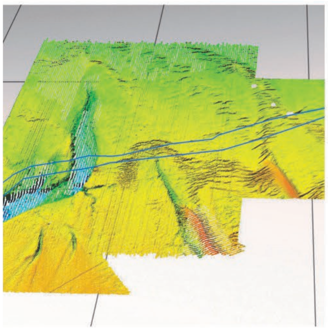
Office for Environmental Protection

Review of the Effects of Underwater Noise on the Achievement of Good Environmental Status in UK Marine Waters

A report for the Office of Environmental Protection

June 2025



Innovative Thinking - Sustainable Solutions

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Document Information

Document History and Authorisation	
Title	Review of the Effects of Underwater Noise on the Achievement of Good Environmental Status in UK Marine Waters
	A report for the Office of Environmental Protection
Commissioned by	Office for Environmental Protection
Issue date	June 2025
Document ref	R4814
Project no	R/5561/01

Date	Version	Revision Details
25/04/2025	1	Issued for client review
30/05/2025	2	Issued for client use
30/06/2026	3	Issued for client use

Prepared (PM)	Approved (QM)	Authorised (PD)
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Suggested Citation

ABPmer, (2025). Review of the Effects of Underwater Noise on the Achievement of Good Environmental Status in UK Marine Waters, A report for the Office of Environmental Protection, ABPmer Report No. R4814. June 2025.

Notice

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Executive Summary

The UK Government has a statutory obligation to achieve Good Environmental Status (GES) for underwater noise under the UK Marine Strategy and several other international initiatives. GES for underwater noise is defined under Descriptor 11 (D11) of the UK Marine Strategy and involves minimising the level of anthropogenic impulsive and continuous noise to an extent that does not adversely affect populations of marine life.

This study builds upon the findings of the recent call for evidence undertaken by the Office for Environmental Protection (OEP) to gather evidence on the drivers and pressures affecting the achievability of GES. This call for evidence identified that further action is needed to meet GES for D11. The call for evidence, amongst other evidence sources (which are discussed in this report), provide the basis of this study.

A thorough literature review has been carried out to describe the types of underwater noise, and their impacts on marine life. This review is based on the best available known evidence sources covering the key receptors that can be affected by underwater noise, namely marine mammals, fish, invertebrates, and diving birds. These receptors fall under GES Descriptors D1 (Biological Diversity) and D4 (Food Webs) of the UK Marine Strategy. Further to this, published reports on industry trends, as well as expert judgement, was used to form evidence-based projections of how underwater noise (and its effect on marine life) is likely to change in the future.

The evidence sources gathered were further reviewed to determine the current status of GES for D11, and the progress that has been made thus far towards achieving GES. Based on this, evidence-based conclusions are provided as to how the UK's policy and regulatory responses may need to change to manage projected future trends. Finally, in support of this, the opportunities and limitations of emerging and innovative technologies (to assess potential strategies to manage and mitigate the impacts of underwater noise) are presented.

This study will support the OEP in making evidence-based decisions to hold the UK Government to account on the implementation of environmental law.

The overarching targets that are required to be met to achieve GES for D11 are defined as follows:

- Target 1: Levels of anthropogenic impulsive noise sounds sources do not exceed levels that adversely affect populations of marine animals; and
- Target 2: Levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely affect populations of marine animals.

Since the first assessment of GES for D11 in 2012, a large number of actions have been undertaken to progress towards achieving GES. The outcome of these has enabled the status of underwater noise to progress from being 'Uncertain' in 2012 to being 'Partially achieved' as of 2025. It should be noted, however, that nuance exists, and GES being partially achieved is not directly related to a measurable reduction in the level of underwater noise. Instead, partially achieving GES for D11 is due to the improved monitoring of anthropogenic impulsive and non-impulsive sounds. This has partly been achieved by fulfilling the indicator for Target 1, to establish a noise registry recording the distribution of anthropogenic impulsive sound sources. The Marine Noise Registry (MNR) was established in 2015 and provides the UK's first mechanism for recording impulsive noise.

In addition to the MNR, several research and monitoring programmes have been undertaken across the UK to gather evidence on the impacts of underwater impulsive and non-impulsive noise which support the achievement of Target 1 and Target 2. These include Defra's Offshore Wind Enabling Actions Programme (OWEAP) and the Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS). Several initiatives and codes have also helped to manage and monitor underwater noise across the UK. These include publishing guidance on mitigation methods, such as the updated unexploded ordnance (UXO) joint position statement, and the introduction of noise thresholds in, for example, harbour porpoise Special Areas of Conservation (SACs).

Whilst these actions have considerably improved the understanding of underwater noise and its effects, compared to, for example 20 years ago, knowledge and evidence is still not at the level required to fully manage and mitigate underwater noise to avoid any potential significant adverse effects. This requirement for more evidence should be considered alongside the challenge that underwater noise is likely to increase, although it is recognised that future spatial-temporal trends across different sectors is uncertain and dependent on global scale pressures. Whilst there is currently expected to be growth in the offshore wind industry and shipping, trends in other sectors, such as tourism, military activity, and oil and gas, are less certain.

As a result, this study has identified that a more holistic and strategic approach to underwater noise management should be implemented to address the uncertainties associated with the population level effects of underwater noise and also anticipated increases in noise generating activities in the future. Key future opportunities and conclusions identified include:

- The development of a UK underwater noise management plan designed to enable strategic monitoring and reporting in order to gather and share evidence across, and beyond the UK. This could involve coordination of management mechanisms, such as for Marine Protected Areas (MPAs), European Protected Species (EPS), and marine spatial planning;
- Increased engagement with international organisations, such as the Contracting Party of The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), to implement regional action plans (RAPs);
- Improved regulatory management through continued development and utilisation of the MNR, and adoption of licence conditions based on the continuous receipt of evidence; and
- Continued investment into technological innovation, including through the provision of subsidies.

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1 Introduction

In the marine environment where light is often limited, the acoustic soundscape is a key source of information for supporting the function of marine organisms. From perceiving their surroundings, communicating, locating food, and finding protection, the ability to hear and interpret sound is essential for marine life, as detailed in Section 4 (Duarte *et al*., 2021).

To maintain a healthy and productive marine environment it is, therefore, essential to manage and minimise the adverse impacts of underwater noise on marine life. This is, in part, addressed through the UK Government's statutory obligation to achieve Good Environmental Status (GES) for underwater noise as defined under Descriptor 11 (D11) of the UK Marine Strategy, required under the Marine Strategy Regulations 2010[1]. D11 outlines the need to monitor and manage the introduction of energy, particularly in the form of sound, into the marine environment due to its potential to disrupt the ecological balance. The targets for D11, and indicators that have been set to achieve the targets, are detailed in Section 1.1.

This report has been commissioned by the Office for Environmental Protection (OEP) to review the extent to which GES for underwater noise has been achieved, as defined in the UK Marine Strategy. The UK Marine Strategy Regulations 2010 were transposed from the European (EU) Marine Strategy Framework Directive[2]. GES now applies as assimilated law under the Retained EU Law (Revocation and Reform) Act 2023[3].

The report also provides evidence-based conclusions that could help to further minimise the impact of underwater noise on marine life. A key driver for this study has been the 2023 call for evidence issued by the OEP to gather evidence on the drivers, pressures, and evidence gaps affecting the achievability of GES. The call for evidence concluded that D11 is a key pressure and one requiring further assessment in order to meet GES (Opergy Group, 2024).

The OEP is a public body established by the Environment Act 2021. The OEP's principal objective is to protect and improve the environment by holding government and other public authorities to account on the implementation of environmental law including commitments and targets to deliver a healthy and productive marine environment. The OEP's work covers England, Northern Ireland and reserved matters across the UK.

This report has been prepared by ABPmer to support the OEP to develop an independent view of the current challenges of achieving GES for D11 by:

- Gathering and undertaking a thorough review of recent literature to develop a robust and up-to-date evidence base detailing the current understanding of the impacts of underwater noise on the marine environment;
- Providing evidence-based projections of the future trends in underwater noise within the UK marine area (e.g. as a result of growth in maritime activities), and assessing how the scale and intensity of these future trends are likely to impact the marine environment and the achievement of GES;

1 The Marine Strategy Regulations 2010 - The Marine Strategy Regulations 2010

2 Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) - Directive - 2008/56 - EN - EUR-Lex

3 Retained EU Law (Revocation and Reform) Act 2023 - Retained EU Law (Revocation and Reform) Act 2023

- Presenting evidence-based advice to identify where and how efforts should be focussed to resolve the current barriers and challenges in achieving GES. This includes projecting how the UK's policy and regulatory responses to underwater noise may need to change according to the future trends identified above, so as to achieve GES; and
- Identifying and evaluating emerging technologies, or other innovation in practice, that could mitigate the impacts of underwater noise that have been identified. This includes assessing their readiness for adoption.

The following section provides an overview of the background to GES and wider commitments related to underwater noise. The remainder of the report has been structured as follows:

Section 2: Approach;
Section 3: Types of underwater noise;
Section 4: Impacts of underwater noise on the marine environment;
Section 5: Future trends in underwater noise;
Section 6: Implications of achieving GES;
Section 7: Future opportunities; and
Section 8: Conclusion.

1.1 Background

The UK is legally obligated under several national and international initiatives to manage the impacts of underwater noise, including under the UK Marine Strategy. The UK Marine Strategy commits the UK to reducing both impulsive and continuous noise levels to a point that does not adversely affect the marine environment by implementing the statutory targets to reach GES. In this way, the UK Marine Strategy provides the framework through which GES is monitored and delivered. GES has been defined for 11 descriptors, with D11 being underwater noise. Other descriptors include cetaceans, seals, birds, fish, and pelagic habitats under D1 to D4, hydrographical conditions under D7, and marine litter under D10. For each of the individual descriptors, targets are used to measure progress towards GES, and indicators are set to achieve the targets.

The framework to achieve GES consists of three components which together set out the strategy for assessing, monitoring, and taking action in order to achieve GES. These components are:

UK Marine Strategy Part One

- Published in 2012 (HM Government, 2012)
    - Defines criteria and targets of each programme of measure (i.e., D11, for underwater noise) and provides the first assessment of the status of GES.
- Published in 2019 (Defra, 2019)
    - Updates the version published in 2012, and provides a more up-to-date assessment of the status of GES.

UK Marine Strategy Part Two

- Published in 2014 (Defra, 2014)
    - Sets out the monitoring programmes that will be used to monitor the progress of each indicator towards achieving GES.
- Published in 2022 (Defra, 2022)
    - Updates the version published in 2014 and provides updated monitoring programmes.

UK Marine Strategy Part Three

- Published in 2015 (Defra, 2015)
  - Sets out the programme of measures that will be used to help achieve GES.
- Published in 2025 (Defra, 2025a)
  - Updates the version published in 2015 and provides an updated programme of measures and an assessment of the status of GES.

The aim of the UK Marine Strategy (and overarching Marine Strategy Regulations 2010) is to protect, preserve, and restore the marine ecosystems in areas where they have been adversely affected by reducing and/or preventing pollution in the marine environment, with a view to ensure there are no significant impacts on or risks to marine biodiversity, human health, or legitimate uses of the sea (UK Government, 2012).

The targets which were updated in 2019[4] used to measure progress towards GES in the future for underwater noise, as defined under D11, are (Defra, 2022):

- **Target one** (impulsive noise): Levels of anthropogenic impulsive noise sounds sources do not exceed levels that adversely affect populations of marine animals; and
- **Target two** (continuous noise): Levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely affect populations of marine animals.

The indicators that been set to achieve the targets are:

- **Indicator one** (impulsive sounds): The number of days and locations where impulsive sounds exceed a certain threshold.
- **Indicator two** (continuous noise): The annual average of the sound level in the 63 Hz and 125 Hz third-octave bands.

The progress towards achieving GES thus far is illustrated in Figure 1. The status of GES has progressed from being uncertain, to partially achieved. Part three of the UK Marine Strategy details that D11 has been partially achieved due to the research and monitoring programmes established since 2012. These have improved the understanding of the impacts of the underwater sounds on marine life (Defra, 2025a). However, it is noted that increased monitoring does not correspond to a reduction in underwater noise levels and improved achievement of GES. Instead, increased monitoring can capture a better understanding and provide a greater driver for reducing underwater noise. In this way, progress towards GES thus far can be viewed as a qualitative rather than quantitative benefit, and the 'partially achieved' status of GES for D11 is not due to a measured reduction in underwater noise.

[4] Previous targets as set out in UK Marine Strategy Part One (2012) are: (1) To establish a 'noise registry' to record, assess, and manage the distribution and timing of anthropogenic sound sources measured over the frequency band 10 Hz to 10 kHz, exceeding the energy source level 183 dB re 1 µPa² m² s; or the zero to peak source level of 224 dB re 1 µPa² m² over the entire UK hydrocarbon licence block area. (2) Surveillance indicator to monitor trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS; average noise level in these octave bands over a year) measured by observation stations.

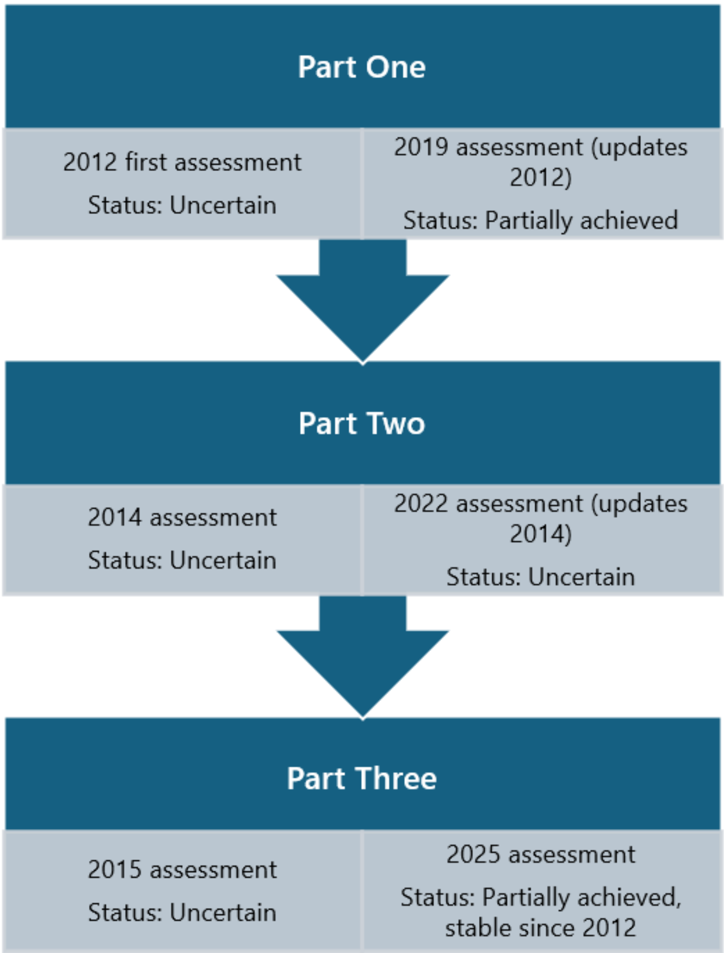


Figure 1. Status assessment and progress to date on descriptor (D11) for underwater noise, part of Good Environmental Status for UK marine waters.

This is not dissimilar to the progress made by Member States of the European Union which are obliged to achieve GES for D11 under the Marine Strategy Framework Directive 2008/56/EC. Member States have reported that progress thus far is, in part, due to the creation of monitoring programmes and noise registers (Tornero Alvarez *et al.*, 2023). For example, the QUIETMED programme involved creating a joint impulsive noise register in the Mediterranean Region. This register aims to serve as a tool to help calculate the spatial-temporal trends in impulsive noise across the Mediterranean region and achieve the impulsive noise MSFD indicator for GES. In addition, the Soundscapes in the North Adriatic Sea project set up a platform for countries in the Adriatic sea to collaboratively monitor and manage underwater noise and directly help Member States achieve GES (MSFD Common Implementation Strategy Technical Group on Underwater Noise TG-NOISE, 2019).

There are numerous other national and international laws and initiatives that consider the pressures on the marine environment, including underwater noise, and aim to avoid or reduce those impacts as far as possible. This includes the UK's commitment as a Contracting Party of The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), and therefore commitment to adhere to the North-East Atlantic Environment Strategy 2030 (OSPAR, 2021), specifically strategic objective eight. This objective, similarly to D11, aims to "*Reduce anthropogenic underwater noise to levels that do not adversely affect the marine environment*". In the strategy there is no direct link between objective eight and GES, as there are for other objectives such as objective five and nine. See Section

6.2.1 for further details on the OSPAR strategy. National legislation includes the Habitats Regulations[5], the Marine and Coastal Access Act 2009[6], and for England only, The Environmental Targets (Marine Protected Areas) Regulations 2022[7].

In addition, underwater noise, including mitigation measures, is considered through environmental assessment legislation across the UK with Scotland and Northern having equivalent regulations to England[8]. For example, the Marine Works (Environmental Impact Assessment) Regulations 2017[9] require regulatory authorities awarding consent for types of projects (that fall under the Regulations) to make their decisions in full knowledge of any likely significant effects on the environment, including underwater noise. The applicant is required to undertake an Environmental Impact Assessment (EIA) which assesses the potential likely significant effects on the environment (including from underwater noise) and the need for mitigation measures to avoid or minimise any significant adverse effects. The potential impacts of underwater noise may also need to be assessed as part of other environmental assessments, such as a Habitats Regulations Assessment (HRA) and Strategic Environmental Assessment (SEA).

5 Including the Conservation of Habitats and Species Regulation 2017; the Conservation (Natural Habitats, etc.) Regulations (Northern Ireland) 1995; the Conservation (Natural Habitats, &c.) Regulations 1994; and the Conservation of Offshore Marine Habitats and Species Regulations 2017.

6 Marine and Coastal Access Act 2009. Part 4 Chapter 1 Marine Licensing and Part 5 Nature conservation

7 The Environmental Targets (Marine Protected Areas) Regulations 2022. Section 3

8 Legislation includes but not limited to the Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 2017; and the Marine Works (Environmental Impact Assessment) (Scotland) Regulations 2017.

9 The Marine Works (Environmental Impact Assessment) (Amendment) Regulations 2017

2 Approach

A thorough review of government strategies and policies, peer reviewed academic literature, the outcomes of research and monitoring initiatives, and grey literature was undertaken to gather a comprehensive evidence base on underwater noise. This was focussed on capturing robust evidence on the types, and impacts of underwater noise within the UK, as well as the latest available information on how underwater noise is being managed in order to progress towards achieving GES.

The review was undertaken using search tools such as ScienceDirect and Google Scholar using search terms designed to capture only the most relevant information. Terms included:

- "underwater noise impacts";
- "underwater noise and Good Environment Status";
- "underwater noise policy";
- "underwater noise management"; and
- "underwater noise mitigation".

It was important to gather information from a range of authors and sources, as action taken towards achieving GES for underwater noise is due to a variety of initiatives and techniques delivered by a range of different bodies. These include both national governing bodies and international organisations, the most prominent being the UK Governments and OSPAR. The key authors and sources targeted in this review included:

- Governments (e.g., UK Government, Welsh Government, and Scottish Government);
- Government departments (e.g., Department for Environment Food and Rural Affairs (Defra), and Department for Energy Security and Net Zero (DESNZ));
- International stakeholders (e.g., OSPAR, International Maritime Organisation (IMO));
- Licensing authorities (e.g., the Marine Management Organisation (MMO), Natural Resources Wales (NRW), Marine Directorate Licensing Operations Team (part of Scottish Government), Department for Agriculture, Environment and Rural Affairs (DAERA));
- Statutory Nature Conservation Bodies (SNCBs) (e.g., Joint Nature Conservation Committee (JNCC), NatureScot, Natural England (NE), NRW);
- Developers (i.e., those responsible for implementing mitigation techniques); and
- Research / academic institutions (e.g., universities, consultancies, non-governmental organisations (NGOs)).

The review sought to capture information on the key industries that produce underwater noise, alongside information on the environments most sensitive to the impacts of underwater noise. This helped to form a robust picture of where mitigation efforts should be focussed. The key sectors and activities identified include:

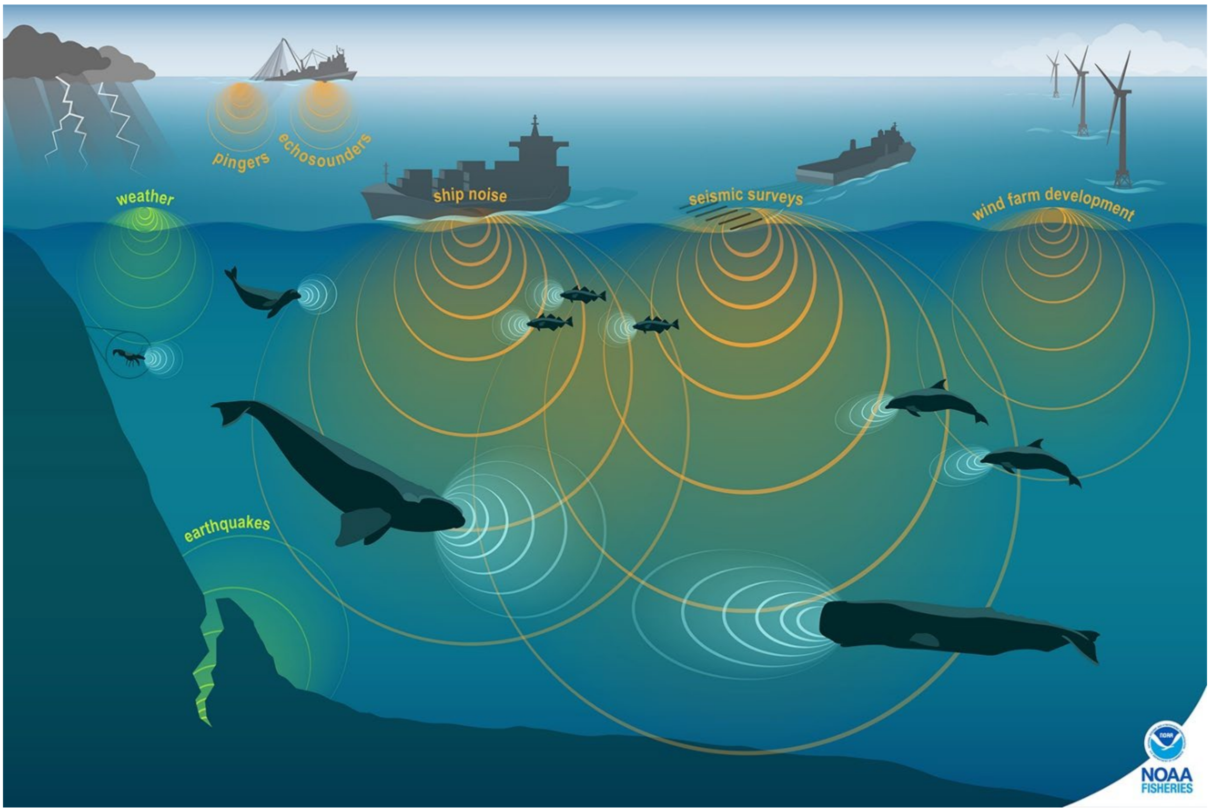
- Offshore energy development;
- Ports and shipping;
- Dredging and aggregates;
- Military activity; and
- Tourism.

The evidence gaps arising from the literature review have also been discussed to highlight areas that should be targeted for further investigation.

3 Types of underwater noise

UK Marine Strategy Descriptor 11 (D11) highlights underwater noise as a significant factor in determining GES of UK marine waters. This descriptor outlines the need to monitor and manage the introduction of energy, particularly in the form of sound, into the marine environment due to its potential to disrupt the ecological balance. D11 is divided into two core criteria: impulsive sound events and continuous low-frequency sound, both of which are assessed in terms of their intensity, frequency, duration, and geographic distribution (Defra, 2025a).

The underwater soundscape comprises a range of both natural and anthropogenic sound sources, which can be impulsive or continuous. Figure 2 is a widely used illustration of the key natural and anthropogenic sources of underwater noise. These sources (as well as others) are discussed in further detail in the sub-sections below.



Source: ©NOAA 2025

Figure 2. Types of underwater noise (NOAA, 2025)

Naturally occurring underwater sounds arise from geophysical events, such as earthquakes and volcanic activity, as well as meteorological conditions, including wind-driven wave action and rainfall. Other natural contributors include the thermal movement of water, ice cracking in polar regions, and biological sources such as fish vocalisations, echolocation clicks of toothed cetaceans, and the whale song (Thomsen *et al.*, 2021; PIANC, 2025).

Over time, human activities have increasingly become dominant contributors to the underwater soundscape. These anthropogenic sources are diverse and include commercial shipping, offshore construction activities such as pile driving (including percussive or impact piling, vibro piling and bored piles), seismic and geophysical surveys, and military or industrial explosions. Other activities include the use of sonar, which involves emitting pulses onto the seabed and measuring its return to detect topographic features, and the use of explosives to dispose of unexploded ordnance (UXO). In addition, sounds are also produced from recreational and tourism activities (namely through vessel movements), through aggregate extraction, navigational dredging, oil and gas drilling, and the operation of offshore energy devices. The cumulative effect of these sources has resulted in elevated background noise levels, with potential negative consequences for marine ecosystems (see Section 4) (Thomsen *et al.*, 2021; PIANC, 2025).

In this context, it is important to distinguish between "sound" and "noise". "Noise" is often described as sound that is not a useful signal or cue, that lacks biological relevance for the receiver, and as such may either be neutral or have adverse effects on critical behaviours such as communication, orientation or predator detection (Van der Graaf *et al.*, 2012; ISO, 2017; Southall *et al.*, 2019). "Sound" is often described as a form of energy (and the source of all noise) that can be categorised as either impulsive (single or multiple pulses) or non-impulsive (non-pulsive) (Southall *et al.*, 2007). From a regulatory and ecological perspective, this definition is important, as it forms the basis of assessing whether a sound source is benign or potentially harmful (PIANC, 2025). For clarity, the terms "sound" and "noise" are used interchangeably in this report.

The term "ambient noise" describes the continuous background sound present in the marine environment. Ambient noise is generated by a combination of sources that are not individually distinguishable (PIANC, 2025), for example, distinguishing between different natural sound sources such as wind and rain. In the marine environment, ambient noise levels are now largely influenced by anthropogenic activities, particularly commercial shipping, which generates broad-spectrum low-frequency noise, although natural processes also contribute. Importantly, underwater noise is typically classified into two categories: "impulsive" sounds, which are short in duration and often high in intensity, and "continuous" sounds, which are lower in intensity but persistent over time (Thomsen *et al.*, 2021). These two categories form the basis of the following sections, which consider their characteristics and ecological significance.

3.1 Impulsive sound sources

Impulsive sounds in the marine environment are characterised by their brief duration (typically lasting a matter of milliseconds to seconds), rapid rise time[10], and high amplitude[11]. These sounds usually occur as isolated events or in repetitive sequences and are capable of travelling long distances in any direction through the water column (Thomsen *et al.*, 2021). Due to their sudden and intense nature, impulsive sounds are considered potentially disruptive (see Section 4) and as a result are a particular focus of the UK Marine Strategy for D11 (Defra, 2025a).

One of the most significant contributors to impulsive underwater noise is percussive piling, a technique commonly used during the construction of wind turbines, bridge supports and port infrastructure. This involves driving large steel piles into the seabed using impact hammers, which creates sharp sound bursts that can propagate widely from the source. Most of this sound is airborne and radiates outwards, but some is transmitted into the water (Bellmann *et al.*, 2020; PIANC, 2025). In addition to underwater noise from construction processes, underwater sounds are also used to deter sensitive species away from construction sites. These are referred to as Acoustic Deterrent Devices (ADDs). Examples of ADDs include pingers, which are small devices often installed in set nets around construction sites which emit sound to deter noise sensitive animals from the site.

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10 The rise time of underwater noise refers to the duration it takes for the sound pressure level to increase from its baseline to its peak value. Impulsive sounds typically have very short rise times, often measured in milliseconds, which can cause sudden and intense disturbances to marine life. Continuous sounds, on the other hand, generally have longer rise times and more gradual increases in sound pressure levels.

11 Amplitude refers to the strength or intensity of the sound wave, measured in decibels (dB). It indicates how loud the noise is.

Seismic surveys, largely used in oil and gas exploration for sub-seafloor imaging, are also a source for consideration. These surveys deploy arrays of airguns, emitting high-pressure pulses of air, generating sound waves capable of penetrating the seabed (OSPAR Commission, 2009; Thomsen *et al.*, 2021).

Another source of impulsive sound is the detonation of explosives, which includes removal of structures from the seabed (in construction and decommissioning zones) and the clearance of UXO (in post-conflict zones). These explosions generate intense acoustic energy and shock waves capable of causing significant adverse impacts on marine ecosystems. While typically infrequent, the intensity of these events warrants careful consideration and management (OSPAR Commission, 2009; PIANC, 2025).

Military activities can also produce impulsive underwater noise, namely through the use of sonar in surveillance operations (as sonar can be used to detect submarines), and explosives in training activities (for weapons testing and detonation of dumped military munitions).

Given their potential scale and intensity, impulsive sound sources represent a challenge. In a regulatory context, the levels of impulsive underwater sounds are recorded and assessed under D11, using standardised reporting frameworks with the aim of understanding the distribution and extent of the impulsive acoustic energy introduced into the marine environment (Defra, 2025a).

3.2 Continuous low-frequency sound sources

Ambient underwater noise refers to the continuous (generally low-frequency) background sound present in marine environments. As described in the introduction to Section 3 above, this background sound comprises both natural (e.g., from weather events) and human-induced (via shipping) sounds. Whilst natural sound contributors have formed part of the marine acoustic environment throughout history, human activity now plays a significant role in shaping the low-frequency marine soundscape (Merchant *et al.*, 2016; Thomsen at al., 2021; PIANC, 2025).

In recent history, the contribution of human activities to the underwater soundscape has grown substantially. Commercial shipping is among the most pervasive of sources, as vessels produce a range of low-frequency noises. In regions with dense maritime traffic, such as shipping lanes and ports, ambient noise levels have been observed to increase significantly (Merchant *et al.*, 2016; Thomsen *et al.*, 2021; PIANC, 2025).

Marine aggregate extraction and navigational dredging is also a contributor to underwater low-frequency noise, particularly during the excavation and placement of material, use of machinery and the propulsion of the vessel during transit. Underwater sounds related to aggregate extraction and dredging can be continuous, cyclical or intermittent depending on the activity but are generally shown to be in the lower range of sound source pressures (PIANC, 2025). The operation of offshore energy infrastructure also produces underwater noise due to the continuous movement of machinery including and parts including generators and mooring lines.

Vibro piling is another example of a continuous anthropogenic sound source. Although vibro piling is considered less harmful than impact piling due to its lower intensity, vibro piling involves prolonged and consistent vibration and acoustic output. As such, its contribution to ambient noise and its cumulative effect in terms of sound exposure can still be relevant, particularly in conjunction with other marine construction activities.

Natural ambient noise remains an integral component of healthy marine ecosystems as natural sounds can serve as environmental cues for biological and physical processes. For example, research has shown that underwater noise can impact oyster settlement patterns (Lillis *et al.*, 2014). Understanding the composition and sources of ambient noise is essential for evaluating their ecological significance and developing appropriate underwater noise regulatory and mitigation strategies (Thomsen *et al.*, 2021; PIANC, 2025).

4 Impacts of underwater noise on the marine environment

Underwater noise, resulting from both natural and anthropogenic sources, can significantly affect a range of species in the marine environment (PIANC, 2025; Williams *et al.*, 2021). The impact of underwater noise is primarily dependent on the sensitivity of the species likely to be affected. Species are often grouped into receptors dependent on their varying hearing abilities. This section reviews the potential impacts of underwater noise on the following four receptors:

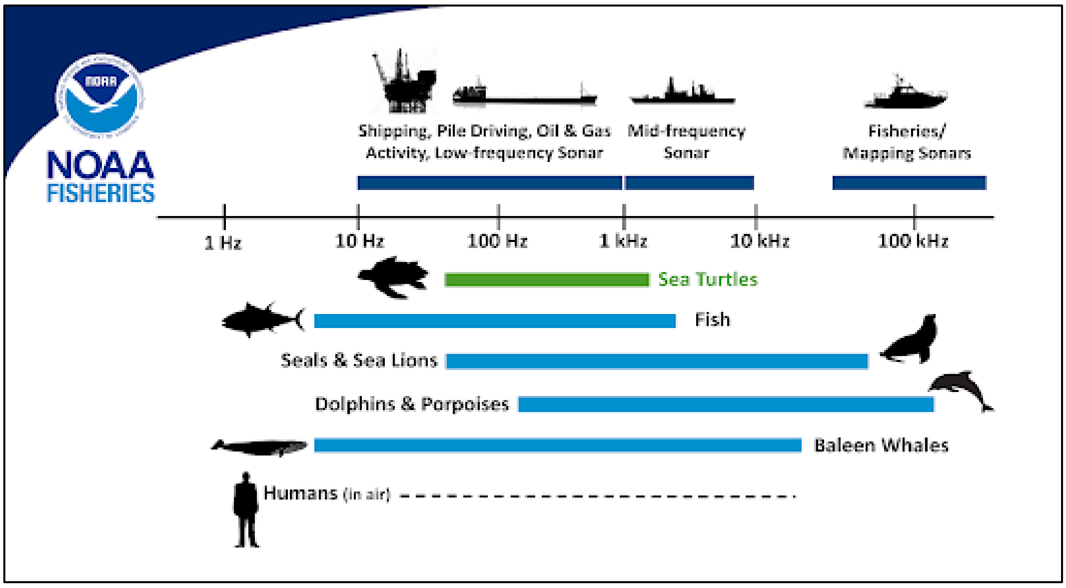
- Marine mammals;
- Fish;
- Invertebrates; and
- Diving birds.

These receptors cover the functional groups that fall under the UK Marine Strategy Descriptor D1 (Biological Diversity) and D4 (Food Webs). For each receptor, effects can broadly be categorised as either physiological (those which can result in physical damage as a result of an animal's stress response) or behavioural (those which can result in changes in an animals' movement as a result of a stress response). Table 1 presents the key physiological and behavioural effects that can impact the receptors, all of which are discussed in further detail in the sub-sections below.

Table 1. Potential effects of underwater noise on key receptors.

Receptor	Physiological effects			Behavioural effects				
	Temporary threshold shift	Permanent threshold shift	Auditory tissue damage	Avoidance Displacement	Change to migration routes	Changes in shoaling behaviour	Stranding	Disruption to predator-prey interactions and/or reproduction
Marine mammals	✓	✓	✓	✓	✓		✓	✓
Fish	✓	✓	✓	✓	✓	✓		✓
Invertebrates				✓	✓			✓
Diving birds				✓				✓

The ability to be impacted by underwater noise depends entirely on the animal's ability to perceive noise in the marine environment. Figure 3 is a widely used illustration of the broad frequency hearing ranges in Hertz (Hz) to Kilohertz (kHz) of the most sensitive receptors to sound pressure (marine mammals and fish), and provides some context for the effects described in the sub-sections below.



Source: © NOAA 2022

Figure 3. **Hearing ranges of noise sensitive species' in the context of anthropogenic sound sources (NOAA, 2022).**

The sections below focus on the impacts on the receptors from anthropogenic sound, though it is acknowledged that impacts can arise due to natural sounds. Marine animals sensitive to underwater noise are habituated to the normal levels of natural noise in their environment, though can be negatively impacted by significant changes to these levels, such as during extreme storm events.

4.1 Marine mammals

Marine mammals are generally recognised as being the most sensitive receptor to anthropogenic underwater sound (PIANC, 2025). Marine mammals are particularly sensitive to underwater noise at higher frequencies and generally have a wider range of hearing than other marine fauna.

The hearing sensitivity and frequency range of marine mammals varies between different species and is dependent on their physiology. Southall *et al.,* (2019) and NOAA (2024) group marine mammals into eight groups according to hearing sensitivity, anatomy and sound production characteristics in order to develop noise exposure criteria. These eight groups comprise:

- Low-frequency cetaceans (e.g., baleen whales such as humpback and minke whales);
- High-frequency cetaceans (e.g., sperm whale and white sided dolphin);
- Very high-frequency cetaceans (e.g., hector's dolphin and harbour porpoise);
- Sirenians (dugongs and manatees);
- Phocid carnivores in water (e.g., harbour and grey seals);
- Phocid carnivores in air (as above, however when air breathing); and
- Other marine carnivores in water and other marine carnivores in air.

As illustrated in Table 1, anthropogenic underwater noise can cause marine mammals a number of physiological and behavioural effects (Gomez *et al.,* 2016). Some examples include long-term avoidance, permanent or temporary reduction in hearing sensitivity often referred to as Permanent Threshold Shift (PTS) or Temporary Threshold Shift (TTS), strandings and changes in their own vocalisation and communication, which can disrupt reproductive and foraging behaviour (PIANC, 2025).

Physiological changes consistent with a stress response have been observed amongst marine mammals (Gomez *et al.,* 2016). Physiological changes, including TTS and PTS have been observed at very high exposure levels, such as offshore impact piling operations. TTS and PTS are injuries which could lead to long term impacts on immunity and survival (Williams *et al.*, 2021).

Physiological effects are easier to quantify than the effects of underwater noise on behaviour, as behavioural reactions are highly variable and context specific (Southall *et al.,* 2007). Behavioural responses to underwater sound are more likely to be observed at low intensity sounds, also described as lower sound pressure levels (SPLs). These reactions may include a brief startle reaction or may result in the animals leaving the area for a period of time. Short and long-term avoidance behaviour has been well documented in response to a number of sources of anthropogenic noise including acoustic deterrent devices (ADDs), vessel noise, seismic activity, and construction (Kastelein *et al.*, 2006; Morton and Symonds, 2002; Radford *et al.*, 2013). Underwater noise has also been shown to disrupt marine mammal diving behaviour by altering descent rates, dive times and dive depths (Radford *et al.*, 2013), as well as disrupting communication amongst marine mammals.

As anthropogenic sounds may interfere with sounds of natural communication, communication behaviours are altered, which is often referred to as 'masking' (Richardson *et al.*, 2013). Marine mammals have been shown to adjust the characteristics of their calls, reduce their amount of calling or cease calling entirely in response to underwater noise exposure (Di Iorio and Clark, 2010; Foote *et al.*, 2004; Parks *et al.*, 2007).

Despite a large body of evidence demonstrating the negative impacts of anthropogenic noise on marine mammals, relatively little work has been done to translate these effects into impacts on survival and reproduction, and determining potential population level effects (Williams *et al*., 2021). The work that has been undertaken thus far indicates that this is due to the large complexity in the mechanisms linking these impacts, but that effects impacting feeding and spawning behaviours could lead to impacts at the population level (Williams *et al*., 2021). In addition, to better understand this, research should be focussed on monitoring the long-term exposure to noise and the cumulative effects this will have.

4.2 Fish

The effects of underwater noise on fish have not been as well documented as the effects on marine mammals (Hawkins and Popper, 2017; Popper *et al.,* 2020). However, the ability to detect and localise the source of a sound is of considerable biological importance to many fish species. Sound is helpful for predator prey interactions, predator avoidance, territorial display and for assessing the suitability of a potential mate (Rako-Gospić and Picciulin, 2019).

Fish can be more sensitive to sound at lower frequencies than marine mammals and generally have a reduced range of hearing. Fish have otolithic organs, which are the dense auditory portions of the ear. These organs are sensitive to particle motion. Particle motion refers to the movement of the surrounding water particles caused by the sound wave as it travels through the water column, it is especially important for locating sound sources through directional hearing (Popper *et al.,* 2014; Hawkins *et al.*, 2015; Nedelec *et al.*, 2015). Although many fish are also likely to detect sound pressure[12], particle motion is considered equally or potentially more important (Hawkins and Popper, 2017). The sensitivity and capability to hear underwater noise can vary substantially between fish species (Hawkins and Popper, 2017; Webb *et al.*, 2008) and is dependent on many factors such as the presence and position of a gas bladder (Popper *et al.,* 2014). Not only is fish sensitivity dependent on the species, but also the level of sound pressure or particle motion, the sound frequency, duration and/or repetition (Hastings and

[12] Pressure fluctuations in the medium above and below the local hydrostatic pressure; it acts in all directions and is a scalar quantity that can be described in terms of its magnitude and its temporal and frequency characteristics.

Popper, 2005). Research has also shown that factors such as location, water temperature, and body conditions also influence the response of fish to underwater noise (Weilgart, 2018).

As presented in Table 1, there are a wide range of potential physiological, behavioural and ecological effects from anthropogenic noise on fish. Physiological impacts include an increase in stress-related cortisol levels, tissue damage, TTS or PTS and immediate death (Wenger *et al.*, 2017; PIANC, 2025). Tissue damage results from the effects of a changing pressure on the gas bladder. Sudden changes in pressure, resulting from impulsive sound sources are more likely to result in damage than gradual changes (Popper *et al.*, 2014). Tissue damage and hearing loss can result in eventual death or may cause fitness impairment until healing occurs, resulting in lower survival rates (PIANC, 2025).

Research has shown a number of fish species experience behavioural responses in reaction to underwater noise, including directional avoidance and startle responses (Roberts *et al.*, 2016a; 2016b; Hawkins *et al.,* 2014). Behavioural changes can potentially result in a number of ecological impacts, including alternations to schooling behaviour, avoidance of important migratory routes, feeding or reproduction grounds which may result in potential population level consequences (Van der Kooij, 2022). Anthropogenic sounds also interfere with biologically important sounds for fish, resulting in masking effects, which is when anthropogenic sounds cause disruption with a marine animal's ability to hear biological cues (Hawkins and Myrberg Jr., 1983).

These physiological and behavioural effects can result in a number of ecological effects. Population consequences may result from temporary or permanent damage to hearing mechanisms and changes in behaviour may alter predator-prey interactions, disrupt foraging and impair reproduction (Rako-Gospić and Picciulin, 2019). For example, avoidance behaviour has been observed in net-penned fish that were exposed to played-back artificial vessel sounds (Weilgart, 2018). Research has also shown that fish experience increased stress (measured by cortisol levels) when similarly exposed to vessel sounds (Weilgart, 2018). In both experiments, it was noted, however, that the reactions were dependant on many factors, as described above.

Future research that has been identified as useful to help address the current knowledge gaps in understanding the impacts of underwater noise on fish, include exploring what makes certain species more vulnerable than others, and researching the behavioural responses of species in terms of their susceptibility to masking and response to sound (Williams *et al.*, 2021). In addition, it has been suggested that research could also explore the impacts and survival of fish that have experienced TTS and tissue damage (Williams *et al.*, 2021).

4.3 Invertebrates

Impacts of underwater noise on benthic invertebrates have been far less documented (Hawkins and Popper, 2017; Southall *et al.,* 2019; Popper *et al.,* 2020). Whilst there is not much research into how marine invertebrates detect sound, they are thought to be particularly sensitive to particle motion (Roberts and Elliott, 2017; U.S Department of the Interior Bureau of Ocean Energy Management, 2012).

Benthic invertebrates are considered to be less sensitive to sound pressure than marine mammals and fish. It is thought this could be due to the lack of gas filled spaces (Edmonds *et al.,* 2016). Invertebrates have much lower sensitivities, below 100 Hz (Hawkins and Popper, 2017; Popper *et al.,* 2020). However, all cephalopods as well as some bivalves, echinoderms, and crustaceans have statocysts which are sac-like structures which include a mineralised mass (statolith) and sensory hairs, which enable the detection of particle motion (Carrol *et al.*, 2017).

Whilst benthic invertebrates are considered less sensitive, they can still potentially be affected by anthropogenic sounds in the marine environment (Williams *et al.,* 2021; PIANC, 2025). Research shows that benthic invertebrates respond to particle motion (Roberts and Breithaupt, 2016). For example, behavioural effects have been recorded in decapod crustaceans, including a change in locomotion activity, changes to predator avoidance behaviour and alteration to foraging behaviour (Tidau and Briffa, 2016). Like marine mammals and fish, invertebrates are also sensitive to masking effects of natural biological sounds (Edmonds *et al.,* 2016). However, the impacts of masking are not well understood as little is known about the role of sound production in invertebrates. Sound may provide a vital role in predator avoidance, foraging or breeding, however, there is also a possibility these sounds are not vital and may be produced incidentally (Williams *et al.,* 2021).

Studies have also demonstrated that noise can cause more significant, permanent damage to biologically important structures of invertebrates, including sensory hairs, antennae and statocysts (André *et al.*, 2011; Edmonds *et al.*, 2016; Mooney *et al.*, 2012). Research by Guerra *et al.,* (2004), for example, found damage to statocysts and organs to seven stranded giant squid after nearby seismic surveys.

There are generally a limited number of studies to show that invertebrates can detect sound even though it is known several invertebrates are capable of producing sound, such as snapping sounds produced by shrimp, and sound from crustaceans as they tap or rub their claws together (Roberts and Elliott, 2017; U.S Department of the Interior Bureau of Ocean Energy Management, 2012). Williams *et al.,* (2021) highlighted key areas required for further research to explore the impacts of underwater noise on benthic invertebrates. This includes more research into how sound propagates along the seabed, invertebrate detection of sound or particle motion and research into differences between invertebrate species.

4.4 Diving birds

Diving birds have the ability to hear both in air and underwater. It is thought many diving birds such as cormorants have anatomical and physiological adaptations for hearing underwater (Larsen *et al.*, 2020). Emperor and King penguins are known to use distinctive vocalisations to identify their partners in busy, noisy colonies (Aubin *et al.,* 2000; Jouventin, 1982), however, the importance of hearing underwater is not clear. It is possible that the ability to hear underwater may be useful for behaviours such as predator avoidance, predator-prey interactions, or even for underwater noise communication as suggested by Thiebault *et al.,* (2019). This study identified that King penguins' vocalisations were used in foraging dives, particularly for chasing prey that were in close proximity, however, the study did not extend to assess the impact of underwater noise on the species.

Diving bird sensitivity to underwater noise (i.e., the frequency at which an individual can perceive sound) is likely to vary between species and between the different sound sources (either impulsive or continuous), however there is very little evidence to identify trends. Hansen *et al.,* (2017), for example, found Great Cormorant have a hearing frequency range between 1 to 4 kHz. McGrew *et al.,* (2022), found Long-tailed ducks and Common eiders to have similar hearing frequency ranges from 1 kHz to 2.96 kHz. Wever *et al.,* (1969), on the other hand, found African penguins have a greater hearing frequency range of between 0.1 to 15 kHz, with peak sensitivities between 0.6 to four Hz.

Diving birds are likely to be exposed to anthropogenic or ambient underwater noise, particularly when diving, however limited research has been undertaken to determine the potential effects (PIANC, 2025). Overall, the physiological and behavioural impacts of underwater noise on diving birds is not well understood.

Evidence which is available, however, identified that African penguins displayed behavioural responses to underwater noise specifically an avoidance behaviour of their preferred foraging areas during seismic activities (Pichegru *et al.,* (2017). In addition, observations of diving birds at the Egmond aan Zee offshore windfarm in the North Sea concluded the potential effects from underwater noise were negligible (Leopold and Camphuysen, 2007). However, this conclusion may have been as a result of the use of effective mitigation techniques such as seasonal restrictions, pinger deterrence methods and a ramp up procedure (Leopold and Camphuysen, 2007).

5 Future trends in underwater noise

There is no doubt that the levels of underwater noise are likely to increase as the marine environment continues to become busier. This is mainly driven by the expansion of the renewable energy industry and increase in shipping activity, as well as the continued operation of other sectors providing essential services. The sounds from these sources should be considered both individually to understand the future noise levels impacting species on a local scale, as well as collectively to understand the cumulative effects. These should also be considered alongside the strategic initiatives or measures that are currently in place to manage underwater noise in the future.

The following sections review these sector specific, transboundary and strategic trends in regard to cumulative impacts. It should be noted that trends in sectors are often based on external influences such as political, economic, environmental, and social drivers. As such, trends that are reviewed in the following sections should be considered as indicative.

5.1 Sector specific trends

Underwater noise will continue to be produced in the marine environment through many of the same activities that currently occur, such as offshore energy generation, shipping, dredging, aggregate extraction, port development, military activity, fishing and tourism. All of these activities will have a role in managing underwater noise by adhering to the shared aims to achieve GES and align with OSPAR's priorities. Understanding the trends of these sectors will help to indicate how and where anthropogenic noise from these sectors will occur in the future. It is acknowledged that other industries use the marine environment such as the cabling sectors (power and telecommunication cables), and emerging sectors such as the carbon capture usage and storage (CCUS), and hydrogen sectors. These sectors are, however, not discussed further as cabling will likely generate small amounts of underwater noise which will not significantly alter the future trends explained below. The emerging industries such as the CCUS, and hydrogen sectors are similarly not discussed further as the levels of noise that will be produced is highly uncertain due to infancy of the sectors and uncertainty in their future expansion.

5.1.1 Offshore energy generation

Oil and gas

It is anticipated that the oil and gas sector, despite being in long-term decline, will continue to operate into the future in order to maintain a stable energy supply during peaks in demand and whilst the transmission of this energy becomes less resilient. The majority of oil and gas infrastructure, and the North Sea Transition Authority's oil and gas licensing rounds indicate where oil and gas exploration will occur in the forthcoming years, this being in the southern North Sea. Sound sources produced from these activities include impulsive noise during drilling and exploration, and ambient noise from vessel movements during operation and maintenance. Underwater noise from exploration of new areas will include sites awarded under the 33rd offshore licence round which is currently focussed around Shetland, Northern North Sea and Central North Sea. Information on the location of the awarded licences, and the duration of drilling at existing sites is, however, not available at the time of writing, though it is likely that exploration of new sites will occur across the next five to 10 years. Updates are published by the North Sea Transition Authority. In addition, in the future oil and gas infrastructure will become decommissioned as they reach the end of their lifespan, and where possible, become re-purposed to support other sectors such as the renewable energy industry (Oil and Gas Authority, 2021), both of which could produce localised noise.

Renewable energy – wind

In regard to renewable energy, operational offshore windfarms, and wave and tidal sites will continue to produce non-impulsive sounds (as described in Section 3) due to the movement of parts including generators and moorings. Evidence suggests the noise from both operational fixed and floating offshore windfarms are characterised as low frequency sounds in the range of 25 to 20 Hz, though it should be noted that frequencies are dependent on many factors, such as rotator speed (Risch, 2008). Other uncertainties arise from the use of new technologies, for which there is typically limited, if any, evidence on the characteristics of the sounds they produce. This is particularly relevant in the context of floating offshore wind, which due to its nascency, is relatively understudied, making impact of newer sound sources such as snapping sounds from snapping of mooring lines uncertain (Cefas, 2022). Non-impulsive sounds that will occur into the future include noise from vessels movements when undertaking operation and maintenance activities.

Existing operational windfarms which will continue to produce underwater noise into the near future are mostly located off the east coast of the UK surrounding East Anglia and the Humber, east Scotland, and seaward from Liverpool Bay (The Crown Estate, 2023). There are far fewer operational wave and tidal sites, in comparison to offshore windfarms, these being located in the areas of the highest wave and tidal resource, off the west coast of the UK and Orkney (RenewablesUK, Undated). The Morlais tidal stream energy development in Anglesey, Wales, for example, has the potential to generate up to 240 megawatts of clean electricity when it is operational. This is expected to be in 2026 (Morlais Energy, 2025).

Looking ahead, the offshore wind sector is set to expand rapidly across the next five to 20 years due to the need to de-carbonise industry and achieve the UK Government's target of 'clean power by 2030' (which will require generating a capacity of 43 to 50 gigawatts (UK Government, 2025), the ambition for Northern Ireland to generate 1 GW by 2030 (Department for Economy, 2022)), and international climate change commitment such as the Paris Agreement (United National Climate Change, 2025). Construction of an offshore windfarm will produce underwater noise through many of the sources described in Section 3. These include seismic and explosive pre-construction surveys, and piling and the use ADDs during construction. Other activities producing underwater noise, though arguable causing less impact, will be from non-impulsive sounds such as dredging (bed preparation) activities.

The future expansion of the offshore wind industry across the UK (which will indicate where underwater noise will be produced) is detailed in The Crown Estate's Marine Delivery Roadmap (2024) and Future Offshore Wind Report (2024). Key future offshore wind developments noted here, which are likely to produce underwater noise in the marine environment, includes the Round 5 floating offshore wind leasing round in the Celtic Sea (The Crown Estate, 2025c) which is set to generate up to 4.5 GW across three project development areas. Figure 4 shows the location of the Round 5 Celtic Sea floating offshore leasing round. In Scotland, Crown Estate Scotland are supporting the UK Government's net zero commitments through the ScotWind leasing round (Crown Estate Scotland, 2023b) and Innovative Targeted Oil and Gas leasing rounds (Crown Estate Scotland, 2023a), the locations of which are included in Figure 4. In Northern Ireland, the expansion of the offshore wind industry is driven, in part, by the Climate Change (NI) Act 2022 (Section 15)[13], in which the Department for the Economy must ensure that at least 80% of electricity consumption is from renewable sources by 2030.A project helping to achieve this is North Channel Wind, a project to generate 1 GW (North Channel Wind, 2023).

13 Climate Change Act (Northern Ireland) 2022

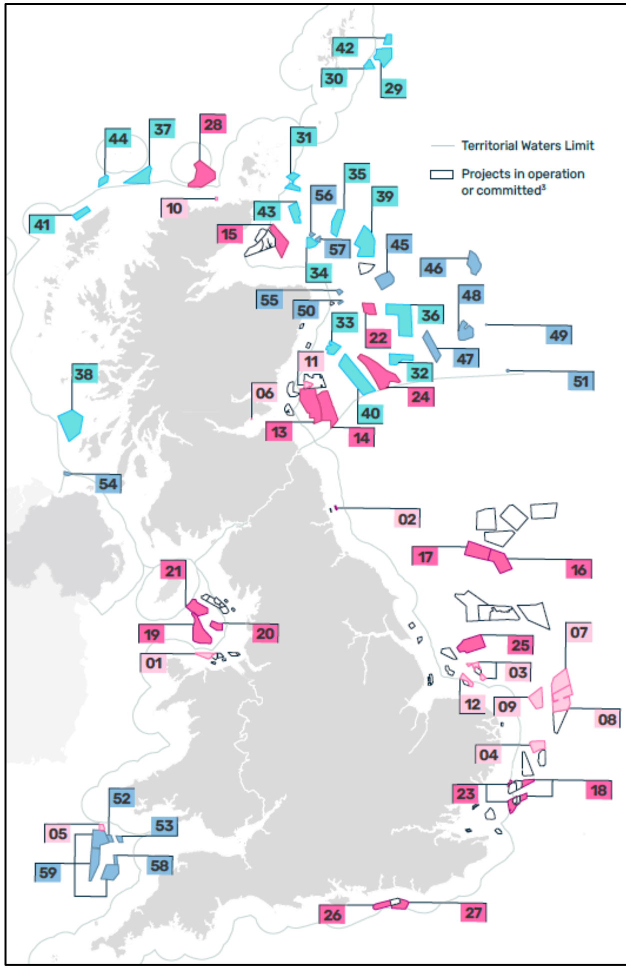


Fig 28

UK offshore wind development pipeline as at 31 December 2024

Consented

Wind farms that have received consent but not yet secured a Contract for Difference

		Up to capacity MW[1]
01	Awel y Môr[Ext]	576
02	Blyth Demonstration Phase 3[T&D]	58
03	Dudgeon Extension[Ext]	402
04	East Anglia ONE NORTH[R3]	950
05	Erebus[T&D]	100
06	Forthwind[T&D, 2]	20
07	Norfolk Boreas[R3]	1,400
08	Norfolk Vanguard East[R3]	1,400
09	Norfolk Vanguard West[R3]	1,400
10	Pentland[T&D, 2]	100
11	Seagreen Phase 1a[R3,2]	500
12	Sheringham Shoal Extension[Ext]	317
Total		**7,223**

In planning

Wind farms for which a consent application has been submitted

		Up to capacity MW[1]
13	Berwick Bank[R3, 2]	4,100
14	Marr Bank[R3,2]	
15	Caledonia[SW, 2]	2,000
16	Dogger Bank South (East)[R4]	1,500
17	Dogger Bank South (West)[R4]	1,500
18	Five Estuaries[Ext]	353
19	Mona[R4]	1,500
20	Morecambe[R4]	480
21	Morgan[R4]	1,500
22	Muir Mhòr[SW, 2]	798
23	North Falls[Ext]	504
24	Ossian[SW, 2]	3,528
25	Outer Dowsing[R4]	1,500
26	Rampion 2 (Rampion Extension)[Ext]	400
27	Rampion 2 (Zone 6)[R3]	800
28	West of Orkney[SW, 2]	2,000
Total		**22,463**

Pre-planning

Wind farms for which a consent application has not yet been submitted

		Up to capacity MW[1]
29	Arven[SW, 2]	1,800
30	Arven South[SW, 2]	500
31	Ayre[SW, 2]	1,008
32	Bellrock[SW, 2]	1,200
33	Bowdun[SW, 2]	1,008
34	Broadshore[SW, 2]	500
35	Buchan[SW, 2]	960
36	CampionWind[SW, 2]	2,000
37	Havbredey[SW, 2]	1,500
38	MachairWind[SW, 2]	2,000
39	MarramWind[SW, 2]	3,000
40	Morven[SW, 2]	2,907
41	Spiorad na Mara[SW, 2]	840
42	Stoura[SW, 2]	500
43	Stromar[SW, 2]	1,000
44	Talisk[SW, 2]	495
Total		**21,218**

Current potential

Projects, leasing rounds and additional capacity subject to AfL, plan-level Habitats Regulations Assessment (HRA), INTOG Sectoral Marine Plan or other pre-conditions

		Up to capacity MW[1]
45	Aspen[TOG, 2]	1,008
46	Beech[TOG, 2]	1,008
47	Cedar[TOG, 2]	1,008
48	Cenos[TOG, 2]	1,350
49	Culzean[TOG, 2]	3
50	Flora[IN, 2]	50
51	Judy[TOG, 2]	15
52	Llŷr 1[T&D]	100
53	Llŷr 2[T&D]	100
54	Malin Sea Wind[IN, 2]	100
55	Salamander[IN, 2]	100
56	Scaraben[IN, 2]	99
57	Sinclair[IN, 2]	99
58	White Cross[T&D]	100
59	Leasing Round 5	4,500
	Additional capacity requests[Ext/R3]	4,000
Total		**13,640**

For the UK offshore wind pipeline as at 31 December 2024, see page 10.

1. Capacities noted are rounded to the nearest whole MW.
2. Managed by Crown Estate Scotland.
3. Under construction or government support on offer.

Ext 2017 Extensions Round project
IN Innovation project, INTOG Leasing Round
R3 Leasing Round 3 project
R4 Leasing Round 4 project
SW ScotWind project
T&D Test & Demonstration scale wind project
TOG Targeted Oil & Gas project, INTOG Leasing Round

Source: ©The Crown Estate 2024

Figure 4. Future offshore wind projects (The Crown Estate, 2024)

In determining the future trends and therefore impacts of underwater noise, it is key to consider the types of noise likely to be produced both spatially and temporally alongside the species likely to be impacted (see Section 4 for potential impact pathways) in order to determine the cumulative impacts that may occur. This is particularly important in areas of ecological importance that overlap with areas of future offshore wind developments.

Renewable energy – wave and tidal

Similarly to offshore wind, construction of wave and tidal energy is set to expand rapidly across the next five to 10 years to support the UK Government's net zero targets. To date (2025 at the time of publishing), the UK has a pipeline for 130 MW of tidal stream capacity to be deployed across England, Scotland, and Wales by 2029 (Grattan *et al*., 2025). In regard to wave energy, the UK has significantly high wave resource, with the potential to generate 24 GW of wave (Noble *et al.,* 2025). Wave Energy Scotland is driving forward wave energy innovation and technology development for this sector.

As a less developed sector, construction methods are not as well established leading to uncertainty in the future impacts of noise from this sector. Nevertheless, it is reasonable to assume that the main sources will similarly be from pre-construction surveys and piling during construction of test and demonstration sites, and the development commercial scale projects. The level of underwater noise and therefore impact of this on marine animals has been monitored at SeaGen 1.2 MW monopile tidal site in Strangford Lough, Northern Ireland. This monitoring found that across three years of post-construction surveys (2008 to 2010), the levels of underwater noise (from turbine operation) was below the levels that are expected to cause auditory impacts to the marine mammals using the site (harbour porpoise, harbour seal, and grey seal). This suggests that there were no negative physiological or behavioural impacts from this source of underwater noise (Phillips *et at.,* 2025). Overall, the monitoring concluded that "*No major impacts on marine mammals have been detected*" (Phillips *et at.,* 2025). The site was decommissioned in 2019. See Phillips *et al.,* (2025) for the outputs of additional tidal monitoring programmes.

A selection of future wave and tidal energy projects in the pipeline across the UK, all of which are likely to produce underwater noise and could potentially impact the marine environment (though the significance of this is unknown), include:

- FABTEST scale wave test site, Falmouth (wave demonstration site expected to commence testing in June 2025 (Falmouth Harbour, 2025));
- Morlais, Anglesey (as discussed above, tidal site expected to become operational in 2026 (Morlais Energy, 2025)); and
- META scale test sites, Milford Haven (various pre-commercial wave and tidal test sites, at various stages of operation (META, 2025)).

5.1.2 Shipping

All forms of shipping (including commercial containers/cargo ships and cruise liners) are recognised by the International Maritime Organisation (IMO) as one of the largest contributors to underwater radiated noise, and requires action in order to minimise the potential adverse impacts on marine life (IMO, 2023). The IMO has undertaken multiple actions to address this, including publishing revised guidelines for the reduction of radiated noise from shipping (IMO, 2023), and establishing a Sub-Committee on Ship Design and Construction (SDC 10). The SDC 10 was formed in 2024 and agreed on an Action Plan which lists tasks to be carried out by countries that are members (of which includes the UK) of the IMO, with the collective aim of reducing underwater noise (IMO, 2024). These tasks listed in the Action Plan include:

- Establishing an experience-building phase during which Member States and international organisations are invited to share lessons learned and best practices that have emerged in the implementation of the Revised Guidelines (IMO, 2023). Key guidelines are detailed in Section 7.7;
- Enhancing public awareness, education and seafarer training;
- Developing targets and policies for underwater noise reduction;
- Developing tools to collect data and share information; and
- Encouraging more research on underwater noise and its impacts on the marine environment.

Shipping traffic across the UK is forecast to remain fairly flat in the short term till 2030 before increasing significantly to 2050. This is presented in the highly referenced 2019 baseline, which predicts freight tonnage through UK ports will increase by 39% by 2050 (DfT, 2019). This will involve optimising the use of artificial intelligence to increase the reliability of supply chain forecasting, and using environmentally sustainable technologies to ensure the sector is cost effective and sustainable (DfT, 2022). Sustainable technologies include those that reduce underwater noise generated by the sector, such as making improvements to propellors and the design of hulls. The complex linkage between the speed at which the industry can quieten ships, whilst expanding as a sector to meet the demand for goods and services is therefore key to consider when forecasting the future underwater noise levels generated by the sector. There is little evidence to predict what this future trend may be, however, it is reasonable to assume that it will take several years, perhaps across at least the next 10 to 20 years for the sector to reduce underwater noise, across the UK, to the level that is proven to not cause an adverse effect on marine life.

5.1.3 Aggregate extraction and navigational dredging

Marine aggregate extraction and navigational dredging are essential services supporting many industries across the UK, including the construction, and shipping sectors. These activities will continue to produce underwater sounds during the duration of the respective aggregate and dredging licences issued. These sounds will be primarily characterised as relatively localised non-impulsive sounds from movement of vessels to, from, and within the aggregate and dredge licence areas, and the contact of aggregate and dredge machinery with the seabed (see Section 3.2). Given these activities are governed by the extents and restrictions (conditions) set by their respective licence (and where required, permits issued by Harbour Authorities) underwater noise from these industries is not expected to cause disturbance to marine life. However, as with all industries, the potential for cumulative impacts will still need to be robustly assessed by developers in the environmental assessments required to be undertaken to support licence applications for consent. There is no evidence to suggest that the existing noise levels produced by these sectors has had a negative impact on marine life. There are also no clear projections of how the magnitude and spatial distribution of dredging activities could change in the future.

5.1.4 Port development

Despite the international driver to minimise underwater noise during shipping activities (see Section 5.1.2), there is a high level of uncertainty regarding future noise levels from port development, which can sometimes involve significant impact piling in the marine environment. Overall, levels are generally anticipated to increase in response to the future trend of increasing offshore renewable energy development, particularly across the next five to 10 years.

There is likely to be an increase in port development into the future including through the construction and expansion of, for example, new terminals, quays and jetties. For example, Belfast Harbour is set to benefit from the largest capital investment the Harbour has seen, in the construction a new deepwater dock to accommodate large cruise vessels and support installation of offshore wind farms. This project is expected to be completed by 2027 (New Civil Engineer, 2025). Drivers for this, in addition to routine maintenance, include to support the offshore wind sector during the construction of windfarms and to support the expansion of green energy sectors such as the CCUS and hydrogen sectors. Port developments are also essential for maintaining both tourist and lifeline ferry services, the aggregate extraction and dredging sectors, and globally important shipping channels. In addition, port expansions enable the UK to respond to changes in future global demands and consumption patterns linked to economic cycles. Future sources of continuous underwater noise, to achieve these, will likely include noise produced during capital dredging requirements to deepen navigation lanes in order to accommodate larger vessels. Other continuous noise will likely originate from any marine piling required for port expansion projects.

Areas across the UK where underwater noise from this sector are anticipated to be most prominent include the possible future development of Port Talbot in South Wales to support the Round 5 floating offshore wind leasing in the Celtic Sea, (ABP, 2024), the Port of Mostyn in North Wales (ABPmer, 2022), and the Port of Cromarty Firth in the East of Scotland (DESNZ, 2025b). Examples of port expansions beyond the offshore wind industry includes construction of the Immingham Green Energy Terminal, a liquid bulk import terminal to help deliver a green hydrogen production facility (Planning Inspectorate, 2025c), and the development of the Immingham Eastern Ro-Ro (roll-on roll-off) Terminal, a new freight ferry terminal to expand and strengthen the UK's supply chain (Planning Inspectorate, 2025b).

5.1.5 Military activity

The types of noise that will be produced from military activities will likely be characterised by impulsive sounds from the use of sonar explosives, and continuous sounds from movement of navy vessels across the UK. It is, however, highly uncertain on where and when these activities will occur, and therefore what the futures trends in underwater noise will be. This is due to limited public data availability, in order to protect national security. If, however, current trends continue, noise from the sector is likely to occur southwest of Cornwall, and the East coast of Scotland (Marine Noise Registry, 2025a). Military activities are exempt from requiring a Marine Licence under Article 4 of the Marine Licensing (Exempted Activities) Order 2011[14]. This means underwater noise produced by the sector in the future will not automatically require noise management measures set through licence conditions.

5.1.6 Fishing and aquaculture

Future underwater noise likely to arise from the fishing sector will namely include continuous low frequency sounds from the movement of fishing vessels transiting to and from fishing grounds, and home and landing ports. In regard to aquaculture, sounds will also likely be produced from the movement of vessels, though less so than for fishing as there are fewer aquaculture sites to transit to/from in comparison to the expanse of UK waters where fish is permitted. In addition, noise will also continue to be produced by contact of aquaculture equipment with the seabed, as would be the case for fishing by trawling. The spatial coverage and intensity of fishing in the UK is likely to remain fairly constant in the short term (across the next five years) to the extent that it will not cause significant change in the underwater noise produced by the sector. This is due to the location of fishing grounds being well established, the exception being climate change, and the pressures from other sea users cause spatial squeeze, and result in the relocation of fishing effort. The trend in this sector further into the future is highly uncertain, but will likely depend on the factors listed above, in addition to future trend in supply and demand, and the regulatory landscape.

[14] The Marine Licensing (Exempted Activities) Order 2011

5.1.7 Tourism

Sources of underwater noise that will likely still occur in the future includes non-impulsive noise from small and localised scale recreational power boating, local boat trips and routine ferry trips in coastal waters, to large scale cruise routes across inshore and offshore areas. The cruising industry, including the number if UK passengers, is forecast to increase steadily over the next five to 10 years (Statista Market Insights, 2025). There is, however, little evidence to determine the impact this will have on the levels of underwater noise in UK waters given that it may not necessarily result in a material increase in the number of cruise vessels or change in existing cruising routes. In addition to vessel movements, underwater noise will also occur from the contact of moorings on the seabed and from the movement of mooring lines in the water column. Although there is little literature to evidence this, moorings are unlikely to have a significant impact on marine life. Future management of tourism activities including recreational boating (namely through licensing and regulatory requirements) will dictate the impacts from underwater noise. Potential management measures and regulatory requirements on the local scale for MPAs could for example include restrictions on access for recreational boating and anchoring in order to safeguard sensitive marine species, as well as speed restrictions. The IMO also regulates cruise vessels as discussed above in Section 5.1.2.

5.2 Transboundary trends

In regard to future trends in transboundary underwater noise, development in particular of offshore windfarms outside of UK waters, for example the Irish Sea, could impact highly mobile species. These will likely include resident marine mammals and fish and also those that use UK waters as part of their migratory route, such as common dolphins, Risso’s dolphins, minke whales, humpback whales, Atlantic salmon and European eel. In addition, vessel movements from shipping and cruising in the English Channel and Baltic Sea could also impact marine mammals occurring in UK waters. The extent to these impacts are, however, highly uncertain and will require assessing the usage of the areas alongside industry trends (which for international waters may be more challenging to obtain).

5.3 Strategic trends

In addition to understanding the future activity of sectors discussed in Section 5.1, existing policies, monitoring programmes, and management measures are strategic initiatives that can also help to indicate the future characteristics and levels of underwater noise. An example of a type of regulatory management measure which can help to indicate future noise levels includes the setting of noise thresholds, as it could be assumed that future noise will not exceed that threshold. For example, the Conservation Objective specified in the five harbour porpoise Special Areas of Conservation (SACs) in English, Welsh and Northern Ireland waters indicates that noise levels should not exceed noise thresholds as discussed in more detail in Section 6.2.6 (Defra, 2025b). In addition, the regulatory obligation to use low noise methods as the default for UXO clearance, as discussed in Section 6.2.1, indicates that future noise levels from this activity will likely be quieter than current levels[15] .

It is also useful to consider the Marine Noise Registry (MNR) as a tool for identifying noise sources likely to occur in the future. In summary, the MNR is a record of anthropogenic impulsive sounds, based on the information that developers have provided in response to Marine Licence conditions where these apply. This would be the case, for example, for the use of pilling during construction (e.g., for offshore energy generation and port development), the use of explosives and seismic surveys (similarly for these sectors), and potentially for military activities where they are not exempt from requiring a Marine

[15] Unless there are extraordinary conditions where low order methods are not viable.

Licence. See Section 6.2.1 for further detail on the MNR. It is, however, only a record of anthropogenic impulsive sounds and therefore likely to be an underestimate of the levels of underwater noise generated by all human activities. It is not possible to quantify the underestimate due to the complexity of cumulative effects.

Proposed anthropogenic activities producing impulsive sounds are recorded in the MNR and provide an indication of the spatio-temporal trends in future underwater noise (JNCC, 2025d). Across 2025 key sound sources include sub-bottom profiling in the west of Scotland and East coast of Scotland extending to the Humber; military sonar between Scotland and Northern Ireland; and impact piling and explosives in southeast England. There is limited data provided in the MNR beyond 2025, with the exception of sub-bottom profiling occurring on a single transect between the Bridlington and Aberdeen (JNCC, 2025d).

In managing future underwater noise produced by different sectors (as discussed in Section 5.1), it is important that monitoring is undertaken to identify feedback loops. This will help to effectively implement any further management measures that might be required, for example to respond to technology adaptations that affect sector-specific noise levels. Given many linkages exist between sectors (including supply chain linkages via the provision of infrastructure) monitoring should be planned and managed at the strategic level. This will help to monitor the cumulative levels of future underwater noise and ensure longer term trends (across the next 20 years) are effectively managed. This will also potentially resolve the key evidence gap of understanding the impacts of underwater noise at the population level, across the UK.

6 Implications for achieving GES

6.1 Current status of GES and underwater noise

The UK Marine Strategy Part One: UK updated assessment 2019 to measure progress towards GES determined that the status of D11 is partially achieved (Defra, 2019). This assessment was based upon measures to develop a noise registry to record the distribution and timing of man-made impulsive noise sources and also to develop a surveillance indicator to monitor trends in ambient noise at sea. The descriptor for underwater noise is only partially achieved as there is uncertainty on the levels and frequency of anthropogenic noise which can cause population and ecosystem level effects (Defra, 2019). Further action is required to understand population and ecosystem level impacts to give greater confidence in achieving GES for underwater noise. An 'uncertain' environmental status assessment for underwater noise GES is also consistent with other territorial assessments such as Gibraltar (Department of Environment, Sustainability, Climate Change and Heritage, 2020).

The UK Marine Strategy Part Three: 2025 UK programme of measures outlined that GES has been partially achieved for underwater noise and that the situation has been stable since 2012 (Defra, 2025a).

6.2 Progress in achieving GES for underwater noise

An updated programme of measures to achieve GES was published in January 2025 in the UK Marine Strategy Part Three (Defra, 2025a). The programme of measures for underwater noise has expanded since the first published programme of measures (Defra, 2015). The UK Marine Strategy Part Three (Defra, 2025a) outlines the delivery of 18 measures which support progress towards GES for underwater noise. Sections 6.2.1 to 6.2.5 below provide a summary of the measures for underwater noise that have been amended or developed over the current cycle of the UK Marine Strategy, or are completely new measures. The UK Marine Strategy Part Three (Defra 2025a) measure codes (e.g. M15.1, M15.2) and action codes (e.g. A15.1, 15.2) are provided for ease of reference.

This report concludes that measures and actions included in UK Marine Strategy Part Three (Defra, 2025a), which are summarised below, are an amalgamation of numerous actions all of which have, to an extent, helped gather evidence that support the progress towards achieving GES. In some cases, the primary driver for measures has not been the UK Marine Strategy. This suggests that there may be some gaps in UK Marine Strategy implementation and reporting the actions for underwater noise.

6.2.1 Measures contributing towards developing noise thresholds:

M15.1: OSPAR North-East Atlantic Environment Strategy

The UK is a signatory to the OSPAR Convention with an agreed vision for a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification. The North East Atlantic Environment Strategy (NEAES) sets OSPAR's vision, strategic and operational objectives to 2030. Objective 8 is to "*Reduce anthropogenic underwater noise to levels that do not adversely affect the marine environment*." Work has been ongoing to develop a Regional Action Plan (RAP) to reduce noise pollution, which will be agreed during 2025. Work has also been ongoing to develop and implement a coordinated monitoring and modelling programme for continuous noise to support an assessment of anthropogenic underwater noise in the OSPAR maritime area (OSPAR, 2021). In the UK, this includes the COMPASS, MarPAMM, JOMOPANS and JONAS project (see Section 6.2.3 for further details), which have helped to inform the OSPAR programme. More information on the progress and success of a coordinated monitoring programme will be available as the RAP develops.

M15.2 Defra Offshore Wind Enabling Actions Programme (OWEAP) underwater noise project

The OWEAP is a Defra and DESNZ programme focused on working to address environmental impacts from offshore wind farm development to reduce consenting delays, support economic recovery and help meet the UK Government's and devolved administration's respective net zero commitments (Defra, 2021). The OWEAP underwater noise project has undertaken a range of activities culminating in the release by the UK Government of an underwater noise package in January 2025. These measures are summarised below.

Reducing Marine Noise Policy Paper

A new policy paper on underwater noise referred to as Reducing Marine Noise was published in January 2025 (Defra, 2025b) which provides a greater steer on underwater noise management in the UK. The policy paper recognises the anticipated increase in underwater noise impacts over the coming years and highlights difficulties in managing impacts in harbour porpoise SACs which often overlap areas of noisy activity and therefore require careful management e.g. offshore wind farm construction. As a result, industry should expect to see changes in the way underwater noise is managed in the marine area.

The paper makes the following statements regarding offshore wind and underwater noise:

- The UK Government intends to consult on an offshore wind piling noise limit. Following this, during 2025 and 2026, Defra will work with developers to gather data to test and refine the consultation outcomes.
- From January 2025, given the expected increase in noise levels and policy commitments, government expect all offshore wind pile driving across all English waters will demonstrate that they have used best endeavours to deliver noise reductions through the use of primary and/or secondary[16] noise reduction methods in the first instance. It is anticipated that this will be demonstrated through the marine licensing process.
- Technologies with more robust evidence regarding efficacy and noise reduction capabilities are likely to face smoother consenting journeys.
- Developers can propose alternative Effective Deterrent Ranges (EDRs) provided robust evidence is provided.
- A wildlife licence will only be granted for piling where the licensing authority is content that it meets legislative tests to meet European Protected Species (EPS) requirements under the Habitats Regulations in both inshore and offshore waters[17].
- Developers who secure the greatest possible noise reductions are less likely to face requests to further explore satisfactory alternatives. Additional costs of noise reduction systems are unlikely to be sufficient justification to discount a satisfactory alternative. Any other justifications to explain why noise reduction is not an alternative should be provided.
- Further guidance has been published as a joint statement from government advisors on the use of noise reduction methods when piling (JNCC *et al.*, 2025).

Beyond offshore wind, the policy paper outlines commitment to minimising continuous and impulsive noise on marine mammals from other sources and that innovation across all industries to minimise noise impacts is encouraged (Defra, 2025b).

With regards to shipping, the Reducing Marine Noise policy paper (Defra 2025b) outlines the government's support of the IMO revised guidelines for the reduction of underwater radiated noise

16 Primary methods aim to reduce noise emissions at sources through modification of the installation method. Secondary methods refer to noise abatement methods such as bubble curtains.

17 Conservation of Habitats and Species Regulation 2017 and Conservation of Offshore Marine Habitats and Species Regulations 2017.

from shipping to address adverse impacts on marine life (IMO, 2023). The UK Government will work with industry and through research to understand where improvements and changes can be made (Defra, 2025b).

The UK Government is also considering where improvements can be made across all industries undertaking geophysical and seismic surveying activities so that impacts are minimised as far as possible (Defra, 2025b).

To meet commitments through the UK Marine Strategy to achieve or maintain GES for underwater noise, Defra and devolved administrations will be considering noise threshold values for introduction across all UK waters for both impulsive and continuous noise sources (Defra, 2025b).

Updated UXO Joint Position Statement

Released as part of the underwater noise package by Government in January 2025, this joint position statement gives clear direction that low order methods[18] should be the default to clear UXOs in the marine space and high order methods[19] should be the last resort (Defra *et al.*, 2025). The joint position statement requires additional information to be provided by developers when applying for a Marine Licence for UXO clearance. Robust evidence is required to support the use of any low order technology, and monitoring may also be required. Marine Licence applications need to be supported by a mitigation plan to demonstrate how potential environmental impacts of UXO clearance will be reduced as far as possible. The development of new methods of clearance with reduced environmental impacts and new tools which utilise known low order methods is welcomed and encouraged by government, regulators and SNCBs (Defra *et al.*, 2025).

6.2.2 Measures associated with activities involving noise production in the marine environment

The actions included below (M15.3 and M15.5) are the only actions included in the UK Marine Strategy Part Three report (Defra, 2025a). Further similar actions may be delivered within the UK which have not been captured as part of reporting for the UK Marine Strategy.

M15.3: The Fish Farming Code of Practice (Scotland) Order 2021 and M15.4 Aquaculture Code of Practice

The Fish Farming Code of Practice (Scotland) Order 2021 makes provisions for the Aquaculture Code of Practice (Scottish Government, 2021a). The Code of Practice sets out expected standards for Aquaculture Production Businesses (APBs) in Scotland in relation to containment of fish-on-fish farms and marine mammal interactions. Non-lethal methods such as ADDs introduce underwater noise into the marine environment to deter marine mammals from fish farms. The Code provides information on the legal use of ADDs and supporting guidance.

M15.5: Scottish Marine Wildlife Watching Code

The Code of Conduct (NatureScot, 2017) provides advice on minimising disturbance on wildlife, including legal requirements. It is acknowledged that other codes of conducts likely to exist, however, this is the only code reported in the UK Marine Strategy Part Three (2025a).

18 Known as low order deflagration, low order clearance is a technique in which the UXO burns out slowly, producing less energy and therefore underwater noise impacts.

19 High order clearance methods involve detonating the UXO which results in an explosion resulting in large amounts of energy.

6.2.3 Activities addressing uncertainty and supporting measures development

A15.1: Defra OWEAP portfolio of research and evidence

A series of reports commissioned by Defra as part of OWEAP have contributed to improving the understanding of impacts and management of underwater noise from offshore wind. These reports have helped to inform Reducing Marine Noise policy (Defra, 2025b) and informed position papers such as the UXO clearance Joint Position Paper (Defra *et al.,* 2025).

The following reports covered potential impacts of underwater noise (Defra, 2022):

- Identification of key species in the UK, with a focus on English waters, sensitive to underwater noise (Williams *et al.,* 2021);
- Initial assessment of candidate stress response variables in juvenile European seabass (Sebire *et al.,* 2022);
- Innovative monitoring of fish distribution and behaviours around floating and fixed wind turbines: a review (Van der Kooij *et al.,* 2022);
- Risk mapping of impulsive noise pollution in UK marine protected areas. (Faulkner *et al.,* 2022); and
- Underwater noise from floating offshore wind: potential impacts on fish and marine mammals (Farcas *et al.,* 2022).

The following reports considered the management of underwater noise from offshore wind (Defra, 2023a):

- An approach to impulsive noise mitigation in English waters (Powell *et al.,* 2022);
- An exploration of time-area thresholds for noise management in harbour porpoise SACs literature review and population modelling (Brown *et al.,* 2023);
- Marine Mammal observations and compliance with JNCC guidelines during explosive operations from 2010-2021(Stone, 2023a);
- Marine Mammal observations and compliance with JNCC guidelines during pile driving operations from 2010-2021 (Stone, 2023b); and
- Meta-analysis of existing static passive acoustic monitoring data for cetaceans scoping stage (Verfuss *et al.,* 2023).

A15.1: Marine Noise Registry (MNR)

The MNR (JNCC, 2025a and b) was established as a commitment made within the UK Marine Strategy Part One (Defra, 2012) to record human activities in UK seas which produce impulsive noise. It is a data input platform for industry and regulators to monitor and help quantify underwater noise pressures on the environment. Maps are produced annually to show the number of days within a set period where impulsive noise has been generated. Data also feeds into the OSPAR Impulsive Noise Registry (OSPAR, 2025). The MNR was upgraded in 2023 and includes a disturbance tool and a cooperation tool to assist regulators and developers in the management of underwater noise. The MNR was launched in 2016 (Defra, 2016) and data is stored on the MNR from 2015 onwards.

A15.2/15.3: Collaborative Oceanography and Monitoring for Protected Area and Species (COMPASS):

The COMPASS project involves using monitoring buoys in the Republic of Ireland, Northern Ireland and West Scotland to record ambient noise levels to contribute towards the effective management of Marine Protected Area (MPAs) (COMPASS, 2025). This project was implemented between 2017 and 2022. Outputs included the characterisation of seasonal and diurnal patterns in harbour porpoise occurrence through broadscale acoustic monitoring (Edwards *et al.,* 2020).

A15.3: Marine Protected Area Management and Monitoring (MarPAMM)

MarPAMM is an environmental project for monitoring and managing a number of protected coastal marine environments in Ireland, Northern Ireland and Western Scotland. An element of this project, which was implemented between 2018 and 2022, focused on the impact of industrial and shipping noise on seal distribution (MarPAMM, 2025). The outputs of the work will support ongoing management and monitoring within the region (MarPAMM, 2022).

A15.3/A15.6: Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS)

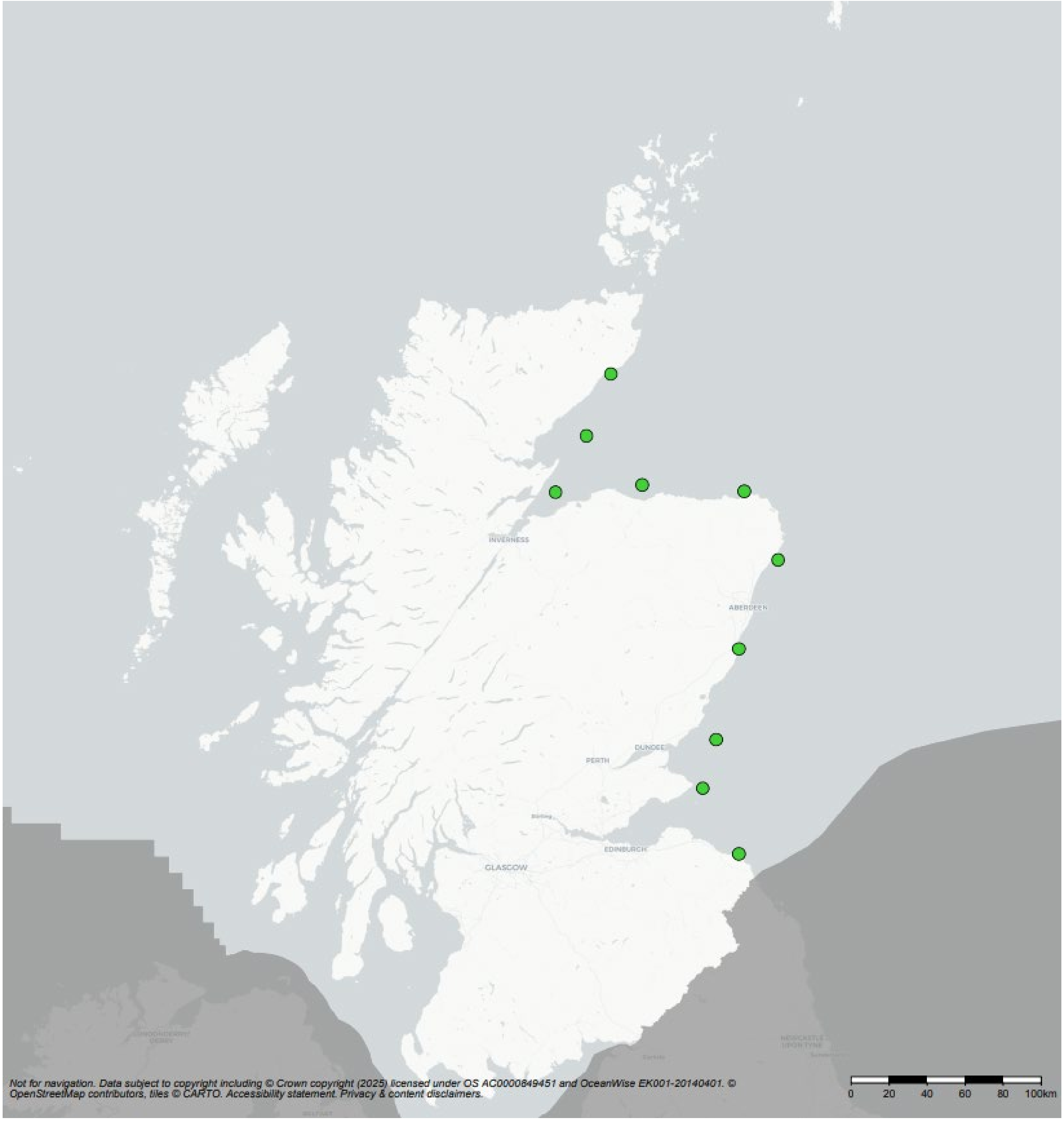
The JOMOPANS project, which was implemented between 2018 and 2021, aimed to develop an operational joint monitoring programme for ambient noise in the North Sea (JOMOPANS, 2025). This work has contributed towards the OSPAR monitoring programme.

A15.4: Joint Framework for Ocean Noise in the Atlantic Sea (JONAS)

The JONAS project, which was undertaken between 2019 and 2021, aimed to address threats to biodiversity from underwater noise pollution through better risk management and monitoring. Monthly noise and risk maps were produced to support better planning and decision making for EU member states. Five case studies were also produced on the impacts and effects of ambient and impulsive noise. An online visualisation platform was also created to make technical material more accessible (JONAS, 2025). The outputs have helped inform the OSPAR programme (see Section 6.2.1).

A15.5: East Coast Marine Mammal Acoustic Study (ECOMASS)

The ECOMASS project, which commenced in 2013, is a long-term ongoing study involving acoustic recorders at thirty locations off the east coast of Scotland to detect cetacean echolocation clicks. At ten of these locations (shown in Figure 5), acoustic recorders have been deployed to monitor ambient noise levels. This data contributes towards the UK Marine Strategy reporting (ECOMASS, 2025).



Source: © Crown Estate Scotland

Figure 5. East Coast Marine Mammal Acoustic Study locations (Marine Scotland, 2025).

A15.7: Scottish Marine Energy Research (ScotMER)

ScotMER is a Scottish Government initiative which identifies and addresses evidence gaps and uncertainties that exist around how offshore renewable energy developments will affect the environment, and to improve the evidence base to inform future decision-making and research. The Scottish Government has worked with experts from academia, industry, environmental NGOs and SNCBs to map out evidence gaps associated with offshore renewable developments. Experts have formed seven ScotMER Receptor Groups: Ornithology, marine mammals, fish and fisheries, diadromous fish, benthic, physical processes and socio-economic. These groups have produced evidence maps to provide a framework to guide and prioritise ScotMER research projects and also provide a platform to communicate needs to a broader stakeholder community and facilitate collaborative research opportunities. The Marine Mammal Receptor Group (Scottish Government, 2024a) and the Diadromous Fish Receptor Group (Scottish Government, 2024b) have produced useful evidence maps to highlight evidence and research gaps. A number of the research programmes have produced useful information to support underwater noise management. This includes regional baseline mapping of marine mammals in Scottish waters to assist in renewable energy leasing and consenting (Hague *et al.*, 2020) and modelling to improve the understanding of renewable energy installations on harbour porpoise (Harwood *et al.,* 2023). Outputs from the ScotMER programme are showcased at an annual symposium (ScotMER 2025), the most recent of which was the seventh annual ScotMER symposium which ran from 25 to 28 February (Scottish Government, 2025).

A15.8: Continuous Noise Monitoring Programme

This programme supports the OSPAR Ambient Noise Monitoring Strategy. The data standard has been based upon the monitoring approach established as part of the JOMOPANS project.

A15.9: UK Offshore Energy Strategic Environment Assessment (OESEA) Research Programme

The OESEA, overseen by the Department for Energy Security and Net Zero (DESNZ, 2024a), is an environmental assessment of UK energy plans and projects undertaken to meet the requirements of the SEA Regulations[20]. The OESEA Research Programme identifies evidence gaps and commissions new research to support the OESEA. Recent research has been undertaken to support the development of low order UXO clearance (DESNZ, 2024b).

A15.10: Offshore Wind Evidence and Change Programme (OWEC)

OWEC is a £50 million Crown Estate investment programme, launched in 2020 (The Crown Estate, 2020), which funds projects to derisk and accelerate marine renewable energy projects whilst supporting a thriving marine environment (The Crown Estate, 2025a).

OWEC is currently funding an underwater noise project – Piloting of Offshore Wind Environmental Mitigation (POWEM). This project is led by Defra who will collaborate with industry on pilot mitigation measures that could further reduce the impact of offshore wind on the marine environment. The project includes a pilot for an offshore wind piling noise limit to reduce the impact of construction noise on marine species (The Crown Estate, 2024).

6.2.4 Offshore Renewables Joint Industry Programme projects on noise

A15.11: DAERA consultation and management of fast craft and personal watercraft in MPAs

Consultation led by DAERA in 2022 proposed management measures on the use of fast craft and personal watercraft in MPAs to reduce disturbance to marine mammals (DAERA, 2022). It was expected that management measures were to be finalised by 2023 and published in 2024 (Defra, 2025a), however further details to confirm this have not been made publicly available at the time of writing.

6.2.5 Measures associated with climate change mitigation and adaptation

M16.1 (unnamed project)

A project title for M16.1 does not exist in the UK Marine Strategy Part Three (Defra, 2025a) report. Available details for this measure are provided below.

The UK Marine Strategy Part Three has identified English, Welsh, Scottish and Northern Ireland climate change adaptation and resilience policies under this measure but has not detailed how it is contributing towards GES for D11 (Defra, 2025b). The Marine Strategy Framework Directive does not specifically address climate change nor is it covered by a descriptor or listed as a pressure (EC, 2025a). Climate

[20] Environmental Assessment of Plans and Programmes Regulations 2004, more commonly known as the SEA Regulations.

Change commitments across England, Wales, and Northern Ireland are to reach net zero greenhouse gas emissions by 2050. This differs to commitments in Scotland where the ambition is to achieve net zero by 2045. At an EU level, the European Green Deal takes action to become climate neutral by 2050 and to preserve ecosystems and biodiversity (EC, 2025b). To reach carbon neutrality by 2050, there will be a large increase in offshore renewable energy which will result in a potential increase I underwater noise impacts on sensitive species. This highlights a need for better alignment between renewable energy and biodiversity policy. Evidence gathering to support this is being progressed through the OWEC programme (see Section 6.2.3). Measures should be identified in future iterations of the UK Marine Strategy to link actions associated with climate change mitigation and adaptation and underwater noise.

6.2.6 Other: Underwater noise management in harbour porpoise SACs

Although not listed in the UK Marine Strategy Part Three, measures taken to manage underwater noise impacts in Harbour Porpoise SACs has contributed towards the achievement of underwater noise GES.

Five harbour porpoise SACs in English, Welsh and Northern Ireland waters were designated in 2019. Statutory authorities are required to implement management of regulated activities to ensure that the Conservation Objectives of SACs can be met. In 2020, JNCC, NE and DAERA produced guidance on assessing the impact of underwater noise disturbance against the Conservation Objectives of harbour porpoise SACs (JNCC, 2020). This requires the impacts of underwater noise to not exceed harbour porpoise disturbance thresholds as outlined below. NRW guidance differs slightly on Effective Deterrent Ranges (EDRs) and has produced a separate position statement on assessing disturbance on harbour porpoise (NRW, 2023). In this statement, NRW notes there is considerable uncertainty surrounding the EDRs which have been calculated (by JNCC/NE/DAERA) and suggests alternative approaches are used when carrying out underwear noise assessments for the purpose of EIAs and HRAs. Further details of NRW's advice is provided in the statement (NRW, 2023).

The implementation of measures to manage disturbance is important in meeting The Environmental Targets (Marine Protected Areas) Regulations 2022[21] which apply only in England. Coordination (i.e., setting disturbance thresholds) by regulators in England has been implemented to manage the cumulative underwater noise impact from multiple activities to ensure these SAC underwater noise disturbance thresholds are not breached. See Box 1 for thresholds.

Regulators identified the potential for high levels of noise disturbance during summer 2024, with worst-case scenario predictions of 50% disturbance daily and seasonally without appropriate aligned management from regulators. The implementation of bespoke management and industry engagement successfully kept disturbance levels below daily and seasonal thresholds. Measures included encouragement of the voluntary use of noise abatement systems during 2024, the requirement of low-order UXO clearance in the first instance, requirement for collaboration, request to work outside the summer period and requirement for regular update to regulators (SAC NRWG, 2024).

Box 1. Disturbance thresholds for harbour porpoises (JNCC, 2020)

Noise disturbance within an SAC from a plan or project, either individually or in combination, is considered to be significant if it excludes harbour porpoises from more than:

1. 20% of the relevant area of the site in any given day; or
2. An average of 10% of the relevant area of the site over a season.

[21] The Environmental Targets (Marine Protected Areas) Regulations 2022.

In regard to Northern Ireland, Northern Ireland's first Environmental Improvement Plan commits to, by 2028, "develop an Underwater Noise Action Plan to support sustainable fisheries targets and protecting nature at sea". It is worth noting, however, that although the Plan refers to GES and the need for underwater monitoring, this measure was not contained within the 2025 programme of measures. The Plan includes a commitment to establishing a long-term monitoring programme, which, if it is coherent to English, Welsh, and Scottish monitoring programmes, could mean underwater noise from the industry is managed at the UK-wide level (DAERA, 2024).

6.3 Uncertainties in achieving GES

The UK Marine Strategy Part One identified uncertainty regarding what levels and frequencies of man-made noise lead to population and ecosystem level effects (Defra, 2019). UK Marine Strategy Part Three further reiterates the main uncertainties are in understanding noise levels which lead to population effects (Defra, 2025a). A great deal of progress has been made over the past five years, particularly in relation to the Defra OWEAP programme. This has helped to better understand the impacts of underwater noise, and implement measures to reduce underwater noise impacts. This is supported through the launch of Reducing Marine Noise policy in January 2025 (see Section 6.2.1).

Understanding the impacts of underwater noise on noise sensitive species is complex (see Section 4) which increases uncertainty on the achievement of GES. The UK Marine Strategy Part Three (Defra, 2025a) suggests a risk-based approach may be required to help overcome this issue and should be explored. This approach has been explored for harbour seal, bottlenose dolphin, herring and cod by applying the underwater noise thresholds for harbour porpoise SACs to consider exposure to relevant impacts (Faulkner *et al.,* 2022). Faulkner *et al., (*2022) identified that in certain locations and circumstances (e.g. fish spawning periods), these species are vulnerable to underwater noise impacts. This risk-based approach could be further investigated to identify when the use of noise abatement and reduction technology could be applied to reduce underwater noise impacts for a range of species.

6.4 Barriers to achieving GES for underwater noise

The UK is currently (2025) only partially achieving GES for underwater noise (Defra, 2025a). This study has concluded that the following challenges or barriers may hinder the progress towards the achievement of GES for underwater noise:

- Scale of projected future increase in underwater noise pressure, as outlined in Section 5;
- A lack of monitoring and direct evidence to understand the impacts of underwater noise across all sensitive species. This is important to identify future measures to work towards GES;
- Policy and incentives to encourage investment and the development of more advanced noise reduction and abatement technology, supported by a UK supply chain;
- A lack of a cohesive UK wide underwater noise management strategy; and
- Unknown or uncertain underwater noise impacts from new developments, activities and technology.

The above barriers and potential solutions are further explored in Section 7.

7 Future opportunities

The review of progress towards GES in Section 6 has identified an increase in measures to address underwater noise impacts over recent years. However, with the continued uncertainties of underwater noise impacts at a population level on sensitive species and with expected increases in noisy activities in the future, it is important to take a more holistic approach to underwater noise management. Such a holistic approach would bring together all actions, including monitoring and adaptive management. The following sections identify a number of opportunities which could be considered to help achieve GES for underwater noise. This includes:

- Improvements in the approach to underwater noise management;
- The role of spatial planning and prioritisation of marine space;
- Regulatory management;
- Policy and incentives;
- Management mechanisms;
- Monitoring and adaptation; and
- Technological solutions.

7.1 Development of a UK underwater noise management plan

Regulators have highlighted the complex nature of managing underwater noise impacts in an increasingly busy sea space (SAC NRWG, 2023 and 2024). Defra (2025b) also recognises that with the increase in underwater noise anticipated over the coming years, it will be increasingly difficult to determine no adverse effect on the integrity of harbour porpoise SACs, which has been a key driver of underwater noise management in recent years. Reducing Marine Noise policy (Defra, 2025b) has outlined that industry should expect to see changes in the way underwater noise is managed and a noise limit is being considered as part of commitments to achieve GES for underwater noise as part of the UK Marine Strategy.

Section 6.2 highlights the numerous measures that are being put in place to progress the understanding of underwater noise impacts across UK seas. A management plan would address the current uncertainty regarding the achievement of GES for underwater noise (Defra, 2019), particularly around addressing the uncertainty of population and ecosystem level impacts. The analysis in Section 6 has demonstrated a lack of coordination across these measures.

To aid government, regulators, SNCBs and industry navigate the complexities of underwater noise management, a holistic UK wide underwater noise management plan could be developed which draws together actions to manage both impulsive and continuous noise within a single plan, as outlined as a potential management framework in Figure 1. The plan would bring together all actions to achieve GES for underwater noise and would be underpinned by a monitoring programme to support adaptive management. This should become an embedded and integral plan within the UK Marine Strategy Part Three Programme of Measures for Descriptor 11. This plan should also align and support the OSPAR underwater noise RAP. Support for an underwater noise management framework would need to be sought across government, with regulators and SNCBs. Resource requirements would also need to be considered in the development of a framework.

The various elements of the potential management framework in Figure 6 are described in further detail in the following sub-sections.

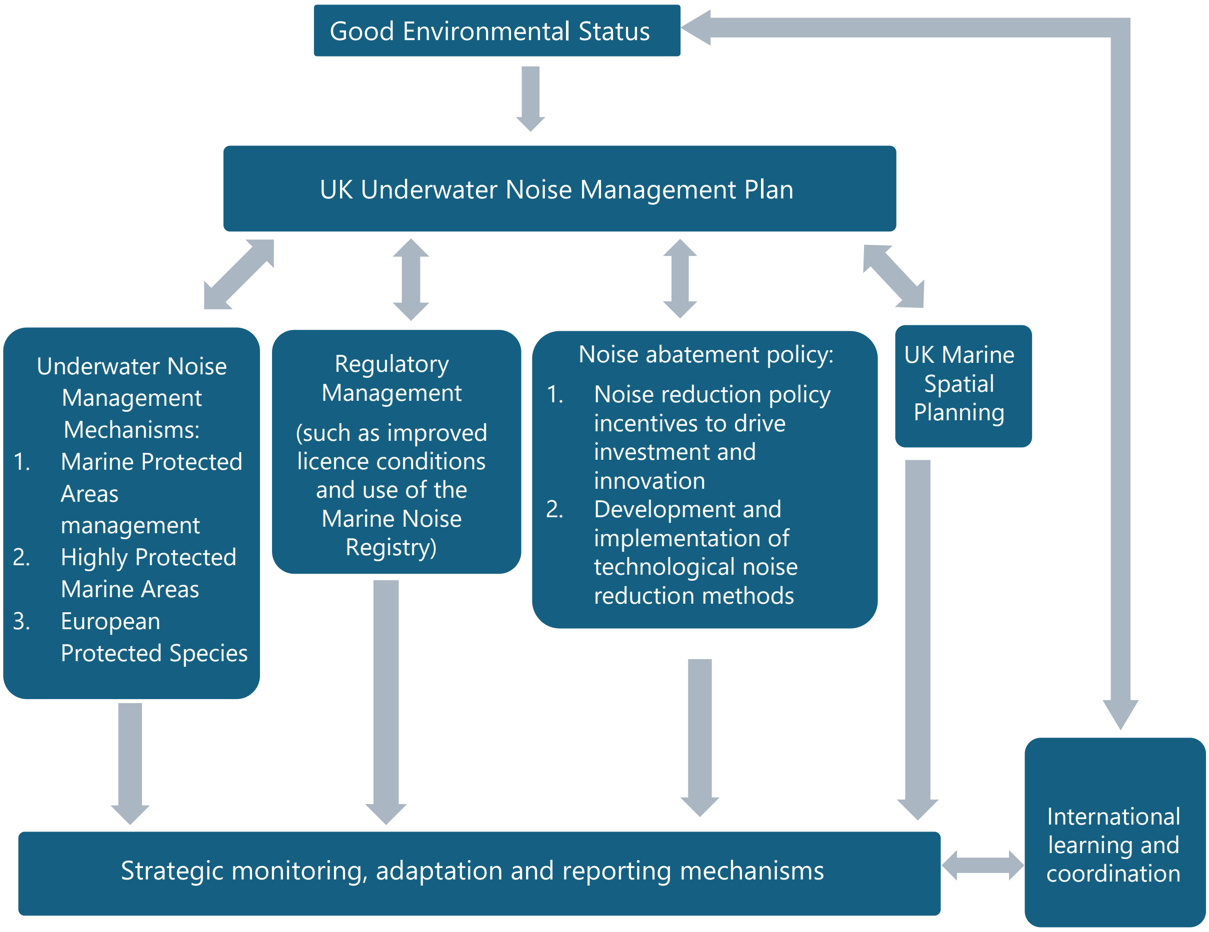


Figure 6. A potential underwater noise management framework.

7.2 OSPAR RAP

The OSPAR underwater noise RAP provides an opportunity to deliver measures at a whole sea scale. This is particularly important when managing cumulative impacts on cetacean species which rely on a whole sea area, as opposed to administrative boundaries. For example, the North Sea is an important area for harbour porpoise, bottlenose dolphins, white-beaked dolphins and minke whale. It is also a very noisy sea-space with multiple developments and noise producing activities taking place across multiple country administrative boundaries.

Continued engagement in the OSPAR underwater noise RAP is suggested to deliver monitoring and action at a whole seas scale to ensure the risks posed from underwater noise can be appropriately managed to achieve GES. This is particularly important considering both the UK and EU's ambition to increase renewable energy deployment to meet net zero targets, which will increase underwater noise levels in the marine environment from construction activities.

7.3 Spatial planning and prioritisation

Spatial planning and prioritisation of marine space is likely to be an important tool in the future for underwater noise management. With the right supporting data and evidence, areas which support the most vulnerable species to underwater noise pressures could be better avoided or impacts mitigated through spatial planning.

A number of areas could be considered to better support the spatial planning of underwater noise impacts. This could include the mapping of data and evidence to highlight hot spot areas for noise sensitive species over seasonal periods and the development and identification of quiet zones/seasons.

A spatial approach to future underwater noise management could help derisk future development at sea by avoiding areas which would require high levels of intervention to reduce impacts. Where avoidance is not possible, a spatial management approach will help to identify risks and management required at the earliest stage. For example, The Crown Estate Whole of Seabed model (The Crown Estate, 2025b) could integrate underwater noise data and evidence at the early leasing identification stage for offshore wind to avoid or incentivise noise reduction, with the ultimate aim of reducing delays and costs at the consenting stage.

Marine plans are underpinned by the UK Marine Policy Statement (HM Government, 2011) and are in place in England, Wales and Scotland, and a draft plan exists in Northern Ireland. The East Marine Plan in England and the Scottish National Marine Plan are currently being updated. The update process could provide opportunities to integrate a more spatial approach to underwater noise management into marine plans. In addition to marine plans, the Environmental Audit Committee's recent report "Governing the marine environment" (Environmental Audit Committee, 2025) calls for the Marine Policy Statement to be updated to reflect the evolving challenges facing the marine environment and to provide greater transparency of the aims and outcomes of the Statement. Defra has also established a Marine Spatial Prioritisation programme, however, very few details are available on the intended outcomes of the programme. Based on the progress of underwater noise policy since the production of the current Marine Policy Statement, a future updated Marine Policy Statement will also support future policy development, prioritisation and spatial planning of underwater noise in marine plans.

It is important to note that the range of noise producing activities at sea are planned through different mechanisms outside of marine plans, and the marine planning process[22]. For example, future offshore wind areas are identified by The Crown Estate through their leasing processes. Marine plans, guided by an updated UK Marine Policy Statement, could provide the opportunity for a more coherent and cross-sectoral approach to underwater noise management.

Challenges around applying a spatial planning approach include understanding the changing distribution of noise sensitive species. For example, as a result of human activities or climate change. To overcome this, spatial areas could be reviewed and updated on a rolling basis rather than fixed spatial zones. Appropriate timescales for the review of noise sensitive zones would need to be determined. For example, Marine plans in England are reviewed every three years, but a longer review period may be required for a noise sensitive zone to ensure enough evidence is available to understand species distribution whilst giving certainty to industry on the location of these zones. It would also be key to consider the impacts and practicality of this on other sectors, particularly those whose location is fixed or constrained by external factors such as environmental conditions or existing infrastructure. As such it would be important to gain comprehensive stakeholder views on this approach.

[22] As established under the Marine and Coastal Access Act 2009; Marine (Scotland) Act 2010; and Marine (Northern Ireland) Act 2013.

A spatial approach to marine planning requires cross government support, which would also need to be considered as a potential challenge and opportunity[23]. Overall, a spatial approach has the potential to help reduce risks to achieving GES for underwater noise.

7.4 Regulatory management

The Reducing Marine Noise policy (Defra, 2025b) has resulted in regulatory change in relation to noise abatement requirements for piling for offshore wind installation and the requirement for quieter technology to remove UXOs. Although other sectors or activities are not specifically considered by this policy, it could provide some direction to the approach that should be taken for other marine developments involving piling, such as port development, to ensure a smoother consenting process. In addition, Defra and devolved administrations are considering noise thresholds for both impulsive and continuous noise sources (Defra, 2025b) which has future regulatory implications.

Based upon the implications of underwater noise policy and the review of information in this report, the following actions are recommended.

7.4.1 Continued development of monitoring tools such as the MNR

Resource and investment by government and industry should be continued to ensure further development of the MNR as a tool to assist in the management of underwater noise impacts. It is a critical tool in reporting on the underwater noise GES and has been used to track the spatio-temporal distribution of impulsive noise in UK waters (JNCC, 2025a). Further investment is required to build on the current use of the MNR and support the further development of the MNR to predict future underwater noise levels. This will in turn help to better plan and manage future development pressures on the marine environment in the long term.

7.4.2 Improved evidence

To give confidence in noise reduction technology and to facilitate the consenting and licensing process, evidence on the efficacy of noise reduction technology will be essential, especially for newer technology. This requirement for improved evidence has been demonstrated through the development and use of low order techniques for UXO clearance (Defra *et al.*, 2025). New guidance for developers could help provide clarity on evidence requirements for licensing. In addition, collaborative approaches to evidence gathering and transparent reporting of evidence could help streamline the consenting process. To be effective this should involve collating, reviewing, and presenting the outcomes of monitoring programmes such as from post-consent monitoring, which are currently not widely shared.

7.4.3 Transparent reporting by regulators

Reporting on progress of the management of underwater noise impacts by regulators is essential to help understand progress towards GES for underwater noise and the effectiveness of management measures. The SAC Noise Regulators Working Group (NRWG) have produced reports in 2023 and 2024 on the progress of underwater noise management in harbour porpoise SACs. The SAC NRWG should continue to be resourced to ensure coordinated management and annual reporting. Steps should be made to review and update progress reports to ensure they meet national and international reporting requirements.

[23] For example, in delivering on requirements as established through the UK Government's Environmental Principles Policy Statement.

Improved underwater noise GES reporting to support the UK Marine Strategy would also be beneficial. For example, it is not clear as to why GES for underwater noise has been only partially achieved in Marine Strategy part three: 2025 programme of measures (Defra, 2025a). Better defined underwater noise GES targets and noise budgets (Merchant, 2019) may assist with this.

7.4.4 Review and expansion of SAC NRWG scope

Currently the SAC NRWG only cover the underwater noise management of harbour porpoise SACs. In considering a noise threshold for both impulsive and continuous noise sources (Defra, 2025b), Defra and devolved administrations should consider the expansion of the SAC NRWG or a similar group to help in the implementation and management of any future noise thresholds for the whole marine environment. This is particularly important given the complexity and interplay of noise impacts at the population scale. This should be explored in more detail once more information is available from government in relation to future noise thresholds.

7.4.5 Noise abatement and reduction policy and incentives

The Reducing Marine Noise policy (Defra 2025b) has given direction for noise abatement and reduction technology for offshore wind piling and the use of quieter technology for UXO removal. Defra and devolved administrations are also considering a noise limit for both impulsive and continuous noise (Defra, 2025b). To deliver this, advancements in technology and development of a noise abatement and reduction supply chain will be required. It is suggested that policy and incentives to support this are considered, possibly through a number of mechanisms as suggested below (see Sections 7.4.7-7.4.12).

7.4.6 The Crown Estate leasing

The Crown Estate lease the seabed for various activities such as offshore wind and aggregates. As part of the leasing rounds, The Crown Estate could include a requirement for noise reduction technology and innovation (see Section 7.7) to be implemented as part of tendering. The Crown Estate could go a step further by introducing environmental criteria into the leasing process, one of which could be to demonstrate measures to reduce underwater noise. The implementation of noise reduction at the early leasing stage would drive innovation to reduce underwater noise impacts whilst reducing consenting risk for individual projects later in the process.

7.4.7 Improved licence conditions

Permission is often granted for development, particularly for large offshore wind projects, with a large Rochdale Envelope (Planning Inspectorate, 2025a). This means that at the time of consent, a number of different (worst case) impact scenarios have been assessed and permitted. The final scope of a development is then refined during the post-consent stage. For example, this is implemented for harbour porpoise SACs through Site Integrity Plans. However, the multiple scenarios during the assessment phase can make it complex for regulators to determine management requirements in harbour porpoise SACs, especially for cumulative impacts.

Progress has been made through the SAC NRWG though coordination and facilitation frameworks with industry (SAC NRWG, 2024). To assist regulators and industry in the planning of activities which produce underwater noise impacts over a multiple years, licence conditions could be considered for future developments and activities to provide updated noise modelling predictions as projects are refined during the post-consent phase. For example, at the Contract for Difference (CfD) and Financial Investment Decision stage. This would give both regulators and industry more certainty of potential cumulative underwater noise impacts and clarity on mitigation requirements a number of years in advance of construction.

Revised monitoring conditions could also be considered to provide a better suite of data and evidence to understand both noise levels generated during construction of development projects and the potential impacts on species. This could form part of a wider strategic monitoring programme (see Section 7.6).

A review of the SAC NRWG coordination and facilitation frameworks with industry could be undertaken. This could consider the roles of regulators and industry, and resource requirements to ensure effective coordination of the licensing of noisy activities.

7.4.8 Supply chain investment

Supply chain investment schemes which specifically fund the environmental supply chain, such as noise abatement and reduction technology, are required. An environmental supply chain scheme will help provide early-stage development funding to ensure measures are in place to reduce both environmental and consenting risks. This approach could also open up the UK as a world leader in environmental supply chains, supporting jobs and growth. Possible schemes which could be explored include The Crown Estate Supply Chain Accelerator (The Crown Estate, 2025d). Alternative and perhaps even new environmental supply chain investment schemes should be investigated and developed.

7.4.9 Government subsidy

Current schemes exist such as the CfD which is used as a mechanism to support low carbon electricity generation (DESNZ, 2025a). CfDs, however, do not include environmental specific criteria in the award. It is also applied at the post-consent stage which may be too late in the process to appropriately drive the development of innovative noise abatement and reduction technology. Applying environmental criteria to a subsidy could drive innovation and encourage the delivery of measures to further reduce underwater noise impacts. Alternative approaches which can be implemented early in the process could be investigated. For example, the German Federal Network Agency, under the Offshore Wind Energy Act, will provide the Ørsted Gode Wind 3 project with a subsidy intended to drive innovation in offshore wind build out. This has resulted in the development of new lower-noise installation methods (Ørsted, 2024) (see Section 7.7).

7.4.10 Planning incentives

A fast-track process for Nationally Significant Infrastructure Projects (NSIPs) has been introduced (MHCLG, 2024). Further fast-tracking could be explored for developments which meet certain environmental criteria. For underwater noise, the criteria could be for developers to demonstrate investment and implementation in measures to reduce underwater noise impacts. Stakeholder engagement on the development of a range of environmental criteria would be important to progress this idea. Clear guidance from government and SNCBs would also be required. Any fast tracking should be subject to the clear application of relevant environmental law and policies.

7.4.11 Collaborations and international partnerships

As outlined in Section 6.2, a number of collaborations have resulted in successful measures to better understand underwater noise levels and impacts in the UK. It is important that resource and funding continues to support these collaborations in order to share and gain evidence and understanding. International opportunities should continue to be explored, particularly those in which the UK already has international obligations e.g. OSPAR.

7.4.12 Continuous noise from shipping activities

The IMO recommends that maritime authorities, financial and insurance institutions and others are encouraged to promote incentivisation schemes to support underwater noise reduction programmes and measures (IMO, 2023). Other options which could be explored include noise permits (Merchant, 2019), rerouting shipping routes to avoid environmentally sensitive areas and introducing reduced port fees for slower or quieter ships. For example, the Port of Vancouver Enhancing Cetacean and Habitat Observation (ECHO) programme offers up to 75% reduction in harbour due rates for shipping lines which make voluntary investments in fuel, technology or environmental management (Port of Vancouver, 2025). The initiative has resulted in an 86% participation rate which equates to more than 5,800 slower or more distanced ship transits within key sensitive areas. Furthermore, humpback whales were detected on 45 days in 2023 compared to 18 days in 2022 (Port of Vancouver, 2024).

The practicalities of implementing these measures would need to be explored, particularly in relation to health and safety but also operation, energy efficiency and economic factors. Internationally coordinated approaches through the IMO or at a regional scale such as OSPAR will potentially be advantageous and should be explored (Merchant, 2019).

7.5 Underwater noise management mechanisms

There are various legislative mechanisms available to support the delivery of underwater noise management which could be explored when considering future management needs. These are outlined below.

7.5.1 Marine Protected Areas (MPAs)

Underwater noise management could be implemented in MPAs to improve the condition of designated features that are sensitive to underwater noise (Section 4). There is an opportunity to further improve underwater noise management using MPA legislation such as:

- Improving evidence to refine existing underwater noise management in MPAs. For example, improved evidence on important areas within harbour porpoise SACs such as feeding, mating, calving and nursery areas could be gathered to refine management;
- Adding features, such as cetaceans and fish which are sensitive to underwater noise impacts, to the existing MPA network to ensure the protected site network is ecologically representative. This would help prevent (or reduce) risk of development and underwater noise production in ecologically sensitive areas; .
- Designation of new MPAs through the identification of key areas at sea for noise sensitive species. For example, foraging and nursery areas. These areas could be further overlayed with underwater noise heat maps to identify areas where underwater noise management would be required. This could be explored as part of the government's plans for an MPA network review (Emma Hardy, *pers. comm*, Coastal Futures conference 2025); and
- Better protection and implementation of underwater noise management within species foraging ranges which are associated with MPAs. This is regularly implemented for birds protected as part of SPA management. For example, photo ID surveys conducted by the Sea Mammal Research Unit in 2024 in the northeast of England between Tynemouth and Bridlington Bay have demonstrated that coastal bottlenose dolphins present in the area belong to the East Coast Scotland bottlenose dolphin population (Ellis *et al.,* in press), which includes the Moray Firth SAC. However, management measures within the potentially functionally linked areas along the east coast of England are not in place.

7.5.2 Highly Protected Marine Areas (HPMAs)

Three HPMAs have been designated in England under the Marine and Coastal Access Act 2009. These are Allonby Bay, North East of Farnes Deep and Dolphin Head. HPMAs are areas of the sea that allow the protection and full recovery of marine ecosystems (Defra, 2023b). There is high-level conservation advice for HPMAs (NE and JNCC, 2022) alongside site specific advice for the three HPMAs. Further exploration and the development of actions could be considered to manage underwater noise impacts within HPMAs and therefore support the full recovery to meet the conservation objectives of the sites. The exploration of noise sensitive species as a criteria for future HPMA designation could also be considered.

7.5.3 European Protected Species (EPS) protection

All cetacean species, marine turtles and Atlantic sturgeon in UK waters are provided protection as EPS under the Habitats Regulations[24]. This requires the UK to implement measures to prevent the capture, killing or disturbance of EPS through their natural range (JNCC, 2025c). Due to the wide range of cetaceans within UK waters, underwater noise management may be better implemented in some circumstances at the EPS level to ensure a wider range of noise sensitive species can be protected. Improved EPS underwater noise management could be considered in a number of ways, such as:

- Through species management plans, such as the development of the UK Dolphin and Porpoise Conservation Strategy (Scottish Government, 2021b), which covers all impact pathways including underwater noise. This has overlap with GES targets for cetaceans, and therefore joint actions for this and underwater noise GES should be considered.

- Better consideration of EPS assessment within plan level assessments (such as for offshore wind sectoral marine plans) for plan-making bodies as required by the SEA Regulations and Habitats Regulations. This would allow underwater noise impacts on cetaceans which are not associated with specific MPAs to be assessed and measures identified at an early stage which would reduce both potential impacts to species and consenting risks.

7.6 Strategic monitoring, adaptation and reporting mechanisms

Measures have been developed to gain a better understanding of underwater noise levels at sea such as through the development of the MNR and a number of ambient noise studies. However, evidence is lacking on the level of noise which can lead to population level effects across noise sensitive species. Part Three of the UK Marine Strategy identifies that without this evidence, more-risk based approaches are likely to be required for the foreseeable future (Defra, 2025a).

Multiple years of data are required to detect species population trends and changes. It is therefore important to develop and implement species monitoring programmes as soon as possible, particularly as the UK seas become more noisy with increased developments and activities. Monitoring should be implemented at an appropriate geographical scale to understand species population effects. For some wide-ranging species, this would require large geographical monitoring schemes. In these circumstances, a strategic approach to data collection would be beneficial. Industries such as the offshore wind sector have shown interest in a more strategic approach rather than monitoring on a project-by-project basis (e.g. Equinor, 2023., RWE, 2025a.)

[24] Conservation of Habitats and Species Regulation 2017 and Conservation of Offshore Marine Habitats and Species Regulations 2017.

A monitoring plan for the Southern North Sea SAC was produced but not implemented, the reasons unknown, which also included outline implementation costs (Wilson *et al.*, 2019). It is concluded that this report is reviewed to identify and implement an underwater noise monitoring strategy for the Southern North Sea SAC. This would meet both developer licensing monitoring conditions and the Government's duty to monitor MPAs. The outcome of the pilot should then be reviewed to inform the merits of (and approach to) a UK wide underwater noise monitoring strategy.

Lessons could be learned from examples of strategic monitoring strategies that have been implemented. For example, the Moray Firth Regional Advisory Group (MFRAG) was established to ensure appropriate and effective monitoring of the impacts of developments to meet requirements of Section 36 consents and Marine Licences for three offshore wind farms (MFRAG, 2025). This monitoring is ongoing and the outputs have not yet been analysed. Adaptations could be involved in the decision making. This could include, for example, the capacity to amend licencing based on best available evidence and technology.

A strategic approach to monitoring both underwater noise levels and population impacts could be undertaken. This would help identify where and when underwater noise levels are impacting on species at a population level to help refine management approaches. For example, the Southern North Sea SAC splits into a large winter and summer seasonal area. Refined information on important areas for life functioning (e.g. feeding, mating, calving and nursery areas) would help identify more specific seasonal areas which may help reduce restrictions on the delivery of noisy activities whilst protecting the most important areas for harbour porpoise. A clear methodology would need to be developed to determine the impact of underwater noise at a population level against other factors such as natural variability as multiple factors can influence species at a population level.

Understanding underwater noise impacts at a population level is complex, particularly on species such as cetaceans which have a wide geographical range. It is concluded that tools should be explored to better understand impacts to assist with underwater noise management. For example, models have been developed to help better determine population scale impacts of underwater noise, particularly in relation to disturbance impacts and renewable energy develop. This includes the Population Consequences of Disturbance (PCOD) model (SMRU, 2025) and the DEPONS model (DEPONS, 2025).

To address the lack of understanding on population scale impacts of underwater noise, it is concluded that a more strategic monitoring programme is developed. This would require a consistent monitoring approach at a geographical scale and time period in which population trends could be detected and understood. A strategic monitoring approach would provide increased certainty in underwater GES assessments. This approach will also allow for a feedback mechanism to assist in the ongoing development and regular update of a UK underwater noise management framework, as proposed in Section 7.1. Resource requirements to support this approach will need to be considered by Government alongside funding mechanisms. Opportunities for private sector funding could also be explored, especially linked to the development of Marine Net Gain policy. Realistic evidence requirements would also need to be considered alongside the development of a risk-based approach (based on the sensitivity of species, the spatio-temporal scale of developments, and other factors) where evidence is lacking as outlined in Section 6.3.

7.7 Technological methods

Technological advancements are key to improving the capability and application of noise abatement systems. It is, however, recognised that limited data is available to understand how sectors (including those discussed in Section 5.1) will specifically commit to developing and implementing these technologies. In regard to offshore energy generation, the UK Government is committed to minimising the impacts of underwater noise whilst accelerating offshore energy development. Specifically, at the Coastal Future 2025 conference, it was noted that developing innovative technologies will be championed to achieve this (Emma Hardy, *pers. comm,* Opening Address at Coastal Futures conference 2025). This will undoubtably include developing novel ways to minimise the levels of impulsive sounds from piling, UXO detonation, seismic surveys, as well as continuous sounds from vessel movements and operating offshore energy sites. In regard to the dredging industry, anecdotally, a recent meeting held with Central Dredging Association representatives indicated that the UK is considered to be at the forefront of underwater noise management techniques at the European level.

A number of reports have been published which provide detailed information on underwater noise abatement technology and the factors impacting their feasibility (OSPAR, 2014; Verfuss *et al.,* 2019; PIANC, 2025; OSPAR, 2024 and NatureScot, 2019). Key technologies in development, undergoing testing, or which are widely used, alongside their respective limitations, are presented in Table 2. This provides an indication of where current development has been focussed and where future efforts to address limitations should be focussed. Further details of these technologies are described below the table.

In addition to the technology-specific limitations detailed in Table 2, anecdotally, other key concerns and barriers have been raised by developers implementing these mitigation technologies, and regulators (such as the MMO, NRW, and DAERA) evaluating their efficacy. These include the lack of evidence proving the efficacy of innovative technologies, and that they will satisfy licence conditions and the requirements of SNCBs. There is also a lack of proof that there is an established, and therefore cost-effective supply chain in place to deliver the technology.

To address this, it is important that information and evidence on existing and new technology is shared both between sectors in the UK, and internationally to ensure the best available technology and practice is implemented (acknowledging there may be limitations due to commercial sensitivities). To facilitate this and grow the evidence base, particularly on emerging technology for which there is a distinct lack of evidence, it would be beneficial to undertake monitoring when technology is implemented, which could be addressed through licence conditions. A database on noise abatement and reduction technology, which is regularly updated, should be produced at a UK and OSPAR level to maximise knowledge sharing and help develop a resilient supply chain across Europe and beyond.

Table 2. Summary of underwater noise abatement and reduction technology

	Technology (types/example)	Benefits	Limitations/innovation required
Impulsive noise	**Bubble curtain** ▪ Big bubble curtain (BBC) ▪ Double big bubble curtain (DBBC)	▪ Widely used and well established. ▪ DBBCs are more effective than BBCs. ▪ Can be used for multiple sources including pilling and explosives.	▪ Limited by depth, is only effective up to approximately 45 m. ▪ Limited by pile size as only effective up to approximately 8 m in diameter.. ▪ Less effective in areas with strong currents..
	Noise mitigation screen or isolation casing ▪ IHC-Noise Mitigation Screen (IHC-NMS) ▪ HydroNAS	▪ Widely used and well established. ▪ Can be used for multiple sources including pilling and oil and gas related activities.	▪ Limited by depth, is only effective up to approximately 45 m. ▪ Limited by pile size as only effective up to approximately 8 m in diameter. ▪ Only suitable to minimise sound from monopile impact piling.
	Encapsulated resonator systems ▪ Hydrosound Damper ▪ AdBm Noise Abatement System (AdBm-NAS)	▪ Unlimited by water depth, in principle (ScotMER, 2022). ▪ Can be used to target specific sound frequencies.	▪ Relatively untested, with a lack of demonstrated commercial use.
	Alternative piling hammers ▪ Vibro piling	▪ Vibro piling is widely used and well established.	▪ Only reduces peak sound pressure levels but can still result in substantial cumulative sound pressure levels.
	Alternative piling hammers ▪ BLUE Piling technology	▪ Not limited by depth. ▪ As this replaces the hammer, there is no expected delay to piling operations.	▪ Only suitable to minimise sound from monopile impact piling. ▪ Requires further testing if piles are to be installed at an angle rather than vertically.
	Alternative piling hammers ▪ Jetting technique	▪ Highly successful in its first commercial trial, where noise levels were reduced by over 99% (Ørsted, 2024).	▪ Only suitable to minimise sound from monopile impact piling.. ▪ Although not tested, sediment type could be a limitation as testing has only been undertaken in soft sandy sediments.

	Technology (types/example)	Benefits	Limitations/innovation required
	Low order deflagration	▪ Specifically targets UXO detonation, making its design more targeted. ▪ Low-order detonation is required, as set out in UK policy (unless otherwise justified).	▪ As it is a more novel technology there is limited evidence proving its efficacy.
Continuous noise	Optimisation of ship design: ▪ Propeller design ▪ Ship hull design ▪ Wake flow Machinery design and modification	▪ Noise reduction alongside potential reduced fuel consumption and emissions of greenhouse gas.	▪ Could be limited due to technical or physical constraints (such as vessel layout, inbuilt systems). ▪ Lack of evidence on the impacts to the vessel's energy efficiency. ▪ Opportunities should be implemented at the design stage to prevent technological or physical constraints.

7.7.1 Impulsive sounds

Bubble curtains

The most established and best tested noise abatement technology used to minimise negative impacts from impulsive sounds (such as piling and explosive operations) is bubble curtains, whereby a continuous 'curtain' of bubbles is produced rising from the seabed to the sea surface forming a barrier to sound waves encompassed in the bubbles. Two configurations are typically used, the most common being the release of a single circle of bubbles surrounding the sound source, knows as Big Bubble Curtains (BBC), or, for mitigating larger sounds, the release of two circles of bubbles (of different diameters in the same location), known as Double Big Bubble Curtains (DBBC).

Whilst this technology is widely used across northern Europe, the feasibility of bubble curtains should be considered as various factors can impact its efficacy. Bubble curtains have been proven to be effective in water depths up to approximately 45 m and become less effective as water depth increases, due to the dispersion of bubbles and the impacts of higher pressure (Cefas, Undated). Similar limitations occur when using bubble curtains in shallow estuarine environments (less than around 20 m), due to the scattering of bubbles across the shallow sediments. Other potential environmental limitations to consider include the strength of currents, particularly in tidal areas (e.g., evidence suggests that in currents above approximately 1 m/s noise attenuation is less effective (Cefas, Undated)), as well as pile size (effective up to a diameter of approximately 8 m, which is a large size pile that would typically be used in larger construction projects such as offshore windfarms). As shown in Figure 7, a BBC has been used in offshore windfarm projects, such as the Borkum West II offshore windfarm off the north coast of the Netherlands (Cefas, Undated).

With regard to offshore windfarms in the UK, bubble curtains have successfully been recently deployed in the Sofia offshore windfarm off the east coast of England, marking the first successful use of this technology in the UK (RWE, 2025b) Evidence is, however, not publicly available to determine the amount of noise reduction it achieved.

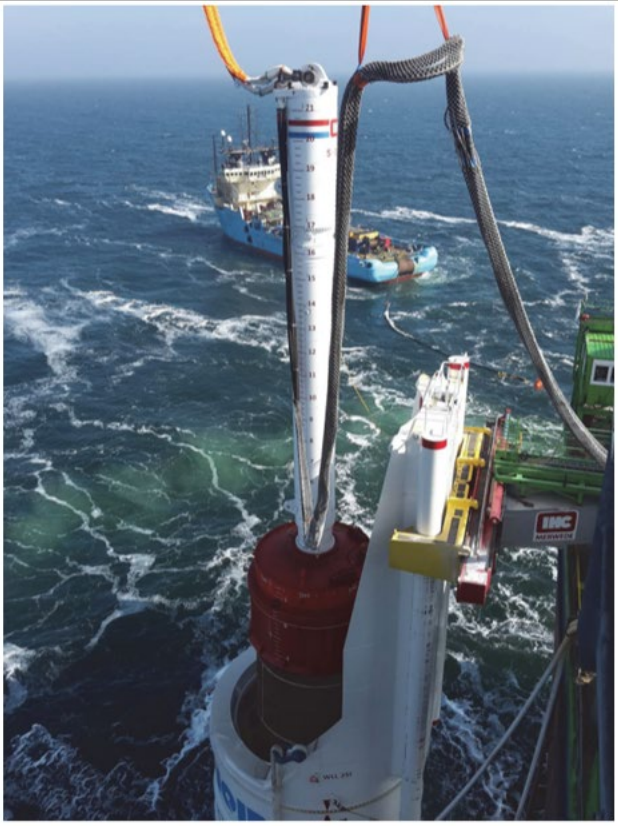
Source: © Hydrotechnik Lübeck GmbH

Figure 7. Jack-up installation vessel at OWF Borkum West II surrounded by a Big Bubble Curtain (NatureScot, 2019)

Noise mitigation screen (or isolation casing)

A noise mitigation screen (or isolation casing) involves encasing a monopile in an unbroken column (casing) which acts as a physical shield in order to quieten sounds radiating from the sound source. If required, the casing can be double layered around the monopile with the interspace between the two layers being pumped with water, or filled with air to create additional barriers. This method is, however, only applicable for mitigating noise from impact piling monopiles. Similarly to bubble curtains, this method can be applied in water depths of up to approximately 45 m and a pile diameter size of approximately 8 m.

Examples of noise mitigation screens include the IHC-Noise Mitigation Screen (IHC-NMS, pictured below in Figure 8) and HydroNAS, as listed in Table 2. There are few examples of projects that have used this type of technology, though evidence that is publicly available has shown that the HydroNAS system, developed by W3G Marine has been successful in reducing underwater noise by 25 dB in sound exposure level, and 35 dB in peak pressure level (Offshore Energy, 2015).



Source: © HC IQIP

Figure 8. Noise mitigation screen/ isolation casing deployed from a vessel surrounding a monopile (dark grey). The hammer (red) is placed on top of the monopile (NatureScot, 2019)

Encapsulated resonator systems

Encapsulated resonator systems involve deploying an array of resonating units around the sound source (usually impact piling) to absorb the emitted sound (JNCC, 2024). Examples of these systems include Hydrosound Dampers (see Figure 9) and AdBm Noise Abatement System, both of which include gas filled elastic 'balloons' based on absorbing and scattering sound. As these systems are fixed to the seabed they are less sensitive to currents (in comparison to bubble curtains), and can also be tuned to dampen particular frequencies (if resonator units emit sounds and 'cancel' out emitted sound produced by the sound source).

Similarly to noise mitigation screens, little publicly available evidence exists to assess the efficacy of encapsulated resonator systems, however, one review has suggested that the technology can reduce noise levels by at least 10 dB (NatureScot, 2019).

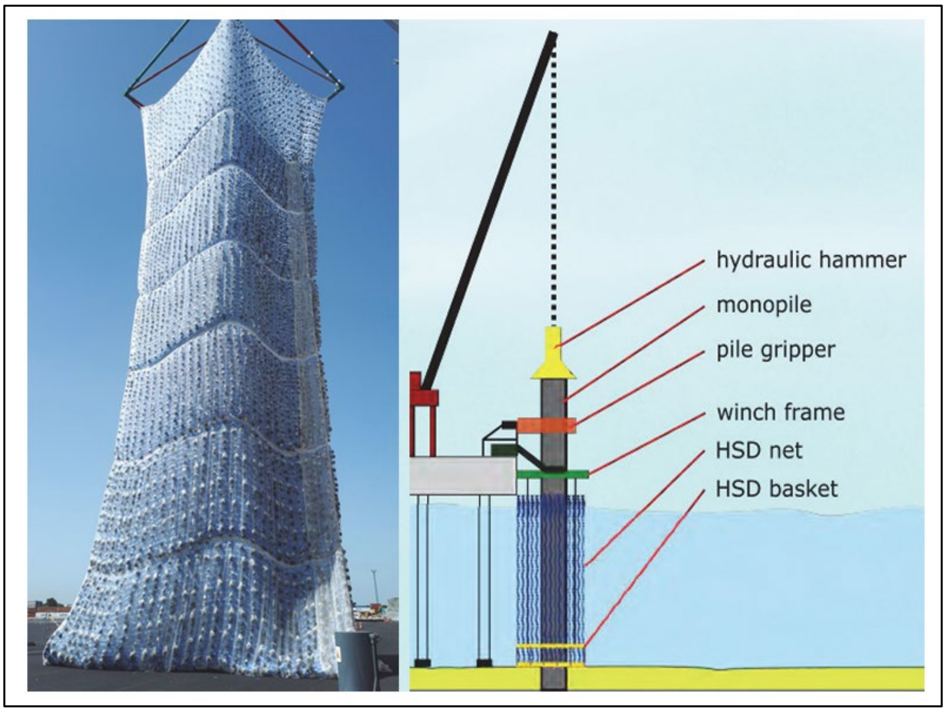


Figure 9. Example of Encapsulated resonator lifted by a crane on land (left), and schematic of HSD-deployment during monopole installation from a jacked-up platform (right)(NatureScot, 2019)

Alternative piling techniques

Vibro piling

Vibro piling is the most commonly used alternative method to impact piling, reducing peak noise levels by vibrating the pile vertically into the seabed. This type of piling produces low vibrating frequencies (resulting in lower peak sound pressure levels i.e., quieter sounds) that are less harmful to marine life compared to the loud, high frequency strikes when impact piling (CSA Ocean Sciences Inc, 2014). However, given the continuous nature of this type of noise, the cumulative sound pressure levels associated with vibro piling can still be substantial, and this activity has therefore required a greater level of evidence to be provided in recent underwater noise assessments to support its use, such as for the Immingham Eastern Roll-on/Roll-off Terminal (IERRT) Project (Associated British Ports, 2022).

BLUE piling technology

Another alternative method to impact piling is replacing solid steel hammers with steel hammers filled with a large volume of seawater in order to emit lower frequency sounds. This is achieved as the movement of water and air within the hammer drives a longer strike and therefore a longer, lower frequency sound (CSA Ocean Sciences Inc, 2014). A pilot project for this technology predicted that it would be capable of reducing underwater noise levels by up to 20 dB (sound pressure level) (The Carbon Trust, 2014). More recently, the Port of Rotterdam tested BLUE pilling technology (BLUE Hammer, 2018), however the outcome for the project, in regard to the noise reduction it achieved, is not publicly available.

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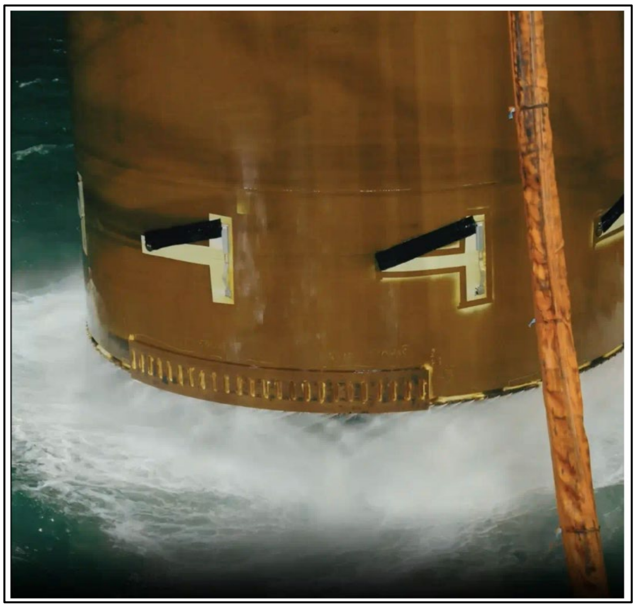
Figure 10. **Fistuca's BLUE Hammer deployed on an installation vessel placed on top of a monopile (NatureScot, 2019)**

Jetting techniques

As detailed in Section 7.4.5, a pilot project undertaken by Ørsted, partly funded by the German Government is developing and testing novel technology to reduce underwater noise by minimising the need for pile driving installation methods. Instead, a patented jetting technology is used to reduce the resistance of sandy soil, allowing the pile foundation to sink into the seabed (Ørsted, 2024). The replacement of pile driving with patented jetting installation technology has proven to be very effective, with noise levels being reduced by 99% at the German Offshore wind farm Gode Wind 3 in the North Sea. This innovative technology has also resulted in a more efficient and cost-effective installation process (Ørsted, 2024). Evidence is, however, not publicly available to understand the impact this might have on other marine species and the benthic habitat. As with all techniques, the efficacy of a noise abatement system should consider wider environmental impacts as well as the benefits of reducing noise levels.



Source: © Ørsted

Figure 11. Jetting noise abatement technique used to install monopile foundations at Gode Wind 3 in Germany (Ørsted, 2024)

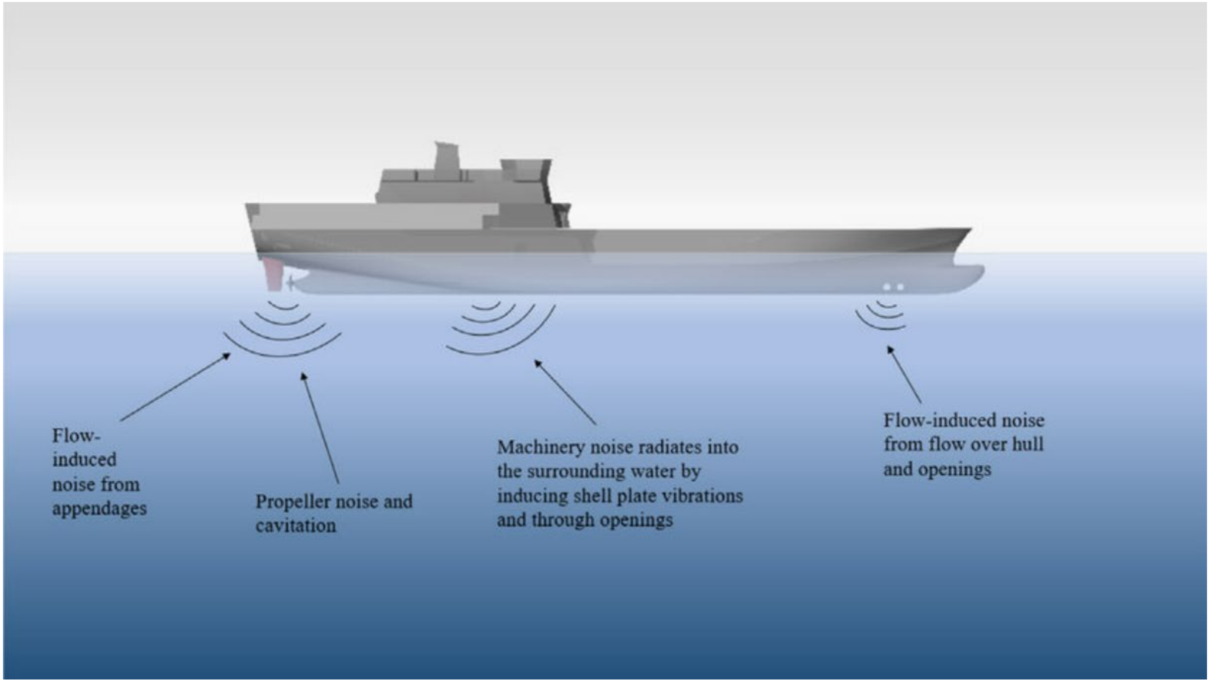
Low order deflagration

Offshore wind farm sites often overlap with historic military conflict or training sites, therefore developers must ensure they have reduced the risk of UXO. Clearance of UXO through high order detonation was the most common practice until deflagration techniques were introduced in the early 2000s (Oliva *et al.*, 2024). Low-order deflagration removes the risk by rapidly burning away explosive material within the UXO, which produces significantly less anthropogenic noise (Robinson *et al.*, 2020). As discussed in Section 6.2 UK policy has been published stating low-order methods (of which low-order deflagration is one) should be the default approach to detonation (Defra *et al.,* 2025).

A project undertaken at the Moray West windfarm has gathered evidence on the benefit of using low order to reduce the impacts of UXO clearance on marine mammals. In this project, 82 UXO were detonated prior to constructing the windfarm, all of which could successfully be detonated using low order methods. Noise measurements were taken at varying distances from the detonations which later was used to inform noise modelling. The data from this project was also used to inform noise modelling and demonstrate the potential to minimise the level of precaution taken in impact assessments to aid licensing decisions (Oliva *et al.,* 2024).

7.7.2 Continuous noise

The main source of continuous noise at sea is from shipping, see Figure 12. Options available to manage noise from shipping fall into the following categories of technological and non-technological methods. Technological methods typically include adapting the design of vessels and their machinery, namely propellors, to produce less sound. Non-technological methods involve implementing operational and policy changes such as reducing vessel speed and re-routing to avoid areas with species which are particularly sensitive or vulnerable to underwater noise impacts.



Source: Smith and Rigby, 2022

Figure 12. Key sources of underwater noise from vessels (Smith and Rigby, 2022).

As detailed in Section 5.1, the IMO has committed to several initiatives to manage and reduce underwater noise and in support of this have issued guidance and recommendation for member states to implement. This is contained within Underwater Radiated Noise Management Planning (IMO, 2023). Within the guidance, there is a strong emphasis on the importance of implementing measures early on in the design process as it is unlikely to be practical for older vessels to fully meet the specifications.

The UK Government states it is in support of the IMO guidance and vessel owners are encouraged to apply them and feedback on their use. There is, however, limited information across the UK, and internationally, to evidence the implementation and therefore effectiveness of the IMO guidance.

Technological measures recommended in the guidelines (IMO, 2023), as well as more widely within literature (ABS, 2021; Smith and Rigby, 2022) include:

- Propellor design and modification:
  - Designing propellers to minimise cavitation (formation of vapour bubbles around a propellor which collapse and produce a shockwave). This could include locating propellors in a preferential location, adapting their physical design, and using wind-assist technologies.
- Hull design and modification:
  - Designing vessel hulls to ensure the wake flowing around the vessel hull is as homogenous as possible, as uneven hulls can lead to uneven wake fields and in turn increase propellor cavitation.
- Wake flow improvements:
  - Several technologies can be used to improve wake flow over the hull, including installation of wake conditioning devices, installing pre-swirl stators, and installing a hub cap with fins. The techniques are all aimed at improving wake flow over a vessel’s hull and improving the efficiency of propellors.

- Machinery design and modification:
    - Installing onboard machinery that has been designed with noise abatement in mind. This could include selecting engines and generators with lower level of vibration, installing vibration isolation mounts, selecting electricity power propulsion systems, and securing loose machinery, all of which are aimed at minimising noise and vibration.

Similarly to the IMO's guidance, there is currently an evidence gap in understanding the benefit these noise reduction methods are currently having (or will have) on the marine environment. It is possible that individual monitoring programmes to determine the efficacy of specific vessel modifications to reduce sound have been undertaken, however, a centralised database storing such outputs does not exist. This is consistent with the wider evidence gap in achieving GES, to monitor and manage the impacts from continuous noise levels on the marine environment.

8 Conclusion

The acoustic soundscape within the marine environment plays a vital role in how marine organisms function. Sound or noise is produced in the marine environment through a range of different sources including from natural processes and anthropogenic activities. Broadly these sounds can be categorised as either impulsive (mainly associated with piling activity), or non-impulsive (mainly associated with natural processes and vessel movements). It is well established and evidenced that underwater noise and vibration can cause adverse physical and behavioural impacts to species that are sensitive to this pressure. These species are principally marine mammals, fish, certain benthic species, and potentially also diving birds (see Section 4).

Managing underwater noise in UK waters to a level that does not adversely impact marine life is required to achieve GES in accordance with the UK Marine Strategy under the Marine Strategy Regulations 2010. This is particularly important as underwater noise in the marine environment is set to increase in the future due to the projected increased use of the marine environment from a range of sectors and activities (see section 5). In summary, future trends are likely to be primarily driven by increases is offshore energy generation, construction, and shipping. This, however, should be considered alongside the projection that monitoring of noise, and the use of noise abatement systems, will increase in the future, both of which will help to minimise any potential increase in noise levels.

Based on efforts thus far, GES has been 'Partially achieved, and stable since 2012' for UK marine waters (Defra, 2025a). As stated throughout this review it should, however, be acknowledged that nuances and complexities exist between the definition of GES, the quantification of noise levels, and the impacts these have on marine life. In this way, progress towards GES thus far is viewed as a qualitative rather than quantitative benefit, as the 'partially achieved' status of D11 is not due to a measured reduction in underwater noise. Nevertheless, significant progress has been made towards achieving GES and better management or protection of the marine environment, particularly the increased monitoring which is helping to capture a better understanding and provide a greater driver for reducing underwater noise.

Overall, despite the UK taking considerable steps forward to managing underwater noise to a level that partially achieves GES, further action is needed. Taking a more holistic and strategic approach to managing underwater noise is considered the best way forward in this report, and has the potential to help achieve GES. Key to meeting this more strategic approach, is the need to develop and implement a strategic management plan such as that shown in
Figure 6. It will also be important to ensure underwater noise management is considered alongside spatial planning and prioritisation more widely, as it is important that efforts to manage underwater noise are sustainable and take account of competing interests and needs in the marine space.

There is a particular need to more effectively manage the impacts of anthropogenic impulsive and non-impulsive sounds at the population level, which is arguably the most significant evidence gap, and one that is suggested to be most appropriately addressed by more effective strategic management. Managing population level effects is considerably more challenging than evidencing the impact of noise on specific species or in spatially independent areas (such as harbour porpoise in SACs, though this is still challenging), as the specific interlinkages between populations, and between the marine environment, are complex and understudied. Addressing this evidence gap will involve implementing strategic monitoring programmes, not only across the UK, but internationally. This is to account for the highly mobile nature of marine mammals. As part of these monitoring programmes, in addition to survey design, it will be key to develop a reporting mechanism that allows outputs to be shared widely across the UK and internationally to maximise knowledge sharing.

Based on this review, key actions that have helped to partially achieve GES for D11 include the increased monitoring of anthropogenic impulsive sounds sources. This has been realised through creating the MNR and the monitoring programmes the UK are participating in. Arguably, however, the ability of the MNR to inform spatial planning and prioritisation of marine space, and strategic decision making, has not yet been evidenced. This would be extremely beneficial and could be achieved by expanding the capability of the MNR to predict future cumulative impacts and include the monitoring of continuous low frequency sounds.

To address this, and to also deliver coherent action, it is key to achieve greater coordination of the relevant parties such as governmental departments, regulatory bodies, SNCBs, NGOs, and developers. This will help enable both sectoral and inter-UK collaboration. This should be developed to ensure coherence at the OSPAR level, and to ensure coordination between policy and delivery bodies. Taking this approach could also help to prioritise underwater noise management and mitigation within spatial planning and prioritisation of marine space.

To effectively manage underwater noise, it is clear that there is an opportunity for more sophisticated noise abatement systems to be developed. To overcome the barriers to expanding the use of innovative noise abatement technologies (such as the lack of data available to evidence their efficacy and promote acceptance by licensing bodies), it is also key that methods are cost effective and able to be adapted for use in varying physical environments (such as in varying depths and currents). The need for this is a concern of both developers investing in the technology, and regulators assessing their suitability to satisfy licence conditions. This is a clear evidence gap, but one that can be addressed by prioritising strategic monitoring and early data gathering from the initial stages of development through to use on a commercial scale.

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10 Abbreviations

ABP	Associated British Ports
ADD	Acoustic Deterrent Devices
BBC	Big Bubble Curtain
CCUS	Carbon Capture Usage and Storage
COMPASS	Collaborative Oceanography and Monitoring for Protected Area and Species
CfD	Contract for Difference
DAERA	Department of Agriculture, Environment and Rural Affairs
DBBC	Double Big Bubble Curtain
Defra	Department for Environment, Food and Rural Affairs
DESNZ	Department for Energy Security and Net Zero
DfT	Department for Transport
D1	Biological Diversity
D4	Food Webs
D7	Hydrographical Conditions
D10	Marine Litter
D11	Descriptor 11
EC	European Community
ECHO	Enhancing Cetacean and Habitat Observation
ECOMASS	East Coast Marine Mammal Acoustic Study
EDR	Effective Deterrent Ranges
EIA	Environmental Impact Assessment
EPS	European Protected Species
EU	European Union
GES	Good Environmental Status
GW	Gigawatt
HM	His Majesty's
HPMA	Highly Protected Marine Area
HRA	Habitats Regulation Assessment
ID	Identification
IMO	International Maritime Organisation
JNCC	Joint Nature Conservation Committee
JOMOPANS	Joint Monitoring Programme for Ambient Noise North Sea
JONAS	Joint Framework for Ocean Noise in the Atlantic Sea
kHz	Kilohertz
MarPAMM	Marine Protected Area Management and Monitoring
MFRAG	Moray Firth Regional Advisory Group
MMO	Marine Management Organisation
MNR	Marine Noise Registry
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MW	Megawatt
NE	Natural England

NEAES	North-East Atlantic Environment Strategy
NGOs	Non-Governmental Organisations
NI	Northern Ireland
NMS	Noise Mitigation Screen
NOAA	National Oceanic and Atmospheric Administration
NRW	Natural Resources Wales
NRWG	Noise Regulators Working Group
OEP	Office for Environmental Protection
OESEA	Offshore Energy Strategic Environment Assessment
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic
OWEAP	Offshore Wind Enabling Actions Programme
OWEC	Offshore Wind Evidence and Change
OWF	Offshore Wind Farm
PCOD	Population Consequences of Disturbance
POWEM	Piloting of Offshore Wind Environmental Mitigation
PIANC	The World Association for Waterborne Transport Infrastructure
PTS	Permanent Threshold Shift
RAP	Regional Action Plan
SAC	Special Area of Conservation
ScotMER	Scottish Marine Energy Research
SDC10	Sub-Committee on Ship Design and Construction
SEA	Strategic Environmental Assessment
SNCB	Statutory Nature Conservation Bodies
SPA	Special Protection Area
TTS	Temporary Threshold Shift
UK	United Kingdom
UXO	Unexploded Ordnance

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

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