Welsh Acoustic Marine Mammal Survey (WAMMS) final field report and data analysis

Report No: 860

Author name: Nathan D. Merchant[1], Rosalyn Putland[1], Gwyn Roberts [2], Gemma Veneruso[2]

Author affiliation:

[1]Centre for Environment, Fisheries & Aquaculture Science (Cefas), Lowestoft, Suffolk, UK

[2]Bangor University, Bangor, Gwynedd, UK

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Author(s): Nathan D. Merchant, Rosalyn Putland, Gwyn Roberts, Gemma Veneruso

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List of acronyms

ARC	– acoustic release cannister
BU	– Bangor University
Cefas	– Centre for Environment, Fisheries and Aquaculture Sciences
dB	– decibel
FFT	– fast Fourier transformation
HOLY	– Holyhead deep
Hz/ kHz	– hertz/kilohertz
NRW	– Natural Resource Wales
PAM	– passive acoustic monitoring
PLIN	– Point Lynas inshore
PLOF	– Point Lynas offshore
PSD	– power spectral density
SAC	– special area of conservation
SPL	– sound pressure level
WAMMS	– Welsh Acoustic Marine Mammal Survey

Crynodeb gweithredol

Cafodd prosiect Arolwg Mamaliaid Morol Acwstig Cymru (WAMMS) ei ariannu gan Lywodraeth Cymru a'i gomisiynu dan Raglen Rhwydweithiau Natur Cyfoeth Naturiol Cymru. Ei nod oedd datblygu dull effeithiol a chadarn o fesur sŵn tanddwr a phresenoldeb morfiligion (morfilod, dolffiniaid a llamhidyddion) mewn ardaloedd morol gwarchodedig (MPA) o amgylch arfordir Cymru. Er mwyn profi a dangos y dulliau monitro hyn, cynhaliwyd astudiaeth beilot 18 mis fel rhan o'r prosiect yn Ardal Cadwraeth Arbennig Forol Gogledd Ynys Môn (SAC). Yn ogystal â dangos sut y gellid monitro mewn mannau eraill yn nyfroedd morol Cymru, darparodd yr astudiaeth beilot hon ddata sylfaenol ar sŵn amgylchynol a chanfu famaliaid morol ar y safle. Pwrpas yr adroddiad hwn yw nodi manylion yr ymgyrch monitro maes hon a chyfosod canlyniadau dadansoddiad data dilynol.

Cynhaliwyd y gwaith monitro maes gan Brifysgol Bangor ar ran Cefas (prif bartner WAMMS), a rhannwyd y tasgau dadansoddi data rhwng Tîm Sŵn a Bioacwstig Cefas (dadansoddi sŵn amgylchynol) a Phrifysgol Bangor (canfod a dadansoddi presenoldeb morfiligion).

Dewiswyd tri lleoliad monitro yn Ardal Cadwraeth Arbennig Forol Gogledd Ynys Môn: un yn Nyfnder Caergybi (HOLY) a dau oddi ar Drwyn Eilian, un 1.7 km oddi ar yr arfordir (PLIN) a'r llall 5.2 km, ar ffin yr Ardal Cadwraeth Arbennig (PLOF). Cwblhawyd pum gweithgarwch cyffiniol ym mhob un o'r tri lleoliad hyn rhwng 8 Mai 2023 a 4 Tachwedd 2024, ac eithrio colli offer mewn dau leoliad (HOLY a PLIN) yn ystod y pedwerydd gweithgarwch, a arweiniodd at fwlch data yn y safleoedd hyn rhwng 4 Ebrill 2024 a 31 Gorffennaf 2024.

Roedd lefelau sŵn amgylchynol yn amrywio ar draws y tri safle, gyda mwy o sŵn llongau yn y ddau leoliad yn Nhrwyn Eilian o'i gymharu â Dyfnder Caergybi. Ar amleddau uwch, roedd cydberthynas rhwng lefelau sain yn y tri safle a chyflymder y gwynt, sy'n cyd-fynd ag astudiaethau blaenorol. Roedd y gydberthynas â chyflymder y cerrynt ar yr amleddau uchaf a fesurwyd yn dangos bod gwaddod yn cael ei gludo o ganlyniad i lif. Ar yr amleddau isaf, roedd cysylltiad cryf rhwng lefelau sain a chyflymder y cerrynt, a oedd i'w briodoli'n rhannol i sŵn llif y llanw (a achoswyd gan dyrfedd o amgylch yr hydroffon), ond roedd hefyd yn gysylltiedig â hunan-sŵn tebygol o'r angorfa. At ddibenion monitro llygredd sŵn tanddwr parhaus dan Strategaeth Forol y DU, cyfrifwyd lefelau sain canolrifol misol ar gyfer y tri safle ar draws yr ystod amledd a gafodd ei fonitro.

Mae'r canlyniadau sŵn amgylchynol yn rhoi darlun manwl nid yn unig o lefelau sŵn yn y safleoedd, ond hefyd yr hyn sy'n sbarduno amrywioldeb yn seinwedd y cynefin morfiligion hwn. Maent hefyd yn darparu sail ar gyfer gwaith pellach posibl i ymchwilio'n llawnach i ffynonellau sŵn llongau a'r prif sectorau sy'n cyfrannu at lygredd sŵn yn yr Ardal Cadwraeth Arbennig.

Nodwyd pum rhywogaeth o forfiligion allweddol i'w blaenoriaethu yn elfen monitro morfiligion y rhaglen fonitro, yn seiliedig ar ba mor aml y maent yn bresennol: llamhidydd (Phocoena phocoena), dolffin trwyn potel (Tursiops truncatus), dolffin cyffredin (Delphinus delphis), dolffin Risso (Grampus griseus), a morfil pigfain (Balaenoptera acutorostrata). Roedd gan y tri safle monitro gyfraddau uchel a rheolaidd o bresenoldeb llamhidyddion a dolffiniaid. Roedd canfod llamhidyddion yn gyffredin iawn, gyda chanfod bob dydd a 60-70% o'r oriau cofnodi yn cynnwys oriau positif o ran llamhidyddion. Roedd presenoldeb llamhidyddion ar ei uchaf yn ystod misoedd y gaeaf. Roedd canfod dolffiniaid hefyd yn gymharol gyffredin gyda 18-33% o'r oriau cofnodi'n cynnwys canfod cliciau dolffiniaid. Roedd dau brif uchafbwynt o ran presenoldeb dolffiniaid, un rhwng mis Awst a mis Hydref, sy'n debygol o adlewyrchu dyfodiad tymhorol dolffiniaid Risso, ac uchafbwynt arall rhwng mis Ionawr a mis Mawrth, o bosibl yn adlewyrchu cynnydd mewn dolffiniaid trwyn potel y dywedir eu bod yn cynyddu mewn niferoedd oddi ar arfordir Gogledd Cymru yn ystod misoedd y gaeaf. Mae'r canfyddiadau hyn yn darparu'r data PAM cyntaf drwy gydol y flwyddyn yn y rhanbarth, gan ddarparu gwybodaeth fanwl am bresenoldeb tymhorol y rhywogaethau hyn mewn tri lleoliad o fewn yr ACA.

Gydag ymchwiliad pellach, byddai'r data canfod morfiligion yn addas iawn ar gyfer modelu ystadegol i egluro dosbarthiad o ran gofod ac amser a niferoedd cymharol y rhywogaethau hyn ac yn gwella'n sylweddol ein dealltwriaeth ecolegol o forfiligion a'u hymddygiad yn yr Ardaloedd Cadwraeth Arbennig. At hynny, gellir defnyddio'r data hyn i ymchwilio i bresenoldeb ac ymddygiad morfiligion mewn perthynas ag amlygiad i sŵn anthropogenig difrifol a chronig yn ogystal ag effeithiau posibl datblygiadau a gweithgareddau morol.

Mae'r gwersi a ddysgwyd drwy'r astudiaeth beilot hon wedi cael eu hymgorffori yn nyluniad rhaglen fonitro Cymru gyfan arfaethedig, y manylir arni mewn adroddiad WAMMS ar wahân.

Executive summary

The Welsh Acoustic Marine Mammal Survey (WAMMS) project was funded by the Welsh Government and commissioned under NRW's Nature Networks Programme. Its aim was to develop an effective and robust method for measuring underwater noise and the occurrence of cetaceans (whales, dolphins and porpoises) in marine protected areas (MPAs) around the Welsh coastline. To test and demonstrate these monitoring methods, an 18-month pilot study was undertaken as part of the project in the North Anglesey Marine Special Area of Conservation (SAC). As well as illustrating how monitoring could be carried out elsewhere in Welsh marine waters, this pilot study provided baseline data on ambient noise and marine mammal detections at the site. The purpose of this report is to set out the details of this field monitoring campaign and to synthesise the outcomes of subsequent data analysis.

The field monitoring was carried out by Bangor University on behalf of Cefas (lead partner of WAMMS), while the data analysis tasks were shared between the Cefas Noise and Bioacoustics Team (ambient noise analysis) and Bangor University (detection and analysis of cetacean occurrence).

Three monitoring locations were selected within the North Anglesey Marine SAC: one at Holyhead deep (HOLY) and two off Point Lynas, one situated 1.7 km from the coast (PLIN) and the other 5.2 km, at the boundary of the SAC (PLOF). Five contiguous deployments were completed at each of these three locations between 8 May 2023 and 4 November 2024, with the exception of equipment losses at two locations (HOLY and PLIN) during the fourth deployment, which resulted in a data gap at these sites between 4 April 2024 and 31 July 2024.

Ambient noise levels differed across the three sites, with the two Point Lynas locations having a greater occurrence of shipping noise compared to Holyhead deep. At higher frequencies, sound levels at all three sites were correlated with wind speed, consistent with previous studies. Correlations with current speed at the highest measured frequencies were indicative of flow-induced sediment transport. At the lowest frequencies, sound levels were strongly correlated with current speed, which was partly attributable to tidal flow noise (caused by turbulence around the hydrophone), but was also linked to probable self-noise from the mooring. For the purposes of monitoring continuous underwater noise pollution under the UK Marine Strategy, monthly median sound levels were computed for all three sites across the frequency range monitored.

The ambient noise results provide a detailed picture not only of noise levels at the sites, but also the drivers of variability in the soundscape of this cetacean habitat. They also provide a basis for potential further work to more fully explore the sources of shipping noise and the main sectors contributing to noise pollution in the SAC.

Five key cetacean species were identified for prioritisation in the cetacean monitoring component of the monitoring programme, based on their frequency of occurrence: harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), and minke whale (*Balaenoptera*

acutorostrata). All three monitoring sites had high and regular rates of both porpoise and dolphin detections. Harbour porpoise detections were highly common, with daily detections and 60-70% of recording hours containing porpoise positive hours. Porpoise presence was highest in the winter months. Dolphin detections were also relatively common with 18-33% of recording hours containing dolphin click detections. There were two main peaks in dolphin occurrence, one from August to October, which likely reflects the seasonal arrival of Risso's dolphins, and another January to March peak, possibly reflecting increases in bottlenose dolphins that are reported to increase in numbers off the North Wales coast in the winter months. These findings provide the first year-round PAM data in the region, providing detailed information on seasonal occurrence of these species at three locations within the SAC.

With further investigation, the cetacean detection data would be highly suited to statistical modelling to elucidate spatiotemporal distribution and relative abundance of these species and greatly improve our ecological understanding of cetaceans and their behaviour within the SACs. Further, these data may be used to investigate cetacean occurrence and behaviour relative to acute and chronic anthropogenic noise exposure as well as potential impacts of marine developments and activities.

The lessons learned through this pilot study have been incorporated into the design of the proposed all-Wales monitoring programme, which is detailed in a separate WAMMS report.

1. Introduction

In 2019, three new Special Areas of Conservation (SACs) were designated in Welsh waters as part of a new UK network of sites: North Anglesey Marine, West Wales Marine, and Bristol Channel Approaches. These marine protected areas cover much of the Welsh marine area, including sites intended for future renewable energy developments. To support the effective management of these new SACs, the monitoring of underwater noise and cetacean presence were identified as a priority for further research under the Welsh Government funded Nature Networks Programme. The present project – the Welsh Acoustic Marine Mammal Survey (WAMMS) – was commissioned to deliver a blueprint for this monitoring programme, including the execution of a pilot monitoring programme in the North Anglesey Marine SAC.

WAMMS consists of two Workstreams:

> **Workstream 1:** Pilot study in North Anglesey Marine Special Area of Conservation (SAC). To define a method for measuring underwater noise and cetacean distribution/ vocalisation patterns at strategic locations within North Anglesey Marine SAC. To then test this method through fieldwork, data collection, and analysis.
> **Workstream 2:** Building on findings from workstream 1 and other similar studies across the UK, to define a costed and logistically achievable method for measuring underwater noise and cetacean distribution/vocalisation patterns across relevant Welsh MPAs.

This report addresses the outcomes of Workstream 1. The outcomes of Workstream 2 are presented in a separate report (Merchant et al., 2025).

The aim of this report is to provide Natural Resources Wales with the results of the 18-month WAMMS pilot study in the North Anglesey Marine SAC, which promised a demonstration of how underwater noise and cetacean occurrence can be monitored in a Welsh marine SAC. These results have informed the monitoring methodology proposed to be applied across all three Welsh marine SACs, as detailed in the Workstream 2 report (Merchant et al., 2025).

The structure of the report is as follows. Section 2 addresses the fieldwork campaign, including details of the monitoring locations, mooring design, scientific instruments, and deployment periods. Section 3 details the data analysis process for both the ambient noise measurements and the cetacean detections. Section 4 presents the results while Section 5 discusses these results in the context of the scientific literature. A brief conclusion is given in Section 6.

2. Fieldwork

2.1. Monitoring locations

The North Anglesey Marine SAC was chosen as a pilot area for monitoring. This area is a key habitat for harbour porpoise and other marine mammals (JNCC 2023) and there is the potential for increased pressure from human activities off the Anglesey coastline, including the installation and extension of offshore windfarms and tidal energy developments.

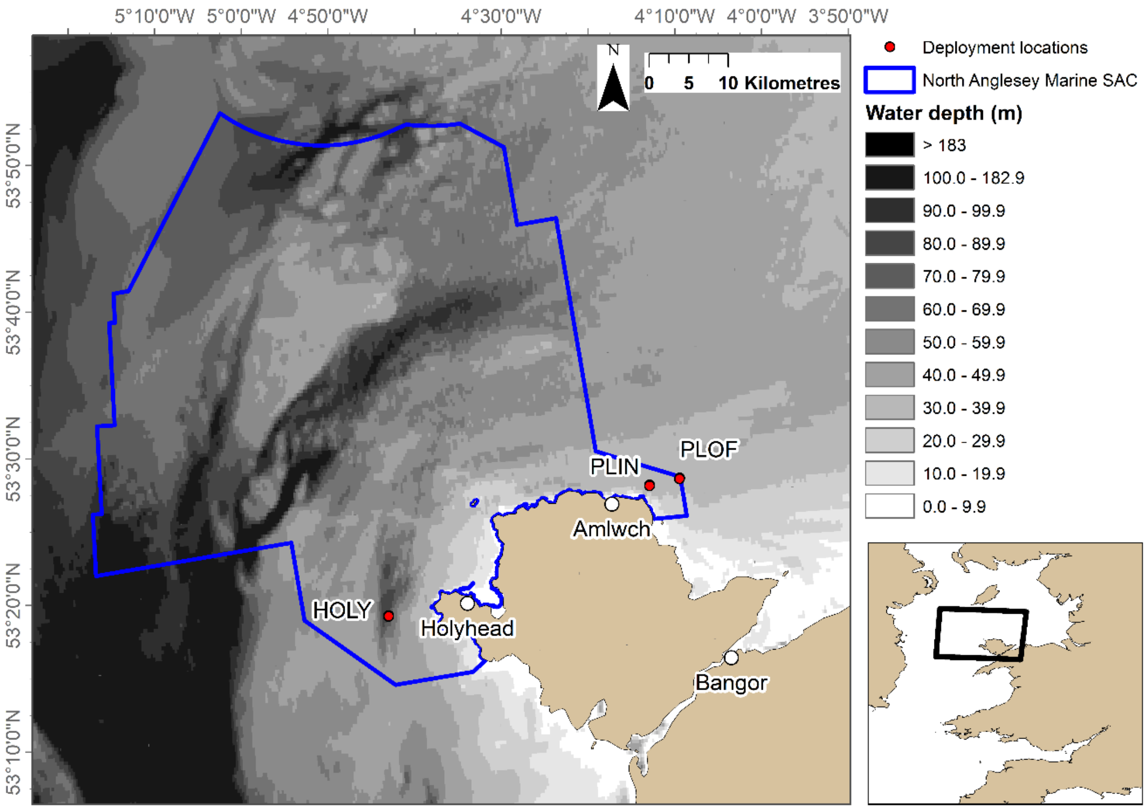

Figure 1: Map of the North Anglesey Marine Special Area of Conservation (SAC) with the red circles marking the three deployment locations (Holyhead deep - HOLY, Point Lynas inshore - PLIN and Point Lynas offshore - PLOF). The greyscale shows bathymetry data (source: EMODNET)and the blue line represents the North Anglesey Marine SAC boundary.

Three monitoring locations (Figure 1) were chosen for the pilot study following discussions between NRW, Bangor University and Cefas. Two locations were chosen off Point Lynas, Northeast Anglesey: one inshore site (1.7 km from the coast) at 33 m water depth, hereafter denoted Point Lynas inshore (PLIN); and one offshore site (5.2 km from the coast) at 35 m water depth, known as Point Lynas offshore (PLOF). The third location was at Holyhead deep (HOLY), West Anglesey, another offshore site (5.4 km from the coast) in deeper waters of 77 - 82 m.

The selection criteria for these sites were based on key areas of interest for marine mammal activity (e.g. where there has been limited monitoring and areas where previous successful monitoring has happened), as well as practical constraints of field monitoring (avoidance of dredging activity, pipelines and cables, fishing activity, considerations of water depth, sediment movement and accessibility given the vessel budget available). For more information on the site selection process, please refer to the methodology report of the WAMMS project (Putland et al., 2023).

To our knowledge, there has been no previous passive acoustic monitoring off Point Lynas, but visual observations from shore have confirmed high sightings rates, with all five target species [harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), and minke whale (*Balaenoptera acutorostrata)*] having been recorded. Having both an offshore and an inshore location allows comparison of sound levels and marine mammal presence in relation to proximity from the coastline, which may have broader relevance for other parts of the SAC.

Previous passive acoustic monitoring at the Holyhead location has reported high rates of Risso's dolphin and harbour porpoise detections as well as regular encounters of bottlenose/common dolphins (Veneruso et al. 2020). It was considered that further monitoring would be helpful to understand detections in deeper water and in proximity to future renewable energy locations.

2.2. Field deployments

2.2.1. Overview

The field monitoring campaign was active from 8 May 2023 to 4 November 2024 (Table 1). Thirteen out of fifteen deployments were successfully recovered, with the lost deployments being the fourth at both Holyhead deep and Point Lynas inshore, which were not recovered due to a lack of response from the acoustic releases. It cannot be known for certain whether these losses were due to displacement of the moorings by other activities in the area or failure of the acoustic releases due to equipment malfunction or insufficient battery charge. However, given the spatial separation of the Holyhead deep and Point Lynas sites, it seems an improbable coincidence for both sites to be disturbed by other activities during the same deployment, and equipment malfunction is perhaps the more likely explanation.

Table 1: Deployment coordinates, equipment, and deployment/recovery dates for all sites in the pilot study.

Station Name	Deployment No.	Latitude	Longitude	Equipment	Deployment Date	Recovery Date
Holyhead deep	001	53°18.003N	4°46.963W	ST600	08/05/2023	10/08/2023
Holyhead deep	002	53°17.940N	4°46.990W	ST600	10/08/2023	25/10/2023
Holyhead deep	003	53°17.942N	4°46.986W	ST600	25/10/2023	04/04/2024
Holyhead deep	004	53°17.945N	4°46.984W	ST600	04/04/2024	**Not recovered**
Holyhead deep	005	53°17.945N	4°46.983W	ST600	31/07/2024	04/11/2024
Point Lynas Inshore	001	53°25.782N	4°16.360W	ST600	08/05/2023	10/08/2023
Point Lynas Inshore	002	53°25.720N	4°16.390W	ST600 and FPOD	10/08/2023	25/10/2023
Point Lynas Inshore	003	53°25.722N	4°16.380W	ST600 and FPOD	25/10/2023	04/04/2024
Point Lynas Inshore	004	53°25.772N	4°16.381W	ST600 and FPOD	04/04/2024	**Not recovered**
Point Lynas Inshore	005	53°25.723N	4°16.376W	ST600 and FPOD	31/07/2024	04/11/2024
Point Lynas Offshore	001	53°26.123N	4°12.891W	ST600	08/05/2023	10/08/2023
Point Lynas Offshore	002	53°26.050N	4°12.930W	ST600 and FPOD	10/08/2023	25/10/2023
Point Lynas Offshore	003	53°26.064N	4°12.912W	ST600 and FPOD	25/10/2023	04/04/2024
Point Lynas Offshore	004	53°26.061N	4°12.901W	ST600 and FPOD	04/04/2024	31/07/2024
Point Lynas Offshore	005	53°26.063N	4°12.902W	ST600 and FPOD	31/07/2024	04/11/2024

2.2.2. Mooring design

A compact SoundTrap mooring design was used which has been tried and tested by Bangor University (BU) in previous projects. It consists of a 75 kg chain anchor clump attached to a Vemco acoustic release (Ascent AR-100-BA) and RS Aqua ARC (acoustic release canister) (RS-Aqua, UK). The SoundTrap (Ocean Instruments, NZ) was suspended above the acoustic release using a submersible buoy and line at approximately two metres above the seabed (Figure 2). From a vessel, the user can signal to the acoustic releases to release via transponder and deck box, removing the requirement of a surface line and buoy which can be subject to drag and loss, particularly in tidal environments. Once released, the positively buoyant ARC plate brings the SoundTrap and acoustic release to the surface for collection. The ARC canister contained 150m x 4mm Dyneema 12-strand rope which was then mounted on the vessel's hauler to allow recovery of the anchor clump.

Figure 2. Example SoundTrap mooring. From left to right: 75kg chain clump, RS Aqua ARC canister and Vemco acoustic release, SoundTrap attached to line with submersible buoy for suspension above the seabed.

In deployments 2 and 3 (10 Aug 2023 – 4 Apr 2024), F-PODs (Chelonia Ltd., UK) were suspended in addition to SoundTraps at the Point Lynas inshore and offshore stations. The aim was to trial the effectiveness of F-PODs in tidal environments by comparing detection patterns with SoundTraps. Of particular interest was the effect of tidal flow on click detections, and for this reason, the Point Lynas stations were chosen for the trial, since the tidal currents are faster than at Holyhead Deep.

2.2.3. Deployment logistics

For mooring turnarounds, spare fully charged and configured SoundTraps purchased for the project were prepared (in addition to F-PODS provided by NRW for the Point Lynas sites for deployment 2 onwards). Acoustic releases, ARCs and associated parts were loaned by BU so that a full spare SoundTrap mooring for each location could be prepared in advance of equipment recovery and re-deployed on the same day that moorings were recovered. This avoided significant gaps in the recordings and maximised boat charter days.

Figure 3. Left: Point Lynas inshore mooring recovered on August 10th 2023 with two floats missing from the ARC mooring system. Right: Example mooring with floats tied to the structure as an extra securing measure.

An issue with the attachment of the mooring legs to the RS Aqua ARC was identified during the first recovery at Point Lynas inshore, since two of the floats detached from the mooring during ascent to the surface (Figure 3). The technical team investigated the other moorings onboard and identified that the anode connections between the legs and attachment points were different in the new versions of the ARC cannisters compared to those that were about to be deployed (older versions owned by BU). A decision was therefore made to continue the deployment of new equipment at the sites. Upon return to land the manufacturer RS Aqua was informed of the issue and their technical team sent new anodes to be retrofitted to all three ARC cannisters purchased for the project (this was completed by BU prior to the deployment on 25th October 2023).

Moderate biofouling was present on the Point Lynas moorings upon recovery; an example recovered mooring is shown in Figure 4.

Figure 4. Left: Photographs of the three deployment moorings on August 10th 2023. At the front of photo Point Lynas offshore, middle Holyhead deep and end Point Lynas inshore. Right: Close up photograph of the biofouling on the Point Lynas offshore mooring.

2.2.4. SoundTrap configuration

SoundTrap 600HFs (Ocean Instruments, NZ) were used to record ambient noise and cetacean vocalisations and were configured using SoundTrap Host software version 4.0.15.23124. Sounds were recorded at a sample rate of 48 kHz to allow assessments of noise up to 24 kHz, and detection of dolphin whistles and minke whale vocalisations.

An integrated SoundTrap click detector was enabled to sample at 384 kHz for detection of dolphin and porpoise echolocation clicks. The detector stored data when high frequency transient sounds > 12 dB above background noise were detected. Click 'snippets' 650 ms before and after each detection were stored, allowing samples of high frequency audio data with coverage of potential cetacean click events; a minimum time between detections (blanking time) of 100 ms was specified (Figure 5).

High sample rate recordings that do not trigger a 'click' detection were discarded by the system, allowing for a much longer recording period. However, the detector has a very low specificity, so the majority of transients are therefore not of marine mammal vocalisations and additional processing stages are required to identify cetacean clicks. See Figure 6 for a summary of the key cetacean data collection and processing steps. Further details of the SoundTrap click detector are available in the user guide (Ocean Instruments, 2023).

To further extend the deployment duration, a duty cycle of 24h on / 24h off was selected, which extended the battery longevity and reduced the data volume. All devices were configured to start recording on the same days.

SoundTrap data were stored on micro-SD cards as .sud files, a packaged file which includes 3X compressed audio (.wav) data, SoundTrap click detector files (.dwv and .bcl) and metadata (.xml).

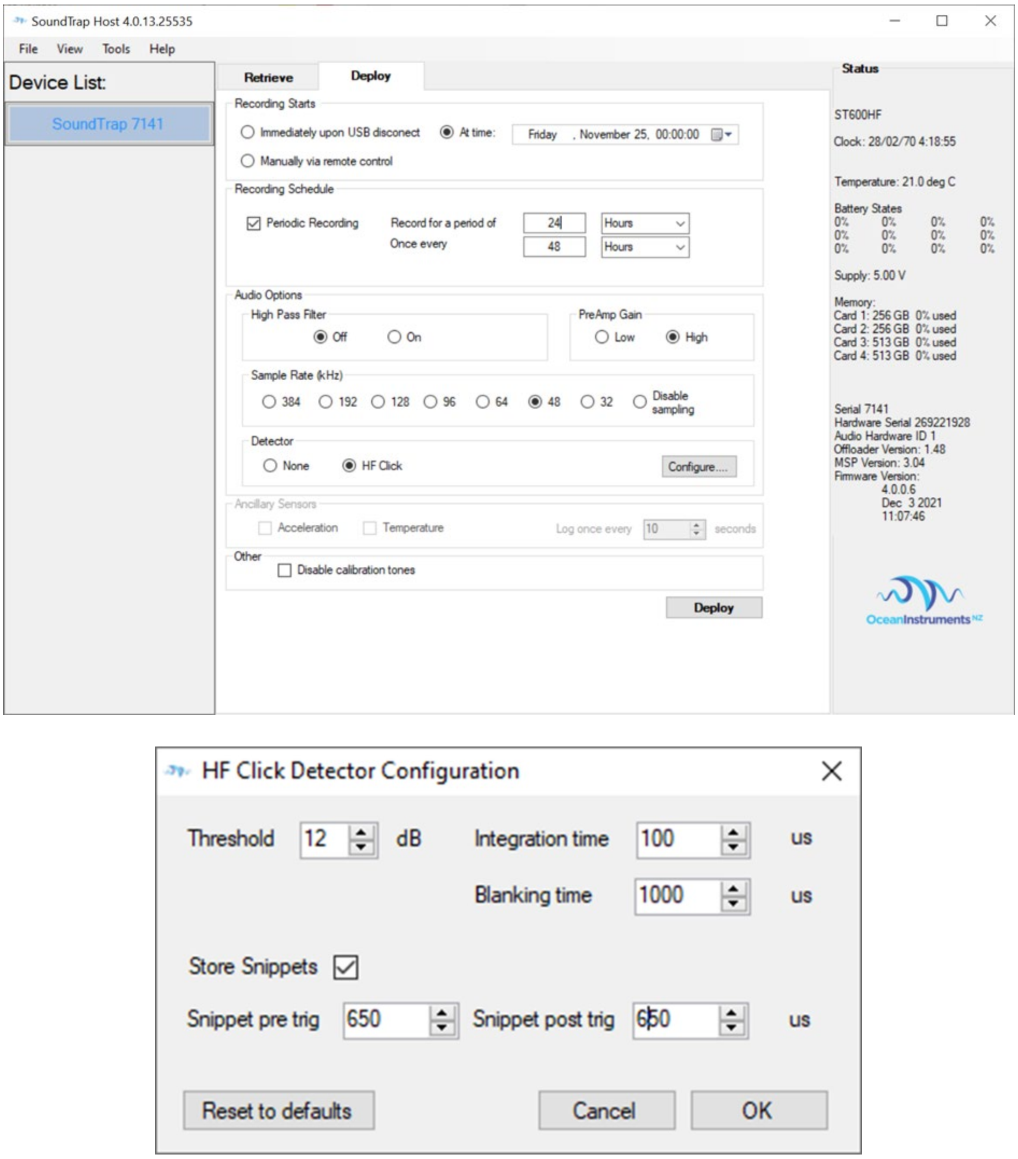

Figure 5 Top: SoundTrap settings configured by recording schedule, filters, and Bottom: optional use of the SoundTrap click detector which is further configured by the user.

2.2.5. F-POD configuration

F-PODs (Full waveform capture POD; Chelonia Ltd., UK) are automated echolocation click loggers which process clicks identified in digitised sound data in real time, saving smaller files containing click information. F-PODs were trialled alongside SoundTraps at the Point Lynas inshore and offshore moorings. The purpose of these trials was to test the efficacy of F-PODs compared to multi-function acoustic recorders such as SoundTraps.

F-PODs were configured with the ‘sonar filter’ on, automatic amplitude threshold off and were logging continuously.

3. Data analysis

3.1. Ambient noise data

3.1.1. Quality checks

The SoundTraps were pre-programmed to begin recording, which meant that some data were captured before and after deployment in the water. These data were removed before analysis such that only full recording days were used for the ambient sound analysis; therefore, data were retained from the day after deployment to the day before collection. Data were checked for missing files by comparing the number and size of files between the logger data and downloaded data. Data were checked to ensure they did not contain non-numerical or infinite values, which cannot be processed and may be indicative of a recording malfunction.

3.1.2. Data processing

Recordings for each deployment were analysed in MATLAB using a modified version of PAMGuide (Merchant et al., 2015), which is used by many labs globally for ambient soundscape analysis (e.g. Fischer et al., 2021). Sound pressure levels were calculated in one-third octave frequency bands ranging from 25 to 24,000 Hz ('ANSI/ASA S1.11-2014/Part 1/IEC 61260:1-2014' 2014)) at 1-second temporal resolution. This analysis provides coverage of the frequency range used by most marine species and is consistent with data processing used for larger UK and European projects (Fischer, Kuhnel, and Basan 2021; Putland et al. 2022) following the definitions of the UK Marine Strategy and EU Marine Strategy Framework Directive.

The processed data were outputted in .csv format, and these one-third-octave band, 1-s resolution data were used as the basis for subsequent spectra, statistical analyses, and comparison with meteorological and oceanographic parameters. These analyses included the production of hourly and monthly median sound levels (across all one-third-octave frequency bands) and overall median, 10^{th} and 90^{th} percentile levels for each monitoring site.

Additionally, selected data were analysed at higher frequency resolution (1-Hz frequency bins rather than the wider one-third-octave bands) for the purposes of source identification.

3.1.3. Auxiliary environmental data

To investigate the influence of meteorological phenomena and tidal currents on ambient sound levels, hourly current speed data were acquired from Copernicus Marine Service (Copernicus, 2025), a widely used set of oceanographic models, while hourly wind and precipitation data were acquired from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 model (ECMWF, 2025).

3.2. Marine mammal data

3.2.1. Raw data processing

All SoundTrap .sud files were downloaded, stored and post-processed using PAMGuard software version 2_02_09 (Gillespie et al., 2008). PAMGuard directly reads and unpacks the .sud files and simultaneously processes the 48kHz audio and SoundTrap click detector data, storing all data in PAMGuard binary files (Figure 6). A schematic of the PAMGuard configuration used to process .sud files downloaded from the SoundTraps is shown in Figure 7. The 48kHz data passes through an FFT module, which calculates a Short-Term Fourier Transform (spectrogram) of the data, which then passes to a whistle detector (Gillespie et al. 2013). The 48kHz data were also decimated to 2kHz for the detection of lower frequency minke whales and then passed through a minke pulse detector. The high frequency SoundTrap Click Detector, used to detect clicks from dolphins and porpoises, ran alongside the other PAMGuard modules to extract and convert click data to binary files and was run through a first-pass harbour porpoise click classifier with frequency sweep using default settings.

SoundTrap data collection	Cetacean event detection – PAMguard	Click classification – MATLAB	Click verification and data exploration – R
• Records audio (WAV files) at user-specified sampling rate • Optional HF click detector (DVW & BCL files) that stores data snippets at max. sampling rate when triggered • All data compressed and packaged in SUD files	• Processes SUD files to enable the detection of cetacean vocalisations amongst other sounds according to user configurated modules (Figure 7) • Exports processed binary files and database and a user display to inspect and label PAM data (Figures 8-12). • Requires further steps (manual / automated) to separate cetacean sounds from noise and classification groups.	• Species group classification using an automated custom clock clustering algorithm • Inputs binary files created by PAMguard, outputs counts of species clicks per minute	• Compare manually verified labelled data with samples of automated classifier outputs to assess classifier performance. • Output data of cetacean detections (porpoise / dolphin presence / absence) for each hour of recording. Exploratory analysis to investigate temporal patterns of presence and comparisons between sites.

Figure 6. Summary of the data collection and processing steps for cetacean click detection and classification.

Details of PAMguard configuration used to process SoundTrap data as per Figure 7 are shown below:

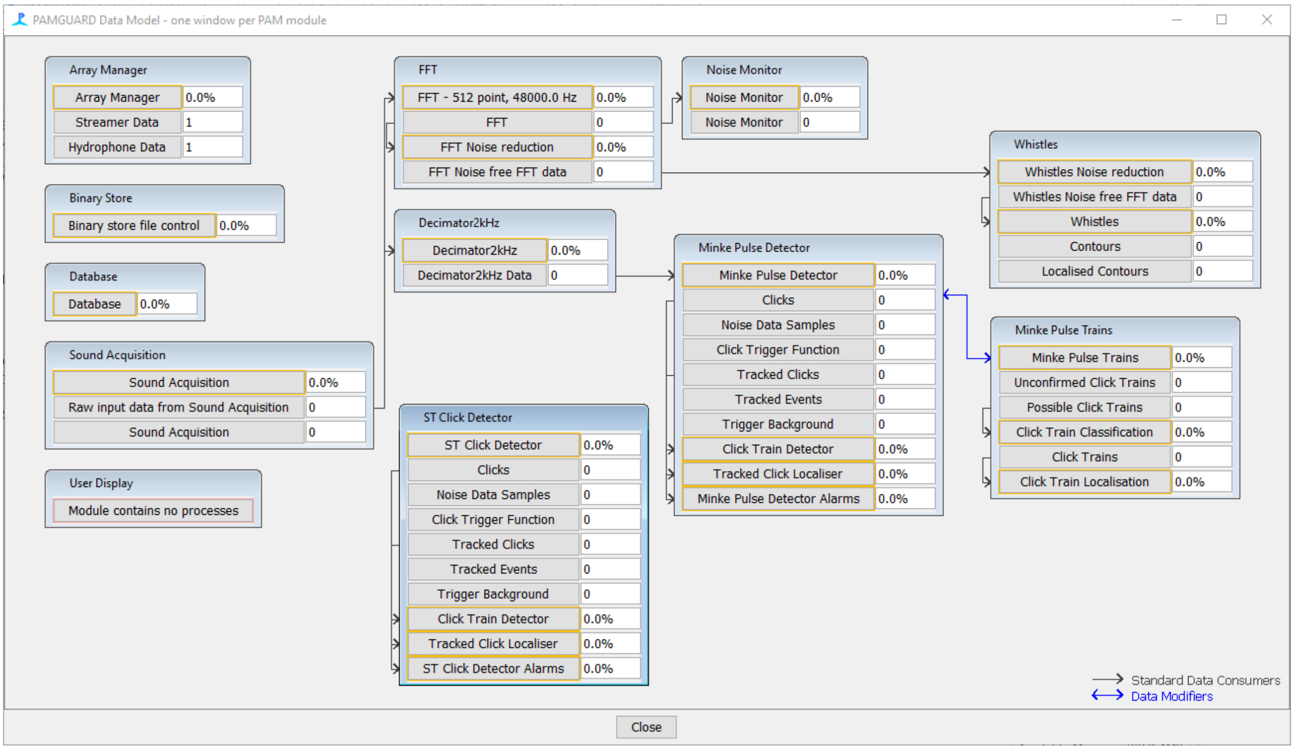

Figure 7. Schematic of the PAMGuard configuration used to process SoundTrap data.

3.2.2. Cetacean event detection

3.2.2.1. Harbour porpoise (*Phocoena phocoena*)

Harbour porpoises produce distinctive narrow-band high frequency (NBHF) echolocation clicks with frequencies centred around 130 kHz, with click rates ranging from <10 ms and 250 ms (Wisniewska et al. 2016) and mean source levels of 191 dB re 1 µPa peak-to-peak @ 1m (Teilmann et al. 2002). Although the existing PAMGuard porpoise click classifier performs reasonably well, manual verification of previous PAM datasets within the region indicated that the classifier reported high rates of false positives. Therefore, further work to fine-tune porpoise classification is required.

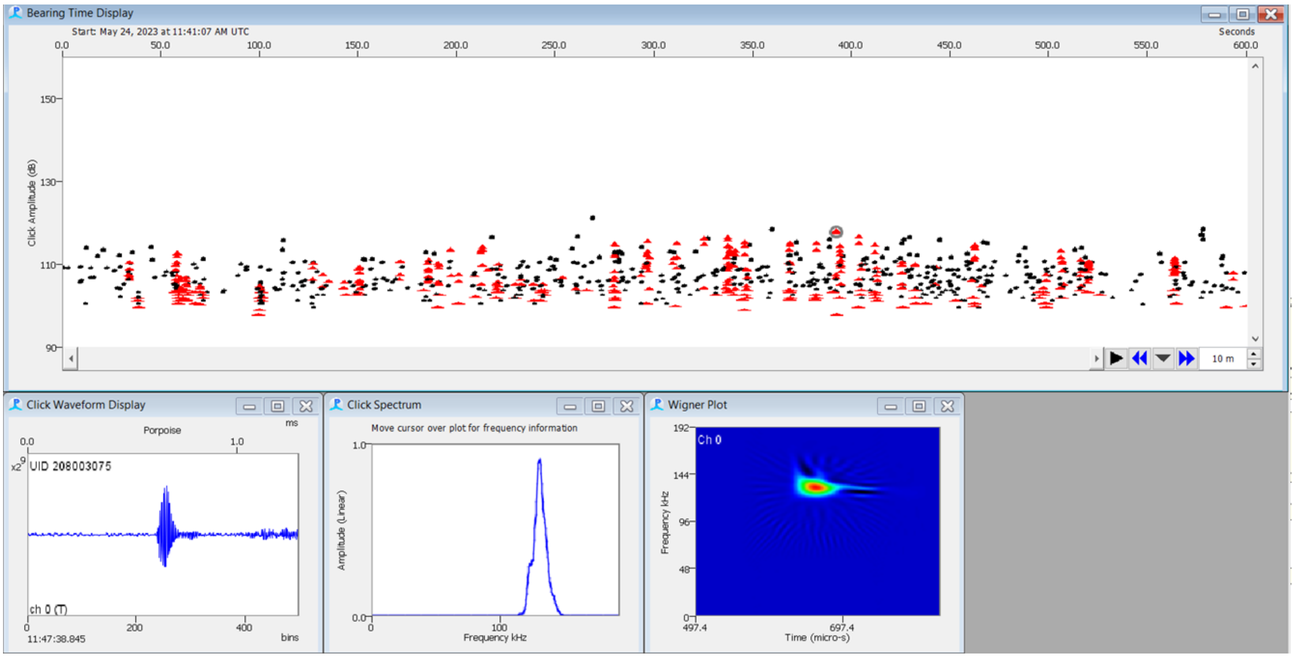

Figure 8. PAMGuard screenshot showing 10 minutes of harbour porpoise clicks. The top panel shows an amplitude-time display with black dots representing unclassified sounds and red triangles showing PAMGuard classification of porpoise clicks. Bottom panels from left to right shows the waveform of a selected click, the frequency spectrum of the click, note the narrow-band spike at ~130 kHz, typical of porpoise clicks and a Wigner plot showing the duration of the click.

3.2.2.2. Bottlenose (*Tursiops truncatus*) and short-beaked common (*Delphinus delphis*) dolphins

Bottlenose and common dolphin clicks are very similar and instruments cannot presently separated them. They produce clicks that have a relatively uniform (broadband) energy that focusses around 20 - 50 kHz, although energy at frequencies of >100 kHz are also present (Palmer et al., 2017; Whitlow, 1993). Dolphin clicks are typically more difficult to classify compared to porpoises, since clicks can be variable in nature and overlap in frequencies with many other sounds. It is for this reason that default automated dolphin click classifiers do not exist. In this pilot study, a novel echolocation click classifier developed by the University of St Andrews was trialled.

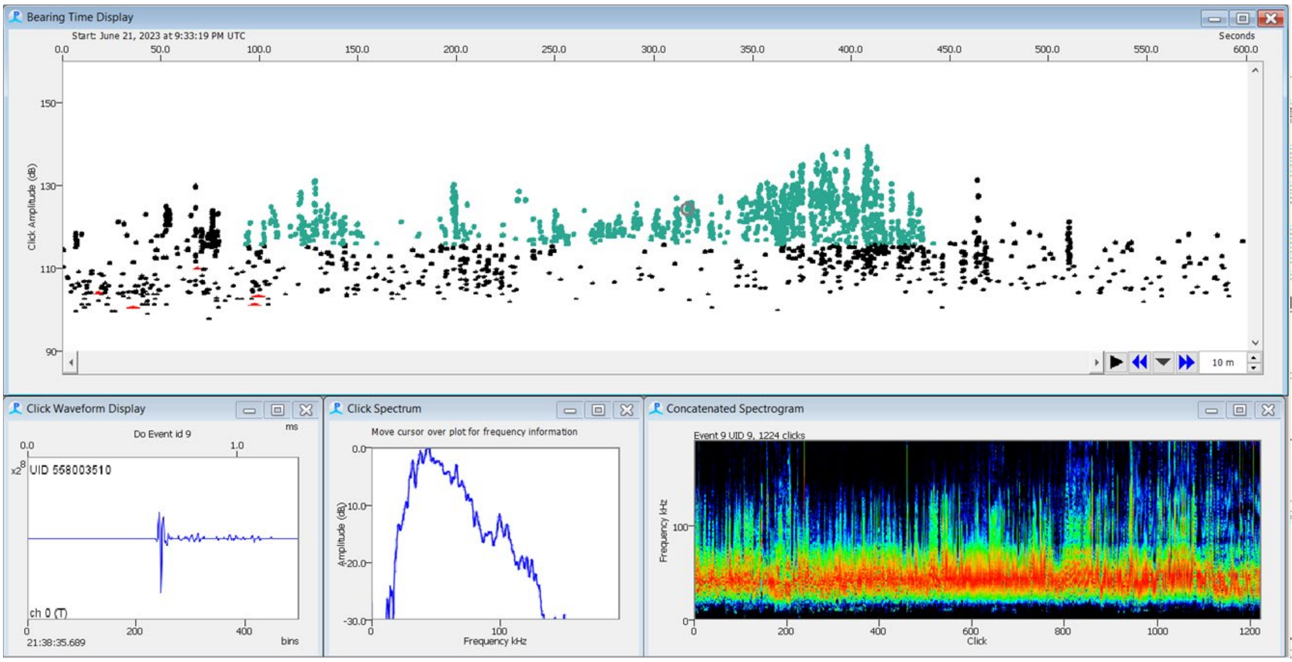

Figure 9. PAMGuard screenshot showing 10 minutes of bottlenose or common dolphin clicks. The top panel shows an amplitude-time display with black dots representing unclassified sounds and green showing manually labelled dolphin clicks. Bottom panels from left to right shows the waveform of a selected click, the frequency spectrum of the click and a concatenated spectrogram showing broadband energy between ~20-50kHz over the duration of the click event.

3.2.2.3. Risso's dolphin (*Grampus griseus*)

Risso's dolphin vocalise within a similar bandwidth to the other dolphin species (20 - 50 kHz) but click energy focusses at specific frequency bands rather than being broadband (Soldevilla et al. 2008; 2017), making this species relatively distinct to bottlenose and common dolphin clicks.

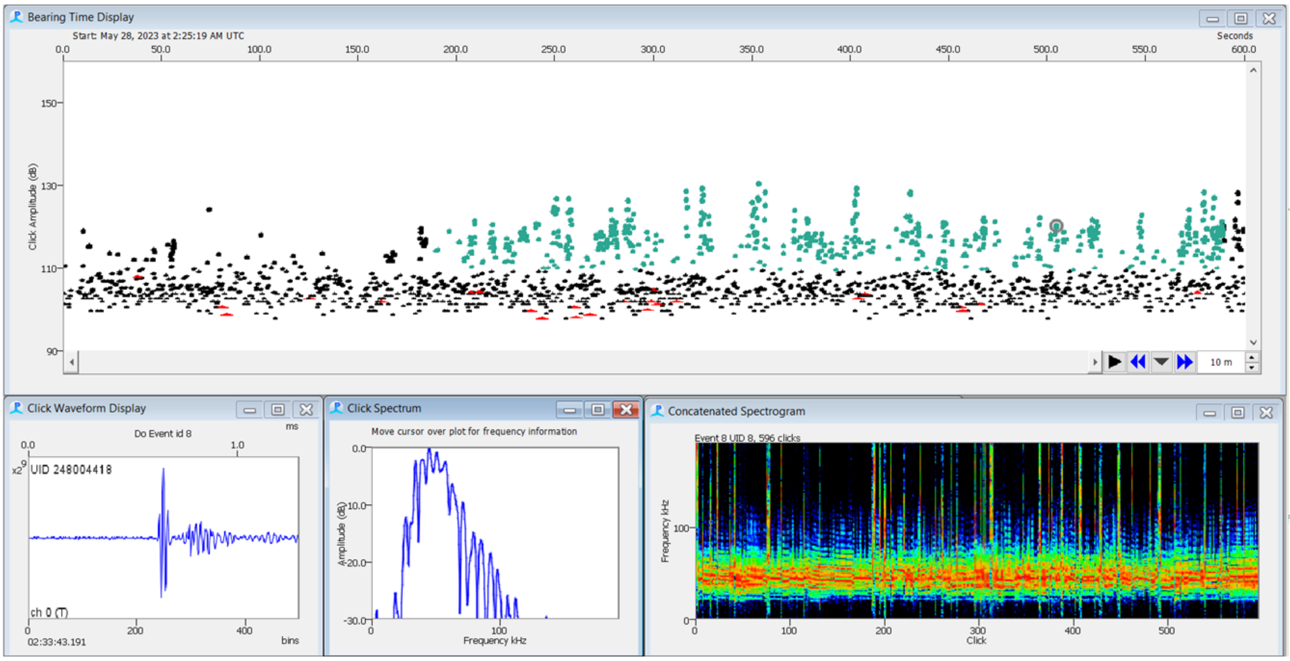

Figure 10. PAMGuard screenshot showing ~10 minutes of Risso's dolphin clicks. The top panel shows an amplitude-time display with black dots representing unclassified sounds and green showing manually labelled dolphin clicks. Bottom panels from left to right shows the waveform of a selected click, the frequency spectrum of the click and a concatenated spectrogram showing energy distributed in bands between ~20-50kHz over the duration of the click event.

3.2.2.4. Dolphin whistles

Dolphin whistles are tonal sounds between ~ 5-15 kHz, primarily used for communication and social behaviour. There was not the scope to analyse both whistles and echolocation clicks in this contract. Since whistles are generally detectable kilometres away from the source and are fewer compared to echolocation clicks, the latter was the priority for analysis and is a better representation of the occurrence of dolphins at specific field sites. However, the whistles recorded may be particularly useful to distinguish between bottlenose and common dolphins and provide behavioural contexts to dolphin presence in the region in future work.

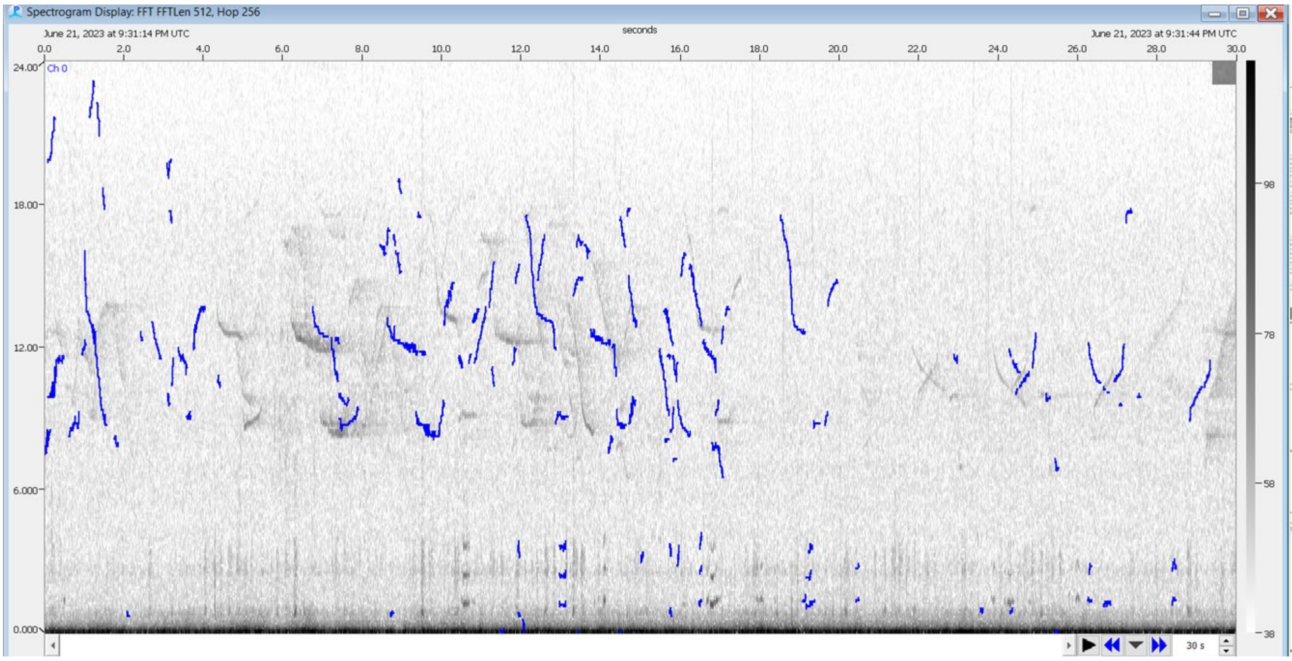

Figure 11. PAMGuard screenshot of a spectrogram showing dolphin whistles. The frequency in kHz is shown on the left Y axis and amplitude on the right Y axis. Whistles in black show the tonal sounds recorded by the SoundTraps and the blue shows whistle fragments that were automatically detected by the PAMGuard whistle and moan detector.

3.2.2.5. Minke whale (*Balaenoptera acutorostrata*)

Minke pulse trains appear as a series of low frequency narrow band calls at ~60 – 90 Hz, separated by around 1s (Risch et al. 2013; 2019). An automated minke pulse detector developed by Dr Denise Risch at the Scottish Association for Marine Science (SAMS) which is integrated in PAMGuard will be trialled with these data.

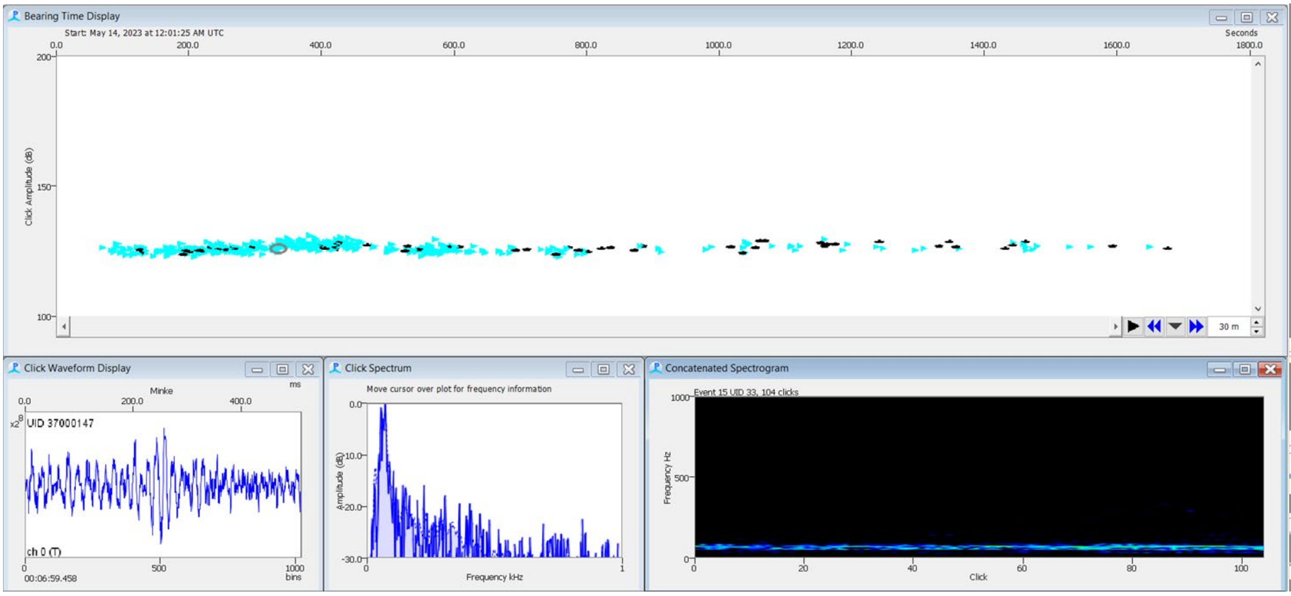

Figure 12. PAMGuard screenshot showing 30 minutes of a minke whale pulse train. The top panel shows an amplitude-time display with black dots representing unclassified sounds and blue showing calls classified by a minke whale detector. Bottom panels from left to right shows the waveform of a selected pulse, the frequency spectrum, and a concatenated spectrogram showing narrowband energy centred at around 70 Hz.

3.2.3. Cetacean click classification

An echolocation click classifier, developed by Dr Douglas Gillespie at the Sea Mammal Research Unit (SMRU), University of St Andrews, was utilised for this study. The classifier was developed for the Menter Môn-Marine Characterisation Research Project (MCRP; Gillespie et al., 2023), also situated on Anglesey, and focussed on the classification of the same small cetacean species and populations as WAMMS.

The click classifier, which uses the PAMGuard binary files was run in MATLAB v2024a (scripts are openly available at https://github.com/douggillespie/soundtrapclickclassifier) and is broken down into a series of steps:

1) Clustering a minimum of 10 clicks with similar parameters,
2) Classification into the different species events with associated scores and writing into the database utilised in PAMGuard,
3) Estimation of ambient noise from click data and establishing six potential amplitude thresholds, where echolocation clicks below these amplitudes are removed,
4) Producing an output of the number of clicks for each species in each minute of data collected for each noise threshold.

These steps were repeated for each deployment at all sites.

3.2.3.1. Validation

Harbour porpoises produce distinctive narrow band high frequency (NBHF) clicks and therefore it was assumed that the click classifier performed well for this species (as is typical in classification of the species in other PAM studies including the MCRP).

Since dolphin clicks are more variable and overlap in frequencies with other commonly produced sounds, a series of validation steps were conducted using data from the first deployment at each site.

a) Assessment of true negatives – missing dolphin detections

For each site, 11 days (24h) of data were manually screened in PAMGuard Viewer for dolphin detections by inspecting click spectra, waveforms, click intervals and amplitudes, according to each species' click characteristics as described in section 3.3.2.1. These samples were compared to classified data to assess whether the classifier was missing genuine dolphin detections.

b) Assessment of false positives – misclassification of dolphin detections

Each dolphin event identified by the classifier was viewed in PAMGuard Viewer and assigned to a species (Risso's dolphin or bottlenose/common dolphin) where possible, according to known click characteristics (see section 3.3.2.1) or labelled as 'other' if the encounter was deemed to be a false positive.

Verified data was then used to create a new copy of detection positive minutes (DPM) datasets run in MATLAB. Both the classifier DPM and verified DPM datasets were concatenated into detection positive hours (DPH) in R software and compared to assess if there were differences between classifier and verified data performance.

3.2.4. Data exploration of cetacean data

Data were formatted and explored in R software, investigating variability in the percentage of porpoise positive hours (PPH) and dolphin positive hours (DPH) per day, relative to date, month, hour of day and moon phase between the sites.

3.2.5. F-POD data

F-POD data were downloaded as .CHE files and processed in F-POD host software into FP1 (raw F-POD data) followed by FP3 (data that had been processed with the KERNO-F classifier) (Ivanchikova & Tregenza, 2023). F-POD click classification is a largely automated process, with options to classify narrow band high frequency species (NBHF, porpoises and other NBHF species, such as Kogia spp.) and 'other cetaceans' (dolphins). It cannot distinguish between species; however, since harbour porpoises are the only NBHF species expected in the region, it was assumed that all NBHF classifications were harbour porpoises. It can be assumed that 'other cetaceans' classifications were dolphins but similarly, these cannot be assigned to the species level. One hundred click train samples from each deployment were manually screened to assess the rate of false positive detections for both porpoises and dolphins. This was achieved by inspecting patterns in click amplitude, click rates and frequencies shown on the software display.

Click detection events were then exported as CSV files and explored in R software using the same environmental variables described in section 3.3.4.

4. Results

4.1. Ambient sound

4.1.1. Overall patterns in ambient sound

The three sites show clear differences in sources and patterns of activity (Figure 13). Holyhead showed a stronger influence of tidal flow noise on low-frequency sound levels, as evidenced by the more intense periodic noise at low-frequencies which correspond to tidal periodicity (Figure 13, label A). This noise is caused by the turbulence of water around the hydrophone and is not sound which is present in the environment, and so is considered self-noise rather than signal.

While only a few ship passages are immediately apparent in the Holyhead data (ship passages appear as brief and intense events spanning a wide range of frequencies, usually with greatest levels between 100 Hz and 1 kHz), both Point Lynas sites show frequent ship passages (Figure 13, label B), suggesting that shipping activity is more intense at these locations.

There were also isolated periods of more sustained noise at all three of the sites: at Holyhead during August 2024, at Point Lynas inshore during October 2023, and at Point Lynas offshore during August-September 2023 (Figure 13, label C). These events were likely due to mooring self-noise and will be explored in more depth in section 4.1.2.

Lastly, during periods of more intense tidal flow noise, there were also higher ambient noise levels observed at the highest frequencies (>10 kHz; Figure 13, label D). Tidal flow noise diminishes with increasing frequency and is generally far below background noise levels at these high frequencies. However, high tidal flow can stimulate sediment transport, which has a characteristic high-frequency sound signature dependent on the grain size of the sediment particles. It is therefore likely that sediment transport is contributing to the soundscape at these frequencies during periods of high tidal flow.

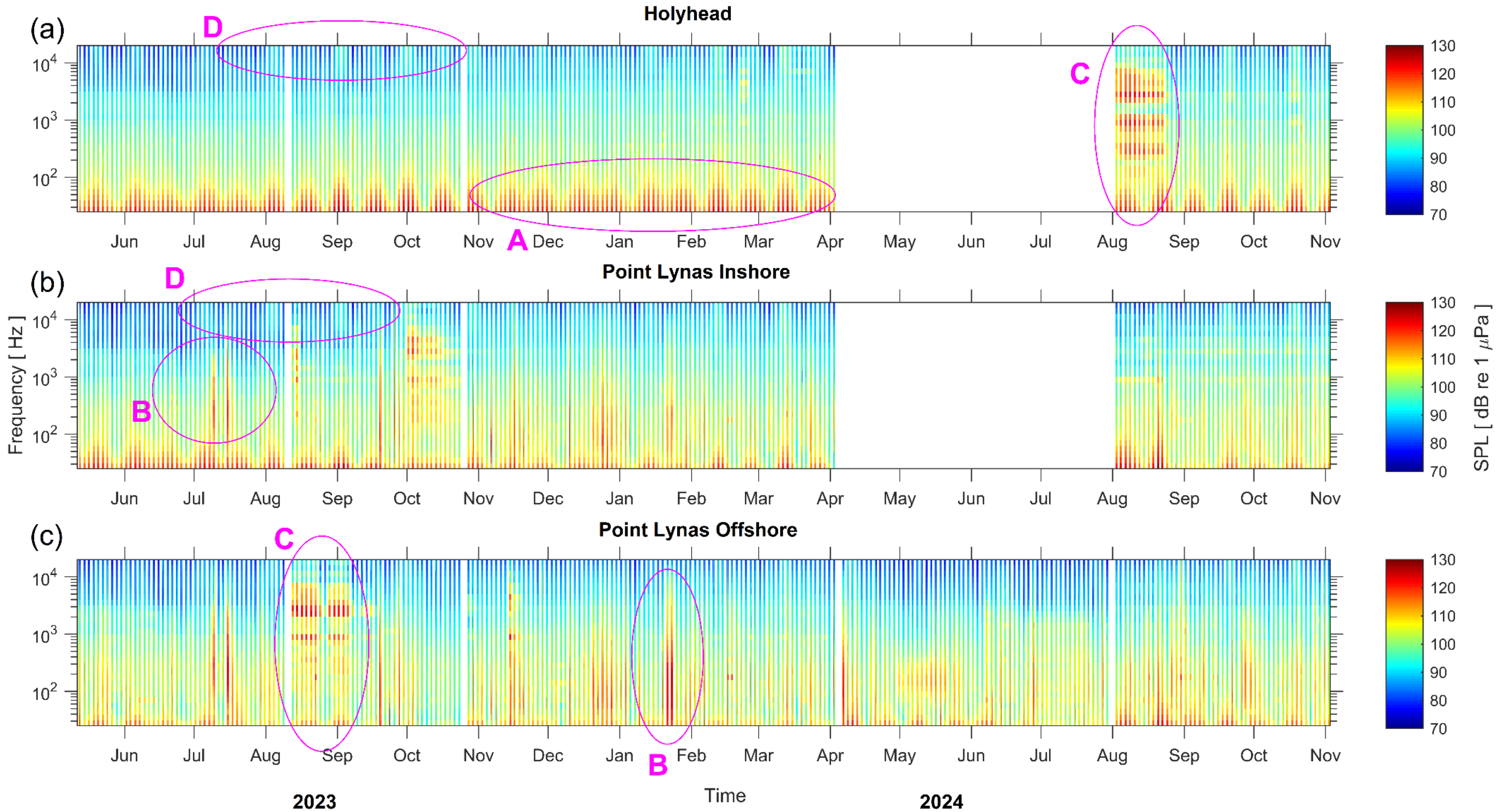

Figure 13 Third-octave band analysis of all ambient noise data recorded across the three monitoring sites. Features highlighted: (A) low-frequency tidal flow noise; (B) ship passages; (C) persistent noise identified as probable mooring self-noise; (D) high-frequency noise attributed to tidal sediment transport.

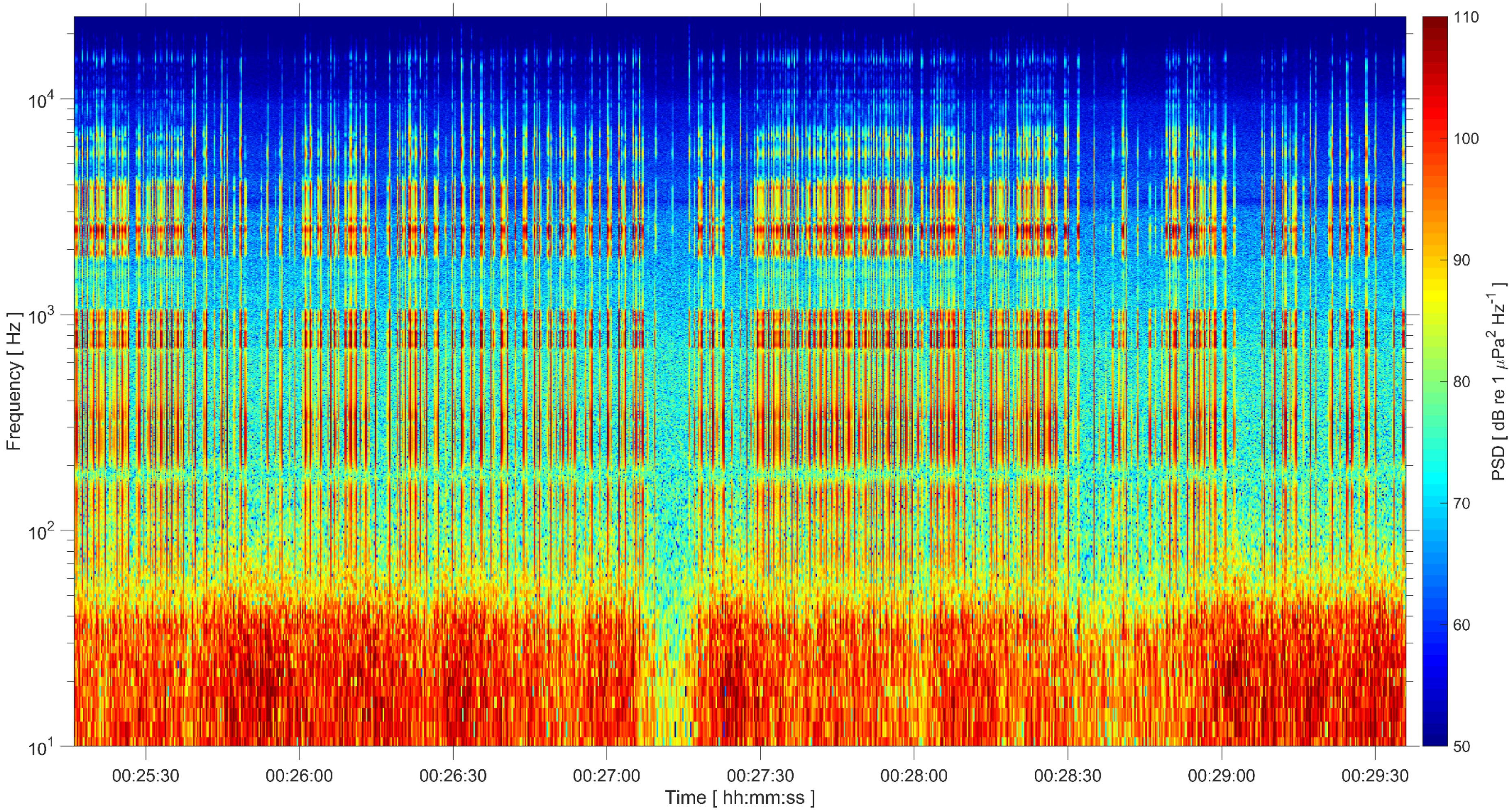

Figure 14. Power spectral density of data recorded at Holyhead site on 5 August 2024 showing contamination of self-noise, likely resulting from mooring rattling during high tidal flow.

4.1.2. Self-noise

The periods of sustained noise identified in section 4.1.1 (at Holyhead during August 2024, Point Lynas inshore during October 2023, and Point Lynas offshore during August-September 2023) were investigated in more depth and found to be caused by self-noise, most likely from moving and rattling of the mooring during periods of high tidal flow. Sample data from the Holyhead site on 5 August 2024 (Figure 14) show a characteristic repetitive knocking sound consistent with parts of the mooring colliding. This likely cause was also confirmed by listening to the audio. This noise was associated with periods of high tidal flow (see also Figure 20 below), and these especially sustained periods of heightened self-noise may be related to the set-up of the mooring on these deployments, the orientation of the mooring, and seasonal peaks in tidal current speed.

At deployment sites with substantial tidal currents, some amount of tidal flow noise is unavoidable, even if specially designed flow shields are used on the mooring (Martin et al., 2012). However, self-noise from the movement of the mooring itself can usually be avoided by careful design to avoid, for example, metal parts coming into direct contact as the mooring moves (Robinson et al., 2014). The mooring design used for this pilot study should therefore be reviewed to determine the cause of this self-noise and to identify potential remedies.

The implications for the analysis of the data are that low-frequency noise associated with periods of high tidal flow will be attributable both to tidal flow noise (turbulence around the hydrophone which is largely unavoidable) and to mooring self-noise, which could likely be reduced in future monitoring by revisiting the mooring design.

4.1.3. Inter-site comparison

While the long-term spectra presented in Figure 13 are indicative of comparative sound levels, this is shown more quantitatively by directly comparing statistical spectra computed across the duration of the study period (Figure 15). For consistency, the Point Lynas offshore data during the fourth deployment (April-July 2024) were excluded from these calculations so that the data from the three sites covered the same period. The median spectra (solid lines) confirm that sound levels at the lowest frequencies were highest at Holyhead, likely due to tidal flow noise and self-noise, while at frequencies associated with shipping noise (~100 Hz – 1 kHz), the Point Lynas sites had higher levels due to greater shipping activity. At the highest frequencies, the spectra converge.

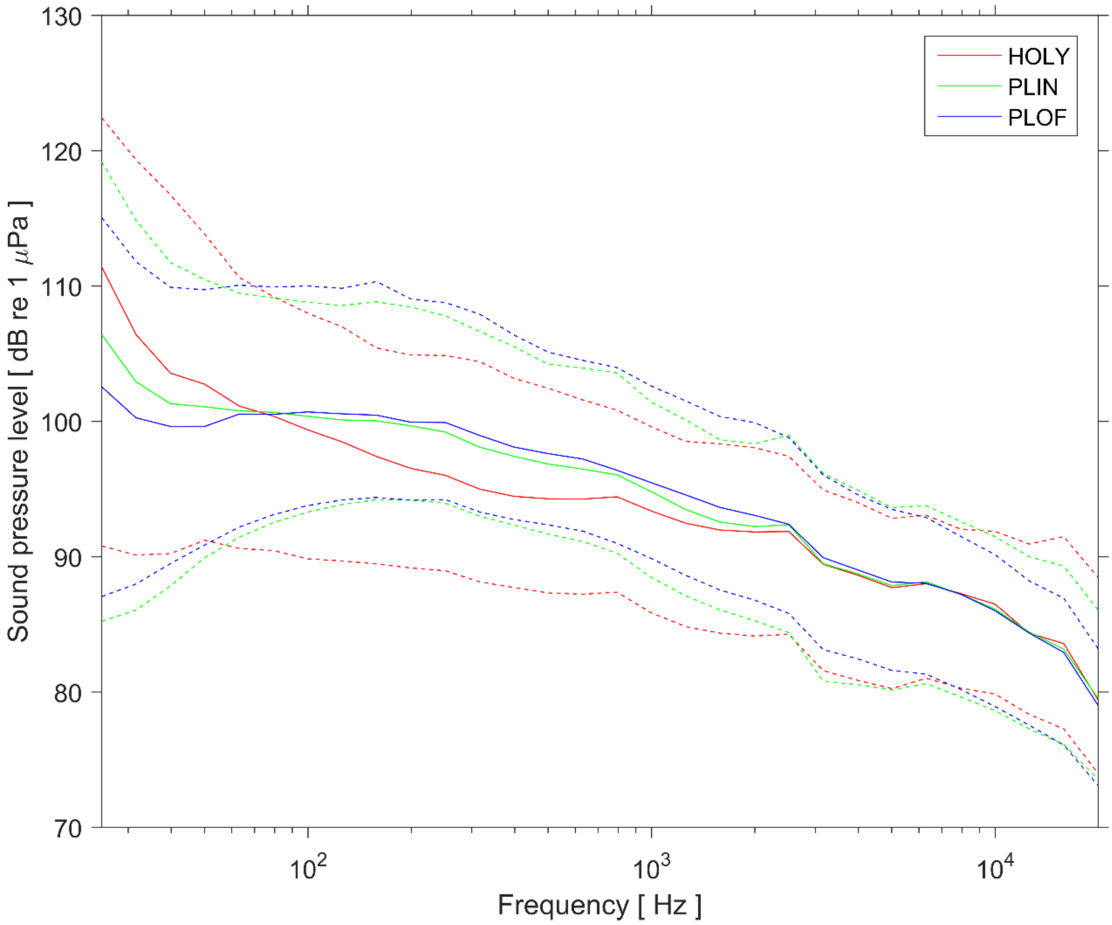

Figure 15 Median one-third octave levels at the three sites (solid lines) with 10th and 90th percentile levels (dashed lines). HOLY = Holyhead, PLIN = Point Lynas inshore; PLOF = Point Lynas offshore.

Another clear difference between sites is that the 10th percentile levels (lower dashed line) at Holyhead were markedly lower, indicating that background noise levels during quiet periods were lower than at the Point Lynas sites, suggesting there were fewer persistent sources of underwater noise, and/or that the location was more acoustically sheltered from distant sources.

4.1.4. Inter-year comparison

For August, September and October, data were successfully gathered in both 2023 and 2024 across all three sites, allowing for comparison of monthly median spectra between the two years (Figure 16). Differences were generally minimal, except for Holyhead in August, due to the exceptional extended event in August 2024, and Point Lynas offshore during October, due to an unusually quiet period in October 2023 (see sections 4.1.1 and 4.1.2).

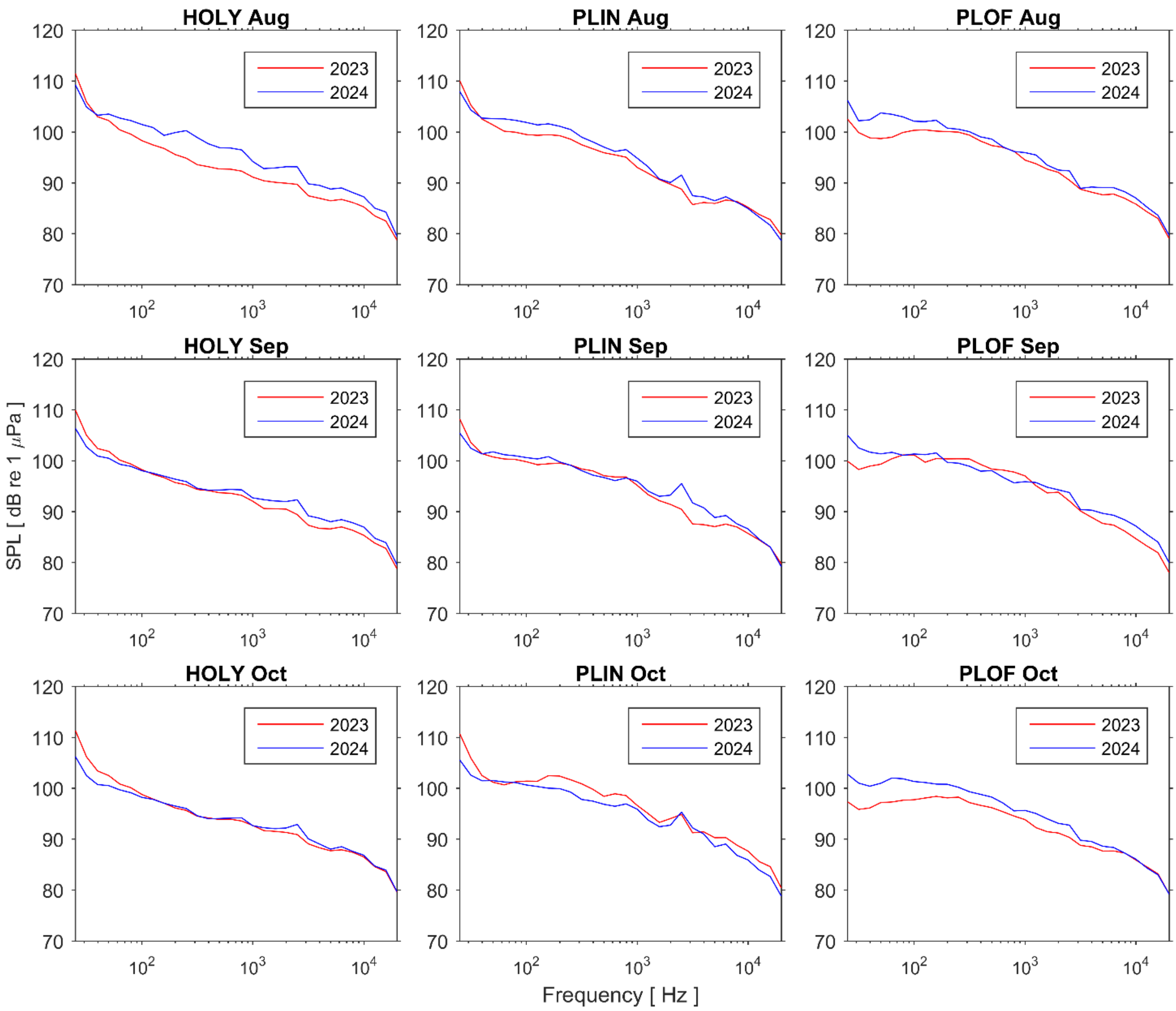

Figure 16 Inter-year comparisons of monthly median one-third octave band levels for all three sites during August, September and October.

4.1.5. Natural drivers of noise variability

The underlying variability of marine soundscapes is typically caused by natural factors such as wind-driven waves, precipitation, and various phenomena linked to tidal/lunar processes such as sediment transport, sound propagation (particularly in very shallow water), and some biological sounds (Staaterman et al., 2014).

To investigate the dependence of sound levels on wind, rain and tides at the sites, hourly median sound levels were matched with hourly data on wind speed, rainfall rate, and tidal current speed. Since the relationship between these parameters and sound levels may be non-linear, a ranked correlation (Spearman correlation) was used to explore the degree of association between the variables, similar to previous published studies (e.g. Merchant et al., 2014).

As expected, tidal current speed was positively correlated with low-frequency sound levels, particularly at the Holyhead site (Figure 17). Weaker correlations to tidal current were also present at high frequencies, likely linked to sediment transport.

Wind speed was positively correlated with sound levels across a wide band of frequencies, particularly above ~2 kHz (Figure 17). This is consistent with the literature, where wind-generated noise spectra have been extensively described (e.g. Vagle et al., 1990; Wenz, 1962). These previous studies have been undertaken in areas with few other sources of noise, or have excluded such noise from the analysis, and report significant wind noise at lower frequencies (500 Hz) than the correlations in the present study indicate. However, as shown in long-term spectra (Figure 13) and the statistical spectra (Figure 15), frequent ship passages were apparent in the approximate range 100 Hz – 2 kHz. The presence of this shipping noise would be expected to dilute the association between wind speed and sound level, and indeed a minima in the correlation coefficients were observed in this range at all three sites (Figure 17), particularly the two Point Lynas sites where shipping noise was more apparent.

Only weak correlations were observed for rainfall rate (Figure 17); however, this should be expected since rainfall is intermittent and sound levels at frequencies at which rain generates noise will usually be dominated by noise caused by other factors.

These associations between sound levels and wind, rain and current can also be observed in scatter density plots of each pair of variables (Figure 18). Analyses of this type could be used to generate empirical models of sound level based on wind and current speed at each site.

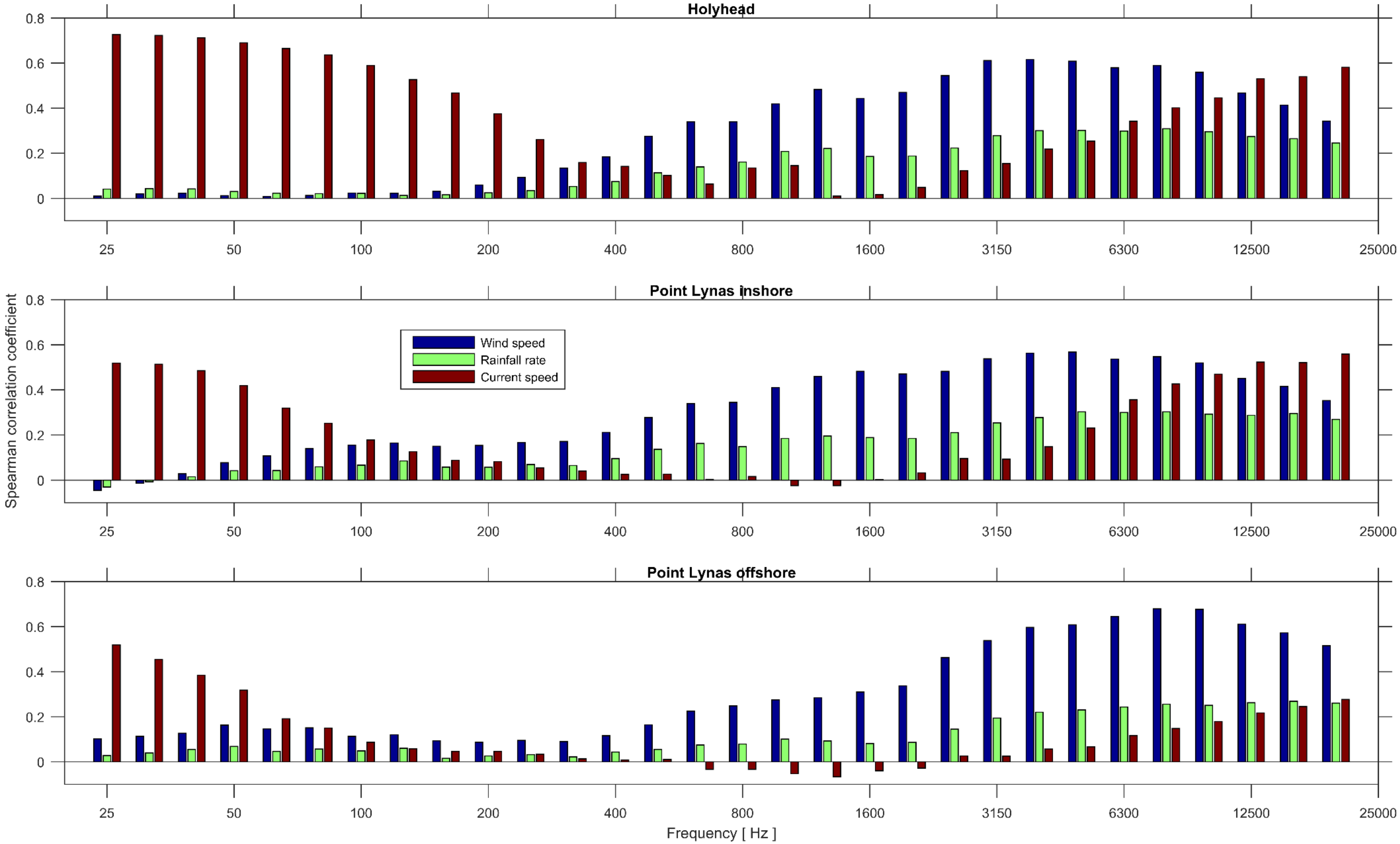

Figure 17 Spearman ranked correlation coefficient for each one-third-octave band sound level against wind speed, rainfall rate, and current speed, computed at one-hour resolution.

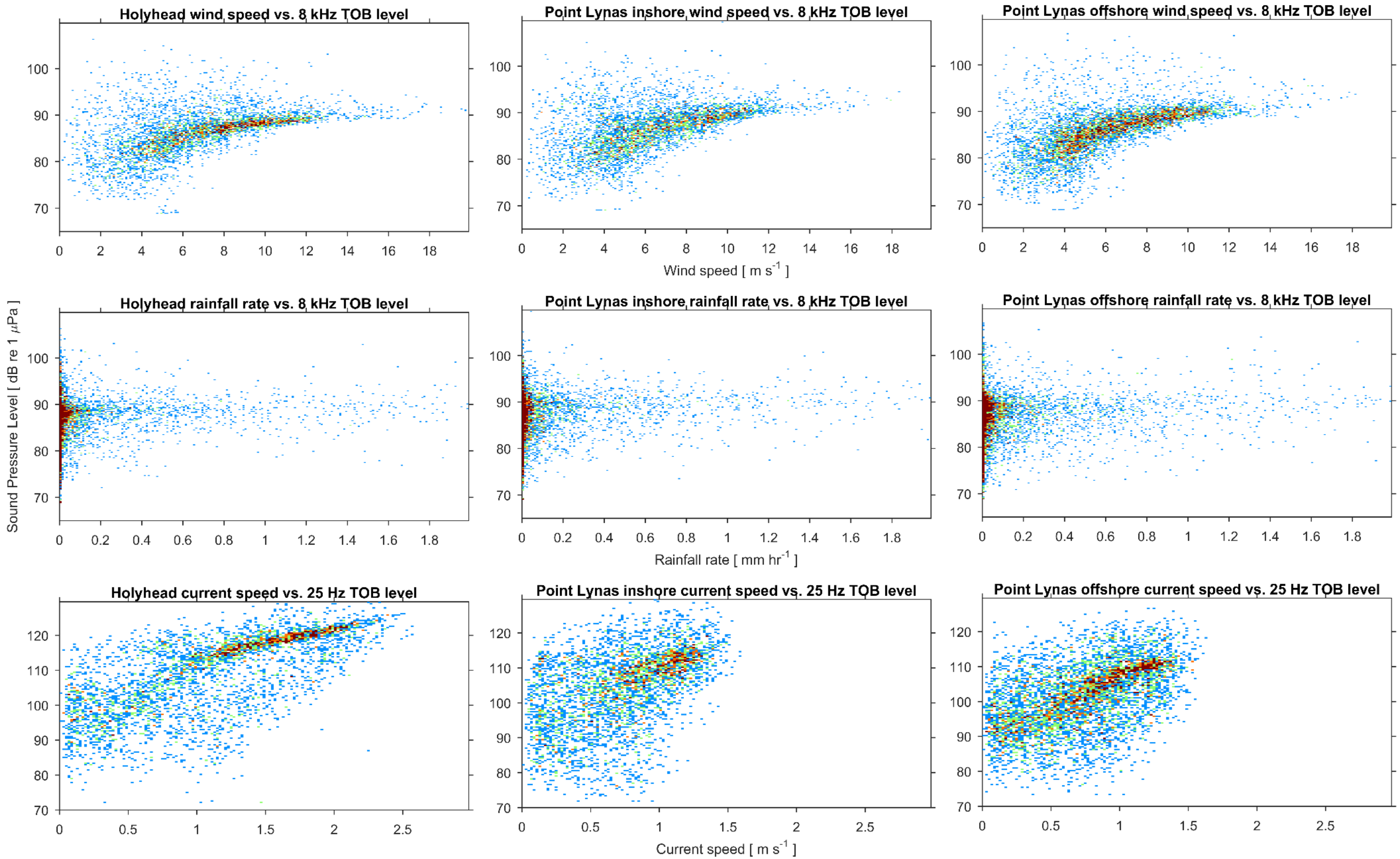

Figure 18 Dependence of sound level on wind speed, rainfall rate, and current speed at selected frequencies.

4.1.6. Human drivers of noise variability

While natural drivers account for much of the soundscape variability at the sites, significant levels of shipping noise were also observed in the long-term spectra (Figure 13). To characterise this source of anthropogenic noise in more detail, sample data were analysed at high temporal and spectral resolution (1-minute time window, 1-Hz frequency bin) during periods of high shipping activity. As discussed above, the Holyhead site had few clear instances of shipping noise evident in the long-term spectra, whereas both Point Lynas sites exhibited substantial levels of activity. This difference could be attributed to lower levels of shipping activity at Holyhead Deep or a more acoustically sheltered placement of the recorder. Examination of the bathymetry at the Holyhead Deep site (Figure 1) shows that Holyhead Deep is a hollow or trench in the seabed which may provide acoustic shelter from more distant sources. A recent AIS density map (Figure 19) also illustrates that despite its proximity to the main shipping route between Holyhead and Ireland, the Holyhead Deep location (see Figure 1) is south of this route in a region of relatively low vessel density, while the Point Lynas sites are in an area with considerable localised traffic. The Point Lynas sites are also in an area of much flatter bathymetry (Figure 1) which may expose them to more distant sources.

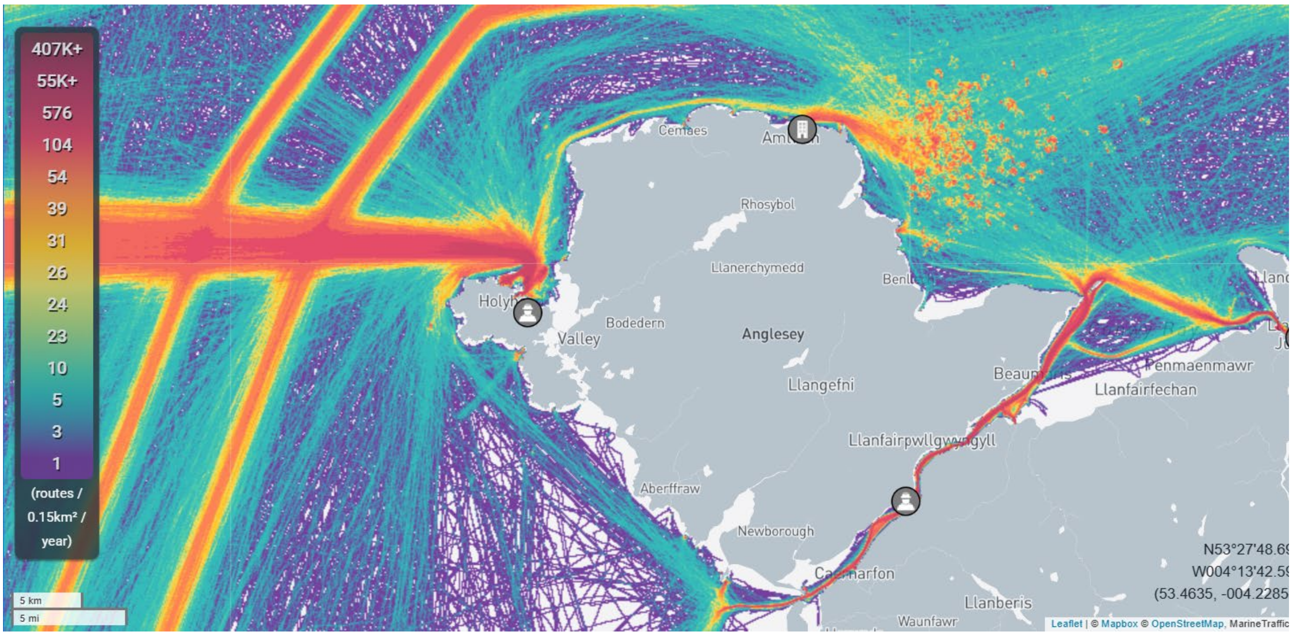

Figure 19. 2023 AIS vessel density in the waters around Anglesey as reported on MarineTraffic.com.

Figure 20 provides an example of a 24-hour period of particularly intense shipping activity at the Point Lynas offshore site on 15th July 2023. Several features are immediately apparent. The undulating horizontal striations between around 50 Hz and 2 kHz which continue throughout the period are the signature of one or more vessels in relatively close proximity to the hydrophone. A minimum 'valley' in this distinctive pattern indicates a closest point of approach between the moving vessel and the hydrophone. This spectral phenomenon is known as the Lloyd's mirror effect, and is caused by acoustic interference between the sound waves coming directly from the vessel and the sound waves from the vessel which have reflected against the sea surface and which add to or subtract from the direct path sound waves, depending on the frequency of sound and the proximity of the vessel (Trevorrow et al., 2008). Between around 10:00 and 22:00, it would appear that a single vessel remained in relatively close proximity to the hydrophone, perhaps at anchor. Further investigation drawing on ship tracking data (e.g. AIS data) could provide additional information about the vessel types present and their configuration relative to the recorder.

Other features are also apparent. At high frequencies, 25 kHz tone was observed (labelled A), most likely from an echosounder aboard the vessel passing at around 03:30. At low frequencies, the tidal periodicity of flow noise can clearly be seen, including the vertical lines characteristic of the knocking sound caused by self-noise discussed above (labelled B). A more typical vessel passage, characteristic of a ship passing through the area rather than lingering near the hydrophone, is highlighted just before 17:00 (labelled C).

This example illustrates how the soundscape between around 50 Hz and 2 kHz can be almost entirely dominated by shipping activity, with implications for species which use sound at these frequencies, for example minke whales, seals, and fish species. The presence of the echosounder signature also highlights that at close range, vessels emit sounds within the optimal hearing range of mid-frequency specialists such as dolphin species.

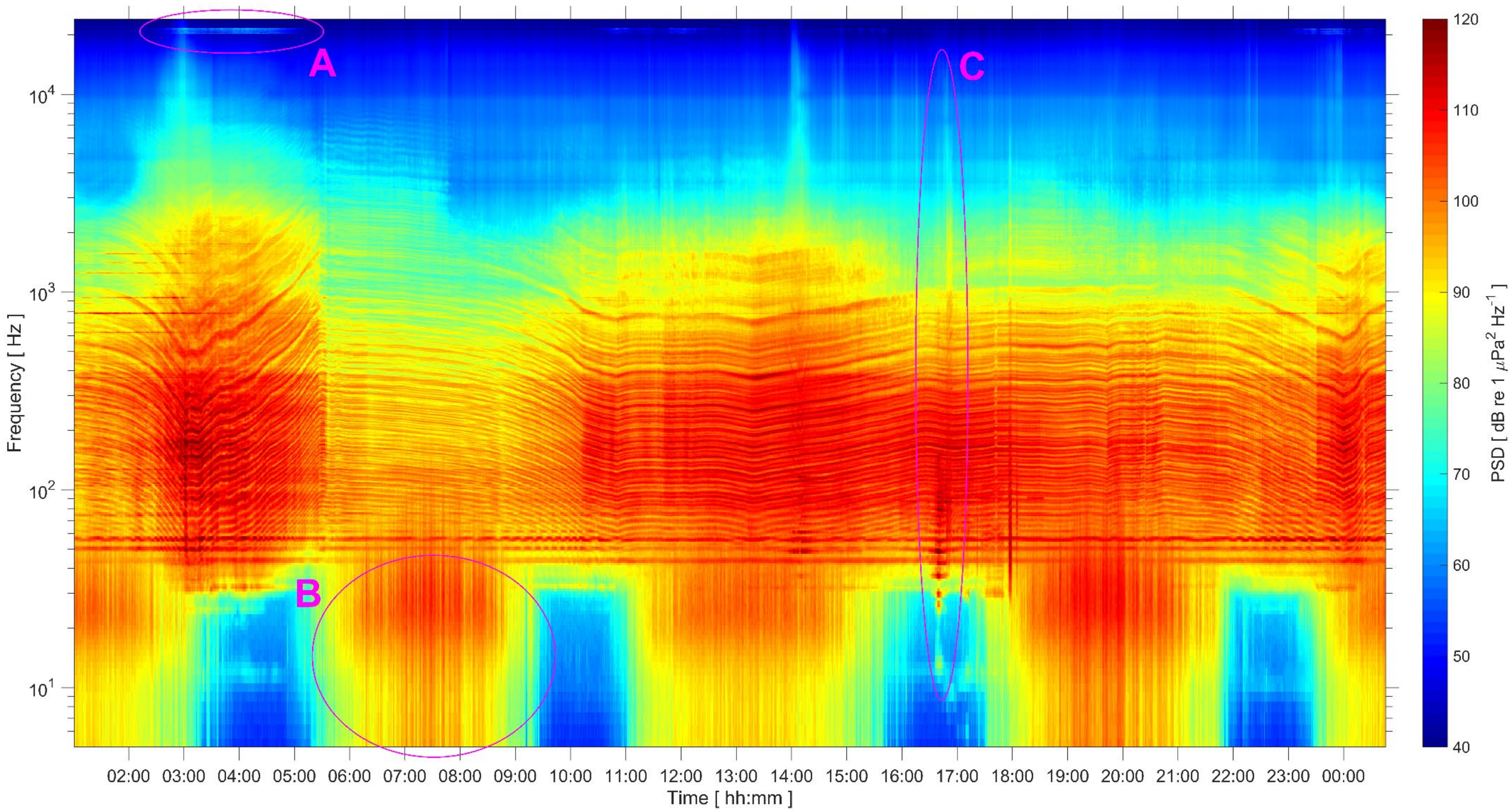

Figure 20. Power spectral density of shipping activity and tidal flow generated noise and self-noise recorded at the Point Lynas offshore site on 15 July 2023. The spectrogram is dominated by the persistent presence of one or more vessels throughout the 24-hr period. (A) 25 kHz echosounder signal from vessel with closest point of approach at ~03:30; (B) tidal flow noise and tidal flow induced self-noise (rattling of mooring); (C) passage of transiting vessel.

4.1.7. UK Marine Strategy monitoring

For the purposes of statutory monitoring of underwater noise under the UK Marine Strategy, passive acoustic data are usually analysed in one-third-octave bands and at a monthly temporal resolution. This analysis approach enables the high volumes of data gathered by sound recorders to be represented in a condensed format which captures seasonal variability as well as variability across the frequency range. As well as being a useful format for reporting UKMS sound levels, it is also convenient for ground truthing modelled maps of shipping noise, which are produced on the same temporal scale.

For completeness and for possible future reporting by NRW, monthly median sound levels across the frequency range are provided for all sites and complete months for which data were successfully gathered (Table 2; Table 3; Table 4). While a detailed comparison of the statistical distribution of sound levels with other monitoring programmes in the region is beyond the scope of the present report, these median TOB sound levels are within the range reported in the North Sea (Basan et al., 2024). Further analysis might reveal differences, for example, in the proportion of time that noise levels are high due to vessel passages, or the proportion of time that noise levels are comparatively low and so may be more favourable in terms of levels of cetacean disturbance.

Table 2. Monthly median one-third-octave band (TOB) sound levels at Holyhead site. All sound levels are expressed in units of dB re 1 µPa.

TOB centre frequency [kHz]	Jun 2023	Jul 2023	Aug 2023	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mar 2024	Apr 2024	May 2024	Jun 2024	Jul 2024	Aug 2024	Sep 2024	Oct 2024
0.025	113.5	113.0	111.5	109.9	111.3	112.9	113.4	113.7	113.8	113.3	-	-	-	-	109.2	106.3	106.2
0.031	108.1	107.4	105.9	105.0	106.2	108.6	109.3	109.8	109.8	109.0	-	-	-	-	104.9	102.7	102.5
0.039	104.5	103.8	103.0	102.4	103.4	105.1	105.7	106.0	106.1	105.5	-	-	-	-	103.3	100.9	100.7
0.050	103.4	102.8	102.2	101.8	102.5	103.6	104.0	104.1	104.7	104.0	-	-	-	-	103.5	100.5	100.5
0.063	101.3	101.0	100.4	100.1	100.8	101.8	102.1	102.0	102.7	102.0	-	-	-	-	102.7	99.3	99.7
0.079	100.3	100.1	99.6	99.3	100.1	101.0	101.1	101.1	102.0	101.4	-	-	-	-	102.2	98.9	99.1
0.100	98.6	98.5	98.3	98.2	98.8	100.1	100.2	100.4	101.3	101.0	-	-	-	-	101.5	98.0	98.2
0.125	97.4	97.4	97.5	97.3	97.9	99.2	99.2	99.4	100.2	99.8	-	-	-	-	100.9	97.5	97.8
0.158	96.1	96.2	96.8	96.7	97.0	97.8	97.9	98.2	98.7	98.4	-	-	-	-	99.3	97.0	97.0
0.199	95.0	95.0	95.6	95.7	96.1	96.8	97.0	97.2	97.5	97.3	-	-	-	-	99.9	96.4	96.5
0.251	94.1	94.4	94.8	95.3	95.6	96.1	96.6	96.8	96.8	96.7	-	-	-	-	100.3	95.9	96.0
0.316	92.8	93.3	93.6	94.3	94.5	95.3	95.8	96.1	95.9	95.8	-	-	-	-	98.9	94.6	94.6
0.398	91.9	92.9	93.2	94.1	94.2	94.7	95.3	95.4	95.1	95.4	-	-	-	-	97.7	94.2	94.0
0.501	91.3	92.6	92.7	93.7	93.9	94.5	95.4	95.3	95.0	95.3	-	-	-	-	96.9	94.2	94.0
0.630	91.3	92.6	92.7	93.6	93.9	94.6	95.6	95.2	94.9	95.1	-	-	-	-	96.8	94.3	94.1
0.794	91.0	92.0	92.3	93.2	93.6	94.8	95.9	96.0	96.0	96.0	-	-	-	-	96.5	94.3	94.2
1.000	89.3	90.4	91.1	92.0	92.7	93.9	95.4	95.9	95.9	96.1	-	-	-	-	94.2	92.7	92.6
1.258	89.3	90.4	90.4	90.6	91.7	93.5	94.7	94.2	93.7	94.2	-	-	-	-	92.8	92.3	92.2
1.584	88.7	89.9	90.1	90.5	91.5	92.6	93.8	93.4	92.8	93.2	-	-	-	-	92.9	92.1	92.1
1.995	88.0	89.3	89.9	90.5	91.3	92.4	93.9	93.4	92.8	93.0	-	-	-	-	93.2	92.0	92.2
2.511	87.9	89.3	89.7	89.4	90.9	92.6	94.3	93.8	93.1	93.3	-	-	-	-	93.2	92.3	92.9
3.162	84.7	86.2	87.5	87.3	89.1	90.1	92.2	92.0	91.7	92.1	-	-	-	-	89.8	89.2	90.1
3.981	83.9	86.1	87.0	86.7	88.3	89.5	91.2	90.7	90.2	90.7	-	-	-	-	89.5	88.7	89.0
5.011	83.2	85.7	86.5	86.6	87.7	88.5	89.8	89.1	88.7	89.2	-	-	-	-	88.8	88.0	88.0
6.309	83.7	86.1	86.8	87.0	87.9	88.7	89.6	89.3	88.8	89.6	-	-	-	-	89.0	88.4	88.5
7.943	83.5	85.7	86.1	86.3	87.4	88.1	88.7	88.3	87.8	88.3	-	-	-	-	88.1	87.8	87.6
10.000	83.0	84.7	85.2	85.3	86.5	87.4	87.9	87.5	87.2	87.9	-	-	-	-	87.3	87.0	86.8
12.589	81.6	82.9	83.5	83.8	84.6	85.0	85.1	84.8	84.7	85.4	-	-	-	-	85.0	84.8	84.7
15.848	80.9	82.1	82.5	82.8	83.6	84.3	84.5	84.3	84.4	85.0	-	-	-	-	84.2	83.9	83.9
19.952	77.5	78.3	78.7	78.7	79.6	79.9	80.1	80.0	80.2	80.8	-	-	-	-	79.4	79.6	79.7

Table 3. Monthly median one-third-octave band (TOB) sound levels at Point Lynas inshore site. All sound levels are expressed in units of dB re 1 μPa.

TOB centre frequency [kHz]	Jun 2023	Jul 2023	Aug 2023	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mar 2024	Apr 2024	May 2024	Jun 2024	Jul 2024	Aug 2024	Sep 2024	Oct 2024
0.025	112.9	109.4	110.1	108.2	110.7	107.0	106.2	104.8	101.3	96.6	-	-	-	-	108.0	105.4	105.5
0.031	107.3	105.4	105.3	103.5	105.9	103.7	103.0	102.1	98.7	94.8	-	-	-	-	104.3	102.4	102.5
0.039	104.0	102.7	102.5	101.4	102.5	102.3	101.7	100.8	98.1	95.0	-	-	-	-	102.7	101.3	101.5
0.050	102.6	101.9	101.4	100.7	101.2	102.1	101.7	100.7	98.6	96.7	-	-	-	-	102.6	101.7	101.5
0.063	102.3	101.1	100.2	100.3	100.7	102.6	101.5	100.0	98.9	97.6	-	-	-	-	102.6	101.2	101.2
0.079	101.2	100.9	100.0	100.2	101.2	101.8	101.4	100.2	99.2	98.4	-	-	-	-	102.3	101.0	101.1
0.100	100.5	100.6	99.5	99.8	101.4	101.6	101.2	100.0	99.2	98.7	-	-	-	-	101.9	100.6	100.6
0.125	99.8	100.2	99.3	99.2	101.4	101.1	101.4	99.7	99.1	99.0	-	-	-	-	101.4	100.3	100.3
0.158	99.5	100.0	99.5	99.4	102.5	100.5	100.3	99.7	100.1	98.7	-	-	-	-	101.6	100.8	100.0
0.199	99.5	99.6	99.3	99.5	102.4	99.9	99.8	99.3	98.9	98.7	-	-	-	-	101.1	99.8	99.9
0.251	99.0	99.1	98.6	99.1	101.7	99.7	99.8	98.9	98.9	98.5	-	-	-	-	100.5	99.1	99.2
0.316	97.8	97.5	97.5	98.4	100.9	98.9	98.5	98.1	98.4	97.5	-	-	-	-	99.0	98.0	97.8
0.398	96.7	96.5	96.7	98.0	99.8	98.3	98.2	97.6	97.5	97.1	-	-	-	-	98.0	97.2	97.5
0.501	95.5	95.5	95.9	97.0	98.4	97.8	98.0	97.5	97.6	96.8	-	-	-	-	97.0	96.7	96.8
0.630	95.0	94.9	95.5	96.8	98.9	97.7	98.0	97.3	97.0	96.7	-	-	-	-	96.2	96.1	96.4
0.794	94.2	93.9	95.0	96.8	98.5	97.0	97.3	96.6	96.0	95.5	-	-	-	-	96.5	96.6	96.9
1.000	92.1	91.4	93.0	95.2	96.6	96.0	96.4	95.9	95.5	95.0	-	-	-	-	94.9	96.0	95.9
1.258	91.2	90.7	91.9	93.3	95.0	94.7	95.5	94.8	94.6	94.4	-	-	-	-	93.1	94.0	93.7
1.584	90.9	89.5	90.7	92.1	93.3	93.8	94.8	94.3	94.3	93.9	-	-	-	-	90.8	93.0	92.4
1.995	90.1	88.3	89.7	91.4	94.0	93.5	94.4	93.9	93.8	93.6	-	-	-	-	90.1	93.2	92.7
2.511	87.7	87.2	88.8	90.4	94.8	93.8	94.4	93.9	93.8	93.5	-	-	-	-	91.5	95.5	95.3
3.162	83.5	83.8	85.7	87.6	91.2	91.3	92.5	92.1	92.1	91.7	-	-	-	-	87.5	91.7	92.2
3.981	82.8	84.4	86.2	87.4	91.4	90.5	91.2	90.5	90.4	89.9	-	-	-	-	87.2	90.7	91.0
5.011	82.2	84.3	85.9	87.0	90.3	89.8	90.5	89.9	89.9	89.4	-	-	-	-	86.5	88.8	88.5
6.309	83.1	85.5	86.6	87.5	90.3	89.9	90.4	89.7	89.6	89.2	-	-	-	-	87.3	89.2	89.0
7.943	83.1	85.4	86.4	87.0	88.8	89.1	89.6	89.0	88.9	88.3	-	-	-	-	86.2	87.6	86.8
10.000	82.9	84.9	85.2	85.7	87.6	87.8	88.3	87.6	87.6	86.8	-	-	-	-	84.9	86.6	85.9
12.589	81.6	83.5	83.8	84.4	85.6	86.0	86.3	85.6	85.8	85.2	-	-	-	-	83.2	84.6	83.9
15.848	80.4	82.5	82.7	83.0	84.6	84.7	85.2	84.2	84.7	83.9	-	-	-	-	81.6	83.0	82.7
19.952	77.1	78.7	79.7	79.7	80.4	80.9	81.2	80.3	80.9	80.3	-	-	-	-	78.6	79.2	78.8

Table 4. Monthly median one-third-octave band (TOB) sound levels at Point Lynas offshore site. All sound levels are expressed in units of dB re 1 µPa.

TOB centre frequency [kHz]	Jun 2023	Jul 2023	Aug 2023	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mar 2024	Apr 2024	May 2024	Jun 2024	Jul 2024	Aug 2024	Sep 2024	Oct 2024
0.025	103.3	103.2	102.5	99.9	97.3	103.3	104.3	104.6	102.7	100.5	102.3	101.2	102.5	100.2	106.2	105.0	102.7
0.031	99.6	101.9	99.9	98.3	95.8	100.9	102.3	101.6	100.4	98.2	99.9	98.5	100.4	99.0	102.2	102.5	101.0
0.039	99.3	101.0	98.9	98.9	96.1	99.9	101.6	100.1	99.5	97.6	98.6	98.5	100.8	100.9	102.4	101.7	100.4
0.050	98.8	101.0	98.7	99.3	97.2	99.2	100.9	100.6	99.3	97.9	99.2	98.7	99.4	99.9	103.7	101.3	101.0
0.063	101.1	101.1	99.0	100.4	97.3	101.4	102.2	100.0	99.8	99.1	99.9	99.9	101.3	101.8	103.5	101.6	102.0
0.079	100.2	101.6	99.9	101.1	97.6	100.1	102.1	100.2	100.1	99.7	100.2	99.9	100.3	100.9	103.0	101.1	101.9
0.100	100.6	102.4	100.3	101.1	97.7	100.7	102.4	99.8	100.1	99.7	100.5	100.6	101.6	102.0	102.1	101.3	101.3
0.125	100.3	102.1	100.4	99.7	98.1	100.1	104.1	99.4	99.9	100.0	100.8	100.5	100.0	101.9	102.0	101.2	101.1
0.158	100.6	101.8	100.2	100.4	98.4	100.0	101.2	99.6	99.7	99.1	99.8	100.2	100.1	100.9	102.3	101.5	100.8
0.199	100.7	101.4	100.1	100.3	98.1	99.3	100.6	98.8	99.0	99.1	99.4	99.4	100.2	100.9	100.8	99.7	100.8
0.251	100.9	101.5	100.0	100.4	98.2	99.9	101.1	98.6	99.1	98.8	99.1	99.1	99.0	100.5	100.5	99.5	100.2
0.316	99.9	99.6	99.4	100.3	97.2	99.2	99.3	97.9	98.6	97.5	97.9	98.0	99.8	100.8	100.1	98.9	99.3
0.398	98.8	98.5	98.2	99.3	96.6	98.3	98.8	97.0	97.6	97.2	97.6	97.5	99.2	100.3	99.0	97.9	98.8
0.501	97.8	97.7	97.3	98.3	96.2	97.6	98.6	96.8	97.5	96.9	97.3	96.6	98.9	99.5	98.6	98.0	98.2
0.630	97.5	97.4	97.0	98.2	95.4	97.6	98.7	96.9	97.5	97.1	96.5	95.5	98.5	98.6	97.1	96.7	97.1
0.794	97.0	96.2	96.2	97.8	94.5	97.3	98.1	96.2	96.9	96.2	95.5	94.1	97.4	98.0	96.2	95.6	95.5
1.000	94.9	93.7	94.5	97.0	93.8	96.4	97.2	95.7	96.3	95.0	94.9	93.2	97.8	98.8	95.9	95.9	95.6
1.258	94.1	93.6	93.7	95.1	92.2	94.9	96.3	94.4	95.3	94.3	94.1	92.3	97.5	98.2	95.5	95.7	95.0
1.584	94.0	92.8	92.7	93.7	91.4	93.7	95.2	93.4	94.3	93.4	93.4	91.6	95.5	95.3	93.5	94.8	94.0
1.995	93.2	91.5	92.1	93.8	91.2	93.3	94.5	93.0	94.0	93.4	92.9	90.4	93.4	92.4	92.5	94.3	93.1
2.511	90.8	90.3	90.5	92.1	90.3	93.3	94.6	93.0	93.9	93.3	92.3	89.1	91.3	88.7	92.4	93.7	92.7
3.162	86.8	87.8	88.8	90.1	88.8	90.7	92.4	91.5	92.4	91.6	90.4	86.7	88.6	86.1	88.9	90.4	89.8
3.981	85.7	87.3	88.2	88.9	88.5	89.8	90.9	89.8	90.6	89.9	88.3	84.6	86.3	84.8	89.2	90.3	89.5
5.011	85.0	86.9	87.7	87.7	87.7	88.7	89.7	88.5	89.2	88.8	87.6	83.7	85.4	84.6	89.1	89.6	88.6
6.309	84.9	87.3	87.8	87.3	87.7	88.7	89.5	88.4	89.0	88.6	87.2	83.0	84.8	83.5	89.0	89.3	88.3
7.943	84.5	86.9	87.0	86.1	87.3	87.9	88.6	87.6	88.0	87.7	86.2	81.9	84.2	82.9	88.3	88.4	87.2
10.000	83.6	85.9	85.8	84.7	85.9	86.5	87.2	86.4	86.6	86.5	85.0	80.5	82.9	81.6	87.0	87.2	86.1
12.589	82.3	84.5	84.3	83.2	84.5	84.7	85.2	84.4	84.8	84.6	83.2	79.1	81.6	80.3	85.2	85.5	84.3
15.848	81.0	83.1	82.9	81.9	83.2	82.8	83.6	83.0	83.6	83.3	82.0	78.0	80.3	79.0	83.6	84.0	83.0
19.952	77.6	79.5	79.0	78.0	79.2	79.2	79.4	78.9	79.3	79.1	77.9	74.8	76.6	75.7	79.7	80.0	79.2

4.2. Marine mammal detections

4.2.1. Cetacean click classification

Click classifier detections were compared with manually verified data from the first deployment at the three sites. The classifier did not miss any dolphin encounters within the screened 24h samples; not all click trains were detected but all encounters were recorded within a few minutes of the manually verified data. This suggests that the classifier is unlikely to miss entire dolphin encounters (true negatives), and later verification steps focussed only on clarifying dolphin events recorded by the classifier.

While visually screening data from deployment 1, it was clear that the classifier regularly misidentified noise as dolphin clicks at all three sites. However, after concatenating into dolphin positive hours, there were no hours where a manually labelled event was not matched by a classifier dolphin click event. Therefore, the classifier was utilised to automate the remaining data. To avoid classifier false positives producing inaccurate click counts per hour that may skew later analyses, dolphin or porpoise positive hours were described as either present (1) or absent (0). The click classifier could not accurately distinguish between the two dolphin species categories, Risso's dolphin and bottlenose/common dolphin, with an error rate of approximately 50% when compared to data that was manually verified to dolphin species level by inspecting the distribution of click frequencies (broadband or banded) via spectrograms. Therefore, other than deployment 1, dolphins were not classified to species level. This will require further manual validation and/or work developing the click classifier in future work.

4.2.2. Cetacean events

4.2.2.1. Harbour porpoise

Harbour porpoise detections were recorded at high rates throughout the year and detected every recording day for the duration of the study (Figure 21). Porpoises were detected up to 100% of (all) hours per day at all three sites, particularly at HOLY where this occurred on 10 days. Porpoise encounter rates were similar between the sites, with 56-70% of recording hours containing porpoise detections (Table 5). Porpoise detection was generally highest in the first months of the year (Jan-Mar) and gradually declined. At HOLY porpoise presence was lowest in spring (Figure 22). Diel patterns of porpoise detections were variable between sites, with peaks at dawn and dusk at the inshore Point Lynas site and to a lesser extent offshore of Point Lynas. Porpoise activity at HOLY was highest in the middle of the day, specifically in summer months (Figure 23; Figure 24). Moon phase seems to have little pattern on porpoise presence, apart from a potentially minor increase in porpoise detections in the new and full moon phases at PLIN (Figure 25). In months where deployments covered both years, seasonal encounter rates and patterns in occurrence were similar between years for PLIN but at PLOF, there were higher detection rates in 2023, that steadily increased throughout the year into autumn. At HOLY, patterns and detection rates were similar between years, except for October, where there were markedly higher detections in 2023 (Figure 21,Figure 26).

Table 5: Harbour porpoise encounter rates (percentage of Porpoise Positive Hours (PPH)) for each of the sites.

Station	Count PPH	Total recording hours	Percentage
HOLY	3260	5092	64.02
PLIN	3570	5079	70.29
PLOF	3646	6513	55.98

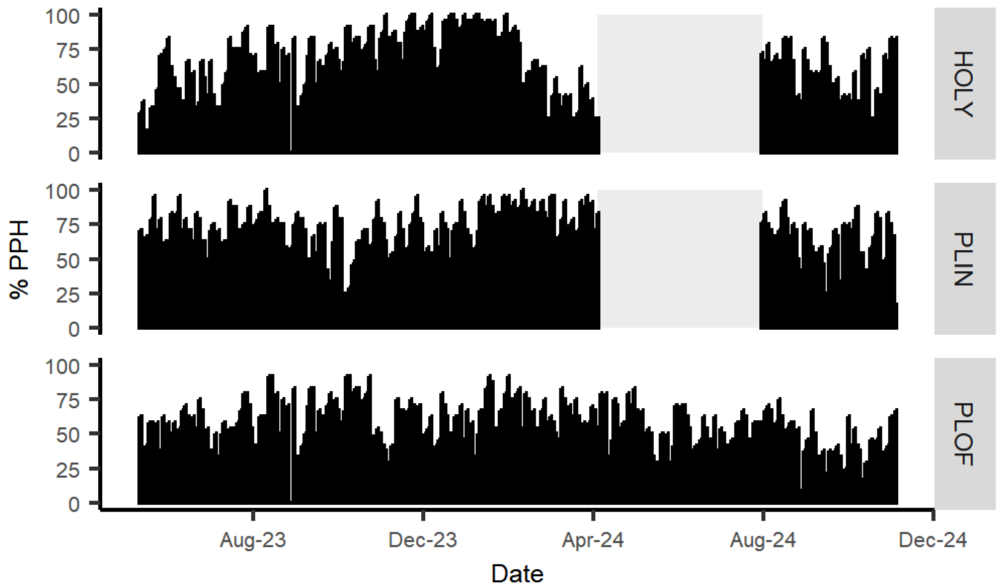

Figure 21. Percentage of porpoise positive hours (PPH) per day at each site. Grey shaded area shows periods of data loss due to instruments being unable to be recovered.

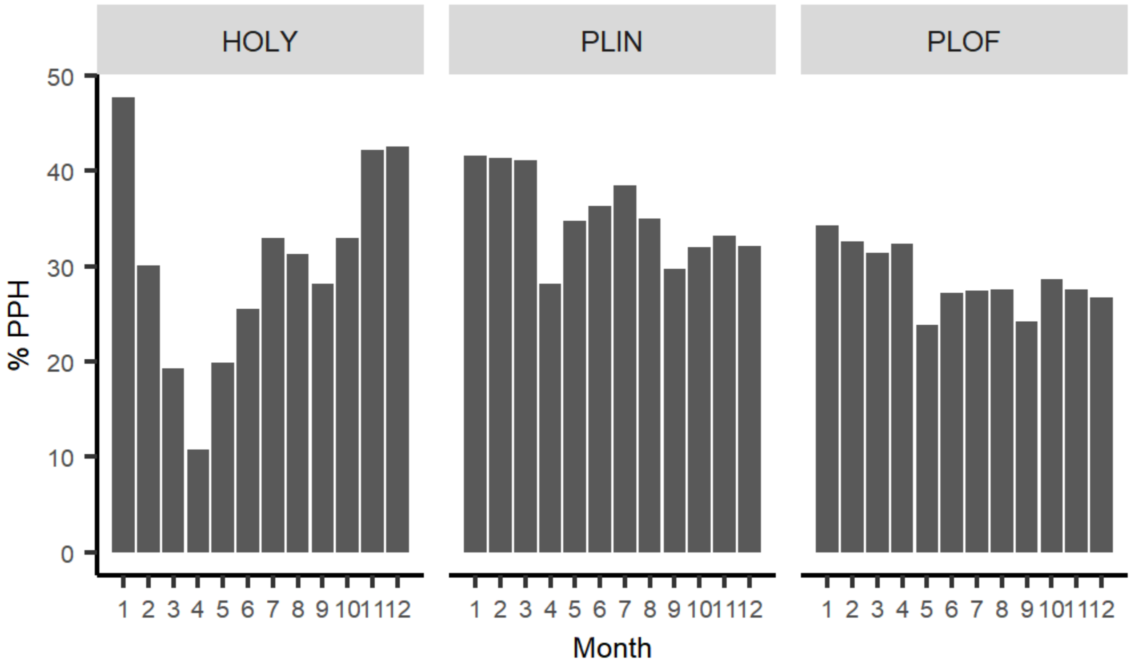

Figure 22. Percentage of porpoise positive hours (PPH) per month at each site.

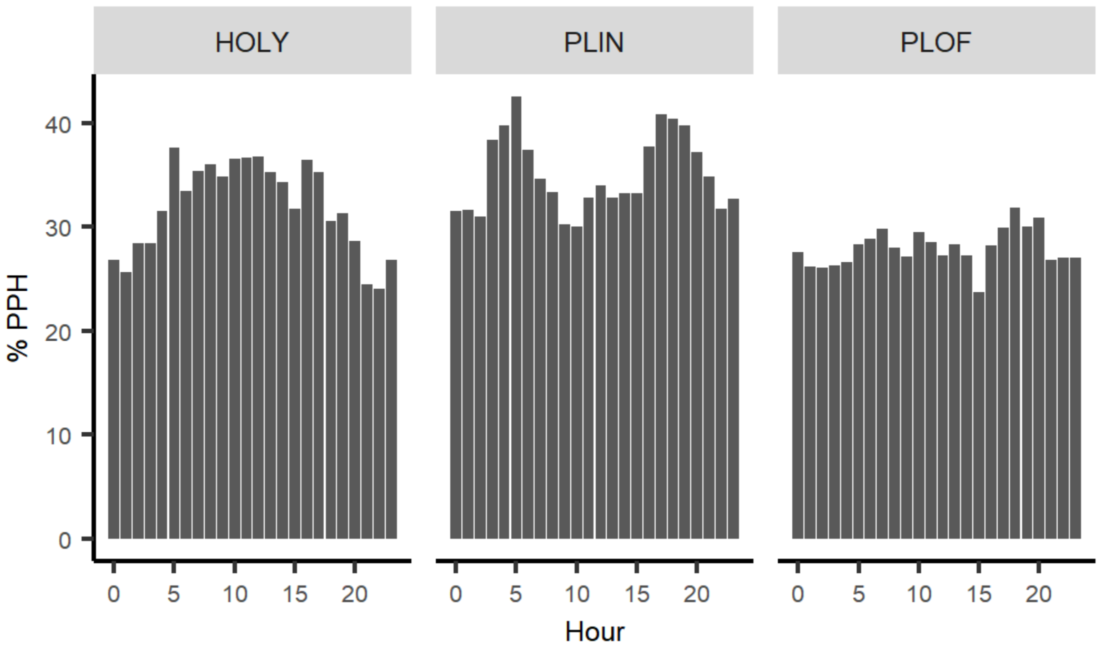

Figure 23. Percentage of porpoise positive hours (PPH) per hour of day.

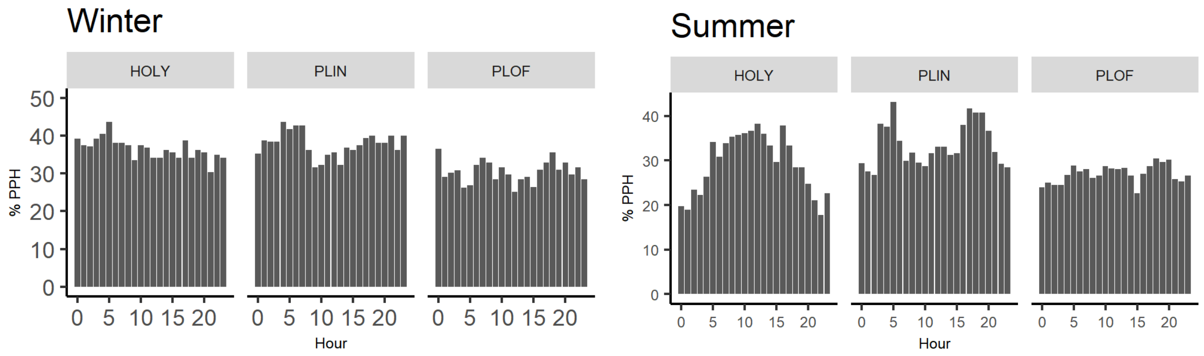

Figure 24. Percentage of porpoise positive hours per hour (PPH) in winter (Nov.-Mar.) and summer (Apr.-Oct.) months.

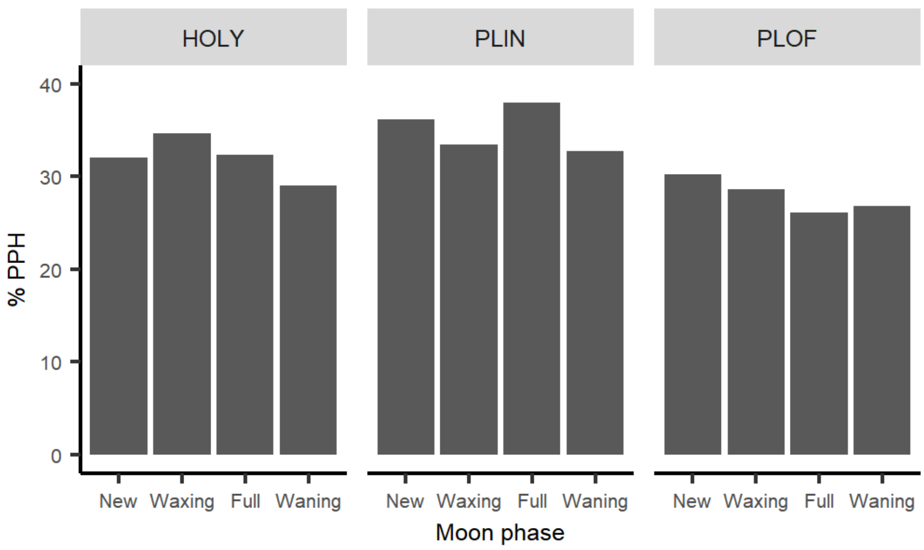

Figure 25. Percentage of porpoise positive hours (PPH) within new, waxing, full and waning moon phases.

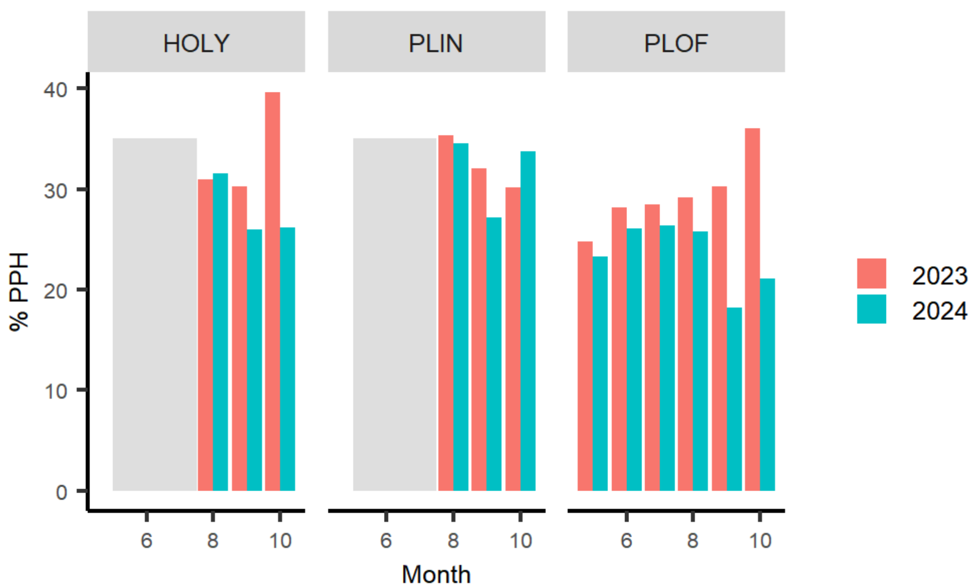

Figure 26. Percentage of porpoise positive hours (PPH) for months where data collection occurred in both years. Grey shading represents period of data loss in 2024.

4.2.2.2. Dolphins

Dolphin detections ranged from 18% DPH at PLOF and 33% at PLIN (Table 6, Figure 27). There were clear peaks in occurrence in late summer-autumn (August-November) and late winter (January-March) at HOLY and PLIN, with dolphin detections lowest in mid-summer. Seasonal distribution was similar at PLOF but at a smaller scale (Figure 28). These peaks may represent the seasonal arrivals of Risso's dolphins to the coastal Irish Sea in late summer and bottlenose dolphins in late winter (Evans & Waggitt, 2023). It was not possible to verify the species groups for the whole period at this stage, since the classifier produced high (~50%) error rates when distinguishing between Risso's and bottlenose/common dolphins. During deployment 1 (May-August 2023), clicks were visually verified in PAMGuard to species level where possible, Risso's dolphins were detected at all three sites, increasing in encounter rates towards the end of the deployment in August. Bottlenose/common dolphin clicks were detected at PLOF and were regular at HOLY from early July (Figure 29). This may represent either common dolphins, that are prevalent in deep waters in summer months, and/or bottlenose dolphins that have also been sighted at sea in this region (Evans & Waggitt, 2023). A sample of detections recorded at PLIN during deployment 3 were visually inspected to species group level and showed that both Risso's dolphins and bottlenose/common dolphins were detected in every month between January and March 2024 (Figure 30). Further inspection of click trains is required to confirm encounter rates of each species group but this initial investigation suggests that Risso's dolphins may be present in the region year-round, which has previously not been documented.

Table 6: Dolphin encounter rates at each site.

Station	Count DPH	Total recording hours	Percentage
HOLY	1327	5092	26.06
PLIN	1691	5079	33.29
PLOF	1154	6513	17.72

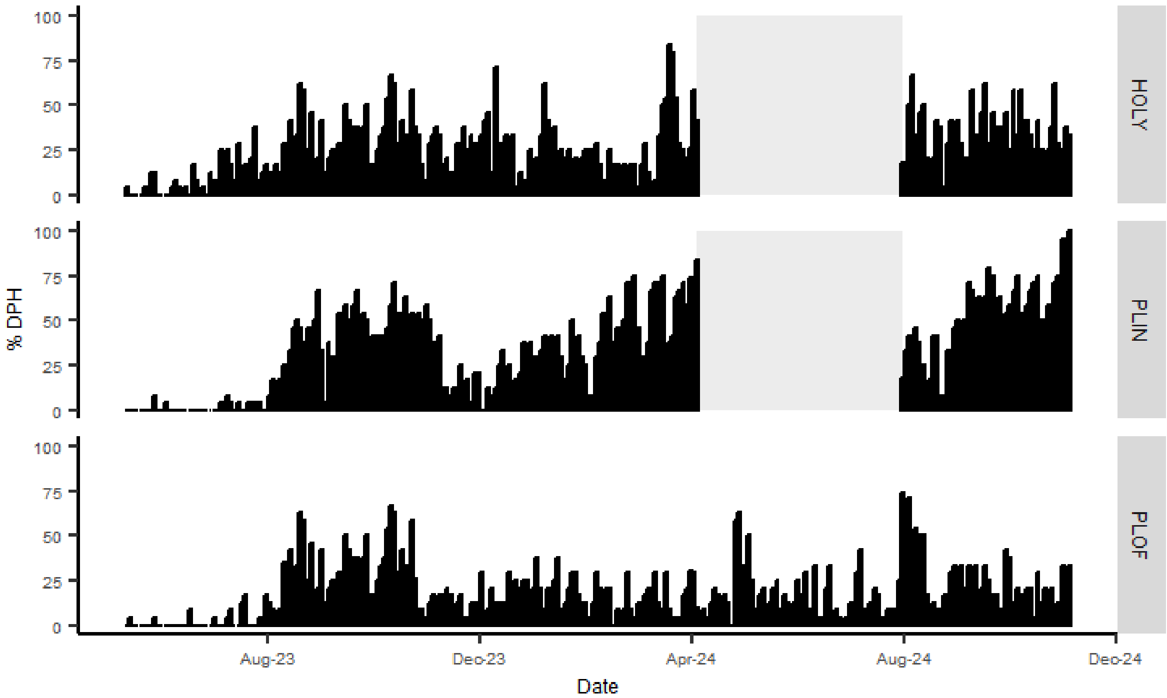

Figure 27. Percentage of dolphin positive hours (DPH) per deployment day.

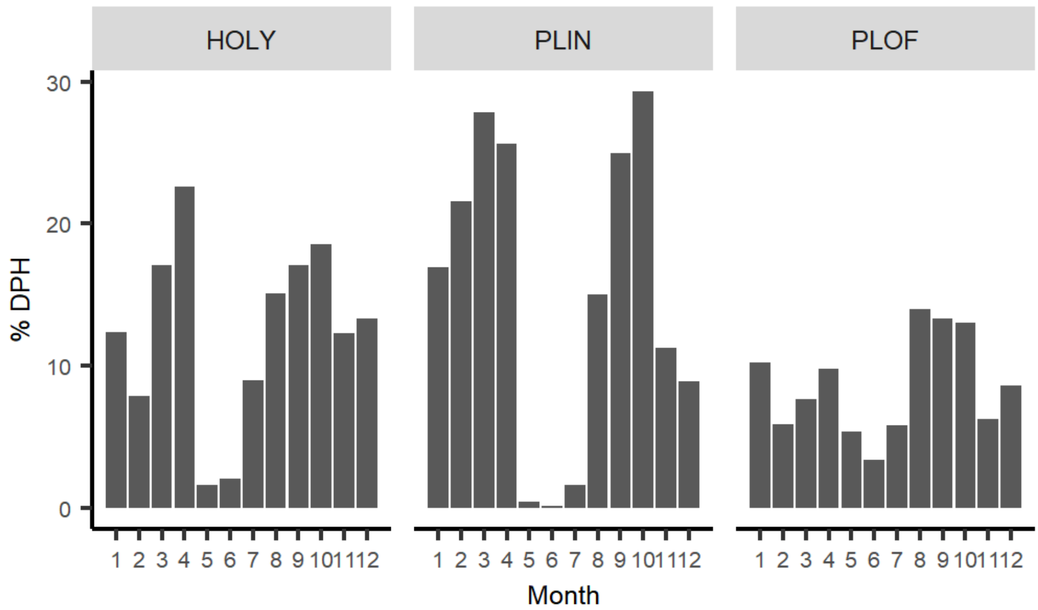

Figure 28. Percentage of dolphin positive hours (DPH) per month.

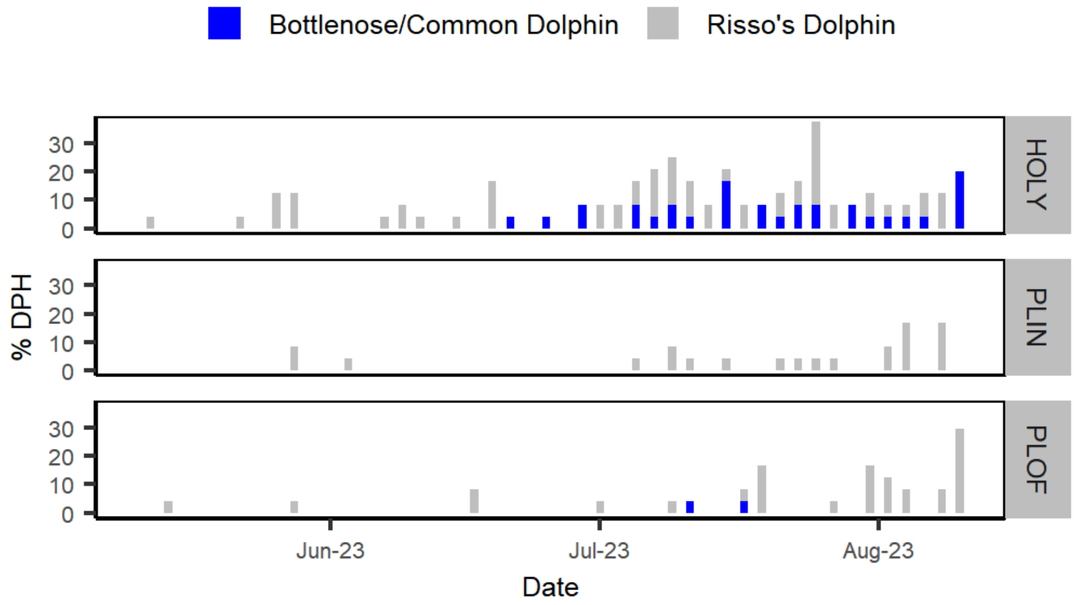

Figure 29. Percentage of dolphin positive hours manually verified to species level for deployment 1 (11 May-10 Aug. 2023).

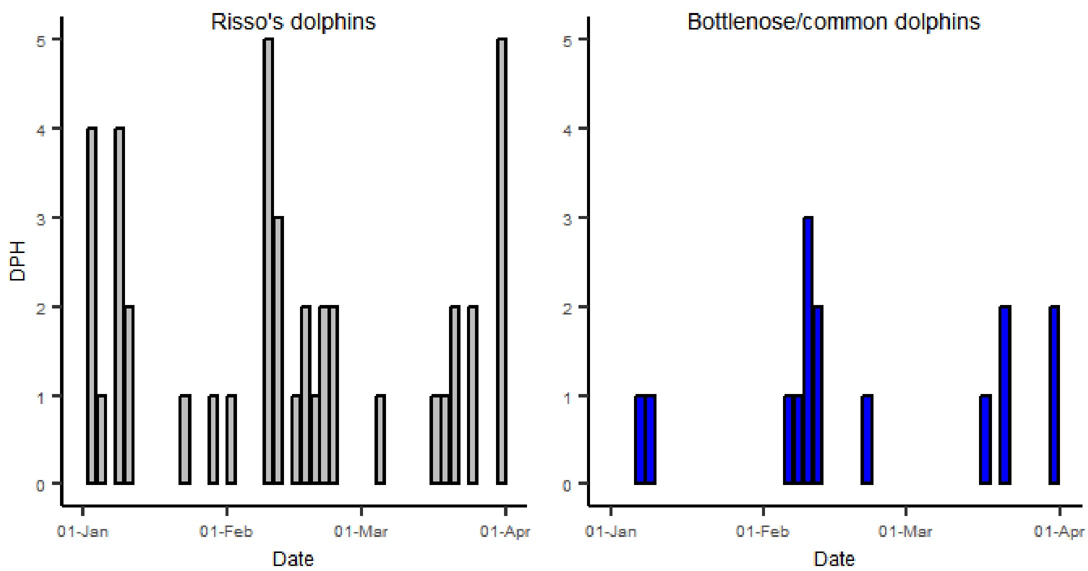

Figure 30. Preliminary sample of observations of dolphin positive hours between 1 Jan. – 31 Mar. 2024 at PLIN, manually verified to species level. Not all detections recorded were verified so is not a true count of detections but serves as an illustration that both species groups were recorded in each month.

At all sites, dolphins showed a clear diurnal pattern, with peak activity at night and fewer detections in daylight hours (Figure 31). In winter months, there was a smaller peak at both Point Lynas sites in the middle of the day (Figure 32).

A closer look at dolphin distribution in late summer months when Risso's dolphins are reported to increase around Anglesey, shows that dolphin presence peaked between August and October at all sites (Figure 33). Investigating diel patterns within these months only, which is likely to represent mainly Risso's dolphin detections, showed a peak in detections at night and was lowest in the morning hours (Figure 34). Dolphin distribution in the winter months appeared to peak between January and March (Figure 35). This may reflect the arrival of bottlenose dolphins that are reported to increase off the northeast coast of Anglesey and the North Wales coast in winter (Evans & Waggitt, 2023). Similarly, diel patterns in winter peaked during night hours (Figure 36).

Moon phase does not seem to be a prominent factor for dolphin occurrence (Figure 37). Detection rates and patterns were similar between years at HOLY and PLIN. At PLOF, dolphin occurrence increased later in 2023 compared to 2024.there were more detections earlier in the summer in 2024 and more detections later in 2023 (Figure 38).

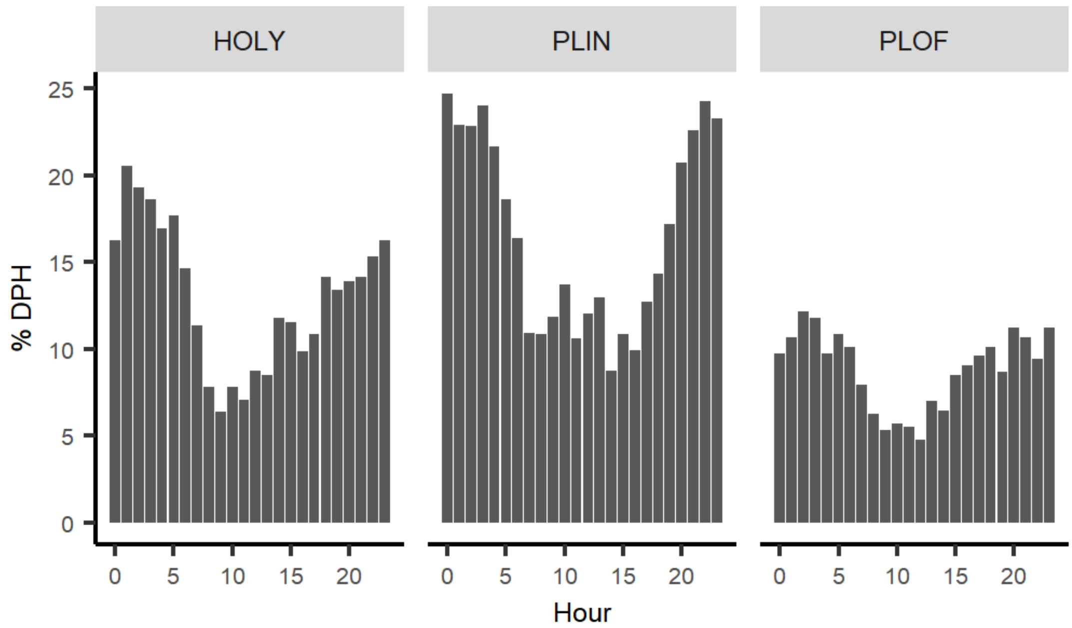

Figure 31. Percentage of dolphin positive hours (DPH) per hour of day.

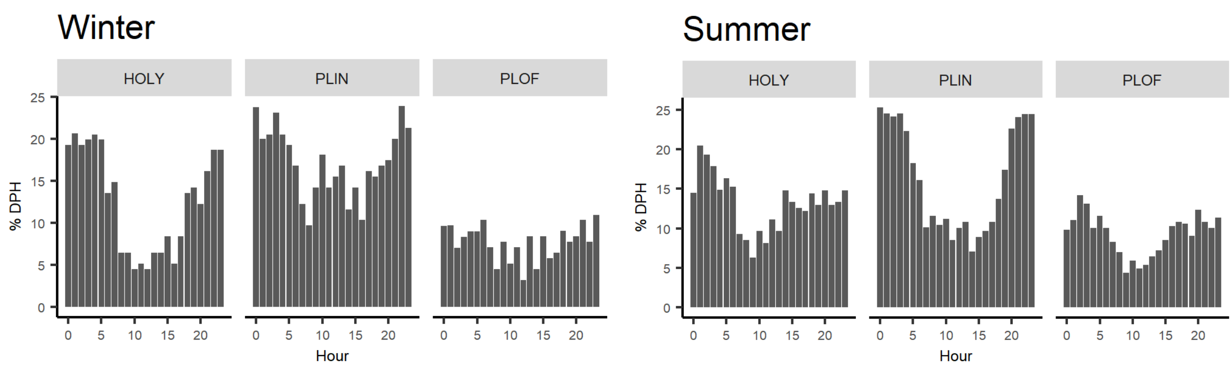

Figure 32. Percentage of dolphin positive hours (DPH) per hour in winter and summer months.

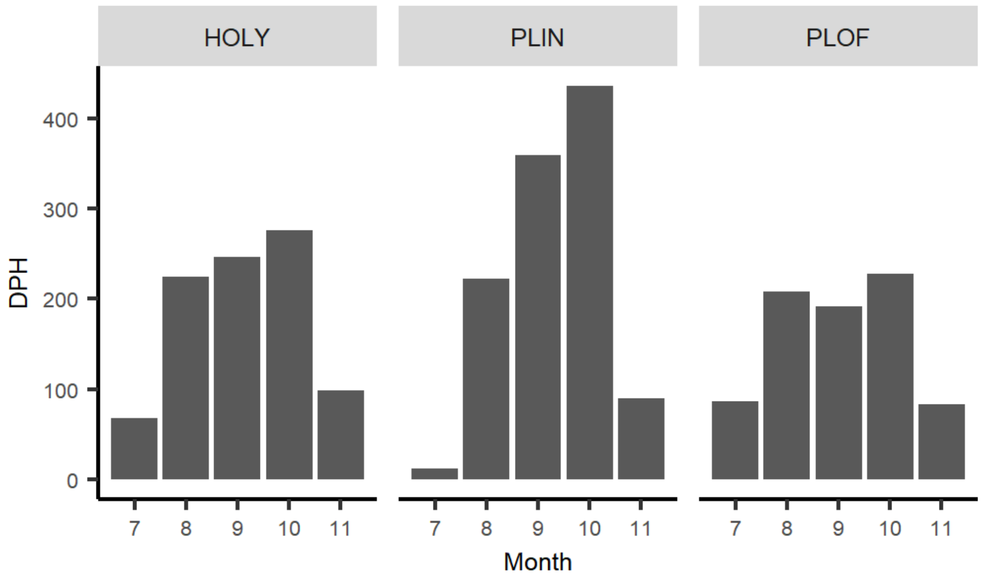

Figure 33. Counts of dolphin positive hours per month between July and November (peak Risso's dolphin season) around Anglesey.

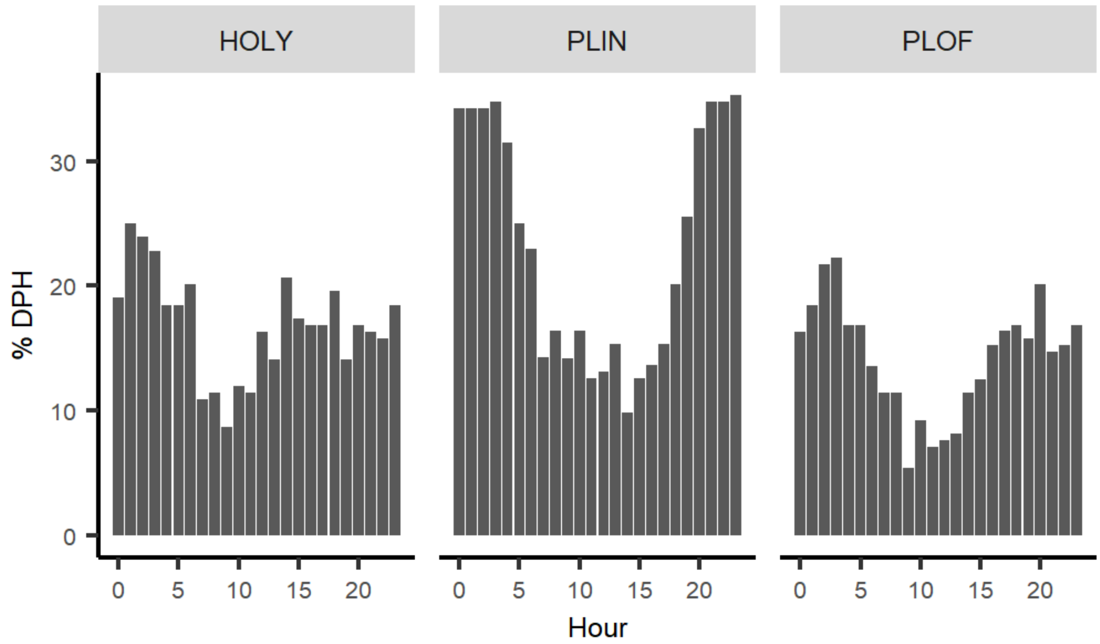

Figure 34. Percentage of dolphin positive hours per hour of day between August and October months.

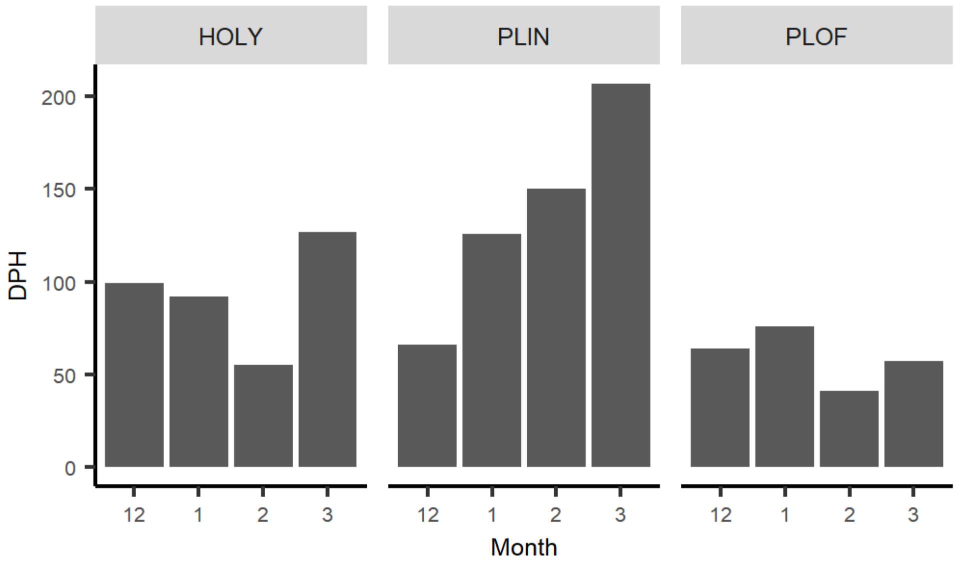

Figure 35. Counts of dolphin positive hours in Nov-May, showing a winter peak in dolphin presence between Jan and Mar at the inshore Point Lynas site

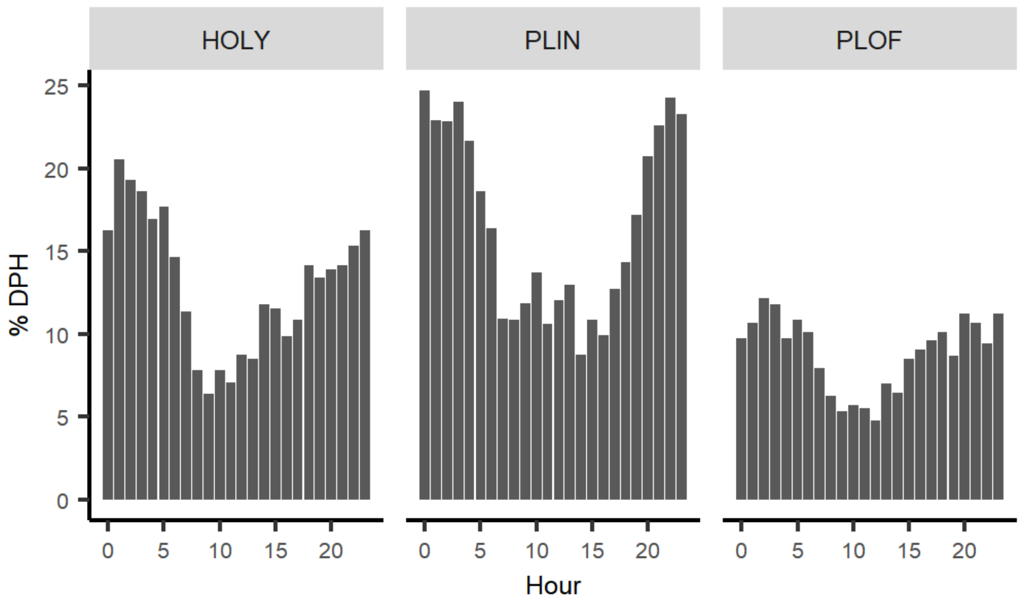

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Figure 36. Percentage of dolphin positive hours per hour of day between Jan. and Mar. 2024.

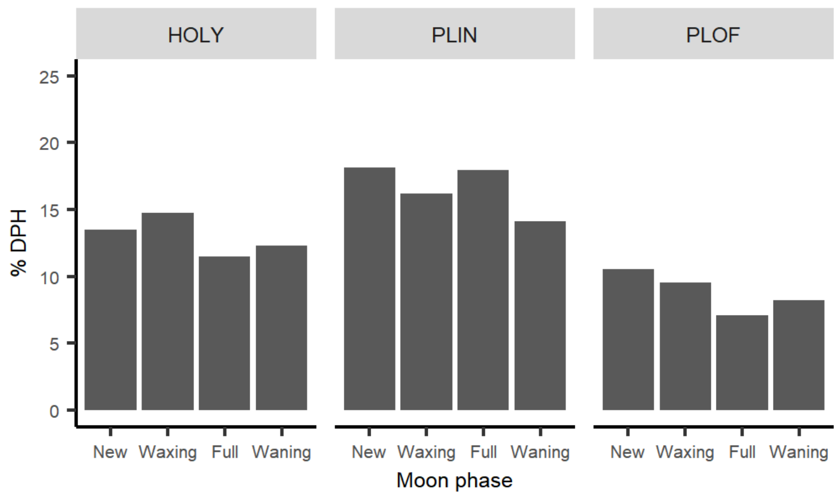

Figure 37. Percentage of dolphin positive hours within new, waxing, full and waning moon phases.

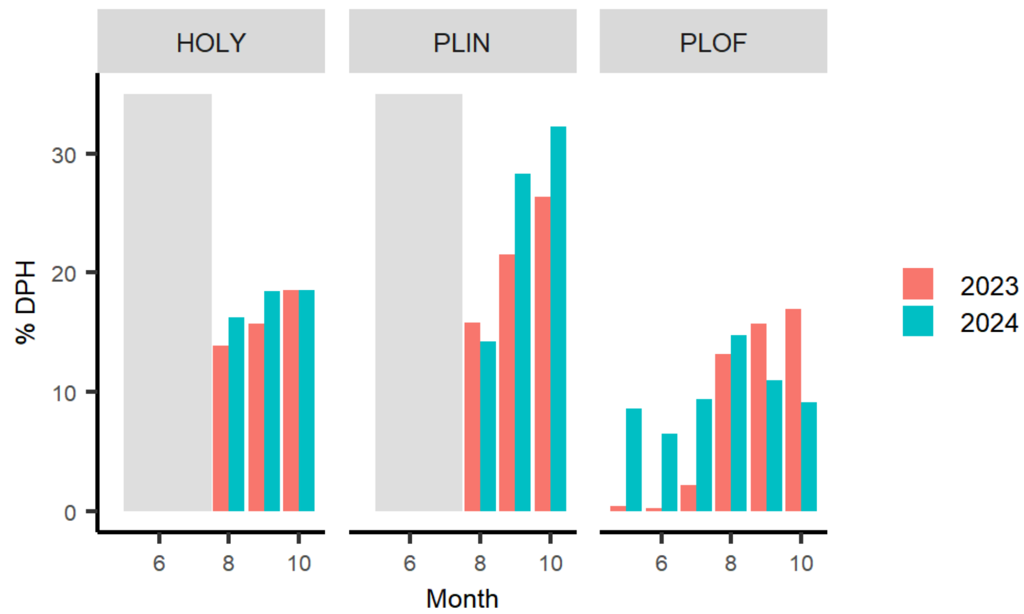

Figure 38. Percentage of dolphin positive minutes per month between overlapping years. Grey shading represents period of data loss in 2024.

4.2.2.3. Dolphin whistles

Dolphin whistles were also recorded; however, there was not the scope within this pilot study to investigate these in detail. In some cases, whistles were present for long periods of time, such as at PLOF, where click detections were fewer (Figure 39). Whistles can be detected at further ranges compared to clicks, so it may be that at PLOF, dolphins were in the vicinity but not at close enough range for click detection. Alternatively, this site may provide a different function for dolphins and therefore result in different vocal behaviour that may be associated with socialising rather than foraging, for example. There is high potential for further study of these data to assess whistle rates at these sites as well as exploring the development of a whistle classifier to identify dolphins to species level.

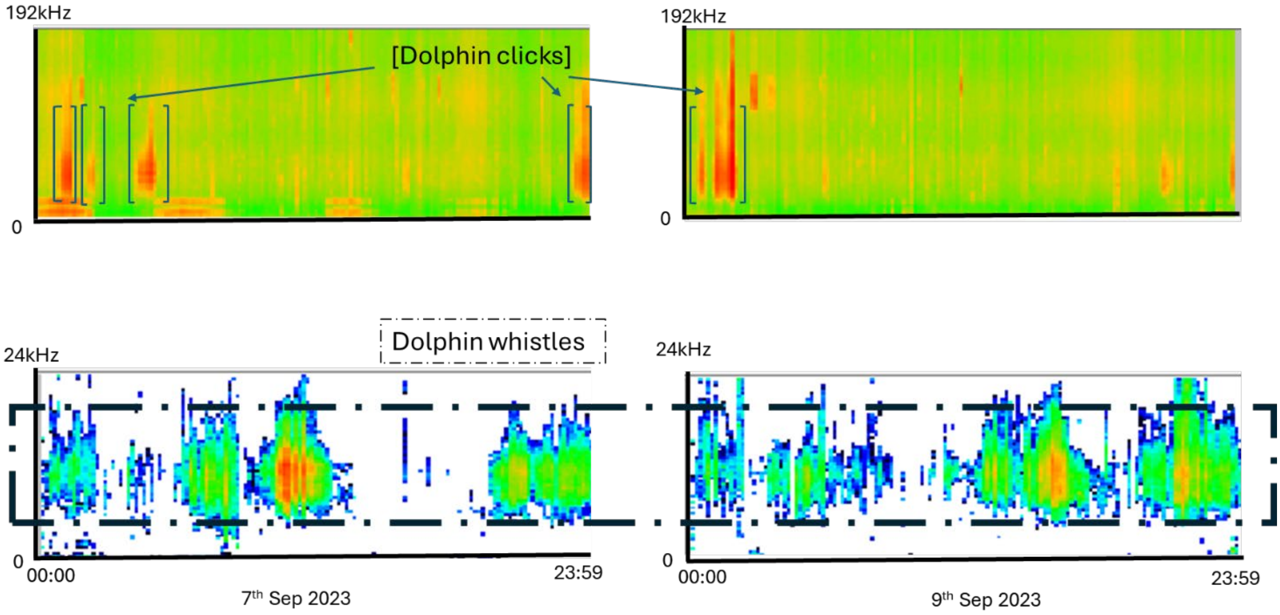

Figure 39. Sample data from PLOF showing high whistle rates (bottom panel) with corresponding click detections (top panel) for a 48h period.

4.2.3. F-POD data

The F-POD also recorded high and regular detections of harbour porpoises (Figure 40).and showed a general increase in detections between late summer and late winter; the SoundTrap data showed a similar trend at PLIN but to a lesser extent. However, SoundTrap data from PLOF differed compared to F-POD data, where detections during the period slightly decreased between August 2023 and April 2024 (Figure 41). Both F-PODs and SoundTraps detected peak porpoise detections at dawn and dusk at PLIN. Diel patterns at PLOF were less clear for both F-PODs and SoundTraps (Figure 42).

F-PODs detected fewer dolphin click trains compared to SoundTraps (Figure 43) and did not match seasonal patterns of occurrence compared to SoundTrap data, particularly in winter months at PLIN (Figure 44). F-POD data did, however, detect a similar diel pattern, with dolphin activity being highest at night (Figure 45).

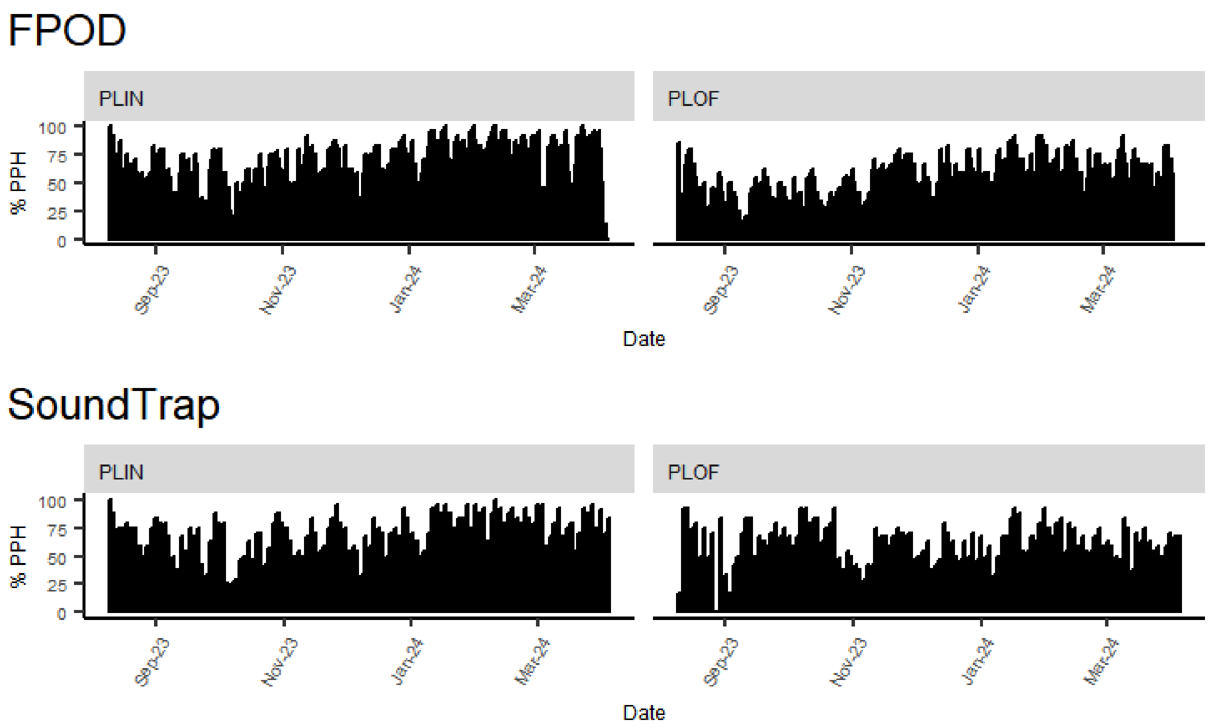

Figure 40. Percentage of porpoise positive hour per day for FPOD and SoundTrap detections for deployments 2 and 3.

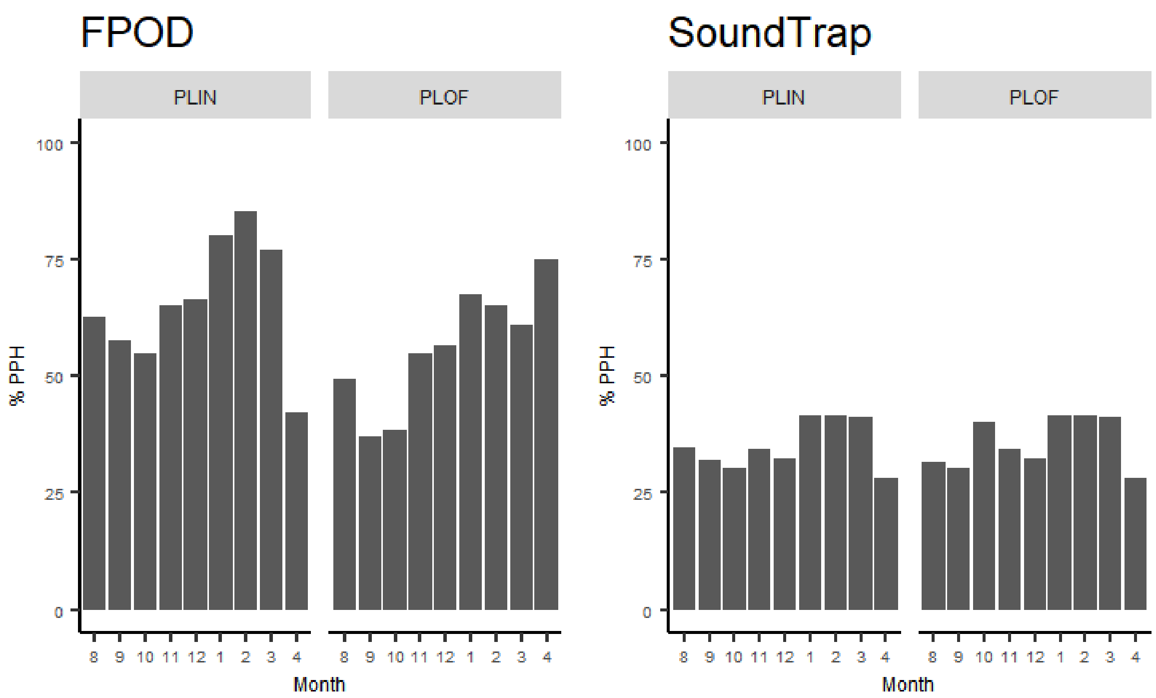

Figure 41. Percentage of porpoise positive hour per month for FPOD and SoundTrap detections for deployments 2 and 3.

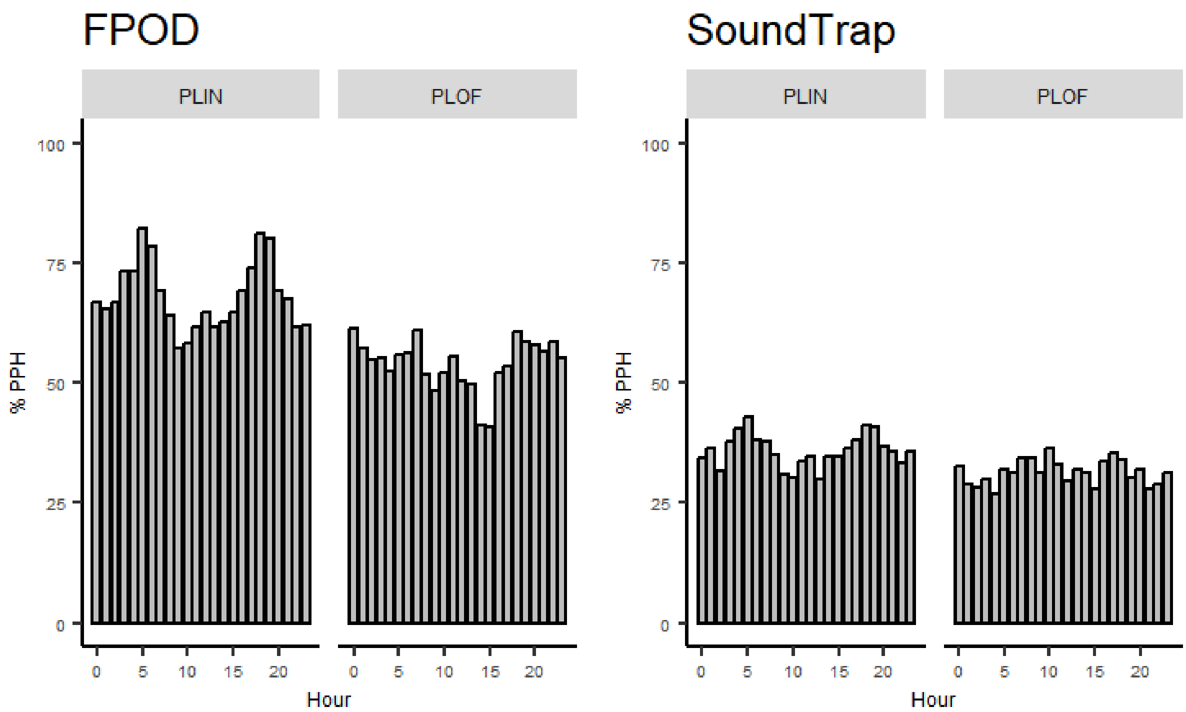

Figure 42. Percentage of porpoise positive hours per hour of day for FPOD and SoundTrap detections for deployments 2 and 3.

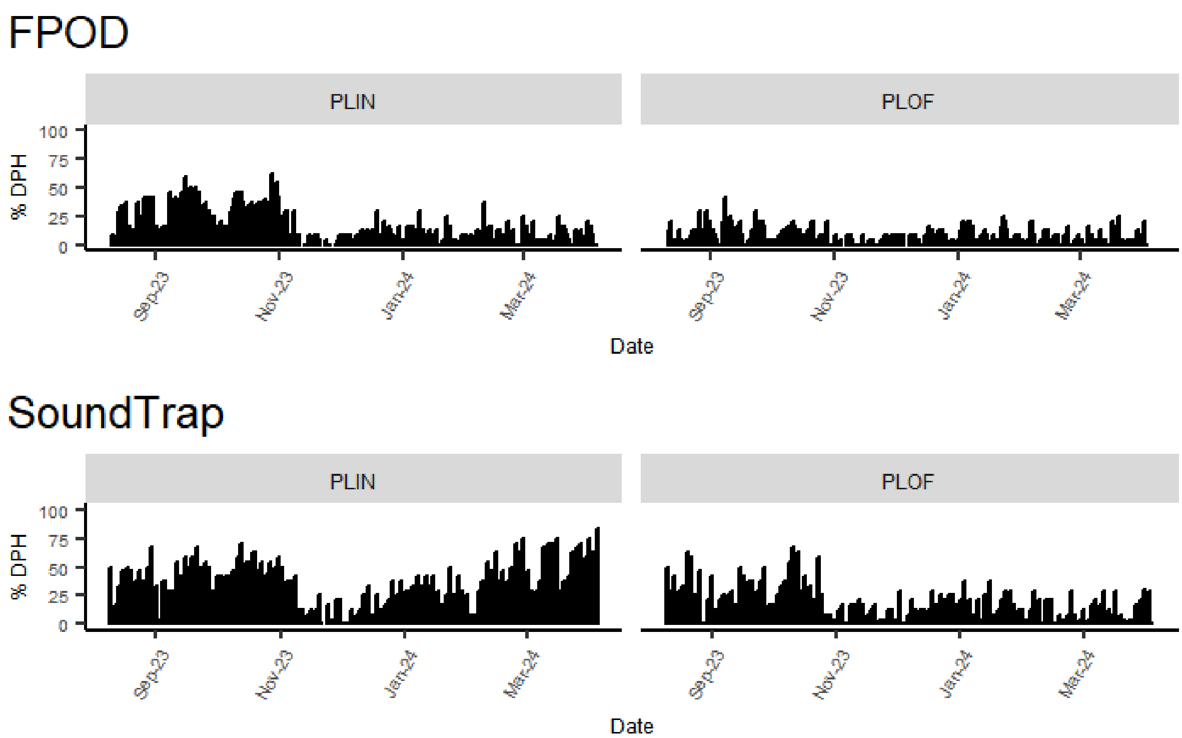

Figure 43. Percentage of dolphin positive hours per day for FPOD and SoundTrap detections for deployments 2 and 3.

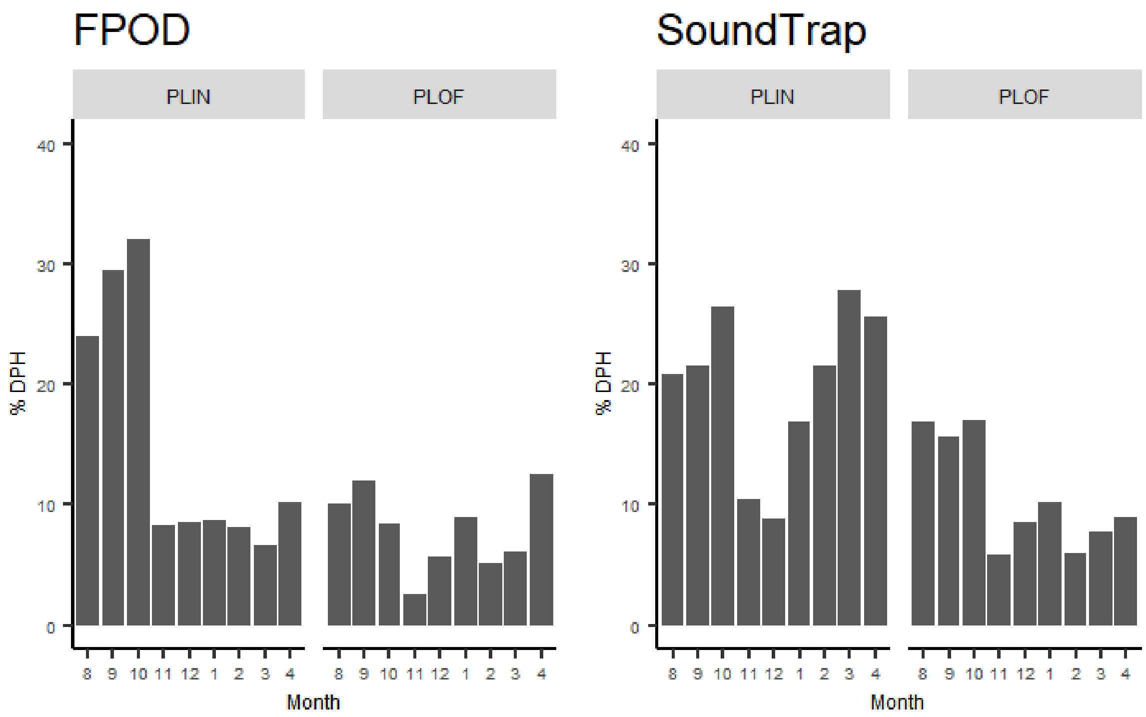

Figure 44. Percentage of dolphin positive hours per day for FPOD and SoundTrap detections for deployments 2 and 3.

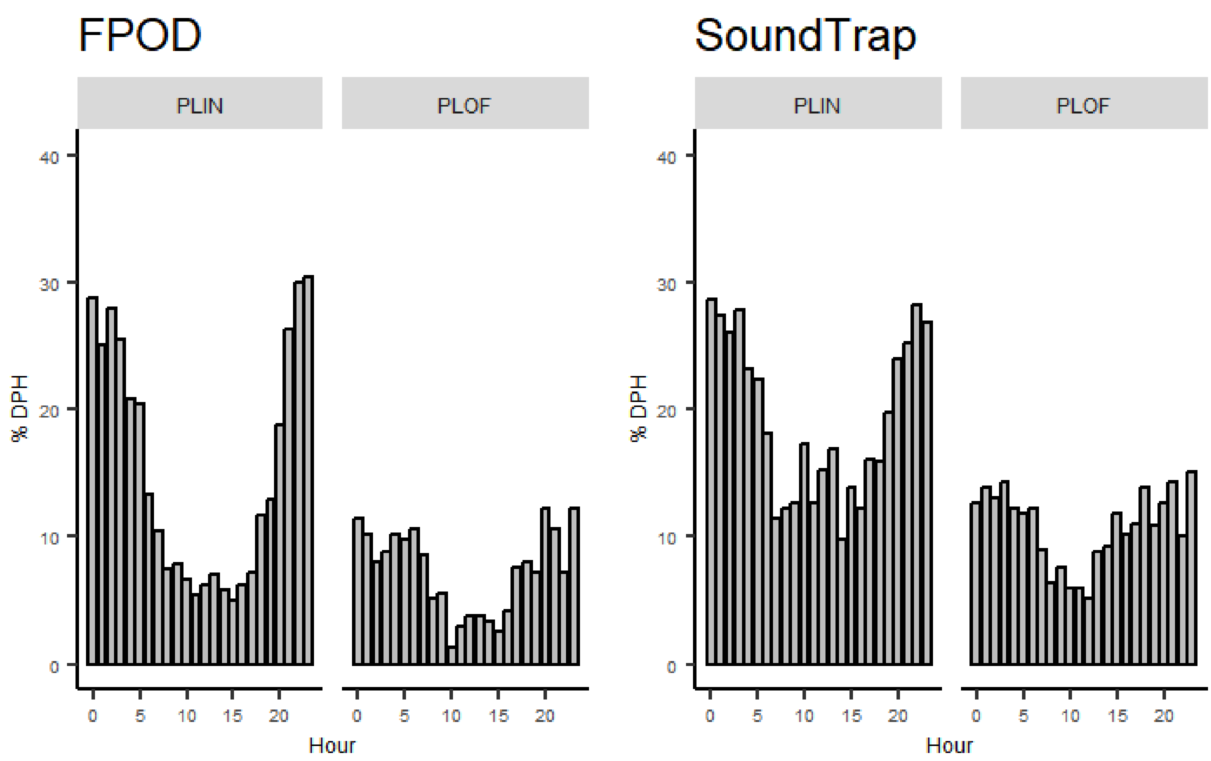

Figure 45. Percentage of dolphin positive hours per day for FPOD and SoundTrap detections for deployments 2 and 3.

4.2.4. Tidal flow noise and acoustic masking

In coastal and tidal environments, tidal currents and sediment flowing past acoustic receivers has been shown to mask cetacean echolocation clicks (Veneruso, 2024). This creates fluctuating detection ranges between acoustic receivers and cetaceans within tidal cycles and variable amplitudes between sites, even at small scales, making direct comparisons between receivers challenging. To avoid misrepresenting patterns of cetacean distribution, setting fixed amplitude thresholds, where clicks below a certain amplitude are removed to standardize across tides and sites, may be necessary prior to statistical modelling (Palmer et al., 2021; Veneruso, 2024). This may be most relevant for investigations of cetacean occurrence and distribution relative to tidal patterns.

4.2.5 Minke whales

The minke whale pulse detector in PAMGuard was triggered regularly, with most detections being false positives; therefore, each detection had to be manually verified. To date this has been completed for deployment 1 only. Three minke whale detections were confirmed; two on 14th May at HOLY and one on 21st Jul. At PLIN (Table 7). There were also several possible minke whale detections recorded at other times but further investigation into the vocalisation characteristics is required for confirmation.

Table 7: Verified minke whale detections during deployment 1

Site	Dep.	Event Start (UTC)	Event End (UTC)
HOLY	1	14/05/2023 00:02	14/05/2023 00:36
HOLY	1	14/05/2023 12:16	14/05/2023 12:39
PLIN	1	21/07/2023 06:03	21/07/2023 06:18

4.3. Sound and cetacean detection comparison

While an in-depth analysis of the relationship between sound levels and cetacean presence was beyond the scope of the project, illustrative examples of time series data were prepared to give an indication of the comparative variability of the data types. The third deployment was selected for this purpose, since it contained the best coverage across all three sites, with five months of continuous data between October 2023 and April 2024. An example for each monitoring location is provided in Figure 46 to Figure 48. Additionally, cetacean counts were inspected in July 2023 specifically and there was no variation in counts of PPH or DPH on 15th July; a day of particularly high shipping activity.

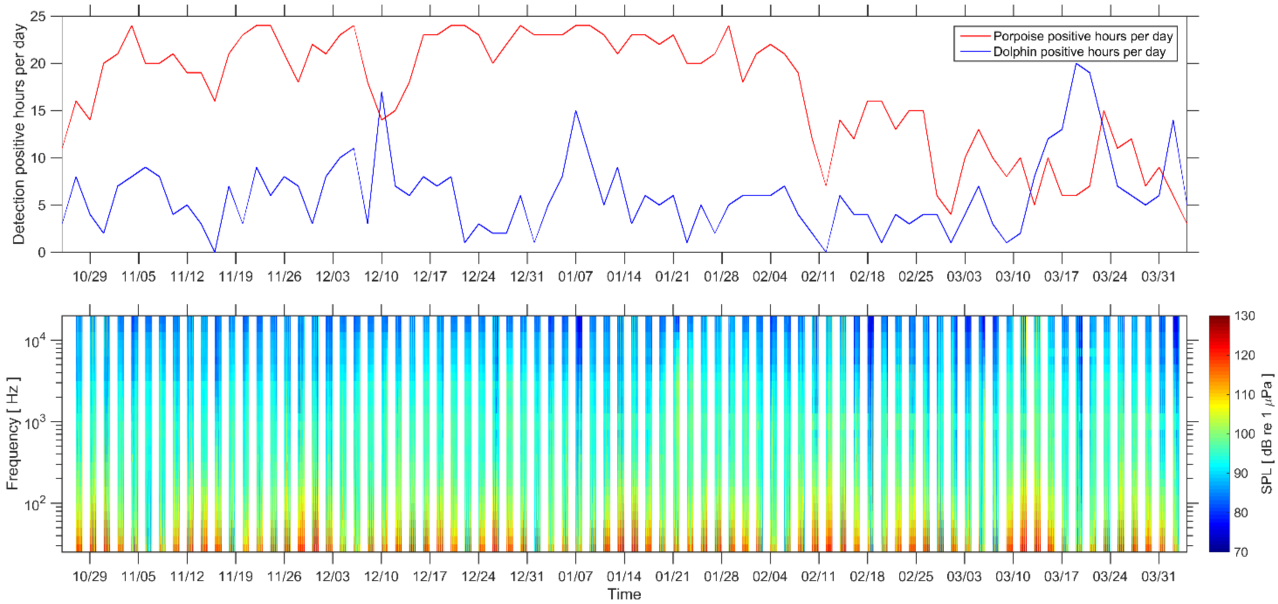

Figure 46. Comparison of daily detection positive hours at Holyhead Deep for harbour porpoise and dolphins (top) and one-third-octave sound levels at hourly resolution (bottom), from October 2023 to April 2024.

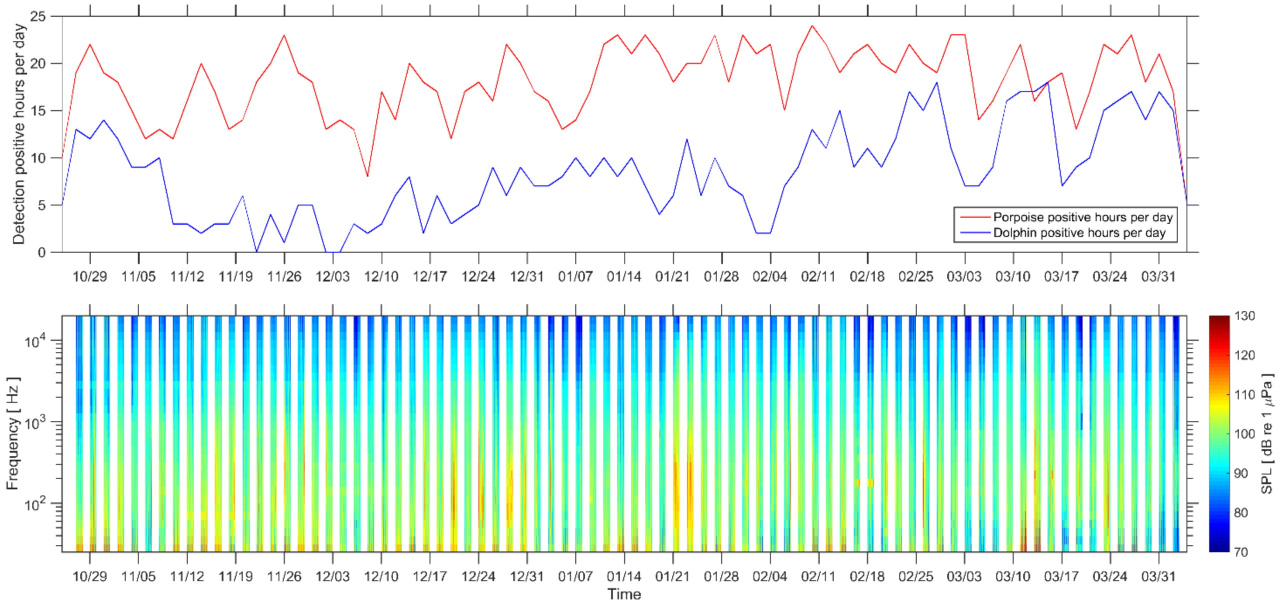

Figure 47. Comparison of daily detection positive hours at Point Lynas inshore for harbour porpoise and dolphins (top) and one-third-octave sound levels at hourly resolution (bottom), from October 2023 to April 2024.

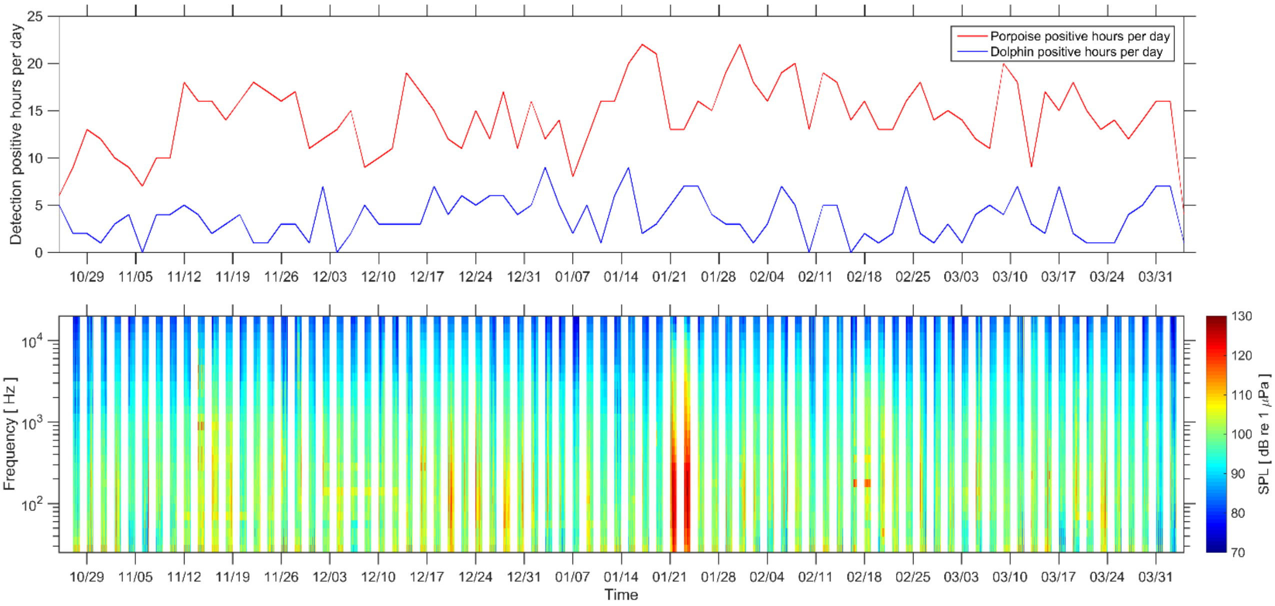

Figure 48. Comparison of daily detection positive hours at Point Lynas offshore for harbour porpoise and dolphins (top) and one-third-octave sound levels at hourly resolution (bottom), from October 2023 to April 2024.

5. Discussion

5.1. Ambient noise

Ambient noise levels differed across the three sites, with the Point Lynas locations having a greater occurrence of shipping noise (Figure 13), which led to higher median noise levels in the range 50 Hz – 2 kHz compared to the Holyhead Deep site (Figure 15). This difference is likely attributable to the more acoustically sheltered location of the recorder at Holyhead Deep, and/or lower levels of ship activity in the immediate vicinity. Above this frequency range, sound levels at all three sites were correlated with wind speed (Figure 17), consistent with many previous studies (e.g. Merchant et al., 2014; Vagle et al., 1990; Wenz, 1962). Correlations with current speed at the highest measured frequencies (Figure 17) are indicative of ambient noise from flow-induced sediment transport (Bassett et al., 2013; Merchant et al., 2014; Thorne, 1986).

At the lowest frequencies, sound levels were also correlated with current speed (Figure 17; Figure 18). To some extent, this correlation can be attributed to tidal flow noise, which is caused by turbulence around the hydrophone and is not indicative of noise present in the environment (Bassett et al., 2014; Robinson et al., 2014; Strasberg, 1979). However, detailed analysis of this noise made clear that a knocking sound, in close proximity to the hydrophone, was also present during high tidal flow periods (Figure 14; Figure 20). This was most likely caused by different parts of the mooring colliding during high flow periods, although the presence of nearby fishing gear cannot be ruled out as a possible cause. As a result, future work should include revisiting the mooring design to identify possible causes of this self-noise and improve the design to the extent possible.

For the purposes of monitoring continuous underwater noise pollution under the UK Marine Strategy, monthly median sound levels were computed for all three sites across the frequency range monitored (Table 2; Table 3; Table 4). Median TOB sound levels were within the range reported for comparable coastal sites in the North Sea (Basan et al., 2024). Further analysis could focus on the audibility of anthropogenic noise, using published audiogram data for the cetacean species of interest. This would give a clearer indication of the proportion of time that cetaceans may be disturbed by human activities in these habitats. These tables provide a cogent summary of the noise levels observed throughout the monitoring study, and could be used in future work to ground-truth modelled shipping noise maps based on ship-tracking data (Farcas et al., 2020; Putland et al., 2022).

The ambient noise results presented in this study suggest several further lines of enquiry for future work. With regard to tidal flow noise, algorithms could be developed to exclude low-frequency data during periods of high tidal flow, to avoid the measurements being contaminated with self-noise, as has been demonstrated in previous work (Van Geel et al., 2020). To better characterise shipping noise, ship-tracking data from the Automatic Identification System (AIS) and Vessel Monitoring System (VMS) could be used to identify vessels and relate shipping noise to individual vessel movements (Hatch et al., 2008; Merchant et al., 2014). More broadly, AIS-based ship noise mapping could be conducted at a fine scale to better understand the distribution of shipping activity and shipping noise in relation sites of greater importance to cetaceans.

5.2. Cetacean detections

This pilot study demonstrates the value of PAM in monitoring cetacean occurrence and provides the basis for developing a longer-term dataset on cetacean distribution from acoustic data in the North Wales region. Unlike visual surveys that are restricted to daylight hours and calm seas, PAM provides data at any time of the day, season, and sea state. This study showed that both porpoises and dolphins were highly abundant in the winter months, in contrast to visual surveys, which are normally conducted in summer. Furthermore, both porpoises and dolphins were detected at high rates at night. Dolphins may use visual cues in daylight hours, resulting in lower echolocation rates during the day, however Welsh waters are highly turbid resulting in poor visibility and variation in echolocation rates alone is unlikely to explain the strong skew towards nocturnal occurrence observed in the data. Therefore, visual surveys may underestimate the occurrence of these species in this region. Additionally, moored PAM collects more data at higher resolutions than visual surveys, making PAM highly suited for cetacean occurrence and monitoring patterns of temporal distribution. The trade-off is that at present, PAM generates large datasets with considerable manual post-hoc processing time to translate audio data into cetacean events.

The click classifier trialled in this study generally performed well with dolphin detections, rarely missing dolphin click trains. The classifier regularly classified false positives but not to the extent that it influenced the rates of present or absent dolphin positive hours each day, showing promise for use in longer-term and wide-ranging PAM studies. The SoundTrap click detector was enabled during data collection to extend deployment durations, while recording ambient sound at 48kHz. The filters built into the SoundTrap click detector that is optimized to detecting higher frequency porpoise clicks, may remove some of the lower frequency information that could be useful to distinguish between dolphins and noise in the species classification step. In future, dolphin click classification may be improved if data is recorded at sampling rate of 96kHz and above, which would then not require the SoundTrap click detector for dolphin click detection. In a longer-term project, more time dedicated to click verification and classifier development is recommended to increase accuracy in dolphin classification and to species groups.

Alternatively, F-PODs which log clicks rather than record audio, have a largely automated post-processing method to extract and classify clicks, resulting in significantly less manual verification required for click classification as well as smaller volumes of data collected. The F-PODs trialled at the Point Lynas sites in this pilot, differed in patterns of distribution compared to SoundTrap data apart from diel patterns. Further, the F-POD detected fewer dolphin clicks compared to SoundTraps and did not detect the winter dolphin peak recorded at PLIN. Since dolphin clicks are relatively broadband and variable, it is currently challenging for any detector or classifier to reliably recognise dolphin events amongst other sounds, as explained within this report. There may be limited scope to investigate, or change click detection parameters in F-POD data due to its proprietary design, making it challenging to assess why there are differences in dolphin distribution patterns between the two instruments. Contrastingly, further investigation of click data recorded by SoundTraps or other acoustic recorders is possible to study dolphin detection and classification. It is likely that acoustic recorders will be better suited to monitor areas where it is important to detect and assess dolphin activity. Further, classifying dolphins to species level is important for licensing conditions and conservation management, since each species of dolphin in the region differs in population size, sensitivity, and legislative protection; this would require the use of acoustic recorders. The click classifier used on SoundTrap data currently does not perform well to species level. However, further work either manually validating dolphin events to species, or making improvements to the classifier as described previously, will enable the separation of Risso's dolphins with bottlenose or common dolphins from SoundTrap data. SoundTraps and other acoustic recorders also have the capacity to record dolphin whistles; it may be possible to train a whistle classifier to distinguish between bottlenose and common dolphins in a longer-term project. Acoustic recorders are therefore recommended for dolphin monitoring. SoundTraps have the capacity to enable the HF click detector, that is optimised to trigger when porpoise clicks are present, meaning that this one instrument can record ambient noise, baleen whale and dolphin tonal calls and high frequency echolocation clicks, satisfying the full scope of the monitoring objectives. If other acoustic recorders are utilised in future projects, which do not have such a capacity to record HF clicks for long periods, F-PODs may be a useful addition for porpoise echolocation click detection.

All the sites selected within the North Anglesey SAC experienced high and regular rates of both porpoise and dolphin detections and provides a first insight into year-round temporal distribution for these species at three locations within the SAC. Further, the study has shown the first inference that Risso's dolphins are present in the region year-round. The scope for this pilot study was to develop a methodology for the preliminary data collection phase (Putland et al., 2023), collect 18 months of data and produce basic exploratory outputs of cetacean detection and distribution. With further investigation, these data would be highly suited to statistical modelling to study spatiotemporal distribution and relative abundance of these species, to greatly improve ecological understanding of cetaceans and their use within the SACs. Further, these data may be used to investigate cetacean occurrence and behaviour relative to acute and chronic anthropogenic noise exposure, as well as potential impacts of marine developments and activities.

6. Conclusions

A key aim of the WAMMS project was to develop an effective and robust method for measuring underwater noise and the occurrence of cetaceans in marine protected areas around the Welsh coastline. The results presented here demonstrate that the WAMMS 18-month pilot study in the North Anglesey Marine SAC has largely achieved this goal, with an extensive characterisation of ambient noise levels and the drivers of noise variability, and a detailed analysis of the occurrence of several cetacean species in these waters. Lessons to be taken forward into the design of the future all-Wales monitoring programme include taking extra precautions with the maintenance of acoustic release systems and revisiting the mooring design to identify sources of possible self-noise during periods of high tidal flow.

Appendix

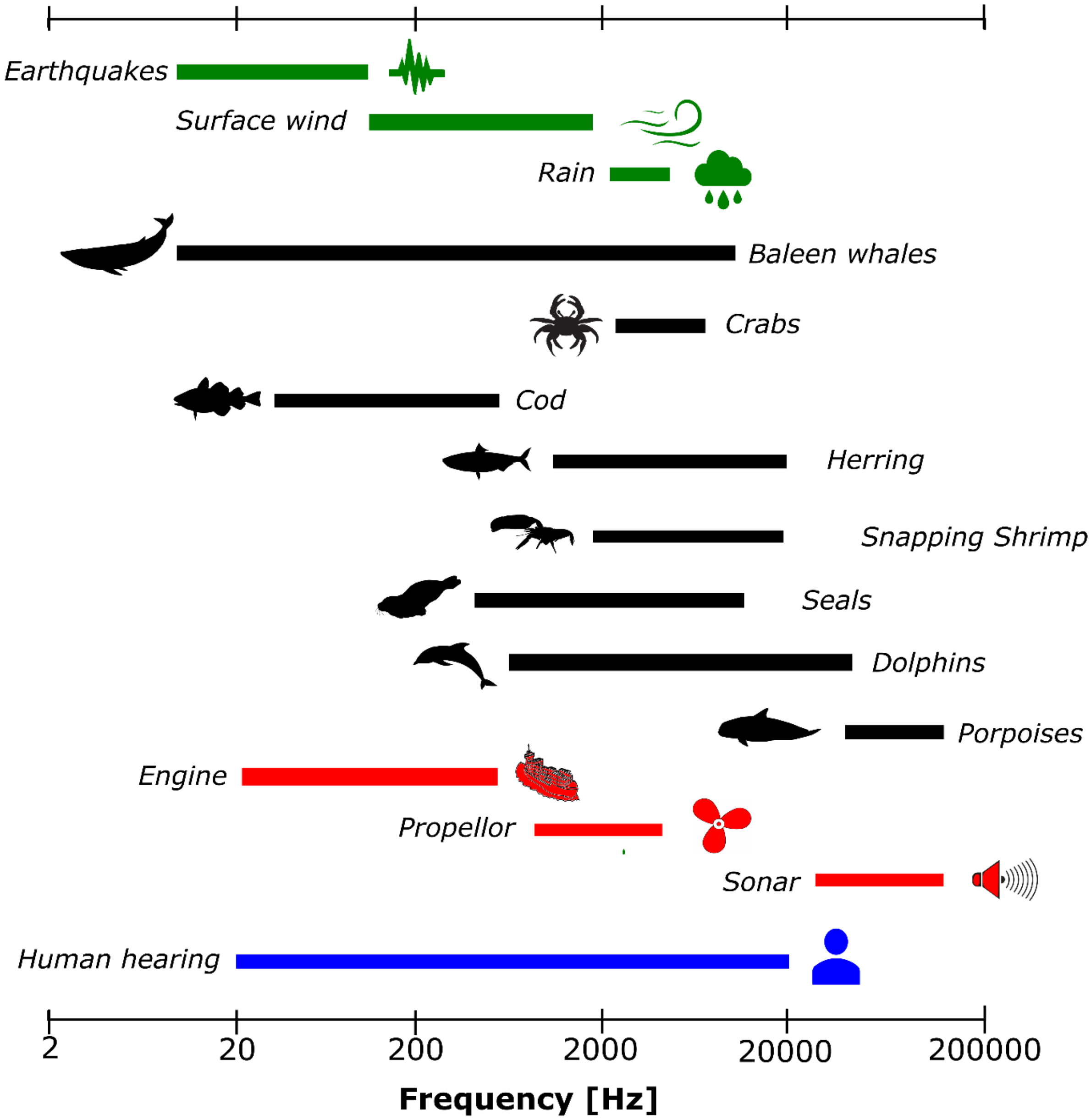

Figure 49: Infographic of the expected frequency ranges for different geological (green), biological (black) and anthropogenic (red) sounds with human hearing represented in blue.

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Appendices

6.1. Data Archive Appendix

Data outputs associated with this project are archived in the Marine Data Exchange on server–based storage at The Crown Estate.

The data archive contains:

[A] The raw data - https://www.marinedataexchange.co.uk/details/TCE-4422/summary

Metadata for this project is publicly accessible through Natural Resources Wales' Data Discovery Service https://metadata.naturalresources.wales/geonetwork/srv (English version) and https://metadata.cyfoethnaturiol.cymru/geonetwork/cym/ (Welsh Version). The metadata is held as record no NRW_DS161355.

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