Welsh Acoustic Marine Mammal Survey (WAMMS) Phase 3 Report: Options for an all-Wales monitoring programme for underwater noise and cetaceans

Report No: 861

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Report series: NRW Evidence Report

Report number: 861

Publication date: May 2025

Contract number: ITT 96114

Contractor: Cefas

Contract Manager: A Zalewski

Title: **Welsh Acoustic Marine Mammal Survey (WAMMS) Phase 3 Report: Options for an all-Wales monitoring programme for underwater noise and cetaceans**

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Quality assurance: Tier 3

Peer Reviewer(s): Tom Stringell and Nicholas Flores Martin

Approved By: J Sharp

Recommended citation for this volume:

Merchant, N.D., Putland, R., Veneruso, G. 2025 Welsh Acoustic Marine Mammal Survey (WAMMS) Phase 3 Report: Options for an all-Wales monitoring programme for underwater noise and cetaceans. NRW Evidence Report, Report No: 861, 53pp, Natural Resources Wales, Bangor

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Crynodeb gweithredol

Mae’r adroddiad hwn yn nodi opsiynau ar gyfer rhaglen fonitro acwstig oddefol yn nyfroedd Cymru a fydd yn cofnodi lefelau sŵn tanddwr a phresenoldeb synau morfiligion. Yn unol â blaenoriaethau polisi a nodwyd gan Cyfoeth Naturiol Cymru, mae'r rhaglen fonitro arfaethedig yn canolbwyntio ar ardaloedd lle disgwylir newidiadau yn y seinwedd oherwydd gweithgarwch morol yn y dyfodol, yn enwedig (ond nid yn gyfan gwbl) o fanteisio ar adnoddau ynni gwynt, llanw a thonnau.

Mae’r cynigion a amlinellir yn yr adroddiad hwn yn rhan o Arolwg Mamaliaid Morol Acwstig Cymru (WAMMS), prosiect a ariennir gan Cyfoeth Naturiol Cymru ac a ddarperir gan Ganolfan Gwyddorau’r Amgylchedd, Pysgodfeydd a Dyframaethu (Cefas) a Phrifysgol Bangor. Amcanion WAMMS yw cynnal astudiaeth fonitro acwstig beilot yn Ardal Cadwraeth Arbennig Forol Gogledd Ynys Môn ac adeiladu ar yr astudiaeth beilot hon i ddatblygu cynigion ar gyfer rhaglen fonitro Cymru gyfan ar gyfer sŵn tanddwr a morfiligion.

Mae dyfroedd Cymru yn cael eu mynychu gan sawl rhywogaeth o forfiligion, a’r pump mwyaf cyffredin ohonynt yw: llamhidydd (*Phocoena phocoena)*, dolffin trwyn potel (*Tursiops truncatus*), dolffin cyffredin (*Delphinus delphis*), dolffin Risso (*Grampus griseus*), a morfil pigfain (*Balaenoptera acutorostrata*). Er bod data ar ddosbarthiad a dwysedd y rhywogaethau hyn yn nyfroedd Cymru, mae ansicrwydd o hyd ynghylch eu presenoldeb a’u hymddygiad tymhorol mewn ardaloedd sy’n bwysig ar gyfer gweithgareddau dynol ac i ba raddau y gallai sŵn o’r gweithgareddau hyn darfu ar forfiligion neu eu dadleoli o’r cynefinoedd hyn. Mae monitro acwstig goddefol (PAM) yn cynnig ffordd gymharol gost-effeithiol o arolygu presenoldeb morfiligion a gellir ei wneud ochr yn ochr â monitro sain tanddwr er mwyn deall seinweddau cynefinoedd morfiligion yn well yn nyfroedd Cymru.

Rydym yn dechrau drwy adolygu’r wybodaeth bresennol ar gyfer dyfroedd Cymru ynghylch dosbarthiad morfiligion, ardaloedd gwarchodedig ar gyfer morfiligion, a gweithgareddau dynol presennol a disgwyliedig. Yna, rydym yn ystyried y gwersi a ddysgwyd o astudiaethau PAM blaenorol a pharhaus yn nyfroedd Cymru, gan gynnwys astudiaeth beilot WAMMS, yn ogystal â rhaglenni PAM perthnasol mewn mannau eraill yn y DU. Gan ddefnyddio’r gwersi hyn a’r llenyddiaeth ehangach, rydym yn nodi’r ffactorau y mae angen eu hystyried wrth ddylunio rhaglen fonitro ar gyfer sain/sŵn tanddwr a synau morfiligion, fel nifer a lleoliad gorsafoedd monitro, dewis a gosod offer, dylunio angorfeydd, a storio a dadansoddi data. Mae’r ystyriaethau hyn yn cael eu dwyn ynghyd â’r anghenion tystiolaeth a nodwyd gan Cyfoeth Naturiol Cymru i lunio set o feini prawf ar gyfer dewis safleoedd monitro ar gyfer rhaglen fonitro Cymru gyfan.

Ar sail y meini prawf dethol hyn, cynigir dau ar bymtheg o safleoedd monitro. Mae’r safleoedd hyn wedi’u gwasgaru ar draws dyfroedd Cymru ac yn perthyn i ddau gategori blaenoriaeth a nodwyd gan Cyfoeth Naturiol Cymru: Blaenoriaeth 1 (9 safle) a Blaenoriaeth 2 (8 safle). Mae’r categorïau blaenoriaeth hyn yn cael eu rhannu ymhellach i safleoedd ar y glannau ac ar y môr (yr oedd 11 a 6 o’r rhain, yn y drefn honno), o ystyried y costau gwahaniaethol sy’n gysylltiedig â chynnal safleoedd monitro ar y môr. Bydd y dull modiwlaidd hwn yn caniatáu i’r rhai sy’n comisiynu’r rhaglen fonitro ei theilwra i gyfyngiadau’r gyllideb a’r blaenoriaethau tystiolaeth sy’n bodoli. O’u hystyried ynghyd â’r ystyriaethau monitro a amlinellir yn yr adroddiad, mae’r argymhellion hyn yn ffurfio glasbrint ar gyfer dylunio rhaglen fonitro Cymru gyfan ar gyfer morfiligion a sŵn tanddwr sy’n ddigonol i fynd i’r afael â’r blaenoriaethau polisi a nodwyd gan Cyfoeth Naturiol Cymru.

Executive summary

This report sets out options for a passive acoustic monitoring programme in Welsh waters which will record levels of underwater noise and the occurrence of cetacean vocalisations. In keeping with policy priorities identified by Natural Resources Wales (NRW), the proposed monitoring programme focuses on areas where changes in the soundscape are expected due to future marine activity, especially (but not exclusively) from the exploitation of wind, tidal, and wave energy resources.

The proposals outlined in this report form part of the Welsh Acoustic Marine Mammal Survey (WAMMS), a project funded by NRW and delivered by the Centre for Environment, Fisheries and Aquaculture Science (Cefas) and Bangor University. The objectives of WAMMS are to carry out a pilot acoustic monitoring study in the North Anglesey Marine Special Area of Conservation (SAC) and to build on this pilot study to develop proposals for an all-Wales monitoring programme for underwater noise and cetaceans.

Welsh waters are frequented by several cetacean species, of which five are most common: harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), and minke whale (*Balaenoptera acutorostrata*). While there are data on the distribution and density of these species in Welsh waters, uncertainties remain around their temporal presence and behaviour in areas important for human activities and the extent to which noise from these activities may disturb or displace cetaceans from these habitats. Passive acoustic monitoring (PAM) offers a relatively cost-effective means to survey cetacean occurrence and can be carried out alongside monitoring of underwater sound to better understand the soundscapes of cetacean habitats within Welsh waters.

We provide a brief overview of existing information on cetacean distributions, protected areas for cetaceans, and current and expected human activities in Welsh waters. We then consider lessons learned from previous and ongoing PAM studies in Welsh waters, including the WAMMS pilot study, as well as relevant PAM programmes elsewhere in the UK. Drawing on these lessons and from the broader literature, we set out the factors which need to be considered when designing a monitoring programme for underwater sound/noise and cetacean vocalisations, such as the number and placement of monitoring stations, equipment choice and set up, mooring design, and data storage and analysis. These considerations are brought together with the evidence needs identified by NRW to form a set of criteria for selecting monitoring sites for the all-Wales monitoring programme.

On the basis of these selection criteria, 17 monitoring sites are proposed. These sites are spread throughout Welsh waters and fall into two priority categories identified by NRW: Priority 1 (9 sites) and Priority 2 (8 sites). These priority categories are further subdivided into inshore and offshore sites (of which there were 11 and 6, respectively), given the differential costs associated with maintaining monitoring sites offshore. This modular approach will allow those commissioning a monitoring programme to tailor it to the budget constraints and evidence priorities at hand. These recommendations form a blueprint for the design of an all-Wales monitoring programme for cetaceans and underwater noise sufficient to address the policy priorities identified by NRW.

1. Introduction

Underwater noise pollution and its effects on marine life are of growing concern to policymakers and environmental managers globally (Duarte *et al.*, 2021). Exposure to anthropogenic noise has been shown to have a number of detrimental effects on marine animals, including auditory impairment, behavioural disturbance, acoustic masking, physiological stress, and development (Williams *et al.*, 2015).

In the case of marine mammals, especially cetaceans, the evidence for adverse effects from underwater noise is particularly strong (e.g. Nowacek *et al.*, 2007; Jensen *et al.*, 2009; Gomez *et al.*, 2016; Russell *et al.*, 2016; Brandt *et al.*, 2018; Erbe *et al.*, 2019; Benhemma-Le Gall *et al.*, 2021). Effects observed in the field include displacement (e.g. Graham *et al.*, 2019), disruption to foraging (e.g. Wisniewska *et al.*, 2018), and acoustic masking in cetaceans (e.g. Kragh *et al.*, 2019). These effects could lead to changes at the population level, but a causal link between noise and population-scale consequences is difficult to determine due to the plethora of factors which affect the growth or decline of a particular population (Pirotta *et al.*, 2018).

Managing the potential effects of human activities on marine mammals requires, *inter alia*, knowledge of the distribution and abundance of target species. Passive acoustic monitoring (PAM) offers a relatively cost-effective means of surveying for cetacean occurrence (Van Parijs *et al.*, 2009), since all cetacean species use sound to navigate and/or communicate. There is also the potential for PAM to be used to estimate cetacean population density (Marques *et al.*, 2013). PAM is less effective, however, for detecting seal species, which vocalise infrequently and do not echolocate. Given the protected status of cetaceans and seals in European waters, the potential impacts of underwater noise on these species are of particular concern to policymakers, and the management of noise in their protected habitats has received growing attention.

In Welsh waters, three Special Areas of Conservation (SACs) were designated for harbour porpoise (*Phocoena phocoena*) in 2019: North Anglesey Marine, West Wales Marine, and Bristol Channel Approaches. There are two further SACs with bottlenose dolphin (*Tursiops truncatus*) as a feature: Cardigan Bay and Pen Llŷn a'r Sarnau SACs; and three SACs with grey seal (*Halichoerus grypus*) as a feature: Cardigan Bay, Pen Llŷn a'r Sarnau and Pembrokeshire Marine SACs. These marine protected areas cover much of the Welsh marine area (see next section). As part of the Welsh Government Nature Networks Programme, the monitoring of underwater noise and marine mammal (particularly cetacean) presence were identified as a priority to support the effective management of these SACs. The present project – the Welsh Acoustic Marine Mammal Survey (WAMMS) – was commissioned to deliver a blueprint for a Wales-wide monitoring programme. This includes the execution of a pilot monitoring programme in the North Anglesey Marine SAC to target harbour porpoise as a key cetacean species and to characterise the underwater soundscape in the sea area around Anglesey where marine development and activity is prominent.

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 sound 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 sound and cetacean distribution/vocalisation patterns across relevant Welsh MPAs.

This report addresses the outcomes of Workstream 2. The outcomes of Workstream 1 are presented in two previous reports (Putland *et al.*, 2023; Merchant *et al.*, 2025), some of which we have reproduced here to support recommendations where relevant.

The aim of this report is to provide Natural Resources Wales with a set of feasible options for an underwater sound and cetacean monitoring programme in Welsh waters. First, we provide the necessary contextual information on human activities and cetacean presence in Welsh waters (Section 2), then set out logistical and scientific considerations for monitoring underwater sound and noise from anthropogenic activity (Section 3) and cetacean sounds (Section 4), drawing on the WAMMS pilot study as well as other relevant monitoring programmes in UK waters. We then set out a proposed prioritisation framework for selecting monitoring sites based on policy priorities and evidence needs identified by NRW as well as the logistical and scientific considerations previously outlined (Section 5). Applying this prioritisation framework, we identify several possible monitoring plans for the Welsh SAC network (Section 6). These options cater to a range of cost and evidence requirements, offering decisionmakers the flexibility to commission a monitoring programme tailored to budgetary constraints and evidence needs.

2. Background

Welsh marine waters contain important marine ecosystems and habitats including protected habitats. They also sustain various human activities including shipping and fishing, and have an abundance of wind, tidal and wave energy to exploit.. To understand how marine species might be affected by underwater noise from current and future human activities, we need to know how animals are using these habitats and to establish baseline levels of sound against which we can detect and monitor change.

This section sets out the foundation of existing knowledge that the all-Wales monitoring programme will build on, summarising current data on the presence and distribution of key cetacean species, protected areas for these species, human activities in Welsh waters, and previous PAM monitoring known to have taken place.

2.1. Key cetacean species

Five key cetacean species have been 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*). This section synthesis baseline knowledge on their presence and distribution in Welsh waters and the characteristics of their vocalisations which can be used for passive acoustic monitoring.

2.1.1. Harbour porpoise (*Phocoena phocoena*)

Harbour porpoise is a widely distributed species in the North Atlantic, with porpoises in the Celtic and Irish Sea considered to form their own distinct Management Unit (IAMMWG, 2023). Trends in population abundance are estimated to be negative, with IAMMWG (2022) indicating a possible decrease, from 98,807 (CV= 0.30; 95% CI: 57,315 170,336) in 2005 to 62,517 (CV= 0.13; 95% CI: 48,324-80,877) in 2016, while SCANS survey estimates from within the Irish Sea indicate a decline from 15,230 in 2005 (Hammond *et al.*, 2013) to 9,376 in 2016 (Hammond *et al.*, 2021). Porpoises are particularly vulnerable to bycatch, in particular from gillnets, with unsustainable mortality levels documented from bycatch in the Celtic Sea (Taylor *et al.*, 2023) but are also sensitive to noise (Southall *et al.*, 2021).

In 2019, a series of UK SACs were designated with harbour porpoise as the primary feature, including three in Wales; North Anglesey Marine, West Wales Marine and Bristol Channel Approaches (Figure 2). Porpoises have been shown to be distributed throughout the Irish Sea and Bristol Channel but are found in particularly high densities in near-shore, tidal environments, suggesting high overlap between porpoises and proposed tidal energy developments in Wales (Shucksmith *et al.*, 2009; de Boer *et al.*, 2014; Nuuttila *et al.*, 2018; Waggitt *et al.*, 2018).

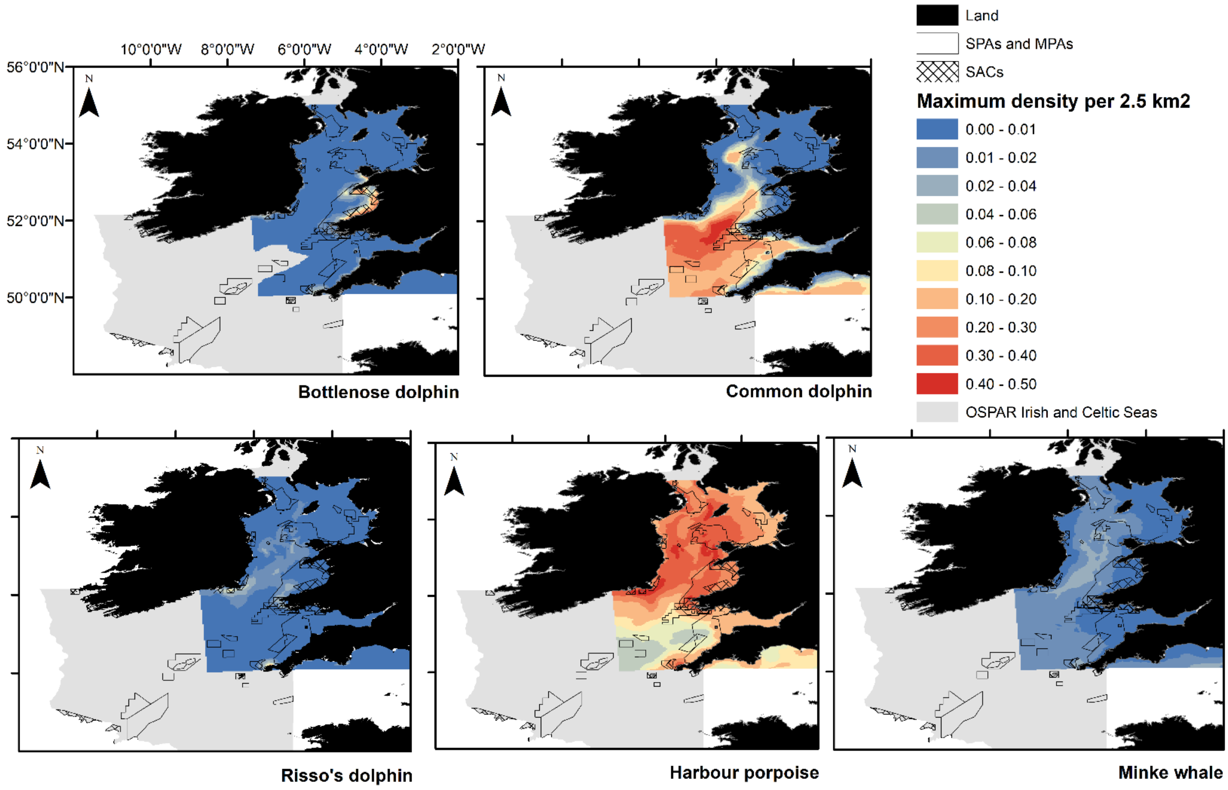

Figure 1: Map of Celtic and Irish Seas area showing cetacean distribution (bottlenose dolphin, common dolphin, Risso's dolphin, harbour porpoise and minke whale) (Putland et al., 2024). Data source: [Modelled Distributions and Abundance of Cetaceans and Seabirds of Wales and Surrounding Waters | DataMapWales (gov.wales)](#).

Harbour porpoises are well suited to PAM studies as they produce high rates of 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 @ 1 m (Teilmann *et al.*, 2002).

2.1.2. Bottlenose dolphin (*Tursiops truncatus*)

Welsh waters host the largest coastal community of bottlenose dolphins in the UK, which ranges from north Pembrokeshire, Cardigan Bay, North Wales and extends out to the Isle of Man. Two SACs have been designated for this species in Cardigan Bay (Cardigan Bay and Pen Llŷn a'r Sarnau SACs) (Figure 2). Most monitoring is focussed on this region, with summer mark-recapture estimates in the wider Bay of between 152-342 animals, with some evidence of a decline or emigration from Cardigan Bay (Evans & Waggitt, 2023). Abundance in the Irish Sea, estimated from the recent SCANS IV aerial survey, shows a likely influx of bottlenose dolphins from the offshore ecotype and estimated more than 8000 animals (Gilles *et al.*, 2023), but this is highly unlikely to represent an increase in the coastal ecotype in the region. Due to the relatively small population size, coastal bottlenose dolphins may be vulnerable to disturbance at the population-level (Booth *et al.*, 2015).

2.1.3. Common dolphin (*Delphinus delphis*)

Typically an offshore and warm water species (>15 C; Cañadas *et al.*, 2009), common dolphin densities appear to have increased within the Irish Sea with most recorded in the Celtic Deep (Evans & Waggitt 2023). Casual sightings also appear to be on the increase, with regular coastal reports off Anglesey, Cardigan Bay and Bardsey Island and the Bristol Channel (Evans & Waggitt, 2023).

Common and bottlenose dolphin echolocation clicks are very similar and cannot presently be separated. 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 (Whitlow, 1993; Palmer *et al.*, 2017).

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

The Risso's dolphin is also a predominantly deep-water species, favouring continental slopes of 200-1200m, but around UK waters it is frequently found at depths of 50-100m (Evans & Waggitt, 2023). However, shallow Welsh waters appear to be important for the species predominantly between the months of June to October with regular sightings of recurring individuals off Pembrokeshire, Bardsey Island, and North and West Anglesey (Evans & Waggitt, 2023). SCANS IV estimated 285 individuals in the Irish Sea (Gilles et al., 2023), and Photo-ID catalogues at Bardsey Island and Anglesey have documented a minimum of 144 individuals (de Boer *et al.*, 2014; Evans and Waggitt, 2023).

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 distinctive in comparison.

2.1.5. Minke whale (*Balaenoptera acutorostrata*)

During the SCANS-IV survey, minke whale abundance estimates were calculated to be 585 individuals in the Irish Sea (Gilles *et al.*, 2023). Sightings tend to be offshore, are few and seasonal, with most sightings April-September (Evans & Waggitt, 2023); therefore, little is known about minke whale occurrence in the region.

Minke pulse trains appear as a series of low frequency narrow band calls at ~60 - 90Hz, separated by around 1s (Risch *et al.*, 2013, 2019). WAMMS will provide the first assessments of minke whale acoustic activity in the region.

2.1.6. Other cetacean species

Other cetacean species have been recorded in low numbers in the Irish Sea, including Atlantic white-sided and white-beaked dolphins and may be detectable using PAM. Killer whales identified from the Scottish West Coast Community (based largely in the Hebrides) are occasionally reported in the Irish Sea, as well as rare sightings of pilot whales. Humpback and fin whale presence has been documented off Pembrokeshire (Evans & Waggitt, 2023).

2.2. Protected areas for cetaceans in Welsh waters

Cetaceans are a qualifying feature in five Welsh SACs: North Anglesey Marine, West Wales Marine, Bristol Channel Approaches, Cardigan Bay, and Pen Llŷn a'r Sarnau (Figure 2). The first three SACs are designated for harbour porpoise, while the latter two have bottlenose dolphin as a qualifying feature. Three SACs also have grey seals as a feature: Cardigan Bay, Pen Llŷn a'r Sarnau and Pembrokeshire Marine SACs.

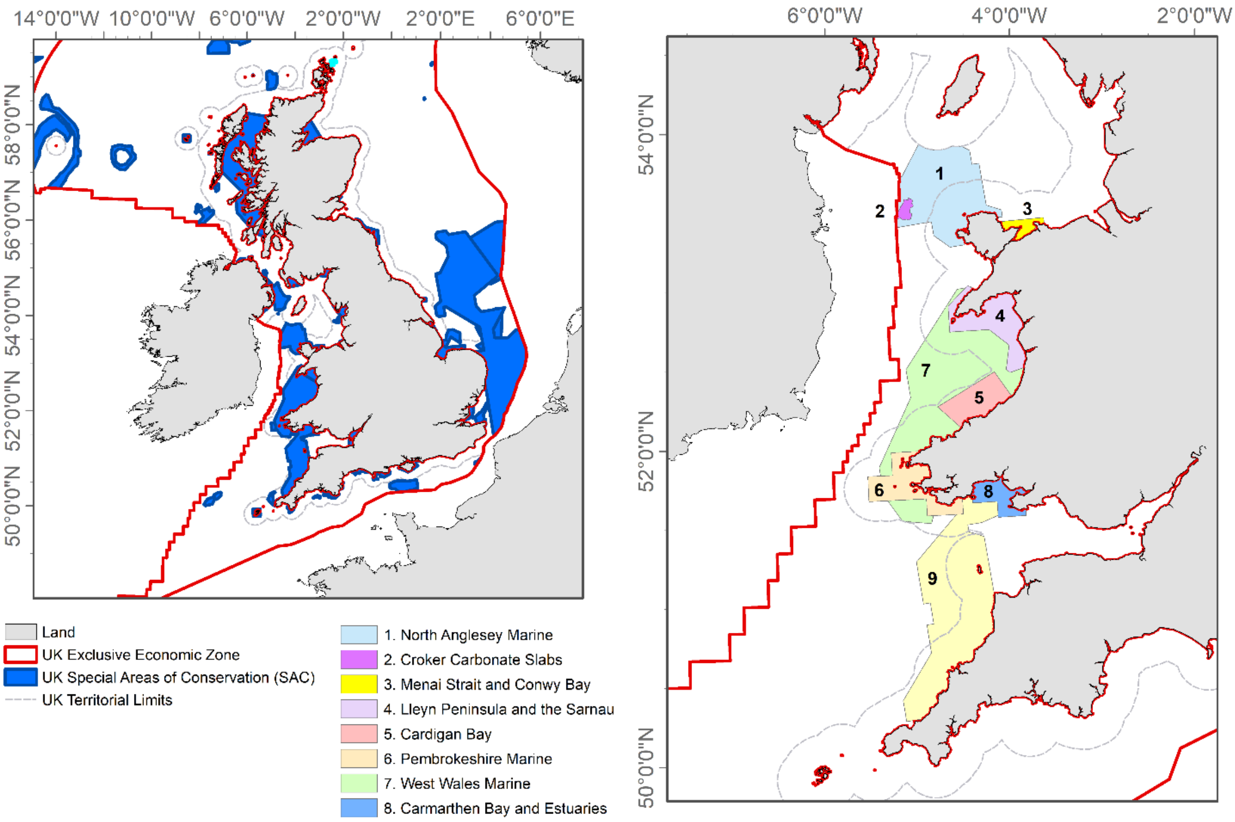

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Figure 2: Special areas of conservation (SACs) in UK (left) and Welsh (right) waters relevant for marine mammals. Note: only those extending into the subtidal are displayed. Pen Llŷn a'r Sarnau is labelled 'Lleyn Peninsula and the Sarnau'.

2.3. Human activities in Welsh waters

Welsh waters support a wide variety of marine activities, including fishing, aggregate dredging, shipping, recreational boating, oil and gas extraction/exploration and marine renewable energy generation. Of these, marine renewable energy and shipping are the sectors expected to see greatest growth in the coming years. Figure 3 shows recent levels of shipping activity based on AIS data, while Figure 4 shows proximity to areas licensed for renewable energy development. In both cases, the areas of greatest activity are off the north and south/southeast coasts of Wales, with comparatively low levels of activity in Cardigan Bay.

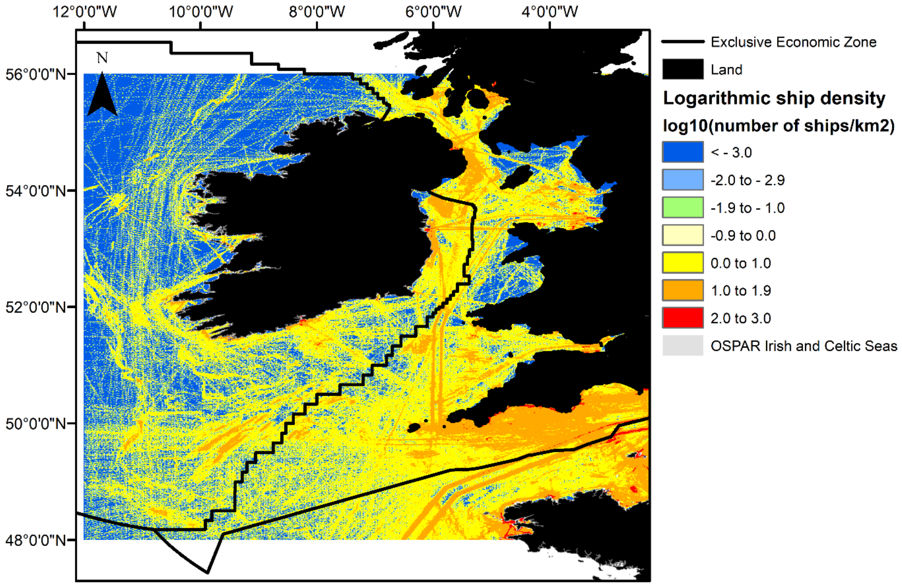

Figure 3: AIS vessel density in the Celtic and Irish Seas area (Putland et al., 2024). Quantity plotted is the logarithmic vessel density (log10(ship counts /km2).

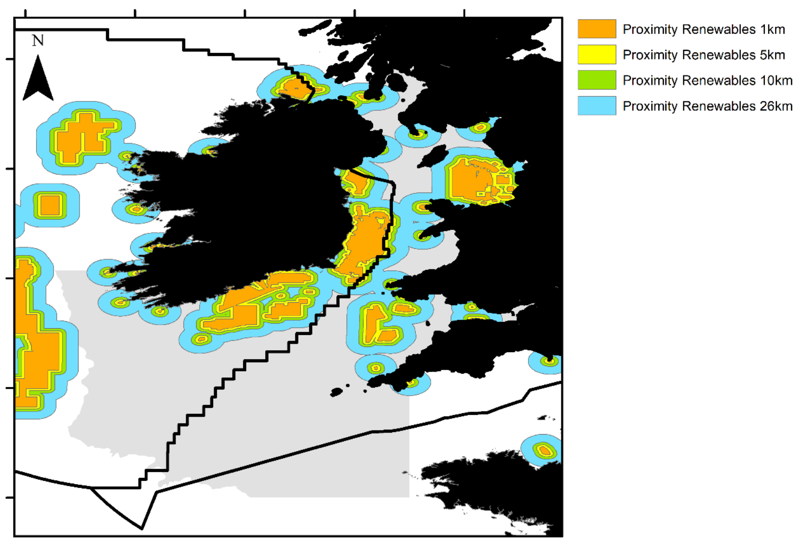

Figure 4: Proximity to areas licensed for renewable energy, in the Celtic and Irish Seas using 1 km, 5 km, 10 km and 26 km based on harbour porpoise effective deterrent ranges (JNCC, 2020) to establish the practical area for monitoring (Putland et al., 2024).

Various passive acoustic monitoring projects have been undertaken in and around Welsh waters in recent years. This section synthesises knowledge gleaned from these monitoring efforts, drawing extensively on a recent Defra-funded report for a proposed Celtic Seas monitoring programme carried out by Cefas (Putland *et al.*, 2024).

2.3.1. WAMMS pilot study

The WAMMS pilot study carried out passive acoustic monitoring at three sites in the North Anglesey Marine SAC between May 2023 and November 2024. Full details of this monitoring campaign are provided in the field report (Merchant *et al.*, 2025). Here, we provide details of the monitoring locations and deployment periods as context for a future all-Wales monitoring network.

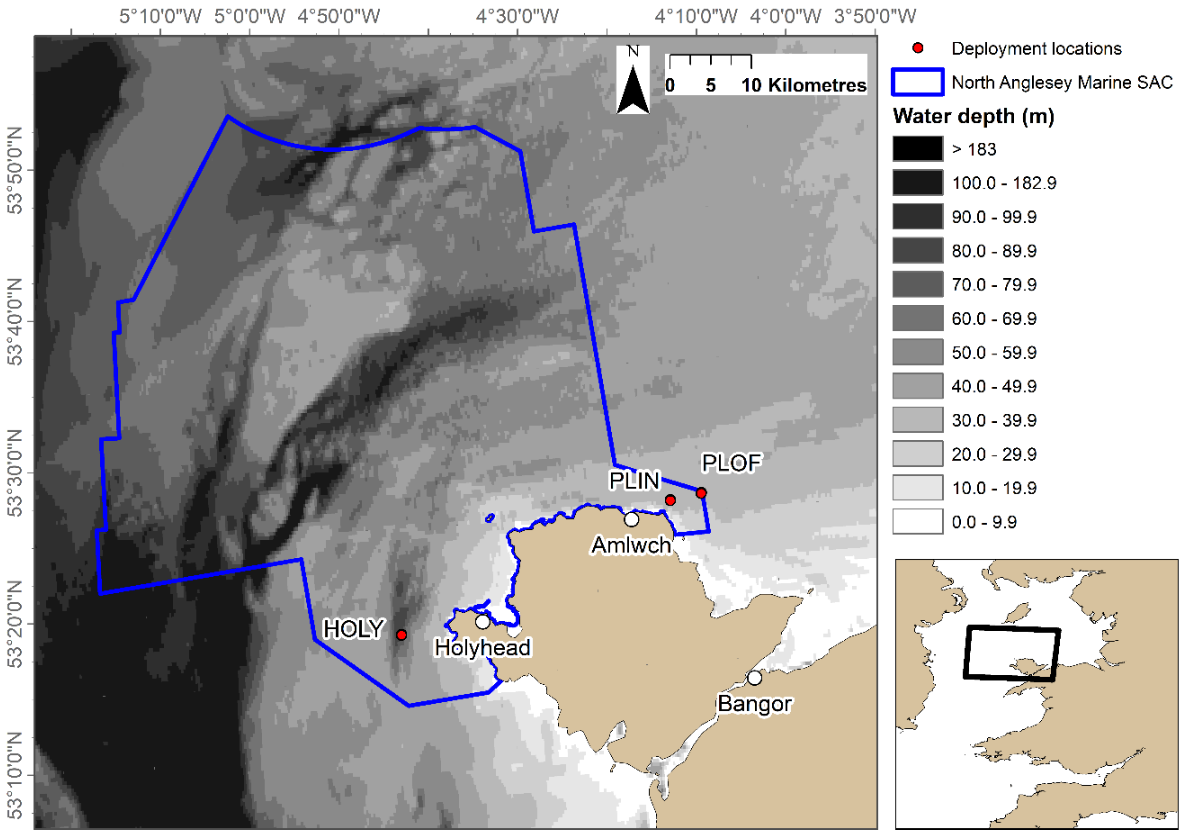

Figure 5: Map of the North Anglesey Marine Special Area of Conservation (SAC) with the red circles marking the three deployment locations (Holyhead deep - HOLY, Point Lynas inshore - PLIN and Point Lynas offshore - PLOF). The greyscale shows bathymetry data from the EMODNET database and the blue line represents the North Anglesey Marine SAC boundary.

Three sites were selected for monitoring in the SAC in consultation with NRW: Holyhead Deep, Point Lynas inshore and Point Lynas offshore (Figure 5). Five contiguous deployments were carried out at three sites between May 2023 and November 2024, with all but two deployments being successfully recovered. The missing deployments were the fourth deployments at Point Lynas inshore and Holyhead Deep, which were unrecovered due to unresponsive acoustic releases (Table 1).

Soundtrap ST600s were used at all sites, recording at 48 kHz on a duty cycle of 24 hours on, 24 hours off. The click detector function was enabled, sampling at 384 kHz for the detection of porpoise and dolphin echolocation clicks. F-POD cetacean echolocation detectors were also deployed at the Point Lynas sites from the second deployment onwards, logging continuously.

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

Station Name	Deployment No.	Equipment	Deployment Date	Recovery Date
Holyhead deep	001	ST600	08/05/2023	10/08/2023
Holyhead deep	002	ST600	10/08/2023	25/10/2023
Holyhead deep	003	ST600	25/10/2023	04/04/2024
Holyhead deep	004	ST600	04/04/2024	**Not recovered**
Holyhead deep	005	ST600	31/07/2024	04/11/2024
Point Lynas Inshore	001	ST600	08/05/2023	10/08/2023
Point Lynas Inshore	002	ST600 and FPOD	10/08/2023	25/10/2023
Point Lynas Inshore	003	ST600 and FPOD	25/10/2023	04/04/2024
Point Lynas Inshore	004	ST600 and FPOD	04/04/2024	**Not recovered**
Point Lynas Inshore	005	ST600 and FPOD	31/07/2024	04/11/2024
Point Lynas Offshore	001	ST600	08/05/2023	10/08/2023
Point Lynas Offshore	002	ST600 and FPOD	10/08/2023	25/10/2023
Point Lynas Offshore	003	ST600 and FPOD	25/10/2023	04/04/2024
Point Lynas Offshore	004	ST600 and FPOD	04/04/2024	31/07/2024
Point Lynas Offshore	005	ST600 and FPOD	31/07/2024	04/11/2024

2.3.2. Celtic and Irish Seas

Putland *et al.* (2024) undertook a review of passive acoustic monitoring in the Celtic and Irish Seas, much of which took place within or near to Welsh waters (Figure 6). The deployment periods and equipment details are provided in Table 2. Ocean Instruments Soundtraps, either the ST300 or ST600 models, were used in all monitoring for which equipment details were available. C-PODs and F-PODs were the device of choice for small cetacean detection (Table 2).

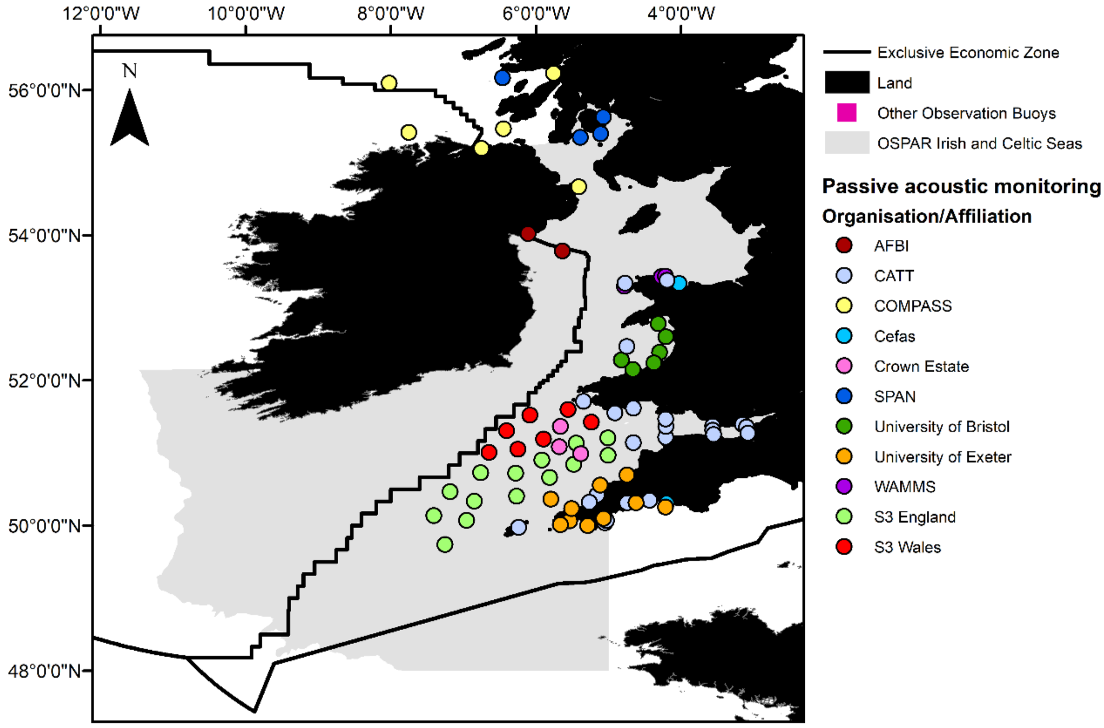

Figure 6: Previous and current passive acoustic monitoring in Celtic and Irish Seas (Putland et al., 2024).

Table 2: Passive acoustic monitoring deployments conducted to date in the Irish and Celtic Seas (Putland et al., 2024). Locations shown in Figure 6.

Organisation/ Project	Latitude	Longitude	Site name	Broadband sound recorder	Small cetacean click detector	Status
AFBI	53.78	-5.63	38A	ST600	CPOD	2017 - Ongoing
AFBI	54.02	-6.11	Carlingford	ST600	CPOD	2019 - 2021
AFBI/COMPASS	54.67	-5.41	Copelands	ST600	CPOD	2018 – Ongoing
Bristol University	52.78	-4.31	Cardigan Bay 1	ST300HF	-	2022 – 2026
Bristol University	52.60	-4.21	Cardigan Bay 2	ST300HF	-	2022 – 2026
Bristol University	52.39	-4.30	Cardigan Bay 3	ST300HF	-	2022 – 2026
Bristol University	52.24	-4.37	Cardigan Bay 4	ST300HF	-	2022 – 2026
Bristol University	52.15	-4.66	Cardigan Bay 5	ST300HF	-	2022 – 2026
Bristol University	52.28	-4.82	Cardigan Bay 6	ST300HF	-	2022 – 2026
CATT	Several coastal sites around SW England and Wales	Several coastal sites around SW England and Wales	Celtic and Irish Seas	-	CPODs and FPODs	2022 - 2027
Cefas	53.34	-4.03	Puffin Island	ST300HF	-	2019 - Ongoing
S3	Several offshore locations. Funding approved	Several offshore locations. Funding approved	Celtic Seas	Recorder type TBD	CPODs and FPODs	Proposed to start 2024
SPAN	55.40	-5.11	South Arran	-	FPOD	2023 - 2027
WAMMS	53.43	-4.27	Point Lynas Inshore	ST600	FPOD	2023 – 2024

Organisation/ Project	Latitude	Longitude	Site name	Broadband sound recorder	Small cetacean click detector	Status
WAMMS	53.44	-4.21	Point Lynas Offshore	ST600	FPOD	2023 – 2024
WAMMS	53.30	-4.78	Holyhead Deep	ST600		2023 - 2024

2.4. Existing monitoring plans

In parallel with the WAMMS project, a Defra-funded study was undertaken to prepare a ‘soundscape monitoring plan’ for the Celtic and Irish Seas which would provide baseline sound levels for the region (Putland *et al.*, 2024). This study proposed 40 monitoring stations (Figure 7), prioritised according to protected areas, species distributions, and proximity to human activities. The stations were also chosen to provide good spatial coverage capturing different water depths, sediment types and habitats.

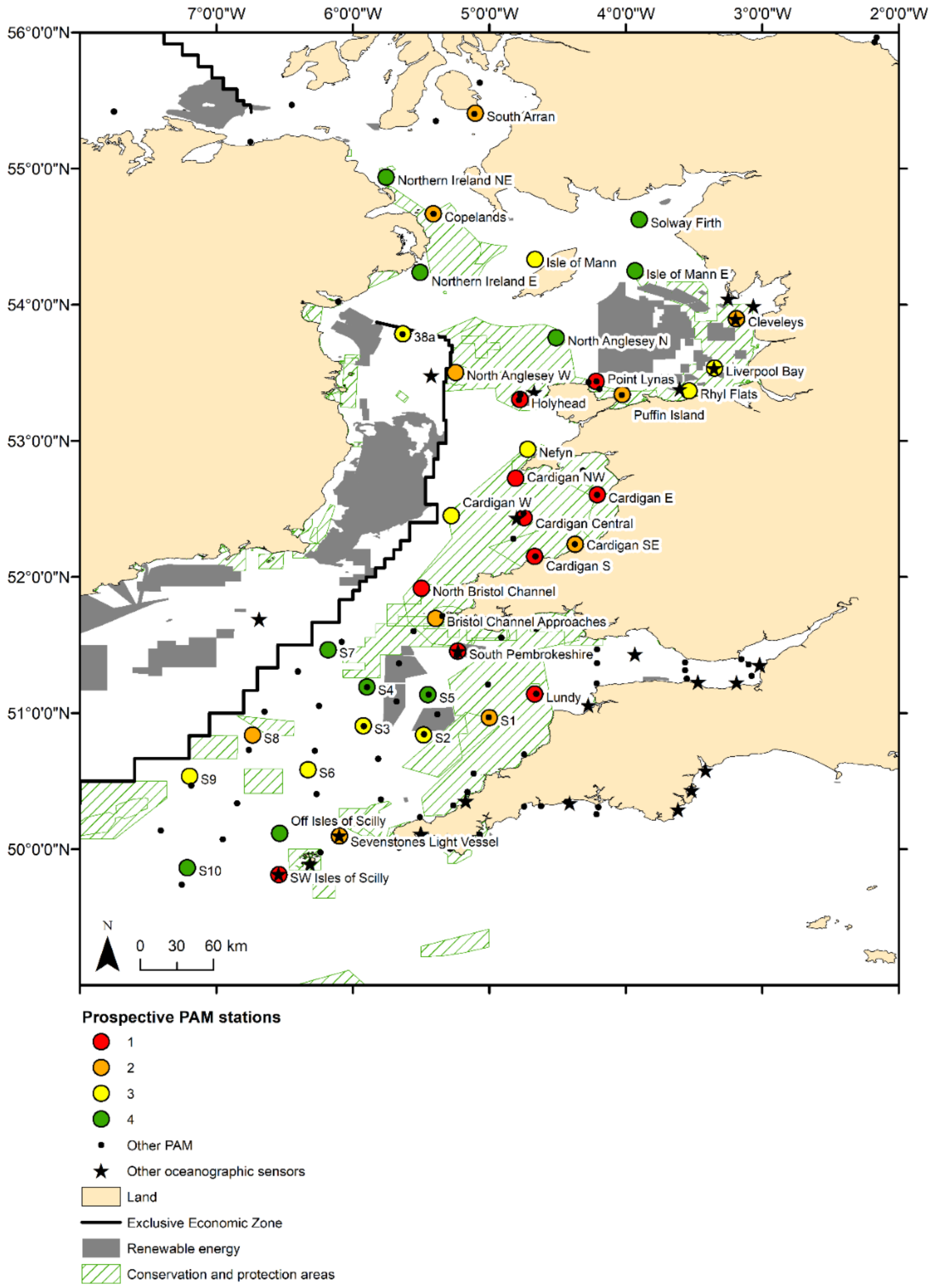

Figure 7: Summary figure of potential PAM stations in the Celtic and Irish Seas identified in the Defra-funded study ‘Soundscape monitoring plan for Irish and Celtic Seas’ (Putland et al., 2024). Colours denote priority rating (1/red being highest priority, see legend) according to criteria from source report.

3. Monitoring considerations

3.1. Noise

This section sets out the choices which need to be made when designing a monitoring programme for underwater noise. These choices include: number and placement of monitoring stations, selection and set-up of equipment, mooring design, data storage and data analysis.

3.1.1. Purposes of underwater noise monitoring

The first consideration when designing an underwater noise monitoring programme is to clearly define its purpose. This will make it easier to specify the nature of the scientific evidence that the programme will be designed to yield.

Underwater noise monitoring programmes may be commissioned for a range of purposes, such as:

- monitoring human activities which produce underwater noise, to better understand their potential effects on marine life (e.g. Merchant *et al.*, 2014; Viola *et al.*, 2017);
- detecting and describing the components of a particular acoustic habitat and their variability (i.e. the *soundscape*) in order to characterise the present/baseline condition of a habitat (e.g. Haver *et al.*, 2018; Basan *et al.*, 2024);
- ground-truthing models and maps of underwater noise pollution to quantify their predictive accuracy (e.g. Farcas *et al.*, 2020; Putland *et al.*, 2022).

Stating this purpose explicitly will help to ensure that scientific outputs from the monitoring programme are suitably focused on the evidence needs of the funders.

3.1.2. Number and placement of monitoring stations

Having established the purpose of the monitoring programme and the type of evidence it is hoped the programme will yield, the next major question is the number and location of monitoring sites. In other words, what are the optimal locations for monitoring and how many sites will be needed?

The number of noise monitoring stations required will vary depending on the purpose of the monitoring programme, the spatial heterogeneity of the study site, and the budget available.

If the study area has significant variability in sediment type, water depth, or presence of sound sources, then this will affect where it is most useful to monitor. For baseline soundscape monitoring, the ideal case would usually be to monitor in locations which collectively offer a representative sample of this spatial variability. Where specific noise sources are to be characterised, locations with a higher occurrence of these sources will be more useful, and so should be prioritised. And where noise models or maps are to be ground-truthed, then locations with the greatest uncertainty in the model predictions will be most valuable. These areas of greatest uncertainty are likely to vary depending on factors affecting sound propagation (e.g. water depth and seabed type) and the proximity to sound sources.

As to the question of how many monitoring stations to deploy, in general it is true to say that a greater number of stations will improve the quality of evidence gained, and that in practice the number of stations is more often limited by budgetary constraints than by a rigorous optimisation, e.g. via a cost-benefit assessment of evidence gained vs. budgetary outlay. As a rule, fewer locations are likely to be needed for model ground-truthing and source characterisation than for baseline soundscape characterisation.

3.1.3. Equipment and set-up

Scientific instruments for recording underwater sound have evolved markedly in recent decades. The integration of hydrophones into small, compact digital recording units has reduced costs and logistical complexity, while advances in data storage capacity has made long-term, continuous recording possible without the use of cabled-to-shore systems, which reduces monitoring costs considerably.

The main considerations when selecting an autonomous underwater sound recorder are the frequency range and sensitivity of the hydrophone, the data storage capacity, and the battery endurance. These latter two factors affect how long the recorder may be deployed for before fresh batteries and/or data storage cards are needed, and so constrain how frequently the mooring needs to be serviced, which is a major determinant of cost. Deployment longevity can be improved by duty cycling the monitoring period, e.g. by monitoring 30 mins in each hour instead of continuously, but the associated loss of data may not be appropriate for some applications.

Regarding the hydrophone, it is preferable for the sensitivity of the hydrophone (the voltage produced when a given sound pressure is received) to be relatively consistent across the frequency range of interest (i.e. having a ‘flat frequency response’). This will reduce distortions in the relative amplitude of different frequencies. It is also important that the sensitivity of the entire recording unit is quantified across the frequency range of interest, i.e. that a calibration is undertaken, so that the true sound pressure received by the instrument can be back-calculated in subsequent analysis (Robinson *et al.*, 2014). Such calibration is typically performed by specialist providers, such as the National Physical Laboratory in the UK, who are able to provide calibrations certified to international standards. It is also possible to calibrate the system sensitivity at a particular frequency using a pistonphone, a small device which applies an oscillating pressure to the hydrophone within a small air volume. Pistonphones are usually inexpensive compared to third-party calibration and are often used to check whether the instrument sensitivity has deviated from the certified level between deployments (Merchant *et al.*, 2015).

In an effort to ensure minimum standards for sound recorders deployed for statutory monitoring under the EU Marine Strategy Framework Directive (whose UK counterpart is the UK Marine Strategy), a set of specifications has been proposed (Dekeling *et al.*, 2014; Robinson *et al.*, 2014; Fischer *et al.*, 2021) which can be used when making procurement decisions (Table 3)

Table 3. Overview of agreed minimum requirements for measurement equipment used for reporting underwater noise for UKMS and MSFD (Putland et al., 2024).

Function	Minimum requirements	Comments
Frequency range	10 Hz – 20 kHz	Focus is on low frequencies (centre frequencies 63 and 125 Hz) in addition to broadband (10 Hz – 20 kHz) and low (20 – 160 Hz), middle (200 Hz – 1600 Hz) and high 2 kHz – 16 kHz) 1/3 octave bands
Dynamic range	At least 16 bits (dyn.range 96 dB), preferably 24 bits (dyn.range 144 dB)	Lowest and highest expected sound pressure should be recorded
Sensitivity	-165 to -185 dB re. 1 V/µPa	n/a
Directionality	Omni-directionality	Sensitivity should be invariant with direction
Sampling rate	At least 44.8 kHz (22.4 kHz freq. range)	Sampling frequency should be at least twice the highest acoustic frequency, that should be recorded
Filtering	Filter characteristics should be known	Low and high pass filtering
System self-noise	6 dB below the lowest expected sound level	n/a

3.1.4. Mooring design

Assuming appropriate recording equipment has been identified, the next step is to design the mooring on which it is to be deployed. We will limit our scope here to the aspects of mooring design which affect the monitoring of underwater sound.

A primary concern when designing a mooring to monitor underwater sound is to avoid self-noise, i.e. noise generated by the mooring itself or by the presence of the instrument in the water column (Robinson *et al.*, 2014; Fischer *et al.*, 2021). Such noise is a contamination of the measurement since it would not be present were the mooring not deployed. The main sources of self-noise are moving parts on the mooring (e.g. chains), cable strum (vibration of mooring cables), and flow noise (turbulence around the hydrophone caused by water flow, similar to a microphone ruffling in the wind). Moving parts which generate noise should be secured to eliminate movement or else avoided altogether. Cable strum can be reduced or avoided by decoupling the sound recorder from the suspension cable (e.g. using elastic rope). Flow noise is more difficult to address but can be reduced by using acoustically transparent flow-resistant housings (Martin *et al.*, 2012).

In addition to addressing self-noise, it is important to deploy the hydrophone at least 1-3 m from the seabed, to reduce the interference of sound waves reflected from the seabed. Biofouling will also affect the effective sensitivity of the hydrophone and may also introduce biological sounds due to the presence of the instrument. Increasing the frequency of redeployment and cleaning will reduce the extent of biofouling.

As well as optimising the acoustical aspects of the mooring, it is important to avoid general mooring hazards such as trawling activity or other mariners. Choosing a mooring design which does not require a surface marker (e.g. using a ‘pop-up’ buoy activated by an acoustic release) can avoid attracting attention to the mooring, but increases the risk of losing the mooring through a failure to recover, e.g. if the acoustic release fails. Further details on all of these risks and mitigations can be found in the literature (Dudzinski *et al.*, 2011; Robinson *et al.*, 2014; Fischer *et al.*, 2021).

3.1.5. Data storage and analysis

Compared to most other types of marine environmental monitoring, passive acoustic monitoring is highly data intensive, with multiple terabytes of data accruing for a single location over a single year. Data management is therefore a critical aspect of any long-term passive acoustic monitoring programme

To ensure adequate resources are available, the volume of data expected to be gathered should be estimated in advance and storage solutions for these data costed into the programme budget. More costly storage with fast access (‘hot storage’) may only be required during data analysis phases of the programme, with data then being transferred to a more economical archival location (‘cold storage’) thereafter.

Similarly to data storage requirements, data processing requirements should be identified in advance and budgeted for. Analysis of passive acoustic data is a specialised field and often involves bespoke computer code to be written, rather than relying on off-the-shelf software. High-performance computing facilities are often required to best exploit the high volumes of data gathered. A data management and analysis plan should therefore be drawn up as a preparatory step in designing the monitoring programme.

The types of outputs required from a noise monitoring programme vary depending on the purpose of the monitoring, but typically involve summary statistics of acoustical metrics, such as the median one-third-octave sound level at a range of frequencies (Merchant *et al.*, 2015). Acoustical metrics suitable for characterising underwater noise have been described as part of previous monitoring programmes (e.g. Merchant *et al.*, 2018), but in general these should be identified according to the specific evidence needs of the programme at hand.

In addition to the passive acoustic data, other data sources are likely to be needed in order to understand the causes of variability in sound levels. Relevant data types include oceanographic (tides, currents, bathymetry), meteorological (wind, rain), geophysical (seabed type, ideally including subsurface profile) and anthropogenic (AIS ship-tracking data, information on planned activities).

3.2. Cetaceans

There is substantial overlap between the considerations outlines for noise monitoring in section 3.1, and cetacean PAM monitoring. The following section outlines some additional relevant considerations and specifics/lessons learnt from the WAMMS pilot study.

3.2.1. Purposes of cetacean monitoring

Acoustic monitoring of cetaceans allows the study of:

- Temporal and spatial patterns in cetacean occurrence.
- Relative abundance and distribution.
- Cetacean occurrence and behaviour relative to acute and chronic anthropogenic noise exposure.
- Potential impacts of marine developments and activities.
- Improved ecological understanding.

3.2.2. Site selection

Sites are typically selected in an area of ecological importance to cetaceans or to study baselines where anthropogenic activities are proposed. These must be balanced with the suitability of habitat for moorings, including nearby vessel and fishing activities, seabed depth and substrate, tidal flows, etc.

Sites with particularly high noise levels can be challenging for cetacean monitoring since cetacean clicks / vocalisations can be acoustically masked from ambient sounds in cetacean frequency ranges, such as sediment transport past hydrophones. Typically, we have recommended deploying moorings on bedrock, to minimise noise from sediment and mobile sand, while avoiding the added risk of burying of instrumentation in sand.

3.2.3. Equipment selection

Acoustic recorders are required for recording baleen whale calls, dolphin whistles and other tonal sounds. Dolphin and porpoise echolocation clicks will also be detected if instruments have a sampling rate capability of 300 kHz+ and high frequency hydrophone sensitivity.

The WAMMS pilot project used SoundTrap 600HFs (Ocean Instruments, NZ) which are well established in other marine mammal PAM studies and has the specifications to detect all the vocalisation types described above. In addition to continuous sound recording capabilities, the SoundTrap has an optional high frequency click detector, which stores snippets of full bandwidth sound data for the detection of dolphin and porpoise echolocation clicks up to 150 kHz. This detector, which disposes of data that is not likely to contain clicks, results in less data storage and thus longer endurance of instruments at sea (e.g., in the WAMMS pilot study, recording at 48 kHz with the SoundTrap click detector enabled, the SoundTraps were estimated to record for 8 months on a 50% duty cycle).

There are several acoustic recorders on the market and endurance of recorders is likely to be an important consideration when selecting instrumentation for long-term monitoring. This project exchanged instruments approximately every four months (before reaching full capacity), balancing the budget available and logistics of offshore operations to service equipment, with the risk of instrument and data loss which increases the longer equipment is left at sea.

Click loggers (C-POD, F-POD, Chelonia Ltd, UK) are also commonly used to monitor cetacean echolocation click detections specifically and have been utilised in earlier PAM monitoring studies (e.g., ECOMMAS and COMPASS). Unlike acoustic recorders, they detect and process cetacean echolocation click detections in real-time, saving smaller files containing digitised click information (Ivanchikova and Tregenza, 2023). This has the advantage of collecting lower volumes of data and less time required for click processing and classification, which may be particularly valuable for long-term projects with multiple stations. The click loggers can distinguish between narrow-band high frequency species (mainly porpoises) and other cetaceans (dolphins). Therefore, they cannot distinguish to species level, nor can they record soundscapes, dolphin whistles or baleen whale calls.

In the WAMMS pilot study, F-PODs (Full waveform capture POD) were trialled in combination with SoundTraps at the Point Lynas sites for several months to test whether patterns in cetacean occurrence were similar between the instruments. Detection rates of porpoises and dolphins did differ compared to SoundTrap click classification, with lower rates of dolphins detected from the F-POD compared to the SoundTraps, in particular. Temporal patterns in porpoise presence were similar between the F-POD and SoundTrap, but differed for dolphins, where the F-POD appeared to miss peaks in dolphin occurrence recorded by SoundTraps in January to March 2024 (Merchant *et al.*, 2025).

Due to the variability of dolphin echolocation clicks and challenges with classification (Section 3.2.4), it may be that automated click detection and classification from the F-POD is not sufficient and there is not much scope within the F-POD to change detection parameters or investigate periods where dolphins were reported absent. Further investigation prior to equipment selection for a longer-term project and considerations relating to priority species, duration of deployments and budgets available for data storage and processing will likely inform which instrumentation to use.

3.2.4. Data processing and click classification

There are several data processing steps to transform PAM data into cetacean encounters as detailed in Merchant et al., (2025). Of these, echolocation click classification is the most complex and in the pilot study required approximately 75% of time allocated to this project. It is recommended that adequate time resource is accounted for in a long-term monitoring programme.

Echolocation click classification

Dolphins produce echolocation clicks with predominant frequencies between 20-50 kHz, overlapping with various biological, environmental, and anthropogenic sounds. This can make distinguishing dolphins from background noise challenging and typically requires validation by eye from an experienced analyst. For long-term PAM monitoring, particularly at sites where dolphin detections are common, this is unlikely to be feasible. Therefore, some level of automation of click classification is required. To date, there is no established dolphin click classifier available. Classifier performance is likely to vary and may be relatively site and species-specific.

For WAMMS workstream 1 pilot study, a dolphin click classifier developed by Dr Douglas Gillespie (Sea Mammal Research Unit, University of St Andrews) was trialled. This classifier was recently developed to classify Risso's dolphin and bottlenose/common dolphins in the Morlais demonstration zone, Northwest Anglesey, as part of the Menter Môn-Marine Characterisation Research Project (MCRP; Gillespie *et al.*, 2023). Due to the vicinity of WAMMS sites and the fact that WAMMS recorders would be detecting the same species, this classifier was tested during the WAMMS pilot study

The classifier was compared with manually verified data from the first deployment at the three sites. It was deemed unlikely to miss entire dolphin encounters (true negatives) but did classify regular false positives, incorrectly identifying noise as dolphin clicks. When concatenating into detection positive hours, however, the outputs collated did not differ from the manually screened data. Therefore, the classifier could be utilised in the WAMMS pilot study but further work on click classification is recommended in a longer-term project. Further, the classifier could not accurately distinguish between the two dolphin categories, Risso's dolphin and bottlenose/common dolphin, with an error rate of approximately 50%. For full details of the click classifier verification procedure see the WAMMS Workstream 1 final report.

Recording at 96 kHz or 192 kHz in future rather than relying on the HF click detector for dolphin detection, may improve classifier performance, since the click detector filters out certain frequencies that may be useful to separate dolphin clicks from other sounds.

The classifier scripts are openly available at
https://github.com/douggillespie/soundtrapclickclassifier.

3.2.5. Data storage and analysis

PAM data storage requirements are similar to those for noise data (section 3.1.5). In some cases, particularly in the study of high frequency echolocation clicks, high data sampling rates are required, resulting in especially large datasets.

SoundTraps specifically produce SUD files, a package of files, that include the WAV file compressed by at least a factor of 3, click detector files (file types bcl and dwv) and a log file. For cetacean data processing, the SUD packages containing all of these files should be stored, and since they are compressed, are smaller in size than raw WAV files.

SUD files can be unpacked directly in PAMGuard software (Gillespie *et al.*, 2008) for streamlined data processing of cetacean data. If not using PAMGuard, SoundTrap Host software will also unpack SUDs to access WAV files and associated files for alternative methods of acoustic data processing and noise assessments.

4. Criteria for recommending monitoring sites

In light of the monitoring considerations set out in Section 3 and policy guidance provided by Natural Resources Wales, a set of criteria for selecting proposed monitoring sites was developed. These criteria will subsequently be applied to the identification of suitable monitoring sites in Section 5. First, we consider the policy priorities outlined by NRW, and then the relevant scientific and logistical factors stemming from the monitoring considerations previously identified.

4.1. Policy priorities

NRW has indicated that priority should be given to monitoring in areas where changes in the underwater soundscape are expected. Such change is likely to occur in areas where future development is anticipated, for example in zones which have been identified as having significant marine renewable energy potential.

Three priority categories have been specified by NRW:

- Priority 1:
  i. Southwest Pembrokeshire
  ii. West coast of Anglesey
  iii. North coast of Wales
  iv. Bristol Channel approaches
- Priority 2:
  i. Llŷn Peninsula
  ii. Cardigan Bay
  iii. Swansea Bay

    iv. Severn Estuary
- Priority 3:
    i. Replication of monitoring in the above areas at different spatial scales

It has also been indicated that where existing monitoring is ongoing, duplication of effort should be avoided, provided these programmes will capture suitable data and make them available to NRW.

4.2. Scientific and logistical factors

In addition to the above priority categories, various scientific and logistical factors affect the suitability of candidate monitoring locations. Six criteria were identified:

i. Proximity to likely development sites, e.g. tidal, wave, and wind resource areas
ii. Proximity to protected areas for cetaceans
iii. Proximity to areas of high cetacean density
iv. Representative coverage of spatial heterogeneity in water depth, seabed/sediment type, distance from shore (ie. inshore vs. offshore), and sound sources present
v. Logistical feasibility: proximity to ports, avoidance of hazards and areas of high sediment transport
vi. Cost of deployment/maintenance

5. Proposed options for all-Wales monitoring programme

5.1. Overview

Based on the criteria outlined in Section 4, seventeen PAM stations are proposed (Figure 8). The stations are categorized according to NRW Priority Category (1 or 2) and distance from shore (inshore or offshore):

- **Priority 1 inshore**: North Wales S (1), South Stack (5), Ramsey Island (11), Pembrokeshire S (13), Bristol Channel E (15)
- **Priority 1 offshore**: North Wales N (2), Holyhead Deep (6), Pembrokeshire W (12), Bristol Channel S (14)
- **Priority 2 inshore**: Point Lynas (3), Bardsey Island (7), Cardigan Bay E (8), Cardigan Bay S (9), Mumbles (16), Severn Estuary (17)
- **Priority 2 offshore**: North Anglesey (4), Cardigan Bay W (10)

These sites provide good coverage of wind, wave and tidal energy resource areas and SACs/high-density regions for cetaceans. The prioritisation of these sites into four categories also allows for a modular approach to the design of the monitoring programme. The full array in the proposed configuration would enable monitoring of relative abundance/encounter rates of cetaceans and spatial and temporal variation in cetacean occurrence around the Welsh coast. It would also be sufficient to ground-truth large-scale sound maps of continuous noise and to provide long-term baseline data on noise levels and their trends in these key development zones. Additionally, there may be opportunities to detect acute effects of noise events on cetacean detection rates. However, for development/activity-specific assessments of noise exposure and its effects on cetaceans, a greater number of PAM stations within the localised study area are recommended.

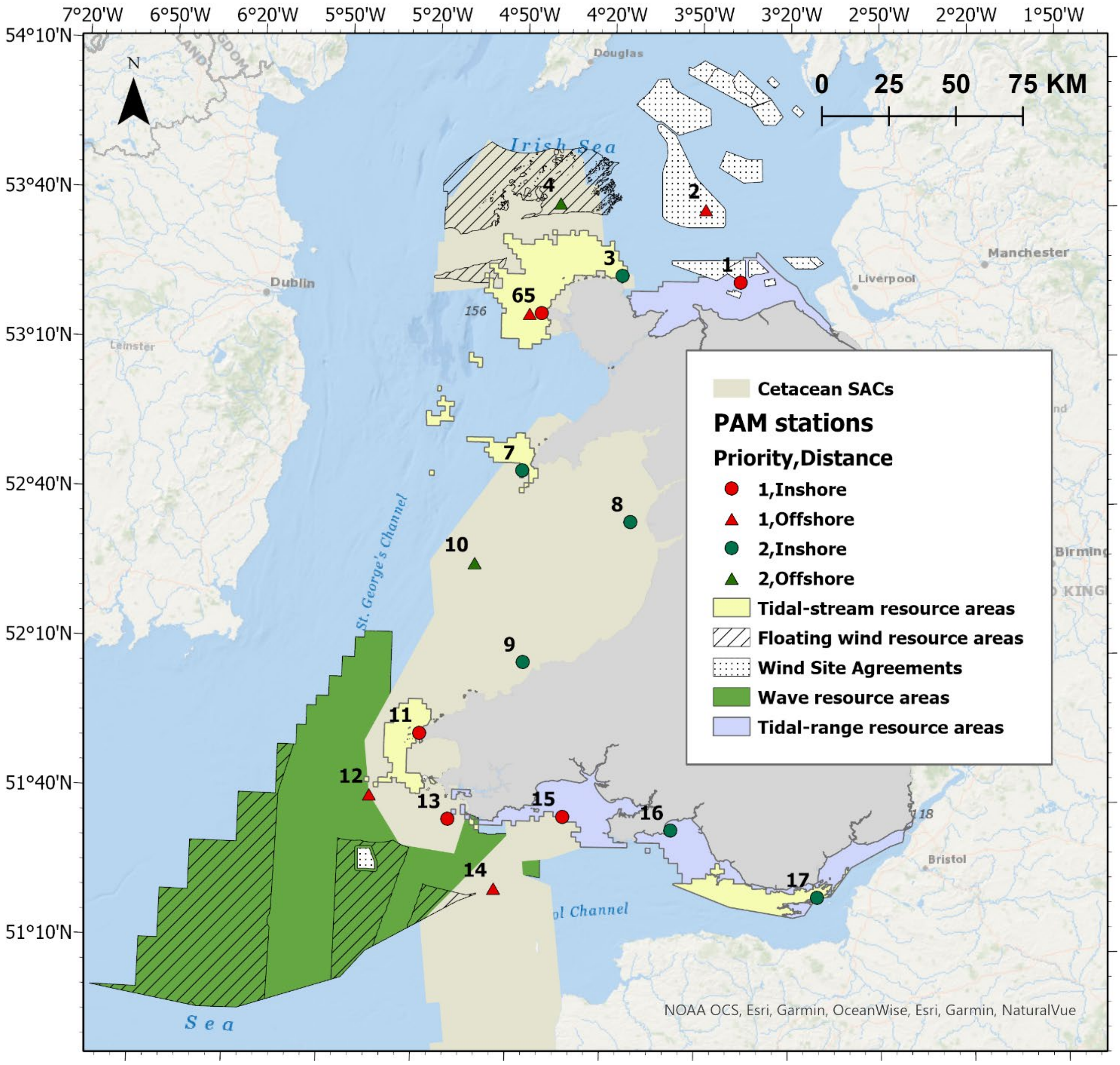

Figure 8. Proposed PAM stations for long-term soundscape and cetacean monitoring in Welsh waters.

Table 4: Proposed PAM stations for a long-term monitoring array for noise and cetaceans in Welsh waters.

ID	PAM station	Priority	Distance	Latitude	Longitude	Selection criteria	Selection criteria
1	North Wales S	1	Inshore	53.416894	-3.614161	Wind energy projects	Marine resource or lease area
1	North Wales S	1	Inshore	53.416894	-3.614161	Tidal-range resource area	Marine resource or lease area
1	North Wales S	1	Inshore	53.416894	-3.614161	Bottlenose dolphin & harbour porpoise	Area of high cetacean activity
2	North Wales N	1	Offshore	53.661088	-3.812322	Wind energy projects	Marine resource or lease area
3	Point Lynas	2	Inshore	53.433903	-4.277207	Harbour porpoise, Risso's, common, bottlenose dolphins, minke whale	Area of high cetacean activity
3	Point Lynas	2	Inshore	53.433903	-4.277207	North Anglesey Marine SAC	Cetacean SAC
3	Point Lynas	2	Inshore	53.433903	-4.277207	Tidal-stream resource area	Marine resource or lease area
3	Point Lynas	2	Inshore	53.433903	-4.277207	Previous PAM data recorded (WAMMS)	Previous PAM data collection
4	North Anglesey	2	Offshore	53.674979	-4.631767	Floating wind resource area	Marine resource or lease area
4	North Anglesey	2	Offshore	53.674979	-4.631767	North Anglesey Marine SAC	Cetacean SAC
5	South Stack	1	Inshore	53.303569	-4.725022	Morlais tidal energy zone	Marine resource or lease area
5	South Stack	1	Inshore	53.303569	-4.725022	North Anglesey Marine SAC	Cetacean SAC
5	South Stack	1	Inshore	53.303569	-4.725022	Harbour porpoise, Risso's, common, bottlenose dolphins	Area of high cetacean activity
5	South Stack	1	Inshore	53.303569	-4.725022	Previous PAM data recorded (Bangor University, Morlais)	Previous PAM data collection

ID	PAM station	Priority	Distance	Latitude	Longitude	Selection criteria	Selection criteria
6	Holyhead Deep	1	Offshore	53.302697	-4.792691	Minesto tidal lease area	Marine resource or lease area
6	Holyhead Deep	1	Offshore	53.302697	-4.792691	North Anglesey Marine SAC	Cetacean sac
6	Holyhead Deep	1	Offshore	53.302697	-4.792691	Harbour porpoise, Risso's, common, bottlenose dolphins, minke whale	Area of high cetacean activity
6	Holyhead Deep	1	Offshore	53.302697	-4.792691	Previous PAM data recorded (Bangor University, WAMMS)	Previous PAM data collection
7	Bardsey Island	2	Inshore	52.774433	-4.81332	Tidal-stream resource area	Marine resource or lease area
7	Bardsey Island	2	Inshore	52.774433	-4.81332	Pen Llŷn a'r Sarnau SAC	Cetacean sac
7	Bardsey Island	2	Inshore	52.774433	-4.81332	West Wales SAC	Cetacean sac
7	Bardsey Island	2	Inshore	52.774433	-4.81332	Harbour porpoise, Risso's, common dolphins	Area of high cetacean activity
7	Bardsey Island	2	Inshore	52.774433	-4.81332	Previous PAM data recorded (Bangor University)	Previous PAM data collection
8	Cardigan Bay E	2	Inshore	52.608677	-4.210024	Pen Llŷn a'r Sarnau SAC	Cetacean sac
8	Cardigan Bay E	2	Inshore	52.608677	-4.210024	West Wales SAC	Cetacean sac
8	Cardigan Bay E	2	Inshore	52.608677	-4.210024	Bottlenose dolphins	Area of high cetacean activity
9	Cardigan Bay S	2	Inshore	52.131869	-4.784309	Cardigan Bay SAC	Cetacean sac
9	Cardigan Bay S	2	Inshore	52.131869	-4.784309	West Wales SAC	Cetacean sac
9	Cardigan Bay S	2	Inshore	52.131869	-4.784309	Bottlenose dolphins	Area of high cetacean activity
10	Cardigan Bay W	2	Offshore	52.462387	-5.06109	West Wales SAC	Cetacean sac
10	Cardigan Bay W	2	Offshore	52.462387	-5.06109	Bottlenose, common dolphins, harbour porpoise	Area of high cetacean activity
11	Ramsey Island	1	Inshore	51.885601	-5.334363	Cambrian Offshore SW Ltd tidal lease site	Marine resource or lease area
11	Ramsey Island	1	Inshore	51.885601	-5.334363	West Wales SAC	Cetacean sac

ID	PAM station	Priority	Distance	Latitude	Longitude	Selection criteria	Selection criteria
11	Ramsey Island	1	Inshore	51.885601	-5.334363	Harbour porpoise	Area of high cetacean activity
11	Ramsey Island	1	Inshore	51.885601	-5.334363	Previous PAM data recorded (SMRU)	Previous PAM data collection
12	Pembrokeshire W	1	Offshore	51.676371	-5.596063	Wave energy resource area	Marine resource or lease area
12	Pembrokeshire W	1	Offshore	51.676371	-5.596063	West Wales SAC	Cetacean sac
12	Pembrokeshire W	1	Offshore	51.676371	-5.596063	Common dolphins	Area of high cetacean activity
13	Pembrokeshire S	1	Inshore	51.600076	-5.167734	Wave energy resource area	Marine resource or lease area
13	Pembrokeshire S	1	Inshore	51.600076	-5.167734	West Wales SAC	Cetacean sac
14	Bristol Channel S	1	Offshore	51.373353	-4.913085	Wave energy resource area	Marine resource or lease area
14	Bristol Channel S	1	Offshore	51.373353	-4.913085	Bristol Channel Approaches SAC	Cetacean sac
15	Bristol Channel E	1	Inshore	51.616667	-4.55	Tidal-range resource area	Marine resource or lease area
15	Bristol Channel E	1	Inshore	51.616667	-4.55	Bristol Channel Approaches SAC	Cetacean sac
16	Mumbles	2	Inshore	51.576774	-3.966534	Tidal-range resource area	Marine resource or lease area
16	Mumbles	2	Inshore	51.576774	-3.966534	Previous PAM data recorded (Swansea University)	Previous PAM data collection
16	Mumbles	2	Inshore	51.576774	-3.966534	Harbour porpoise	Area of high cetacean activity
17	Severn estuary	2	Inshore	51.354835	-3.177358	Tidal-stream and range resource area	Marine resource or lease area

5.2. Selection features

The selection features for each proposed site are detailed in Table 4, and include:

- Marine resource or current lease areas (focusing on renewable energy)
- Cetacean SACs
- Regions of known ecological importance or high sightings rates for cetaceans
- Previous PAM data collection and therefore knowledge of the site

Many of these proposed stations are sited in similar locations to those proposed in the Defra-funded soundscape monitoring plan for the Celtic and Irish Seas (Figure 7) since many of same criteria apply to both projects (Putland *et al.*, 2024).

5.3. Indicative costing

To give an indication of the scale of costs associated with each set of proposed locations, we compiled illustrative costings for the Priority 1 and Priority 2 inshore and offshore sites as set out in Section 5.1, using recent estimates made by Putland et al (2024) for the Celtic and Irish Seas.

These estimates are for the field monitoring aspects only and do not include staff time for data analysis or administrative tasks such as risk assessments or securing marine licences, since costs for these aspects will vary widely depending on the organisation fulfilling them. For example, staff time to analyse a year of data from one station could vary from days (e.g. basic noise analysis) to multiple months (e.g. detailed species detection and identification of species and analysis of occurrence in relation to other data sources) depending on the depth and type of analysis required.

Itemised costs used in the estimates are provided in Table 5. Each of the site categories is then costed separately: Priority 1 inshore (Table 6), Priority 1 offshore (Table 7), Priority 2 inshore (Table 8), Priority 2 offshore (Table 9).

Table 5. Cost estimates for field components of a passive acoustic monitoring programme, assuming only one type of recording device is used (Putland et al., 2024)

Cost category	Cost Category	Estimated cost range	Comments
Acoustic equipment	Autonomous hydrophone system	~ £3,000 – £10,000	Also need to consider import taxes and cost of delivery for overseas manufacturers.
Acoustic equipment	Calibration	~ £1,500	Recommended to calibrate every 3-5 years
Acoustic equipment	Data storage	~ £5,000	Often paid per year. Range depends on size required and whether available as direct access or stored on data archives where data needs to be rehydrated to access.
Mooring	Acoustic release	~ £5,900 (+ £8,340)	1 x ARC system from RS-AQUA (deck unit and transponding hydrophone needed for communication)
Mooring	Lander/mooring cost	£1,000 - £8,000	Lower end cost for simpler mooring design with anchor chain clumps, rope and subsurface floats, higher end cost for a lander with trawl protection (see section 3.2 for more information)
Mooring	Miscellaneous mooring costs	~ £1,000	Certain components may need to be replaced each deployment such as batteries for acoustic releases, anodes, shackles etc.
Mooring	Storage costs for equipment	~ £1,000	Per month. External storage facilities may be needed depending on size and weight of equipment.
Mooring	Surface marker/ guard buoy hire and servicing	£5,000 - £13,500	Per year cost depending on supplier and distance offshore

Cost category	Cost Category	Estimated cost range	Comments
Mooring	Time for personnel to prepare mooring and service equipment	Needs to be factored in	Depends on daily rate of staff
Marine licence	Natural Resources Wales	£1,000 - £3,000	Licence application for duration of deployment/recovery period
Marine licence	Time for personnel to submit permissions/ notice to mariners	Needs to be factored in	Depends on daily rate of staff
Vessel costs per deployment/recovery[1]	Large research vessel (such as RV Endeavour or RV Corystes)	£10,000 - £30,000	Including fuel and personnel onboard
Vessel costs per deployment/recovery[2]	Large commercial vessel (using company such as Trinity House or Briggs)	£3,500 - £12,000	Depending on if coastal or offshore.
Vessel costs per deployment/recovery[3]	Small charter vessel (such as fishing vessel)	£2,000 - £3,000	Typically limited to coastal operations
Vessel costs per deployment/recovery[4]	Courier costs for equipment to port	£500 - £2,000	Depends on distance to port call
Vessel costs per deployment/recovery[5]	Time for personnel to verify vessel risk assessments, charter vessel and manage courier of equipment	Needs to be factored in	Depends on daily rate of staff

[1] Note that vessel costs are based on most recent deployment costs, plus 5% added for inflation of fuel and personnel costs.
[2] Note that vessel costs are based on most recent deployment costs, plus 5% added for inflation of fuel and personnel costs.
[3] Note that vessel costs are based on most recent deployment costs, plus 5% added for inflation of fuel and personnel costs.
[4] Note that vessel costs are based on most recent deployment costs, plus 5% added for inflation of fuel and personnel costs.
[5] Note that vessel costs are based on most recent deployment costs, plus 5% added for inflation of fuel and personnel costs.

*Table 6: Illustrative annual budget for the five Priority 1 inshore stations (North Wales S, South Stack, Ramsey Island, Pembrokeshire S, Bristol Channel E; see Figure 8, Table 5) excluding data analysis and staff time for administration, e.g. of risk assessments. *based on one vessel servicing two northern stations in one day and another servicing the three southern stations in one day, with five deployments/recoveries required for each site.*

Cost category	Individual cost	No. of stations	No. of deployments	No. vessel days	Expected cost	Total cost
Acoustic recording equipment	~£5,500	5	NA	NA	~£27,500	~£131,840
Calibration	~£1,500	5	NA	NA	~£7,500	NA
Acoustic release - Receiver	~£5,900	5	NA	NA	~£29,500	NA
Acoustic release - Deck unit and transponding hydrophone for project	~£8,340	1	NA	NA	~£8,340	NA
Mooring - Infrastructure (anchor, chain, rope, floats etc)	~£1,500	5	NA	NA	~£7,500	NA
Mooring - Consumables (batteries, shackles, anodes etc.)	~£1,000	5	NA	NA	~£5,000	NA
Vessel costs - Small charter vessel	~£3,000	5	4	10* + 4 contingency	~£42,000	NA
Marine licence	~£2,000	NA	NA	NA	~£2,000	NA
Data storage	~£2,500	NA	NA	NA	~£2,500	NA

*Table 7: Illustrative annual budget for the four Priority 1 offshore stations (North Wales N, Holyhead Deep, Pembrokeshire W, Bristol Channel S; see Figure 8, Table 5) excluding data analysis and staff time for administration, e.g. of risk assessments. *based on one vessel servicing two northern stations in one day and another servicing the two southern stations in one day, with five deployments/recoveries required for each site.*

Cost category	Individual cost	No. of stations	No. of deployments	No. vessel days	Expected cost	Total cost
Acoustic recording equipment	~£5,500	4	NA	NA	~£22,000	~£242,440
Calibration	~£1,500	4	NA	NA	~£6,000	NA
Acoustic release - Receiver	~£5,900	4	NA	NA	~£23,600	NA
Acoustic release - Deck unit and transponding hydrophone for project	~£8,340	1	NA	NA	~£8,340	NA
Mooring - Infrastructure (anchor, chain, rope, floats etc)	~£1,500	4	NA	NA	~£6,000	NA
Mooring - Consumables (batteries, shackles, anodes etc.)	~£1,000	4	NA	NA	~£4,000	NA
Vessel costs - Small charter vessel	~£12,000	4	4	10* + 4 contingency	~£168,000	NA
Marine licence	~£2,000	NA	NA	NA	~£2,000	NA
Data storage	~£2,500	NA	NA	NA	~£2,500	NA

*Table 8: Illustrative annual budget for the six Priority 2 inshore stations (Point Lynas, Bardsey Island, Cardigan Bay E, Cardigan Bay S, Mumbles, Severn Estuary; see Figure 8, Table 5) excluding data analysis and staff time for administration, e.g. of risk assessments. *based on the Point Lynas site being included in existing vessel days for Priority 1 inshore, plus one vessel servicing three mid-Wales sites and another servicing two southern stations (as an additional day for vessel servicing southern Priority 1 inshore sites), with five deployments/recoveries required for each site.*

Cost category	Individual cost	No. of stations	No. of deployments	No. vessel days	Expected cost	Total cost
Acoustic recording equipment	~£5,500	6	NA	NA	~£33,000	~£147,240
Calibration	~£1,500	6	NA	NA	~£9,000	NA
Acoustic release - Receiver	~£5,900	6	NA	NA	~£35,400	NA
Acoustic release - Deck unit and transponding hydrophone for project	~£8,340	1	NA	NA	~£8,340	NA
Mooring - Infrastructure (anchor, chain, rope, floats etc)	~£1,500	6	NA	NA	~£9,000	NA
Mooring - Consumables (batteries, shackles, anodes etc.)	~£1,000	6	NA	NA	~£6,000	NA

Cost category	Individual cost	No. of stations	No. of deployments	No. vessel days	Expected cost	Total cost
Vessel costs - Small charter vessel	~£3,000	6	4	10* + 4 contingency	~£42,000	NA
Marine licence	~£2,000	NA	NA	NA	~£2,000	NA
Data storage	~£2,500	NA	NA	NA	~£2,500	NA

*Table 9: Illustrative annual budget for the two Priority 2 offshore stations (North Anglesey, Cardigan Bay W; see Figure 8, Table 5) excluding data analysis and staff time for administration, e.g. of risk assessments. *based on one vessel servicing each station on separate days, with five deployments/recoveries required for each site.*

Cost category	Individual cost	No. of stations	No. of deployments	No. vessel days	Expected cost	Total cost
Acoustic recording equipment	~£5,500	2	NA	NA	~£11,000	~£211,640
Calibration	~£1,500	2	NA	NA	~£3,000	NA
Acoustic release - Receiver	~£5,900	2	NA	NA	~£11,800	NA
Acoustic release - Deck unit and transponding hydrophone for project	~£8,340	1	NA	NA	~£8,340	NA
Mooring - Infrastructure (anchor, chain, rope, floats etc)	~£1,500	2	NA	NA	~£3,000	NA
Mooring - Consumables (batteries, shackles, anodes etc.)	~£1,000	2	NA	NA	~£2,000	NA

Cost category	Individual cost	No. of stations	No. of deployments	No. vessel days	Expected cost	Total cost
Vessel costs - Large charter vessel	~£12,000	2	4	10* + 4 contingency	~£168,000	NA
Marine licence	~£2,000	NA	NA	NA	~£2,000	NA
Data storage	~£2,500	NA	NA	NA	~£2,500	NA

5.4. Optimisation options

While we believe that the proposed array would meet the evidence needs as outlined by NRW, there may be reasons to reduce or augment the number of stations deployed in some areas. Here, we weigh some of the cost and evidence considerations of doing so.

5.4.1. Priority 1 vs. Priority 2

The full array proposed offers a representative coverage of Welsh waters, with an emphasis on marine resource areas (largely renewable energy) and known cetacean habitats. Limiting the array to Priority 1 areas would still offer some coverage of the main energy development sites, but would leave gaps in the coverage of cetacean habitats, notably the Priority 2 sites in mid-Wales and the Severn Estuary. If large-scale changes in the distributions of cetacean species occur as a result of marine development, then these Priority 2 sites may be important for understanding how these distributions have changed. They also provide important baseline cetacean occurrence data to inform broader conservation objectives.

5.4.2. Fine-scale monitoring

The proposed array addresses large-scale monitoring of Welsh waters, but it does not include fine-scale variations in distribution. Finer scale monitoring may be beneficial to better understand broader patterns in cetacean distribution, such as the variability in occurrence with distance from shore. The design of the ECOMMAS array on the east coast of Scotland addressed this question, with each of the ten sites consisting of a transect of three monitoring locations at an increasing distance from shore. Adding cetacean detectors in such a configuration at the key monitoring sites could provide valuable information on this question.

5.4.3. Replication

The proposed array design prioritises spatial coverage over replication at the same site. However, this approach risks underestimating the uncertainty in cetacean detection data, which can vary greatly over even a small area. Deploying multiple cetacean detectors in close proximity at some locations could help to better quantify the uncertainty in these measurements.

While underwater noise measurements tend not to be as variable, there is still value in deploying multiple recorders in a localised area where there are significant uncertainties about sound propagation, since the propagation loss from a specified source (such as a passing ship) can be better estimated where there are multiple receivers.

5.4.4. Offshore stations

Deploying monitoring stations offshore is generally more costly and may be more logistically complex than monitoring near to shore. Reducing the number of offshore stations bmay therefore be considered a straightforward approach to reducing the cost and complexity of the monitoring programme. However, this is likely to come at the cost of significant evidence.

Current knowledge of cetacean occurrence in Welsh waters is biased toward coastal, near-shore observations, despite many marine development areas being sited offshore (Figure 8). Furthermore, offshore PAM stations provide important information on cetacean ranges. It is currently not clear if some cetacean species leave Welsh waters altogether at certain times of year or whether instead they move offshore within Welsh waters. Knowledge of whether these species have viable alternative habitat offshore has implications for the consequences of displacement from coastal activities.

Similarly, offshore stations provide important evidence on underwater noise levels. In deeper offshore waters, sound can propagate further, and so each monitoring station will tend to have a larger acoustic ‘catchment’ of sound, and therefore be representative of a larger area than a site in shallower coastal waters. There is also a bias towards inshore monitoring for underwater noise, meaning that sound maps used to guide policy are less thoroughly ground-truthed in offshore areas than regions close to shore, increasing the uncertainty in predictions, and therefore the uncertainty in policy decisions informed by these sound maps.

References

Basan, F., Fischer, J.-G., Putland, R., Brinkkemper, J., de Jong, C. A. F., Binnerts, B., Norro, A., *et al.* 2024. The underwater soundscape of the North Sea. Marine Pollution Bulletin, 198: 115891. Elsevier.

Benhemma-Le Gall, A., Graham, I. M., Merchant, N. D., and Thompson, P. M. 2021. Broad-Scale Responses of Harbor Porpoises to Pile-Driving and Vessel Activities During Offshore Windfarm Construction. Frontiers in Marine Science, 8: 735. https://www.frontiersin.org/article/10.3389/fmars.2021.664724.

Booth, C. G., Sparling, C. E., Plunkett, R., Scott-Hayward, L., and Rextad, E. 2015. Collision Risk Simulation Modelling: Marine Mammals and Deep Green Device at Holyhead Deep- Final Report. Report Number SMRUC-MIN-2015-007. Provided To Minesto UK LTD, June 2015 (Unpublished).

Brandt, M. J., Dragon, A. C., Diederichs, A., Bellmann, M. A., Wahl, V., Piper, W., Nabe-Nielsen, J., *et al.* 2018. Disturbance of harbour porpoises during construction of the first seven offshore wind farms in Germany. Marine Ecology Progress Series.

Cañadas, A., Donovan, G. P., Desportes, G., and Borchers, D. L. 2009. A short review of the distribution of short-beaked common dolphins (Delphinus delphis) in the central and eastern North Atlantic with an abundance estimate for part of this area. NAMMCO Scientific Publications, 7: 201–220.

de Boer, M. N., Simmonds, M. P., Reijnders, P. J. H., and Aarts, G. 2014. The influence of topographic and dynamic cyclic variables on the distribution of small cetaceans in a shallow coastal system. PLoS One, 9: e86331. Public Library of Science San Francisco, USA.

Dekeling, R., Tasker, M., Van der Graaf, A. J., Ainslie, M., Andersson, M., André, M., Castellote, M., *et al.* 2014. Monitoring Guidance for Underwater Noise in European Seas. JRC Scientific and Policy Report EUR 26557 EN, Publications Office of the European Union, Luxembourg, 2014. https://dx.doi.org/10.2788/29293.

Duarte, C. M., Chapuis, L., Collin, S. P., Costa, D. P., Devassy, R. P., Eguiluz, V. M., Erbe, C., *et al.* 2021. The soundscape of the Anthropocene ocean. Science, 371.

Dudzinski, K. M., Brown, S. J., Lammers, M., Lucke, K., Mann, D. a, Simard, P., Wall, C. C., *et al.* 2011. Trouble-shooting deployment and recovery options for various stationary passive acoustic monitoring devices in both shallow- and deep-water applications. The Journal of the Acoustical Society of America, 129: 436–48. http://www.ncbi.nlm.nih.gov/pubmed/21303023 (Accessed 19 November 2014).

Erbe, C., Marley, S. A., Schoeman, R. P., Smith, J. N., Trigg, L. E., and Embling, C. B. 2019. The Effects of Ship Noise on Marine Mammals—A Review. https://www.frontiersin.org/article/10.3389/fmars.2019.00606.

Evans, P. G. H., and Waggitt, J. J. 2023. Modelled Distribution and Abundance of Cetaceans and Seabirds in Wales and Surrounding Waters. NRW Evidence Report, Report No: 646. Natural Resources Wales, Bangor. 354 pp.

Farcas, A., Powell, C. F., Brookes, K. L., and Merchant, N. D. 2020. Validated shipping noise maps of the Northeast Atlantic. Science of the Total Environment, 735: 139509.

Fischer, J. G., Kuhnel, D., and Basan, F. 2021. JOMOPANS Measurement Guidelines: WP5 Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (Jomopans).

Gilles, A., Authier, M., Ramirez-Martinez, N. C., Araújo, H., Blanchard, A., Carlstrom, J.,

Eira, C., *et al.* 2023. Estimates of cetacean abundance in European Atlantic waters in summer 2022 from the SCANS-IV aerial and shipboard surveys. Final report published 29 September 2023. 64 pp. https://tinyurl.com/3ynt6swa.
Gillespie, D., Mellinger, D. K., Gordon, J., Mclaren, D., Redmond, P., McHugh, R., Trinder, P. W., *et al.* 2008. PAMGUARD: Semiautomated, open source software for real-time acoustic detection and localisation of cetaceans. Journal of the Acoustical Society of America, 30: 54–62. Curran Associates.
Gillespie, D., Veneruso, G., Rapson, K., Vince, E., and Sparling, C. 2023. Passive Acoustic Monitoring (PAM) – Static PAM array to measure the temporal and spatial distribution of vocalising cetacean species in and around the development site. Menter Môn-M.
Gomez, C., Lawson, J. W., Wright, A. J., Buren, A. D., Tollit, D., and Lesage, V. 2016. A systematic review on the behavioural responses of wild marine mammals to noise: the disparity between science and policy. Canadian Journal of Zoology, 94: 801–819.
Graham, I. M., Merchant, N. D., Farcas, A., Barton, T. R., Cheney, B., Bono, S., and Thompson, P. M. 2019. Harbour porpoise responses to pile-driving diminish over time. Royal Society Open Science, 6: 190335. https://doi.org/10.1098/rsos.190335.
Hammond, P. S., Macleod, K., Berggren, P., Borchers, D. L., Burt, L., Cañadas, A., Desportes, G., *et al.* 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation, 164: 107–122.
Hammond, P. S., Francis, T. B., Heinemann, D., Long, K. J., Moore, J. E., Punt, A. E., Reeves, R. R., *et al.* 2021. Estimating the abundance of marine mammal populations. Frontiers in Marine Science, 8: 735770. Frontiers Media SA.
Haver, S. M., Gedamke, J., Hatch, L. T., Dziak, R. P., Van Parijs, S., McKenna, M. F., Barlow, J., *et al.* 2018. Monitoring long-term soundscape trends in U.S. Waters: The NOAA/NPS Ocean Noise Reference Station Network. Marine Policy, 90: 6–13.
IAMMWG. 2022. Updated abundance estimates for cetacean Management Units in UK waters. JNCC Report No. 680 (Revised March 2022), JNCC Peterborough, ISSN 0963-8091.
IAMMWG. 2023. Review of Management Unit boundaries for cetaceans in UK waters (2023). JNCC Report 734, JNCC, Peterborough, ISSN 0963-8091.
Ivanchikova, J., and Tregenza, N. 2023. Validation of the F-POD—A fully automated cetacean monitoring system. Plos one, 18: e0293402. Public Library of Science San Francisco, CA USA.
Jensen, F., Bejder, L., Wahlberg, M., Aguilar de Soto, N., Johnson, M., and Madsen, P. 2009. Vessel noise effects on delphinid communication. Marine Ecology Progress Series, 395: 161–175. http://www.int-res.com/abstracts/meps/v395/p161-175/ (Accessed 24 October 2014).
Kragh, I. M., McHugh, K., Wells, R. S., Sayigh, L. S., Janik, V. M., Tyack, P. L., and Jensen, F. H. 2019. Signal-specific amplitude adjustment to noise in common bottlenose dolphins (Tursiops truncatus). Journal of Experimental Biology, 222: jeb216606. https://doi.org/10.1242/jeb.216606.
Marques, T. a, Thomas, L., Martin, S. W., Mellinger, D. K., Ward, J. a, Moretti, D. J., Harris, D., *et al.* 2013. Estimating animal population density using passive acoustics. Biological reviews of the Cambridge Philosophical Society, 88: 287–309. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3743169&tool=pmcentrez&

rendertype=abstract (Accessed 31 July 2014).
Martin, B., Whitt, C., McPherson, C., Gerber, A., and Scotney, M. 2012. Measurement of long-term ambient noise and tidal turbine levels in the Bay of Fundy. *In* Australian Acoustical Society Conference 2012, Acoustics 2012: Acoustics, Development, and the Environment.
Merchant, N. D., Pirotta, E., Barton, T. R., and Thompson, P. M. 2014. Monitoring ship noise to assess the impact of coastal developments on marine mammals. Marine Pollution Bulletin, 78: 85–95. Elsevier Ltd.
Merchant, N. D., Fristrup, K. M., Johnson, M. P., Tyack, P. L., Witt, M. J., Blondel, P., and Parks, S. E. 2015. Measuring acoustic habitats. Methods in Ecology and Evolution, 6: 257–265.
Merchant, N. D., Farcas, A., and Powell, C. P. 2018. Acoustic metric specification: Deliverable 6/1/1 of EU INTERREG project Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS). 25 pp.
Merchant, N. D., Putland, R. L., and Veneruso, G. 2025. Welsh Acoustic Marine Mammal Survey (WAMMS) Phase 3 Report: Options for an all-Wales monitoring programme for underwater noise and small cetaceans. Cefas Project Report for Natural Resource Wales. 24 pp.
Nowacek, D. P., Thorne, L. H., Johnston, D. W., and Tyack, P. L. 2007. Responses of cetaceans to anthropogenic noise. Mammal Review, 37: 81–115. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2907.2007.00104.x/pdf (Accessed 7 November 2014).
Nuuttila, H. K., Bertelli, C. M., Mendzil, A., and Dearle, N. 2018. Seasonal and diel patterns in cetacean use and foraging at a potential marine renewable energy site. Marine Pollution Bulletin, 129: 633–644. Elsevier.
Palmer, K. J., Brookes, K., and Rendell, L. 2017. Categorizing click trains to increase taxonomic precision in echolocation click loggers. The Journal of the Acoustical Society of America, 142: 863–877. AIP Publishing.
Pirotta, E., Booth, C. G., Costa, D. P., Fleishman, E., Kraus, S. D., Lusseau, D., Moretti, D., *et al.* 2018. Understanding the population consequences of disturbance. Ecology and Evolution, 8: 9934–9946. Wiley-Blackwell. https://doi.org/10.1002/ece3.4458.
Putland, R. L., de Jong, C. A. F., Binnerts, B., Farcas, A., and Merchant, N. D. 2022. Multi-site validation of shipping noise maps using field measurements. Marine Pollution Bulletin, 179: 113733. https://www.sciencedirect.com/science/article/pii/S0025326X22004155.
Putland, R. L., Merchant, N. D., and Veneruso, G. 2023. Welsh Acoustic Marine Mammal Survey (WAMMS) Methodology Report. Cefas project report for Natural Resources Wales. 26 pp.
Putland, R. L., Farcas, A., and Faulkner, R. 2024. Soundscape monitoring plan for Irish and Celtic Seas: considering the potential of impacts to marine mammals and fish from future offshore wind developments. Report to UK Department for Environment, Food & Rural Affairs. 102 pp.
Risch, D., Clark, C. W., Dugan, P. J., Popescu, M., Siebert, U., and Van Parijs, S. M. 2013. Minke whale acoustic behavior and multi-year seasonal and diel vocalization patterns in Massachusetts Bay, USA. Marine Ecology Progress Series, 489: 279–295.
Risch, D., Wilson, S. C., Hoogerwerf, M., Van Geel, N. C. F., Edwards, E. W. J., and Brookes, K. L. 2019. Seasonal and diel acoustic presence of North Atlantic minke

whales in the North Sea. Scientific Reports, 9: 3571. Nature Publishing Group UK London.
Robinson, S. P., Lepper, P. A., and Hazelwood, R. A. 2014. Good Practice Guide for Underwater Noise Measurement.
Russell, D. J. F., Hastie, G. D., Thompson, D., Janik, V. M., Hammond, P. S., Scott-Hayward, L. A. S., Matthiopoulos, J., *et al.* 2016. Avoidance of wind farms by harbour seals is limited to pile driving activities. Journal of Applied Ecology, 53: 1642–1652.
Shucksmith, R., Jones, N. H., Stoyle, G. W., Davies, A., and Dicks, E. F. 2009. Abundance and distribution of the harbour porpoise (Phocoena phocoena) on the north coast of Anglesey, Wales, UK. Journal of the Marine Biological Association of the United Kingdom, 89: 1051–1058. Cambridge University Press.
Soldevilla, M. S., Henderson, E. E., Campbell, G. S., Wiggins, S. M., Hildebrand, J. A., and Roch, M. A. 2008. Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks. The Journal of the Acoustical Society of America, 124: 609–624. AIP Publishing.
Soldevilla, M. S., Baumann-Pickering, S., Cholewiak, D., Hodge, L. E. W., Oleson, E. M., and Rankin, S. 2017. Geographic variation in Risso's dolphin echolocation click spectra. The Journal of the Acoustical Society of America, 142: 599–617. Acoustical Society of America.
Southall, B. L., Nowacek, D. P., Bowles, A. E., Senigaglia, V., Bejder, L., and Tyack, P. L. 2021. Marine mammal noise exposure criteria: assessing the severity of marine mammal behavioral responses to human noise. Aquatic Mammals, 47: 421–464. European Association for Aquatic Mammals.
Taylor, N., Authier, M., Banga, R., Genu, M., Macleod, K., and Gilles, A. 2023. Marine mammal bycatch. *In* OSPAR, 2023: The 2023 Quality Status Report for the Northeast Atlantic. OSPAR Commission, London. https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/marine-mammal-bycatch.
Teilmann, J., Miller, L. A., Kirketerp, T., Kastelein, R. A., Madsen, P. T., Nielsen, B. K., and Au, W. W. L. 2002. Characteristics of echolocation signals used by a harbour porpoise (Phocoena phocoena) in a target detection experiment. Aquatic Mammals, 28: 275–284. EUROPEAN ASSOCIATION FOR AQUATIC MAMMALS.
Van Parijs, S., Clark, C., Sousa-Lima, R., Parks, S., Rankin, S., Risch, D., and Van Opzeeland, I. 2009. Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. Marine Ecology Progress Series, 395: 21–36. http://www.int-res.com/abstracts/meps/v395/p21-36/ (Accessed 8 November 2014).
Viola, S., Grammauta, R., Sciacca, V., Bellia, G., Beranzoli, L., Buscaino, G., Caruso, F., *et al.* 2017. Continuous monitoring of noise levels in the Gulf of Catania (Ionian Sea). Study of correlation with ship traffic. Marine Pollution Bulletin, 121: 97–103.
Waggitt, J. J., Dunn, H. K., Evans, P. G. H., Hiddink, J. G., Holmes, L. J., Keen, E., Murcott, B. D., *et al.* 2018. Regional-scale patterns in harbour porpoise occupancy of tidal stream environments. ICES Journal of Marine Science, 75: 701–710.
Whitlow, W. L. A. 1993. The Sonar of Dolphins. Springer.
Williams, R., Wright, A. J., Ashe, E., Blight, L. K., Bruintjes, R., Canessa, R., Clark, C. W., *et al.* 2015. Impacts of anthropogenic noise on marine life: Publication patterns, new discoveries, and future directions in research and management. Ocean and Coastal

Management, 115: 17–24.
Wisniewska, D. M., Johnson, M., Teilmann, J., Siebert, U., Galatius, A., Dietz, R., and Madsen, P. T. 2018. High rates of vessel noise disrupt foraging in wild harbour porpoises (Phocoena phocoena). Proceedings of the Royal Society of London B: Biological Sciences, 285. The Royal Society. http://rspb.royalsocietypublishing.org/content/285/1872/20172314.
Wisniewska, D. M. M., Johnson, M., Teilmann, J., Rojano-Doñate, L., Shearer, J., Sveegaard, S., Miller, L. A., *et al.* 2016. Ultra-High Foraging Rates of Harbor Porpoises Make Them Vulnerable to Anthropogenic Disturbance. Current Biology, 26: 1441–1446.

Appendices

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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