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Collaboration for Environmental Mitigation & Nature Inclusive Design (CEMNID)

Mitigation Measures Efficacy Review

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EXECUTIVE SUMMARY

The Scottish Offshore Wind Energy Council (SOWEC) established the Collaboration for Environmental Mitigation & Nature Inclusive Design (CEMNID) Project to address two key knowledge gaps with regard to environmental uncertainty in relation to impacts from offshore wind developments during construction and operational phases. The CEMNID Project aims to address knowledge gaps through provision of key deliverables including a mitigation efficacy review (current deliverable) for a subset of key mitigation measures considered to be of greatest relevance and importance to OWFs in Scotland.

A screening process, using information and key findings contained within the Mitigation Measures Literature Review (A100906-S00-A-REPT-002) and the Good Practice Library (other deliverables from the CEMNID Project), was undertaken for this efficacy review. This involved screening identified mitigation measures to a subset of key measures relevant to Scottish OWFs that would be subject to a more detailed efficacy review. Four emerging key themes came out of this screening exercise relating to underwater sound (Table 2-1 ,Section 2.2.1); avian collision risk (Table 2-2, Section 2.2.2), avian disturbance and displacement (Table 2-3; Section 2.2.3) and Electromagnetic Fields (EMF) (Table 2-4, Section 2.2.4). The following efficacy review focuses on these themes which relate primarily to the following receptors Marine Mammals, Ornithology, Benthic Ecology, Fish and Shellfish.

This review concluded that the effective use of Acoustic Deterrent Devices (ADDs) for deterring marine mammals from a project area has been demonstrated at a number of offshore wind farms within Scotland, including the Beatrice Offshore Wind Farm and Moray East Wind Farm. Alternative Unexploded Ordnance (UXO) clearance method in the form of Low Order Deflagration (LOD), where high explosive filling is combusted whilst avoiding the reaction becoming a high-order detonation, shown significant reduction in underwater noise levels in recent trials conducted by Robinson *et al*. (2020). LOD was successfully used in Danish waters (Lepper *et al.*, 2024) and during UXO clearance campaign on the Moray West OWF (Abad Oliva *et al.*, 2024). The effective use of low-noise installation methods (such as the use of alternative pile driving techniques (e.g., vibropiling/vibrohammer) and the drill-drive-drill methodology) has been demonstrated by a number of offshore wind farms within Scottish waters. In 2023, the Moray West Offshore Windfarm demonstrated the low-noise capabilities of the vibropiling technique as a viable method for reducing the potential impacts of underwater sound, with the Aberdeen Offshore Wind Farm and Seagreen Offshore Wind Farm further proving the efficacy of low-noise installation techniques through their adoption of suction foundation technologies (Power, 2018).

The review covered mitigation measures relating to avian collision risk (as presented in Table 2-2) and considered *in situ* adjustments of project design parameters (such as offshore turbine layout and minimum air gap) in relation to their potential impacts on collision risk for seabirds. There is some evidence that some seabird species can avoid collision, as demonstrated by the two year study at Aberdeen Bay Wind Farm however further evidence during operation on other wind farms is required to understand what mitigation is likely to be most effective for avoiding collision, especially in relation to cumulative effects.

The efficacy mitigation measures relating to EMFs (as presented in Table 2-4) reviewed considered both *in situ* assessment and modelling outputs. One particular study into the influence of subsea cables and associated EMF on the receiving environment concluded that the level of exposure to EMF exposure for key receptors was influenced by the depths at which the cable was buried and the position of the animal within the water column (Hutchison *et*

al., 2021). Available *in situ* EMF emissions from subsea cables demonstrate a rapid decrease in the strength of the magnetic field with distance from the cable, the zone affected decreasing significantly in areas where the cable is buried or additional cable protection is applied (i.e., where there is no exposed cable laid directly on the seabed) (BOEM, 2023; Hutchison *et al*., 2020). There remains uncertainty into the potential impacts of EMFs on marine animals, with the need for further *in situ* EMF measurements required before a detailed understanding of the potential impacts and mitigation can be developed.

There was a general lack of readily available post-construction monitoring evidence in the offshore wind industry in Scotland to inform this review. This report has considered publicly available sources of information in addition to expert and up-to-date knowledge within Xodus and across the CEMNID Project Steering Group (PSG). Longer term studies and data sets were few, owing to the small number of operational wind farms within Scotland, despite the large number of OWFs in development and therefore research extended to other countries. Recently, some key outputs have emerged from the projects in the Moray Firth, which make up amongst the most mature developments in Scotland. Relatedly, there is a lack of centralisation to store monitoring information and data for OWFs. This review considers there is a large opportunity for knowledge sharing and information storage across marine industries such that future processes, and implementation of mitigation measures, can be improved.

1 INTRODUCTION

1.1 Background to the CEMNID Project

The twin crises of climate change and biodiversity loss are arguably the greatest environmental challenges of our era. Energy production from renewable sources (e.g. offshore wind farms) is key for reducing carbon emissions and achieving the Net Zero target by 2045 in Scotland. However, these offshore renewable developments may have adverse environmental impacts on marine species and habitats, hindering biodiversity recovery. The implementation of effective mitigation measures, as well as the development of practices supporting nature recovery present both challenges and opportunities for the sustainable development of the offshore wind sector globally.

The Scottish Offshore Wind Energy Council's (SOWEC) Barriers to Deployment – Enabling Group established the Collaboration for Environmental Mitigation and Nature Inclusive Design (CEMNID) Project to address two key knowledge gaps with regard to environmental uncertainty in relation to impacts from offshore wind developments during construction and operational phases. These gaps are:

- To identify the most appropriate mitigation measures for species receptors that can be applied to offshore wind developments in Scotland, when applying mitigation hierarchy; and
- Identify opportunities to apply Nature Inclusive Design (NID) to Scottish offshore wind projects in order to contribute to biodiversity enhancement and nature positive outcomes from such developments.

It is recognised that a key barrier to the consenting and deployment at pace of offshore wind farms is environmental uncertainty, including in relation to impacts from developments during construction and operational phases and the efficacy of environmental mitigation and enhancement measures such as Nature Inclusive Design (NID). These uncertainties directly contribute to risks and delays in the consenting and deployment of Scottish offshore wind developments and therefore threaten the achievement of Scotland's net zero and nature positive targets. Dealing with these uncertainties also exacerbates resourcing pressures across the consenting system for developers, regulators, advisory bodies and NGOs, increases development costs and risks irreversible wildlife losses. To accelerate consenting and facilitate the sustainable and rapid expansion of offshore wind deployment in Scotland, environmental uncertainties associated with offshore wind development therefore urgently need to be addressed.

By addressing the above mentioned gaps, the CEMNID Project seeks to develop a holistic framework to identify and apply good practice environmental mitigation, and to provide some understanding on how to deliver environmental benefit through embedding NID in Scottish offshore wind development projects. This will help address key barriers to consenting and deployment and will support Scottish offshore wind projects to tackle the climate and nature crisis in tandem.

The overarching objectives of the CEMNID Project are therefore to:

- Provide a clearer understanding of how to apply the mitigation hierarchy in offshore wind developments in Scotland;

- Summarise good practice[1] environmental mitigation measures that could be deployed using the mitigation hierarchy;
- Identify the principles of NID for offshore wind development, including how these relate to the mitigation hierarchy;
- Identify ecologically promising and practically applicable NID measures that could be applied to Scottish offshore wind projects; and,
- Provide evidence to support the consenting requirement to implement nature-positive development in the marine environment and thereby comply with adopted National Planning Framework 4 and emerging policies, including National Marine Plan 2.

The CEMNID Project is overseen by a steering group comprising technical and consenting experts drawn from offshore wind developers, consultees and regulators. The Project secured funding from Crown Estate Scotland and approval from SOWEC, resulting in Xodus Group Limited (Xodus) being commissioned to deliver the Project scope in line with the objectives. This document has been prepared by Xodus.

1.2 Outputs of the CEMNID Project

The CEMNID Project aims to achieve the objectives outlined above through provision of the following key deliverables:

- Mitigation Measures Literature Review (A100906-S00-A-REPT-002):
  - Literature review and associated research regarding the use of environmental mitigation measures for Scottish and other relevant offshore developments which, based on objective criteria, are considered to represent good practice;
- NID Literature Review (A100906-S00-A-REPT-003):
  - Literature review and associated research on international evidence of NID approaches which are assessed as ecologically promising, practically applicable, and relevant to offshore wind deployment in Scotland;
- Mitigation Measures Efficacy Review and Good Practice Library (current deliverable; A100906-S00-A-REPT-004):
  - Development of a Good Practice Library for environmental mitigation and an associated efficacy review for a subset of key measures;
- NID Suitability Review and SWOT analysis (A100906-S00-A-REPT-005):
  - Strength, Weaknesses, Opportunities and Threats (SWOT) feasibility analysis of identified options for their applicability to offshore wind in Scotland, and associated NID suitability review focusing on ScotWind option areas and supporting infrastructure corridors to determine habitat and species suitability;
- Final Report (A100906-S00-A-REPT-007):
  - Structured report including discussion of mitigation good practice and guidance on implementing NID at a project level.

[1] *Good practice defined in this context as "Good practice is defined as a process or methodology that has been consistently shown to work well and to achieve reliable results" (IEEM, 2021).*

1.3 Aim of the deliverable

This deliverable aims to review the efficacy of a subset of key mitigation measures that are considered to be of greatest relevance and importance for offshore wind farm development in Scotland. The methodology of how this has been approached is discussed further in Section 2.1. The efficacy review will build on the key findings of the Mitigation Measures Literature Review (A-100906-S00-A-REPT-002), which took a holistic look at offshore wind mitigation measures and provides a more focussed assessment of the effectiveness of key mitigation measures identified therein and screened into the Good Practice Library.

2 EFFICACY REVIEW

2.1 Methodology

A screening process, using information and key findings contained within the Mitigation Measures Literature Review and the Good Practice Library, was undertaken for this efficacy review. This involved narrowing down identified mitigation measures to a subset of key measures relevant to Scottish OWFs that would be subject to a more detailed efficacy review.

In summary, the steps taken in the screening process for identifying the subset of mitigation measures were as follows:

- Mitigation measures within the Good Practice Library, which are already included in UK policy, used as industry standard practice and/or technically applicable to Scottish offshore windfarms;
- Mitigation measures applicable to key receptors relevant to Scottish OWFs and specifically relevant to ScotWind;
- Mitigations that were categorised as being either primary and/or secondary mitigations (tertiary mitigations were excluded).

Background information was compiled on the available/deployed mitigation measures in offshore wind as part of the Mitigation Measures Literature Review. In summary, the CEMNID Project has had a focus on ecological and abiotic receptors; therefore, in developing the Good Practice Library, the full list of mitigations identified in the literature review were screened down into the most promising and relevant measures deemed to be good practice for Scottish OWFs. Mitigation measures were listed in the Good Practice Library for the following receptors:

- Physical Processes;
- Sediment / Water Quality;
- Benthic Ecology;
- Fish and Shellfish;
- Marine Mammals; and
- Ornithology.

During the screening exercise, the subset was initially defined by sorting the measures according to whether they constituted primary or secondary mitigation. According to the IEMA (2016) definition, primary mitigation is an intrinsic part of a project's design and should be described in the design evolution narrative and included within the project description. Depending on the specific set of circumstances of a development, some of these primary measures may also be considered as secondary measures that are featured in mitigation plans following the assessment of environmental effects. As this is a factor inherent within, and unique to, each project, this was considered to be the most informative avenue for further investigation herein. Tertiary measures which are required regardless of any EIA assessment, for instance, as a result of legislative requirements and/or standard sectoral practices, were not considered further in this efficacy review.

Four emerging key themes came out of this screening exercise relating to underwater sound (Table 2-1 ,Section 2.2.1); avian collision risk (Table 2-2, Section 2.2.2), avian disturbance and displacement (Table 2-3; Section 2.2.3) and

Electromagnetic Fields (EMF) (Table 2-4, Section 2.2.4). The following efficacy review focuses on these themes which relate primarily to the following receptors Marine Mammals, Ornithology, Benthic Ecology, Fish and Shellfish.

The Mitigation Measures Literature Review explains the process by which mitigation measures were screened in or out of the Good Practice Library. Many of the tertiary mitigation measures that encompass Environmental Management Plans (EMP) and related construction and operational plans were not included in this library, as these were not in themselves considered mitigation measures, rather more the mechanism to document and describe approaches to mitigation during relevant phases of the development (e.g., Construction Environmental Management Plans (CEMP) that typically contain within them a number of proposed mitigation measures for construction activities). As such, this document does not discuss the effectiveness of management plans.

A key consideration in the screening exercise for this efficacy review was if mitigation measures were driven by a technical or engineering project requirement with resultant ecological benefits. This was considered important as it could be construed that such measures were not ecologically driven, despite having resultant ecological benefits (e.g. wind turbine spacing, which is determined by technical requirements first and foremost, rather than avian collision risks). This factor was taken into account in the Good Practice Library and where it was deemed that the environmental merits of mitigation measures were robust and represent good practice, they were screened into the library. However, these types of measures were not considered further in this efficacy review, with one important exception that relates to the burial of cables and EMF. Other impacts to marine benthic receptors such as the requirements to microsite and reduce rock placement were also not considered further in this review, as micrositing is considered an avoidance measure and the reduction/optimisation of rock placement is another instance where the measure is driven primarily by engineering requirements.

Beyond this, the subset was further refined in accordance with the mitigation measure hierarchy. Avoidance measures were discounted from further consideration as it is assumed that avoidance of impact likely avoids effects on receptors. Impact minimisation measures were instead the focus of the subset in this review.

It is important to note that this efficacy review can only report upon available evidence with regards to the implementation and success of mitigation measures. In the Mitigation Measures Literature Review, monitoring reports were consulted to help determine if any of the mitigation measures that were proposed could be deemed to have been successful or not. This exercise was inconclusive, particularly with regard to key biological receptors such as birds, mammals and fish. Overall, the monitoring reviewed did not identify major shifts in baseline conditions and therefore it could be deduced that the mitigations deployed were relatively successful in that no deleterious effects were recorded.

2.2 Efficacy Review

2.2.1 Mitigations associated with anthropogenic underwater sound

The potential impacts of underwater sound on acoustically-sensitive receptors such as marine mammals are influenced by both the nature of the sound within the marine environment (e.g., if the sound is intermittent or continuous) and the auditory thresholds of the animal. A considerable focus of existing research into the potential impacts of anthropogenic underwater sound on marine mammals considers construction and pre-construction activities associated with offshore development (such as geophysical surveys, piling and UXO clearance). The mitigation measures considered within this section are considered relevant to the minimisation of potential impacts to marine mammals within the marine environment. However it should be noted that the implementation of any of these mitigation measures has the potential to reduce or minimise potential impacts to other key receptors within the marine environment (i.e., fish and ornithology).

Mitigation measures adopted in consideration of the potential impacts of anthropogenic underwater sound on marine mammals can be implemented throughout project development, with primary mitigation measures adopted as part of the primary design of a project (i.e., soft start piling procedures) and tertiary mitigation measures implemented throughout the operational lifecycle of the project (i.e., the development and adherence to a Marine Mammal Mitigation Protocol (MMMP)).

This section considers the effectiveness of those mitigation measure which go beyond standard project design, particularly in instances when routine measures such as standard piling protocols are not considered sufficient to reduce the potential impacts associated with anthropogenic underwater sound. Further consideration is given to the application of mitigation measures associated with UXO clearance. Table 2-1 below outlines the key measures that were considered for further review of efficacy on noise.

Table 2-1 Mitigations relating to underwater sound screened in to efficacy review

MITIGATION MEASURES INCLUDED IN LIBRARY	KEY RECEPTORS
Potential use of Acoustic Deterrent Devices (ADDs) as an active method of deterring animals from the zone of potential injury	Marine mammals
Lift and relocation of UXO from the project area (avoidance of clearance or detonation)	Marine mammals
Disposal of UXO (if cannot be avoided or relocated) through the use of low noise clearance methods (e.g., Low Order Deflagration)	Marine mammals
Adoption of low-noise installation methods such as alternative pile driving techniques (e.g., vibropiling/vibrohammer), suction caissons/buckets and the drill-drive-drill methodology. These measures can be implemented as either full or partial foundation installation.	Marine mammals
Use of bubble curtains for noise abatement at source. Bubble curtains can be adopted as part of project development (i.e., piling) or during pre-installation works (UXO clearance).	Marine mammals

Use of ADDs

ADDs refer to a variety of acoustic devices which can be used to deter marine mammals from approach an area where pre-installation or construction works are being undertaken. ADDs have been used across marine industries to reduce the potential risk of injury to marine mammals as a result of anthropogenic underwater sound. There are a number of existing reports that review the effectiveness off commercially available ADDs, with consideration given to the acoustic characteristics of the device and their effectiveness at deterring marine mammals from an area over a sufficient duration and distance to reduce the potential for injury to animals as a result of anthropogenic underwater sound.

The development of Beatrice Offshore Wind (BOWL), Moray East and Moray West OWF within the Moray Firth have incorporated the use of ADDs into the project piling strategy. The Moray Firth is a biologically diverse and valuable environment for UK cetacean and pinniped populations, with the most northerly resident population of bottlenose dolphins present within these waters year-round (WDC, 2024; MMPATF, 2024). As such the ADDs proposed for use during the construction of BOWL and Moray East were subjected to a risk assessment which sought to demonstrate that adoption of these mitigation procedures would present a negligible additional risk to key marine mammals receptors within the region. Construction monitoring during the course of piling activities at the Moray East Wind Farm demonstrated that the use of ADDs prior to soft start piling resulted in harbour porpoises moving away from the noise source prior to the commencement of piling activities (Graham *et al.*, 2019). Further research by Thompson *et al.* (2020) demonstrated that, following exposure to ADDs, acoustics detections of porpoise within an area decreases for 3 hours, with the minimum time to the first porpoise detection post-ADD playback greater than 2 hours for sites within 1 km of the playback (Thompson *et al.*, 2020).

The successful use of ADDs has been demonstrated in offshore wind development across Europe. Before piling of offshore wind farm foundations in Germany, ADDs were deployed at four offshore construction sites to monitor harbour porpoise acoustic detections at different distances up to 10 km from the piling operation (Voß *et al.*, 2023). It was concluded that harbour porpoise detection rates during ADD operations decreased by between 30 to 100% at a distance of 750 m from the source compared to 6 hours before the ADD was turned on. Furthermore, reduced detection rates were observed up to a distance of approximately 2.5 km from the source when the ADD was switched on for over 40 minutes (Voß *et al.*, 2023).

As part of the review of ADD efficacy, it is important to consider whether the proposed mitigation measure has the potential to incur unintended consequences on the key receptor. The frequency of the ADD device deployed within the marine environment and the duration of ADD operations should be considered in the efficacy of reducing potential injury to marine mammals as a result of anthropogenic underwater sound, without introducing a new source of acoustic injury. Acoustic devices specifically designed for mitigation purposes, such as acoustic porpoise deterrents (APDs) (e.g., FaunaGuard Porpoise Module; SPL = 172 dB re 1 µPa (rms) @ 1m at 60 to 150 kHz) aim to deter animals from the construction site without leading to large-scale disturbance (Voß *et al.*, 2023). In 2021, Todd *et al.* undertook a desk-based noise-propagation modelling analysis of six commercially used ADD models, exploring the potential for auditory impacts on marine mammals (using the Southall *et al.*, (2019) criteria). It was concluded that, depending on operational characteristics, ADDs were predicted to result in a Temporary Threshold Shift (TTS) to Very High Frequency (VHF) cetaceans (e.g., harbour porpoise) at a range of between 4 -31 km, with a reduction in source level the single variable causing the greatest reduction in potential impacts to marine mammals from modelled ADDs (Todd *et al.*, 2021). Further research suggests that the response of marine mammals to ADD playback was sufficiently conservative to reduce the potential risk of injury to marine mammals from anthropogenic underwater sound associated with offshore construction, however further regulatory consideration should be given to optimising ADD source signals and/or the deployment schedules of ADD devices within the marine environment to minimise the potential for broad-scale disturbance to marine mammals (Thompson *et al.*, 2020).

Lift and relocation of UXO

Where UXO are present within the marine environment and within the boundaries of an offshore development, the lift (recovery) and relocation (or wet storage) approach presents the lowest potential for injury or disturbance to marine mammals as a result of underwater sound (negating the requirement for high or low-order clearance). Within Scotland, wet storage of UXO was more recently adopted as part of the development of the Neart Na Gaoithe Offshore Wind Farm. Where it was determined that a UXO identified within the project area was safe for recovery, the object was safely lifted a few metres from the seabed and relocated to a pre-determined site outside the project area where it was returned to the seabed (NnG, 2021). As outlined within the Neart Na Gaoithe Offshore Wind Farm UXO underwater sound monitoring report (NnG, 2021), 16 UXO were safely wet stored using this approach.

Low noise clearance of UXO

Low Order Deflagration (LOD) is an alternative method for high-order UXO clearance (detonation). The approach constitutes a less damaging, less destructive approach to UXO clearance which causes the UXO to ignite and burn out rather than detonate. LOD is outlined in the recent JNCC draft guidance on minimising the effects of UXO (JNCC, 2023) and is currently considered the primary alternative to high order clearance, with the Scottish Government marine environment: unexploded ordnance clearance joint interim position statement recommending that low noise alternative to UXO clearance should be prioritised over high order detonations (Scottish Government, 2022).

In situ comparisons of high-order UXO clearance and LOD in the Danish Great Belt compared the underwater sound produced by high-order detonations with that produced by deflagration (Lepper *et al*., 2024). The study assessed the sound-propagation model for six *in situ* UXO detonated using LOD. It was concluded that, while significant acoustic pressure levels from field measured data for high and low-order detonation events were present out to a range of >20 km, LOD events were typically around 15 dB to 20 dB lower in amplitude for both sound exposure level (SEL) and zero-to-peak linear source levels ($L_{p,pk}$) when compared to high-order detonation (Lepper *et al*., 2024). While underwater acoustic levels for LOD were lower than those associated with high-order detonation, LOD does still present a significant noise source within the marine environment, with the potential for injury and/or disturbance to marine mammals possible over a range of several kilometres from the source. As such it was the recommendation of Lepper *et al*. (2024) to adopt LOD methodologies for UXO clearance in combination with other mitigation measures (such as the use of abatement methodologies) in order to further reduce the potential for injury or disturbance to marine mammals (Lepper *et al*., 2024).

In 2023, the Moray West Offshore Windfarm undertook a UXO clearance campaign prior to construction works. Eighty-two UXOs were successfully cleared with the use of LOD. Calibrated noise measurements were made at 1 km, 5 km, and 10 km from the noise source at 31 locations. The highest measured $L_{0\text{-}pk}$ sound level was 208.4 dB re 1 µPa, recorded at a range of 1 km, which constitutes a 22 dB reduction in noise level when compared with the predicted modelled sound level for a high-order detonation of this UXO ($L_{0\text{-}pk}$ = 228 dB re 1 µPa at 1 km) (Abad Oliva *et al*., 2024). Obtained data suggest that the worst case impact ranges for marine mammals were for very high-frequency cetaceans (harbour porpoises), with auditory injury impact ranges below 1.5 km. However, this is reduced when compared against 2.55-14.25 km impact ranges predicted for equivalent high-order detonations of these UXOs (Abad Oliva *et al*., 2024).

Low-noise installation methods

While this efficacy review does not consider mitigation by avoidance, the adoption of low-noise installation methods for offshore wind foundation installation are considered to present a partial alternative to impact piling, therefore reducing underwater sound within the marine environment.

In 2023, the Moray West Offshore Windfarm selected Vibro Lifting Technology for upper monopile installation within the array. While the vibropiling technique is not necessarily considered capable of driving the full pile into the seabed, it can initiate pile penetration, thus reducing the duration of impact piling at the site. As such, where technically viable (owing to ground conditions and pile type), and where key receptor sensitivity is such that additional mitigations should be applied, low-noise installation methods such as vibropiling present a viable method for reducing the potential impacts of underwear sound for offshore construction.

Wind turbine foundations installed by suction (i.e., suction buckets, suction caissons, suction piles, or suction anchors) utilise the pressure difference generated between the sides of the bucket and the surrounding water at the seabed to install the foundation without the requirement for any mechanical force (Ørsted, 2024). The efficacy of suction buckets within Scotland was demonstrated at the first commercial-scale suction bucket foundation was installed at Vattenfall's 11-turbine European Offshore Wind Development Centre (EOWDC) (also known as the Aberdeen Wind Farm) (Power, 2018). Most recently suction caisson foundations were installed at the Seagreen Offshore Wind Farm site.

The drive-drill-drive technique for pile installation has proven efficacy across a number of offshore wind developments. The method combines drill and hammer techniques for installation, thereby saving installation time, negating the cost associated with temporary casing, grout or concrete and reducing the size of the piling hammer. Furthermore, relief drilling inside and below the pre-driven pile significantly reduces the energy required to install the pile to the target depth (ACTEON, 2024). In Scotland the drive-drill-drive technique was most recently adopted as part of the Neart Na Gaoithe Offshore Wind Farm installation methodology as it was considered an appropriate approach to the ground conditions of the offshore array area (Mainstream Renewable Power, 2019).

It is important to recognise that the selection of an alternative low-noise installation method is highly dependent on the nature of the offshore environment (i.e., sediment type and subsurface geology). Furthermore, the selection of alternative, low-noise installation methods will incur an additional cost for the specialised vessels and/or equipment that are required to complete construction works.

Bubble curtains

Bubble curtains are formed by releasing compressed air through one or more nozzle hoses that are laid on the seafloor around a piling operation into the water column (Verfuss *et al*, 2019). As the air ascends from the seabed and to the water's surface a vertical curtain of bubbles is built along the length of the tube, absorbing, reflecting and scattering underwater sound from the piling operations and thereby reducing the associated underwater sound profile (Verfuss *et al*, 2019).

The use of bubble curtains as a noise mitigation measure for offshore pile driving is well demonstrated. In 2019, two offshore windfarms under construction in Belgian waters (the Northwester 2 and Seastar projects) adopted the double big bubble curtain in order to minimise the underwater sound levels emitted from piling activities. in situ measurements of the underwater sound generated during the 14 full-pile driving events undertaken for both windfarms concluded that measured zero to peak sound levels (L_{z-p}) for both sites ranged from 183 to 193 dB re 1μPa when normalised to a distance of 750 m from the source equating to an estimated sound reduction of 20 dB re 1 μPa for Northwester 2 and 12 to 20 dB re 1 μPa for Seastar (Norro, 2021).

While there is evidence of a notable decrease in underwater sound from offshore construction following the implementation of bubble curtain mitigation, Brandt *et al* (2016) highlighted the various factors affecting underwater sound propagation (i.e., pile diameter, water depth, sediment type) which have the potential to impact the efficacy of bubble curtains (Brandt *et al*., 2016). Further research presented by Verfuss *et al.* (2019) highlighted the operational limits of bubble curtains with regard to the water column, with bubble curtains operating best at a slack tide to avoid the drifting of bubbles which may result in gaps in the bubble curtain (Verfuss *et al*., 2019). It is further acknowledged that this condition would often not be appropriate for offshore wind farm construction works and that additional design an installation requirements would be required to ensure the efficacy of the bubble curtain is sufficient (i.e., deploying the bubble curtain in an oval shape with the point of the oval ring greater than 70 m away from the pile position facing the current) (Verfuss *et al*., 2019).

While the efficacy of bubble curtains as a mitigation measures against underwater sound from piling operations has its operational limits, the combined potential of bubble curtains with other forms of mitigations (e.g., LOD UXO clearance) is recommended in consideration of the residual potential for injury and/or disturbance to marine mammals following low-order detonation of UXOs (as detailed above). Quarry trials of bubble curtain mitigation for UXO removal undertaken by Cheong *et al* (2023) demonstrated that bubble curtains achieved a reduction in peak sound pressure level of between 13 dB and 17 dB and in SEL of between 7 dB and 8 dB (for experimental trials of UXO deflagration within Limehillock Quary) (Cheong *et al*., 2023).

Other novel noise abatement measures for piling include resonator systems and other similar barriers that have been tried and tested for piling of offshore wind foundations (Verfuss *et al*., 2019; ACCOBAMS 2019). Their merits were considered against their applicability to Scottish offshore windfarms and it was considered that these barrier type noise abatement measures were less suitable in Scottish waters due to technical constraints such as water depths (>40 m) involved. Although there is currently little evidence of their efficacy in deeper water, there are some manufacturers that indicate that such systems (e.g. HydroNAS) can be adapted to suit a range of water depths. Therefore, it is considered that these noise abatement measures can potentially present another mitigation option to piling noise in sensitive areas and therefore included within library of good practice. It is recommended that if taken forward, any novel noise abatement measure should be accompanied with appropriate monitoring to enable demonstration of effectiveness.

2.2.2 Mitigations associated with collision risk

With the acceleration of offshore wind development, the potential risk of collision between offshore ornithology and wind turbines is considered a key environmental concern when project location and design parameters are being reviewed. The mitigation measures outlined within this section are considered relevant to the minimisation of potential impacts to offshore ornithology as a result of increased collision risk with offshore infrastructure.

Mitigation measures adopted in consideration of the potential impacts of collision risk on offshore ornithology are primarily implemented as the concept stage of project development, with any mitigation measures included in the library (as outlined in Table 2-2) adopted as part of the primary design of a project.

Table 2-2 Mitigations relating to collision risk screened in to efficacy review

MITIGATION MEASURES INCLUDED IN LIBRARY	KEY RECEPTORS
Consideration of turbine layout: by avoiding placing turbines in areas of relatively high utilisation for offshore ornithology species	Ornithology
Maintenance of a minimum air gap between WTG turbine blades and the sea surface	Ornithology

Consideration of turbine layout

A key mitigation measures for reducing the potential for collision risk between offshore ornithology and WTGs can be applied at the early stage of project development through turbine layout within the array area. There is existing evidence to suggest that reducing the number of turbines per km^2 within the marine environment will reduce potential collision risk for seabird (Brabant *et al*., 2022), with Croll *et al* (2022) suggesting that alterations to turbine layout within an offshore wind farm may be an important element of a future comprehensive impact avoidance framework (Croll *et al*., 2022).

Averting collision risk through consideration of turbine layout has been applied to offshore wind farms within the UK. In 2019, the Examining Authority, Natural England and the Royal Society for the Protection of Birds (RSPB) sought further mitigation options for the Norfolk Vanguard Offshore Wind Farm to negate the potential for negative effects on seabirds (as identified through the project Environmental Statement). One of these mitigation measures included a revision of the wind turbine layout where the following maximum criteria was imposed: no more than two-thirds of the turbines originally proposed as part of the Environmental Statement will be installed in Norfolk Vanguard West; and no more than half of the turbines will be installed in Norfolk Vanguard East (MacArthur Green, 2019). A second impact assessment considering these imposed mitigation measures as the worst case collision prediction for each species saw a reduction in potential collision mortality of 34% (MacArthur Green, 2019).

Maintenance of a minimum air gap

A key factor in bird collision risk with offshore WTG blades is the proportion of birds that are estimated to fly at collision risk height (Martin and Banks, 2023). While many bird species will avoid an offshore wind array, with a study into northern gannets concluding that around 89% of birds predominantly avoided an offshore wind farm off the coast of Germany (Leemans and Collier, 2022), some bird species have been known to pass through or forage within offshore wind farms (Peschko *et al*., 2021).

Existing research into the movements of seabirds throughout an offshore turbine array reveals that most seabirds fly near the sea surface (<5 m), avoiding collision with turbine places higher above the sea surface (BTO, 2013). However other studies have noted that recent compilations of flight heights for seabird species indicate that collision risk increases for birds which are flying below the swept area of the rotor blade (Davies and Band, 2012). Further modelling studies for a number of bird species have concluded that increasing the clearance of blade height above the water surface will significantly reduce the numbers of bird collision with offshore WTGs (as presented in Figure 2-1) (Davies and Band, 2012).

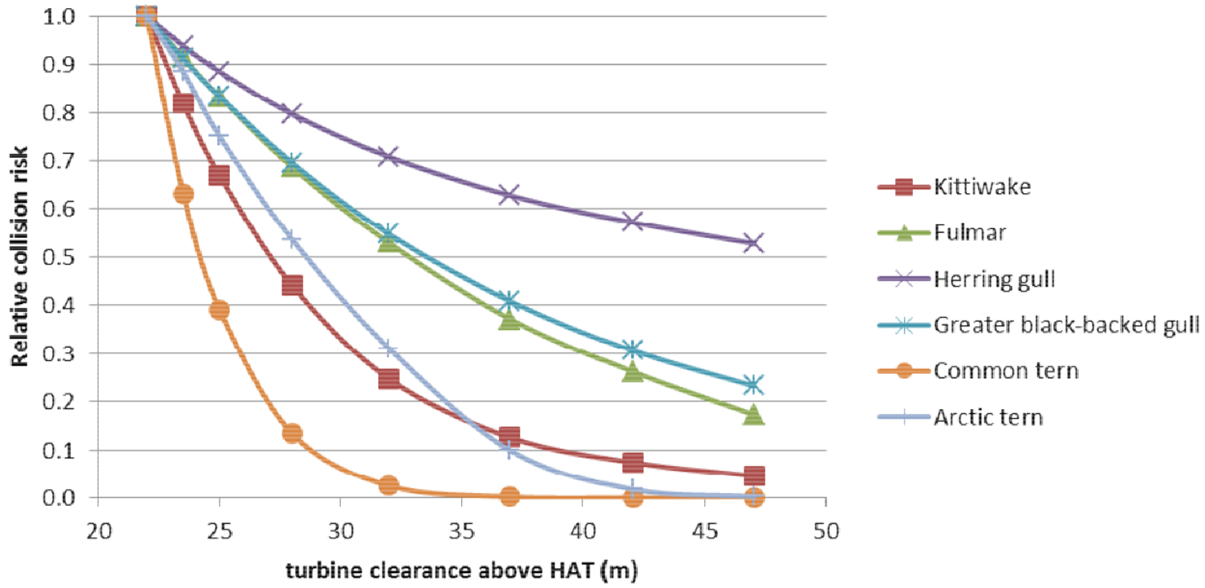

Figure 2-1 Relative collision risk for seabird species with turbine clearance (Davis and Brand, 2012)

As detailed in the Mitigation Measures Literature Review, there are a number of blade air gap distances adopted for offshore wind farm developers within Scotland (and the wider UK). For some of these offshore wind farms, post-construction monitoring has been undertaken to assess collision risk and provide *in situ* evidence of the effectiveness of blade clearance above sea level at particular offshore wind farms. Post-construction collision risk monitoring for the Aberdeen Bay Offshore Wind Farm utilised radars and cameras to monitor how birds behaved in the Aberdeen Bay and wider North Sea over a period of two years. The result of the survey concluded that birds amended their movements to avoid rotor blades and as such not a single collision between a bird and a rotor blade was recorded throughout the two year monitoring campaign (Vattenfall, 2023). However, as highlighted in the Mitigation Measures Literature Review, these observations were based on the design parameter of a 25 m blade clearance above sea level, with large turbines (164 m diameter) and a relatively slow rotation speed (13.98 rpm). It was considered that these WTG design parameters were adequate to reduce bird collisions to a negligible level (Vattenfall, 2023).

As described above, in 2019 an assessment of additional mitigation measures for the Norfolk Vanguard Offshore Wind Farm was undertaken in consideration of reducing potential collision risk for seabirds. One of these mitigation measures including increasing turbine draught height from 22 m to 27 m. Following a second assessment of potential impacts considering these additional mitigation measures (including increased turbine height) it was concluded that the average collision risk (across species) for the project was reduced by 65% compared to the Environment Statement (MacArthur Green, 2019).

A further mitigation to reduce collision risk to seabirds included the painting of turbine towers or blades to make them more visible. There is some evidence to suggest that such measures are effective in reducing collisions and much of this comes from data acquired from onshore windfarms and associated collision with raptors; May *et al*. (2020) reported a 70% reduction in collisions. As such, making offshore turbines more visible to seabirds may further reduce the collision risk and could be relatively easy incorporate into design as has been proposed by Martin and Banks (2023). However, there is lack of empirical data in this application to offshore windfarms means that there is no clear cut evidence that such a measure is effective. As such, while painting turbines might have some potential in minimising collision risk on offshore windfarms, these were omitted from good practice library based on insufficient evidence. These measures should not be precluded from future consideration, should further evidence for their suitability come to light. It is worth noting that increasing the visibility of rotor blades may in turn alter the visual impact to land, particularly if the windfarm is close to shore. This may be an unintended consequence of this measure that would need to be taken into account if it was to be carried out as a pilot study on a demonstrator project, for instance.

2.2.3 Mitigations associated with disturbance and displacement

Under the IALA and MCA Marine Guidance, appropriate lighting of offshore infrastructure is required in order to aid navigation and ensure the safety of users of the marine environment, as such it is not possible to totally remove artificial lighting from offshore infrastructure. This section considers the effectiveness of mitigation measures which may be applied to WTG and vessel lighting within the marine environment, thus reducing the potential for disturbance and displacement for seabird species. Table 2-3 outlines the key mitigation measures that were considered for further review.

Table 2-3 Mitigations relating to disturbance and displacement screened into efficacy review

MITIGATION MEASURES INCLUDED IN LIBRARY	KEY RECEPTORS
Minimisation of lighting on offshore infrastructure during the operational phase. Where offshore lighting or marking is necessary, the requirements of International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and MCA Marine Guidance will be adhered to.	Ornithology
Control of construction and operation vessel movements and management of associated vessel lighting during operations within the marine environment.	Ornithology

Minimisation of lighting on offshore infrastructure

Vision is the primary sensory system for offshore bird species, thus the rapid development of offshore renewable energies and the presence of artificial lighting atop each individual WTG presents a potential source of visual disturbance for bird species. Artificial lighting on offshore infrastructure has the potential to result in either a positive (increased activity that would normally only occur during daylight hours) or negative effect, including attraction to lights (phototaxis) or increased energetic costs for birds flying greater distances to avoid an offshore array area (NatureScot, 2020; Croll *et al*., 2022).

In 2019, Dorsch *et al.* published a German tracking study of seabirds in areas of planning offshore wind farms, with particular consideration given to the potential for disturbance to offshore diving bird species (Dorsch *et al*., 2019). The study concluded that diving bird species were recorded in significantly reduced numbers around offshore wind farms with diving bird species almost absent out to a distance of 5 km from the structure, with a significant disturbance effect was still recorded up to a distance or 10-15 km from the structure (Dorsch *et al*., 2019). The study further concluded that diving bird species (namely red-throated divers) kept a greater distance from OWFs at night when WTGs were illuminated with red aviation lights and white navigation lights (Dorsch *et al*., 2019). A further study by

May *et al* (2017) assessing the flight response of birds to (ultra)violet lighting on offshore wind farms concluded that, compared to a control area where no WTGs were present, bird flight activity (abundance) was 27% lower within the offshore array area when the ultraviolet light was on and average flight altitude (vertical displacement) increased by 7 m (May *et al*., 2017).

Existing evidence suggests that the selection of the colour, angle, and mode of lighting on offshore infrastructure has the potential to reduce disturbance and/or displacement impacts for birds. Research presented by Poot *et al.* (2008) demonstrates that down-lighting shields bright light from most nocturnally flying birds, therefore reducing disturbance during dark-hours (Poot *et al*., 2008). There is evidence that some seabirds species can be attracted to artificial lights associated with offshore structures (Weise *et al*., 2001). A mitigation that was included in the good practice guidance was the minimisation of light use during operation and steer towards using blinking light as opposed to continuous light. Such measures have been shown to reduce but not eliminate collisions with migratory birds. This measure is supported by studies such as Rebke *et al*., (2019) and in particular a review undertaken by NatureScot (2020). It has been reported that birds are more attracted to red lights than other colours, therefore a different colour could be utilised such as white or green lights which are thought to be less attractive to birds and therefore less likely to result in the risk of collision. In particular as white light contains red light, it is thought that green would be a better alternative. Indeed, commitments on reducing lighting and avoiding excessive lighting was identified in a number of Scottish Windfarm developments as indicated in the Mitigation Measures Literature Review.

Additional research by Defingou *et al.* (2019) suggests that disturbance and/or displacement from an offshore array area may be further minimised by illuminating WTG lights only when the airspace and marine space adjacent to the array is occupied (Defingou *et al*., 2019). Applying this methodology to German installations saw a reduction in aviation lighting by over 99% (Defingou *et al*., 2019). For Scottish windfarms, such measures could be considered where deemed to be relevant although considerations to maritime and aviation safety would need to be considered.

Research suggests that the effects of displacement from a single, small-scale offshore wind array to birds utilising the marine space may be minor, owing to the highly mobile nature of bird species and the wide-spread availability of their food throughout the marine environment (Croll *et al*., 2022). However it is considered that displacement effects will become more severe in the presence of larger offshore wind array, where the energetic costs of avoiding WTGS become more difficult to compensate, or where displacement from one offshore wind farm acts cumulatively with displacement effects from another offshore development within the marine area (Croll *et al*., 2020).

Control of vessel movement and lighting

There is evidence to suggest that artificial lighting produced by vessels operating at night within the marine environment results in a negative behavioural effect to seabirds, including birds becoming disorientated and confused (Goad *et al*., 2023). Research presented by Leemans and Collier (2022) states that, when approached by small boats, moulting common eiders (*Somateria mollissima*) were displaced by an average distance of 771 m from their original location, with most flocks resuming their normal behaviour within 10 min after the cessation of vessel activity (Leemans and Collier, 2022; Dehnhard *et al*., 2020). The types of vessels required for the construction, operation and maintenance and decommissioning of an offshore wind farm are typically large and slow moving. As such it is considered that the average disturbance distance presented by Leemans and Collier (2022) will be significantly larger than the observed 771 m average disturbance for small boats.

Modelled results and behaviour data into light mitigation for reducing vessel interactions with seabirds (Goad *et al.*, 2023) has been analysed to provide a series of recommendations and mitigation standards for reducing impacts to offshore bird species. These recommendations include establishing what level of vessel lighting is required for different marine environments and when or where it may be possible to operate a 'dark ship' (particularly during poor visibility conditions) (Goad *et al.*, 2023). It is further recommended that light 'spill' from vessels should be monitored, with consideration given to the placement of lights on vessels and the use of shade/non-reflective surfaces to reduce the potential for disturbance to birds utilising a shared marine space with vessels (Goad *et al.*, 2023).

2.2.4 Mitigations associated with electromagnetic fields (EMFs)

Some marine animals have evolved to be able to detect electric and magnetic cues to navigate through the marine environment, hunt for prey or detect predators. As such any potential interference with these natural vital cues through the introduction of anthropogenic sources of electromagnetism have the potential to result in an effect (which can be either positive or negative) on marine animals across tropic levels, from bottom dwelling prey species to apex predators.

Electromagnetic fields (EMF) can occur as both magnetic (B) fields or induced electrical (iE) fields in the marine environment. They can occur in association with electricity transmission infrastructure including both inter-array cables and high-voltage export cables. Electrical transmission can be either as direct current (DC) or alternating current (AC). AC cables, typically used for electricity transmission or distribution over shorter distances, have very weak associated EMF B-fields because of the alternating polarity of the current, and the influence of these fields is only detectable over very short distances. DC cables, typically used for interconnectors and bootstrap links over larger distances, can have higher associated B-fields.

The effects of EMF on marine animals are largely unknown, with very few *in situ* measures recorded. As such the mitigation measures identified in Table 2-4 and the existing research presented within this section draw on modelling results and standard recommendations for further work to improve industry understanding of the potential effects of EMF on key receptors. As the configuration and design of an offshore cable, coupled with the depth at which the cable is buried along its length are primary considerations in the design of an offshore wind farm, both mitigation measures have been considered together within the efficacy review below.

Table 2-4 Mitigations relating to disturbance and displacement screened in to efficacy review

MITIGATION MEASURES INCLUDED IN LIBRARY	KEY RECEPTORS
Cable configuration and design to reduce EMF emissions	Fish/shellfish Benthic ecology
"Minimise" environmental exposure to EMF by increasing the distance between receptors and cable surface by burying the cables via trenching or external protection (EMF). Cables, wherever possible, should be buried to a minimum target depth (0.6 m) as appropriate, therefore reducing receptor exposure to EMF	Fish/shellfish Benthic ecology

In the absence of extensive *in situ* measures for EMF emissions from subsea cables, many of the existing mitigation measures proposed (including target cable burial depths and the application of additional cable protection) are based on available modelling data. One particular study by Hutchison *et al*. (2021) utilised conceptual and interpretive models to explore the influence of cable properties and burial depth on direct current magnetic field (DC-MF) on sensitive marine species. The study found that the level of exposure of EMF to an animal moving along a length of cable is influenced by the depth at which the cable is buried in combination with an animal's position within the water column (Hutchison *et al*., 2021). It was further concluded that greater cable pair separation increased the deviations from the geomagnetic field and deeper cable burial reduced the deviations (Hutchison *et al*., 2021). Distance from the cable has the largest influence on magnitude of EMF.

As EMF emissions from subsea cables decrease rapidly with increasing distance from the cable, burying cables (via simultaneous lay and burial, or post-lay trenching) or applying additional cable protection (e.g., rock berms) is proven to substantially reduce the levels of EMFs within the water column (BOEM, 2023). A study by Hutchison *et al.* (2020) concluded that the total zone affected by cable induced magnetic fields (for both direct current and alternating current) was 5 – 10 m on either side of the cable, as such the potential area of influence was influence was considered to be 10 – 20 m wide (Hutchison *et al*., 2020). There is increasing scientific evidence that the burial of offshore cables does mitigate against the potential effects of EMF on key receptor species, with recommendations of burying inter-array and export cables to a maximum target depth of 2 m reducing the magnetic field on the seafloor by approximately four-fold (BOEM, 2023).

Across available publications it was noted that uncertainty into the potential impacts of EMFs on marine animals remains, and that additional research and *in situ* EMF measurements are required. While the application of additional cable protection (burial, rock protection, mattressing etc.) is effective at reducing EMF emissions for inter-array and export cables laid on the sea floor, further consideration for ScotWind projects which will deploy floating wind technology is required. As dynamic inter-array cables present within the water column cannot be protected by rock dump or burial, alternative monitoring and mitigation measures must be identified for floating offshore wind sites (UK Government, 2023).

3 DISCUSSION

The efficacy of mitigation measures relating to underwater sound (as presented in Table 2-1) give consideration to both *in situ* assessment and modelling outputs. The effects of each mitigation measure is influenced by both the nature of the receiving environment (including sediment type of subsurface geology) and the type of infrastructure that will be installed and utilised as part of the project (including foundation type and project vessel type). The *in situ* use of ADDs for deterring marine mammals from a project area has demonstrated that acoustic detections of harbour porpoise within a project area and adjacent waters decreased for a duration of 3 hours post-ADD playback (Thompson *et al*., 2020). The effective use of ADDs for deterring marine mammals from a project area has been demonstrated at a number of offshore wind farms within Scotland, including the Beatrice Offshore Wind Farm and Moray East Wind Farm. Alternative UXO clearance methods, in the form of LOD, have shown significant reduction in underwater noise levels in recent trials conducted by Robinson *et al*. (2020). LOD was successfully used in Danish waters (Lepper *et al.*, 2024) and during the UXO clearance campaign on the Moray West OWF (Abad Oliva *et al.*, 2024).

The effective use of low-noise installation methods (such as the use of alternative pile driving techniques (e.g., vibropiling/vibrohammer) and the drill-drive-drill methodology) has been demonstrated by a number of offshore wind farms within Scottish waters. In 2023, the Moray West Offshore Windfarm demonstrated the low-noise capabilities of the vibropiling technique as a viable method for reducing the potential impacts of underwater sound, with the Aberdeen Offshore Wind Farm and Seagreen Offshore Wind Farm further proving the efficacy of low-noise installation techniques through their adoption of suction foundation technologies (Power, 2018). The efficacy of the drill-drive-drill technique was most recently demonstrated at the Neart Na Gaoithe Offshore Wind Farm (Mainstream Renewable Power, 2019). The final mitigation measure considered for underwater sound was bubble curtain technology. The use of bubble curtains as noise mitigation technologies for offshore pile driving has been well demonstrated at two offshore wind farms under construction in Belgian waters (the Northwester 2 and Seastar projects). *In situ* measurement of underwater sound for piling driving activities at both wind farms concluded that the use of bubble curtains (normalised over a distance of 750 m) reduced the levels of underwater sound by 20 dB re 1 μPa for Northwester 2 and 12 to 20 dB re 1 μPa for Seastar (Norro, 2021). It was noted that bubble curtains effectiveness are limited by water depth and are therefore not expected to be applicable to mitigation of piling in deeper water of Scottish offshore Windfarms arrays but may still be applicable for UXO clearance, for instance. While the mitigation measures identified for underwater sound have the ability to minimise potential impacts to marine mammals alone, there is evidence to suggest that the use of two or more of these mitigation measures in combination (e.g., the use of bubble curtains around low-noise UXO clearance operations (LOD)) may improve their effectiveness as a mitigation measures (Brandt *et al*., 2016).

The efficacy of mitigation measures relating to collision risk (as presented in Table 2-2) gives consideration to *in situ* adjustments of project design parameters (such as offshore turbine layout and minimum air gap) in relation to their potential impacts on collision risk for seabirds. In 2019, the amended impact assessment for seabird collision risk at the Norfolk Vanguard Offshore Wind Farm considered a revision of wind turbine layout and situation within the project area. The assessment concluded that these updates would reduce collision mortality of all species assessed by 34% compared to the findings of the initial Environmental Statement (MacArthur Green, 2019). Further to an update to turbine layout, the turbine draught height within the Norfolk Vanguard Offshore Wind Farm was increased from 22 m to 27 m, resulting in the average collision risk (across species) for the project reducing by 65% compared to the findings of the original Environmental Statement (MacArthur Green, 2019).

The efficacy of mitigation measures relating to disturbance and displacement (as presented in Table 2-3) considers the impacts of infrastructure and vessel lighting on seabirds through both *in situ* assessment and modelling outputs. These is existing evidence to suggest that the selection of lighting colour, angle and mode on offshore infrastructure has the potential to reduce disturbance and/or displacement impact for seabirds, with Poot *et al.* (2008) demonstrating the effectiveness of down-lighting shields on bright lights for nocturnally flying birds (Poot *et al*., 2008). Furthermore, the methodology of only illuminating WTGs when the associated airspace and marine space is occupied (as applied to German installations) demonstrated a reduction in aviation lighting by 99% (Defingou *et al*., 2019). Modelled results and behaviour data into light mitigation for project vessels concluded that mitigation measures such as establishing what level of vessel lighting are required for different marine environments and where it might be possible to operate a 'dark ship' proved effective for minimising disturbance and displacement to seabirds (Goad *et al*., 2023). Despite evidence of seabird disturbance and displacement from an area as a result of the physical presence of lighting associated with offshore infrastructure and project vessels, further research suggests that the effects of displacement from a single, small-scale offshore wind farm and associated vessel operations may be minor, owing to the highly mobile nature and wide-spread distribution of seabirds (Croll *et al*., 2022). It is therefore considered that displacement effects will become more severe in the presence of a larger offshore wind array, where the energetic cost of avoiding the WTGs may be greater, or where a project and associated vessel movements act cumulatively with another offshore development within the marine environment (Croll *et al*., 2020).

The efficacy of mitigation measures relating to EMFs (as presented in Table 2-4) gives consideration to both *in situ* assessment and modelling outputs. One particular study into the influence of subsea cables and associated EMF on the receiving environment concluded that the level of exposure to EMF exposure for key receptors was influenced by the depths at which the cable was buried and the position of the animal within the water column (Hutchison *et al*., 2021). Available *in situ* EMF emissions from subsea cables demonstrate a rapid decrease in the strength of the magnetic field with distance from the cable, the zone affected decreasing significantly in areas where the cable is buried or additional cable protection is applied (i.e., where there is no exposed cable laid directly on the seabed) (BOEM, 2023; Hutchison *et al*., 2020). There remains uncertainty into the potential impacts of EMFs on marine animals, with the need for further *in situ* EMF measurements required before a detailed understanding of the potential impacts can be developed.

Over the course of gathering data for the literature review, and in undertaking this efficacy review, having devised an initial approach by which to conduct the review (set out in Section 2.1), key challenges and knowledge gaps became evident. Principally, there is a general lack of readily available post-construction monitoring evidence in the offshore wind industry in Scotland. This report has considered publicly available sources of information in addition to expert and up-to-date knowledge within Xodus and across the CEMNID Project Steering Group (PSG). Longer term studies and data sets were few, owing to the small number of operational wind farms within Scotland, despite the large number of OWFs in development and therefore research extended to other countries. Recently, some key outputs have emerged from the projects in the Moray Firth, which make up amongst the most mature developments in Scotland. Relatedly, there is a lack of centralisation to store monitoring information and data for OWFs. This review considers there is a large opportunity for knowledge sharing and information storage across marine industries such that future processes, and implementation of mitigation measures, can be improved. The Offshore Wind Evidence and Knowledge Hub (OWEKH) is an example of such a knowledge sharing platform[2].

In addition to the above, the existing monitoring evidence that has been collected as part of projects/developments aims to address potential post-construction impacts on receptors. Monitoring generally focusses on the receptors themselves to corroborate the proposed impacts identified through the EIA process and does not aim to measure the success or efficacy of mitigation measures. Consequently, there is no clear metric by which efficacy would be measured. Instead, the findings of this efficacy review are often dependent on assumptions made during monitoring survey design. This detracts from the certainty with which efficacy of mitigation measures can be stated. As such, there was an overall lack of substantive or robust evidence on mitigation efficacy that could be derived from monitoring reports.

Another consideration when interrogating post-construction monitoring data, is that the data collected only represents a snapshot in time. Without temporal consideration, the longevity of success attributed to mitigation measures is difficult to determine. Generally, post-consent monitoring is planned over an extended period of time.

Lastly, it is important to acknowledge the influence of natural variation or wider processes, such as climate change, which may affect receptors. There may be numerous factors responsible for any perceived changes to a receptor, beyond the influence of mitigation measures. Some of these variables may not be obvious or immediately realised. This applies to natural fluxes and shifts in environmental conditions and receptor distributions that may have no relation to the offshore wind development. In addition to unpredictable but ongoing processes such as climate change, outbreaks of diseases (e.g. avian flu), changes in fishing patterns driving, or in response to, changing species distributions; all of which may present anomalous results.

[2] *https://owekh.com/home*

4 CONCLUSION AND NEXT STEPS

The monitoring reports and evidence reviewed throughout the course of this study indicated that there was no robust evidence on whether existing good mitigation practices were effective or not. However, the monitoring practices undertaken and subsequent monitoring data, where available, show no significant effects on key receptors and therefore this can be interpreted (tentatively) that the residual effects following the incorporation of primary and secondary mitigations in Scottish windfarms to date, seem to have reduced the potential impacts to insignificant levels and can be seen to be effective.

However, this conclusion is strongly caveated in that it is based on limited data sets which are all relatively short-term in nature. There are uncertainties in cumulative effects and large scale changes in species distribution and indeed the true nature of the effects, such as seabird collisions through the effects of lighting (especially nocturnal species) and the long-term implications of non-fatal effects on marine fauna from EMF. These are important areas for our understanding where data gaps remain. Environmental baselines fluctuate with time and in response to climate change (especially sea temperature); this means that understanding mitigation measure success is complicated by these factors. It is therefore recommended that mitigation measure adoption should an adaptive process that is based on the most up-to-date knowledge at the time.

In order to gather more robust evidence of mitigation efficacy it is recommended that further trials and pilots are undertaken to demonstrate mitigation efficacy (e.g. as part of demonstrator projects) on for example, the following topics:

- Under water noise mitigation, including within deep water; and
- Lighting studies on offshore marine birds – for example, to reduce attraction and collision risk and different types of lighting (e.g. colour variations, blinking continuous).

In addition, incorporating long-term monitoring plans into OFW consents on key mitigation measures could help provide evidence on the effectiveness of the mitigation measures.

There is the opportunity for knowledge sharing and information storage across marine industries with regards to mitigation measures such that future processes, and implementation of mitigation measures, can be improved. The Offshore Wind Evidence and Knowledge Hub (OWEKH) is an example of such a knowledge sharing platform.[3]

[3] *https://owekh.com/home*

5 REFERENCES

ACCOBAMS (2019). Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS). Methodological Guide – Guidance on underwater noise mitigation measures. Seventh Meeting of the Parties to ACCOBAMS. ACCOBAMS-MOP7/2019/Doc 31Rev1. Available at: https://accobams.org/wp-content/uploads/2022/11/MOP8.Inf44_Methodological-guide-noise-V3.1.pdf

ACTEON. 2024. Drive-Drill-Drive Technique For Pile Installation. Available online at: https://acteon.com/blog/drive-drill-drive-technique-for-pile-installation/

Abad Oliva, N., Jameson, D., Lee, R., Stephenson, S., Thompson, P. 2024. Low order deflagration of unexploded ordnance reduces underwater noise impacts from offshore wind farm construction. Ocean Winds. Available online at: https://oceanwinds.com/wp-content/uploads/2024/05/OW-UXO-BusinessCase.pdf

BOEM. 2023. ENVIRONMENTAL STUDIES Electromagnetic Fields (EMF) from Offshore Wind Facilities. Available online at: https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/BOEM-Electromagnetic-Fields-Offshore-Wind-Facilities_1.pdf#:~:text=As%20EMF%20from%20undersea%20power%20cables%20decrease%20rapidly,target%20depth%20of%20between%203%20and%206%20feet.

Brabant, R., Vanermen, N., Dgraer, S. 2022. Turbine size impacts the number of seabird collisions per installed megawatt and offers possibilities for mitigation. Available online at: https://biblio.naturalsciences.be/library-1/rbins-staff-publications-2022/techreportreference.2023-03-02.6175920106

Brandt, M.J., Dragon, A., Diedreichs, A., Schubert, A., Kosarev, V., Nehls, G., Wahl, V., michalik, A., Braasch, A., Hinz, C., Ketzer, C., Todeskino, D., Gauger, M., Laczny, M. and Piper, W. 2016. Effects of Offshore pile driving in harbour porpoise abundance in the German Bight. Assessment of Noise Effects Final report. Offshore Forum Windenergie. Available at : https://tethys.pnnl.gov/sites/default/files/publications/Brandt-et-al-2016.pdf

BTO. 2013. High flying birds at greater risk of collision with offshore wind turbines. Available online at: https://www.bto.org/about-bto/press-releases/high-flying-birds-greater-risk-collision-offshore-wind-turbines

Cheong, SH., Wang, L., Lepper, P., Robinson, S. 2023. Characterisation Of Acoustic Fields Generated By UXO Removal Phase 5 Quarry Trials Of Bubble Curtain Mitigation. Available online at: https://eprintspublications.npl.co.uk/9817/1/AC22.pdf

Croll, D.A., Ellis, A.A., Adams, J., Cook, A.S.C.P., Garthe, S., et al. 2022. Framework for assessing and mitigating the impacts of offshore wind energy development on marine birds. Biological Conservation. 276. Available online at: https://www.sciencedirect.com/science/article/pii/S0006320722003482

Davies, I. and Band, B. 2012. Turbine height as a management tool for collision risk to birds at offshore wind farms. Available online at: https://tethys.pnnl.gov/sites/default/files/publications/ICES_2012_Turbine_Height_Management_Tool.pdf#:~:text=Fo r%20such%20species%2C%20increasing%20the%20clearance%20above%20the,increasing%20clearance%20of%20turbine%20blades%20above%20the%20water

Defingou, M., Bils, F., Horchler, B., 2019. PHAROS4MPAs: A Review of Solutions to Avoid and Mitigate Environmental Impacts of Offshore Windfarms. BioConsults on behalf of WWF France, France.

Dehnhard, N., J. Skei, S. Christensen-Dalsgaard, R. May, D. Halley, T.H. Ringsby & S.-H. Lorentsen, 2020. Boat disturbance effects on moulting common eiders Somateria mollissima. Marine Biology. 167(1).

Dorsch, M., C. Burger, S. Heinänen, B. Kleinschmidt, J. Morkūnas, G. Nehls, P. Quillfeldt, A. Schubert, R. Žydelis. 2019. DIVER – German tracking study of seabirds in areas of planned Offshore Wind Farms at the example of divers. Final report on the joint project DIVER, FKZ 0325747A/B, funded by the Federal Ministry of Economics and Energy (BMWi) on the basis of a decision by the German Bundestag. Available online at: https://www.bioconsult-sh.de/fileadmin/user_upload/Publikationen/2019/BMWi-Fkz0325747A_B_final_150dpi.pdf

Goad, D., Middlemiss, K., Cieraad, E., Duke, K., Bell, H., Le Lec, M., Le Lec, M., Fischer, J., Taylor, G., Maris, V. 2023. MIT2022-06 Light mitigation: Reducing vessel interactions with seabirds Final Report. Available online at: https://www.doc.govt.nz/globalassets/documents/conservation/marine-and-coastal/marine-conservation-services/reports/202223-annual-plan/mit2022-06-lighting-mitigation-final-report.pdf#:~:text=Artificial%20light%20produced%20by%20vessels%20operating%20at%20night,vessel%20%28vessel%20strikes%29%20and%20subsequently%20injury%20or%20death

Graham, I.M., Merchand, N.D., Farcas, A., Barton, T.R., Cheney, B., Bono, S., Thompson, P.M. 2019. Harbour porpoise responses to pile-driving diminish over time. Royal Society of Open Science. Available online at: https://royalsocietypublishing.org/doi/10.1098/rsos.190335

Hutchison, Z.L., Gill, A.B., Sigray, P., He, H., King, J.W. 2020. Anthropogenic electromagnetic fields (EMF) influence the behaviour of bottom-dwelling marine species. Scientific Reports. 10. Available online at: https://www.nature.com/articles/s41598-020-60793-x

Hutchison, Z.L., Gill, A.B., Sigray, P., He, H., King, J.W. 2021. A modelling evaluation of electromagnetic fields emitted by buried subsea power cables and encountered by marine animals: Considerations for marine renewable energy development. Renewable Energy. 177. pp. 72-81. Available online at: https://www.sciencedirect.com/science/article/abs/pii/S0960148121007175

JNCC. 2023. DRAFT guidelines for minimising the risk of injury to marine mammals from unexploded ordnance clearance in the marine environment. Available online at: https://jncc.gov.uk/media/8419/draft-marine-mammal-guidelines-unexploded-ordnance.pdf

Leemans, J.J. and Collier, M.P. 2022. Update on the current state of knowledge on the impacts of offshore wind farms on birds in the OSPAR Region: 2019-2022. Available online at: https://www.ospar.org/site/assets/files/1389/bird_litt_review_2029_2022_final.pdf

Lepper, P.A., Cheong, SH., Robinson, S.P., Wang, L., Tougaard, J., Griffiths, E.T., Hartley, J.P. 2024. In-situ comparison of high-order detonations and low-order deflagration methodologies for underwater unexploded ordnance (UXO) disposal. Marine Pollution Bulletin. 199. Available online at: https://www.sciencedirect.com/science/article/pii/S0025326X23014005

MacArthur Green. 2019. Norfolk Vanguard Offshore Wind Farm Offshore Ornithology Cumulative and In-combination Collision Risk Assessment (Update). Available online at: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010079/EN010079-002930-ExA;%20AS;%2010.D7.21_Offshore%20Ornithology%20Cumulative%20and%20In-combination%20Collision%20Risk%20Assessment%20Update.pdf

Mainstream Renewable Power. 2019. Chapter 5: Project Description. Available online at: https://marine.gov.scot/sites/default/files/chapter_5_-_project_description.pdf

Martin, G.R. and Banks A.N. (2023). Marine birds: Vision-based wind turbine collision mitigation. Global Ecology and Conservation. 42 Available online at: https://www.sciencedirect.com/science/article/pii/S2351989423000215

May, R., Nygård, T., Falkdalen, U., Astron, J., Hamre, Ø. and Stokke, B.G. (2020). Paint it black: Efficacy of increased wind turbine rotor blade visibility to reduce avian fatalities. Ecology and Evolution. Pp 8927-8935.

May, R., Astrom, J., Hamre, O., Dahl, E.L. 2017. Do birds in flight respond to (ultra)violet lighting? Avian Research. 8(33). Available online at: https://avianres.biomedcentral.com/articles/10.1186/s40657-017-0092-3

Morary Offshore Windfarm (West) Limited. 2022. UXO Clearance Environmental Report: Document Name: 8460005-DG0207-MWW-REP-000001. Available online: https://marine.gov.scot/sites/default/files/supporting_document_2.pdf

MPATF. 2024. Moray Firth to Humber Estuary IMMA. Available online at: https://www.marinemammalhabitat.org/factsheets/moray-firth-to-humber-estuary-imma/

NatureScot. 2020. The Effect of Aviation Obstruction Lighting on Birds at Wind Turbines, Communication Towers and Other Structures. Available online at: https://www.nature.scot/sites/default/files/2020-10/Wind%20farm%20impacts%20on%20birds%20-%20Turbine%20lighting%20and%20birds%20-%20Information%20Note.pdf

NnG. 2021. Neart na Gaoithe Offshore Wind Farm: Unexploded Ordnance – Underwater Noise Monitoring Report. Available online at: https://marine.gov.scot/sites/default/files/nng-nng-ecf-rep-0033_uxo_underwater_noise_monitoring_report_3.0_redacted.pdf

Norro. 2021. An Evaluation Of The Noise Mitigation Achieved By Using Double Big Bubble Curtains In Offshore Pile Driving In The Southern North Sea Chapter 2. Environmental Science, Engineering. Available online at: https://www.semanticscholar.org/paper/AN-EVALUATION-OF-THE-NOISE-MITIGATION-ACHIEVED-BY-2/49e6b27dc90b29d962709481ab321b5b6f9e3885#citing-papers

Ørsted. 2024. Ørsted's experience with suction bucket jackets. Available online at: https://orsted.com/en/what-we-do/renewable-energy-solutions/offshore-wind/technology/suction-bucket-jacket-foundations

Peschko, V., B. Mendel, M. Mercker, J. Dierschke & S. Garthe, 2021. Northern gannets (Morus bassanus) are strongly affected by operating offshore wind farms during the breeding season. Journal of Environmental Management 279: 111509.

Poot, H., B. J. Ens, H. de Vries, M. A. H. Donners, M. R. Wernand, and J. M. Marquenie. 2008. Green light for nocturnally migrating birds. Ecology and Society. 13(2). pp. 47.

Power. 2018. Vattenfall Pioneers Innovative Offshore Wind Foundations. Available online at: https://www.powermag.com/vattenfall-pioneers-innovative-offshore-wind-foundations/

Rebke, M., Dierschke, V., Weiner, C.N., Aumüller, R., Hill, K., Hill, R. (2019). Attraction of nocturnally migrating birds to artificial light: The influence of colour, intensity and blinking mode under different cloud cover conditions. Biological Conservation 233: 220–227. Available online at: https://doi.org/10.1016/j.biocon.2019.02.029

Stephen P. Robinson, Lian Wang, Sei-Him Cheong, Paul A. Lepper, Francesca Marubini, John P. Hartley, Underwater acoustic characterisation of unexploded ordnance disposal using deflagration, Marine Pollution Bulletin, Volume 160, 2020, 111646, ISSN 0025-326X, https://doi.org/10.1016/j.marpolbul.2020.111646. (https://www.sciencedirect.com/science/article/pii/S0025326X20307645)

Scottish Government. 2022. Policy Paper: Marine environment: unexploded ordnance clearance joint interim position statement. Available online at: https://www.gov.uk/government/publications/marine-environment-unexploded-ordnance-clearance-joint-interim-position-statement/marine-environment-unexploded-ordnance-clearance-joint-interim-position-statement

Thompson, P.M., Graham, I.M., Cheney, B., Barton, T.R., Farcas, A., Merchant, N.D. 2020. Balancing risk of injury and disturbance to marine mammals when pile driving at offshore windfarms. Ecological Solutions and Evidence. 1(2). Available online at: https://besjournals.onlinelibrary.wiley.com/doi/10.1002/2688-8319.12034

Todd, V.L.G., Williamson, L.D., Jiang, J., Cox, S.E., Todd, I.B., Ruffert, M. 2021. Prediction of marine mammal auditory-impact risk from Acoustic Deterrent Devices used in Scottish aquaculture. Marine Pollution Bulletin. 165. Available online at: https://www.sciencedirect.com/science/article/abs/pii/S0025326X21002058

Vattenfall. 2023. Unique study: birds avoid wind turbine blades. Available online at: https://group.vattenfall.com/press-and-media/newsroom/2023/unique-study-birds-avoid-wind-turbine-blades

Verfuss, U.K., Sinclair, R.R. & Sparling, C.E. 2019. A review of noise abatement systems for offshore wind farm construction noise, and the potential for their application in Scottish waters. Scottish Natural Heritage Research Report No. 1070. Available online at: https://www.nature.scot/sites/default/files/2019-07/Publication%202019%20-%20SNH%20Research%20Report%201070%20-%20A%20review%20of%20noise%20abatement%20systems%20for%20offshore%20wind%20farm%20construction%20noise%2C%20and%20the%20potential%20for%20their%20application%20in%20Scottish%20waters.pdf

Voß, J., Rose, A., Kosarev, V., Vilela, R., Opzeeland, I.C., Diederichs, A. 2023. Response of harbor porpoises (Phocoena phocoena) to different types of acoustic harassment devices and subsequent piling during the construction of offshore wind farms. Frontiers of Marine Science. 10. Available online at: https://www.frontiersin.org/articles/10.3389/fmars.2023.1128322/full

Weise, F.K., Montivecchi, W.A., Davoren, G.K., Huettmann, F., Diamond, A.W. and Linke, J. 2001. Seabirds at Risk around Offshore Oil Platforms in the North-West Atlantic. Marine pollution Bulletin 42:1285-1290. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0025326X01000960

WDC. 2024. Bottlenose Dolphins – Moray Frith, Scotland. Available online at: https://uk.whales.org/whales-dolphins/how-we-help/bottlenose-dolphins-moray-firth-scotland/