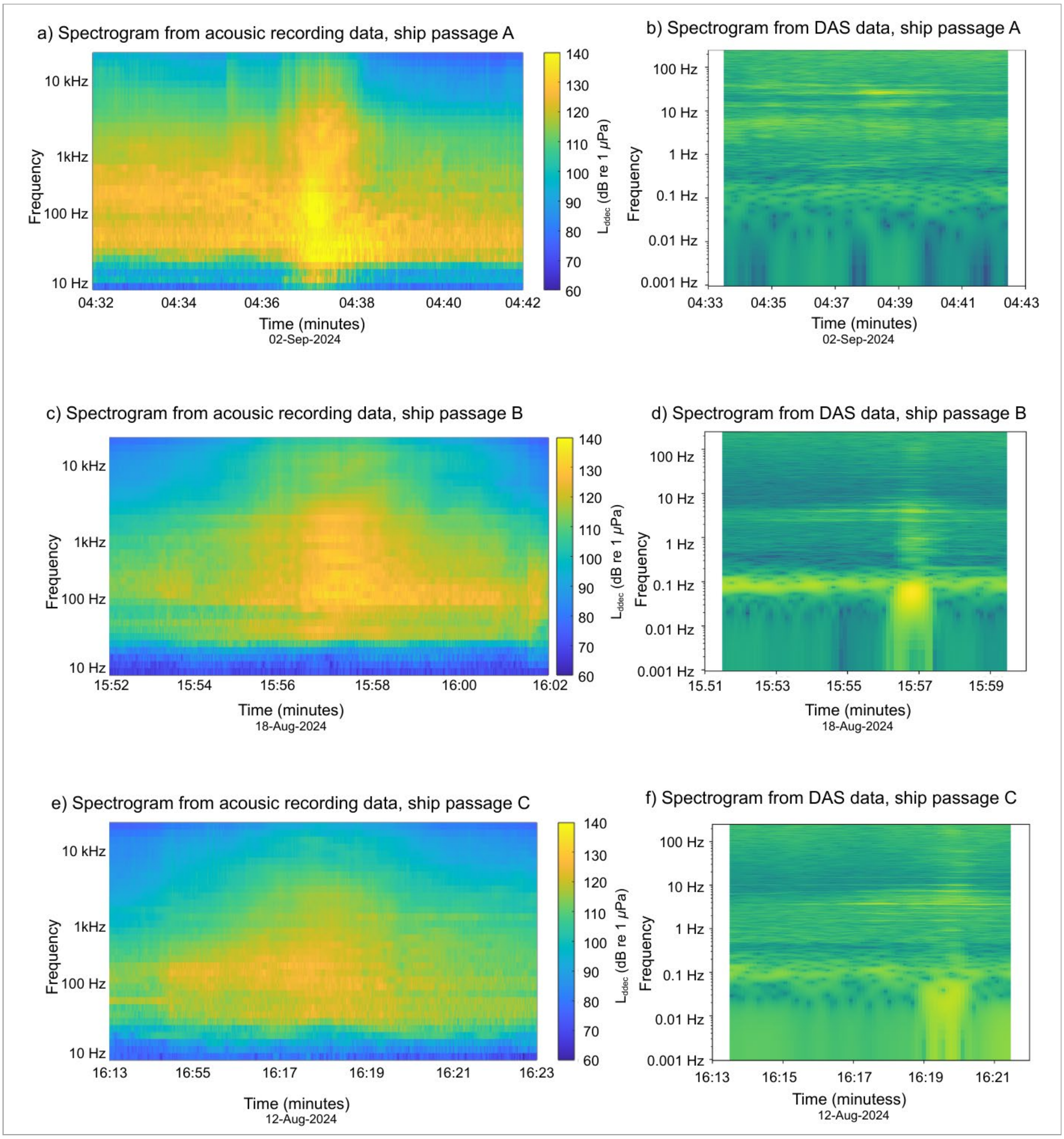

Figure 3.1. Spectrograms of ship passages A, B and C. SoundTrap recordings (a, c, e) and DAS data (b, d, f). Note that the Y-axes of the sound data and the DAS data are not aligned due to differences in the frequency range of the SoundTrap and the DAS system.

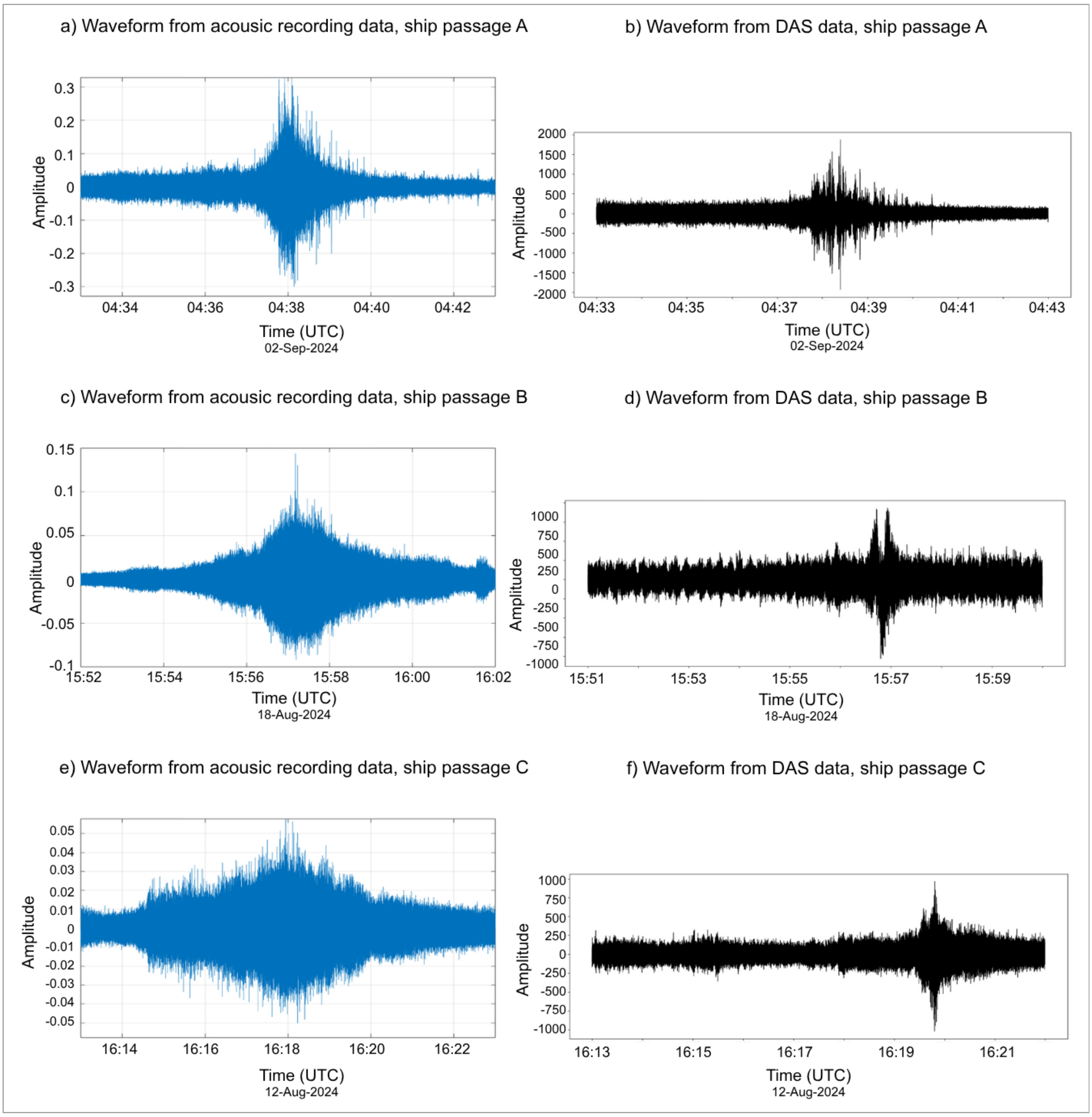

Figure 3.2. Waveforms of ship passages A, B and C. SoundTrap recordings (a, c, e) and DAS data (b, d, f).

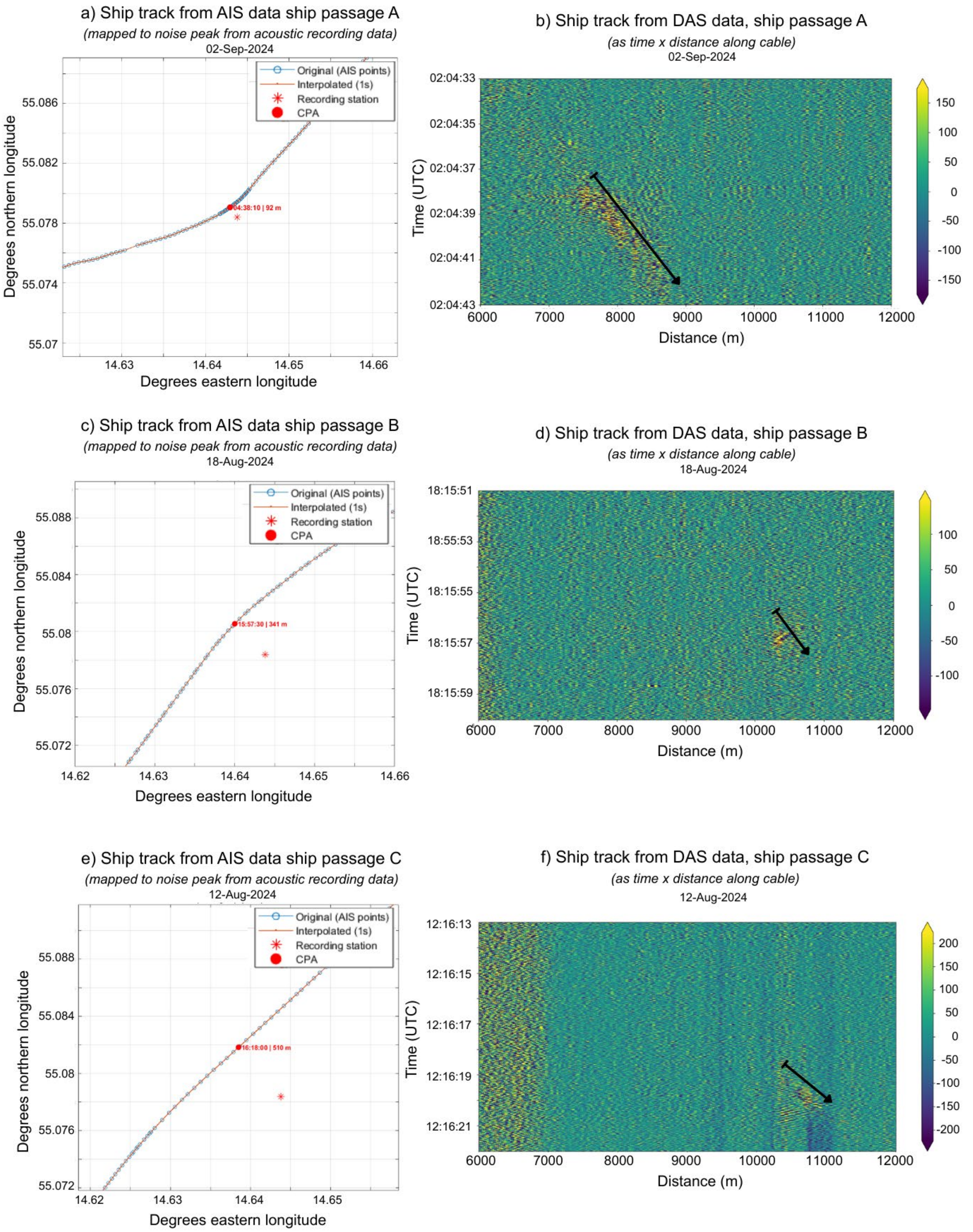

Figure 3.3. Vessel tracks of ship passages A, B and C. Plots a, c and e illustrate the travel path of the vessel based on AIS signal with indication of the closets point of approach (CPA) to the recording station (SoundTrap). Plots b, d and f display strain along a selected range of the cable (y-axis, here 6 – 12 km from the interrogator land station outwards along the cable) as the vessel travels through the area within the time frame (indicated by x-axis). The path of the vessel is highlighted by the black arrows. The colour map represents the strain rate (= dislocation) the cable experienced in this time and space, with increased strain as the map gets closer to yellow. The more intense yellow colouring between 7 - 9 km (plot b) and 10 – 11 km (plots d and f) corresponds to the same time and location the vessel passage was recorded by SoundTrap and AIS data.

3.1.4 Vessel Localisation in Time-Distance – Tracking & Trajectory

Detecting the location of a signal source generally requires an array of receivers. The DAS system, which records at multiple nodes along the cable as specified by the interrogator, acts as a linear array over the length of the cable. The data can thus be represented in a manner similar to the spectrogram, but with time on the vertical axis and distance on the horizontal axis, allowing for tracking individual vessels over distance when signal-to-noise ratios allow. Similar to a spectrogram, the colour indicates the signal amplitude, but across all frequencies. These tracks of the path of the vessel can be compared to the associated AIS data points – here in relation to the location of recording stations H3.

The time-distance plot from ship passage A (Figure 3.3, plot b) shows an elevated signal spread along both the distance and time axes, which indicates the movement of a vessel along the cable. The time-distance plot of ship passages B and C (Figure 3.3, plots d and f) have a more local signature in time and distance, suggesting the ship may have crossed the cable perpendicularly.

4 Discussion

This pilot study addressed the potential of using seabed fibre optic cables to monitor continuous low-frequency underwater noise using DAS technology, specifically within the framework of monitoring for the MSFD descriptor 11. The proposal described assessments of feasibility and requirements to implement DAS as a cost-effective dual-use monitoring method, utilising existing seabed fibre-optic cables to measure low-frequency noise from anthropogenic sources, such as passing ships.

The results demonstrate that DAS recordings can be matched with acoustic signals from sound recordings. These findings agree with previous studies that successfully detected and tracked ships along fibre cables using DAS (Paap et al., 2025; Rivet et al., 2021; Shao et al., 2025; Thiem et al., 2022). The crucial questions, however, are whether these DAS detections show characteristics, including peak amplitude and frequency spectrum, that correspond to characteristics from the sound recordings and whether all ships detected in the acoustic data could also be found in the DAS data.

4.1 From Detection to Sound Levels to Monitoring

4.1.1 Performance of Ship Detections

In this pilot study, we successfully detected and validated AIS-enabled vessel passages on the Bornholm fibre-optic cable using DAS technology. The time-distance representation from the DAS data (Figure 3.3), along with a clear amplitude peak in the signal waveform (Figure 3.2), shows characteristics that a detection algorithm could automatically identify for loud vessels.

Rivet et al. (2021) and Landrø et al. (2022) both note the potential to apply ship noise models to DAS-detected vessels to quantify noise levels. One important factor, however, is the successful detection of a ship. DAS is inherently directional, with very low detection rates for vessels sailing on a track perpendicular to the cable (Wilcock et al., 2023). In scenarios where a vessel directly crosses the cable perpendicularly, as opposed to travelling longitudinally, the characterising strength of the DAS as a sensor that detects strain and the corresponding cable displacement at multiple nodes over a relatively longer timeframe is ineffective. The geometry of a perpendicular cable crossing results in a highly insensitive angle for the DAS system, due to the very short duration and the limited section of the cable affected. This contrasts with the acoustic recordings, where the hydrophone itself is omnidirectional. This difference in signal strength is evident in the spectrograms in Figure 3.1. The waveforms in Figure 3.2 may also indicate less overall energy detected by the DAS observations. A recent study off the coast of Oregon reported that only a few vessels were detectable on the studied DAS-enabled cable, but AIS data showed that at least 30 vessels passed the cable during the timeframe (Horne et al., 2025).

It was beyond the scope of this pilot study to conduct a comprehensive comparison of acoustic recording detection versus DAS data detections. However, when combined with AIS data, this could yield valuable insights into the performance of ship detection with DAS technology. This would then inform the feasibility of using the detections and identified vessel characteristics to develop ship noise models that supplement continuous noise monitoring.

4.1.2 Ship noise characterisation

For noise monitoring, recordings from calibrated hydrophones such as the SoundTraps are used to calculate absolute received broadband sound levels and sound levels of selected frequency bands, such as those relevant to local marine life.

In Figure 3.1, the spectrograms from the acoustic recordings differ considerably from those of the DAS data, even when detecting the same vessel passage and despite the fact that the SoundTraps were co-located close to the cable. Other than differences in exact location, a possible explanation may be twofold. First, there is a large difference in sample rate between the two methods: while the hydrophones sampled at 48 kHz allow measurement of frequencies up to the 24 kHz Nyquist sample rate, the 500 Hz DAS sampling rate only allows for measuring signals with frequencies up to 250 Hz. Secondly, DAS does not measure the acoustic pressure directly but rather the strain on the cable caused by the particle motion component of the sound field (see Figure 1.1), further complicating comparison. While the DAS system measures the strain rate and hence deformation of the fibre caused by acoustic pressure, the SoundTrap measures acoustic pressure changes directly. Thus, as the two methods measure two different components of the sound field that in turn vary with range to a moving vessel, direct comparisons of received noise levels are complicated.

Interestingly, even in the frequency range covered by both recording systems (10 Hz-250 Hz), the distribution of energy across frequencies seems to differ considerably, with DAS measurements recording less energy in the higher frequencies. In ship passage 1 (Figure 3.1, plots a and b), the vessel passage was recorded very clearly in both systems. However, the DAS spectrogram shows an energy peak mainly around 50 Hz and below, while the hydrophone recorded intense noise in the entire shared low-frequency range and even above 10 kHz. A study by Wilcock et al. (2023) also noticed the absence of acoustic energy above 60 Hz during their study. This may point to some insensitivity on the part of the DAS system at higher frequencies, possibly due to poor coupling to the sediment, and raises the question if increasing the sampling rate of an interrogator system would actually allow detection of higher frequencies along the cable.

4.1.3 Monitoring Continuous Low-Frequency Noise

Detecting individual vessels and measuring their absolute sound levels is based on clear peaks in selected frequency bands. Monitoring continuous low-frequency noise requires that the ship noise can be better described in a quantitative way beyond simply detecting peaks, and for the entire timeframe that the vessel noise may be audible to marine life.

Comparing the spectrograms (Figure 3.1) and the waveforms (Figure 3.2), it appears that the vessel passages are recorded for more extended periods on the acoustic data up to 5 minutes, compared to the DAS observations of > 60 seconds. This indicates a generally poorer sensitivity of the DAS system compared to the acoustic recorders, most likely reflecting that the DAS system is limited by self-noise, rather than ambient noise and seen by the much lower signal-to-noise ratio in the DAS data. This self-noise can be inherent to the lasers and electronics themselves and hence a property of the equipment per se, but could also reflect that the ambient noise in the sediment is higher than the corresponding ambient sound pressure in the water column. If this is the case, this increased ambient noise in the sediment could be due to, for example, animals, microbiological activity or microseismic coupling into the fibre from the sediment. In busy shipping channels like the one offshore of Bornholm, acoustic data typically shows a clear signal of continuous low-frequency noise, which may not be visible in DAS data if the microseismic noise in the range sampled by DAS is high.

The shorter detection on a single DAS node may be partially compensated by the greater spatial resolution of the cable. However, this is highly dependent on the vessel path. While the larger spatial resolution may very well increase the range for vessel detection, it does not necessarily assist in quantifying the duration of elevated local noise levels as actually propagated by the ship.

4.2 Feasibility of DAS Technology for Soundscape Monitoring

Currently, the major limitation of DAS technology is the lack of a system calibration. The frequency and amplitude sensitivities, as a function of the cable's physical properties, including environmental dynamics, as well as the overall detection probability, must be properly calibrated for DAS data to be usable for long-term noise monitoring, because this monitoring relies on calibrated, absolute noise level measurements. Validation and calibration of the DAS system are challenged by a multitude of factors, which are highlighted below.

4.2.1 Absolute Measurements

Given the multitude of factors that potentially influence cable sensitivity, a comparison of the systems would require a study and dedicated analysis over a larger range of scenarios and potentially differing interrogator settings than was possible in this pilot study. It must be established whether robust correlations exist between metrics of the magnitude of the DAS recordings and sound pressure levels obtained from the sound recorders for the same ship passage. In such an analysis, the inherent directionality of the DAS recordings must be included, preferably in a way such that the conversion from DAS amplitude to sound pressure can incorporate the influence of directionality.

Another aspect to consider is finding a compromise in the exact deployment location: While a placement close to the Bornholm harbour area facilitated a high detection of potential vessels, it increases the influence of background noise from close-by vessels that are less ideal for establishing an absolute measurement for calibration purposes. Hence, a less busy section of the cable may be preferred for such measurements.

Influence of Cable Properties

The Bornholm cable, covering 120 km in total with channels spaced every 10 m, represents an array of 12,000 trace points. Each of these trace points differs in its sensing properties (and hence its sensitivity to external strain) based on factors such as cable-seabed coupling, sediment type, curves and bends, and minor defects along the cable. Further, sensitivity, or rather signal-to-noise ratio, decreases with distance along the cable due to a weaker laser signal and increased backscatter. This means the same signal could be detected differently even among two neighbouring nodes, calling for a very complex calibration procedure with potentially individual sensitivities assigned for each node along the cable.

This issue is partially resolved by using a gauge to smooth the strain across consecutive nodes. However, at absolute levels, this may require different approaches to account for changes in sensitivity along the cable, which may even vary dynamically over time.

An important point to note is that calibrations for a commercial sound recorder are generally relatively stable within the same device series; however, each DAS system (and cable) will require its own calibration, due to the unique cable properties and environmental factors. This limits the applicability of a calibration of one system to systems in other locations, since parameters influencing the system’s response may not be fully understood. However, successful calibrations at other cables will inform how best to calibrate new systems.

Finally, it is to be noted that not every fibre optic cable may be suitable for DAS measurements overall or for selected DAS use cases like ship noise monitoring, due to the properties of the cable itself or how it is coupled to the seafloor, which may lead to insensitivities and the distinct static and dynamic local environmental features.

Detection Probability

In addition to understanding the conversion of DAS measurements to absolute sound pressure measurements, the overall sensitivity of the system to the detection of discrete events remains to be determined. Previous studies have noted that vessels crossed the DAS-enabled cable as visible from AIS data without being detected by the DAS system (Horne et al., 2025), and Wilcock et al. (2023) noted that the detection range for vessels on the DAS system was considerably lower than the range for marine mammal calls in their study. With the spatial resolution, however, the range could still be larger than that of acoustic recording stations.

Detections of unique vessel passages are highly dependent on a number of constantly varying factors, such as distance to the cable, angle of approach, and the cable's coupling to the seafloor. To fully investigate the relationship between these variables and absolute sound pressure levels, resource efforts must be applied across the entire data set, not just selected events. Additionally, neither building a detection algorithm nor manually screening the full DAS data set to estimate the detection rate of AIS vessels (and/or vessel passages detected by the SoundTrap) was feasible within the scope of this pilot study. However, such validation is essential before DAS can be employed for the detection of non-AIS vessels. Further, limited information is available on the detection of smaller non-AIS vessels and their ability to cause strain along a cable.

In acknowledgement of the difficulty of calibrating the system to absolute measurements, other studies have suggested the spatial resolution of DAS may be best used to optimise vessel detection, including the detection of ship criteria such as size or type (Paap et al., 2025), and then coupling them with existing and enhanced noise models for monitoring low-frequency ship noise. The advantage of leveraging DAS detections for noise models over pure AIS data is the potential to detect non-AIS and dark ships (i.e., vessels that turn existing AIS systems off), too. Hence, the detection probability of a DAS system must be understood to leverage the spatial resolution of DAS without suffering from the drawbacks of uncalibrated measurements.

4.2.2 DAS Systems in Denmark

Currently, the only DAS data collection we are aware of in Denmark is through the partnership between GEUS and the Bornholm cable examined in this report. In the future, the IOEMA fibre cable project (https://ioemafibre.eu/ioema-project/) may install interrogators along the cable running from France to Norway. This would allow DAS data collection that would include waters off Denmark's west coast.

5 Conclusion

The pilot study aimed to assess the potential of using DAS technology along telecommunication cables in Danish waters as cost-effective monitoring systems for continuous low-frequency noise from shipping. Some of the key characteristics of the two different measuring methods are listed in Table 5.1.

Table 5.1. Comparison of key characteristics of DAS systems and traditional sound recorders of particular relevance for long-term monitoring of ship noise.

	DAS	Sound recorder
Sensitivity	Self-noise limited above 10-20 Hz	Limited by ambient noise up to at least 500 Hz
Frequency range	Current systems in practice limited to 500 Hz	Usable to beyond 100 kHz, but self-noise limited at higher frequencies
Calibration	No simple way to convert to absolute sound pressures	Absolute levels attainable within 1-2 dB
Data management	Real-time processing required, but not yet available	Continuous recordings for several months possible, with subsequent off-line processing
Flexibility	Location of cable is fixed, and cable length and cable characteristics have major influence on what performance can be achieved	Location of recording stations can be changed from deployment to deployment
Investment	Interrogator is expensive, but one-time investment. Cable paid by the owner.	Low investment in instruments for a single station
Running costs	Low. Data collection and setup can be done remotely.	High, requires regular visits with ship/boat.

In short, the DAS data collected through this pilot project demonstrates that the DAS technology is not yet sufficiently mature to be worthy of consideration as a supplement to the current sound recorder-based monitoring in Danish waters. The critical observations can be summed up in the list below:

- DAS technology cannot at present contribute in a meaningful way to the Danish underwater noise monitoring.
- The most important open issue is whether it is possible to convert DAS data into sound pressure levels, as required by the current monitoring, and if so, if it can be done with sufficient accuracy.
- It is questionable whether the large investment in interrogators and development of analysis tools will make DAS-based monitoring economically competitive compared to present-day monitoring with sound recorders.
- DAS technology on existing fibre cables could contribute additional data on levels of ship traffic in selected locations in Danish waters, especially the Belts and Straits.
- It remains to be studied if such DAS data constitutes added value compared to AIS-based modelling, justifying the additional costs.

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