ORJIP Project 4, Phase 1

Use of Deterrent Devices and Improvements to Standard Mitigation during Piling

Offshore Renewables Joint Industry Programme (ORJIP)

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Use of Deterrent Devices and Improvements to Standard Mitigation during Piling

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EXECUTIVE SUMMARY

Background

The offshore wind industry has expanded rapidly in recent years, with current and planned capacity in the UK double that of Denmark, the next highest producer of offshore wind energy. This rapid advancement in the UK offshore wind farm industry has been accompanied by an increase in the risks, but also the understanding of the issues, challenges and potential solutions for mitigation against potential injury and disturbance to marine mammals from underwater noise during piling.

Regulation and guidance in the UK

The legislation that drives marine mammal protection is the EC Habitats Directive, under which all species of cetaceans are listed on Annex IV as European Protected Species (EPS) and bottlenose dolphin, harbour porpoise, minke whale, grey and harbour seals are listed on Annex II[1]. This legislation is transposed into the UK territories and offshore waters by respective Habitats Regulations (0 – 12 nautical miles)[2] and the Offshore Marine Regulations (as amended 2009 and 2010) (> 12 nautical miles). EPS are protected by law from (amongst others) injury, killing or deliberate (including 'reckless') disturbance. Scotland has the most stringent regulations pertaining to disturbance, in that the Conservation (Natural Habitats, & c.) Regulations 2004 (as amended) in Scotland to 12 nautical miles offer protection of the individual marine mammal, rather than at a population level. This study has therefore taken the Scottish case as the most rigorous criteria when reviewing the efficacy of current and potential mitigation measures. Annex II species must be protected through the designation of conservation areas called Special Areas of Conservation (SACs), which form part of the EU's 'Natura 2000' network of protected sites.

The UK Government has a legal obligation to adequately transpose the Habitats Directive and the strict protection afforded to cetacean species as European Protected Species (EPS), as well as Annex II species associated with Special Areas of Conservation. Failure to do so could expose the UK to legal action by the European Commission (EC) with a consequent risk, if the failure is not addressed, of incurring infraction fines. Offshore wind farm developers have a legal obligation to carry out robust Environmental Impact Assessments (EIA) of their potential projects, and on Award of Consent, monitor and manage potential impacts on marine mammals as specified in their Marine Licences. Failure to do so may result in fines or the revocation of said Marine Licences. The regulators and statutory nature conservation bodies have an overarching duty to oversee compliance with UK and EC regulations and directives. Breach of such requirements by any of these interested parties may ultimately create unacceptable financial and reputational risk to the UK taxpayer and offshore wind farm industry.

Consent conditions and the transposed environmental management measures must strike a careful balance, be appropriate and proportional to the risks posed by the development of the project, allow the delivery of offshore wind projects which are technically and economically viable, have acceptable levels of environmental impact, and ultimately comply with legal requirements to maintain populations of European Protected Species and Annex II species at a 'favourable conservation status' (effected through process such as EPS licensing and Habitats Regulations Appraisal). There is therefore a high level of interest from all parties to have the right marine mammal mitigation protocol in place.

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[1] *Note grey and harbour seals are not listed as EPS and do not have protection under the Habitats Regulations. However, these species are listed as Annex II species and they are afforded protection in so far as special areas of conservation (SACs) must be established, steps must be taken to avoid deterioration of habitats within those SACs and action must be taken for activities impacting on Annex II species from the SAC, even when they are outside it (see Section 2.2.3 for a more detailed description of the applicable legal requirements).*

[2] *In accordance with Article 6.3 of the Habitats Directive, a Habitats Regulation Assessment (HRA) is carried out for all OWF projects as part of the consenting process to ascertain whether that project, alone or in combination with other plans and projects, will not have an adverse effect on the integrity of a Natura site in view of the sites conservation objectives.*

Definition of Disturbance

It is also important to note that the current definition of disturbance to seals across the UK inshore territories (i.e. in England, Northern Ireland and Wales) makes it an offence to disturb a significant group of seals, whilst in Scotland it is also an offence to cause the disturbance of an individual animal. Under the Offshore Marine Regulations (OMR), marine mammals within the UK Continental Shelf (>12 nautical miles) are protected at a population level. These distinctions have been taken into consideration throughout this study, and in all references to 'applicable UK legislation' or 'applicable UK guidance'.

During the development of an offshore wind farm (OWF), mitigation is applied to reduce the risk of an offence occurring to negligible levels in the first instance under the relevant marine licensing for the site, and where injury or disturbance to marine mammals cannot be completely mitigated during piling activities in the construction phase of wind farms, a wildlife or EPS Licence. Such licences allow for derogation from the prohibition of injury or disturbance, providing that the Licensing bodies are satisfied that a number of specific tests have been passed. The deployment of ADDs would therefore not be considered as a disturbance offence, as deployment should always be accompanied by an EPS Licence.

When assessing the risk of committing an injury or disturbance offence, guidance is provided on a site specific basis from the relevant Statutory Nature Conservation Bodies (SNCB). Written guidance for English and Welsh territorial waters and UK offshore (> 12 nautical miles) is available in the form of general guidance on EPS (JNCC, 2010a in prep) and a piling protocol (JNCC, 2010b). The recommendations made in this guidance were considered best practice (although not legally binding) for piling operations at their time of preparation.

The general guidance (JNCC, 2010a in prep) is currently being revised by Defra and Marine Scotland (separately due to the distinction between a disturbance offence in Scotland and the other UK territories). It is therefore timely given the pending R3 and STW OWF projects and greatly expanded evidence base to revisit the current guidance and develop a roadmap of recommendations towards future proofing any subsequent revisions to the JNCC mitigation protocol.

ORJIP Project 4

Marine Scotland, The Department of Energy and Climate Change (DECC), The Carbon Trust and The Crown Estate, along with the offshore wind development community are working together to implement an Offshore Renewables Joint Industry Programme (ORJIP) of works to fund and deliver strategic research projects to reduce consenting risk for offshore wind projects in UK waters. Addressing strategic evidence gaps is a high priority for the offshore wind sector as it will play a significant role in 'de-risking' future projects. The outputs of this proposed programme are required to inform both consent and licence applications and advice and decisions by the UK regulatory authorities.

Xodus Group Ltd, in partnership with SMRU Marine, were contracted by DECC on behalf of the ORJIP Interim Working Group (IWG)/ORJIP Programme Group to conduct Phase 1 of ORJIP Project 4, a desktop review and set of advisory services regarding Acoustic Deterrent Device (ADD) use and improvements to standard mitigation measures currently used in the UK (marine mammals observers (MMO), passive acoustic monitoring (PAM) and soft starts) during piling. It should be noted that whilst ADDs are not considered 'standard mitigation' they have been employed as part of the Marine Mammal Mitigation Programme (MMMP) at a number of UK OWFs, as well as being standard practice in a number of European countries.

The aim of ORJIP Project 4 is to (see ITT in Appendix A for further details of the exact scope):

- Review, test and/or develop ADDs or other deterrent devices for multiple marine mammal species, thus reducing reliance on visual observations and increasing construction time available by removing daylight/sea state restrictions on piling activity.
- Conduct field tests in realistic conditions to provide evidence that devices will provide the required level of risk reduction for the species concerned.

- Develop protocol(s) for the use of ADD(s) as agreed with industry, advisors, regulators and NGOs.

The specific scope of Phase 1 of ORJIP Project 4 is a desk based study to review and make recommendations associated with current and potential mitigation against the direct or indirect injury to marine mammals during piling. Phase 2 of Project 4 will include the field research to test and/ or develop ADDs or other deterrent devices. The Phase 1 review has included a review of the research project scopes proposed by ORJIP for Phase 2, as presented in the annex of the ITT (see Appendix A). Detailed methodologies and costings for the research projects are outside the scope of Phase 1. A detailed assessment of the findings and recommendations of Phase 1 will be carried out by ORJIP to inform the commissioning of work under Phase 2 and the development of the relevant detailed methodologies.

Project Scope and Rationale

It is acknowledged that both injury and disturbance of marine mammals caused by piling in the marine environment are important issues each requiring due consideration. However, addressing the (increasing) risk of injury offences has been identified as a primary consenting risk for offshore wind projects in UK waters. As such ORJIP has commissioned this strategic research project to focus on mitigation to reduce the risk of injury offences in isolation (note environmental sensitivities and contexts differ between OWF sites; hence, developers will make informed choices as to any future discretionary 'Offshore Wind Accelerator' projects they join).

It is widely accepted that disturbance to marine mammals (and the potential for population effects) during piling is a current challenge and should certainly be given due consideration during future reviews, field research and individual development assessment; however it is not addressed any further in this report. This approach, although not holistic, is viable because Acoustic Deterrent Devices (ADD) would be turned off once piling commences therefore potential disturbance impacts would be secondary to the potential impacts of piling (i.e. it is not envisaged that there will be any increase in the size of the zone of disturbance (or injury)). All references to disturbance in this report (unless clearly mentioned otherwise) therefore apply to disturbance in association with the use of ADD.

ADDs are referred to under an array of different terms, including Acoustic Mitigation Devices (AMDs), Acoustic Harassment Devices (AHDs), 'scrammers', 'scarers' and 'pingers'. For the remainder of this report we have excluded pingers from our generic description 'ADD'. These are discussed in more detail in Section 1.5 and Appendix E.

Project 1 recognises that multiple deployments of single species specific ADDs are not the preferred industry option (due to increased HSE risks associated with the deployments etc). The focus of the research recommendations and the ADDs taken forward in this review have therefore been identified as being most likely to progress the development of multi species ADDs within the timeframe required by the UK OWF industry.

The remainder of the report presents a précis of the current evidence base to support mitigation against injury in marine mammals during piling, and recommendations on the scope of the ADD research topics currently proposed for Phase 2 of this research project. The key output comprises a research and recommendation roadmap that will enable ORJIP to focus its research and support efforts on topics that will make a material difference to the industry.

The mitigation techniques have been assessed only in terms of their ability to reduce the risk of injury. Their ability to mitigate disturbance/behavioural effects has not been considered. However, the potential for disturbance to arise as a result of the mitigation measure itself, rather than the piling noise, has been included in the assessment; for example, the potential for noise emitted by an ADD to cause additional disturbance of marine mammals during OWF construction.

Challenges and Recommendations

All environmental, technical and practical aspects of the current mitigation techniques used in the UK have been reviewed. While there are site specific issues and uncertainties surrounding the efficacy of certain mitigation techniques used to date, it has been possible to identify seven key generic drivers and supporting parameters important to interested parties (regulators, statutory advisors, offshore developers, non-government organisations (NGO), service providers and researchers) in the development of offshore wind projects. The drivers are:

- Efficacy – the ability of the mitigation technique to achieve its desired effect;
- Unintended consequences – such as introducing additional disturbance/risk of injury as a result of using a particular mitigation technique;
- Practicality – the practical aspects of a mitigation technique;
- Regulation & legislation - the extent to which a mitigation technique is compliant with national and international legislation;
- Installation schedule – the impact of using a mitigation technique on the installation schedule, such as additional offshore time due to delayed piling;
- Cost – cost associated with a mitigation technique, excluding costs associated with installation schedule impacts; and
- Health and Safety – the H & S implications associated with implementing a mitigation technique (e.g. H & S risk associated with deployment and recovery of ADD).

Through detailed technical evaluation of the evidence base a short list of recommendations pertaining to the research topics proposed in the "Current (16 December 2012) draft of the structure and content of ORJIP Project 4, Phase 2" (ORJIP, 2012) has been formulated, with specific reference to which research areas should be taken forward by Project 4, which could be improved based on the available evidence base and which should be prioritised to enable any current knowledge gaps identified in this review to be closed out.

Development of the UK marine mammal mitigation protocol

The current marine mammal mitigation protocol during piling (JNCC, 2010b) was developed from guidance related to the seismic sector and a significantly smaller OWF evidence base in terms of the number of MMO reports and relevant research papers available at the time. At that time the scale of OWFs and their potential impact zones were much smaller than the proposed R3 and STW sites. The general recommendations presented here have benefited from the larger evidence base now available (MMO, MMMP reports etc), as well as the increased expertise and knowledge of developers, regulators, advisors and NGOs gained since the last guidance revision (thanks goes to these parties for the time given during the extensive study related consultation and contributions). As a result, we hope that the recommendations that have been produced highlight some important points that will prove useful in the further development of guidelines.

Overall, there is consensus on the need to improve on current UK mitigation techniques, and that advancements in research and industry plus the policy lessons learned from elsewhere in Europe have increased the potential for incremental changes to be viable. The challenge facing the next steps in the ORJIP Project 4 process is to collaboratively develop a clear roadmap for achieving a site specific mitigation framework that is compliant with legislative requirements, achieves environmental protection, and positively enables sustainable development of offshore wind.

The five species/functional groups prioritised by the ORJIP to be included in Project 4 are harbour porpoise, bottlenose dolphins, minke whales and harbour and grey seals. For the purpose of this review these species were grouped into four sub-groups due to their priority status and functional hearing grouping (Southall *et al.*, 2007).

Based on the noise modelling results, it is concluded that it is not possible at this time to recommend a "one size fits all" mitigation protocol. Consequently, one of the primary recommendations is that a site specific risk based approach[3] is adopted for marine mammal mitigation. It should be noted that for some sites and species, ADDs may not provide a solution unless multiple ADD devices can be deployed over a wide area. Given the large number of vessels involved in an OWF construction programme (e.g. piling vessels, multiple support vessels), deploying several ADD devices across a number of locations may be a workable solution.

A key output of this review was the identification of critical knowledge gaps surrounding mitigation (see Annex 2 of Appendix A). These have been identified, and suggested research programmes, study sites and preliminary costings have been provided to guide future research into the utility of ADDs as mitigation (covered in detail in Section 5.2). A brief summary is provided in the table below. As defined in the Project 4 brief, the specific methodologies to be employed in the research programmes recommended below have not been defined here as this will be carried out as part of Phase 2.

Summary of suggested research programmes, study sites and preliminary costings for research into ADD use as marine mammal mitigation

Species	Key questions	Research approach	Approximate Costs	Timescale	Potential test sites
Harbour porpoise	1. Can the effective range for harbour porpoises be manipulated by altering ADD signals? 2. Do harbour porpoises respond to signals designed to elicit a startle response? 3. What is the long term effectiveness of the devices?	Testing candidate ADD signals using a combination of focal behavioural observations or static moored structures in the open sea and arrays of PAM to measure wider scale responses over a range greater than can be monitored visually. Long term effectiveness should be investigated in conjunction with construction monitoring programmes.	£200k-250k for ADD playback experiments. Additional £200k for wider static PAM array.	At least 1 year (summer season of fieldwork plus analysis and reporting time). Longer term data collection during construction.	The Moray Firth The Southern North Sea, adjacent to the Humberside and Lincolnshire coast. Consented wind farm sites.
Grey and harbour seals	1. How do grey and harbour seals respond to ADD signals in the 'offshore' environment? 2. What is the effective range of the various candidate deterrents and can it be manipulated? 3. How context specific are responses? 4. Do they habituate to the candidate signals	A combination of seal tracking methods involving capturing and tagging of a sample of seals at haul out sites in proximity to the field trial sites, tracking them in real time and carrying out targeted behavioural response trials from a boat using the candidate ADDs. Long term effectiveness should	£350k-400k.	At least 1 year (summer season of fieldwork plus analysis and reporting time).	Harbour seals: The Wash and Moray Firth; grey seals: Moray Firth, The Farne Islands and Forth and Tay.

[3] *This refers to the consideration of all physical and biological characteristics of a site e.g. geo-acoustic properties of seabed, bathymetry, mammal densities and ecological importance as feeding or breeding grounds. Such site specific data are used to inform the EIA process. Significant impacts are discussed and an appropriate MMMP should be included as part of this EIA process pre-consent.*

Species	Key questions	Research approach	Approximate Costs	Timescale	Potential test sites
	and how is this affected by context?	be addressed by monitoring effectiveness as ADD use is rolled out in construction projects. Potential also to target animals that are already tagged to provide additional background data on these individuals to inform the efficacy and potential additional impacts of ADDs. Care will however need to be taken to ensure that the addition of the ADD work would not compromise the required outcomes of the tagging work.			
Bottlenose dolphin	1. How do bottlenose dolphins respond to ADD signals in the offshore environment? 2. What is the effective range of the various candidate deterrents? 3. How context specific are responses? 4. Do they habituate to the candidate signals and how is this affected by context?	Testing candidate signals using a combination of focal behavioural observations or 3D hydrophone arrays deployed from boats or static moored structures in the open sea and arrays of PAM devices to measure wider scale responses. Concurrent acoustic recording of call types can add context to behaviour and trials can be focussed to determine differential responses in foraging animals versus those engaged in other behaviours. Individual recognition of some animals may allow the potential to study the effect of repeated exposure over time. Wider acoustic monitoring arrays could be used to examine wider scale responses of dolphins, outside of what can be monitored visually. Long term	£200k-250k for playback experiments. Additional £200k for wider static PAM array.	At least 1 year (summer season of fieldwork plus analysis and reporting time).	Moray Firth, Cardigan Bay, and Grampian and Angus.

Species	Key questions	Research approach	Approximate Costs	Timescale	Potential test sites
		effectiveness should be addressed by monitoring effectiveness as ADD use is rolled out in construction projects.			
Minke whale	1. How do minke whales respond to various types of ADD signals? 2. How do minke whales respond to ADD signals in the offshore environment? 3. What is the effective range of the various candidate deterrents? 4. How context specific are responses? 5. Do they habituate to the candidate signals and how is this affected by context?	Responses to playback from boats would be measured using visual tracking methods. Although dedicated studies unlikely to be cost effective for this species and best approached opportunistically during work tailored for other species. Long term effectiveness should be addressed by monitoring effectiveness as ADD use is rolled out in construction projects.	Uncertain – may add days on to boat costs for studies considered above but highly dependent on encounter rates.	Uncertain and highly dependent on encounter rate.	No specific site recommended, instead opportunistic trials if/when minke whale encountered during trials for other species. Selection of sites where minke whale sightings can be high (e.g. Moray Firth during summer) may improve the encounter rate.

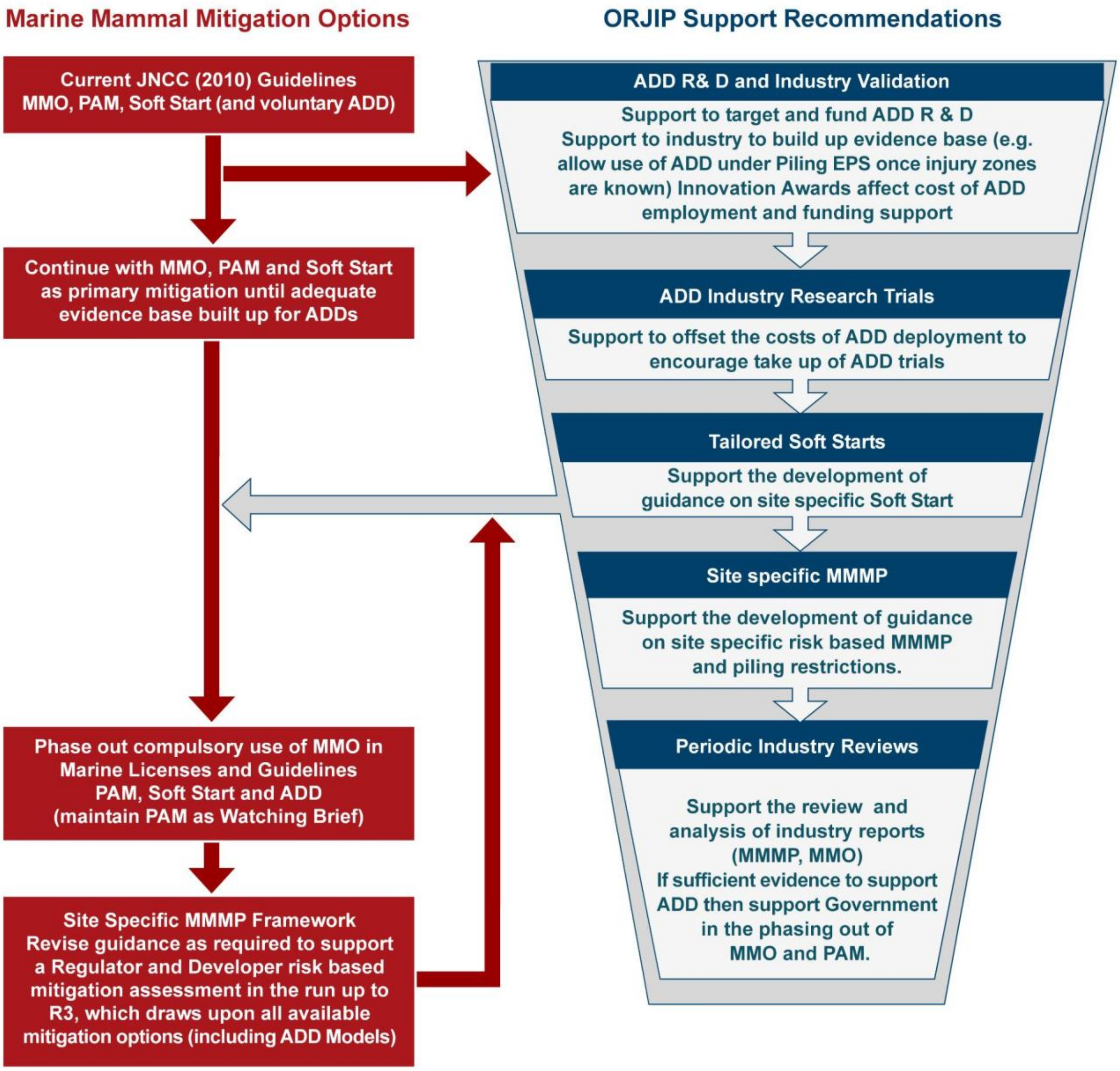
In addition to the species specific recommendations provided above, a series of general recommendations are provided for consideration when revising UK piling mitigation guidance (encompassing site specific SNCB advice and the current marine mammal mitigation protocol (MMMP) (JNCC, 2010b)). These are as follows:

- The current MMMP (JNCC, 2010b) is fit for purpose for current small scale piling operations but there is potential to progress this ‘starting point’ guidance to accommodate the increasing risks posed by the larger scale OWF developments proposed for the UK sector;
- The cost benefit of investing in the development of ADD outweighs the cost benefit of continuing to prioritise current passive mitigation options;
- An incremental approach to revising the current piling mitigation protocol (JNCC, 2010b) is required in order to allow time to develop and validate ADD as a viable MMMP for UK offshore wind farms;
- When developing the scope of Project 4, ORJIP identified that the ideal outcome of this project would be the development of ADD devices that can be proven to be a best practice mitigation option for use for one or, ideally all, of the priority species identified in this study (see the Phase 1 ITT in Appendix A for further details of the rationale);
- A secondary outcome would be the take up of ADD and tailored soft start as the primary and preferred best practice MMMP mitigation option in the UK, although it is noted neither are universally applicable (e.g. the type of soft start that can be applied may be affected by the nature of the substrate);
- There are a number of other mitigation techniques used elsewhere in Europe, such as noise abatement and alternative construction techniques, that may be worthy of consideration (but are not within the scope of this project);

- The ultimate objective of ORJIP Project 4 is the development of a risk based project specific MMMP Framework, that enables Developers to select and agree with Regulators the best mitigation options based on their particular site characteristics (e.g. priority species present, water depth, pile size/hammer energy, substrate type, distance offshore, installation and support vessel set up); and
- A roadmap approach to research and (further) develop or validate potentially viable ADD options and support the evolution of applicable UK piling mitigation guidance that will serve to support all UK territories in a move towards a site specific MMMP Framework that covers multiple species at the same OWF site.

Recommendations roadmap

The 'roadmap' schematic below synthesises the ORJIP Project 4 recommendations and general recommendations that were raised by interested parties for consideration to support the implementation of the outputs of ORJIP Project 4. The top left hand box presents the current starting point i.e. the JNCC (2010b) marine mammal mitigation guidance and the techniques implemented by the OWF sector as standard (e.g. MMO and PAM) and voluntarily (e.g. ADD). The last box on the left shows the perceived ultimate end point of ORJIP Project 4 i.e. standardised site specific risk based MMMP Framework assessments to be carried out pre-consent. The boxes in between represent one possible scenario in terms of the incremental steps that could be made to support the evolution between the two as the evidence base to support the take up of ADD by the OWF sector. The linked boxes on the right hand side presents one possible research and support services scenario that could be considered to progress the adoption of ADD as a primary and preferred best practice MMMP mitigation option in the UK.



Finally, a project of this nature has the potential to influence a broad range of stakeholders affected by the development of offshore renewables (from NGOs through to piling service providers). Every effort has been made to provide a balanced perspective during this independent review; however the findings will no doubt be subject to varying views. It will therefore be essential for the success of ORJIP that all industry stakeholders continue to work together to reach consensus on how best to take these recommendations forward. Compromises may need to be made; however, any step change improvements to current guidelines, no matter how incremental, have the potential to ultimately make a material difference to the industry.

All recommendations made in this report are therefore the professional opinions of the research team and not the direct views of DECC or the ORJIP Project Steering Group (PSG), and as such the UK regulators or industry are not held to implement these recommendations.

ACRONYMS

ADD	Acoustic Deterrent Device
AHD	Acoustic Harassment Device
ALARP	As Low As Reasonably Practicable
AMD	Acoustic Mitigation Device
BAT	Best Available Technology
CAPEX	Capital Expenditure
CCW	Countryside Council for Wales
CDM	Construction (Design and Management) Regulations
COWRIE	Collaborative Offshore Wind Research into the Environment
CTV	Crew Transfer Vessel
dB	Decibel
DECC	Department of Energy and Climate Change
Defra	Department of Environment, Food & Rural Affairs
EC	European Commission
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EPS	European Protected Species
ES	Environmental Statement
ESW	Effective Strip Width
EU	European Union
FEPA	Food and Environment Protection Act
FLO	Fisheries Liaison Office
GPS	Global Positioning System
H & S	Health and Safety
HF	High frequency
HLV	Heavy Lift Vessel
HR	Habitats Regulations
HSE	Healthy and Safety Executive
HSWA	Health and Safety and Work Act
IAMMWG	Inter-Agency Marine Mammal Working Group
ICES	International Council for the Exploration of the Sea
IV	Installation Vessel
JCP	Joint Cetacean Protocol
JNCC	Joint Nature Conservation Council
LCOE	Levelised Cost of Energy
LF	Low frequency
MF	Mid frequency

MMD	Marine Mammal Deterrent
MMM	Marine Mammal Mitigation
MMMP	Marine Mammal Mitigation Protocol
MMO	Marine Mammal Observer
MoD	Ministry of Defence
MoE	Measure of Effectiveness
MS	Marine Scotland
MZ	Mitigation Zone
NE	Natural England
NERC	National Environmental Research Council
NRW	Natural Resources Wales
OMR	Offshore Marine Regulations
ORJIP	Offshore Renewables Joint Industry Programmes
OWF	Offshore Wind Farm
PAM	Passive Acoustic Monitoring
pk-pk	Peak to peak (difference between maximum negative and positive amplitudes of a waveform).
PPM	Psychophysical Model
PSD	Power Spectrum Density
PSG	Project Steering Group
PTS	Permanent Threshold Shift
R & D	Research and Development
R1/2/3	Round 1/2/3
RMS	Root Mean Square
RTT	Real Time Tracking
RUK	RenewableUK
SAC	Special Area of Conservation
SEL	Sound Exposure Level
SNCB	Statutory Nature Conservation Body
SPL	Sound Pressure Level
STW	Scottish Territorial Waters
SV	Survey Vessel
TCE	The Crown Estate
TTS	Temporary Threshold Shift
UHF	Ultra High Frequency
UK	United Kingdom
VDRM	Value, Decision, Risk, Management

1 INTRODUCTION

Marine Scotland (MS), The Department of Energy and Climate Change (DECC), The Carbon Trust, The Crown Estate (TCE) and the offshore wind development community are working together to implement an Offshore Renewables Joint Industry Programme (ORJIP) of works to fund and deliver strategic research projects to reduce consenting risk for offshore wind projects in UK waters. Addressing strategic evidence gaps is a high priority for the offshore wind sector as many potential future offshore wind projects are at risk. Offshore wind developments in UK waters are progressing rapidly and the outputs of this proposed programme are required to inform consent and licence applications and advice and decisions by the UK regulatory authorities.

Following consultation with the UK Underwater Noise Group and the offshore wind industry improvements to standard mitigation measures associated with potential injury effects of underwater noise on marine mammals came through as being a priority consenting risk to the offshore wind farm (OWF) industry. The focus of this first ORJIP (ORJIP Project 4) is therefore the strategic data collection and technology research to develop solutions on behalf of offshore wind developers to address this risk.

This review constitutes Phase 1 of ORJIP Project 4 (project specification described in Invitation To Tender provided in Appendix A). This review summary has been prepared by Xodus Group Ltd, in collaboration with SMRU Marine, who were commissioned to undertake the work by DECC as representatives of the ORJIP Interim Working Group (IWG)/ORJIP Programme Group.

1.1 Background

The rapid development of the offshore wind farm (OWF) sector in the UK (see Appendix B) has been accompanied by growing concern over the effects of construction noise on marine mammals, which are particularly sensitive to sound (Madsen *et al*., 2006). Amongst these concerns is the effect of noise emitted during pile-driving (piling), which is often a necessary step in attaching the wind turbine foundations to the seabed[4]. Together with seismic surveys, piling is generally thought to represent one of the most intense anthropogenic noises in the marine environment (Gordon *et al.,* 2003, Bailey *et al*., 2010), and has the potential to cause permanent hearing damage in marine mammals (Southall *et al*., 2007) (see Appendix K for a detailed acoustic review and detailed definitions). Consequently, the direct impacts of piling on marine mammals have been at the forefront of stakeholders' concern and uncertainty surrounding the prediction and mitigation of such impacts presents a significant risk to OWF deployment, particularly in light of the requirements of the EU Habitats Directive and Marine Strategy Framework Directive.

To date the Marine Licences issued to OWFs within the English and Welsh territories have focused on the current piling protocol (JNCC, 2010b), which forms part of the more general guidance on EPS (JNCC, 2010a in prep). The JNCC protocol, which was considered best practice when produced, outlines three principal measures by which this may be achieved: two involve monitoring of a mitigation zone to ensure no animals are present, either visually using MMOs or acoustically, using PAM, and one involves gradually ramping up the pile-driving force (soft start), which should allow marine mammals to vacate the area. Each of these measures imposes inherent financial, schedule and H & S safety risks during their implementation. There is also significant uncertainty among OWF developers and other stakeholders as to the effectiveness of these mitigation measures, as they are currently employed.

The UK is rapidly approaching the construction phase of its Round 3 (R3) and Scottish Territorial Waters (STW) OWFs, which have larger turbines, larger footprints, are more numerous and are located further offshore than R1 and R2 developments. As a result, the potential impacts of piling on marine mammals are likely to get more complex, as are the risks associated with their mitigation. Partially in response to this evolution in scale of the UK OWF sector, the current EPS guidance (JNCC, 2010a in prep) is being revised by Defra and Marine Scotland (separately due to the distinction between a disturbance offence in Scotland and the English and Welsh nearshore and UK offshore territories). It is therefore timely given the pending Round 3 and STW

[4] *Note piling is required for monopoles and pin piles (within jackets), gravity bases are another form of turbine foundation that does not require piling.*

projects and greatly expanded evidence base to revisit the current piling mitigation guidance (JNCC, 2010b) and site specific advice by SNCBs and develop a roadmap of recommendations towards future proofing any subsequent revisions to the JNCC marine mammal mitigation protocol (MMMP).

A potential mitigation solution currently receiving increasing interest and attention (e.g. Gordon *et al.,* 2007, Brandt *et al.,* 2013) is to move animals out of high risk areas close to piling through the use of aversive sounds emitted by an acoustic deterrent device (ADD). Should such an approach prove to be effective in reducing the risk of marine mammals sustaining injuries as a result of piling, it could be of great benefit to the offshore renewables sector, as well as the animals themselves. However, from an ecological perspective there is a multiplicity of factors that need to be taken into account and assessed in order to provide scientifically sound and objective advice on the use of ADDs, for example species specificity, habituation and potential injury due to sound from the deterrent devices (see Section 3.4.4 where further information can be found on the ADDs). Increasing current understanding of such issues - which are fundamentally different to the use of ADD in aquaculture - plus the use of soft start, is a fundamental aspect of Project 4 Phase 2 as it will contribute to the ultimate aim of the project, which is to achieve a more reliable, repeatable and cost effective method for ensuring that marine mammals are not injured during offshore piling activity.

1.2 Aims and Purpose of Phase 1

The aim of ORJIP Project 4 is to (see ITT in Appendix A for further details of the exact scope):

> Review, test and/or develop ADDs or other deterrent devices for multiple marine mammal species, thus reducing reliance on visual observations and increasing construction time available by removing daylight/sea state restrictions on piling activity;

> Conduct field tests in realistic conditions to provide evidence that devices will provide the required level of risk reduction for the species concerned; and

> Develop protocol(s) for the use of ADD(s) as agreed with industry, advisors, regulators and NGOs.

The scope of Phase 1 of ORJIP Project 4 is to review and make recommendations associated with current and potential mitigation against the direct or indirect injury to marine mammals during piling; with a specific focus on the need to review, test and/or develop acoustic deterrent devices (or other deterrent devices) and soft-start procedures for multiple marine mammal species to inform Phase 2 of Project 4 (see Appendix A for further information).

The purpose of this study is to provide an independent and balanced assessment of the challenges facing regulators, their advisors and industry in the implementation of effective marine mammal mitigation, particularly as development programmes for Round 3 OWFs gather pace. It brings together environmental management experience gained by industry during Rounds 1 and 2 and on-going topical research, whilst talking into account the uncertainties around the implications of implementing the current mitigation protocol (JNCC, 2010b) at proposed Round 3 sites, which differ markedly from previous projects in their design envelopes, costs and operational risk. The ultimate goal of this project is not to simply deliver a list of recommendations, but practical solutions and advice on how best to progress both Project 4, and the industry as a whole. This report has been produced by Xodus Group and SMRU Marine on behalf of DECC and the ORJIP.

The review is based on an evidence base of industry reports (available marine mammal observer (MMO) and marine mammal mitigation protocol (MMMP) reports), the latest research, and consultation with interested parties (including statutory nature conservation bodies (SNCBs), developers, researchers and non-government organisations). Every attempt has been made to capture the concerns and/or lessons learned from all interested parties and to ascertain and collate all available pertinent information. However, there may be other concerns and data that are emergent, commercially sensitive or not necessarily captured at the time of writing. Despite this, there is sufficient detail to open up these findings for consideration.

In accordance with the ethos of ORJIP this review has been founded on the views shared by all interested parties, the overarching vision being to help build a better knowledge base that considers the policy, practical and economic constraints experienced by the sector. It is timely that developers and regulators engage in a more meaningful way to balance statutory requirements with the practicalities of working in the marine environment. Only through open discussion between developers and regulators will more collaborative and creative approaches to offshore wind development be reached, thus ensuring practices remain responsible and sustainable (RUK, 2010).

Given current understanding of injury versus disturbance of these marine mammals, consideration of mitigation of disturbance, habitat exclusion or behavioural effects has been decoupled from this review. However, it should be noted that these are important factors that could potentially lead to population level impacts, and under current legislation, must be addressed accordingly during the assessment of individual projects. The relative technology status of detect and deter devices has also precluded detailed consideration, in favour of deter only devices, although the former have been assessed as far as possible.

1.3 Approach

The approach taken for this project relied on a small core team managing and delivering the review (made up of specialists from Xodus and SMRU Marine) and ensuring the data gathering and synthesis was carried out in a consistent fashion, drawing on various technical specialists.

In recognition of the large amount of existing R&D and primary and grey literature reviews on this topic (such as Gordon *et al.,* 2007, Coram *et al.,* 2013) and the collaborative and cooperative ethos of ORJIP, the project built upon existing work, capturing through an interview process lessons from European projects, as well as extracting and synthesising relevant data from existing reports. To ensure that the project balanced the broad range of considerations, a formalised decision making process was adopted. This process entailed an initial workshop during the early stages of the project, at which end users (including developers, consenting bodies, health and safety representatives and piling equipment operators) identified and discussed the specific criteria for evaluating the current and potential future mitigation solutions. This approach was designed to ensure that the study focused on the most important topics, and ensured that recommendations made as part of this study fully capture the needs of the target end users.

The overarching research question used to frame the review was agreed with the ORJIP project steering group at the beginning of the process:

Considering the evidence and experience from the application of existing techniques for mitigating the effects of piling noise on marine mammals (MMOs, PAM and soft starts), as well as the potential use of ADDs, what improvements can be made, and what is the best approach to adopt going forward, taking into account the future development of the offshore wind sector?

The key steps in the process are as follows:

- From existing information and completed review work a number of ‘scenarios’ were established for evaluation;
- Review of soft start, PAM, MMO and ADD data available (relevant to each of the criteria identified in an initial workshop – see Appendix F and G);
- Development of a gap analysis, and data gathering plan /questionnaire;
- Capture, synthesis and assessment of data by the respective industry specialists (Xodus, SMRU Marine), and presentation to the steering group;
- Any information gaps were then addressed either through consultation or using in-house experience;
- The core specialists then reconvened for the second phase workshop to score and rank the mitigation solutions based on the criteria and scenarios accepted by the steering group, established at the outset of the project; and
- Finally, the workshop output was used to develop recommendations.

It is important to acknowledge that a project of this nature has the potential to influence a broad range of stakeholders affected by the development of offshore renewables. Every effort has been made to provide a balanced and objective review; however, it will no doubt be subject to varying views and comments from the wider ORJIP research group and other interested parties, which is welcomed and appreciated.

It should also be noted that all recommendations made in this report are the professional opinions of the research team and not those of DECC or the wider ORJIP research group, and as such the UK regulators or industry are not held to implement these recommendations.

1.4 Priority species

The five priority species identified by ORJIP for inclusion in this review have been categorised into four functional hearing groups (Southall *et al*., 2007). This approach closely matches that of the majority of UK offshore wind farm Environmental Statements (ES), which tend to focus on the following species as representatives of each functional group:

- High-frequency cetaceans: represented by harbour porpoise;
- Mid-frequency cetaceans: represented by bottlenose dolphins;
- Low-frequency cetaceans: represented by minke whale; and
- Pinnipeds (in water): represented by grey and harbour seals. N.B. where sufficient data exist, these species have been assessed separately, but this has not been possible for all aspects of the review.

The distribution and abundance of these species are displayed in Appendix C. Grey and harbour seals have been placed into the same functional hearing group (pinnipeds in water) for certain parts of the analysis.

It is important to consider the mitigation of effects of pile driving noise on other marine species, such as fish, turtles and birds. Not only are many of these types of animal of high conservation priority themselves, but may have important ecosystem links to marine mammals e.g. fish, which are a key food source for many marine mammal species. However, in order to ensure that the present review achieved its primary objectives, the focus will remain on the five species/four functional groups identified.

It is further important to note that cumulative effects of multiple mitigation techniques used in an area would be assessed as part of the Cumulative Impact Assessment (CIA) in the ES. The range of species that would be addressed is the same as the degree to which the chosen five priority species are accepted as representative.

1.5 Definitions of ADD and standard mitigation measures

For the purposes of this review the following definitions, which are based primarily on the piling mitigation protocol (JNCC, 2010b), have been used for each of the mitigation measures. More detailed descriptions of each of the techniques are provided in Appendix E. Note in Scotland the principle is the same however the size of the mitigation zone, duration of soft start etc. are agreed on a case by case basis.

1.5.1 Marine Mammal Observers (MMOs)

MMOs visually monitor a predefined mitigation zone during the period leading up to the commencement of piling, usually from an elevated platform on a dedicated survey vessel or the installation vessel. The current mitigation protocol (JNCC, 2010b) states that the pre-piling search should be a minimum of 30 minutes. The extent of the mitigation zone represents the area within which a marine mammal is likely to be subjected to levels of sound that may cause injury, which is highly dependent on a number of factors. It is therefore determined on a project specific basis, but should be no less than 500 m in radius. If the MMO detects a marine mammal within the mitigation zone during the pre-piling search period, piling is prohibited from commencing any earlier than 20 minutes after the last detection.

1.5.2 Passive Acoustic Monitoring (PAM)

PAM can be defined as a hydrophone system that is deployed from a vessel and works by detecting the vocalisations made by some odontocetes (toothed whales and dolphins) for echolocation and communication and is especially useful for detecting porpoises (Khyn *et al,.* 2012). It is a useful supplement when conducted in conjunction with MMO visual observations, and is often the sole means of detection during periods of darkness or low visibility. The acoustic monitoring adheres to the same mitigation zone protocol described above for MMOs. The area that can be monitored is dictated by the range of the hydrophones and the manner in which they are deployed. If deployed from a static position the range is approximately 250 m for porpoises, but if towed from a vessel that is able to move around a pile more comprehensive coverage of the mitigation zone may be achieved (though possible interference caused by vessel noise must be considered). PAM must be set up and deployed by trained PAM operatives, who may also be trained MMOs, allowing for role switching where necessary.

1.5.3 Soft starts

Soft start refers to the incremental ramping up of the pile driving hammer's blow energy over a defined period, until full operational power is achieved (JNCC, 2010b). Their use as a mitigation measure is based on the principle that a gradual increase in piling noise should deter any marine mammals from the location, allowing them time to swim to a safe distance before the noise reaches a sufficient level to cause injury. The current mitigation protocol (JNCC, 2010b), applicable in English territories, stipulates that the duration of a soft start should be "not less than 20 minutes".

Soft starts are implemented at the commencement of piling. If a mammal is detected during the soft start, it is recommended that piling should cease if possible, and not be resumed until there are no further detections for 20 minutes or at the least the power should not be further increased until the marine mammal exits the mitigation zone, and there are no further detections for 20 minutes. Should there be a break in piling of greater than 10 minutes, the MMO/PAM pre-search and soft start procedures are repeated.

In general, a soft start of approximately fifteen minutes is required for engineering purposes (such as ensuring correct monopile alignment), irrespective of the MMMP. These have been referred to throughout the report as '**engineering soft starts'**. Two other terms have also been used throughout the report: '**mitigation soft start'**, which refers generically to any soft start that has been extended beyond the required engineering soft start for the purpose of marine mammal mitigation; and '**standard soft start'**, which refers to a soft start that adheres to the JNCC (2010b) guidelines described above i.e. not less than 20 minutes.

1.5.4 Acoustic Deterrent Devices (ADDs)

The principle behind the use of ADDs is that they produce an aversive signal that causes a marine mammal to move away from the piling event and out of the zone of potential injury. ADDs have been used widely in an attempt to deter mammals from aquaculture facilities and fishing gear, but have only recently been adopted as a method of deterring them to a 'safe distance' from the impact zone surrounding a piling event (Gordon *et al.,* 2007). ADDs are presently employed as a voluntary supplement to the 'standard' components of a MMMP in the UK and have been used at a number of UK OWFs sites. In contrast, a number of European countries stipulate the use of ADDs as a standard component of their MMMPs (Appendix F).

When used as a mitigation measure during OWF development, ADDs are typically deployed from an MMO survey vessel or installation vessel, but unlike PAM, do not require a trained operator to deploy them. JNCC (2010b) recommend that they should only be used in conjunction with visual and/or acoustic monitoring, positioned as close to the pile installation as possible, and activated only during the pre-piling search. The guidelines also require that the potential effectiveness on the species likely to be present is considered, and that an EPS licence might be required to authorise an intentional disturbance. Information on the requirement for a

Wildlife Licence and the screening and application process is available in Marine Management Organisation (2013).

ADDs are referred to under an array of different terms, including Acoustic Mitigation Devices (AMDs), Acoustic Harassment Devices (AHDs), 'scrammers', 'scarers' and 'pingers'. These are discussed in more detail in Appendix E. For clarity, and because the unifying feature between all available devices is the intention to deter animals from a specific area using acoustic signals, Acoustic Deterrent Device (ADD) has been adopted in the present review as a generic term to cover all types of device.

1.5.5 Noise abatement and alternative construction techniques

It should also be noted that the assessment of noise abatement and alternative construction techniques during piling is outside the scope of this project, although it is recognised that these are important concepts and a necessary consideration during the EPS licensing procedure.

1.6 Structure of Report

In order to maintain a concise and coherent narrative in the present report, the detailed analyses and results have been consigned to Appendices. This approach allows the main body of text to draw together the key issues and findings in an easily comprehensible fashion, whilst providing the detail and paper trail behind the results for those who are interested.

A breakdown of the review objectives, as detailed in the invitation to tender, together with references to the sections within which those objectives are dealt with is provided below in Table 1.1.

Table 1.1 Objectives of the review and the sections in which they are met

Task/Objective		Relevant section(s) of report
For each constructed wind farm in Europe, a description of:	MMOs, ADDs or other deterrent devices if used, how they were deployed (from buoys, vessels, construction barges), location in respect of piling operation, conditions when deployed (night time, fog etc.), any issues with deployment, time between using ADD and piling;	3.2, 3.3, Appendix G
	The potential for adverse effect on protected species;	3.4, Appendix K, Appendix L
	Any PAM undertaken and results;	3.2, 3.3, Appendix G
	Protocol adopted;	Appendix G
	Any information on the effective spatial range of the method used;	3.2, 3.3, Appendix K
	Records kept (including marine mammals seen);	Appendix G
	Any evidence of habituation of target species to the deterrent;	3.3, 3.4.1
	Any evidence of species specificity;	3.2, 3.3, Appendix K, Appendix L
	Costs of using MMOs/Deploying ADDs or other deterrent devices, including costs of installation, operation and maintenance;	3.6
	Any implications of using MMOs/ADDs for the activities being undertaken (time delays, costs); and	3.5, 3.7, Appendix M

Task/Objective		Relevant section(s) of report
	EPS Licensing of activities (whether a licence was required, process to obtain).	Appendix G
A parallel review of the use of soft-start procedures in piling operations at European wind farms. In addition to the factors listed above, the review reports on:	The relative noise emissions during soft-start and full power piling, and the potential for soft-start to lead to negative impacts on protected species, i.e. physiological or behavioural effects in mammals;	3.3, Appendix K
	The feasibility of applying soft-start in UK wind farm projects and waters;	3.5, 3.7, Appendix K, Appendix M
	The compatibility of soft-start with various types of piling equipment;	3.3, 3.7, Appendix M
	Evidence for the effectiveness of soft-start in protecting sensitive species; and	3.3.1, Appendix K
	The role of other noise sources, e.g. vessels in disturbing mammals within the immediate vicinity of piling operations.	Appendix K
A review of comparative aspects of Health and Safety issues related to the range of mitigations, including current measures and the actual and potential use of ADDs.		3.7, Appendix M

2 BACKGROUND

2.1 Introduction

The scope of this study is to consider measures to mitigate lethal, physical and Permanent Threshold Shift (PTS) injury from offshore wind piling activities. Whilst legislation regarding injury can therefore be considered of most relevance, proposed mitigation measures may introduce the potential for both injury and disturbance offences (albeit at a much smaller scale) and thus applicable UK legislation and guidance for both injury and disturbance is considered below (see Appendix D for a detailed summary). In addition, it will be necessary for any field trials of acoustic deterrents to consider the likelihood of both injury and disturbance offences.

2.2 Legislation, Regulations and Guidance in the UK

2.2.1 Legislation and Regulations

The key overarching legislation regarding the protection of marine mammals is the EC Habitats Directive (92/43/EEC); this Directive lists all cetaceans in Annex IV (making them European Protected Species; EPS) and lists harbour porpoise, bottlenose dolphins and grey and harbour seals in Annex II (requiring that Special Areas of Conservation must be designated for these species). All cetaceans are also listed on Annex IV, which requires regular assessments of their conservation status covering abundance, distribution and the pressures and threats experienced. The Habitats Directive is transposed into UK law by the 'Habitats Regulations': in England and Wales this is achieved through The Conservation of Habitats and Species Regulations 2010 (as amended), in Scotland by The Conservation (Natural Habitats, &c) Regulations 1994 (as amended) and in Northern Ireland by The Conservation (Natural Habitats &c.) Regulations 1995 (as amended). The Habitats Regulations apply only as far as the limit of territorial waters (12 nautical miles from baseline) and it is instead The Offshore Marine Conservation (Natural Habitats &c.) Regulations 2007 (the "Offshore Marine Regulations", OMR as amended 2009 and 2010) that apply on the United Kingdom Continental Shelf.

2.2.2 Cetaceans

All species of cetaceans are listed in Schedule 2 of the Habitat Regulations and Schedule 1 of the OMR as EPS, giving them legal protection from (amongst other specifics) injury, killing or deliberate (including 'reckless') disturbance. Whilst the English, Welsh, Irish and UK offshore marine area Regulations make it an offence to disturb a significant group of animals, in Scotland the Habitats Regulations also make it an offence to disturb individual animals (note, however, that the same protection to whale and dolphin species from disturbance is provided by Wildlife and Countryside Act 1981 (as amended), except in Northern Ireland). The protection given to these species is summarised in Table 2.1.

Table 2.1 Summary of cetacean/seal protection provided by legislation described herein

Region	Cetacean Protection			Seal Protection
	Injury or killing	Disturbance of significant groups	Disturbance of individuals	
England <12 nautical miles	Yes.	Yes.	Yes.	Cannot kill or injure during close season or on east coast at any time.
Wales <12 nautical miles	Yes.	Yes.	Yes.	Cannot kill or injure during close season.

Region	Cetacean Protection			Seal Protection
	Injury or killing	Disturbance of significant groups	Disturbance of individuals	
Northern Ireland <12 nautical miles	Yes.	Yes.	No.	Cannot kill or injure at any time of the year. Cannot disturb at any haul-out.
Scotland <12 nautical miles	Yes.	Yes.	Yes.	Cannot kill or injure at any time of the year. Cannot disturb individuals or groups of animals. Cannot disturb at significant haul-outs.
UK Offshore Marine Area >12 nautical miles	Yes.	Yes.	No.	Cannot kill or injure at any time of the year.

2.2.3 Seals

Grey and harbour seals are not listed as EPS and do not have protection under the Habitats Regulations. However, these species are listed as Annex II species and they are afforded protection in so far as special areas of conservation (SACs) must be established, steps must be taken to avoid deterioration of habitats within those SACs and action must be taken for activities impacting on Annex II species from the SAC, even when they are outside it.

However, there is alternative legislation in the UK territories that provides more specific protection to these species. In England and Wales the Conservation of Seals Act (1970) makes it an offence to kill, injure or take seals by certain methods during specified closed seasons (the Marine and Coastal Access Act 2009 made the Marine Management Organisation the competent authority in respect of licensing under the Conservation of Seals Act). In England killing, injuring or taking is prohibited at any time of the year for much of the east coast. Additionally, The Conservation of Habitats and Species Regulations 2010 describes a similar restriction on killing or taking. In Northern Ireland The Wildlife (Northern Ireland) Order 1985 gives protection to grey and harbour seals at all times of the year, making it an offence to kill or take seals.

In Scottish inshore waters it is an offence to kill, injure or take a seal at any time of year except to alleviate suffering or where a licence has been issued to do so by Marine Scotland under the Marine (Scotland) Act 2010. Under the same Act, it is an offence to intentionally or recklessly harass seals at significant haul-out sites (although these sites are yet to be designated). The Habitats Regulations in Scotland further make it an offence to disturb individual seals as well as groups of seals. The protection given to these species is summarised in Table 2.1.

2.2.4 Supporting guidance

Both Defra and Marine Scotland are preparing to release separate guidance on 'The Protection of marine EPS from Injury and Disturbance' (Defra, in prep; Marine Scotland, in prep) which will each provide the UK OWF sector (and other offshore industry) with best practice guidance for minimising impacts to marine species. Defra guidance will be aimed at the English, Welsh and UK offshore marine areas and, although not legally binding, will form the basis of the UK's legal obligation to adequately transpose the Habitats Directive. The Scottish guidance will meet that obligation in Scottish territorial waters. Similar, separate guidance does not exist for Northern Ireland. Whilst the two guidance documents will provide broadly similar advice, there are two key differentiators:

- Whilst the Scottish guidance will be a new document, the Defra guidance will be a re-release of the Joint Nature Conservation Committee (JNCC, 2010a in prep) guidance. The JNCC (2010a in prep) guidance is the current guidance on EPS and its contents are consequently the basis of many of the Marine Licences for OWFs in the UK.
- The Defra guidance will provide advice on what might constitute significant disturbance i.e. that it is likely to be detrimental to the animals of an EPS or significantly affect their local abundance or distribution. The Marine Scotland guidance will reflect the Habitats Regulations in Scotland that make it an offence to disturb individuals as well as groups of animals (note, however, that the same protection to whale and dolphin species from disturbance is provided by Wildlife and Countryside Act 1981 (as amended) in English territorial waters).

In addition to the Defra and Marine Scotland guidance, the mitigation of potential underwater noise impacts arising from piling during OWF construction (and other offshore industry) is covered in the 'Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise' document (JNCC, 2010b). The main provisions of the JNCC piling protocol (JNCC, 2010b) require the:

- Production of an Environmental Management Plan (EMP);
- Deployment of dedicated, suitably experienced and trained Marine Mammal Observer (MMOs); and
- Use of Passive Acoustic Monitoring (PAM).

as key components of a marine mammal injury mitigation plan.

A 'mitigation radius' is also required around the piling activity, the purpose of which is to provide an adequate area of mitigation and monitoring which should encompass, as a minimum, any potential injury zone of the piling activity. The extent of a mitigation zone should be considered during the Environmental Impact Assessment (EIA) and agreed with the regulatory authority. Although the protocol states the radius should be 'no less than 500 m', in practice in the offshore environment (across all industries) a 500 m zone is often adopted by default without reference to specific impact ranges presented or discussed in the Project Environmental Statement (ES). A soft start involving the gradual ramping up of piling power over a period of no less than 20 minutes is also a standard requirement. The 20 minute period was deemed to be sufficient as a result of analysis carried out for a group of 'Thames' R2 developments (London Array, Greater Gabbard and Thanet) by Subacoustech (Subacoustech, 2006). Whether this applies to what is currently being envisaged for R3 and STW OWF projects is uncertain. Regarding the use of ADDs as part of a mitigation programme for offshore developments, the excerpt below, taken from the Defra guidance (Defra, in prep – previously JNCC 2010a), summarises the SNCB's current stance:

"Until further research is carried out, and for activities where the risk of injury or death cannot be considered to be negligible, JNCC, Natural England and CCW currently recommend the use of ADDs as tentative acoustic mitigation devices. However, their use should be short-term…and always additional to the main mitigation measures…If used for a short period of time, these devices are unlikely to affect any EPS in a way that would result in disturbance or injury under the HR/OMR."

The definitions and requirements of each of the marine mammal mitigation techniques considered in the JNCC mitigation protocol (JNCC, 2010b) have been summarised in Appendix E. Scottish SNCBs provide similar mitigation advice as the current JNCC mitigation protocol (JNCC, 2010b), with the agreed mitigation techniques and mitigation zones agreed on a site specific basis.

For the remainder of this study all references to generic 'legislation' and 'general guidance' take into consideration the clear distinction between applicable legislation and guidance pertaining to the various UK territories and offshore marine area.

2.3 Status of Marine Mammal Mitigation in the UK

An overview of the Marine Mammal Mitigation applied at UK offshore wind farms sites is presented in Appendix G, together with a summary of available MMO/construction reports.

It is currently common practice in English territorial waters for soft starts, MMO and PAM to be universally applied, with little or no variation in consent conditions between sites. ADDs have also been employed by several developers.

The review of licence conditions from the initial UK developments in 2004 through to those presently entering their construction phase revealed a clear evolution in requirements (Table F.1). Initially no specific mitigation was specified, after which casual untrained MMOs were utilised. Next, trained MMOs and soft starts were specified, and this was soon followed by the requirement for PAM during periods of low visibility. The requirement for ADDs has not appeared in any of the FEPA/Marine Licences scrutinised during this review, suggesting they have been used as a voluntary supplement by developers.

The reports available for review at the time of submitting this piece of work do not represent all constructed offshore wind farms in the UK. Nevertheless, the information highlighted some key points that were integral to the review process, such as:

- Detection rates of MMO and PAM appear to be extremely low, with very low numbers of sightings yielded by often thousands of hours of effort, though there is some variability between sites. It is difficult to determine whether this is due to low marine mammal densities in the area, the fact that the animals are scared away from the area, that other human factors such as fatigue or lack of experience played a role, or that these methods have a low detection probability.
- A significant amount of piling at night or periods of restricted visibility occurs, usually with just PAM and soft starts as mitigation[5];
- MMO and PAM have usually been implemented using a dedicated survey vessel, but what limited experience there is of deploying these mitigation measures from the pile installation vessel has been positive (subject to the availability of a suitable observation platform);
- ADDs have been successfully deployed by client representatives or crew members from the installation vessel, but attempts to deploy pingers from independent buoys have proven challenging;
- A variety of ADDs have been used across several projects, applied when piling commences at night as compensation for not being able to visually monitor the mitigation zone, rather than a standard mitigation measure; and
- ADDs have generally been activated 30 minutes before a soft start, after 30 minutes of PAM, and have not been allowed to run for longer than 1 hour.

This information has been derived from a variety of sources, including MMMPs, MMO reports, FEPA licences and interviews with industry specialists. A summary of the methodologies employed during this study and key consultation and workshop output are provided in Appendix H. Further information on the practicality of ADD deployment is provided in Section 3.7.

Further information on the efficacy of MMO and PAM is provided in Section 3.2.

2.4 Regulations and Guidance Outside of the UK

A summary of marine mammal mitigation procedures and legislation used in the UK, Germany, Denmark and the Netherlands is provided in Appendix G and Section 2.5 below, which draw on information provided in Ludeke *et al*. (2012), and the ICES marine mammal working group report (ICES WGMME, 2010). It is

[5] *It should be noted that JNCC guidelines make a distinction between piling which commences during times of good visibility and continues into a period of poor visibility/ night-time, and piling that commences during times of poor visibility (including night-time conditions). The statement in the text above refers to the latter, though the former is also a common occurence.*

particularly pertinent to note it is standard practice for regulators and advisors to evaluate marine mammal mitigation permits and conditions on a case by case basis (as it is in the UK), however there are a wider suite of marine mammal mitigation techniques approved by the European SNCBs for use by developers elsewhere in Europe.

The recommendation (by European SNCBs or advisors) to use ADD is common practice at the majority European wind farm sites. Other marine mammal mitigation approaches used elsewhere in Europe during piling include noise abatement techniques; spatial and/or temporal restrictions to avoid sensitive habitats or seasons; plus alternative construction techniques such as vibratory hammers, screw-piles, and alternative foundations designs (van den Akker & van den Veen, 2012). Each of these solutions has previously come under scrutiny for use in the UK; for instance, many are still in early development, some are very costly and only applicable under very specific circumstances and environmental conditions and are therefore not considered suitable for the proposed UK offshore wind farm sites, and some do not address the issue of injury.

Given the compact scope of this project such mitigation options have not been considered further in this review; however, some of these options may well prove effective for use when considered on a site by site basis. The few offshore wind farms constructed to date have been of a relatively small size. The planned R3 and STW OWFs will result in several more and larger OWFs with a considerable increase in the number and size of turbines and therefore have much greater construction periods affecting larger areas. Licensing authorities will therefore need to consider the potential need for mitigation measures to limit the area and/or period of disturbance if significant impacts on sensitive populations are predicted.

2.5 Status of Marine Mammal Mitigation outside of the UK

OWF developments outside the UK rely on the use of ADDs and spatial/temporal restrictions to a much greater extent than the UK. Reports prepared by MMOs post-operation, as described for the UK in the previous section, are not produced elsewhere in Europe, primarily because there is no requirement for a dedicated observer/MMMP facilitator. A summary of confirmed mitigation use at European OWF sites is provided in Appendix G. The information presented in the appendix highlights some important differences between the types of mitigation measures that are employed at European and UK OWF sites, as well as differences in the way in which the same measures are applied. For instance:

- Live monitoring and enforcement of a mitigation zone during piling via MMO and/or PAM is generally restricted to the UK, although there are often different and sometimes onerous mitigation requirements elsewhere. It is noteworthy to mention that visual observers have been employed outside of the UK in other industries, for example; during seismic surveys in the United States (Compton *et al.*, 2008), Brazil (Parente & Araujo, 2011), Ireland and Greenland (personal communication, anon.), as well as during naval sonar exercises in some parts of the United States (Dolman *et al.*, 2009);
- Soft starts are widely used throughout Europe, but do not adhere to a defined protocol, except in the UK (i.e. prescribed minimum period of soft start – see JNCC, 2010b);
- Outside the UK mitigation measures are generally deployed from installation vessels (or in some instances noise abatement vessels), and as such, do not require a dedicated mitigation team;
- ADDs are used in the UK as a supplementary measure during darkness or periods of low visibility to account for not being able to visually monitor a mitigation zone. Conversely, elsewhere in Europe, ADDs are applied as standard during all piling activity (however, there is some variability in the placement of the devices and periods they are run for); and
- Much of the reporting on these issues outside of the UK comes from focused research projects as opposed to construction reports.

3 EVIDENCE REVIEW

3.1 Overview

This section presents the key findings of the desk based review, which draws on a large body of source data, including:

- Primary and grey literature;
- Industry and construction reports;
- Information captured during two project workshops attended by a wide range of stakeholders and interactive review of initial findings, involving the ORJIP project steering group;
- Bespoke predictive modelling work conducted for the review; and
- Information provided during one to one interviews conducted by the project team.

Much of the detailed data and analyses have been placed in Appendices, which are referred to throughout the following sections. This evidence review has been used to:

- Inform the 'ranking of mitigation options' exercise, based on the criteria developed during the stakeholder workshops (Section 4); and
- Inform, rationalise and develop recommendations (Section 5).

> Note the current JNCC guidance on marine mammal mitigation protocols during piling (JNCC, 2010b) was developed from guidance related to the seismic sector and during the relative infancy of the OWF industry, when a considerably smaller number of MMO reports and relevant research papers were available. At that time the size of OWF turbines and monopile foundations were smaller than those being proposed for R3 and STW projects, as were the predicted piling impact zones. There is now a larger evidence base and industry stakeholders including developers, regulators, advisors and NGOs have a greater degree of experience and expertise. Consequently, any future revision of the guidelines will benefit from this greater knowledge and a clearer picture of the OWF industry's future.
>
> The evidence base presented here aims to provide a clear comparison of the effectiveness of possible new approaches with the capabilities of procedures in the current piling mitigation protocol. The recommendations made in this review have been identified to respond to the gaps identified in our current evidence base whilst being mindful to set realistic goals.
>
> The implementation of (any of) the research recommendations made, and any step change improvements to current guidelines, no matter how incremental, will ultimately make a material difference to the industry and should be promoted.

During the two structured workshops conducted at the beginning of the review process (attended by a wide range of mitigation end users, including developers, piling contractors, SNCBs, regulators, academics and NGOs) the criteria identified as being most important to mitigation end users were identified as:

- Efficacy;
- Unintended consequences;
- Practicality;
- Regulation & legislation;
- Installation schedule;
- Cost; and

- Health and safety.

The criteria/drivers helped focus and prioritise the information obtained and assessed by the technical review team. A summary of the evidence base has been presented in the section below to reflect these key criteria/ drivers.

3.2 Efficacy of passive marine mammal mitigation

Passive mitigation techniques rely on the detection of marine mammals within the mitigation zone. The passive techniques that are included in the current UK mitigation protocol are MMO and PAM. The efficacy of both is discussed below.

3.2.1 MMO

Although the effectiveness of MMOs has been discussed extensively in previous reviews, e.g. Gordon *et al.* (2007); Shepherd *et al.* (2006), Parsons *et al.* (2009) and the JNCC guidelines themselves, little work has been carried out to specifically assess the effectiveness of MMO mitigation for pile driving activities. Too few data have been collected to date during OWF construction to allow any analysis or comparison with sightings rates from other survey methods. The general picture is that sightings rates are low during MMO pre-piling watches, which could be a result of ineffective detection but could also be a result of data collected to date being in areas of relatively low marine mammal density, or could be a result of the activity preceding piling itself leading to avoidance of the area.

Animals may go undetected for a number of reasons which generally fall into two main categories:

- Perception bias (animals which are present and visible at the surface but are not detected due to observer not seeing them), and
- Availability bias (animals which are present but are not visible at the surface because they are underwater).

Factors such as sea state, weather, observer experience, number of observers, distance from observer, level of observer fatigue, species and group size can have a considerable influence on the probability that an animal (or group of animals) will be detected at the surface (e.g. Barlow *et al*., 2001, Palka *et al.,* 1996, Berggren *et al.,* 2008). The Palka *et al.* (1996) paper demonstrated that the sighting rate of harbour porpoises was 80% lower in sea state 2 and 3 than in sea state 0.

The MoD carried out a review of the effectiveness of mitigation for preventing auditory injury as a result of military sonar exercises (Internal Communication (MoD UK) based on study carried out August 2000). They calculated a 'Measure of Effectiveness' (MoE) for each technique for the ability to detect, identify and localise individuals from different species, using a probabilistic approach which takes into account the sum of all the individual components that make up the probability of correctly detecting a marine mammal. The MoE of visual monitoring was only 15% across all species. The calculation involved a degree of subjectivity in the assessment and evaluation of the parameters owing to lack of data and data are averaged over all seasons, times of day and conditions, taking data from literature concerning animal behaviour and experienced MoD marine mammal observers.

It should be noted that although the MoD report defines the probabilities as being for detection and classification of marine mammals, it appears on analysing the report in greater detail that the MoEs have been calculated for detection only. Presumably (although this has not been confirmed with the report's authors), it was assumed that a well-trained and experienced MMO would be able to classify all of the marine mammals that they were able to see.

The range over which this was estimated was 2 km therefore the value for a 500 m rangewould be higher than this. The MoD study's individual MoEs for different aspects of visual monitoring have been reassessed as part of this study in order to calculate an amended MoE for visual monitoring over a zone of up to 500 m radius (i.e.

for the "standard" size of the JNCC mitigation zone[6]). These are presented in Table 3.1. It should be noted that these have been calculated based on summer conditions which are relatively favourable for visual observations; in winter the calculated MoEs will be much lower.

The considerations made in the MoD report and the wider literature relating to marine mammal line transect surveys can be used to provide an indication of the likely detection rates. It can clearly be seen that the main factors affecting the probability of detection are the likelihood of the surfacing part of the animal being conspicuous enough to allow detection and the probability of mammals being obscured by waves. This latter factor will be considerably lower in winter when there is a much greater likelihood of rough seas. In any case, the using MMOs to detect harbour porpoise and seals in particular is likely to be very ineffective.

Table 3.1 Calculated species specific MoE for visual monitoring based on experienced MMO and conditions favourable to detection

Description	Species	Assumptions	Score
Probability that the size and colour of the surfacing part of the animal is conspicuous enough to allow detection.	Harbour porpoise	At a range of 200 - 500 m in favourable conditions assuming a well-trained, experienced observer.	0.2
	Bottlenose dolphin		0.75
	Minke whale		0.55
	Harbour seal		0.1
	Grey seal		0.1
Probability that visibility is satisfactory to allow detection.	Harbour porpoise	For a range of 200 - 500 m in summer (probability would be lower in winter).	0.98
	Bottlenose dolphin		0.98
	Minke whale		0.98
	Harbour seal		0.98
	Grey seal		0.98
Probability of mammals not being obscured by waves.	Harbour porpoise	For a range of 200 - 500 m in summer (probability would be lower in winter).	0.1
	Bottlenose dolphin		0.8
	Minke whale		0.6
	Harbour seal		0.1
	Grey seal		0.1
Probability that the animal will be at the surface for a sufficient length of time or behaving conspicuously enough to allow detection.	Harbour porpoise	Based on probability of animal having surfaced after 30 minutes.	1
	Bottlenose dolphin		1
	Minke whale		1
	Harbour seal		0.9
	Grey Seal		0.9
Probability that the observer will be sufficiently attentive for seeing the animal.	Harbour porpoise	Takes into account fraction of the day when daylight permits observation (taken as 1 assuming no piling at night), probability of not being distracted (taken as being 0.95 for experienced, motivated, well trained personnel) and probability of not being dazzled by sunlight (taken to be 0.99 based on experience of MoD	0.94
	Bottlenose dolphin		0.94
	Minke whale		0.94
	Harbour seal		0.94

[6] *The 500 m mitigation zone is usually monitored using two MMOs either side of a vessel, thus requiring that each monitors to a distance of 250 m.*

Description	Species	Assumptions	Score
	Grey seal	personnel).	0.94
Overall species specific MOE of visual monitoring.	Harbour porpoise	Based on conditions favourable for visual monitoring in summer and assuming well trained, attentive, highly motivated MMO.	0.018
	Bottlenose dolphin		0.553
	Minke whale		0.304
	Harbour seal		0.008
	Grey seal		0.008

3.2.2 PAM

As is the case for visual monitoring during pre-piling watches, the only work that has directly assessed the effectiveness of PAM is the MoD commissioned work described above (Internal Communication (MoD UK) based on study carried out August 2000). The report concluded that PAM effectiveness was very low (5% in total over the 2 km range for all species), although it must be kept in mind that the work covers a range of species to which PAM is known to be highly insensitive. Nevertheless, detection rates for harbour porpoises, which PAM is most sensitive to because of their regular and characteristic vocalisations, were still very low (with a calculated MoE of 0.00). In addition the values of MoE were low as a consequence of the measure being assessed requiring the ability to detect and classify animals as well as to determine whether the animal is within a critical range. If the requirement had been to detect and classify only, the MoE would have been higher. The calculated MoEs from the MoD study for the key species are summarised in Table 3.2.

Table 3.2 Calculated species specific MoE for passive acoustic monitoring

Description	Species	Assumptions	Score
Overall species specific MOE of passive acoustic monitoring	Harbour porpoise	Assessed over a range of 2 km.	0.00
	Bottlenose Dolphin		0.07
	Minke Whale		0.06
	Harbour Seal		0.05
	Grey Seal		0.05

Detection probability is less dependent on weather conditions and sea state, but is likely to be affected by a number of other factors such as background noise, particularly vessel noise if the hydrophone is being towed, the species being considered and species specific factors such as frequency and directionality of vocalisations. Multiple hydrophones are required to estimate the range and bearing to detections using the timed difference of arrival of sound on the different hydrophones. Multiple hydrophones must be arranged in a 3D array to avoid left-right ambiguities in the bearing information or where the array is moving such as in a towed array, target motion analysis (using relative difference in movement of the boat and of the animals) can be used to determine the position of the detection. Detection probabilities are rarely quantified for acoustic surveys but there are reports of visual sightings which are not matched with acoustic detections (Rhyl Flats MMO report). Data collected from decades of seismic mitigation surveys have demonstrated that acoustic detection rates within the 500 m zone were lower than visual detection rates for several species (Stone, 2013 in draft). Sample sizes for sperm whales and harbour porpoises were too low to test but for Atlantic white-sided dolphins and the groups of all small odontocetes, all delphinids and all cetaceans, statistically significant differences were found.

3.2.2.1 Species specific discussion of effectiveness of passive marine mammal mitigation

As discussed in Section 3.2.1, there is very little data to directly assess the effectiveness of visual observation during mitigation for pile driving. Therefore information on the effectiveness of visual observations from line transect surveys for marine mammals has been examined as a proxy. In assessing the effectiveness of visual MMOs use has been made of g(0) values from the literature as an indication of how effective visual detection mitigation methods may be for each species. The quantity denoted by g(0) is the probability of detection of animals on the trackline during line transect surveys and is a key concept in distance analysis (Buckland *et al.*, 2001). A g(0) of 1 means that all the animals are detected, and a g(0) of 0.5, for example, means that only half of the animals present are detected. Effective strip width (ESW), which is mentioned throughout Table 3.3, is a measure of how far animals are seen from a ship transect line, and therefore how much area is effectively searched (Barlow *et al.*, 2011). It is important to highlight that there are several differences between vessel based line transect surveys and mitigation surveys from either a dedicated survey vessel circling around a fixed point or observations from a fixed, stable, elevated platform and therefore effectiveness of MMO observations may be different. It is difficult to predict how different it may be; in either case, (observers on vessels circling around a site or on a fixed stable platform) observers are unlikely to be able to maintain full 360^{o} observation of the whole mitigation zone and areas of the zone will not be continually monitored. In addition marine mammals will often be moving through the mitigation zone and the opportunities for spotting animals are likely to be similar regardless of how long the observer is observing a fixed area. Issues affecting effectiveness relating to sea state and experience of the observer are likely to be similar across different survey methodologies. The effectiveness of passive marine mammal mitigation techniques is discussed in Table 3.3. In assessing the effectiveness of visual MMOs use has been made of g(0) values from the literature as an indication of how effective visual detection mitigation methods may be for each species. The quantity denoted by g(0) is the probability of detection of animals on the trackline during line transect surveys and is a key concept in distance analysis (Buckland *et al.*, 2001). A g(0) of 1 means that all the animals are detected, and a g(0) of 0.5, for example, means that only half of the animals present are detected. Effective strip width (ESW), which is mentioned throughout Table 3.3, is a measure of how far animals are seen from a ship transect line, and therefore how much area is effectively searched (Barlow *et al.*, 2011).

Table 3.3 Species specific discussion of effectiveness of passive marine mammal mitigation

Harbour porpoise	Dolphin sp.	Minke whale	Grey and harbour seals
MMO			
Maximum possible detection ranges are high (sightings of harbour porpoise during the SCANS II surveys were made at distances of 1550 m and greater) yet sighting probabilities are typically low and detection probability drops off quickly as sea state increases (e.g. Palka, 1996, Northridge *et al.* 1995, Laake *et al.* 1997). In the recent Phase II analysis of the Joint Cetacean Protocol (JCP) data resource, only surveys carried out in sea state 2 or less were included as those in higher sea states were considered unreliable (Paxton *et al.* 2011). JCP analysis identified a g(0) for harbour porpoise of 0.43 for small[7] boats, and 0.20 for large boats (Paxton *et al.* 2011), effectively meaning that between a half to 80% of animals are missed depending on the survey vessel. Detection	There are fewer estimates available for dolphin species compared to harbour porpoise, but where they exist, they suggest relatively higher sighting probabilities for dolphin species. The JCP phase II analysis reported a g(0) of 0.8 for small boats and 0.5 for large boats (Paxton *et al*., 2011). Barlow (1995) reported g(0)s of 0.74-0.77 for large and small delphinids respectively for group sizes of 1-20 and a g(0) of 1 for larger groups. A g(0) of 0.93 for common dolphins was estimated by the proportion of sightings by primary observers during a survey of the western approaches of the English	Similarly there are fewer estimates for larger whale species and those that are available suggest sighting probabilities for whale species are generally higher than for porpoises. The JCP phase II analysis reported a g(0) of 0.54, which was derived from SCANS II survey data (Paxton *et al*., 2011). Barlow (1995) reported 0.9-1 for large whales depending on group size and 0.84 for small whales. g(0) derived for minke whales from a survey	Because seals are not traditionally surveyed using boat based surveys, there are very few published estimates of g(0). Gordon (2012) calculated an availability correction for seals based on the proportion of time they spend diving and predicted a g(0) (unadjusted for perception bias) of 0.46 for grey seals. If perception bias correction was included, the detection probability would be even lower. ESW for both seal species from

[7] *Small boats refer to vessels with an observer eye level height < 5 m above sea level, big boats refer to those with an observer eye level height between 5 and 10 m.*

Harbour porpoise	Dolphin sp.	Minke whale	Grey and harbour seals
functions fitted to the data also demonstrated that sighting probability dropped with distance and dropped rapidly beyond about 200 m (Paxton *et al.*, 2011). Other studies have also reported g(0)'s of around 0.33 in surveys from boats in the North Sea typical of those used for MMO mitigation (Gordon, 2012). Effective half strip widths from ship based surveys have been reported at 200 m (Bjorge and Oien, 1995), between 100 m and 400 m depending on sea state (Palka, 1996) and 180 m (Gordon, 2012).	Channel (De Boer *et al.*, 2008). ESW's for dolphin species have been reported as 250m for common dolphins (De Boer *et al.*, 2008).	Oien (1990) in Norwegian waters was 0.56. ESW for minke whales in Greenland was 216m, but this was based on a small number of sightings (Heide-Jorgensen *et al.*, 2007).	the same survey was 215 m.
PAM			
Porpoise echolocation click trains are high frequency and narrowband (centred around 130 kHz). Although porpoise signals are distinctive and easy to detect and classify, detection ranges are comparatively short, at a few hundred metres, due to the high frequency nature of porpoise vocalisations and the rapid attenuation of high frequency noise in sea water. Based upon theoretical considerations, harbour porpoise clicks should be detectable out to approximately 800 m. However results from SCANS II suggested that porpoises can be reliably detected to a range of 200-300 m (SCANS II, 2008) and recent work using a quieter boat in the North Sea at proposed offshore wind farm sites have reported reliable detection ranges of around 400 m (Gordon, 2012). Detection probabilities are not often quantified during acoustic surveys but Gordon, (2012) calculated an acoustic g(0) based on the number of matches between visual and acoustic detections during a towed hydrophone survey of 0.45, suggesting that fewer than half of porpoise sightings were also detected acoustically. The proportion of acoustic detections that were also matched with visual sightings was lower at 0.33. It is important to note that these probabilities do not rely on perfect detection by either method, but are simply a reflection of the number of matches between the two methods (from a number of trials where matches would be expected).	Detection ranges for dolphin species are higher than for harbour porpoises and studies with static acoustic logging devices such as TPODs and CPODs have shown that detection range for dolphins are approximately 1 km (Philpott *et al.*, 2007, Elliott *et al.*, 2012) but detection probability decreases with increasing distance, Elliot *et al.* (2012) demonstrated that detection rates decreased with increasing distance from the device and that within 500 m, 47% of all groups sighted, were detected acoustically.	Minke whales do not reliably vocalise and therefore PAM is not a suitable method for detection for this species.	Seals do not reliably vocalise and therefore PAM is not a suitable method for detection for this species.

Harbour porpoise	Dolphin sp.	Minke whale	Grey and harbour seals
Tougaard *et al*. (2005) reported a detection probability of 81% within 100 m of a TPOD and 31% between 100 and 200 m.			

3.2.3 Summary

While the use of MMOs and PAMs may not be considered by industry to be the most practical and have some limitations, as highlighted above, their use may still be considered to be the most suitable by the SNCBs for preventing injury to EPS. The most appropriate MMMP for a particular OWF site should therefore be agreed through consultation with SNCBs. Further assessment to quantify the efficacy of MMO and PAM would also be of benefit to inform the selection of the most appropriate MMMP.

3.3 Efficacy of active acoustic marine mammal mitigation

Active mitigation techniques emit a deterrent stimulus aimed at deterring marine mammals from the mitigation zone. The active mitigation techniques that are referenced in the current UK mitigation protocol are soft start and ADD. The efficacy of both is discussed below.

3.3.1 Soft start

There is considerable literature relating to piling noise underwater (e.g. Matuschek and Betke, 2009, De Jong and Ainslie, 2008, Ainslie *et al.*, 2012, Wyatt, 2008, Nedwell *et al.*, 2007, Nehls *et al.*, 2007, Thomsen *et al.*, 2006, Bailey *et al.*, 2010, Nedwell and Howell, 2004, Nedwell *et al.*, 2003, Thomsen *et al.*, 2006). An introduction to piling acoustics, key concepts and terminology is provided in Appendix K. There is however very little available empirical evidence to support the effectiveness of soft starts, other than the 'common sense' assumptions that animals will start to move away at the onset of piling noise. There is some data from seismic survey mitigation to suggest that soft starts during surveys using airgun arrays are effective at reducing impact. Stone (2013 in draft) analysed data from over 9,000 sightings of marine mammals made during mitigation watches and demonstrated that sightings rates were significantly lower for cetaceans during soft starts than when the airguns were not firing and on surveys with large airguns more cetaceans were heading away from the survey vessel during the soft start than at any other time (although these results were limited to only a few species or species groups).

Key points from available data and acoustic modelling carried out to inform this project (see Appendix K and Figures 3.1 to 3.3 for the full modelling output and discussion) for different piling scenarios using various different criteria[8] derived from Southall *et al.* (2007) and Lucke *et al.* (2008) are as follows:

- The effectiveness of soft start is dependent upon many factors, not least the pile size, hammer blow energy, substrate, pile penetration, water depth (and for ADD, target species) etc.;
- The ramp up of energy required for engineering reasons is for a shorter period of time, and sometimes uses a higher initial hammer blow energy, than the "soft start" protocol required to reduce risk of injury to marine mammals;
- The relationship between the distance a mammal can swim during the soft start and the size of the injury zone with no soft start governs the efficacy of the soft start procedures;
- For certain pile diameters the initial hammer blow of a soft start may be sufficient to inflict PTS, highlighting the need for additional mitigation such as ADD deployment prior to soft start in some scenarios (see Section 3.3.2 below); and
- Soft start should ideally be tailored to ensure that all animals can swim twice the distance of the injury zone during the soft start time in order to gain significant reductions in the potential for injury, but excessive precaution beyond that (i.e. much longer soft starts) will yield negligible gains in terms of reducing the potential area over which injury may occur[9].

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[8] *The issue of which injury thresholds are most appropriate is constantly changing depending on on-going research and analysis. It is beyond the scope of this report to advise which criteria should be adopted or are most robust and therefore the various scenarios have been assessed using a range of current criteria, in order to understand how the adoption of different criteria could affect the findings of this study. These range from the Southall et al. (2007) criteria for onset of PTS in cetaceans and pinnipeds using un-weighted instantaneous peak pressure level and cumulative M-weighted sound exposure level (SEL) to criteria derived from the Lucke et al. (2008) values for onset of TTS using instantaneous un-weighted peak pressure level and cumulative (derived M-weighted SEL).*

[9] *This conclusion was reached based on the results of the acoustic modelling, as described in Appendix K, which showed that the efficacy of soft start procedures depends on the size of the potential injury range and that a marine mammal needs to travel at least twice the distance of the predicted injury range in order for soft start to be*

JNCC guidelines suggest that a soft start time of 20 minutes will be effective for a potential injury zone radius of up to 1 km. This is sufficient for smaller piles[10] (which require a lower hammer energy to drive them), assuming that the Southall *et al*. (2007) criteria are robust enough to protect all marine mammals from injury. However, for much larger[11] pile sizes/hammer energies and lower injury criteria (e.g. if the Lucke *et al*. (2008) criteria for harbour porpoise were adopted) a longer soft start time could be required.

Note that given the information available at the time of writing this review, there was insufficient evidence to inform whether there is potential for ADD to replace soft starts.

3.3.2 ADDs

The latest information on the status and effectiveness of all available ADDs (and other deterrent devices) for the priority species of concern for offshore wind developments in UK waters is presented in Appendix L and summarised in Table 3.4 below.

> All references to disturbance in this report (unless clearly mentioned otherwise) apply to disturbance in association with the use of ADD. The impacts of piling should be considered on a case by case basis during consent. ADD would be turned off once piling commences therefore potential impacts would be secondary to the potential impacts of piling.

Key points:

- ADDs would be operated before piling starts and turned off once the piling soft start commences;
- The noise level and potential zone of disturbance due to ADDs is unlikely to be as great as the disturbance zone due to piling (particularly for larger piles) so it is not envisaged that there would be any increase in the size of the zone of disturbance (or injury);
- An ADD would have to evoke a response of at least a Response Score 6 or 7 in order to be effective in reducing the likelihood of injury for any mammal within the potential injury zone[12]. This is higher than the Response Score of 5 benchmarked as being potentially significant by JNCC; and
- For some piling scenarios or species it may be necessary to deploy multiple ADD devices over a wider area in order to adequately cover the potential PTS zone. Considering the large number of vessels involved in an OWF construction programme (e.g. piling vessels, multiple support vessels), deploying several ADDs across a number of locations is likely to be a workable solution.

The EPS guidance (JNCC, 2010a in prep) indicates that a score of 5 or more on the Southall *et al.* (2007) behavioural response severity scale could be significant (see Table K.2 in Appendix K – severity scale definitions). The more severe the response on the scale, the lower the amount of time that the animals will tolerate it before there could be significant negative effects on life functions, which would constitute a disturbance under the relevant regulations.

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most effective, but increasing/decreasing the injury zone above or below that point doesn't markedly affect the reduction in size of the zone.

[10] *The size of pile for which a 20 minute soft start would be sufficient will depend upon several factors including the hammer energy, injury criteria, assumed mammal swim speed and site specific factors such as bathymetry and sound speed profile.*

[11] *It is beyond the scope of this project to provide a definitive cut-off point beyond which standard JNCC mitigation would no longer be effective. As stated in the text, the effectiveness of soft start procedures will depend upon the size of the injury zone which is itself dependent on numerous factors. The effectiveness or otherwise of mitigation measures should be assessed on a site specific basis as part of the impact assessment.*

[12] *This is because a response score of 6 is the lowest score which includes a fleeing response. If the response score was less than 6 the animal would not flee and therefore the ADD would be ineffective at causing the animal to vacate the injury zone.*

- It would clearly be desirable to minimise the extent of any disturbance introduced as a result of using ADDs and it is therefore recommended that further research be conducted to help understand the levels of sound from ADDs that are required to evoke a flee response and to use this data to fine tune ADD acoustic outputs to strike the right balance between preventing injury and disturbance (see Section 5 for a detailed discussion on the Project 1 recommendations);
- It is important to understand that exposure to sound levels in excess of a given behavioural change threshold do not necessarily imply that the sound will result in significant disturbance as defined in legislation; and
- It is also necessary to understand the likelihood that the mammals will be exposed to that sound and whether the numbers exposed are likely to be significant at the population level. The mammal density in the area as well as the size of the zone over which marine mammals need to be displaced, over and above that expected from the piling, are therefore important considerations. However, the findings of the present review suggest that ADD displacement/disturbance is likely to be considerably less than that associated with piling (Section 3.4.2).

Given that ADD use is likely to be relatively short term and unlikely to add significantly to the overall duration of emitted noise during OWF construction, it is unlikely that ADD use in OWF mitigation will increase the proportion of days in which noise levels exceed any thresholds defined under the Marine Strategy Framework Directive (MSFD) for impulsive sound.

ADD Soft Start

The residence times would need to be relatively high for ADDs at current source levels to produce injury therefore a requirement for an ADD soft start or pre-deployment watch is not thought to be necessary to prevent injury provided animals will move away once they are activated (see Table K.3 presented in Appendix K for further information). For devices which were not included in Table K.3, and if source levels are increased in future, a site and device specific assessment should be made to ensure that there is minimal risk of auditory injury from the ADDs themselves. Some devices (e.g. Genuswave, Sea Life Guard) have the capacity to be ramped up to provide a soft start.

3.3.3 Species specific discussion of effectiveness of active MMM

Injury due to sound can occur due to instantaneous exposure to high sound pressure levels or due to cumulative sound energy received over time due to multiple events. For offshore piling, it is important to sum up the acoustic energy that a mammal is exposed to due to the multiple hammer strikes used to drive the pile.

The results of the acoustic modelling are presented in Figures 3.1 to 3.3 which show the predicted PTS range for different piling scenarios[13] using various different criteria, derived from Southall *et al*. (2007) and Lucke *et al*. (2008).

The red lines on the graph represent the maximum start range within which a marine mammal could be injured assuming that it starts swimming away from the noise source immediately upon hearing the onset of piling. For the areas inside this zone, if the marine mammal swims away from the pile at the stated swim speed then it may not have time to vacate the area before is exposed to sufficient cumulative sound energy to cause injury.

The different shades of green represent what is considered the minimum and maximum range of effectiveness of ADDs, the hatched area represents the theoretical 500 m MMO range (i.e. the mitigation zone suggested by current MMMP (JNCC, 2010b)).

[13] *In the case of soft start, it was assumed that the each pulse SEL will initially be attenuated by 10 dB re 1 μPa2s and will increase over a period of 20 minutes during the soft start procedures until reaching the full blow energy. The "no soft start" scenario was modelled by assuming a 3 dB reduction in the first few blows with energy increasing to full over a five minute period. The "no soft-start" scenario can therefore be considered to be the same as an engineering soft-start.*

It should be borne in mind that the ranges for exceeding the various injury criteria have been rounded for ease of reading and to reflect the potential for errors and variability in the predictions. Because piles are a large, distributed, sound source it is difficult to predict likely noise levels very close to the pile and very small injury ranges (of less than a few tens of metres) may well be an over-prediction.

The results of the modelling show that the efficacy of soft start procedures depends on the size of the potential injury range. This is because soft start procedures rely on a mammal swimming away from the source of noise at the onset of piling. Depending on the assumed swim speed and direction, a mammal will be able to swim a discrete distance within the soft start time. Assuming a mammal can swim at an average speed of 1.5 m/s away from the pile, the distance covered during the 20 minute soft start period would be 1.8 km. If the injury zone (i.e. the zone within which the mammal could be injured if it starts swimming as soon as it hears commencement of piling) is much smaller than the potential swim distance, then the mammal has plenty of time to swim outside of the injury zone before the end of the soft start. However, if the potential injury zone is much larger than the distance it can travel, then the soft start will be much less effective. The acoustic modelling showed that a marine mammal needs to travel at least twice the distance of the predicted injury range in order for soft start to be most effective, but increasing/decreasing the injury zone above or below that point doesn't markedly affect the reduction in size of the zone.

It should also be noted that impact range is not a hard and fast 'line' which has impact on one side and no impact on the other – impact is more probabilistic than that, dose dependency in PTS onset, individual variations and uncertainties regarding behavioural response and swim speed/direction all mean that in reality it is much more complex than drawing a contour around a piling location. These diagrams are therefore simplistic representations of 'potential impact range' designed to provide an understandable way in which a wider audience can appreciate the complexities and thus inform their decision making.

The assumption used in the modelling is that, upon hearing the onset of piling activity, the mammal would move away from the sound source, hence the first pulse would provide the highest 'dose' of sound, with each subsequent pulse contributing less to their exposure as they move away from the source.

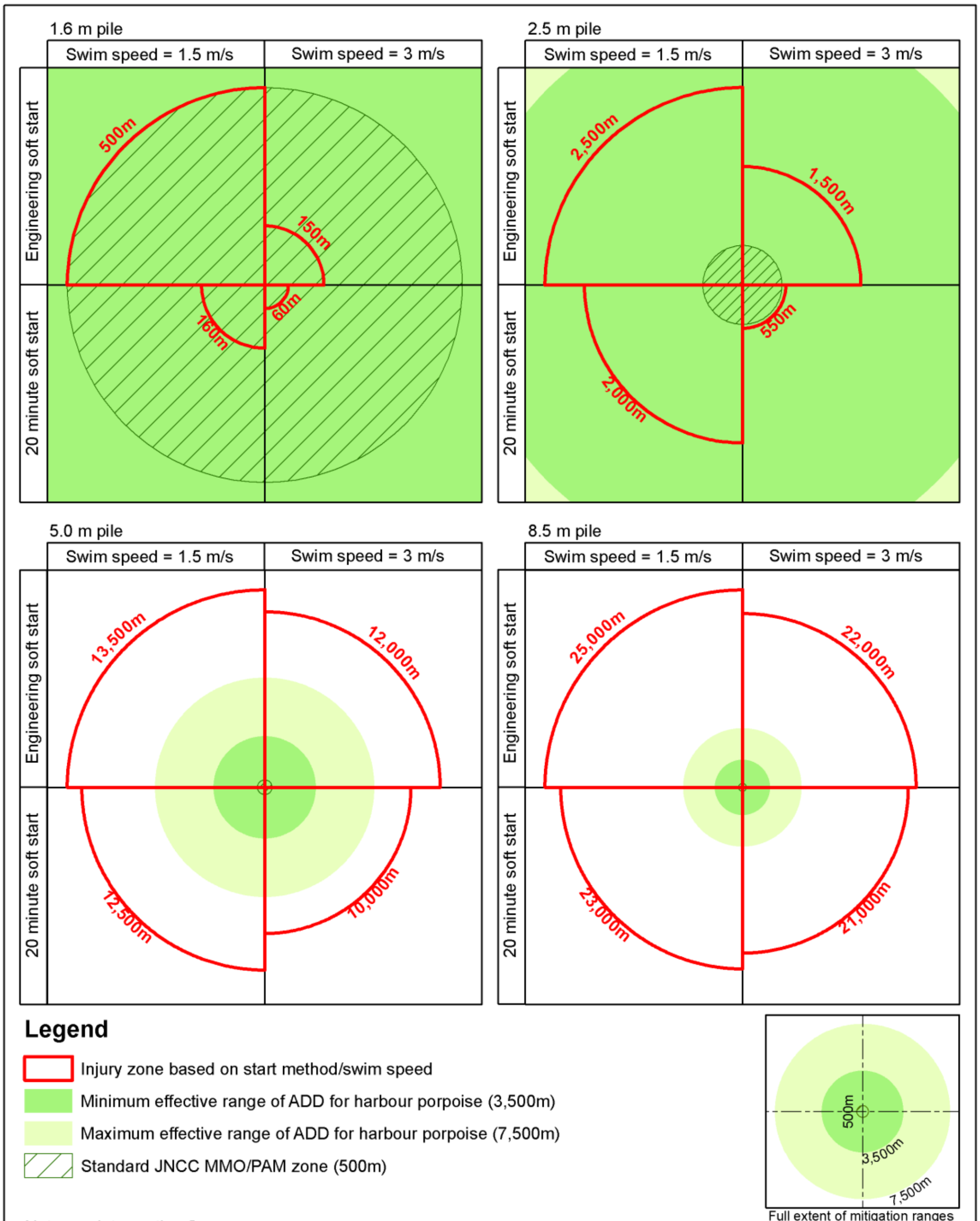
It must be noted that behavioural response data to pile driving noise for marine mammals is generally lacking. However, data from acoustic monitoring studies around piling sites suggest that harbour porpoise will move away from the source of piling to approximately 20 km (Brandt *et al.*, 2011, Dähne *et al.*, 2013). There are even fewer data for seal species and other cetacean species. However, some inferences can be made to responses to other pulsed sounds by harbour seals and other seal species (Thompson *et al.*, 1998, Gordon *et al.* 2004). These suggest that the assumptions about behavioural responses in the modelling are generally valid; at high sound levels, the majority of animals are likely to exhibit behavioural responses (by moving rapidly away from the source) to pile driving sounds and that the proportion of animals responding will decrease as a function of received noise level.

Given the general paucity of data on the behavioural responses by marine mammals to piling noise; therefore it is not surprising that swim speeds in response to sound have not generally been reported. However, there are a number of studies that have provided details of swim speeds by pinnipeds. Although complicated by the fact that different metrics are often used between studies (e.g. daily travel rate vs. instantaneous swimming speed), they do provide a basis for making estimates of the rate at which seals may efficiently swim away from a noise source. Available studies on swim speeds by harbour and grey seals suggest that these species primarily swim at approximately 1 - 1.4 ms^{-1} which appears to match the most efficient speeds measured during energetic studies (Davis *et al.*, 1985; Hind and Gurney, 1997; Gallon *et al.* 2007, Thompson and Freda, 1993). Given that seals are likely to be exhibiting rapid avoidance behaviour (e.g. Thompson *et al.* 1998) to the noise, a swim speed value towards the upper end of those reported may be most appropriate; therefore, a value around 1.5 ms^{-1} is estimated as a sustainable fleeing speed to be used here.

There are fewer data available on the swim speeds of harbour porpoises. Otani *et al.* (2002) reported a tagged harbour porpoise swimming at speeds up to 4.3ms^{-1} with distance covered per day of 53 km which equates to a long term travel rate over a day of 0.6 ms^{-1} which is consistent with the values reported by Westgate *et al.* (1995). Otani *et al.* (2002) also reported that the minimum cost of transport during underwater swimming was demonstrated at speeds of 1.3 - 1.5 ms^{-1}, therefore a swim speed of 1.5 ms^{-1} is also likely to be appropriate for harbour porpoises. This more conservative swim speed allows some headroom to account for the potential that the marine mammal does not swim directly away from the source, could change direction or does not maintain a fast swim speed over a prolonged period.

It should be noted that the acoustic modelling and therefore the figures do not include the effect of the effective "extended soft start time" afforded by use of ADDs. In a typical ADD deployment, the ADDs would be started nominally 30 minutes before commencement of the soft start to piling. This effectively extends the soft start time, albeit not over the entire injury zone for some of the larger predicted injury ranges. The figures are meant as an indicative visual method of comparison of the potential injury zones and estimated range of ADD effectiveness.

The acoustic modelling is not intended to represent a site specific assessment but is intended to represent a range of generic cases to demonstrate the hypothetical effectiveness of soft starts, and this should be borne in mind when interpreting the results.



Notes on interpreting figures:
(1) The ranges represented by the red lines are the range outside of which an animal must be at the beginning of the piling sequence to acquire a cumulative noise dose below the injury threshold, assuming a flee response.
(2) The modelling results presented are for generic and hypothetical piling scenarios. Small changes in the source levels used and other modelling assumptions could radically alter these predictions.

Figure 3.1 Estimated radius of injury zones with and without soft-start for different piling scenarios and swim speeds for harbour porpoise using criteria adopted from Lucke *et al.* (2008)

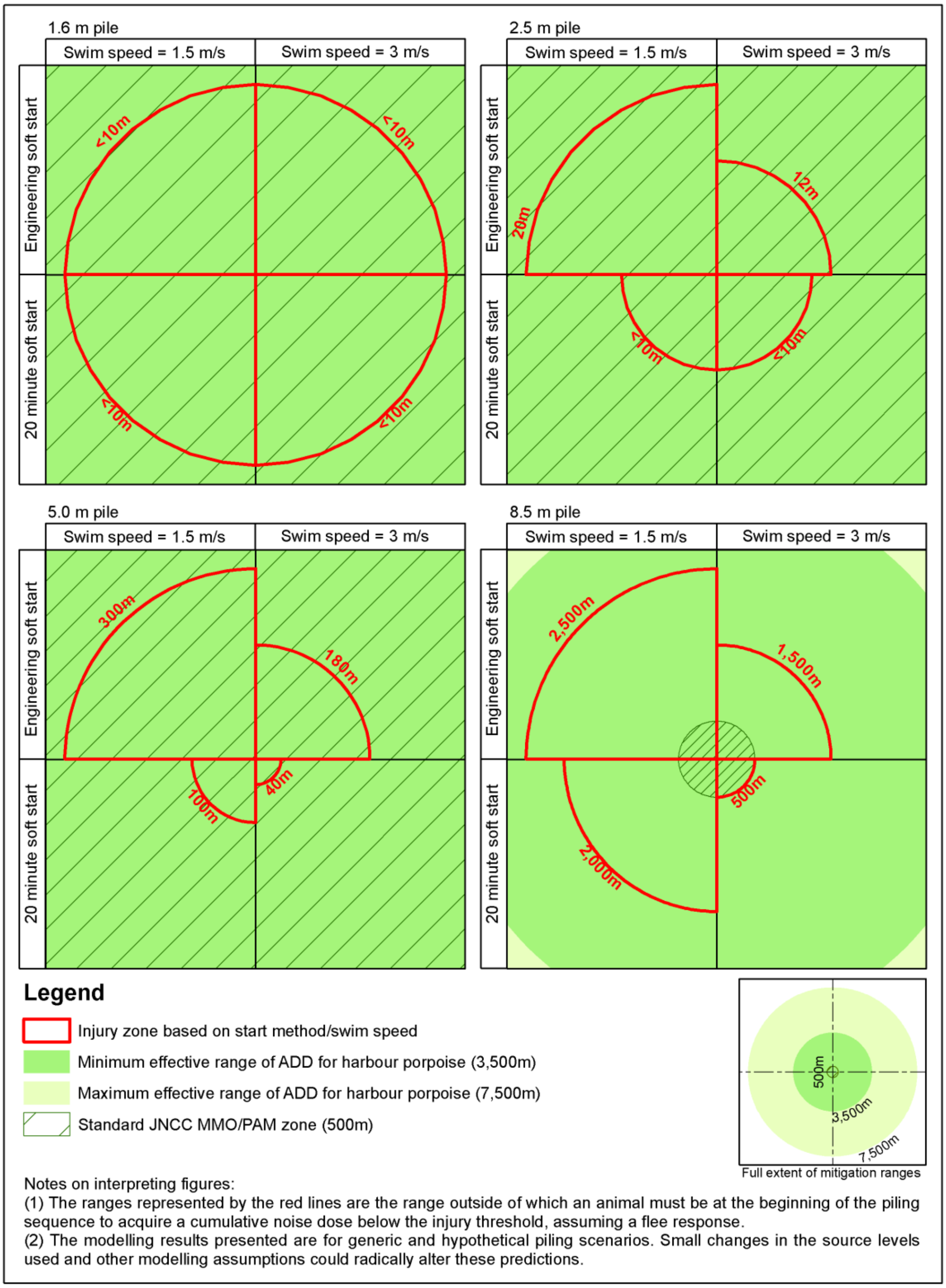
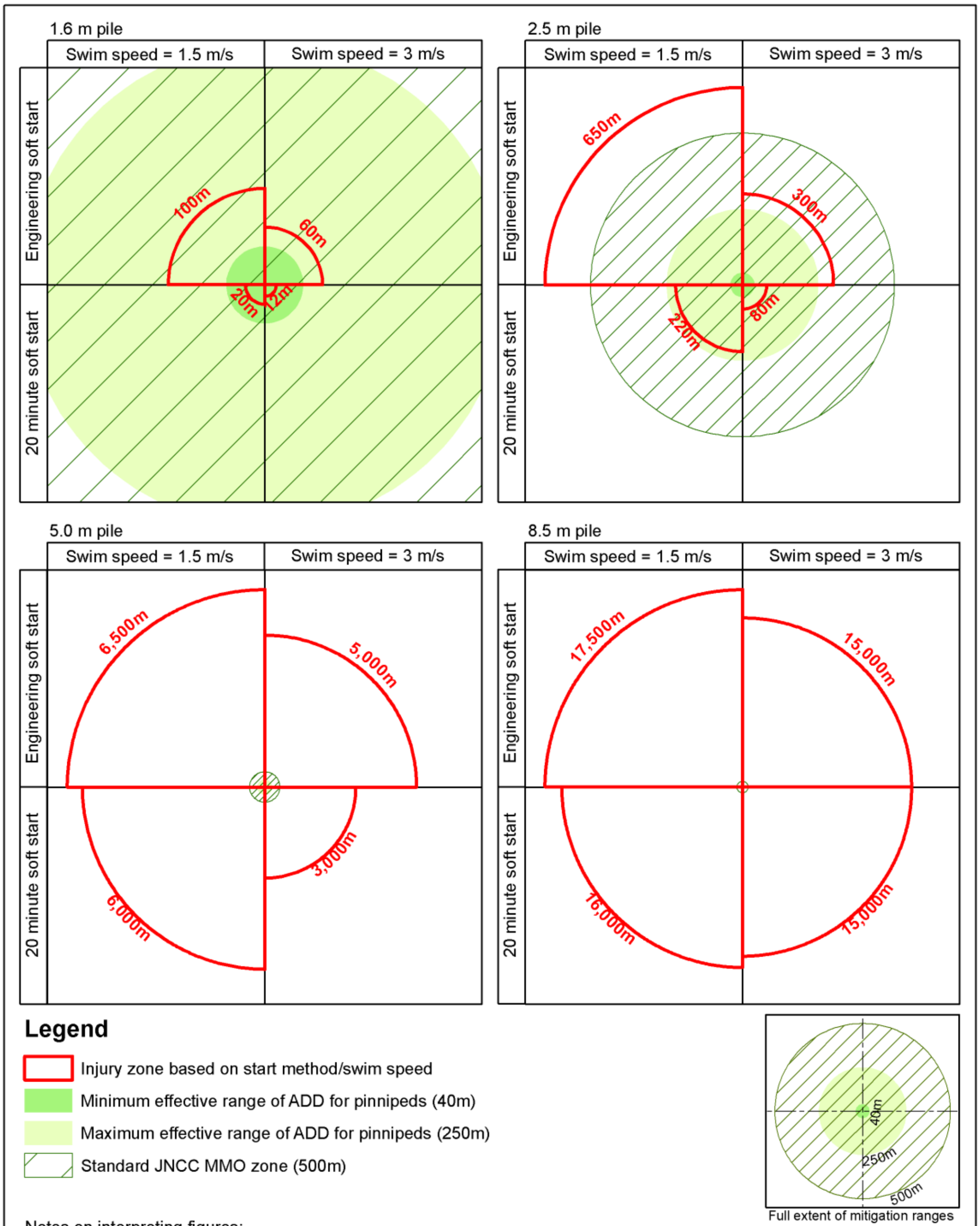


Figure 3.2 Estimated radius of injury zones with and without soft-start for different piling scenarios and swim speeds for harbour porpoise using criteria adopted from Southall *et al.* (2007)



Notes on interpreting figures:
(1) The ranges represented by the red lines are the range outside of which an animal must be at the beginning of the piling sequence to acquire a cumulative noise dose below the injury threshold, assuming a flee response.
(2) The modelling results presented are for generic and hypothetical piling scenarios. Small changes in the source levels used and other modelling assumptions could radically alter these predictions.

Figure 3.3 Estimated radius of injury zones with and without soft-start for different piling scenarios and swim speeds for Pinnipeds using criteria adopted from Southall *et al.* (2007)

The noise modelling results in the preceding diagrams shows that under some circumstances (e.g. where seals are present or for harbour porpoise if the Lucke criteria are adopted) there are unlikely to be workable solutions using a single ADD for larger pile sizes. However, if the Southall criteria for harbour porpoise are considered to be robust, a single ADD would be sufficient (and more than sufficient in the case of smaller piles).

> Based on the noise modelling results, it is concluded that it is not possible at this time to recommend a "one size fits all" mitigation protocol. Consequently, one of the primary recommendations is that a site specific, risk based approach is adopted for marine mammal mitigation. It should be noted that for some sites and species, ADDs may not provide a solution unless multiple ADD devices can be deployed over a wide area.

3.3.4 Technology readiness - ADD development

There is, unfortunately, no single simple definition of what makes an ideal ADD for use in the OWF sector. This review has therefore been focused on the empirical evidence base for effectiveness and calculations for each device. During this process it has been found that 'effectiveness' cannot be related to a simple threshold of output. ADD differ in many other respects (frequency, pattern of sound production etc), as discussed further in this section and Appendix L.

Over the last two decades, a variety of acoustic devices have been designed for aquaculture and capture fisheries (reducing by-catch or reducing depredation) and reviewed for their effectiveness in various settings (see Gordon *et al*., 2007; Dawson *et al*., 2013; Coram *et al*., 2013); Götz and Janik, in press). In a review commissioned by COWRIE, Gordon *et al.* (2007) and more recently Coram *et al.* (2013), in a Scottish Government funded review (currently in draft), provide a detailed background of the principles of using aversive sounds to deter marine mammals from areas of pile driving to reduce the risk of auditory injury and provide an overview of the types of sounds that might be capable of causing marine mammals to move out of an 'exclusion zone'. In another recent COWRIE study, Nedwell *at al.*, (2010) carried out an assessment of acoustic output of a number of different potential Acoustic Mitigation Devices (AMDs). In addition to this, COWRIE commissioned SEAMARCO in the Netherlands to carry out studies on the audibility of three candidate acoustic deterrent devices and their effects on the behaviour of captive harbour seals and harbour porpoises. The evidence base used to inform the current review built upon the results presented in these studies.

Our initial review identified a total of 34 devices from 22 manufacturers. Many of these devices were 'pingers' or devices designed specifically for reducing by-catch or depredation from nets and generally produce sounds of much lower intensity and have a limited range. Therefore, in combination with the consideration that they have been known to attract seals to a prey source ('dinner bell' effect) they have been excluded from the detailed review. A useful review of such devices is however available in the following Defra funded project:

http://www.marinemanagement.org.uk/fisheries/monitoring/regulations_cetaceans.htm.

Six of the identified ADDs were taken forward in the detailed review presented in Appendix L. The selection criteria for the devices taken forward in this study were based on a number of features:

- Features of the acoustic output have been characterised or described and are in the hearing range of the UK species of interest and have source levels at an intensity which could lead to behavioural responses;
- Data from published studies demonstrate a measurable aversive response to the device in one or more of the UK species of interest; and
- The device is currently commercially available or currently in development for commercial application.

The 'off-the-shelf' devices selected to review were the Airmar, Lofitech, Ace Aquatech and Terecos. Also considered were the Genuswave system currently in development by the University of St Andrews and the Sea Life Guard system currently in development by SEAMARCO (see Appendix L for their acoustic characteristics). Each device was chosen for different reasons – some devices had more evidence available relating to the effectiveness for the priority species (e.g. Lofitech), others offered more flexibility in terms of potentially providing a multispecies solution for use in the OWF industry (Genuswave and Sea Life Guard). Table 3.4 below summarises the available data describing effectiveness of the selected ADDs.

Although all six of these devices could be taken forward to field trials to further assess effectiveness for the UK priority species, there is a limit to the number of devices that can be effectively tested over the timescales required for the UK offshore wind industry (and the associated cost implications), therefore some prioritisation is necessary. The detailed review identified that three of the six devices had the greatest potential to provide a multispecies solution for mitigation at offshore wind farms. Only one of these is currently commercially available (Lofitech), one is expected to become commercially available (Genuswave) and the Sea Life Guard device is likely to need further development before it can be considered appropriate for this application. We therefore recommend that the Lofitech and Genuswave devices are prioritised for further field research.

Table 3.4 Summary of available data describing effectiveness of the selected ADDs

Device details	Harbour porpoise	Harbour seal	Grey seal	Bottlenose dolphin (& other dolphin species)	Minke whale
Airmar dB plus II – a multi-transducer array which emits brief pulses which are 1.4 ms long at 40 ms intervals in 2.25 s long trains. Various field measurements of source level suggest it ranges between 179 to 192 dB re 1 µPa @ 1 m (rms) (Jacobs and Terhune, 2002, Lepper *et al.,* 2004, Brandt *et al*., 2012) with peak pressure of 204 dB re 1 µPa @ 1 m. There have been numerous field and captive trials on seals and harbour porpoise to date in varying water depths. Habituation in seals varied depending on setting, most notably in the presence of food motivation. No habituation was evident in the field trials (tested by the relationship between playback number and the count of seals). These devices are used widely (35%) in the Scottish aquaculture industry, Northridge *et al.* (2010), suggesting a degree of habituation may be expected in these seal populations. Harbour porpoises studies reported striking deterrence results Johnston (2002) and Olesiuk *et al.* (2002) both reported striking results in deterrence of harbour porpoises around devices. The dramatic effect of the Airmar device on porpoises is likely because of the sensitivity of odontocetes is higher at the peak frequency of the device (at 10 kHz odontocete hearing is 15–20 dB more sensitive than pinniped hearing). Similar studies on the west coast of Scotland exhibited habituation by porpoise possibly due to the high use of Airmar at fish farm sites throughout their home range. Morton (1997) reported a reduction in the number of sightings of humpback, grey and minke whales in the Broughton Archipelago over the period when salmon farms in the area were using Airmar ADD devices followed by a substantial recovery in sighting rates after ADD use was stopped. Observations from the Isle of Lewis in Scotland suggest that a “resident” minke whale could detect an operating Airmar but did not change its behaviour in any way that could be considered a cause for concern (Fairbairns et al., 1994; Gordon and Northridge, 2002).					
Efficacy & range	> Yes - Effective to 3.5 km (Olesiuk *et al.,* 2012).	> No observable response (Jacobs and Terhune, 2002); and > Deterrence to 50 m (Yurk and Trites, 2000).	> Anecdotally initially effective at reducing predation (see below); and > Avoidance responses shown down to RL of ~144 dB re 1 µPa (low sample size).	> No information.	> Limited evidence in grey literature (see above).
Potential for Habituation	> Olesiuk (2002) found no evidence for habituation but only over 3 weeks.	> Mate and Harvey (1986) found seals swimming with head above the water - possible behavioural adaptation; > The lack of response found by Jacobs and Terhune (2002) was hypothesised to be as a result of habituation; > Rapid habituation (after a few exposures) shown at received levels of 146 dB re 1 µPa (Götz & Janik	> Many authors describe, usually anecdotally, the habituation at aquaculture installations (Shaughnessy 1996, Schotte and Pemberton 2002, Mate and Harvey 1986, Iwama *et al.,* 1997); > Aquaculture managers have also reported reduced effectiveness over time in surveys (Northridge *et al.,* 2010); and > Rapid habituation (after a few exposures) shown at received levels of 146 dB re 1 µPa (Götz & Janik (2010).	> No information.	> No information.

Device details	Harbour porpoise	Harbour seal	Grey seal	Bottlenose dolphin (& other dolphin species)	Minke whale
		(2010); > In areas where they are used in aquaculture, seals may be attracted to this ADD (Rudin, 2013).			
Lofitech - a high output seal scarer which comprises a transducer connected to a separate control unit via a 25 m long cable. The unit emits 500 ms long pulses in variable length blocks containing a random number of pulses. The minimum pulse interval within blocks is approx. 0.5 s and consecutive blocks are separated by 20-60 s intervals (Gotz and Janik, in press). The signal is comprised of a number of very narrow band emissions with a peak at about 15 kHz. Field studies to test effectiveness in deterring harbour porpoise from around piling areas (Brandt *et al*., 2012 and Brandt *et al*., 2013). Effective deterrence was achieved over long ranges during the North Sea trials (detection rates: zero close to the device, 86% lower than baseline at 750 m, and 96% lower at 7500 m). Lack of clear evidence of a reduction in the exclusion effect with range suggests that 7500 m should not be considered the maximum effective range. Detection rates 9 and 12 hours after the trial they were no longer significantly reduced. Various field and captive trials with seals have also proved successful (Graham *et al*., 2009, Harris, 2011, D. Thompson, SMRU personal communication, Götz and Janik, 2010, Kastelein *et al*., 2010). Results were similar to the Ace-Aquatech in that although captive seals initially responded, subjects habituated in the presence of food motivation. In the field the deterrence range was approximately 60 m, although the sample size from field trials was small. As part of a recent Marine Scotland funded project, trials measuring the behavioural responses of harbour seals to the Lofitech seal scarer were carried in Kyle Rhea in June 2013 (personal communication, Dave Thompson (SMRU)). Seals were followed when they moved out of the narrows into open water in the Sound of Sleat or into Loch Alsh. A total of 20 individual trials were performed using both the ADD and killer whale vocalisations. Preliminary observations suggest avoidance responses to the ADD but these remain to be fully analysed.					
Efficacy & range	> Yes - Effective to 7.5 km (Brandt et al. 2012a, 2013).	> Anecdotal from recent preliminary observation from SMRU field trials (personal communication, D. Thompson); and > Responses demonstrated in captive harbour seals although range not determined (Götz & Janik, 2010).	> Fjalling *et al.* (2006) reported reduced predation at fish traps; > Gotz (2010) reported deterrence up to 60m using synthesised signal (Same SPL would be found at 140 m normally); > Harris (2011) reduced number of seals upriver of device; and > Some animals showed avoidance responses down to RL of ~140 dB re 1 μPa (Götz & Janik, 2010).	> No information.	> No information.
Potential for Habituation	> No but trials only over 3 months	> Yes, rapid habituation (after a few exposures) shown at received levels	> No – but trial short NESFC (2008); > Yes – although effective throughout and	> No information.	> No information.

<table>
<tr><th>Device details</th><th>Harbour porpoise</th><th>Harbour seal</th><th>Grey seal</th><th>Bottlenose dolphin (& other dolphin species)</th><th>Minke whale</th></tr>
<tr><td></td><td>(Brandt et al., 2012a, 2013).</td><td>of 146 dB re 1 μPa (Götz & Janik, 2010).</td><td>between seasons, over the season % damaged fish increased in AHD traps (Fjalling et al. 2006);
> Harris (2011) found a small number of seals resilient to the Lofitech ADD in river fisheries; and
> Yes, rapid habituation at received levels of 146 dB re 1μ Pa (Götz & Janik, 2010).</td><td></td><td></td></tr>
<tr><td colspan="6">Ace Aquatech Seal Scrammer - marketed as an ‘offshore’ mitigation device to “push marine mammals to a safe distance in preparation for loud underwater operations such as pile driving”. It can be deployed at greater depths than the standard 'aquaculture' model; has more randomised or controlled sound varieties; and manual controls over frequencies, volume and spacing, with AC mains or DC battery operation. The transducer can be operated from a surface control box or by using an optional sonar trigger. It can also be programmed to emit noise on a timed basis and can emit a 5 second burst of noise between 6 and 72 times per hour. Manufacture source level, 194 dB re 1 μPa @ 1 m (unknown whether rms, pk or pk-pk), Lepper et al. (2004) 193 dB re 1 μPa @ 1 m (rms) and Nedwell et al. (2010) 184 dB re 1 μPa @ 1 m (rms). Nedwell et al. (2010) characterised that one complete cycle of transmission lasts approximately 5 seconds with the signal being composed of many short individual pulses each lasting around 0.01s. These pulses vary in both amplitude and frequency throughout the duration of the signal. Gotz and Janik (in press) report that the pulses are centred at 28 different frequencies, arranged in 64 random sequences. Field research by the manufacturers claim high success rates at deterring seals (Ace-Hopkins, 2002a; Ace-Hopkins, 2002b; Ace-Hopkins, 2002c; Ace-Hopkins, 2004; Ace-Hopkins, 2006) and whilst these demonstrate that useful data can be collected with industry collaboration, ideally research should be conducted and reported by independent researchers. In captive trials grey and harbour seals also found to initially respond then habituate rapidly in the presence of food motivation (Götz and Janik, 2010). In the field the deterrence range was approximately 60 m, although deterrence was not complete, with 50% of animals remaining within 60m. Kastelein et al. (2010) found that harbour porpoises swam significantly faster, showed more leaping behaviour and had a greater mean distance from the device at higher broadcast levels. Seals hauled out more and spent more time with their heads above water as sound source as levels increased. Based on the sound levels that caused behavioural effects, Kastelein et al. (2010) concluded that the Aquatech would be likely to deter porpoises at ranges between 0.2 and 1.2 km. For seals it should be effective at ranges of between 0.2 and 4.1 km. There is no information available on the potential deterrence performance of the Ace-Aquatec on any other species of marine mammal. Nedwell et al. (2010) calculated the pk-pk and rms dB_{ht} values at various ranges from an operating device and for harbour porpoises the dB_{ht} (rms) ranged from 120 dB_{ht} at 1 m to 108 dB_{ht} at 80 m. This suggests that according to the classification of dB_{ht} scale by Nedwell et al. (2007), where values of 90 dB_{ht} and over may indicate the potential for strong avoidance, deterrence might be expected beyond this range. For harbour seals the equivalent value at 80 m was 91 dB_{ht} suggesting that harbour seal deterrence might be expected out to this range. It is important to note that these are theoretical ranges and the dB_{ht} metric as a predictor of behavioural response is yet to be fully validated in any marine mammal species. Although an analysis presented in Thompson et al. (2013), using data from Brandt et al. (2011) suggests that the pattern of changes in reduced detection rates with distance from a pile driving operation was in reasonable agreement with expectation from predicted avoidance using the dB_{ht} scale (i.e. at levels of 90 dB_{ht} and above, the reduction in acoustic detections was over 80%).</td></tr>
</table>

Device details	Harbour porpoise	Harbour seal	Grey seal	Bottlenose dolphin (& other dolphin species)	Minke whale
Efficacy & range	> No information.	> Responses demonstrated in captive harbour seals although range not determined (Götz & Janik, 2010).	> ~ 50% of animals showed avoidance responses shown down to RL of ~138-140 dB re 1µPa (low sample size); several animals remained within 40 m of device (RL>144 dB re 1 µPa).	> No information.	> No information.
Potential for Habituation	> No information.	> Rapid habituation shown at received levels of 146 dB re 1 µPa (Götz & Janik, 2010).	> Rapid habituation shown at received levels of 146 dB re 1 µPa (Götz & Janik, 2010).	> No information.	> No information.
Terecos – a device that emits four different programs of different sequences of continuous and time variant tonal blocks, which are periodically changed by the manufacturers in order to reduce the likelihood of habituation (Coram *et al*., 2013). One of the least powerful devices used routinely (42%) at Scottish aquaculture sites (Northridge *et al*., 2010). Less reliable source level, with reports ranging from 178 to 184 dB re 1 µPa @ 1 m (Olesiuk *et al*., 2010, Lepper *et al*., 2004). Tested by Gotz and Janik (2010) in field and captive trials, with no detected deterrence effect on seals around a haul out site. In captive trials, there was an aversive response but again the response rapidly diminished in the presence of food (Gotz and Janik, 2010). During field tests on porpoise at a fish farm in Scotland, POD detection rates were found to be reduced at the four closest sites, which were all within 1000 m. The lower acoustic power output than the Airmar dB Plus II (Lepper *et al*., 2004; Gotz and Janik, in press) may be the reason for the difference in response between the devices on harbour porpoises.					
Efficacy & range	> Northridge et al. (2010) suggested possible reduction in acoustic behaviour up to around 1 km.	> Responses demonstrated in captive harbour seals although range not determined (Götz & Janik, 2010).	> No deterrence range found but low sample size (Götz & Janik, 2010).	> No information.	> No information.
Potential for Habituation	> No information.	> Rapid habituation shown at received levels of 146 dB re 1 µPa (Götz & Janik, 2010).	> Rapid habituation shown at received levels of 146 dB re 1 µPa (Götz & Janik, 2010).	> No information.	> No information.
Genuswave – device is currently in development under patent. It comprises a control unit, a power source, amplifier and transducer. The device has been designed to elicit acoustic startle response (ASR), a well-known reflex arc in terrestrial mammals. For the signal to be effective, the stimulus has to reach a 'startle threshold' amplitude in the first 12 ms regardless of the eventual intensity of the stimulus. Most importantly the likelihood of eliciting the startle response depends only on a few simple factors like rise-time, bandwidth, intensity and duration. Whether or not animals that are startled actually leave the area thus does not depend on the level of arousal in the animal and on whether or not the sound is perceived as a					

Device details	Harbour porpoise	Harbour seal	Grey seal	Bottlenose dolphin (& other dolphin species)	Minke whale
threat, but on a factor that is independent of these other parameters. Repeated exposure to the signal reinforces the acoustic startle response reflex therefore increasing aversive responses in the mammals over time (Gotz and Janik, 2011). This device uses startle stimuli specifically designed for marine mammals and its effectiveness on both harbour and grey seals has been demonstrated in several captive and field trials over ranges of 60-250 m (Götz, 2008; Götz & Janik, 2011) and the long term effectiveness has been demonstrated during trials lasting over a year at a fish farm (Götz, personal communication). Current version not designed to affect harbour porpoises (Scottish Government work) however it is possible to modify the signal to produce sounds which will elicit startle responses in other species and this is part of the commercial development currently taking place. Proven understanding of the underlying mechanisms responsible for the aversive response enables the signal to be modified to work for a range of species. Habituation is unlikely as sensitisation to the signal will increase the flee responsiveness of individuals on repeated exposure.					
Efficacy & range	> At frequency tested, shown to not affect porpoises (Gotz, 2008), same theory could be applied to cause porpoise specific startle response but as yet untested.	> Yes – fish farm trials up to 250 m from loudspeaker (Götz, 2008); > Visual observations at haul out (60-70 m); avoidance responses down to RL of 145 dB re 1µPa (Götz, 2008).	> Visual obs. at haul out (60-70 m) (Götz & Janik, 2010).	> Same theory could be applied to dolphins; startle responses and thresholds measured in captive dolphins and a false killer whale but behavioural response in the wild untested. (Thomas Götz, personal communication).	> Gotz (2008) measured closest approach of 1,109 m (direction of travel was towards device). Sample size too small to analyse.
Potential for Habituation	> Sensitisation should lead to increased responsiveness.	> Sensitisation should lead to increased responsiveness (Götz & Janik 2011).	> Sensitisation leads to increased responsiveness (Götz & Janik 2011).	> Sensitisation should lead to increased responsiveness (Götz & Janik 2011).	> Sensitisation should lead to increased responsiveness (Götz & Janik 2011).

3.3.5 Other candidate aversive sounds

In addition to the commercially available devices, other sounds with the potential to be likely candidates for mitigation of pile driving induced auditory injury include those with:

i) Biological significance (e.g. predator vocalisations), and
ii) Those which were "inherently aversive" (Coram *et al*., 2013). Research on what makes sound "pleasant" or "unpleasant" include Zwicker & Fastl (1990), Fletcher & Munson (1933), Borchgrevink (1975) and McDermott and Hauser (2004).

Other candidate aversive sounds tested to date include:

- A series of candidate psychophysical model sounds tested by Gotz and Janik, (2010), in which 'roughness' (or dissonance), perceived as unpleasant by humans, also caused the strongest avoidance responses in seals, suggesting that sensory pleasantness may be the result of auditory processing that is not restricted to humans.
- Kastelein *et al*. (2006) subjected seals to four series of tone pulses together spanning a broad frequency range between 8 and 45 kHz over a 40 trial days. The findings suggested that operating ADDs for only short periods may be more effective and less likely to result in habituation by the seals than operating them continuously. The deterrent effect of these sounds was not tested in the presence of food motivation.
- Kastelein *et al*. (2012) found during captive harbour porpoises exhibited "sudden flinch[14]" responses to low (1-2 kHz) and mid (6-7 kHz) frequency "sweeps". They found that porpoises exhibited such a flinch at similar sound pressure levels for mid frequency signals without harmonics and low frequency signal with harmonics (~35-40 dB re 1 μPa above the detection threshold). Low frequency signals with harmonics elicited a flinch response at higher sound pressure levels (~60 dB re 1 μPa above the detection threshold).
- SEAMARCO has developed a modular multispecies acoustic deterrent system, named the Sea Life Guard. Currently only the fish module has been tested in captivity and in the field but porpoise and seal modules are also in development. Details of the nature of the sound types emitted from these modules is not available and therefore it is difficult to assess the potential effectiveness under field conditions although it is clear that many years of research into the behavioural responses of captive seals and porpoises by Kastelein and colleagues forms the basis for the selection of the sound types.
- Predator sounds to deter marine mammals is sometimes effective but is not advisable as an avenue for deterrence around marine constructions due to the potential for habituation from repeated playbacks. It also poses a threat for the species that habituates, since it would lead to decreased predator avoidance when under an actual threat from the predator. There is also likely to be a degree of geographical variation in response depending on previous exposure to predator threat.

3.3.5.1 Operational risk

During operation of ADDs, consideration must be given to the risk of active devices becoming detached and remaining active. Some devices (e.g. the Lofitech) need to be activated and turned off via a control panel connected to the transducer, others can be remotely controlled for example using a sonar trigger (Ace-Aquatech) or using the GSM network (Genuswave). The fish-farm type devices – high powered ADDs like Airmar, Lofitech - would typically need to be operated from aboard a boat or fixed platform unless an

[14] *While they used the term "startle" in their paper, this is not the same response as the one elicited by the Genuswave device. Kastelein et al. used the term "startle" in a more colloquial sense meaning a sudden response. We therefore refer to these responses here as a sudden flinch instead.*

engineering solution was made so that they could be operated from a self-contained. In this case there would be some potential for loss of the entire system. Unless solar power were used, there would be a finite power supply so the device wouldn't run for more than a few days at most. This kind of system would almost certainly need to be moored somehow, and any failure that resulted in the device drifting free would be likely to separate the transducer from its power supply. Where independent systems are being developed, it would be a sensible precaution to incorporate a suitable GPS enabled transmitter – vhf, satellite or GSM (cellular). If the device were still operating then a directional hydrophone would also allow it to be located and deactivated.

3.3.6 Candidate ADDs

Three ADDs were taken forward as potential devices to further test as part of Project 4. These devices, with the potential to be tested for each species, are the Lofitech, the Genuswave, and if it can be developed for field use within the timeframe required, Kastelein's multispecies porpoise/seal device (additional funding is however likely to be necessary for this).

These candidate devices were selected for a number of reasons based on the available evidence base including: potential across the species, the status of the technology, flexibility for deployment in a range of situations; and the potential for future development.

3.4 Unintended consequences to marine mammals

3.4.1 Habituation

The effects of ADDs may diminish over time: either through classic habituation, development of learned behaviour that avoids the stimulus or reduced response due to hearing damage and reduced sensitivity. This is a common and well documented problem for the use of ADDs in the aquaculture industry. Although habituation is very likely where motivation to be in a particular place may be high, such as for seals around fish farms, it is less clear whether habituation will be a problem when the ADD signal is associated with piling noise, which has been shown to cause sustained and repeated behavioural responses in harbour porpoises (e.g. Brandt *et al.,* 2012b, Dähne *et al.,* 2013) and has been predicted for many other species of marine mammals (e.g. based on the results from seismic air guns reported in Thompson *et al*. (2009).

3.4.2 Additional injury and disturbance

As surmised in Section 2.4, an important impact to consider when using ADDs is that their use involves introducing additional noise into the marine environment. ADDs rely on behavioural disturbance to work. The deployment of ADDs should not, however, be construed as a disturbance offence, as deployment should always be accompanied by an EPS Licence (see Section 2.1 for definition of a disturbance offence in Scotland, English territories and offshore UK and EPS).

The ADDs will be operated before piling starts and turned off once the piling soft start commences. Therefore, use of ADDs will result in potentially disturbing sound occurring for a slightly longer period than soft start piling alone. The noise level and potential zone of disturbance due to ADDs is considered unlikely to be as great as the disturbance zone due to piling (particularly for larger piles) so it is not envisaged that there will be any increase in the size of the zone of disturbance (or injury).

Disturbance is unlikely to be considered as severe an impact as injury as it is a temporary impact, although disturbance is likely to occur over a much wider spatial range than injury. On balance, it is considered that the benefits in terms of reducing the likelihood of injury far outweigh the slight increase in time over which disturbance may occur. However, it would clearly be desirable to minimise the extent of any disturbance introduced as a result of using ADDs and it is therefore recommended that further research be conducted to help understand the levels of sound from ADDs that are required to evoke a flee response (in an individual animal) and to use this data to fine tune ADD acoustic outputs to strike the right balance between preventing injury and disturbance (see Appendix L– Table L.3).

In addition there is a risk that using ADDs may add to the degree of disturbance and displacement from important habitats, however the currently predicted displacement ranges for piling are well beyond the effective ranges of ADD devices. For example, harbour porpoises are suggested to be displaced by at least 20 km during pile driving (e.g. Brandt *et al.*, 2011, Dähne *et al.*, 2013) whereas the reported displacement range for ADDs for harbour porpoises were between 3.5 and 7.5 km for the Airmar and Lofitech respectively, although it must be noted that these limits reflect the monitoring range rather than the effect limits. It is unlikely that the potential for disturbance presented by the ADD deployment will add significantly to the displacement as a result of the pile driving itself, particularly if the ADD deployment is limited to short periods before the onset of piling and during any breaks in piling. For species where there is less empirical information about the potential for displacement during piling (e.g. seal species), the nature of the balance of risk between pile driving induced displacement and ADD use is less certain.

3.5 Impact on offshore construction schedule

Installation vessel costs on an offshore construction project form a substantial element of the capital investment, therefore project developers invest significantly in planning operations to be carried out as effectively and efficiently as possible. Examples of considerations influencing the installation schedule include:

- Foundation type;
- Contracting strategy;
- Metocean conditions;
- Vessel and equipment selection;
- Port Infrastructure and logistics; and
- Consent conditions/site specific constraints.

Schedules developed are highly project specific and may therefore vary considerably between sites and across developers. Consultation highlighted the importance of the following key parameters in considering the impact of mitigation measures on the foundation installation schedule:

1. **Impact on project duration:** Any mitigation activities which cannot be performed in parallel to construction works, or which require better weather conditions than installation activities will have implications on the overall construction schedule adding both direct costs and project risk.
2. **Level of uncertainty introduced into the programme:** Uncertainty impacts projects in a number of ways including; efforts to quantifying risk, contractual negotiations, insurance, and perhaps most critically, can influence project finance costs (i.e. the cost of capital to the project). For capital projects which already carry high risk, any mitigation measures that add additional uncertainty have the potential to add significant cost to the overall development.
3. **Logistics:** Offshore lifts, equipment handling, personnel transfers, and additional offshore vessel operations add cost, H & S risk, and management burden to projects – adding direct cost to construction estimates, and potential additional time if they cannot be carried out in parallel to the main construction activities.

The key findings used to inform the study evidence base were as follows:

- The evidence review has shown to date there were installation delays due to marine mammals in the mitigation zone on only four of the 11 projects for which we have reviewed MMO reports. These delayed 15 out of 656 piling events, with a total delay of 236 minutes. We note that details of delays are not publicly available for all projects. There is insufficient evidence to suggest that experience to date will be reflected in future projects. Limitations include incomplete data on delays to projects to date and limited understanding of the factors driving delay frequency. For example, the low incidence of delays experienced to date may relate to low population densities in the developed areas, MMO/PAM efficacy, increased construction noise and vessel movements in the area prior to the pre-piling search or other as yet unknown factors.

- Soft starts are the only mitigation option that directly increases the installation time for each pile. This is in the order of minutes per pile, and is widely viewed as a manageable addition to construction programmes (based on the general requirement for a soft start of 5-15 minutes for engineering purposes and standard mitigation soft start of 20 to 30 minutes i.e. typically an additional 5-15 minutes). These values are indicative and will vary between sites. ADDs, as an active deterrent, can be used in parallel to construction works and do not add uncertainty (provided they can be deployed without a pre-ADD deployment search), as the start of construction will not depend on evidence of marine mammals leaving the site. From a logistics perspective they can be mobilised with the installation vessel and deployed by existing crew, and provide the most compelling solution from an installation schedule perspective.
- MMOs and PAM are passive approaches to mitigation which introduce significant uncertainty (due to the potential to miss marine mammals within the MZ) and add logistical complexity to a construction programme, particularly when dedicated survey vessels are required.
- Looking forward to future offshore wind developments, measures which provide effective active mitigation i.e. that drive mammals out of injury zone to the required distance and within a specified time, are preferable to passive measures, in terms of their likely effects on construction schedule.

Although the evidence review has shown that to date piling restrictions have not been necessary during poor visibility/outside daylight hours, this may not remain the case for future projects. The possibility of piling restrictions at future OWF sites during limited visibility increases the potential value of effective ADDs (or other active deterrents) as a mitigation option.

The financial value of effective ADDs as a mitigation option which could enable piling operations during poor visibility is highly dependent on the site location and varies due to metocean differences, propensity to fog and seasonal daylight hour variations. However as an indication night time working restrictions and poor visibility could be assumed to increase an overall schedule (and cost) by 30% or more, as operators would need to wait for clear visibility or daylight before starting work on a new pile. This value will increase on future OWFs because of the considerable increase in the number and size of turbines.

3.6 Impact on costs

3.6.1 Overview

The parameters identified in terms of mitigation solution costs were:

- Capital cost;
- Operating costs;
- Impact on overall project costs (i.e. significance in terms of Levelised Cost of Energy, LCOE).

All mitigation costs are capital costs of the offshore wind farm project assessed on a day rate basis. The direct costs of vessels, staff and equipment for all mitigation approaches within the scope addressed in this report will have a negligible effect on LCOE. Therefore this parameter has not been addressed and the analysis is focussed on the cost of mitigation with respect to the foundations installation costs.

3.6.2 Methodology

The cost element of the evidence review sought to understand the indicative cost implications of the various mitigation options, and provide an indication of any potential financial benefit of the options under consideration.

The methodology adopted was as follows:

- Identify the key cost drivers for each mitigation option (i.e. vessel, equipment, people);
- Identify a reasonable range of costs for the items based on recent experience and industry knowledge;
- Validate the costs through interviews and steering group review;
- For the mid-range costs build up a simple estimate for actual mitigation costs per pile (and review the sensitivity to changes in piling rate);
- Present the data as a percentage of pile installation cost; and
- Investigate the financial upside for the mitigation solutions.

3.6.3 Data sources

In order to evaluate the costs associated with the mitigation options without requiring the presentation of commercially sensitive information, a series of assumptions have been made which are presented below. These assumptions have been validated through discussions with industry participants and are indicative of current costs.

The aim has been to establish ballpark, relative costs of the options as a percentage of foundations installation cost rather than absolute exact figures. Actual costs for different sites may vary widely depending on site conditions, installation strategy and market conditions at that time. Therefore we have focussed on establishing the relative costs of the various mitigation options and identifying key cost drivers. The assumptions do not take into account project management, overheads etc., which will not vary between mitigation options.

The various cost variables and drivers are summarised below in Table 3.5.

Table 3.5 Summary of available data describing effectiveness of the selected ADDs

Item	Examples of cost variables/drivers	Cost basis used in analysis
Foundation Installation Cost	> Contracting strategy; > Foundation type; > Project location; and > Construction strategy.	> Installation vessel day rate (i.e. assuming an average piling rate of n piles per day).
Soft start	> Vessel costs; > Duration of soft start; and > Number of soft starts per pile.	> Installation vessel day rate (i.e. additional time added to schedule).
MMO & PAM	> Experience of observer/operator; > Equipment selected; > Observation platform used (survey or installation platform).	> MMO/PAM day rate; > Survey vessel day rate; and > Equipment hire day rate.
ADD	> Device selected; > Number of devices; > Auxiliary equipment required e.g. cables, power, certification for offshore use; and > Training.	> Device purchase price.

The cost assumptions used in the analysis are shown in the Table 3.6 below.

Table 3.6 Summary of cost assumptions used in the analysis

	Day Rates (£/day)		
	low	*mid*	*high*
Foundations Installation Vessel	75,000	150,000	200,000
MMO/PAM Survey Vessel			
Survey vessel incl. fuel and fees	3,000	4,500	6,500
Personnel			
MMO	300	400	450
PAM Operator	350	430	475
Equipment			
PAM equipment hire	250	450	900
High power ADD - Purchase Price	6,000	N/A	10,000

Based on the assumptions on daily cost rates presented in the above tables, the mitigation costs per pile (assuming it takes two days to install a pile) has been calculated as a percentage of the foundation installation vessel cost and the results are presented below Table 3.7. This demonstrates that ADDs deployed by installation vessel crew members are significantly cheaper than all other mitigation options[15]. It should be noted that two days per pile is a conservative estimate based on the installation of a large monopile and should be treated as indicative only. Installation rate for smaller piles and pin piles is likely to be much higher. The manner in which mitigation costs change depending on pile installation rate is explored further on the following page and in Table 3.8.

The relative increased cost of a soft start if the installation vessel is subject to restrictions which lead to non-productive time reflects the shorter working window available. The percentage cost ranges presented are a result of the difference in installation vessels cost (i.e. the low versus high range). Potential installation cost savings from increasing the time available for piling, by removing any restrictions on piling in poor visibility or at night, are not considered in this section on mitigation costs, but in Section 3.5 on installation schedule.

Table 3.7 Summary of mitigation cost per pile as a percentage of the foundation installation vessel cost

Mitigation solution	Basis	Cost as a % of foundation installation vessel cost per pile
	Pile Installation Rate per 24 hours	*0.5*
Soft start	15 minute additional vessel time (5-15 minutes engineering soft start and 15 minutes extra for mitigation) - assuming 24 hour operations.	1%
Soft start	15 minute additional vessel time - assuming 6 hours non-productive time due to inability to operate outside daylight hours.	1.5%
MMOs only	2 x MMOs based on a dedicated survey vessel.	3.5 - 5%

[15] *Note vessel crew members may not be the most appropriate personnel to carry out this role, and appropriate training will be needed for all potential ADD operators to keep devices working offshore. Dual role crew members may be cost effective, however non-dedicated MMOs are not encouraged by SNCBs.*

Mitigation solution	Basis	Cost as a % of foundation installation vessel cost per pile
	Pile Installation Rate per 24 hours	*0.5*
survey vessel based		
MMO & PAM survey vessel based	2 x MMOs and 1 PAM operator + equipment based on a dedicated survey vessel.	4 – 5.5%
MMO & PAM installation vessel based	1 MMO & 1 PAM operator + equipment based on an installation vessel.	1 – 1.5%
ADD deployed from installation vessel by MMO	Assuming that 2 ADDs could be used for a 12 month campaign – during which 180 piles installed (1 every 2 days).	< 1%
ADD deployed by installation vessel crew member or e.g. FLO	Assuming that 2 ADDs could be used for a 12 month campaign – during which 180 piles installed (1 every 2 days).	< 0.02%

The way in which costs of mitigation change depending on the installation rate for piles has also been calculated. Table 3.8 shows the estimated mitigation cost per pile for the various mitigation solutions as a function of the number of piles installed, with installation rates varying from one pile every two days, to four piles per day. This reflects expected variation in piling rates due to different ground conditions at OWF sites.

For higher piling rates per vessel (more than two piling events per day) a doubling of MMO and PAM operators has been assumed, to ensure full cover through shift work. This would need to be reviewed on a project case-by-case basis due to the inefficacy of MMOs outside daylight hours.

Table 3.8 Summary of the cost estimates for the various mitigation solutions

Mitigation Solution	Basis	Ballpark Cost Estimate of Mitigation Solution based on Piling Rate							
	No. of piles installed per day	**0.5**		**1**		**2**		**4**	
	Installation Cost per Pile	150,000	400,000	75,000	200,000	37,500	100,000	18,750	50,000
		Low dayrate	*High dayrate*	*Low dayrate*	*High dayrate*	*Low dayrate*	*High dayrate*	*Low dayrate*	*High dayrate*
Soft Start	15 minute additional vessel time - assuming 24 hour operations	391	1,042	781	2,083	1,563	4,167	3,125	8,333
MMOs only Survey Vessel Based	2 x MMOs based on a dedicated survey vessel Team doubled up for 2+ piles per day	3,600	7,400	3,600	7,400	4,200	8,300	4,200	8,300
MMO & PAM Survey Vessel Based	2 x MMOs and 1 PAM operator + equipment based on a dedicated survey vessel Team doubled up for 2+ piles per day	4,200	8,775	4,200	8,775	5,150	10,150	5,150	10,150
MMO & PAM	1 MMO & 1 PAM operator + equipment based on an	900	1,825	900	1,825	1,550	2,750	1,550	2,750

Mitigation Solution	Basis	Ballpark Cost Estimate of Mitigation Solution based on Piling Rate							
	No. of piles installed per day	**0.5**		**1**		**2**		**4**	
	Installation Cost per Pile	150,000	400,000	75,000	200,000	37,500	100,000	18,750	50,000
		Low dayrate	*High dayrate*	*Low dayrate*	*High dayrate*	*Low dayrate*	*High dayrate*	*Low dayrate*	*High dayrate*
Installation Vessel Based	installation vessel								
ADD deployed from installation vessel by MMO	Assuming that 2 ADDs required for a 12 month campaign. For piling rates up to 1 per day = 1 MMO required, for 2+ piles per day 2 MMOs required	366	560	333	505	616	927	608	914
ADD deployed by installation vessel crew member	Assuming that 2 ADDs required for a 12 month campaign (assuming no impact of increased duty cycle on ADD)	66	110	33	55	16	27	8	14

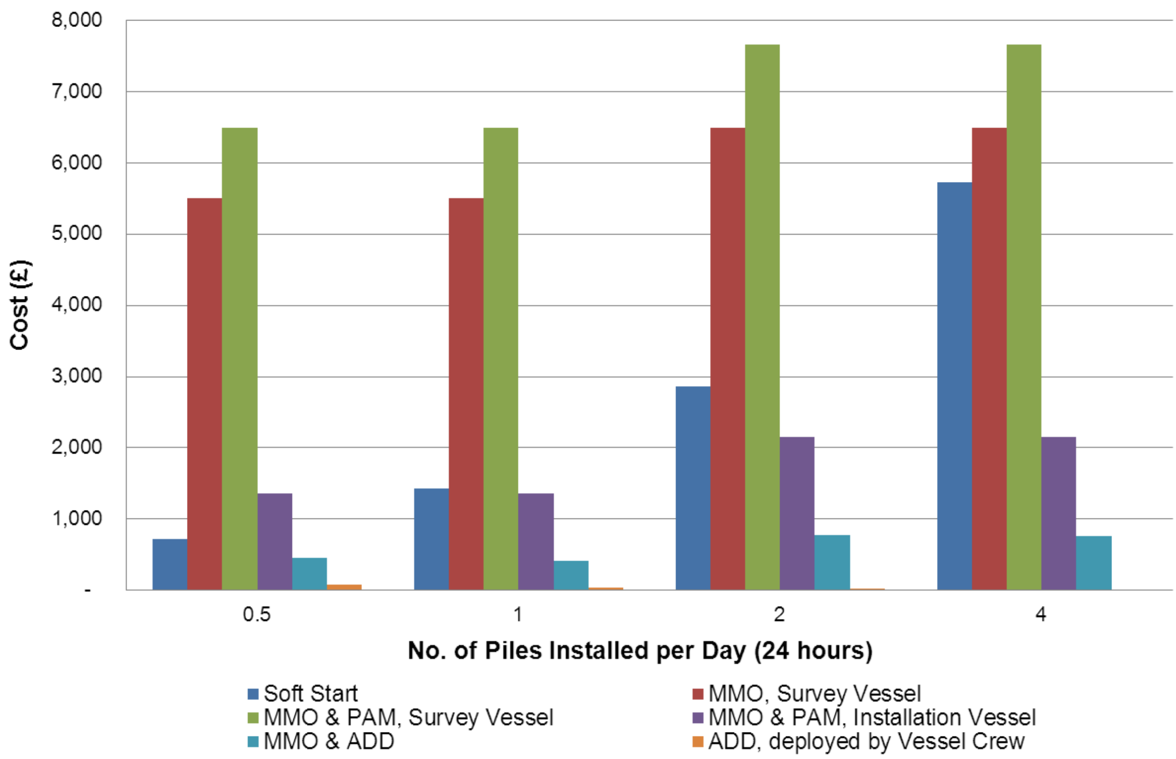


Figure 3.4 Impact of piling rate on mid-range mitigation cost (cost per pile)

Based on the above analysis, the key findings are:

- There is a significant difference in the range of costs of the mitigation solutions in the order of several thousand between the lowest (ADD deployed by installation vessel crew) and highest (MMO and PAM on survey vessel) values; and
- Mitigation costs do not scale equally with an increase in piling rate. For example, for higher pile installation rates (e.g. pin piles in some cases), the relative significance of soft start cost becomes more significant, due to the soft start period representing a higher proportion of total piling time.

3.7 Practical deployment considerations and scalability of mitigation solutions

3.7.1 Overview

One of the key messages gathered during the consultation carried out as part of this study is that mitigation solutions need to be practical. This was defined as options that can:

- Operate on demand and according to the specification requirements (i.e. that they are reliable);
- Be made available for deployment within the timescales required;
- Be deployed relatively easily, and
- Provide a solution of a size and scale that is manageable and proportionate given the context of an offshore foundations installation campaign.

Each of the mitigation measures highlighted in Section 1.5 have been assessed against these criteria in Appendix M drawing on two principal data sources; information and reports available in the public domain (in particular MMO construction reports) and telephone interviews with representatives from project developers and from marine mammal mitigation service providers. The key findings are presented below, followed by a more detailed discussion and evidence review. Note H & S and cost issues are reported in subsequent sections and are therefore not included here.

3.7.2 Key findings

Soft starts are a highly deployable solution requiring in general a manageable modification to operational procedures. However, soft starts cannot always be carried out for technical reasons, in particular following a piling break due to issues relating to specific ground conditions. The risk associated with this will vary with the length of the piling break, as it is likely that it will take several hours for marine mammals to return to the site following a piling break. This is a site and location specific consideration and therefore, for some projects, we anticipate that soft start alone will not provide a 100% reliable solution. However, with this exception there is no evidence to suggest that soft starts will become less practically viable for future projects.

Projects have generally managed the practical deployment of MMOs very well. Records show that for the vast majority of the time they have been available on site to perform the required observations. However the preparation, planning and co-ordination effort required to deliver a workable solution should not be underestimated. The survey vessel based methods and approaches used for the near shore projects become less practical as projects move further offshore. Careful consideration will need to be given to vessel selection, logistics and the potential requirement for extended periods of on-site working to meet the pile installation rates and operational conditions that may be achievable with the latest generation of installation vessels. It may be possible to yield significant gains in practicality (as well as cost and H & S) by deploying MMOs and PAM from installation vessels, rather than a dedicated survey vessel. This approach has been adopted in a number of projects and has been deemed a success. The potential advantages of such an approach are discussed further in Section 3.8 and Appendix M.

PAM has been used with mixed success. The method requires experienced operators who understand the equipment and its limitations, which are significant. Experienced user feedback suggests that the towed method of deploying PAM is less than ideal, suffering from interference with vessel systems (although this approach is frequently recommended to developers by advisory bodies). In some cases better results have been achieved through deployment from the installation vessel, although this does require additional hydrophones to cover the area. We have assumed that appropriate vessels would be selected by developers to match the installation requirements, including the necessary space and other requirements for PAMs and MMOs if required.

Experience with ADD is still at an early stage in this sector but evidence suggests that the technology offers a practical, reliable solution (for some species) that can be deployed from the piling vessel with no disruption to operations, assuming developers select appropriate installation vessels and crew to operate ADDs if this approach was chosen.

3.8 Health & Safety

3.8.1 Overview

Health and Safety is a major priority for the offshore wind sector. The parameters identified by the workshop group for assessing the issues with respect to the mitigation options were:

- Offshore manhours;
- Location of mitigation work (i.e. not all offshore hours are equally hazardous);
- Number of people; and
- Additional obstructions (equipment required, location of equipment, additional navigational hazards, collision risk).

3.8.2 Data sources

This assessment has been carried out at a generic level, as risks are project and site specific, and approaches will depend on the relevant safety management systems in place. It has not been possible to obtain any examples of risk assessments to inform the discussion. Therefore the evidence discussed is that obtained through the interview process and based on H & S data kindly made available through the data gathering process. Critically, the results presented in here do not represent a formal risk assessment with consideration of hazards, outcomes and potential mitigation actions.

3.8.3 Health and Safety Regulations

The legal framework for delivering offshore wind in the UK consists of a number of acts and regulations which are outlined in detail in the 2013 RenewableUK Offshore Wind and Marine Energy Health and Safety Guidelines. Of key significance to this review are:

3.8.3.1 The Health and Safety at Work etc. Act 1974 (HSWA)

The Health and Safety at Work Act makes those who create risks, in the course of work activity, responsible for protecting workers and the public from the consequences of their activities (HSE, 2001). The regulations generally adopt a “goal-setting” approach, in that they set objectives and leave duty holders to determine the best way of achieving these objectives, rather than imposing particular approaches, standards or technical solutions. This requires duty-holders to address hazards which are ‘reasonably foreseeable causes of harm’ taking into account ‘reasonable foreseeable events and behaviour’. Central to this is the requirement for responsible parties to reduce risk to a level that is as low as reasonably practicable (ALARP).

It is normal practice for businesses in the UK to develop safety management systems to address these requirements within the context of their organisation and activities. When considering if a risk has been reduced to ALARP, control measures can be compared against recognised and relevant good industry practices, current legislation, available technology, and relevant good practices that have been demonstrated elsewhere (RenewableUK, 2013).

3.8.3.2 Construction (Design and Management) Regulations 2007 (CDM)

The Construction (Design and Management) Regulations (CDM) provide a framework for the management of construction projects, and are currently used as the framework for offshore wind. The aims of CDM are to:

- Improve the planning and management of projects from the very start;
- Identify hazards early on, so that they can be eliminated or reduced at the design or planning stage, and the remaining risks can be properly managed;
- Target effort where it can do the most good in terms of Health and Safety; and
- Discourage unnecessary bureaucracy.

The emphasis of the HSWA and CDM are both on eliminating risks and demonstrating that risks are proportionate and have been reduced as far as practicable.

The risks associated with marine mammal mitigation are dependent on risk perception, and whilst not hazardous per se, simply by deploying MMOs, PAM operators and crew into an offshore environment creates a H & S risk that will need to managed and justified.

Examples of relevant risks include:

- Slips, trips and falls;
- Seasickness;
- Fatigue; and
- Navigational hazards and collision risk.

Through consultation, it was identified that deploying and recovering survey equipment on board survey vessels is generally recognised as the service providers (PAM operators) biggest H & S risk. This review therefore included consideration of information including the method of deployment, deck space required and any potential need for cranes or winches as well as consideration of best practice for how many people should actually be involved in the deployment and recovery to ensure this is done safely.

3.8.4 Health and safety statistics

Health and safety data is gathered by contractors as a requirement of the project developer. Data has been obtained for a total of eight projects; representing 73,643.5 total exposure hours worked during the provision of mammal mitigation services, including MMO & PAM operators and vessel crews. The projects represent a mix of approaches: projects A-F involved MMOs operating from independent survey vessels; for Project G MMOs implemented mitigation for one installation vessel from an independent survey vessel and for a second piling vessel from the installation vessel itself; Project H involved MMO teams on two installation vessels.

These data are presented below in Tables 3.9 and 3.10. They show that for the projects for which information has been obtained there have been:

- No reportable incidents;
- Two first aid cases (one every 4.2 years) - Note: both were minor with no lost time; and
- Two near-misses.

The incidents reported are described below in Table 3.9 (letters cross reference to Table 3.10, where more detailed statistics on the MMMPs are provided). Both first aid cases occurred on the installation vessel whereas one of the near miss incidents involved the survey vessel (and was potentially serious).

Table 3.9 Health and safety incidents associated with marine mammal mitigation at UK OWFs

Project reference (see Table 3.10)	Details of incident
A (Other)	Survey vessel ran over discarded rope, fouling prop. Returned to port under one engine. MMOs transferred to Installation Vessel by CTV.
B (Near Miss)	MMO Survey vessel forced to take evasive action to avoid collision with a vessel within 500 m Marine Mammal Mitigation Zone.
C (Other)	Pinger lost overboard, not recovered (H & S issue associated with efforts made by crew to retrieve the pinger).
D (Other)	Pinger lost overboard, recovered within 24 hours (H & S issue associated with efforts made by crew to retrieve the pinger).
E (Other)	MMO fainted and fell on deck. Minor neck sprain sustained.
F (Near Miss)	Survey vessel lost power and was assisted to shore by another vessel. No injuries or lost MMO time.
G (First Aid)	MMO wearing hard hat walked into an overhead obstruction, suffered minor neck sprain.
H (First Aid)	MMO exercising (off duty) slipped and sustained minor abrasion wound to hands.

Table 3.10 Health and safety statistics associated with MMMP at 8 OWFs[16]

Project	Foundation installation strategy	MMO Strategy	Max number Survey vessels used (at a time)	Working Arrangements	Extra HSE training required?	Hours Mobilised	Survey Vessel Crew		MMOs		Total Exposure Hours Worked	Fatalities	Permanent Total Disability	Permanent Partial Disability	Restricted Work Case	Medical Treatment Case	Total Recordable Cases (TRC)	RIDDOR (for UK)	TRC Frequency	First Aid Cases	Near Misses	Other Incidents
					NB standard = sea survival		N	Hours Offshore	N	Hours Offshore												
A	1 piling vessel	2 MMOs on survey vessel	1	Port to port (up to approx. 24 hours)		350	3.0	1050	2	700	1750	0	0	0	0	0	0	0	0	0	0	A
B	1 piling vessel	2 MMOs on survey vessel	1	Port to port (up to approx. 24 hours)		559	2.5	1397	2	1118	2515	0	0	0	0	0	0	0	0	0	B	C,D
C	1 piling vessel	3 MMOs on survey vessel	1	Port to port (up to approx. 24 hours)		426	2.5	1065	3	1279	2344	0	0	0	0	0	0	0	0	0	0	0
D	1 piling vessel	3 MMOs on survey vessel	1	24 hour operations		432	3.5	1514	3	1297	2811	0	0	0	0	0	0	0	0	0	0	E
E	up to 3 piling vessels	3 MMOs on survey vessel	3	Port to port (up to approx. 24 hours)		1083	2.5	2708	3	3249	5957	0	0	0	0	0	0	0	0	0	0	0
F	1 piling vessel	3 MMOs on survey vessel	1	Port to port (up to approx. 24 hours)		18	2.0	36	3	54	90	0	0	0	0	0	0	0	0	0	0	0
G	2 piling vessels	3 MMOs on installation vessel; 3 MMOs on survey vessel	1	Rotation offshore via CTV; Survey Vessel 24hr ops	BOSIET, Working at Height	5256	3.0	15768	6	31537	47305	0	0	0	0	0	0	0	0	2	F	0
H	2 piling vessels	3 MMOs per installation vessel	0	Rotation in port or offshore via CTV	BOSIET, Working at Height	1812	0.0	0	6		10872	0	0	0	0	0	0	0	0	0	0	0
					Totals	**9937**		**23538**		**39233**	**73643.5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**2**	**4**

The summary table below (Table 3.12) provides a qualitative review of the relative risks associated with each option. Clearly the specific risks are highly vessel and site specific and dependent on risk awareness, and the behavioural safety culture of the team carrying out the relevant mitigation activity, as well as the control measure put in place.

16 *The Hours Offshore columns in Table 3.10 refer to hours worked offshore by the full time survey vessel crew versus hours worked offshore by the MMOs.*

Table 3.11 Key to be used in combination with Table 3.12

Measure of risk introduced
Low additional risk introduced through mitigation measure.
Measure introduces additional project HSE risk.
Measure introduces significant project HSE risk.

Table 3.12 Summary of the relative risks associated with individual mitigation measures

Mitigation measure	Parameter	Key risks /evidence from review	Considerations for future projects (R3 /STW/R2 extensions)
Soft start	Offshore manhours	Additional vessel time for the installation barge (when considered in isolation from the pre-soft start search) – but no significant increase in hazardousness of activities.	No change unless site specific considerations. Weather restrictions may put pressure on pile durations. Additionally there is potential that specific environmental concerns may also cause restrictions (as observed in the EU), such as fish spawning, which would also increase schedule pressure. Potential for additional engineering risk (in terms of damage to hammer/pile through ineffective strikes) could lead to increased exposure hours to resolve.
	Location	Offshore construction - on installation vessel. No additional personnel required – impact is (low) additional vessel time in a hazardous environment.	No significant change.
	No. of people	No additional people required.	No additional people required.
	Additional obstructions	No additional obstructions.	No additional obstructions.
MMO on dedicated survey vessel	Offshore manhours	Approximate minimum of 5 to 8 hours per person per piling operation including transit (highly variable depending on approach and site characteristics. Subject to occasional long delays when there are technical problems on installation vessel that delay piling).	For projects further from shore this is likely to increase significantly.

Mitigation measure	Parameter	Key risks /evidence from review	Considerations for future projects (R3 /STW/R2 extensions)
	Location	In transit then at offshore construction site - within vessel exclusion zone therefore high(er) risk than e.g. guard vessel opportunities for MMOs and PAM operators to rest can be limited by conditions on smaller survey vessels.	No significant change.
	No. of people	Generally at least 2 MMOs plus vessel crew - at least 4 people.	Additional crew will be required for offshore operations (day boat work unlikely to be feasible).
	Additional obstructions	(Potential) additional vessel on site therefore additional marine co-ordination/collision risk/navigational hazard. However where projects have successfully used guard vessels for MMO work, this risk is reduced.	Additional vessel on site therefore additional marine co-ordination/collision risk/navigational hazard.
PAM on dedicated survey vessel	Offshore manhours	Approximate minimum of 5 to 8 hours per PAM operator per piling operation including transit (highly variable depending on approach and site characteristics. Subject to occasional long delays when there are technical problems on installation vessel that delay piling).	For projects further from shore this is likely to increase significantly.
	Location	In transit then at offshore construction site - within vessel exclusion zone therefore high(er) risk than e.g. guard vessel. Opportunities for PAM operators to rest can be limited by conditions on smaller survey vessels.	No significant change.
	No. of people	Generally at least 1 PAM operator plus vessel crew offshore - at least 3 people. In practice the vessel crew are 'shared' with the MMOs (therefore risk not 'additive').	No significant change.
	Additional obstructions	Additional vessel on site with towed array therefore additional marine co-ordination/collision risk/navigational hazard – and (slightly) reduced manoeuvrability.	No significant change.
MMO on installation vessel	Offshore manhours	Installation vessel based.	No significant change.
	Location	Offshore construction site - on the installation vessel.	No significant change.
	No. of people	1 or 2 MMOs ++ (depends on viewing options and piling schedule)	No significant change.

Mitigation measure	Parameter	Key risks /evidence from review	Considerations for future projects (R3 /STW/R2 extensions)
	Additional obstructions	No additional obstructions, lifts or equipment. Greatly improved welfare conditions for MMO Team (over survey vessel approach).	No significant change.
PAM deployed from installation vessel	Offshore manhours	Installation vessel based.	No significant change.
	Location	Offshore construction site - on the installation vessel.	No significant change.
	No. of people	1 or 2 additional people on the installation vessel.	No significant change.
	Additional obstructions	Use of PAM equipment will create some additional risk.	No significant change.
ADD assuming deployed from installation barge	Offshore manhours	Installation vessel based.	No change.
	Location	Offshore construction site - on the installation vessel.	No change.
	No. of people	1 unless deployed by existing crew member or person offshore (relatively lowest risk option in terms of number of people).	No change.
	Additional obstructions	Use of ADD equipment will create some additional risk.	No change.

3.8.5 Conclusions on Health and Safety

The emphasis of the HSWA and CDM regulations on eliminating risks and demonstrating that risks are proportionate and have been reduced to ALARP encourages developers to consider, through a risk assessment and review process, the operational requirements associated with marine mammal mitigation activities.

Although this will need to be considered on a case by case basis, the option of locating MMOs and PAM onto the installation vessel has significant potential to reduce health and safety risk, both by providing a greater opportunity to rest between piling events (reducing the risks associated with fatigue), and through the elimination of the potentially hazardous activity of a small vessel operating for extended periods within the safety exclusion zone of the installation vessel.

The increased risks associated with operations further from shore, potentially in higher sea states, are anticipated to favour any measure which can lead to a reduction in offshore man-hours. This is especially the case where these hours are associated with additional vessels operating within exclusion zones. In addition, the increased distance from shore makes it more difficult to ensure that MMOs (if survey vessel based) are present at all piling events, unless vessels selected are capable of safely handling the weather, without compromising the well-being of the MMOs, meaning larger vessels, which will lead to cost increases.

The risk based approach defined by the legislation requires context specific, informed decision making to balance the drive to reduce offshore manhours against the requirement to implement effective mitigation to safeguard marine mammals.

3.9 Evidence review summary

3.9.1 Passive mitigation techniques

3.9.1.1 Current efficacy

MMO

Although not directly quantified for MMO mitigation pre-piling watches, data from line transect literature suggests that visual observation is a poor method for ensuring detection of harbour porpoises at the distances required for piling mitigation. MMOs are likely to be more effective for detecting seals, dolphin species and larger whale species, although clearly not all animals will be detected given the sighting probabilities and limitations discussed above and some animals will be exposed to the risk of auditory injury from pile driving. The exact magnitude will vary on a site specific basis, depending on the specifics of the piling at the site and the local density of each species and likelihood of occurrence.

PAM

PAM is useful for detecting harbour porpoises within 200-300 m of the PAM system although the directionality of clicks may limit the effectiveness and clicks will only be reliably detected if the animal is orientated towards the PAM system. Detection probabilities for porpoise and dolphins within the ranges typical for mitigation zones have been shown to be approximately 50% or less. PAM is not reliable for detecting other common UK marine mammal species. Although the use of PAM can enhance the overall detection probability for some species within close ranges, the sole use of PAM for mitigation purposes is not recommended.

3.9.1.2 Scalability and future development

As predicted impact ranges increase, the effectiveness of current passive mitigation practice decreases. This is simply because the proportion of the impact range that can be effectively monitored using current practice will decrease as impact range increases (Figure 3.1 to Figure 3.3). Other options will need to be considered for monitoring and mitigation over larger impact ranges.

Detection over larger areas is challenging but can be achieved using a variety of methods. Multiple deployments of visual observers over the range required would be impractical and very costly. Potential options include spatial networks of real time PAM arrays, such as those being currently developed in some German offshore wind farm projects (personal communication, Georg Nehls) by Seiche[17] and real time monitoring buoys being developed by PAMBuoy[18]. These systems are self-powered using batteries or solar power and have on-board detection and classification software. Detection data can be sent from networked buoys to a central base station and then transmitted wirelessly over 3G or satellite networks to monitoring stations on a vessel or onshore. Array designs can be implemented over large areas with spacing dependent on the required range. This will only work for species which reliably vocalise.

Note PAMBouys will still require regular servicing as will be subject to failure and/or be lost to waves, vessels and fishery activity.

3.9.1.3 Practicality, cost, installation schedule and H & S

Table 3.13 (below) summarises the key considerations and available evidence in terms of the 'practicality', installation schedule, cost and health and safety, including comments on the how these may change for future projects.

[17] *http://seiche.heroku.com*

[18] *http://www.pambuoy.co.uk/pambuoy/pambuoy-variants/pambuoy-mitigate*

Table 3.13 Key considerations and available evidence in terms of the 'practicality', installation schedule, cost and health and safety for passive techniques

Considerations for MMO & PAM	Comments, drivers, dependencies	Evidence from review	Considerations for future projects (R3/ STW/R2 extensions)
Practicality			
Ability to operate on demand and according to the specification requirements (i.e. reliability)	> Driven by the MMM platform selected and human factors considerations. > Importance of suitable vessel selection, is it well maintained? Is the vessel specification suitable for the anticipated conditions and duties? > Human Factors - does the vessel provide suitable facilities for performing work duties and resting between piling operations? Is the vessel comfortable in anticipated conditions and capable of remaining at sea for required duration? > Wellbeing and alertness of observer directly related to quality of observations.	> From the construction reports reviewed only a small number (< 5) non-conformances reported due to MMO/PAM issues.	> In order to maintain a similar approach on projects further from shore vessels may need to operate 24/7 and remain at sea for extended periods. > Step change in vessel specification may be required.
Available for deployment within the timescales required	> Managed through contracting strategy – small workboats readily available, depending on market conditions. > Bed space on installation vessel can generally be negotiated as a project requirement given sufficient notice.	> No evidence found to suggest that survey vessels difficult to contract given sufficient notice. > In terms of 'deployability' there is no evidence of any shortage of trained MMOs, although experience has been shown to be critical (Stone, 2013 in draft). > MMOs and PAM operators can be trained in short space of time – anecdotal evidence suggests no shortage experienced to date.	> Heavily dependent on project phasing and construction strategies - unlikely to be an issue.

Considerations for MMO & PAM	Comments, drivers, dependencies	Evidence from review	Considerations for future projects (R3/ STW/R2 extensions)
Ease of Deployment	> Dependent on relative distance between construction site and suitable mobilisation Port. > Marine co-ordination effort.	> Interviews emphasised that it is not only the cost but overheads/project burden associated with planning and co-ordinating MMO & PAM activities on a project. > Not 'easy' to deploy MMO or PAM but has been made workable. > PAM – static deployment from installation vessel preferable to towed array from independent vessel due to the potential HSE risks associated with towed array entanglement (Pers. comm.,).	> As projects move further from shore the 'ease' of deployment reduces. Driven by weather considerations and transit distances.
Size and scale of solution - is it manageable and proportionate given the context of an offshore foundations installation campaign?	> Vessel, crew + team of minimum 3 working or on stand-by for during of piling operations.	> Consent requirements, therefore accepted as compulsory.	> Likely to become more difficult to manage based on current approaches.
Installation schedule			
Overall impact on the programme duration	> Dependencies on the critical path. > Ability to de-couple from installation vessel operations.	> Projects have managed to decouple MMO & PAM through careful planning. Importance of communication highlighted as key to effective operations. > Negligible schedule impact experienced due to extremely low sightings/detections.	> Challenges with sightings in sea state > 2, coupled with PAM limitations suggest that additional/alternative solutions may be necessary.
Level of uncertainty introduced into the programme	> With what level of certainty can the activity be planned? > How weather dependent? Amount of contingency required?	> High potential level of uncertainty but not manifested to date.	> Experience on projects to date not necessarily relevant or representative due to different mammal population densities /habitats.

Considerations for MMO & PAM	Comments, drivers, dependencies	Evidence from review	Considerations for future projects (R3/ STW/R2 extensions)
Logistical implications	> Number and type of offshore lifts, equipment handling, personnel transfers, Additional offshore vessel operations and complexity.	> Offshore personnel, transfers, and additional offshore vessel operations add schedule risk and management burden to projects.	> Transfer distance/times, weather risk, requirement for vessels more suited to working further offshore.
Cost			
Capital cost	> All activities treated as project development CAPEX.	> See tables in Section 3.5.	> Survey Vessel costs likely to increase substantially, particularly if installation strategy and distance from ports demand extended durations offshore.
Operating costs	> n/a	> n/a	> n/a
Impact on overall project costs (i.e. significance in terms of LCOE)	> In some cases there is a possibility that marine mammal risk could impact the cost of capital to projects (i.e. finance).	> Not assessed.	> n/a
Health & Safety			
See Table 3.12			

3.9.2 Active mitigation techniques

An alternative form of acoustically monitoring a mitigation zone for the presence of marine mammals is active acoustic monitoring - the detection, localisation and classification of marine mammals via active sonar, which eliminates the need for an animal to vocalise before being detected. This technique is currently used at the SeaGen tidal turbine in Strangford Narrows in Northern Ireland to detect marine mammals prior to shutdown of the turbine to avoid the risk of collisions between the turbine and the marine mammals. This system is relatively short range (up to 80 m with a 180º beam width) and it is likely that a longer range system would be required to monitor effectively around piling operations. There is an inherent trade-off between tracking/monitoring range and resolution (low frequency sounds travel further). Active sonars also emit sound and depending on the frequency and source level of the system, there is the possibility that sonar signals will cause behavioural responses in marine mammals. The hearing and vocal ranges of many marine mammal species overlap with the transmission frequencies of many of the commercially available sonar systems (approximately 12 to 150 kHz) (Hastie, 2012). Thus the choice of sonar must take into account potential negative effects. Whilst some degree of deterrence may be desirable within this context, there is currently a great deal of concern surrounding the potential impacts of the use of sonars on marine mammals (Southall *et al*. 2013) therefore any use of active sonar needs to be carefully considered. Such detailed considerations are outside the scope of the current review.

Both active and passive acoustic monitoring systems will require an operator to run, although detection could be automated using automatic software and detection data incorporated into an automatic system (dependent on the rate of false positives). Whilst active acoustic monitoring is not strictly an active mitigation technique (its primary purpose is to monitor a mitigation zone for the presence on marine mammals, not actively deter them), it could be incorporated into a ‘detect and deter’ system though further feasibility studies (this could also apply to some PAM equipment). Development work would be required to design and test the effectiveness of such systems. As discussed in the ADD efficacy section, careful design of operation modes would have to be employed to ensure that over larger areas, animals did not become trapped, or confused and ‘herded’ towards the piling sound.

Note the use of sonar as ADD could result in long range behavioural responses by seals, minke whales etc. Specific research would still need to be carried out to develop an applicable sonar device, and the long sound range adapted to function as an ADD. The further development of off the shelf ADD was considered more cost effective than the development of sonar, this option has therefore not been considered further in this present review.

3.9.2.1 Current efficacy

Soft start

The efficacy of soft start procedures has been studied in Section 3.2.1 and in Appendix K. Soft start procedures do not eradicate all possibility of injury occurring. In particular, it is possible that for very large piles, injury could occur during the very first hammer blow over a fairly wide area even during soft start. However, soft start will still reduce the potential injury range compared to no soft start and therefore “unintended consequence” is not an additional consequence of the soft start, but rather a question of efficacy.

ADD

It is clear that there are some promising ADD devices available for use in providing reliable marine mammal deterrence (for some species) at OWF sites and that devices are currently being used during wind farm construction in the UK and Europe (see Section 3.3.2 and Appendix L). These devices are likely to be resulting in a real reduction in risk of injury, for harbour porpoises in particular (the exact quantification of reduction is highly dependent on total extent of impact zone overall).

However there are some remaining uncertainties ahead of further research into responses achieved at sites typical of those likely to be used for future OWF projects. However, promising research, *e.g*. Brandt *et al.* (2012, 2013), suggests that ADDs can significantly reduce the risk of auditory injury to harbour porpoise during piling for predicted injury ranges of up to 7 km (Section 3.3.2 and Appendix L). Further testing of devices may be necessary to provide confidence in the effective ranges reported to date.

There is also no reliable evidence base for all species of concern in the UK. In general, studies carried out to date suggest that ADDs can be effective at moving harbour porpoises to reasonable distances but evidence for consistent seal deterrence is equivocal. Sounds which elicit startle responses may be more consistently reliable than those which rely on a more generalised aversive response but there are uncertainties over the effective range of devices. It may be possible to ramp up the source level of devices to increase the effective range. Such increases in source level may have the potential to increase the risk of auditory injury from the ADDs themselves, but if there is confidence in their deterrent properties, and ramp up protocol is carefully designed, and individual pulses are short, this risk can be minimised. With the exception of studies on porpoises (Johnston, 2002, Olesiuk *et al.,* 2002 and Brandt *et al.,* 2012, 2013), reported deterrence ranges are relatively low (in the region of tens to the low hundreds of metres). Pingers are used in conjunction with ADDs throughout much of Europe; however, there are concerns over these devices eliciting a 'dinner bell' effect, particularly for pinnipeds. Consequently, it is suggested that ADDs with soft starts capabilities and used and further developed (see recommendations regarding manipulation of ADD effective range in Section 5.1.2).

It also remains to be seen whether habituation will be a problem when using devices for the mitigation of pile driving and this is a key area for investigation. Given that the ADD signal would be followed up by aversive pile driving noise, which may provide additional reinforcement to the flee response, it seems unlikely that habituation will be a problem. However, in areas particularly important for foraging, the positive motivation to remain in that area cannot be ruled out. Such a situation has been shown to arise around fish farms, where the strong driver of abundant food overcomes the irritation presented by pingers. For devices where the mechanism underlying the response is not well understood, it is difficult to predict how responses may change over time whereas signals which elicit physiological responses through the startle reflex are likely to be more consistent in eliciting a response.

3.9.2.2 Scalability and future development

Soft start

From an engineering and practicality standpoint, there is no evidence to suggest that a 20 minute soft start will not be viable for R3 and STW OWF sites. Implementing a soft start inevitably extends the overall time spent piling (generally an additional 5 to 15 minutes per pile) and, in doing so, may marginally increase the period within mammals may be disturbed. This is considered to be of minor consequence, particularly when balanced against the potential benefits of reducing the likelihood of a PTS injury, which may be considered a more severe impact, albeit that disturbance occurs over a much wider area.

Piles with very large diameters, which need greater hammer blow energy during installation (such as those being proposed in R3 and STW OWF EIA design envelopes), may require soft starts of a significantly longer duration than is currently recommended in order to achieve an appropriate level of risk reduction. Therefore, they may not represent a realistic mitigation option if used in isolation. The size of pile for which a 20 minute soft start would be sufficient will depend upon several factors including the hammer energy, injury criteria, assumed mammal swim speed and site specific factors such as bathymetry and sound speed profile. It is beyond the scope of this project to provide a definitive cut-off point beyond which standard JNCC mitigation soft starts would no longer be effective.

ADD

There is unlikely to be a one-size fits all solution for all wind farm projects, given the variety of species likely to be of concern at different sites, the variations in site specific piling parameters and the range of environmental variation across sites. There is a clear need to develop a risk based approach and design mitigation appropriately on a project-specific basis taking into consideration site specific characteristics.

Behavioural responses to ADD are not easy to predict, and the evidence base presented here is indicative of the levels of variability in response within and between species, and within and between devices. Behavioural responses to aversive sound are best viewed probabilistically. Factors other than the absolute level and frequency of the sound level can affect probability of response and these include previous experience, behavioural context and motivational state. While the study of the responses of animals in captivity can help elucidate some of these factors (because some of the variable conditions can be controlled), captive studies may not always provide useful predictions of responses in the wild. Captive studies can help address questions such as the detection thresholds for different sounds for different species and there have been some extremely useful results from captive research such as the finding that rapid habituation to otherwise aversive sounds can occur when animals are food motivated. However behavioural responses of captive animals are not likely to be representative of their free-living counterparts and it is currently unknown how free living animals may respond to ADD signals across a range of habitats.

3.9.2.3 Practicality, cost, installation schedule and H & S

It is not envisaged that, once devices have been developed and the efficacy of the devices for UK offshore waters validated, there would be any major reliability challenges experienced with ADD technology. However, more detailed assessment could be completed and if necessary additional analysis and/or testing undertaken. The successful development of ADDs appropriate for the priority species and potential R3 and STW OWF sites may have significant installation schedule and cost advantages over PAM/MMO passive approaches.

Table 3.14 (below) summarises the key considerations and available evidence in terms of the 'practicality', installation schedule, cost and health and safety, including comments on the how these may change for future projects for ADD and soft start.

Table 3.14 Key considerations and available evidence in terms of the 'practicality', installation schedule, cost and health and safety for active techniques

Considerations for ADD & soft start	Comments, drivers, dependencies	Evidence from review	Considerations for future projects (R3/ STW/R2 extensions)
Practicality			
Ability to operate on demand and according to the specification requirements (i.e. reliability)	> Mean time between failures, mean time to repair. > Technology/operational specification and requirements.	> High power seal scarer technology - no known reliability issues, technology is simple and designed for marine environment/to be robust.	> No major reliability challenges envisaged with ADD technology however more detailed assessment could be completed and if necessary additional analysis &/or testing undertaken.
Available for deployment within the timescales required	> Technology or operational 'gap' or limitations.	> Evidence in place for some existing ADD devices – devices in development could be developed and tested in time given sufficient market pull. > Soft Starts already feasible however could benefit from deeper understanding of efficacy and guidance on how to design and implement procedures recognising the practical and technical requirements of the operation.	> For larger pile sizes and more sensitive species (Pinnipeds) or more conservative criteria (e.g. Lucke instead of Southall for porpoises), a single ADD may not provide a sufficient deterrent range. Consequently, networks or arrays of ADDs may be the most effective solution, but clearly come at a cost in terms of practicality. Despite this, the large number of vessels involved in an offshore construction programme that could potentially be used to deploy ADDs suggest this would be a workable solution.
Ease of Deployment	> Component parts, weight, size and shape, hazards, mode of operation.	> Anecdotal evidence suggests that ADDs are relatively easy to deploy by a single person. > Soft Start requires no additional equipment but must be executed within the complexities and practical limitations of a major construction operation.	> Potential to modify ADDs to ensure fail safe, to meet specific vessel requirements/incorporate i.e. cable management if value adding.

Considerations for ADD & soft start	Comments, drivers, dependencies	Evidence from review	Considerations for future projects (R3/ STW/R2 extensions)
Size and scale of solution - is it manageable and proportionate given the context of an offshore foundations installation campaign?	> Level of effort/resources/complexity relative to the task.	> ADDs – current devices highly deployable and manageable. > Soft Start – as defined, (notwithstanding piling events which are not compatible with soft start), are widely seen as operationally manageable.	> Dependent on project specific mitigation requirements, however not anticipated to be a major or disproportionate.
Installation schedule			
The overall impact on the programme duration	> Dependencies on the critical path. > Ability to de-couple from installation vessel operations.	> Soft start manageable. > ADD use has been subject to pre-deployment search in (small) number of UK cases discussed - this combined passive/active approach will reduce potential benefit of ADD if required moving forward.	> Depending on whether tailored, and how the soft start and ADD deployment may evolve not deemed significant on the overall duration – in fact major advantage over PAM/MMO passive approaches.
The level of uncertainty introduced into the programme	> With what level of certainty can the activity be planned? > How weather dependent? Amount of contingency required?	> Active approaches – low increase in uncertainty on overall schedule.	> Major benefit over passive approaches.
The logistical implications	> Number and type of offshore lifts, equipment handling, personnel transfers, Additional offshore vessel operations and complexity.	> Low, manageable - less logistical implications if ADD can be deployed by existing, trained crew member and soft start monitored/recorded without additional crew offshore.	> Project dependent, likely to be low. > Soft start – if tailored, implications on the installation schedule may change.
Cost			

Considerations for ADD & soft start	Comments, drivers, dependencies	Evidence from review	Considerations for future projects (R3/ STW/R2 extensions)
Capital cost	> All activities treated as project development CAPEX.	> See tables in Section 3.5.	> ADDs negligible. > Soft start relatively (minor) higher cost/risk as piling rate increases or piling restrictions introduced.
Operating costs	> n/a	> n/a	> n/a
Impact on overall project costs (i.e. significance in terms of LCOE)	> In extreme case marine mammal risk could impact on cost of capital to projects – this is less likely if active measures can be proven to be effective.	> No significant impact on LCOE envisaged.	> No significant impact on LCOE envisaged, significantly better than MMP/PAM approaches, particularly if deployed from survey vessel.
Health & Safety			
	See Table 3.12		

4 DISCUSSION

4.1 Overview

The evidence base and consultation (structured interviews (Appendix J), workshop sessions (Appendix I), and informal discussions) are deemed to be representative of current understanding of the UK offshore wind sector and mitigation practices at this point in time, and how offshore wind farm development and potential mitigation technology is envisaged to evolve in the future.

Overall, there is consensus that there is scope to improve the current guidance on UK marine mammal mitigation for piling. It is acknowledged that significant advancement has been made in our understanding of the potential impacts of piling and mitigation options since the last JNCC mitigation protocol was published in 2010. The developments in ADD research, industry and policy adoption and developer lessons learned from UK and elsewhere in Europe provide reassurance that change to the current mitigation protocol is viable. The challenge facing ORJIP will be to make sure that any research initiatives taken forward during the subsequent phases of Project 4 are viable, focussed on closing out specific knowledge gaps and will ultimately give the industry, regulators and advisors the tools they require to agree on any (incremental) changes to current JNCC protocol and site specific SNCB guidance

The purpose of this initial desk-top review and information gathering exercise is to determine whether a second phase to test and/or further develop ADDs is worthwhile and to assist in defining the scope of any works. The remainder of this report is therefore focussed as follows:

1. A summary of the mitigation scenarios considered as part of this study given the need for scalability.
2. A short list of recommendations pertaining to the research topics proposed in the “Current (16 December 2012) draft of the structure and content of ORJIP Project 4, Phase 2”, and specifically which research areas should be taken forward by Project 4, which could be improved based on the available evidence base and which should be prioritised to enable current knowledge gaps to be closed out.
3. Additional general recommendations (e.g. concerning policy and guidance) to support the implementation of the findings of Project 4.
4. The identification of potentially suitable field trial locations, including the results of a GIS heat mapping exercise undertaken to inform the identification process.
5. General conclusions and recommendations, including the presentation of a recommendations ‘roadmap’ – from a starting point of the current mitigation protocol (JNCC, 2010b) guidelines to the ultimate end point of a risk based project specific MMMP framework that covers multiple species at the same site.

4.2 Ranking the assessed mitigation options

Based on the ‘point in time’ assessment of available mitigation techniques currently used in the UK, the following three mitigation scenarios came out as being the most viable options (listed in order of ranking – highest first) for use during the installation of a hypothetical 5 m monopole in the future[19], namely:

> **Ranked 1st : ADD and soft start;**

[19] *The mitigation options were scored for against a typical mid-range monopole piling scenario in the UK (using a hypothetical nominal diameter of 5 m for the purposes of the exercise; said 5 m monopole was perceived by the research team to be a realistic mid-range R3/STW pile diameter, rather than a worst case extreme, and a likely representative of piling that is currently being carried out for the OWF sector in Europe (e.g. London Array, 4.7 m, Greater Gabbard, 5.2 m monopoles). It is further noted that the largest piles that we were made aware of during our research was DanTysk OWF which have installed 6 m monopoles).*

- **Ranked 2nd : PAM, MMO, soft start and ADD; and**
- **Ranked 3rd : PAM, MMO, and soft start.**

Through discussion it was concluded that the mitigation options ranked 2nd and 3rd provide a realistic reflection of the approaches currently being adopted by some UK offshore wind farms. The highest ranking mitigation option also highlights the potential within the existing evidence base for the use of ADD and soft start in isolation in certain site specific cases (dependent upon the species in question), pending further research.

The findings also reflect a common sense path to achieving this mitigation objective in the future (i.e. the industry should continue to use the full suite of available techniques whilst ADD and tailored soft starts are being advanced technologically and an evidence base is being built up to validate their efficacy, thus giving regulators and industry the tools to support the scaling back of passive acoustic options in favour of ADD and soft start as (one of a suite of) preferred best practice mitigation options. The ultimate objective is to develop a site-specific MMMP Framework, that enables regulators and developers to select the best mitigation solutions based on site specific characteristics (e.g. priority species present, water depth, pile diameter, hammer energy, depth, substrate type, distance offshore, installation and support vessel set up).

5 RECOMMENDATIONS

5.1 Background

The following sections aim to address the project brief, which is to provide a foundation review of all pertinent information (available at the time of writing) to be considered by the ORJIP, and develop recommendations that will be used to form the basis for the final design of Phase 2 and for decisions regarding Renewables Industry funding for further development and/or testing of ADDs or other deterrent devices. As defined in the project brief (see Appendix A) specific methodologies have not been defined here because they fall under the Project 4 Phase 2 brief.

Any recommendations taken forward by ORJIP will need to be realistic, focussed and able to help inform and support any (incremental) revisions to the current piling mitigation protocol (JNCC, 2010b) and site specific SNCB guidance. The short and longer-term recommendations made here have the potential to benefit OWFs currently being constructed and marine licensing for future R3 and STW OWFs. It has however been recognised that given the current theoretical construction schedules for R3 and STW OWFs, there is a finite amount of time available to carry out further research.

This review has therefore aimed to identify a number of short-term practical industry focussed research projects that could be taken forward as part of the ORJIP to test the usefulness of ADDs. Ideally the research recommendations made would involve the testing of a range of ADDs for effectiveness across multiple species. Given the differing characteristics and encounter rates of the priority species groups, there are several challenges to achieving this 'research ideal', for instance variable and context specific animal behavioural responses. We envisage that one to two field seasons of data collection on seal species, harbour porpoise and bottlenose dolphin should provide sample sizes sufficient to provide confidence in the efficacy of the tested devices, and determine whether the effective ranges of devices can be manipulated to provide the required flexibility. Minke whales are rather more challenging to study because encounter rates are variable and unpredictable and survey methodologies are less developed. This is explored further in the relevant section below (Section 5.2.4).

It is also recommended that longer term effectiveness should be addressed as part of ADD field trials during the construction phase of planned OWF developments. However, if the short term trials into the effectiveness of signals can demonstrate that ADD are unlikely to lead to habituation then there may be less need for an extensive industry trial prior to considering revising current mitigation guidance.

In addition to recommendations pertaining to the research topics proposed for Phase 2 of this study, the research team has included a number of general recommendations that reflect the transitional support that will be required to reduce the current reliance on passive mitigation, for ADDs to gain widespread acceptance within the UK OWF industry, and ultimately, for the continuing improvement and optimisation of marine mammal mitigation.

> The current marine mammal mitigation protocol during piling (JNCC, 2010b) was developed from guidance related to the seismic sector and a significantly smaller OWF evidence base in terms of the number of MMO reports and relevant research papers available at the time. At that time the scale of the OWFs and their associated piling impact zones were much smaller than has been predicted for the upcoming R3 and STW sites. The general recommendations presented here have benefited from the larger available evidence base now available (MMO, MMMP reports etc.), as well as the increased expertise and knowledge of developers, regulators, advisors and NGOs, gained since the last guidance revision (thanks goes to these parties for their contributions of time and information to this study). As a result, we hope that the recommendations that have been produced highlight some important points that will prove useful in the further development of applicable guidance.

5.1.1 Research gaps

It is considered that areas for further work fall into three categories; viz:

- **Uncertainties about how marine mammals react to ADDs** (this review has highlighted the differences in state of knowledge between the various species and hearing groups);
- **Technology development** (improvements required to ADD technology in order to effectively mitigate the risk of injury for multiple species and sites); and
- **The need for revisions to the current piling mitigation protocol** in order to further promote a risk based approach and the use of ADDs as one of a suite of mitigation techniques approved for use by SNCBs in site specific guidance.

The following sections discuss the uncertainties and key questions along with recommendations and further studies that may be required, as well as indicative costs.

5.1.2 ADD efficacy

As summarised in Section 3.2.4 there are a number of very promising ADD devices on the market. However, before adoption of ADD use in a mitigation strategy can be fully supported there are a number of uncertainties that need to be addressed and these currently differ between priority marine mammal species. These are:

1) Can basic deterrence using (any) candidate signals be demonstrated at appropriate effective ranges, and in any environment?
2) Can this deterrence be demonstrated in environments similar to those where UK OWFs are likely to be constructed?
3) How long term[20] is this response? Is there evidence for any habituation in the context of a piling operation?
4) What is the flexibility of the effective range of devices that have already been developed – i.e. can the signal be modified to manipulate the effective range to ensure that disturbance is minimised whilst ensuring protection from injury?

These questions have been answered to a greater or lesser degree for the species considered in this review. Table 5.1 summarises our review of the evidence base to date and highlights where the key gaps are for each species.

[20] *Long term in this context means over the timeframe required for the construction of a typical R3 and STW offshore wind farm, i.e. over multiple years.*

Table 5.1 Summary of evidence base for ADD effectiveness for the 5 priority marine mammal species

	Harbour porpoise	Grey seal	Harbour seal	Bottlenose dolphin	Minke whale
Q1 Basic deterrence	✓	✓	✓	×	×
Q2 Deterrence in 'Offshore' environment	✓	×	×	×	×
Q3 Long term responses	×	×	×	×	×
Q4 Flexibility of effective range	×	×	×	×	×

5.1.3 Candidate ADDs

Although the requirements for each species may differ slightly given what evidence already is available, it is recommended that the main candidate ADDs that are tested for each species are the Lofitech, the Genuswave, and if it can be developed for field use within the timeframe required, Kastelein's multispecies porpoise/seal device (additional funding is likely to be necessary for this). It should be noted that some of these devices have the flexibility to play a variety of candidate aversive sounds which could further improve performance. However, testing numerous candidate devices, with multiple candidate signals, would lead to more costly, lengthy and complex field trials. Consequently, we have focused on providing recommendations related to the testing of devices and signals that are available now (or in the very near future), rather than suggesting investment of research funding into future unknowns.

5.2 Species specific recommendations

Whilst currently available ADDs could be adopted with reasonable confidence for harbour porpoise (although it would be useful to replicate the effective range study carried out by Brandt *et al.* (2013) at another site to determine how site specific this response may have been) there are uncertainties over the effectiveness of ADDs for the other priority marine mammal species. The following sections outline the priority research for each species.

> It must be highlighted that the studies required to carry out behavioural response research are time consuming, expensive and logistically difficult. A large degree of effort must be expended to obtain what can be a small sample size. However these studies are achievable with the right degree of investment. The military and the oil and gas industry have been funding large scale behavioural responses studies on large whale species for the last two decades (e.g. SOCAL in the US, Southall et al., 2012, BRAHSS in Australia and the 3S project in Norway) and these have been major undertakings, involving large multidisciplinary research teams. The resulting small sample sizes and high variability in field conditions require the use of complex analytical methods. A dedicated project, MOCHA, has been set up to develop and apply sophisticated statistical methods to the analysis of these data. The research recommended to be carried out in Phase 2 will benefit from all of the work in this area and the research community's experience in dealing with these challenges. In addition, behavioural response studies on harbour porpoise (Brandt et al., 2013) and on seals (on going NERC funded RESPONSE study at SMRU, recent Marine Scotland funded ADD playback trials) have also been carried out recently and suitable methodologies have been demonstrated and tested in the field.

5.2.1 Harbour porpoise

5.2.1.1 Uncertainties/key questions

There is a growing evidence base to support the adoption of ADDs to reduce the risk of auditory injury to harbour porpoise during piling. The remaining uncertainties are related to long term responsiveness and whether the effective range can be manipulated depending on the mitigation zone required for a given project.

5.2.1.2 Recommendations/further studies

The priority research for harbour porpoises is the testing of existing ADD device signals to determine site specific variation in effective range, whether the effective range can be manipulated and the efficacy of signals designed to elicit a 'startle response'.

A practical short term research topic would be playback experiments[21] on wild harbour porpoises using a combination of focal behavioural observations (to measure close range responses) and static moored acoustic recorders in the open sea (to measure wider scale responses). Context specificity may be less of an issue for harbour porpoises as the evidence base to date suggests that deterrence is reasonably complete out to large ranges, indicating little variability in response in a variety of habitats. However, passive acoustic monitoring during playbacks or as part of the industry trials (i.e. carried out at commercial OWF construction sites) could help to elucidate the behavioural context of responses.

Note there are systems that have the flexibility to incorporate new sounds, however field research to test a different number of sounds will require more field trials which will increase cost and complexity. This review has therefore focused on the testing what is available in the short-term, rather that recommending further investment in lesser known (albeit potential longer-term) options.

5.2.1.3 Pre-requisite considerations and costs

An EPS licence will be required for this type of field trial, therefore we recommend that a protocol is developed that will ensure that any resulting disturbance will not significantly affect individual animals or local populations as a whole.

Other activities being carried out in the area will also need to be considered whilst planning and licencing for these field trials to ensure that there is not the potential for significant cumulative impacts.

The costs involved for an independent fine scale behavioural response study for one ADD sound, involving visual observations from a vessel, would be in the region of £100k to £150k.

For the testing of more than one ADD sound, costs could extend to £200k to £250k.

An additional standalone array of 10 autonomous acoustic loggers and moorings, installation, service and data retrieval visits would cost in the region of £200k.

Such costs would also depend on any synergies with other monitoring programmes (e.g. Marine Scotland Strategic east coast PAM studies; SAMMO PamBuoy deployment (passive acoustic monitoring study being carried out by the University of St Andrews with monitoring locations off St Andrews Bay, Angus and Aberdeenshire coasts) or any industry-led PAM studies at OWF sites, this would be particularly pertinent at any proposed sites with high harbour porpoise density).

Other Species

For the other species considered in this review, there are major uncertainties that need to be addressed before adoption of ADD use in a mitigation strategy can be fully supported. We have identified a number of specific research questions that could be addressed during Phase 2 of this project and these are listed below, per species group, in order of priority.

[21] *The process of replaying pre-recorded acoustic recordings to monitor response in target to marine mammal species.*

5.2.2 Grey and harbour seal

5.2.2.1 Uncertainties/key questions

1. How do grey and harbour seals respond to ADD signals in the 'offshore' environment?
2. What is the effective range of the various candidate deterrents and can it be manipulated?
3. How context specific are responses? For example do seals respond differently when they are exposed to ADDs when travelling compared to when they are foraging? This will have implications for the degree of effectiveness at different sites depending on seals' functional use of the area.
4. Do grey and harbour seal habituate to the candidate signals and how is this affected by context?

5.2.2.2 Recommendations/further studies

A priority short term research project that would address questions 1 - 3 would be to carry out a targeted behavioural response trial(s) using a combination of seal tracking methods. Such research would involve capturing and tagging of a sample of seals at haul out sites in proximity to the areas of interest (Section 5.7), tracking them in real time and carrying out targeted behavioural response trials from a boat using the candidate ADD systems (using the devices themselves or utilising a playback system for playing alternative signals, such as that used by Gotz and Janik (2010)). In order to address question 4, long-term studies could be undertaken at active OWF sites and in conjunction with construction monitoring programmes.

5.2.2.3 Pre-requisite conditions and costs

Given that most concentrations of harbour and grey seals are associated with SAC populations, there are likely to be licencing requirements for such trials, so protocols need to be developed to ensure that any resulting disturbance will not significantly affect SAC integrity. There is also the potential for incidental exposure to cetaceans therefore an EPS licence will be also be required. As mentioned for harbour porpoises, all other activities being carried out in the area will also need to be considered whilst planning and licencing for these studies to ensure that there is not the potential for significant cumulative impacts.

Based on costs for the recent Marine Scotland funded work in Kyle Rhea, it would cost approximately £200k to carry out a single study to test the effectiveness of a single ADD, tagging approximately ten seals (including RTT tags, SPOT tags, base stations and a direction finder system) and working at sea over a period of approximately a month carrying out response playbacks. Costs to cover both species would be approximately £350k to £400k.

Fine scale responses can be measured using real time tracking (RTT). It is unlikely that seals can be reliably encountered in sufficient numbers to carry out meaningful playback trials at sea and the possibility of tagging animals provides opportunities for the collection of data that is currently not possible for cetaceans. Techniques available for RTT of seals include a new UHF tracking system which was commissioned and tested by the Sea Mammal Research Unit (SMRU) in collaboration with the NERC/Defra RESPONSE project. When used in conjunction with small satellite tags (ARGOS tags), this system can measure both close range and wider scale responses to ADDs for targeted playback trials in the field with both harbour and grey seals, (as well as providing wider scale responses, the data from the ARGOS tags can be used to locate animals in the field that may not have returned to the primary haul out site). The movement data from the tags will provide information on the effective range of the different signals. For both species, the real time movement data can be used to infer whether seals are primarily foraging or travelling (McConnell et al. 1999).

5.2.3 Bottlenose dolphin

5.2.3.1 Uncertainties/key questions

1. How do bottlenose dolphins respond to ADD signals in the offshore environment?

2. What is the effective range of the various candidate deterrents?
3. How context specific are responses? For example do dolphins respond differently when they are exposed to ADDs when foraging compared to when they are engaged in other behaviours?
4. Do bottlenose dolphin habituate to the candidate signals and how is this affected by context?

5.2.3.2 Recommendations/further studies

Bottlenose dolphins may be considered to be less at risk of auditory injury than the other species considered here, given that on the east coast of Scotland their distribution is very 'coastal' and does not overlap considerably with the predicted injury ranges from the areas currently identified for OWF development. Populations in other parts of the UK (the South West of England and Cardigan Bay in Wales) may range more widely over potential wind farm sites. As well as testing commercially available devices, experimental playback methodology for research on wild bottlenose dolphins is established (Gannon *et al*., 2002, King and Janik, 2013) and can easily be used for behavioural response studies to other sounds. Concurrent acoustic recording of call types can add context to behaviour and trials can be focussed to determine differential responses in foraging animals versus those engaged in other behaviours. Individual recognition of some animals may allow the potential to study the effect of repeated exposure over time. Wider acoustic monitoring arrays could be used to examine wider scale responses of dolphins, outside of what can be monitored visually (as described above in the harbour porpoise section).

5.2.3.3 Pre-requisite conditions and costs

An EPS licence as well as a licence to carry out research on an SAC population will be required for this type of study therefore it is important that a protocol is developed that will ensure that any resulting disturbance will not significantly affect individual animals or local populations as a whole. Protocols will need to take into account that these are resident populations and therefore the potential for repeated exposure to the same individuals will need to be considered. Other activities being carried out in the area will also need to be considered whilst planning and licencing for these studies to ensure that there is not the potential for significant cumulative impacts.

Considering this as an independent study, the costs involved would be in the region of £100k - £150k for a field study to measure the short term response to a single device. For the testing of more than one ADD sound, costs could extend to £200k to £250k. As discussed in the harbour porpoise section, an additional standalone array of 10 autonomous acoustic loggers and moorings, installation, service and data retrieval visits would cost in the region of £200k – it may be possible to identify sites where both species could be targeted and therefore these costs would be shared across the species (see below). Such costs would also depend on any synergies with other monitoring programmes.

5.2.4 Minke whale

5.2.4.1 Uncertainties/key questions

For minke whale there is very little data on the response to ADDs so even very basic deterrence would need to be demonstrated:

1. How do minke whales respond to ADD signals?
2. How do minke whales respond to ADD signals in the offshore environment?
3. What is the effective range of the various candidate deterrents?
4. How context specific are responses? For example do minke whales respond differently when they are exposed to ADDs when foraging compared to when they are engaged in other behaviours?
5. Do minke whale habituate to the candidate signals and how is this affected by context?

5.2.4.2 Recommendations/further studies

It is unlikely that a sufficient sample size could be achieved that would answer all of these questions, so demonstrating basic deterrence should be a priority. Although the number of minke whale sightings can be high during the summer months in some coastal areas around the UK, the potential for achieving an adequate sample size during a dedicated study is uncertain. Given this uncertainty it would not be cost effective to carry out a dedicated study for minke whale alone. Rather, it would be preferable to carry out response trials to minke whales opportunistically during studies targeted at other cetacean species. Responses to playback from boats would be measured using visual tracking methods. However data from monthly boat or aerial marine mammal surveys from OWFs around the UK could be examined in more detail to ascertain whether there are any areas which have reliably high encounter rates for minke whales to justify targeted studies.

5.2.4.3 Pre-requisite conditions and costs

The same EPS licencing considerations as described for harbour porpoise and bottlenose dolphins are also relevant for minke whales. Also, as previously discussed the issues associated with disturbing seals for which SACs have been designated must be considered

It is not possible to provide an estimate for costs of minke whale field trials given the recommendation that they should be carried out on an opportunistic basis during field trials for the other species. It is possible that sightings would be sufficiently high to add days on to boat costs for the field trials suggested above, but clearly this is highly dependent on encounter rates.

5.3 Technology development

5.3.1 Uncertainties/key questions

1. What is the effective range of the various candidate deterrents under field conditions?
2. Can the range be understood, extended and reduced under certain circumstances?
3. Can new sounds be developed for target species that aren't currently available?
4. Can the devices be developed to reduce the likelihood of habituation?

5.3.2 Recommendations/further studies

Once the efficacy of current candidate devices has been understood, these studies should be used to inform the future enhancement and development of the ADDs. In particular, it will be important to ensure that the studies can demonstrate a dose-response relationship including the noise level received by the mammal and the frequency and temporal characteristics of the sound. Past studies have primarily concentrated on the response of animals to the sound with very little attention being paid to the received sound level and characteristics that evoked that response – i.e. the dose.

A review of the various measurement reports pertaining to different ADDs shows that there is a great deal of variability regarding how the sound they produce is measured and reported. This makes the job of establishing the level and character of sound that elicits a response very difficult and also presents difficulties to those who require sufficiently detailed noise data to undertake noise impact studies for the use of the devices. It is therefore recommended that a standardised measurement protocol is put in place for the measurement and description of the acoustic outputs from ADDs. This should include methods for measuring and reporting on the acoustic sound level (e.g. peak pressure level, SEL and rms levels), frequency characteristics (third-octave band levels/PSD) and temporal characteristics (waterfall plots/time histories etc.). Such a protocol could be developed based on work currently underway on the standardisation of underwater noise measurement by TNO (Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk), NPL (National Physical Laboratory) and others.

It is anticipated that networks of deterrent devices could be installed over large areas in order to extend the range of the devices. Some careful consideration would have to be given to how these systems would be coordinated to avoid confusing or trapping animals and potentially herding them towards the piling. Some devices currently being developed (e.g. Genuswave) provide a potential solution by acting as coordinated networks that can be remotely activated. An alternative approach would be to increase the range of devices by increasing the sound power level, although this has the potential to increase the risk of causing injury to marine mammals. This risk could be reduced by carefully ramping up energy output over time. As a rule of thumb, the power rating of the ADD would need to be roughly quadrupled in order to double the effective range (although there are many factors that could affect this).

It will also be important to review and link in to EU knowledge and experience as it is considered that there is more to learn about the approaches being taken in other countries.

5.3.3 Costs

The costs for studying the effective range of deterrent devices and mammal response was covered in the preceding sections. It is likely that once some of the questions relating to range and mammal response are answered the ADD manufacturers will be keen to make use of that enhanced understanding to develop new devices. It is not therefore expected that any additional costs would be required over and above those already discussed, other than those borne by ADD manufacturers the eventual cost of the ADDs themselves.

The cost of producing an ADD test protocol (Table 5.2) is uncertain at this point as it will be dependent on how much could be taken from current standardisation of measurement of underwater noise measurement by TNO, NPL and others.

5.4 Policy/guidance/approach

5.4.1 Uncertainties/key questions

1. There is a need to improve UK wide mitigation guidance to further promote a risk based approach on a project-specific basis.
2. Further work is needed to ensure that the ADDs do not cause disturbance over an unnecessarily large area whilst remaining effective[22].
3. If soft start is to be used in conjunction with ADDs there is a need to adopt a simple protocol for defining how the two mitigation techniques should work together.

5.4.2 Recommendations/further studies

The current piling mitigation protocol (JNCC, 2010b) allows for some flexibility of approach in specifying mitigation. However, the fact that the protocol suggests a fixed mitigation zone and soft start time may lead to use of insufficient mitigation in some circumstances. It is therefore recommended that the protocol be revised to further promote a risk based approach on a project specific basis, encouraging the use of ADDs where appropriate. At present, JNCC plans to continue to review its mitigation guidelines (seismic/piling and explosive) with some regularity so that these reflect current understanding of the science and remain practical and applicable. There are plans to review the piling guidelines very shortly and the recommendations in this report will be an essential component of the review, including the recommendation for more guidance on soft starts and project specific/ risk based approach.

If soft starts are to be used in conjunction with ADDs there is a need to adopt a simple protocol for defining the soft start procedures and in particular for determining the required soft start time in order for soft start to be effective.

[22] *For small pin piles current ADD devices may be overpowered, potentially eliciting a flee response over a greater area than necessary.*

Said guidance should ensure that all soft start times are determined on a project specific basis, the potential injury zone and on the requirement to reduce hammer energy to a sufficiently low value (e.g. at least a tenfold reduction in energy) and not to ramp up the hammer energy too quickly[23]. Because the size of the potential injury zone (and therefore the soft start time requirement) is primarily dependent on the criteria adopted, it will also be important to provide guidance on which criteria should be adopted.

A UK wide application of risk based site specific mitigation strategy development would encourage the use of appropriate mitigation measures and prevent insufficient mitigation being applied, it should also encourage the scaling down of ADDs where appropriate to minimise the potential for widespread disturbance.

5.4.3 Costs

The anticipated cost to produce a practical guidance note that is agreed with developers, regulators, NGOs and SNCBs is £5, 000 – £10,000.

5.5 Draft Phase 2 research topics

This section compares the above research recommendations against the research topics presented in the current (16 December 2012) draft of the structure and content of ORJIP Project 4, Phase 2, specifically focussing on which research areas we recommend should be taken forward by Project 4, which could be improved based on the available evidence base and which should be prioritised to enable current knowledge gaps to be closed out. This is summarised in the following table, overleaf (Table 5.2). The anticipated duration of the proposed research is 2 years, subject to unavoidable consequences.

[23] *It is recognised that under certain circumstances it may not be practical to implement soft starts due to engineering constraints. This further highlights the importance of a risk based approach that provides the flexibility to respond to a variety of scenarios. A realistic worst case scenario for the project in terms of soft start will be required to inform the Design Envelope and design commitments at EIA. Engineering specific piling protocols are ascertained on a site by site basis based on the knowledge of the parameters of the site (including water depth, geophysics and substrate). Environmental advisors will need further involvement during the selection of the site piling protocol, however, if this step is carried out pre consent then this information could be front loaded during FEED to address any perceived challenges.*

Table 5.2 Summary of research topics

	Title	Scope of Work	Task summary	Product	Cost	Comments
Proposed research package	**1.Understanding aversive sounds**	To further advance our knowledge of what would be an effective deterrent sound for these animals, individually or collectively, including comparisons of “natural” and “synthetic” sounds.	Dependent on the results from the current SMRU work, undertake research and, if possible/practicable, experiments to further our understanding of sounds which deter animals from a given area of the sea.	Report(s) describing what aversive sounds are for different species. A methodology/ protocol for measuring the effectiveness of ADD/deterrent devices.	Developing and testing (captive animals): Budget approx. - £100k. Conducting Tests in realistic field conditions: Budget approx. £100k to £200k.	*Part of this scope has already been covered in the current review and there is evidence (Section 3.3.2) that some devices are effective and others provide good candidates for further testing.*
Recommended revised scope (if applicable)		*See Section 3.3.2 for Key uncertainties surrounding current ADD effectiveness*	*See Section 5.2 for recommended field studies*	-	*Budgets need to be revised upwards.*	-
Proposed research package	**2. Develop effective ADDs**	Develop effective ADD for: > Grey and harbour seals; > Harbour porpoise; > Bottlenose dolphin and common dolphin; and > Minke whale.	Produce specification for an ADD which could then be given to manufacturers.	Specification leading to device production.	Specification – Approx. Budget £30k. Actual Device – Approx. Budget £50 – £100k.	*Development of ADDs for some of these species already underway.*
Revised scope (if applicable		*Specifications already exist for some potential aversive sounds.* *Some devices already in development.* Potential candidates:	*Further develop ADD specifications.*	*Modular device design for multispecies use.*	*Minimal for the specification once the experimental work above has been carried out.*	-

	Title	Scope of Work	Task summary	Product	Cost	Comments
		> Modular device design of Ron Kastelein; and > Genuswave 'startle-response' device already in production for seals, signal would need to be developed for harbour porpoise, minke whale and dolphin sp. Note that bottlenose has been used here as a representative of other delphinids, including the common dolphin.				
	3. Develop ADD test protocol	Produce a protocol for testing the reliability of ADDs, i.e. testing the level and quality of the sound emitted, should be developed so that manufacturers can use it.	This protocol should set out a repeatable methodology including describing the equipment and process to be followed by manufacturers etc. when describing the aversive sound produced by their particular equipment.	A test protocol with standards for measurement and reporting.	*Costs uncertain depending on how much could be taken from current standardisation of measurement of underwater noise measurement by TNO, NPL and others.*	*It has been identified through the current review that there is a wide range of output values reported from available ADDs and therefore a repeatable protocol to test ADDs prior to use and intermittently throughout operation is required.*
	4. Guidance note	Produce a practical guidance note that is agreed with developers, regulators, NGOs and SNCBs. This protocol should aim to minimise the use of MMOs offshore.	Protocol should also aim to help with the consenting issues in relation to the use of ADDs in English, Scottish, Welsh and Northern Irish waters to detail deliberate disturbance issues and inform the licence application process.	Guidance note.	£5-10k.	*Protocol needs to be informed by the findings of our review on efficacy, potential for negative effects, practicalities, cost and H & S. Assumption is that ADD use is a tool which can be adopted on a site by site basis if appropriate. Guidance should be developed to encourage the site specific approach.*

	Title	Scope of Work	Task summary	Product	Cost	Comments
			As part of the protocol, a feedback loop for providing information on the effectiveness of ADDs could also be developed.			

For clarity, the costs presented above were estimated on the assumption that each research project will be carried out independently. Should it be possible to carry out field trials at a single site for a number of species then these costs (including number of staff, vessels and equipment) will be lower than the simple addition of costs across all the independent studies. However the overall duration of trials in a single location will need to increase to ensure adequate sample sizes for multiple species and therefore the extent of the reduction in cost will depend on the encounter rate of each species.

5.6 Field trial sites

As discussed further in Section 5.2, any field test sites selected should have a high enough encounter rate for target marine mammal species to provide a robust data set. Long term research in such field trial sites has two key limitations:

- It is unlikely that a trial would be licenced given the potential for a significant effect on local populations; and
- The effect of piling itself may limit habituation so testing in isolation without the piling context may not be appropriate.

For these reasons it is recommended that the questions of long term effectiveness are addressed separately as part of ADD field trials during the construction phase of planned OWF developments and that short term field trials focus on specific questions outlined above for each species. For the longer term effectiveness it will be desirable to specify targeted data collection at construction sites of consented projects, as ADD use is adopted during construction (based on the findings of the short term field trials). However, if the short term trials into the effectiveness of signals can demonstrate that ADD are unlikely to lead to habituation then there may be less need for an extensive industry trial prior to considering revising current mitigation guidance.

5.6.1 Site selection

From a cost and practical perspective it would be preferable to have a single site and a single experimental framework to carry out the recommended short term studies; however it may be necessary to focus effort on a number of sites. The rationale behind this is that siting all of the ORJIP related studies at one site may lead to a build-up of exposures by the resident population of marine mammals. A varied number of sites would allow the research to:

- Maximise the likelihood of testing across a variety of site characteristics (thus increasing the likelihood that the research will be applicable to current and future OWF sites);
- Obtain an adequate sample of the species of interest;
- Limit the sound exposure levels imposed on a specific population; and
- Ensure sample independence.

In addition to logistical and site characteristics, the following factors have been taken into consideration during the identification of sites suitable for trials:

- Given the difference in techniques proposed for measuring the responses to noise between seals and cetaceans, it is likely that that separate studies will need to be carried out for seals and cetaceans;
- A single site may be identified to focus cetacean trials, primarily on harbour porpoise but other species may also be studied opportunistically;
- Haul out areas can be targeted for tagging seals which can then be tracked anywhere at sea;

- Opportunistic playback experiments could be carried out if cetacean sightings were made during seal tracking studies, wherein ADDs are deployed and responses are visually or acoustically monitored; and
- From a risk perspective, bottlenose dolphin and minke whale are probably lower priorities for research. Although it must be borne in mind that for developments proposed in areas where these species might be important, without this further work ADDs are unlikely to form an important part of mitigation strategy at these sites and more reliance may need to be placed on passive mitigation methods.

5.6.2 Heat mapping

A heat mapping exercise was carried out to inform the selection of recommended field trial sites for which sufficient data was available at the time of the study[24] for harbour porpoise, harbour and grey seal (see Appendix H).

The key parameters that informed the selection of the proposed sites included:

- High species density[25] for each of the priority marine mammal species, in order to achieve adequate sample sizes;
- Water depths characteristic of proposed OWF sites, to ensure representativeness;
- Within close enough proximity to a suitable port to allow easy mobilisation and safe passage/working.

For simplicity, locations for each of the three species were considered in isolation, as shown in Figures 5.1 to 5.3 below. Sites for bottlenose dolphin were determined based on expert judgement, but it is recommended that they be re-assessed once the upcoming JNCC Joint Cetacean Project data becomes available.

It is further appreciated that a full discussion of the appropriateness of these sites and the development of the protocols for any trials will be needed with regulators and SNCBs. Detailed consideration will also be need to be given to other activities taking place in the region with the potential to contribute to cumulative impacts and licensing considerations (as discussed above) will be important in shaping protocols. However the key potential sites identified in principle based on the criteria discussed above are as follows:

5.6.2.1 Harbour porpoise

As mentioned above it is recommended that the selection of a suitable field site should be informed by other monitoring programmes (e.g. Marine Scotland Strategic east coast passive acoustic monitoring studies; SAMMO PamBuoy deployment (PAM study being carried out by the University of St Andrews with monitoring locations off St Andrews Bay, Angus and Aberdeenshire coasts) and any industry-led PAM studies at OWF sites (which would be particularly pertinent at any proposed sites with high harbour porpoise density such as The Wash).

5.6.2.2 Dolphins

Potential study sites for the behavioural responses of dolphins to ADDs include areas where dolphins are known to regularly forage such as parts of the Moray Firth and the Grampian and Angus coastlines in Scotland.

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[24] The research team is however aware of other data sources for harbour porpoises identifying other more localised areas may have higher density than the SCANS maps presented below. Such data was however not available at the time of writing but should be given further consideration when finalising the field test sites.

[25] Whilst it is impossible to define an exact density above which a site would be considered, the key requirement is that the likelihood of encountering marine mammals at sea is high enough to ensure an adequate sample size.

5.6.2.3 Seals

Several sites have been identified as having the potential to carry out these studies. The main requirements being: areas where there are concentrations of seals at accessible haul out sites (for capture of animals and siting of base stations) associated with areas of high densities of seals at sea to maximise the chances of finding tagged animals at sea.

Harbour seals: tend to be more predictable in their movements showing a greater degree of site fidelity and therefore may be more amenable to tracking studies of this type than grey seals. However harbour seal populations are in decline in several parts of East Scotland so it is unlikely that licences would be granted for this type of study at any of the haul outs in East Scotland associated with Special Areas of Conservation. **The Wash or North Norfolk (Blakeney Point, Scroby Sands)** are therefore identified as good candidate sites for studies on harbour seals[26].

Grey seal: populations around North Sea coasts are not in decline and there is a wider choice of sites at which to tag animals. Large concentrations of grey seals haul out regularly at known haul out sites on the east coast of Scotland, for example, many hundreds to a few thousand grey seals regularly haul out at **Abertay sands at the mouth of the Tay Estuary**. There are foraging hotspots in the **outer Forth and Tay around sand banks such as Wee Bankie and Marr Bank** but there may be concerns that carrying out playbacks in areas where harbour seals associated with declining populations may be present. Grey seals are much more wide ranging than harbour seals so it may prove more challenging to relocate tagged animals in the field. ARGOS telemetry and a mobile tracking team will be key to ensuring that animals can be located and targeted for response studies.

There are also large haul outs of grey seals around the **Welsh coastline**. Haul outs at the **Dee Estuary** could also potentially provide a tagging site to track grey seal responses to ADD signals.

5.6.2.4 Minke whale

Dedicated field trials for minke whale are unlikely to be cost effective, so it is suggested that response trials for this species are undertaken opportunistically during studies designed for other species. Nevertheless, it may be advisable to select sites that where the probability of minke whale sightings is high, such as the Moray Firth during summer.

5.6.2.5 Multi species field sites

As discussed above in the introductory text to Section 5, an experimental framework at a single site that could be adopted across multiple species would be preferable. To carry out trials at a single site to cover multiple species, there will need to be compromises in terms of encounter rates for multiple species as there is little overlap in the highest density areas for all species. Sites with the potential for reasonable encounter rates of several species include parts of the Moray Firth and the Aberdeenshire coastline.

Given the techniques required for real time tracking of individuals it is unlikely that behavioural response studies could be carried out on several species using the same series of exposures and multiple series of exposures will be required to cover enough individual responses for each species. Consideration will also need to be given to the degree of independence between exposures, particularly for seals if the same tagged individuals are exposed to multiple exposures. The presence of static acoustic devices in these regions may enable the incidental measurement of the wider scale responses of cetaceans during exposures directed at seals, but the likelihood of this will depend on baseline levels of acoustic activity prior to exposures and also will be reliant on seals tagged at haul outs travelling to these areas.

[26] *Note although the implications of conducting trials near SAC are unlikely to impact Wash seal SAC as seal home ranges are well known, there is the potential for impact on the grey seal Donna Nook colony. Given that grey seals range widely careful site selection is required if this site is taken forward to fully eliminate any potential impact.*

5.6.2.6 *Heat mapping summary*

Examples of the heat mapping used to inform the selection of the recommended test sites summarised below are shown in Figures 5.1 – 5.3.

For harbour porpoise:

- The Southern North Sea, adjacent to the Humberside and Lincolnshire coast.

For harbour seals (tagging at a haul out and tracking in real time at sea):

- The Wash; and
- Moray Firth.

For grey seals (tagging at a haul out and tracking in real time at sea):

- Moray Firth;
- The Farne Islands; and
- Forth and Tay (with playbacks only taking place where animals tracked outwith area used by harbour seals, i.e. further offshore).

For bottlenose dolphin (due to insufficient mapping data, locations based on professional knowledge rather than heat mapping):

- Moray Firth;
- Cardigan Bay; and
- Grampian and Angus.

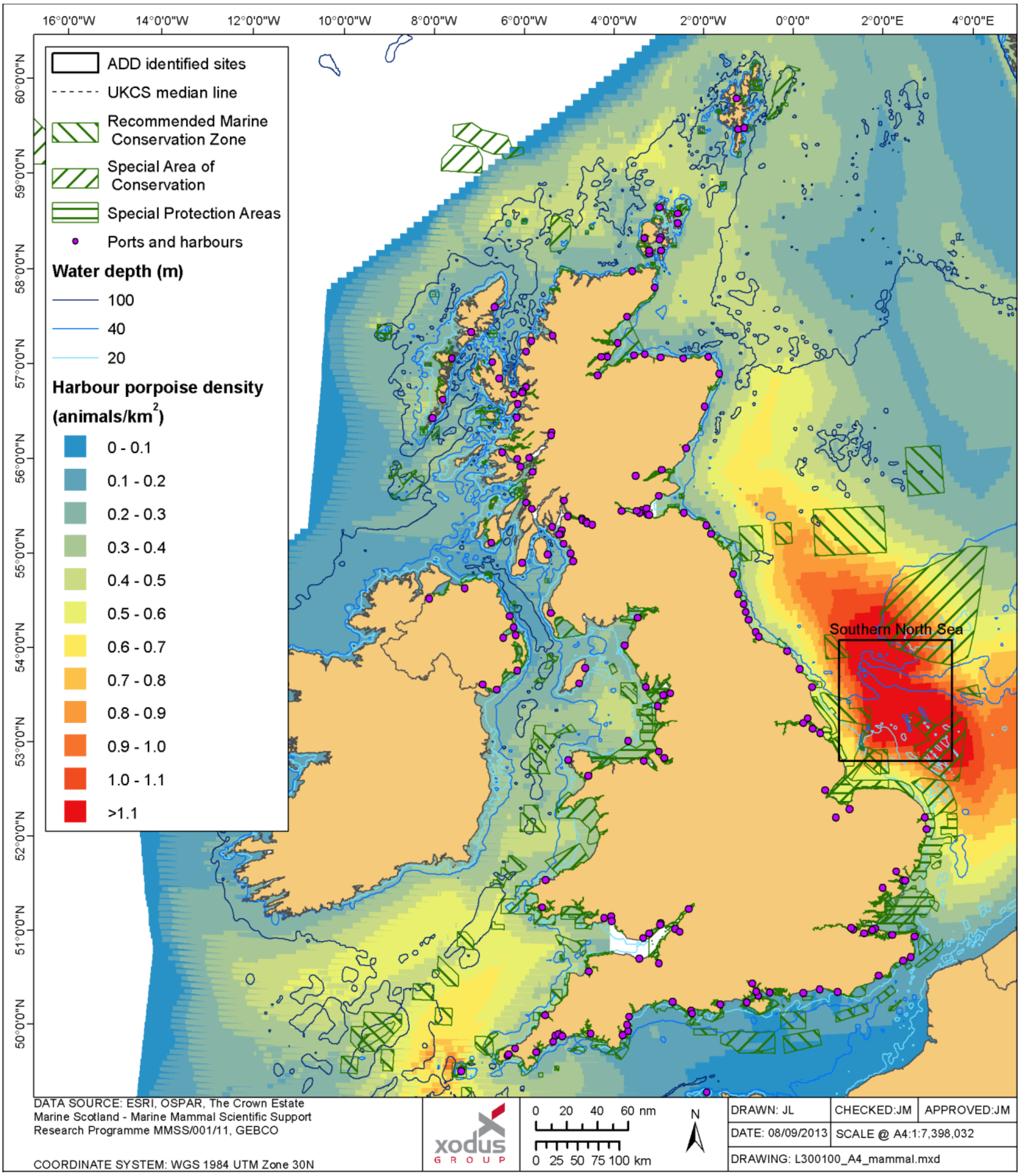

Figure 5.1 Identified field trial site locations for harbour porpoise

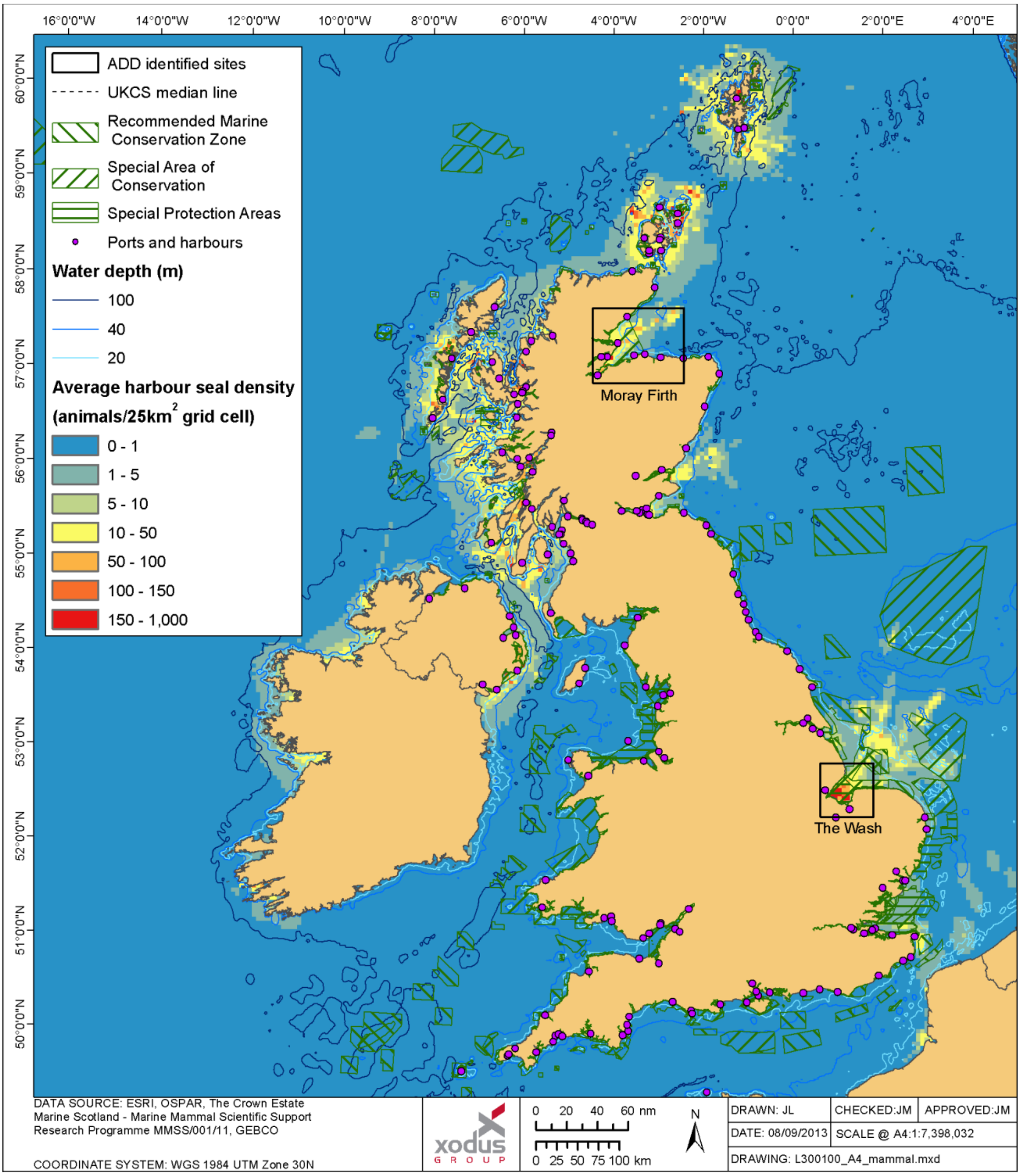

Figure 5.2 Identified field trial site locations for harbour seals

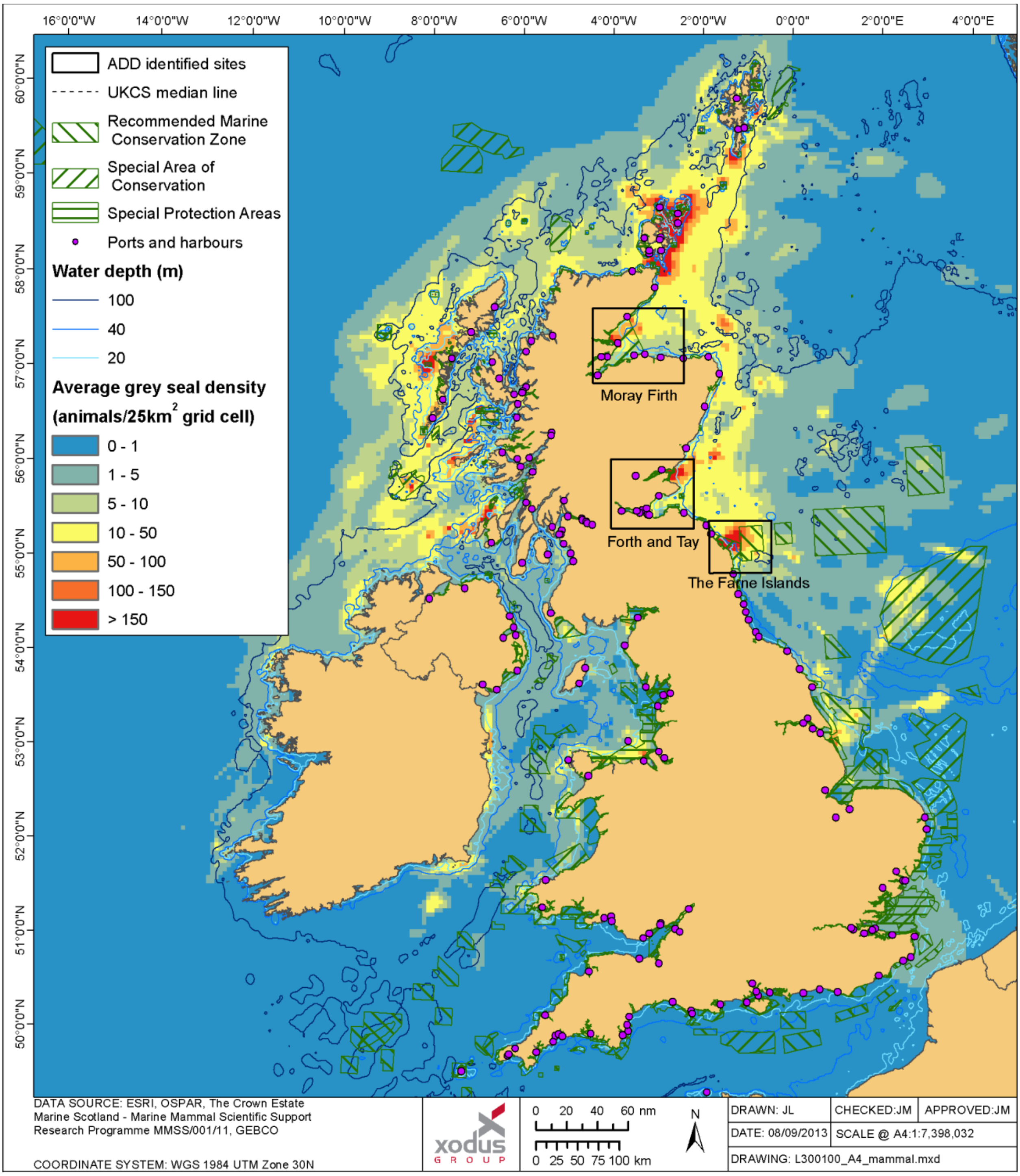

Figure 5.3 Identified trial site locations for grey seals

6 CONCLUSIONS & RECOMMENDATIONS ROADMAP

The current piling protocol (JNCC, 2010b) forms part of the more general guidance on EPS (JNCC, 2010a in prep). The recommendations made in these non-statutory guidance were considered best practice for piling operations at their time of preparation. The general guidance is currently being revised by Defra and Marine Scotland (separately due to the distinction between a disturbance offence in Scotland and the other UK territories). It is therefore timely, given the pending Round 3 and STW OWF projects and greatly expanded evidence base, to revisit the current mitigation protocol (JNCC, 2010b) and develop a roadmap of recommendations towards future proofing any subsequent revisions.

The following conclusions have been made as part of this initial phase of ORJIP Project 4:

- The current JNCC MMMP is fit for purpose for current small scale piling operations but there is potential to progress this 'starting point' guidance to accommodate the increasing risks posed by the larger scale OWF developments proposed for the UK sector;
- The cost benefit of investing in the development of ADD outweighs the cost benefit of continuing to prioritise current passive mitigation options;
- An incremental approach to revising current guidance is required in order to allow time to develop and validate ADD as a viable MMMP for UK offshore wind farms;
- The first ideal outcome of ORJIP Project 4 would be the development of ADD devices that can be proven to be a best practice mitigation option for use for one or, ideally, all of the priority marine mammal species identified in this study;
- The second ideal outcome would be the take up of ADD and tailored soft start as the primary and preferred best practice MMMP mitigation option in the UK;
- The ultimate end point of ORJIP Project 4 should be a risk based project specific MMMP Framework, that enables developers to select and agree with regulators the best mitigation options based on their particular site characteristics (e.g. priority species present, water depth, pile size, hammer energy, substrate type, distance offshore, installation and support vessel set up); and
- A roadmap approach to research and (further) develop or validate potentially viable ADD options and support the evolution of applicable UK guidance that will serve to support all UK territories in a move towards a site specific MMMP Framework.

6.1 Recommendations roadmap

The 'roadmap' schematic overleaf (Figure 6.1) synthesises the ORJIP Project 4 recommendations and general recommendations that were raised by interested parties for consideration to support the implementation of the outputs of ORJIP Project 4. The top left hand box presents the current starting point i.e. the JNCC (2010b) marine mammal mitigation guidance and the techniques implemented by the OWF sector as standard (e.g. MMO and PAM) and voluntarily (e.g. ADD). The last box on the left shows the perceived ultimate end point of ORJIP Project 4 i.e. standardised site specific risk based MMMP Framework assessments to be carried out pre-consent. The boxes in between represent one possible scenario in terms of the incremental steps that could be made to support the evolution between the two as the evidence base to support the take up of ADD by the OWF sector. The linked boxes on the right hand side presents one possible research and support services scenario that could be considered to progress the adoption of ADD as a primary and preferred best practice MMMP mitigation option in the UK.

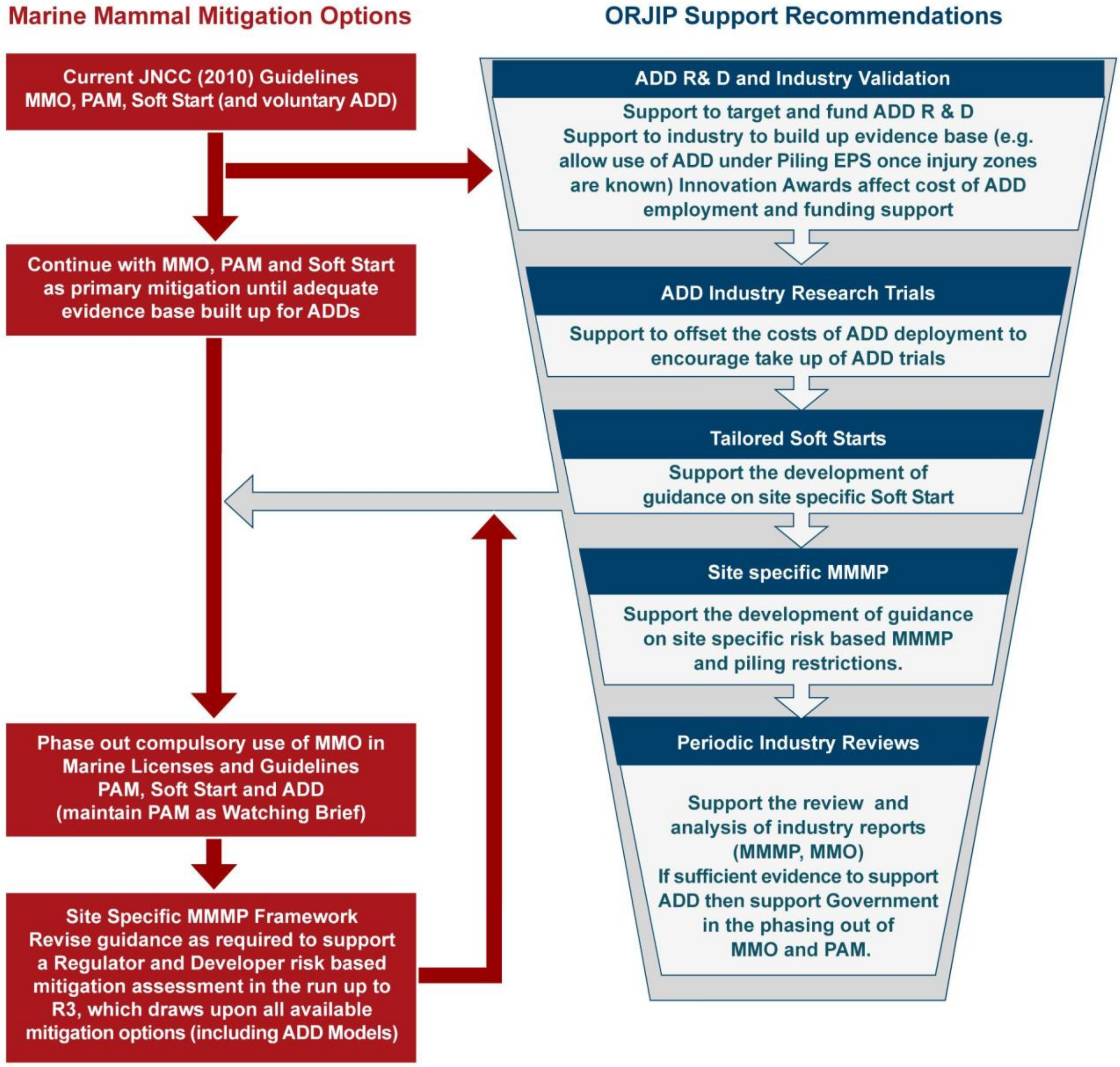

Figure 6.1 Recommendations roadmap schematic

Finally, a project of this nature has the potential to influence a broad range of stakeholders affected by the development of offshore renewables (from NGOs through to piling service providers). Every effort has been made to provide a balanced perspective during this independent review; however the findings will no doubt be subject to varying views. It will therefore be essential for the success of ORJIP that all industry stakeholders continue to work together to reach consensus on how best to take these recommendations forward. Compromises may need to be made, however any step change improvements to current guidelines, no matter how incremental, have the potential to ultimately make a material difference to the industry.

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APPENDIX A ORJIP PROJECT 4 PHASE 1 INVITATION TO TENDER

Commissioning Specification

Invitation to quote for
Offshore Renewables Joint Industry Programme –

Project 4: Use of Deterrent Devices and Improvements to Standard Mitigation Measures during Piling
Phase 1: Review of Acoustic Deterrent Device use and soft-start procedures to date in relation to offshore wind farms, and refinement of scope of works for Phase 2 of Project 4

Summary of Requirement

You are hereby invited to submit a costed proposal for desk based review and advisory work comprising Phase 1 of the Strategic Joint Industry Project 4 on the "Use of Deterrent Devices and Improvements to Standard Mitigation Measures during Piling" as part of a programme of work to be carried out through the Offshore Renewables Joint Industry Programme (ORJIP).

The proposal should be based on the provision of a set of preparatory review and advisory services required for the successful implementation and management of Project 4.

The work will be carried out for the Department of Energy and Climate Change (DECC), representing the ORJIP Interim Working Group (IWG) / ORJIP Programme Group. The successful contractor will report to a Project Manager appointed by the Interim Working Group/Programme Group. DECC is commissioning this work on behalf of the ORJIP Interim Working Group (IWG) and in collaboration with the ORJIP Interim Programme Group (IPG). It is anticipated that by the time of contracting, the programme will be established and the IWG and IPG will be superceded by the ORJIP Programme Group.

The projects within the ORJIP are important to the full range of stakeholders affected by the development of offshore renewables. In recognition of this, ORJIP is adopting a strong collaborative and cooperative approach across all industry stakeholders in developing the programme of projects, and in the delivery of these projects. Indeed, it is essential for the success of ORJIP that all industry stakeholders continue to work together on both the scoping and planning of the projects, and in management and execution of the work. This ethos must be reflected in proposal.

Background

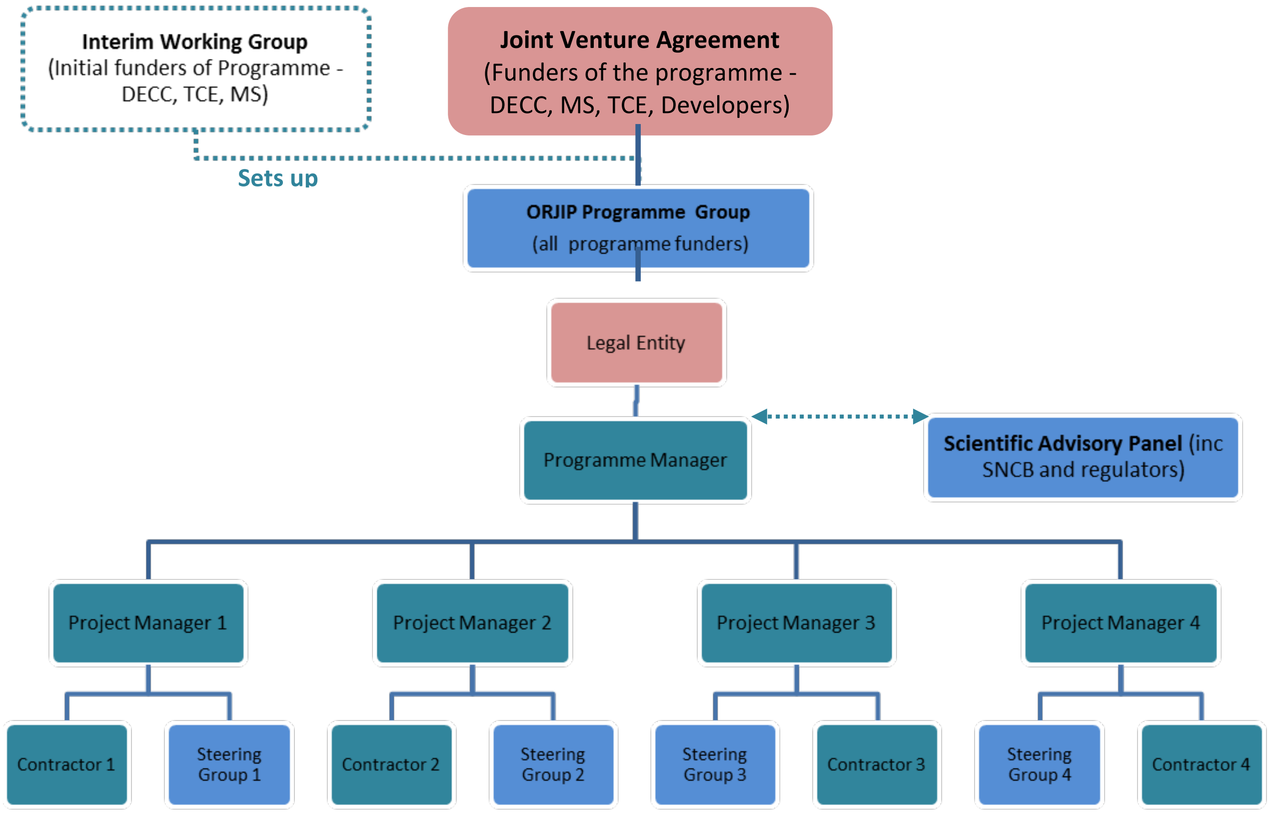
Marine Scotland (MS), The Department of Energy and Climate Change (DECC) and The Crown Estate (TCE) and the offshore wind Development community are working together to implement a Joint Industry Programme of works to fund and deliver strategic research projects to reduce consenting risk for offshore wind projects in UK waters. Addressing strategic evidence gaps is a high priority for the offshore wind sector as much of the potential pipeline of offshore wind projects is at risk. Offshore wind developments in UK waters are progressing rapidly and the outputs of this proposed programme are required to inform consent and licence applications and advice and decisions by the UK regulatory authorities. The first ORJIP projects will focus on strategic data collection and technology research to develop solutions on behalf of offshore wind developers to two priority consent (planning) risks – uncertainty about potential impacts on bird species from collision, and potential effects of underwater noise on marine mammals.

Following consultation with the UK Underwater Noise Group, the Strategic Ornithological Support Services (SOSS) group and the offshore wind industry, four priority Joint Industry Projects have been identified:

1. **Bird avoidance behaviour and collision impact monitoring**: Field studies to monitor avoidance behaviour in and around operational offshore wind farms and any collisions with turbines;
2. **Evidence gathering for Population Consequences of Acoustic Disturbance (PCAD) model**: To develop and implement improvements to the application of a PCAD framework to impacts of renewable energy projects on marine mammals;
3. **Noise mitigation technologies for piled foundations in deeper water:** Testing of devices or systems for the reduction of pile driving noise at source;
4. **Improvements to standard mitigation measures during piling:** Review, test and develop acoustic deterrent devices to be used as a substitute for Marine Mammal Observers, particularly in situations where the use of Observers creates significant safety concerns.

A number of options have been considered for the establishment and management of the joint industry programme. It has been agreed that there is significant benefit from a strategic UK-wide approach to the management of this programme. The proposal is that if industry and SNCB support is secured, a simple, independent entity will be created which will act as counterparty to the funding parties and the programme management and project delivery services.

The organisation chart below sets out our current expectations for the governance:



Roles and Responsibilities

<u>Interim Working Group:</u>

The Interim Working Group (IWG) comprises the initial funders of the programme (i.e. DECC, MS, TCE) who are currently making preparations for establishing a proposed structure for the programme governance and funding. The IWG is also leading on the initial scoping of the programme of projects, in consultation with industry, regulators, Statutory Nature Conservation Bodies (SNCBs) and Environmental NGOs. The Working Group is liaising with the offshore wind industry via the Interim Programme Group (IPG) to promote the proposals, with a view to securing commitment to providing the required financial resources to take the projects forward. Once the funding commitments are in place, and the legal entity is set up with the Programme Manager and Programme Group in place, the IWG will be dissolved and its members will join the Programme Group.

<u>Interim Programme Group:</u>

In December 2012, industry lead representatives for the development of ORJIP established an Interim Programme Group (IPG) in the run-up to final industry decisions on establishing and funding the programme in April 2013. The IPG works closely with the IWG to finalise governance and funding arrangements, approve final project scopes and agree arrangements for tendering processes.

<u>ORJIP Programme Group</u>:

The Programme Group would include all funders of the programme (including developers and DECC, MS, TCE). It would be responsible for reviewing the strategic direction of the programme, alignment of projects with the agreed scope and ensuring the benefits delivered by the project(s) are in line with the business case. The Programme Manager and Project Manager(s) would be appointed by and report to the Programme Group.

Project Steering Groups:
Each of the projects would be managed by a Project Manager and advised by a Project Steering Group. The Project Manager(s) would report to the Programme Manager. The Project Steering Group(s) would be appointed by the Programme Group and usually chaired by the Project Manager. The Project Steering Group(s) would be responsible for supporting the Programme Group in ensuring the benefits from the project are realised.

Scientific Advisory Panel:
The Scientific Advisory Panel will be responsible for advising the Programme Group on the scientific approach to the projects, including arrangements for peer review. The IWG is considering the best ways for regulators and SNCBs to be involved in the programme, in consultation with the relevant bodies, and it is likely that they will be represented on the SAP, along with relevant academics.

Other potential sources of funding
The IWG is also engaging investigating opportunities for obtaining funding for the Programme from other souces, including the Research Councils, UK Government and European Commission.

Project 4: Use of Deterrent Devices & Improvements to Standard Mitigation Measures during Piling.

1. Aims and Objectives

During the installation of piles offshore, developers are required to adhere to a Marine Mammal Mitigation Protocol which is intended to prevent injury to marine mammals. Measures include the use of Marine Mammal Observers (MMOs), delay in commencement of piling if marine mammals are present, limitation of piling to daylight hours and certain sea states, and possible use of Passive Acoustic Monitoring (PAM) devices. An alternative to either visually or acoustically making sure an area is 'clear' of marine mammals is to displace marine mammals away from an area before piling commences using Acoustic Deterrent Devices (ADD).

The aim of this project is to:

- Review, test and/or develop ADDs or other deterrent devices for multiple marine mammal species, thus reducing reliance on visual observations and increasing construction time available by removing daylight/sea state restrictions on piling activity.
- Conduct field tests in realistic conditions to provide evidence that devices will provide the required level of risk reduction for the species concerned.
- Develop protocol(s) for the use of ADD(s) as agreed with industry, advisors, regulators and NGOs.

2. Background to the project

During Rounds 1 and 2 of offshore wind farm development, the Statutory Nature Conservation Bodies (SNCBs) and wind farm developers agreed methods to minimise the risk of direct injury to marine mammals by using MMOs or PAM to ensure an area was clear of marine mammals prior to piling commencing. This is set out in JNCC (2010)[1].

These protocols have allowed the development of offshore wind farms to proceed. However, the effectiveness and costs associated with implementing such protocols have been questioned by developers and NGOs. Implementation of these measures for Scottish Territorial Waters and UK Round 3 projects will be more difficult owing to the scale of projects, the distance offshore, challenging construction programmes, multiple activities within zones and across sea areas, increasing issues with MMO availability and the Health and Safety implications of operations offshore.

COWRIE[2] commissioned reports on ADD including:

- DETER-01-07 - SMRU Ltd (2007) 'Assessment of the potential for acoustic deterrents to mitigate the impact on marine mammals of underwater noise arising from the construction of offshore wind farms.'
- SEAMAMD-09 'Acoustic mitigation devices (AMDs) to deter marine mammals from pile-driving areas at sea: Audibility and behavioural response of a harbour porpoise and harbour seals.'
- SUBAMD-09 'Measurements of underwater noise generated by Acoustic Mitigation Devices (AMDs)

The SMRU (Sea Mammal Research Unit) study investigated the potential for using ADDs for mitigation during wind farm construction, explored the types of acoustic signals that might be suitable for this application and reviewed the devices available for producing them in the field. Studies undertaken by Seamarco and Subacoustech aimed to quantify the performance of some existing ADDs and to develop practical field equipment. Subacoustech examined a set of pre-selected devices to test for loudness and emitted frequencies to get an idea of the variability across and within device types. Seamarco performed experimental tests looking at the behavioural reactions of porpoises and seals towards ADD in their captive facilities. The current project will take advantage of the background work described in these reports, and build on the opportunities that they identified.

Current measures for mitigation during wind farm construction often include the adoption of soft-start procedures to piling operations. There is a need to review the feasibility and effectiveness of soft-start procedures, answering questions such as what technology is compatible with soft-start. It is possible that the size of the hammers likely to be used in UK waters may result in very loud noise emissions, despite the relatively low piling energy used during soft-starts.

In order to achieve a more reliable, repeatable and cost effective method for ensuring that marine mammals are clear of the direct injury zone, a joint industry project (ORJIP Project 4) has been developed. When considering the scope of work covered by Project 4, marine mammal species to be addressed include:

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[1] Joint Nature Conservation Committee (JNCC) (2010) Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise August 2010' is available online: http://jncc.defra.gov.uk/pdf/JNCC_Guidelines_Piling%20protocol_August%202010.pdf

[2] COWRIE - Collaborative Offshore Wind Research Into the Environment (UK

- grey and harbour seals,
- harbour porpoise,
- bottlenose, white beaked and common dolphin (or dolphin sp.) and
- minke whales (where possible).

The work will be phased with an initial desk-top review and information gathering exercise (Phase 1)_used to inform whether a second phase, to test and/or develop ADDs further, is worthwhile and the exact scope of any works. SMRU are currently undertaking work on acoustic deterrents for Marine Scotland mainly focused on their applicability for fish farming and wet renewables, and this proposed JIP will take account of the outputs from the existing MS project to ensure best uses of available resources.

The work already commissioned by Marine Scotland aims to:

- Assess the capability and merits of existing non-lethal devices in effectively deterring marine mammals, considering their potential for use in different scenarios.

- Assess the relative effectiveness of existing devices on marine mammals, considering whether any efficiency improvements can be made by best practice in using these devices (taking into account any ecological consequences that could arise from these improvements)

SMRU are currently undertaking a Literature Review on the effectiveness of ADDs on marine mammals using primary and grey literature (and existing reviews) which will produce a synthesis as a single concise assessment of effectiveness. SMRU will use this synthesis to explore and highlight the potential benefits and shortcomings of the available methods and elaborate on the experimental approaches that will be required for policy objectives to be met in a satisfactory manner. SMRU will include measures other than acoustic deterrence in this synthesis including the use of Conditioned Taste Aversion and its potential application for marine mammals, and recent studies at SMRU on the use of electric fields to deter pinnipeds. This report is due March 2013.

The purpose of this document is to invite tenders to undertake Phase 1 of Project 4, i.e. to undertake and report on a series of desk studies.

Project 4: Phase 1 : Services required

Review of the use of Marine Mammal Observers, Acoustic Deterrent Devices (and any other deterrent devices) and soft-start procedures in relation to offshore wind farm projects to date

This review shall include (but not be limited to):

- For each constructed wind farm in Europe, a description of:
    - MMOs, ADDs or other deterrent devices if used, how they were deployed (from buoys, vessels, construction barges), location in respect of piling operation, conditions when deployed (night time, fog etc.), any issues with deployment, time between using ADD and piling;
    - The potential for adverse effect on protected species;
    - Any Passive Acoustic Monitoring undertaken and results;
    - Protocol adopted;

    - Any information on the effective spatial range of the method used;
    - Records kept (including marine mammals seen);
    - Any evidence of habituation of target species to the deterrent;
    - Any evidence of species specifificity;
    - Costs of using MMOs/Deploying ADDs or other deterrent devices, including costs of installation, operation and maintenance;
    - Any implications of using MMOs/ADDs for the activities being undertaken (time delays, costs);
    - EPS Licensing of activities (whether a licence was required, process to obtain).
- A parallel review of the use of soft-start procedures in piling operations at European wind farms. In addition to the factors listed above, the review should report on:
    - The relative noise emissions during soft-start and full power piling, and the potential for soft-start to lead to negative impacts on protected species, i.e. physiological or behavioural effects in mammals;
    - The feasibility of applying soft-start in UK wind farm projects and waters;
    - The compatibility of soft-start with various types of piling equipment;
    - Evidence for the effectiveness of soft-start in protecting sensitive species;
    - The role of other noise sources, e.g. vessels in disturbing mammals within the immediate vicinity of piling operations .
- A review of comparative aspects of Health and Safety issues related to the range of mitigations, including current measures and the actual and potential use of ADDs.

The contractor should assess the status of all available ADDs (and other deterrent devices), which ones are feasible for the species of concern for offshore wind developments in UK waters, and make recommendations regarding the need to test and demonstrate the effectiveness of those off-the-shelf devices not yet proven for offshore wind. After collating the above information, the contractor should draw conclusions as to the effectiveness of available devices in ensuring marine mammals (emphasising the species of concern) are not subject to direct injury from piling activities alongside the costs (financial, time and other resources) of using ADDs. The contractor should explicitly address Health and Safety aspects of the mitigation methods discussed, including the use of MMOs. The report should aim to provide a Cost Benefit Analysis (if possible) of the use of ADDs to date to allow industry to better understand the costs of using ADDs, any limitations and to fully understand their effectiveness in deterring marine mammals from an area.

This review should also consider the potential negative impacts of introducing further sound into the marine environment through the use of ADDs and any implications with regard to the requirements of European environmental protection Directives, specifically the Habitats Directive (including EPS disturbance licensing) and the Marine Strategy Framework Directive.

This review should lead to recommendations, with clear justification, regarding which elements of Phase 2 (see Annex), if any, should be commissioned, and provide costings for these elements. As part of this, the contractor should consider the selection of sites for the field trials envisaged in Phase 2, including consultations with relevant regulators and SNCBs. While it is expected that the broad concepts of Phase 2 will not be altered, the contractors may make recommendations for amendments to the scopes of the individual elements of Phase 2 for technical/scientific reasons, project feasibility or textual clarity. The review will be considered alongside work being undertaken by SMRU for Marine Scotland, as a basis for the final design of Phase 2 and for decisions regarding Renewables Industry funding for further development and/or testing of ADDs or other deterrent devices.

Project outputs

At the end of the contract, the successful contractor will provide DECC, representing the ORJIP Interim Working Group / Programme Group, with the following outputs:

- The draft final report which should cover the policy and scientific background to the work, the methodologies employed, results, conclusions and recommendations in relation to the aims and objectives set out above. This draft report should be submitted no less than one month before the end of the contract and should contain an Executive Summary (no more than two sides). The final report should be submitted to DECC no more than four weeks following receipt of comments on the draft final report.

- The draft and final reports should be supplied in an electronic format compatible with Microsoft Word. The final report should also be provided as a paper copy. Potential contractors should indicate in their tender who will have the main responsibility for writing the report.

- A research summary. This should be a 2-4 page summary of the main findings of the research and should be produced separately from the final report. This summary should not be simply a bulleted version of the points in the main report, but should be a wider look at what the findings mean in a wider policy context and may be edited by the ORJIP Interim Working Group.

- Two oral presentations of their research findings to the ORJIP Interim Working Group / Programme Group or other interested parties (such as other elements of the ORJIP structure, or the UK Underwater Noise Group and others, as may be required).

Skills and Experience

Offshore wind is expected to make a significant contribution to meeting the UK's 2020 renewable energy target and to decarbonisation ambitions beyond 2020. The central range for offshore wind deployment in DECC's Renewable Energy Roadmap (2011) indicated up to 18GW of offshore wind could be deployed by 2020. This would equate to approximately £36 billion of investment in new offshore wind farms[3]. The ORJIP programme therefore has the potential to lessen the consenting risk for up to £36billion of offshore wind investment (12GW) by 2020[4]. Uncertainty about impacts on birds and marine mammals already presents a significant risk to deployment given the requirements of the EU Birds and Habitats Directives. In order to be successful in reducing that risk, ORJIP projects must produce high quality outputs that are designed to meet the needs of industry and to inform the advice and decisions of statutory advisers and regulators. Changes to the standard mitigation measures for piling noise have the potential to significantly reduce the installation costs of offshore wind farms, through increasing the width of the operating window in

[3] The Renewables Roadmap indicates a central range that up to 18GW of offshore wind could be deployed by 2020. Figures from the 2011 DECC RO Banding Report show that 1 MW of installed capacity represents approx £3million of investment.

[4] Of the 18GW 2020 deployment figure, 2.3GW is constructed, 1.3GW is consented and under construction, and 2.4GW is consented inland awaiting construction. This leaves 12 GW of offshore wind deployment left to 2020 under the roadmap central range.

terms of both weather and time of day, and to reduce the complexity of operations and health and safety risks to staff involved.

In order to execute Phase 1 of ORJIP Project 4, it is anticipated that the successful contractor will exhibit, among others, the following range of skills and experience:

- Understanding of the requirements under EU and UK legislation for protection of marine mammal species;
- Practical understanding of piling operations at sea;
- Practical understanding of the operation of mitigation measures for acoustic disturbance during piling;
- Understanding and experience of the management of Health and Safety issues related to acoustic impact mitigation measures during piling at sea;
- Understanding of the science underlying aversive behaviour in marine mammals arising from exposure to acoustic stimuli;
- Knowledge of the technical issues involved in the development of acoustic deterrent devices;
- Understanding, and preferably experience, of testing the performance of acoustic deterrents, and of assessing their efficacy at sea.
- Experience of undertaking authoritative reviews in relevant applied science areas
- Experience of presenting structured reviews of science and engineering project options

Tender

Tenders are invited to propose a work programme designed to meet the above objectives, requirements and timetable. Tenders should include a time schedule for the work that identifies the main tasks and key milestones that will be used to monitor progress. The following information should be included in the tender document:

- Name of the organisation/consortium with which the contract would be placed;
- A statement of their understanding and interpretation of the purpose of the role of the programme outlined for Project 4 Phase 1;
- Demonstration of the required skills and experience as set out above;
- Explanation of how the work would be undertaken, including how the contractor would bring added value to the project;
- Costings (VAT must be shown separately).

Schedules to Tender

A. METHOD STATEMENT

Tenderers should provide a detailed response to the following:

1. Their approach to meeting the requirements set out in the Specification, including how they would:
    - Undertake the specified desk studies
    - Develop advice and recommendations regarding the scope and implementation of Phase 2 of Project 4.
2. How they will ensure consistency of approach to information gathering, evaluation and report writing, across individuals and between organisations.
3. The proposals for quality assurance mechanisms.
4. The key risks perceived to Phase 1 and the proposed approach to managing these risks.
5. The constraints which they perceive may impinge on the ability to provide a satisfactory service.
6. Any potential conflicts of interest by the tenderer, potential collaborators or sub-contractors and how these would be managed.
7. Recommendations for reviewing progress with the ORJIP Interim Working Group at the key points throughout the project.

B. STAFFING

1. The tenderer should provide details of who will manage this contract, including their location during the project, experience of managing similar contracts and a copy of their curriculum vitae. Details of how the project will be managed must be provided.

2. If more than one member of staff is proposed for working on the project, then the tenderer should provide a curriculum vitae of all the staff proposed, their role and proposed input (days) to the project. The information should be tailored to demonstrate experience and skills pertinent to this requirement. Each CV should be no more than 2 sides of A4 paper and as a minimum should:
    - Include details of each individual's relevant qualifications and membership of relevant organisations / professional bodies;
    - Detail where similar work has been undertaken;
    - State other relevant work experience.

Scoring

The proposal will be scored with the following weighting:

30% - Project method statement and schedule
30% - Technical capability relevant to the project and evidence of capability of delivering high quality scientific review and advisory services
15% - Project management arrangements and risk management plan
25% - Value for money

<u>Scoring Method</u>

Each element set out above will be given a score ranging from 0 to 5 as follows:

Score	Description
0	**Unacceptable:** Proposal does not meet the requirement. Does not comply and/or little or no evidence to support the response.

1	**Serious reservations:** Proposal significantly fails to meet the requirement with major reservations.
2	**Minor reservations:** Proposal satisfies the requirement with minor reservations.
3	**Satisfactory:** Proposal satisfies the requirement.
4	**Above Satisfactory:** Proposal satisfies all requirements and exceeds some requirements.
5	**Excellent:** Proposal meets the requirement and exceeds most of the major requirements. Evidence identifies factors that will offer significant added value and/or innovative solutions.

Selection

It is anticipated that candidates will be invited to attend an interview within a few weeks of the closing date for applications. The exact time and place is yet to be determined but bidders should make themselves available for interview in the weeks commencing 29th April and 13th May 2013.

Project Management

- The contract will be supervised by an official nominated by the ORJIP Interim Working Group who will act as Project Manager and be responsible for the day to day management of the contract. The Project Manager will chair steering group meetings and act as the principal point of contact for the ORJIP Interim Working Group / ORJIP Programme Group.

- A steering group will be established to manage and oversee the project, consisting of representatives nominated by the ORJIP Interim Working Group, the ORJIP Interim Programme Group and other interested parties and technical experts as considered appropriate. The steering group will monitor progress and provide guidance as required. The steering group will meet with the contractor after the contract has been let and then at intervals to be decided by the Project Manager.

- The contractor will be expected to engage in a close working relationship with the Project Manager and the ORJIP system.

The customer will be Sophie Thomas in the Office for Renewable Energy Deployment at the Department of Energy and Climate Change.

Questions about the ITT should be addressed to Sophie Thomas: Sophie.Thomas@decc.gsi.gov.uk or Tel: 0300 068 5803. In order to maintain transparency and equality all questions, unless commercially confidential, asked by, and answers given to, individual bidders will be recorded and circulated in an anonymised form to all bidders. The deadline for final questions will be 20th March to enable bidders to consider any additional information before finalizing their proposals and responses given by 27th March.

Timescale

You are instructed to provide 4 priced copies of your tender and all documents by **noon on 10th April 2013** which should be sent to;

Sophie Thomas
Area 4A
Office of Renewable Energy Deployment
Department of Energy and Climate Change
3 Whitehall Place
London
SW1A 2HH

Tel; 0300 068 5552
Email – Sophie.Thomas@decc.gsi.gov.uk

Electronic submissions will be accepted if received by the deadline and followed by signed paper copies within three (3) days.

Annex

Current (16 December 2012) draft of the structure and content of ORJIP Project 4, Phase 2.

Potential future projects are described in Phase Two however, **it is expected the scope of these will change depending on results from the review(s) described above. There will be a need for the detailed assessment of the outcome of Phase 1 prior to any decisions regarding the commissioning of work under Phase 2.**

It is suggested that a call for research and development of deterrent devices is made with the following brief scopes provided as guidance. However, researchers in the marine mammals and noise field may have other more effective ideas and the call for research and development should seek to capture these views. The SMRU review of effectiveness of ADD/other deterrent devices will be a useful resource to shape the scope of work.

It has also been suggested that any further research could be focussed by considering:

- Deter only devices
- Detect and deter devices

While it is possible that a 'Detect and Deter' approach could minimise the risk to animals habituating or learning to tolerate sound exposure as the ADD would only be triggered when marine mammals are present in an area, the current need is to focus on the deterrent aspect of the device, not detection, especially as the combined technology is still in development.

The current anticipated level of funding is primarily designed to enable testing of existing ADDs, or to modify them to address a wider range of species. If it becomes clear that there is a significant gap in the currently available devices and that a new device needs to be designed and developed, it is likely that additional funding would be necessary for extensive device development. On the other hand, other sources of funding may become accessible for such R+D work.

1. Understanding Aversive Sounds

The use of deterrent devices has been based mainly upon seals (grey and harbour) as these were developed for the fish farming industry where seals have been the main issue. For piling of offshore wind farms, more species need to be taken into account such as harbour porpoise, bottlenose, white beaked and common dolphin and minke whales. One suggested scope of work is to further advance our knowledge of what would be an effective deterrent sound for these animals, individually or collectively, including comparisons of "natural" and "synthetic" sounds.

Task

Dependant on the results from the current SMRU work, undertake research and, if possible/practicable, experiments to further our understanding of sounds which deter animals from a given area of the sea. This could include further examination of noises produced by predators so that the detail of the frequency, loudness and types of noise are better understood. The results from this work should be useful for developing new and innovative deterrent devices. Research should also consider whether any sounds may attract species into a sea area and any potential negative effects.

At this stage understanding the 'signals' that will be effective as a deterrent is key and once these 'signals' are better understood, the task of developing an effective piece of equipment to play any sounds into the marine environment could be undertaken by commercial manufacturers.

Effort should also be put into understanding how frequently deterrent devices would need to be used, for instance, the maximum time between a break in piling before an ADD needs to be activated again.

In order to truly understand if a sound will act as a deterrent, a statistically significant sample of response in realistic field conditions will be required. This will be needed to provide evidence to all (SNCB, NGO, developer) that ADD could replace the use of MMOs and allow operations when MMOs are not effective (darkness, fog, rougher sea conditions). Alongside developing aversive sounds, researchers should provide a robust methodology for testing responses on the marine mammals species listed above.

Researchers should also consider potential negative impacts on other species such as human (commercial divers) and birds.

Product

Report(s) describing what aversive sounds are for different species, if there is an overall deterrent sound that can be used for multiple species without causing significant injury, and evidence to show how effective aversive sound can be in moving animals away from a sea area. This may not be feasible however and the report may need to focus on possible aversive sounds and the effectiveness of these sounds tested as construction offshore continues.

A methodology/protocol for measuring the effectiveness of ADD/deterrent devices

Costs

- Developing and testing (on captive animals) aversive sounds further, taking ethical issues into account: Budget approx. - £100,000
- Conducting Tests in realistic field conditions which minimise interferences from other noisy or disturbing activities: Budget approx. £100,000 to £200,000

2. Develop effective ADDs

The above scopes will all provide information as to what makes an effective ADD. Ideally, this information should all be used to develop specifications for more effective ADDs or ADDs for species other than seals. This task will not be a quick process and could take a number of testing/development cycles of device modification before a truly effective system (combination of hardware, acoustic output and protocol for use) is designed. Ideally, a single system should be specified and tested that is effective for all the priority species.

Task

Using the above reports/other information develop effective ADD for:

- Grey and harbour seals,
- harbour porpoise,
- bottlenose dolphin and common dolphin, and
- minke whales.

There will need to be devices which are practical to deploy and suitable for use during piling operations and give confidence that sensitive animals are likely to be deterred from entering or remaining within a zone around piling operations within which acute injury may occur (up to approx 750 m radius). New techniques must be effective to 700/750m or beyond to take account of the increasing power of piling hammers, and to provide a single solution to the need to protect vulnerable species. Consideration should be given as to how devices are used to lessen the need for human involvement to minimise costs and risks associated with deployment. Ideally, any devices developed would be applicable to a number of species. The ADD(s) should also be cost-effective to produce at a mass scale and consideration should be given as to how the ADD(s) would be used in the field such as the ability to turn the ADD(s) on/off remotely and deployment at sea. Consideration should also be given to developing an ADD which cycles through a variety of aversive sounds to avoid habituation.

It has been suggested that rather than develop actual deterrent devices, Task 2 could focus on producing specifications for deterrent devices and manufacturers left to develop the actual device.

Product

A cost-effective, easily reproducible ADD or ADDs which can be deployed during wind farm piling operations to effectively move all animals away from the direct injury zone.

Or

A specification for deterrent devices.

Costs

Specification – Approx Budget £30,000
Actual Device – Approx Budget £50 – £100,000

3. Develop ADD Test Protocol

To truly understand whether ADDs can effectively ensure that no marine mammals are in the direct injury zone, all ADDs used should be tested to ensure consistency in sound produced and resulting responses from marine mammals.

Task

To date, testing of ADDs has been undertaken using a variety of methods. It is suggested that a protocol for testing the reliability of ADDs, i.e. testing the level and quality of the sound emitted, should be developed that manufacturers can use.

- A protocol could be developed for recording and measuring the noise produced by an ADD. This protocol should set out a repeatable methodology including describing the equipment and process to be followed by manufacturers etc. when describing the aversive sound produced by their particular equipment. As the use of ADDs increases offshore it is vital that users can have confidence that the equipment being deployed is emitting the sound(s) as described – some previous testing has shown there is a high degree of variance and this may open up questions as to the use and effectiveness of ADDs.

Product

Report(s) describing how ADDs should be tested (ideally through agreement amongst interested parties such as ADD manufacturers, SNCBs and NGOs) that can be shared amongst researchers, developers, regulators and government advisors. This should be a practical methodology that is easily repeatable.

Cost

Approx Budget - £20 - £30,000

4. Guidance Note

To ensure ADDs are used correctly offshore, a guidance note should be produced on their use offshore during piling operations.

Task

Produce a practical guidance note that is agreed with developers, regulators, NGOs and SNCBs. This guidance note should aim to minimise the use of MMOs offshore. The guidance note will also aim to help with the consenting issues in relation to the use of ADDs in English, Scottish, Welsh and Northern Irish waters to detail deliberate disturbance issues and inform the license application process. As part of the guidance note, a feedback loop for providing information on the effectiveness of ADDs could also be developed.

The guidance note should standardise the use of ADDs offshore and lead to more effective mitigation within the injury zone for marine mammal species whilst minimising cost and H&S risk to industry and those offshore. It should be based on practical experience of deploying ADDs offshore.

Product

Guidance note

Cost

Approx Budget - £5 – £10,000

RISKS TO NOTE

- When previously working on the development of ADDs during COWRIE projects, testing/development of ADDs was sometimes held back by commercial issues such as ADD manufacturers not wanting their devices tested/subject to scrutiny and commercial issues such as who owned patents etc. on developed ADDs.
- There is a need to ensure that the development of ADD decreases the use of MMOs offshore so that cost saving and H&S risk reduction is delivered.
- There is a possible need to assess the risk from displacement effects created by the ADDs.
- Potential costs identified with testing the various technologies will be clarified during further consultation and iteration of the outline project scope.

APPENDIX B STATUS OF EUROPEAN OFFSHORE WIND INDUSTRY

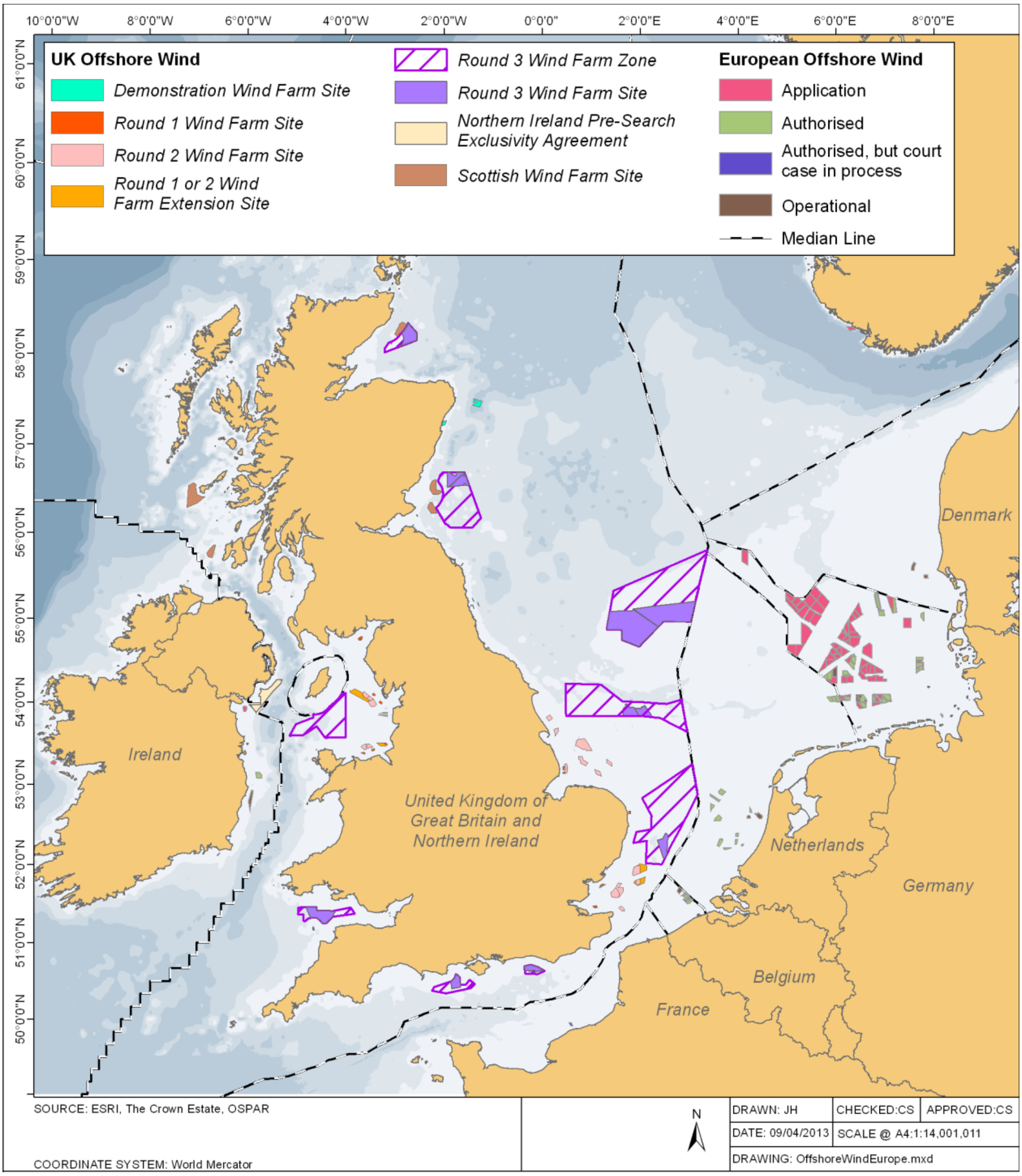


Figure B.1 European offshore wind industry

APPENDIX C ABUNDANCE AND DISTRIBUTION OF FIVE PRIORITY MARINE MAMMALS

These figures have been produced using marine mammal data from a variety of sources that have each used different sampling techniques. For further details refer to the original sources referenced on each of the maps.

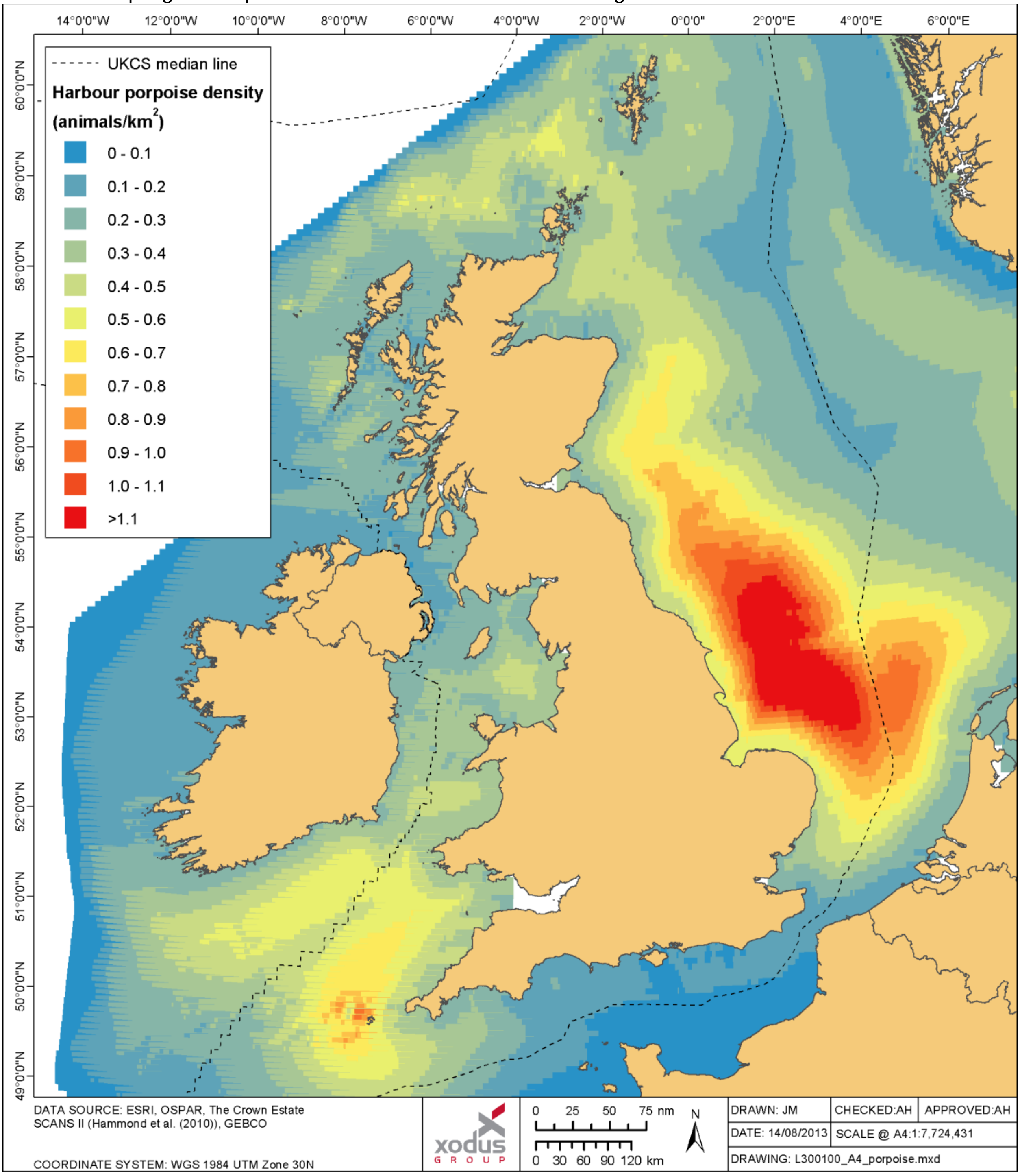


Figure C.1 Distribution of harbour porpoise *Phocoena phocoena* in UK waters

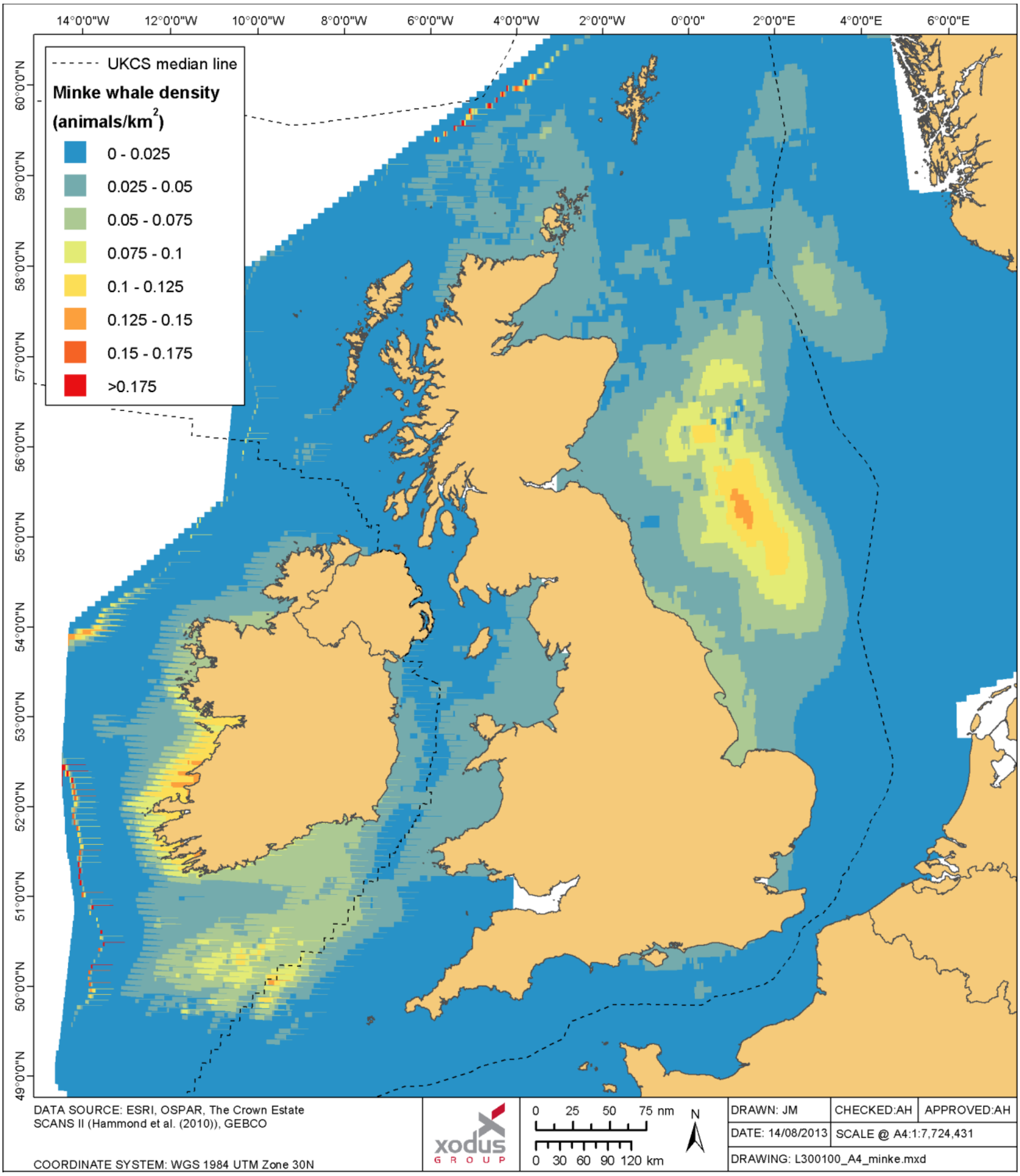


Figure C.2 Distribution of minke whale *Balaenoptera acutorostrata* in UK waters

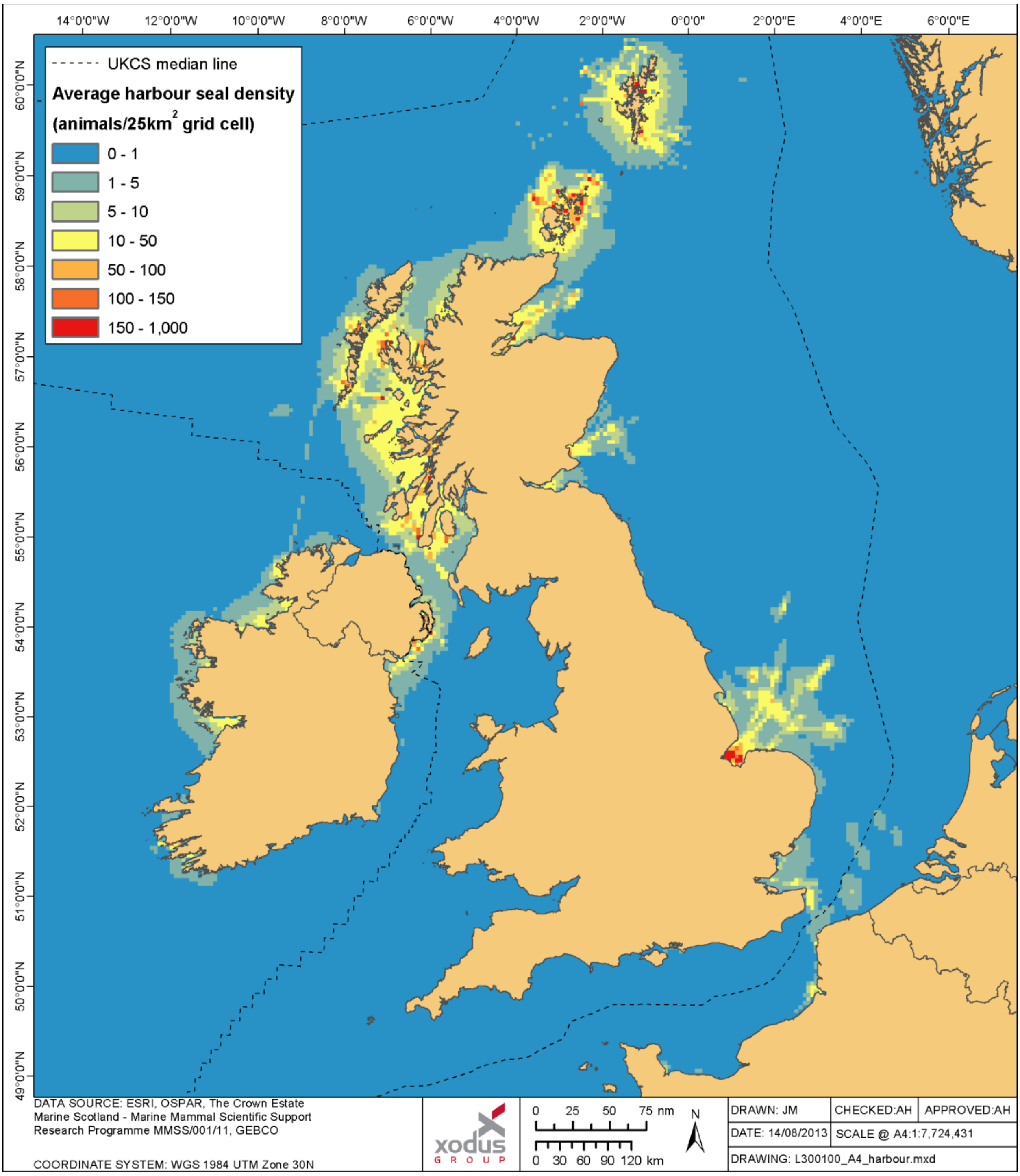


Figure C.3 Distribution of harbour seal *Phoca vitulina* in UK waters

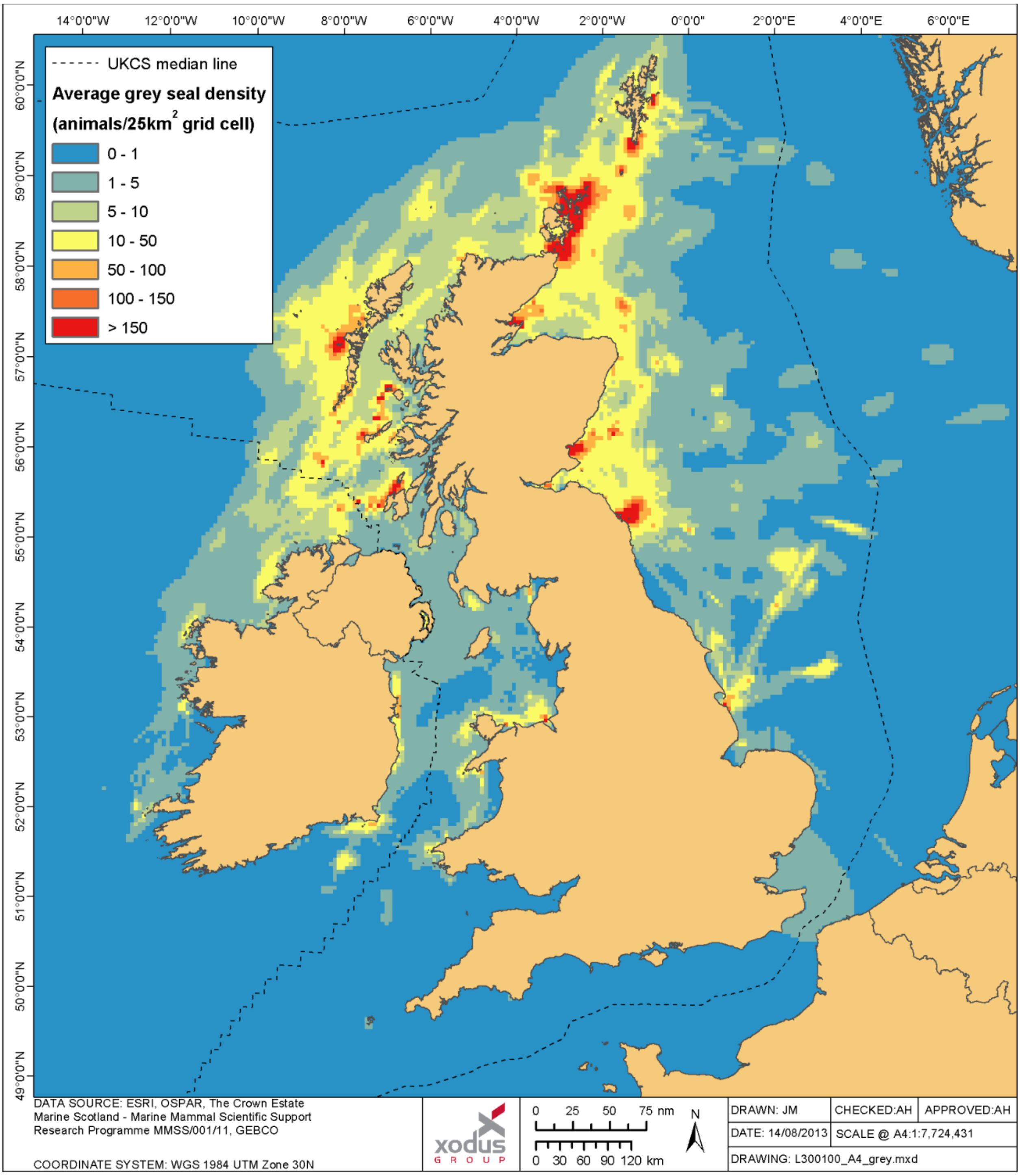


Figure C.4 Distribution of grey seal *Halichoerus grypus* in UK waters

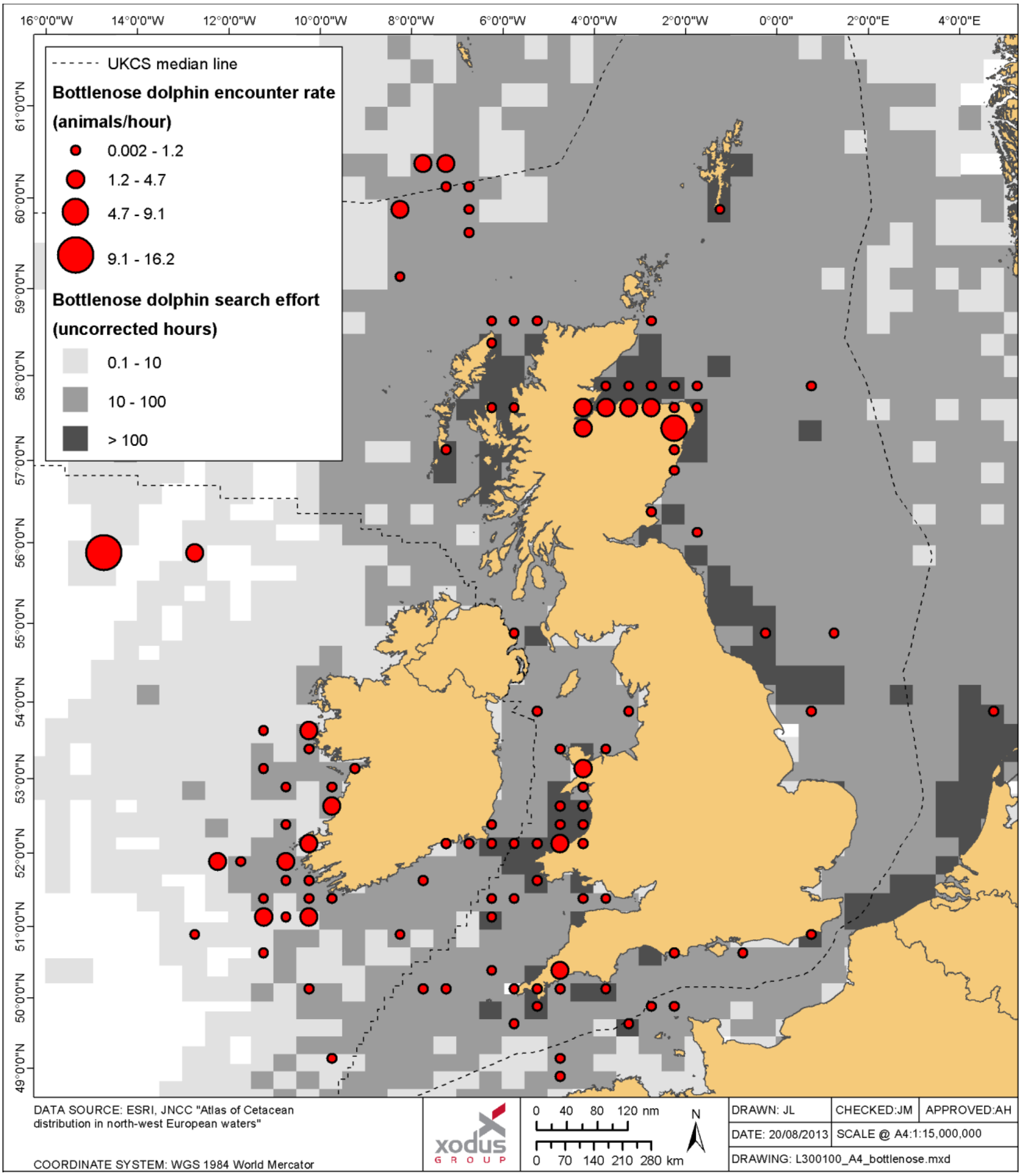


Figure C.5 Distribution of bottlenose dolphin *Tursiops truncatus* in UK waters (due to the relatively course grid resolution of the source data and central placement of encounter symbols, encounters within grid cells overlapping the coastline may appear to be on land, when in fact they correspond to the marine portions of that grid cell)

APPENDIX D OVERVIEW OF LEGISLATION RELEVANT TO THE PROTECTION OF MARINE MAMMALS

Table D.1 Legislation relevant to the protection of marine mammals

Legislation	Species	Details
The Berne Convention 1979	All cetaceans, grey and harbour seal.	The Convention conveys special protection to those species that are vulnerable or endangered. Appendix II (strictly protected fauna): 19 species of cetacean. Appendix III (protected fauna): all remaining cetaceans, grey and harbour seal. Although an international convention, it is implemented within the UK through the Wildlife and Countryside Act 1981 (with any aspects not implemented via that route brought in by the Habitats Directive).
The Bonn Convention 1979	All cetaceans.	Provides protection for migratory animals, which are listed on Appendix II of this Convention, over all or part of their natural range through international cooperation. Migratory species that have been categorised as being in danger of extinction throughout all, or a significant proportion of, their range are listed on Appendix I of the Convention. In order to achieve this, a number of legally binding agreements have been made by contracting parties, one of which is the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) (see below).
Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS)	Odontocetes.	Under this agreement, provision is made for the protection and management of odontocetes through research, monitoring, pollution control, raising public awareness and reducing problems such as by-catch and disturbance.
The Wildlife and Countryside Act 1981 (as amended)	All cetaceans.	Schedule five: all cetaceans are fully protected within UK territorial waters. This protects them from killing or injury, sale, destruction of a particular habitat (which they use for protection or shelter) and disturbance. Schedule six: common dolphin, bottlenose dolphin and harbour porpoise; prevents these species being used as a decoy to attract other animals. This schedule also prohibits the use of vehicles to take or drive them, prevents nets, traps or electrical devices from being set in such a way that would injure them and prevents the use of nets or sounds to trap or snare them.
The Countryside and Rights of Way Act 2000	All cetaceans.	Makes it an offence to deliberately or recklessly damage, or disturb any cetacean in English and Welsh protected waters under this Act.
OSPAR	Bowhead whale, northern right whale, blue whale, and harbour porpoise.	OSPAR has established a list of threatened and/or declining species in the north-east Atlantic. These species have been targeted as part of further work on the conservation and protection of marine biodiversity under Annex V of the OSPAR Convention. The list seeks to complement, but not duplicate, the work under the EC Habitats and Birds directives and measures under the Berne Convention, the Bonn Convention.
The Conservation of Habitats and Species	All cetaceans, grey and harbour seal.	In England and Wales, The Conservation of Habitats and Species Regulations 2010 (as amended) consolidate all the various amendments made to the Conservation (Natural

Legislation	Species	Details
Regulations 2010		Habitats, &c.) Regulations 1994, implementing the requirements of the Habitats Directive into UK law (on land and inshore waters (0 – 12 nm)). All cetacean species are listed under Schedule 2 (European Protected Species (EPS)) and all seals are listed under Schedule 4 (animals which may not be captured or killed in certain ways). For more details please refer to Section 2.2.
The Habitats Regulations 1994 (as amended in Scotland)		Implements the species protection requirements of the Habitats Directive in Scotland on land and inshore waters (0-12 nautical miles). Following a European Court of Justice ruling against the UK Member State in 2005, there have been several amendments to the Regulations which apply only to Scotland (including in 2004, 2007, 2008(a), 2008(b), 2011 and 2012). Thus, the Scottish Regulations do not mirror the 2010 Regulations, which apply in England and Wales. For more details please refer to Section 2.2. Provides the protection afforded to European protected species (EPS) of animals and plants (those species listed on Annex IV of the Habitats Directive whose natural range includes Great Britain). A small overlap with the Wildlife and Countryside Act 1981 may be removed following successful passage through the Scottish Parliament of the Wildlife and Natural Environment Bill.
Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007 (as amended)	All cetaceans, grey and harbour seal.	The Offshore Marine Conservation Regulations 2007 (as amended) apply the Habitats Directive to marine areas within UK jurisdiction, beyond 12 nautical miles, and provide further clarity on the interpretation of "disturbance" in relation to species protected under the Habitats Directive. Thus, enabling energy developers to better qualify and, where possible, quantify, the impacts on marine mammals and determine whether the potential disturbance is permissible as part of a consented development.
UK Biodiversity Action Plan (BAP)	Location specific.	Seek to ensure that nationally and locally important species and habitats are conserved and enhanced in a given area through focused local action.
Marine (Scotland) Act 2010	Grey and harbour seal.	Part 6 concerns the conservation of seals, and makes it an offence to kill, injure or take seals. The Act exempts activities for which a European Protected Species Licence has been granted (under Regulation 44 of the Conservation (Natural Habitats) Regulations 1994).
Nature Conservation (Scotland) Act 2004	All cetaceans.	Contains measures to improve the existing species protection offered by the Wildlife and Countryside Act 1981, including the extension of existing protections for cetaceans from intentional disturbance to encompass protection from 'reckless' disturbance in line with that offered by the CROW Act 2000 in England and Wales.

APPENDIX E DETAILS OF MARINE MAMMAL MITIGATION TECHNIQUES USED IN THE UK

The marine mammal mitigation techniques detailed in the guidance document (JNCC, 2010b) share a common principle in that they each seek to reduce the probability of a marine mammal sustaining an auditory injury by ensuring individuals are outside of a theoretical impact zone (also known as mitigation zone (MZ)) surrounding the piling location. MMOs and PAM do so passively, by monitoring the presence of mammals within a predefined MZ prior to the commencement of piling, whilst soft starts and ADDs are intended to actively discourage individuals from the area.

E.1 Marine Mammal Observers (MMOs)

MMOs, as well as PAM, are used to monitor a predefined MZ during the period leading up to the commencement of piling, to ensure that no marine mammals are present. MMOs achieve this via visual observation of the MZ, usually from an elevated platform on a dedicated survey vessel or the installation vessel. Their primary role is to detect marine mammals and recommend a delay in commencement of piling activity should any be identified within the MZ, but they also serve an ancillary function by providing advice on the implementation of the MMMP to the installation crew.

Marine mammals are visible when they surface to breathe between dives and for some species it is the only way of feasibly detecting them. Visual observation can be limited by a number of factors, including visibility, sea state, species, group size and composition, experience of observer and level of fatigue.

The current piling mitigation protocol (JNCC, 2010b) states that the pre-piling search should be a minimum of 30 minutes. The extent of the MZ represents the area within which a marine mammal is likely to subjected to levels of sound that may cause injury, which is highly dependent on a number of factors such as pile size, hammer energy, water depth, substrate type and species specific sensitivity. Consequently, the guidelines recommend that the extent of the MZ should be determined on a project specific basis, but should be no less than 500 m in radius. If the MMO or PAM operative detect a marine mammal within the MZ during the pre-piling search period, piling is prohibited from commencing any earlier than 20 minutes after the last detection.

MMOs and PAM operatives also monitor throughout the soft start and in some cases during the actual piling. The response to detection during piling will depend on what has been agreed with the relevant agency or regulator, but JNCC (2010b) state that if a marine mammal enters the MZ during soft start, wherever possible the piling should cease, or at least hammer energy should not continue to be ramped up. Conversely, once piling reaches full power there is no requirement to cease piling if a marine mammal enters the MZ, since it is deemed to have entered the area 'voluntarily'. JNCC (2010b) also recommend that once a break in piling exceeds 10 minutes, the 30 minute pre-piling watch and soft start procedure should be repeated. Observations carried out during full power piling leading up to a break can contribute to the 30 minute pre-piling watch, meaning excessive delays in re-starting the soft start can be avoided by maintaining MMO visual surveys throughout the piling procedure.

E.2 Passive Acoustic Monitoring (PAM)

PAM works by detecting the vocalisations made by some odontocetes (toothed whales and dolphins) for echolocation and communication. It is especially useful for detecting porpoises, because their unique sonar signals possess features that make them readily distinguishable from other sounds in the ocean (Kyhn *et al*., 2012). PAM is a useful supplement when conducted in conjunction with MMO visual observations because it provides a means of detecting animals beneath the sea surface, and is consequently thought to improve the probability of detecting marine mammals that vocalise frequently and distinctively, such as harbour porpoise and sperm whale (MMOA, 2013).

PAM equipment consists of a number of hydrophones that are deployed into the water column, usually from the MMO survey vessel or installation vessel. Detected sounds are processed and classified in real-time using specialised software. The acoustic monitoring adheres to the same MZ protocol described above for the MMOs. The range monitored is dictated by the range of the hydrophones; when these are static the range is only likely to be 250 m (or so) for porpoises, but if towed, vessels will move around the pile trying to achieve full coverage of the MZ. PAM must be setup and deployed by trained PAM operatives, who may also be trained MMOs, allowing for role switching where necessary.

PAM is frequently used as the sole detection method whilst piling during periods of darkness or limited visibility. The JNCC mitigation protocol (JNCC, 2010b) states that a developer wishing to pile at night might need to demonstrate that "such piling is essential for commercial viability" and that they will provide "enhanced detection of marine mammals (e.g. increased number of PAM systems and PAM operatives for commencement of piling during night-time)". It is important to distinguish that this refers to piling that commences during darkness, rather than piling that commenced in good visibility, but continued uninterrupted into the night. The latter would require no additional monitoring under current guidance.

PAM systems have limited effectiveness for species that do not produce vocalisations, only vocalise above water or vocalise infrequently.

E.3 Soft start

Soft start refers to the incremental ramping up of the pile driver's hammer energy over a defined period of time, until full operational power is achieved (JNCC, 2010b). Their use as a mitigation measure is based on the principle that a gradual increase in piling noise should deter any marine mammals from the location, allowing them time to swim to a safe distance before the noise reaches a sufficient level to cause injury. In theory, an animal further from a noise source will receive lower exposure levels and a lower peak sound pressure level.

The specifics of the soft start procedure will depend on a number of engineering constraints, such as hammer and pile design and seabed geology. In general, a soft start of approximately 5-15 minutes is necessary from an engineering perspective. If soft start is to be used as mitigation, some degree of extension to this period is usually required. The current mitigation protocol (JNCC, 2010b) stipulates that the duration of a soft start should be "not less than 20 minutes".

Soft starts are implemented at the commencement of piling. If a mammal is detected during the soft start it is recommended that piling should cease if possible and not be resumed until there are no further detections for 20 minutes. However, if a marine mammal enters the MZ during full power there is no requirement to cease piling becuase the animal is thought to have 'voluntarily' entered the area. Should there be a break in piling of greater than 10 minutes, the MMO/PAM pre-search and soft start procedure are repeated.

E.4 Acoustic Deterrent Devices (ADDs)

The principle behind the use of ADDs is that they produce an aversive signal that causes a behavioural response in a marine mammal. ADDs have been used widely in an attempt to deter mammals from aquaculture facilities and fishing gear, but have only recently been adopted as a method of deterring them to a 'safe distance' from the impact zone surrounding a piling event (Gordon *et al*., 2007).

When used as a mitigation measure during OWF development, ADDs are typically deployed from an MMO survey vessel or installation vessel, but unlike PAM, do not require a trained operator to deploy them. JNCC (2010b) recommend that they should only be used in conjunction with visual and/or acoustic monitoring, positioned as close to the pile installation as possible, and activated only during the pre-piling search. The guidelines also require that the potential effectiveness on the species likely to present is considered, and that a wildlife licence might be required to authorise an intentional disturbance.

There are a range of ADDs currently available, or in development, and wide variation in the power and frequency output of different devices according to the purpose/species for which they were designed. They are referred to under an array of different terms, including Acoustic Mitigation Devices (AMDs), Acoustic Harassment Devices (AHDs), 'scrammers', 'scarers' and 'pingers'. Historically, this differentiation has been made on the basis of the devices' power output, for instance JNCC (2010b) state that "ADDs (or pingers), are generally low power devices (less than 150 dB re: 1 µPa at 1 m) used on fishing nets to prevent entanglement by alerting the animals to the presence of the net, while AHDs (or scarers) produce high power sounds (more than 180 dB re 1 µPa at 1 m) and are usually used to permanently prevent seals from getting close to fish farm pens. ADD development has since evolved to include array type devices, covering the spectrum of sound outputs. The distinction between ADDs and

AHDs in the current MMMP (JNCC, 2010b) therefore requires consideration. For clarity, and because the unifying feature between all available devices is the intention to deter animals from a specific area using acoustic signals, Acoustic Deterrent Device (ADD) has been adopted in the present review as a generic term to cover all types of device, excluding pingers (see below).

It should be noted that the small, low powered devices originally designed to be attached to fishing gear and most frequently referred to as 'pingers' have been excluded from this review due to their lower intensity (lower range) and lack of deterrence effects on seals (dinner bell effect). However, it should be noted that these are used in conjunction with more highly powered ADDs throughout much of Europe. A more detailed review of pingers would be beneficial to fully evaluate their potential for the UK OWF sector.

APPENDIX F EU PRACTICE FOR MARINE MAMMAL MITIGATION WHEN PILING

The table below (Table F.1), which collates information from Ludeke *et al*., (2012) and the ICES marine mammal working group report (ICES WGMME, 2010), presents the general guidelines for marine mammal mitigation during piling for each of the top five OWF developing countries in the EU. For a more detailed analysis of MMMPs employed at individual sites in the UK and elsewhere in Europe, refer to Appendix G on the following page.

Table F.1 EU practice for marine mammal mitigation during piling

Country	Soft start	MMO and or/ enforcement of a mitigation zone	ADD	Seasonal restrictions in piling (for marine mammals)	OWF development in Natura 2000 sites	Noise limits	Restriction on contemporaneous piling
Belgium	Yes, taken up in permit and not standardised.	No.	Yes, taken up in permit.	Yes, but advice only: no piling between 1st January and 30th April.	Not *a priori* forbidden.	No.	No.
Denmark	Yes, but not standardised.	No.	Yes.	No.	Yes, conditions apply.	No.	No.
Germany	Yes.	No.	Yes.	No.	Not since establishment of marine spatial planning regulations.	160 dB SEL and 190 dB SPL at 750 m from piling event.	No.
The Netherlands	Yes (personal communication, *anon.)*	No.	Yes, in general guidance.	Yes, no piling between 1st January and 1st July.	Not *a priori* forbidden.	No.	No more than one construction activity in which piles are driven at any one time.
United Kingdom	Yes.	Yes, plus live PAM.	Occasionally, judged on case by case basis.	No, but some seasonal restrictions for fish spawning grounds.	Not *a priori* forbidden.	No.	No.

APPENDIX G ANALYSIS OF MITIGATION TECHNIQUES USED AT UK AND EU OWFS

This Appendix presents a case by case analysis of the MMMPs employed at OWF sites throughout Europe. For a summary of MMMP guidance for individual countries, please refer to Appendix F on the preceding page. Table G.1 presents details of MMMPs implemented at OWFs in the UK. This information has been sourced from site specific MMO reports and construction reports, environmental statements, and FEPA/Marine Licences, as applicable. In the UK, MMOs are required to provide a detailed report on the implementation of the MMMP, which contains information such as hours of search effort, non-compliance events, number of mammal sightings, and cumulative piling delays due to marine mammal sightings. The results of these have been summarised in Table G.2, and the locations of the OWF sites described in Table G.1 and G.2 are displayed in Figure G.1.

Details of the mitigation techniques used elsewhere in Europe are provided in Table G.3. Construction/MMO reports similar to those described above are not produced elsewhere in Europe, so much of the information in Table G.3 has been sourced from peer-reviewed papers or personal communications with individuals involved in each of the respective projects.

Table G.1 UK OWFs and MMMP details

Wind farm details						Marine Mammal Mitigation Plan				
Name	**Location**	**Commissioned**	**Capacity (MW)**	**Operator**	**Approximate footprint (km^2)**	**MMO**	**PAM**	**Standardised Soft starts**	**ADD**	**Additional information/licence details**
North Hoyle	Irish Sea	2004	60	RWE	10	N	N	N	N	No mitigation specified in licence.
Scroby Sands	S. North Sea	2004	60	E.ON	4	N	N	N	N	No mitigation specified in licence.
Kentish Flats	S. North Sea	2005	90	Vattenfall	10	N	N	N	N	No mitigation specified in licence.
Barrow	Irish Sea	2006	90	Centrica/DONG	10	Y (crew)	N	N	Y	No information provided on pinger. Licence does not specify dedicated or trained observer and construction reports unclear about level of visual monitoring provided by vessel crew. Additionally, ADD/pinger not mentioned in licence.

Wind farm details						Marine Mammal Mitigation Plan				
Name	**Location**	**Commissioned**	**Capacity (MW)**	**Operator**	**Approximate footprint (km^2)**	**MMO**	**PAM**	**Standardised Soft starts**	**ADD**	**Additional information/licence details**
Burbo Bank	Irish Sea	2007	90	DONG	10	N	N	Y	N	Only soft start mentioned in licence. No record or MMO activity in reports.
Rhyl Flats	Irish Sea	2009	90	RWE	10	Y	Y	Y	N	Not in directly specified in licence, but Soft start, MMO and PAM covered in construction report.
Gunfleet Sands 1+2	S. North Sea	2009	108	DONG	8	Y	N	Y	N	Soft start, trained/experienced MMO + PAM (for low vis) stipulated in licence and confirmed in MMO reports.
LID	S. North Sea	2009	194	Centrica	20	Y	Y	Y	N	Soft start, trained/experienced MMO + PAM (for low vis) stipulated in licence and confirmed in MMO reports.
Robin Rigg	Irish Sea	2010	180	E.ON	18	Y	N	Y	Y	Trained MMOs used.
Thanet	S. North Sea	2010	300	Vattenfall	35	Y	Y	Y	N	Soft start, trained/experienced MMO + PAM (for low vis) stipulated in licence and confirmed in MMO reports.
Walney Phase I	Irish Sea	2011	183.6	DONG	28	Y	Y	Y	Y	Soft start, trained/experienced MMO + PAM (for low visibility) stipulated in licence and confirmed in MMO reports. No mention of pinger/ADD in licence.
Walney II	Irish Sea	2012	183.6	DONG	45	Y	Y	Y	N	Soft start, trained/experienced MMO + PAM (for low visibility) stipulated in licence and confirmed in MMO reports.

Wind farm details						Marine Mammal Mitigation Plan				
Name	**Location**	**Commissioned**	**Capacity (MW)**	**Operator**	**Approximate footprint (km^2)**	**MMO**	**PAM**	**Standardised Soft starts**	**ADD**	**Additional information/licence details**
Ormonde	Irish Sea	2012	150	Vattenfall	10	Y	Y	Y	N	Soft start, trained/experienced MMO + PAM (for low visibility) stipulated in licence and confirmed in MMO reports.
Greater Gabbard	S. North Sea	2012	504	SSE/RWE	146	Y	Y	Y	N	Soft start, trained/experienced MMO + PAM (for low visibility) stipulated in licence.
Gwynt y Mor	Irish Sea	Construction	567	RWE	80	Y	Y	Y	N	Soft start, trained/experienced MMO + PAM (for low visibility) stipulated in licence.
West of Duddon Sands	Irish Sea	Construction	389	Scottish Power/DONG	67	Y	Y	Y	N	Soft start, trained/experienced MMO + PAM (for low visibility) stipulated in licence.
Lincs	S. North Sea	Construction	270	Centrica	41	Y	Y	Y	N	Soft start, trained/experienced MMO + PAM (for low visibility) stipulated in licence.
London Array 1	S. North Sea	Construction	630	DONG/E.ON/MASDAR	121	Y	Y	Y	Y	Soft start, trained/experienced MMO + PAM (for low visibility) stipulated in licence and confirmed in MMO reports. No mention of pinger in licence conditions
Sheringham Shoal	S. North Sea	Construction	315	STATOIL & STATKRAFT	35	Y	Y	Y	N	Soft start, trained/experienced MMO + PAM (for low visibility) stipulated in licence.
Teesside	N. North Sea	Construction	62.1	EDF	10	Y	Y	Y	N	Soft start, trained/experienced MMO + PAM (for low visibility) stipulated in licence.
Humber Gateway	S. North Sea	Consented	219	E.ON	25	Y	Y	Y	?	Info sourced from MMMP. ADDs being considered for night piling. No mention of their use in the licence.

Table G.2 Summary of UK MMO reports (IV = installation vessel, SV = dedicated survey vessel)

OWF	Piling		MMO			PAM			Total detections per offshore man hour	Piling delays		ADD		Observation notes/additional details
	Day /night (or bad vis.)	MMMP compliance	Location	Time (mins)	Detections (in/out of MZ)	Location	Time (mins)	Detections (assumed in MZ)		No.	Total delay (mins)	Location	Model	
Barrow	?	?	IV	Unknown	0/0	N/A	N/A	N/A	0.00	0	0	IV	Pinger	One of construction crew was designated as MMO. Information sourced from high level report, not MMO report.
Gunfleet Sands demonstration site	0/2	2/2	SV	23 (as piling was in the dark)	0/0	SV	696	0	0.00	0	0	IV	Airmar DB Plus II	AHD deployed by client rep. on IV, 30 minutes before soft start, after 30 minutes of detection free PAM. Never deployed for longer than 60 minutes to prevent habituation – this was contractor's judgment, not guidance.
Gunfleet Sands I + II	28/24	51/52	SV	1,963	0	SV	4,020	0	0.00	0	0	N/A	N/A	Non-compliance event due to incorrect tidal predictions preventing MMO team from reaching site. Only PAM used during the night time piling, which represented nearly 50 % of activity. The only marine mammal sighting made throughout the project were made during piling.

OWF	Piling		MMO			PAM			Total detections per offshore man hour	Piling delays		ADD		Observation notes/additional details
	Day /night (or bad vis.)	MMMP compliance	Location	Time (mins)	Detections (in/out of MZ)	Location	Time (mins)	Detections (assumed in MZ)		No.	Total delay (mins)	Location	Model	
LID	43/20	55/63	SV	4,955	3/13	SV	5,155	0	0.16	0	0	N/A	N/A	13 sightings included 11 seals (largest group size of 2) and 3 porpoises. 2 non-compliance events due to inability to soft start for two 're-drive' scenarios, which prohibited soft start. These 2, plus a further 6 were also non-compliant with the MMP because adverse weather or operational issues prevented mobilisation of the MMO, so FLO had to fill in. KEY POINT: 20 night time starts using PAM had no chance of detecting seals. MMO report recommended ADD should be used in future. 2 of 26 piling events in the Lynn field were non-compliant with the soft start protocol, reaching maximum hammer energy before 20 minutes had elapsed. This was necessary because both were re-drive operations into hard substrate.
London Array I	135/42	177/177	SV	32,798	8/5	SV	40,596	2	0.0010	3	90	IV	Airmar DB Plus II	AHD deployed by IV personnel 30 minutes before soft start, after 30 minutes of detection free PAM. Was never deployed for longer than 60 minutes to prevent habituation – this was contractor's judgment, not

OWF	Piling		MMO			PAM			Total detections per offshore man hour	Piling delays		ADD		Observation notes/additional details
	Day /night (or bad vis.)	MMMP compliance	Location	Time (mins)	Detections (in/out of MZ)	Location	Time (mins)	Detections (assumed in MZ)		No.	Total delay (mins)	Location	Model	
														guidance. Modified soft start because of issue with chalk setup (chemical and physical reactions cause resistance of substrate to increase over time once piling has started, so it is necessary to install the pile as quickly as possible). ADD used in combination with PAM during dark starts or adverse weather. ADD failed once due to battery not being charged. NOTE: Number of bad visibility/night time piling events estimated from number of piling events that were not accompanied by visual monitoring, which can be found in the MMO report. In some areas of the London Array site there was a thin veneer of sand overlying hard chalk substrate. There was concern that conducting standard soft starts might lead to undue stress/damage to the pile if it became 'stuck' in the chalk as a result of setup. The standard soft start protocol was modified to allow a higher initial energy level.

OWF	Piling		MMO			PAM			Total detections per offshore man hour	Piling delays		ADD		Observation notes/additional details
	Day /night (or bad vis.)	MMMP compliance	Location	Time (mins)	Detections (in/out of MZ)	Location	Time (mins)	Detections (assumed in MZ)		No.	Total delay (mins)	Location	Model	
Ormonde	147/49	196/197	SV	17,727	0/7	SV	25,344	1	0.027	0	0	N/A	N/A	2 MMO + 2 PAM operators. Sightings: 5 harbour porpoise, 2 grey seal, 1 small whale. PAM detection did not have corresponding visual observation, and did not cause delay as it occurred before pre-watch period commenced.
Rhyl flats	20/5	25/25	SV/IV	3,552	1/0	SV	4,331	0	0.017	1	42	N/A	N/A	PAM did not detect sighted porpoise. MMOs transferred to IV for 1 pile due to anchor issues. PAM were unable to accompany. Approach deemed successful and accepted for later projects.5 piles were monitored using only PAM due to darkness.
Walney I	9.8 % of piling activity at night.	55/55	SV	6,720	0/3	SV	7,860	0	0	0	0	Buoys	Aqua-mark 210 pinger	Daylight 2 MMO + 1 PAM. Night 2 PAM. Pinger initially used during night time piling to supplement PAM. Pinger deployed on buoys for longer than 60 minutes. Reported much difficulty – issues with manoeuvring around other vessels and timing deployment/extraction.
Walney II	22.5 % of piling activity at	54/55	SV	7,620	1/3	SV	9,840	0	0.0024	0	0	N/A	N/A	Daylight 2 MMO + 1 PAM. Night 2 PAM. One partially unmitigated event due to adverse weather and scheduling issues. 1 H & S event – minor collision

OWF	Piling		MMO			PAM			Total detections per offshore man hour	Piling delays		ADD		Observation notes/additional details
	Day /night (or bad vis.)	MMMP compliance	Location	Time (mins)	Detections (in/out of MZ)	Location	Time (mins)	Detections (assumed in MZ)		No.	Total delay (mins)	Location	Model	
	night.													between MMO and anchor buoy. Required some repair work but did not impact upon MMMP. Sighting inside MZ was harbour porpoise, 20 minutes prior to commencement of pre-watch. Sightings outside of MZ or during transit included 1 seal, 1 group of dolphins travelling through site after a very busy 4 day period, a small group of porpoise and a dolphin.
Gwynt y Mor	-	-	-	13,602	8/24	-	28,748	-	0.035	5	59	-	-	-
Lincs	-	101/102	SV	16,744	6/0	SV	35,547	-	0.022	6	45	IV	Airmar dB Plus II	Supplementary use of ADD. Non-compliance event due to breakdown of MMO vessel.

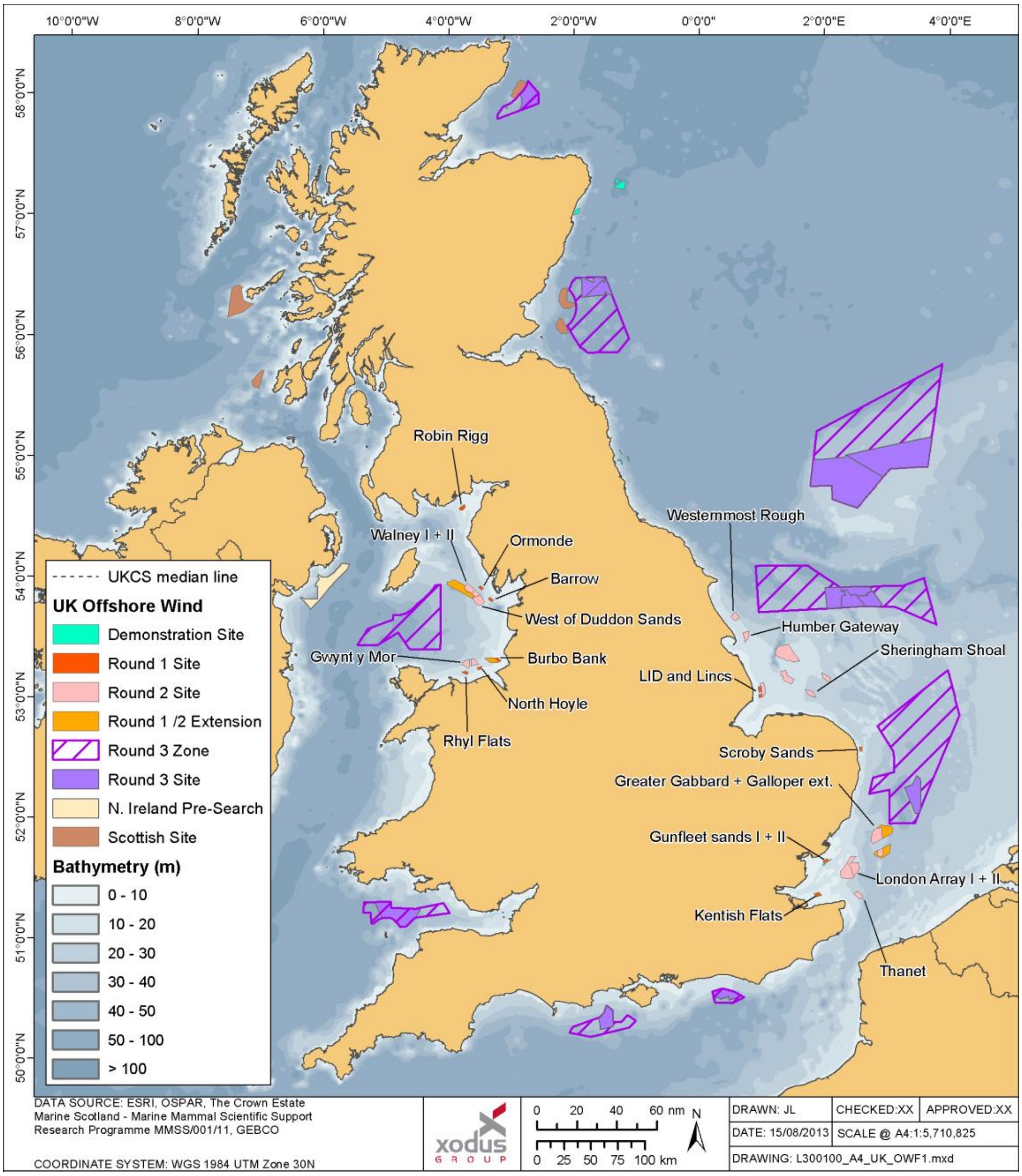


Figure G.1 Locations of OWFs described in Table G.1 and G.2

Table G.3 Marine mammal mitigation used during construction of European OWFs

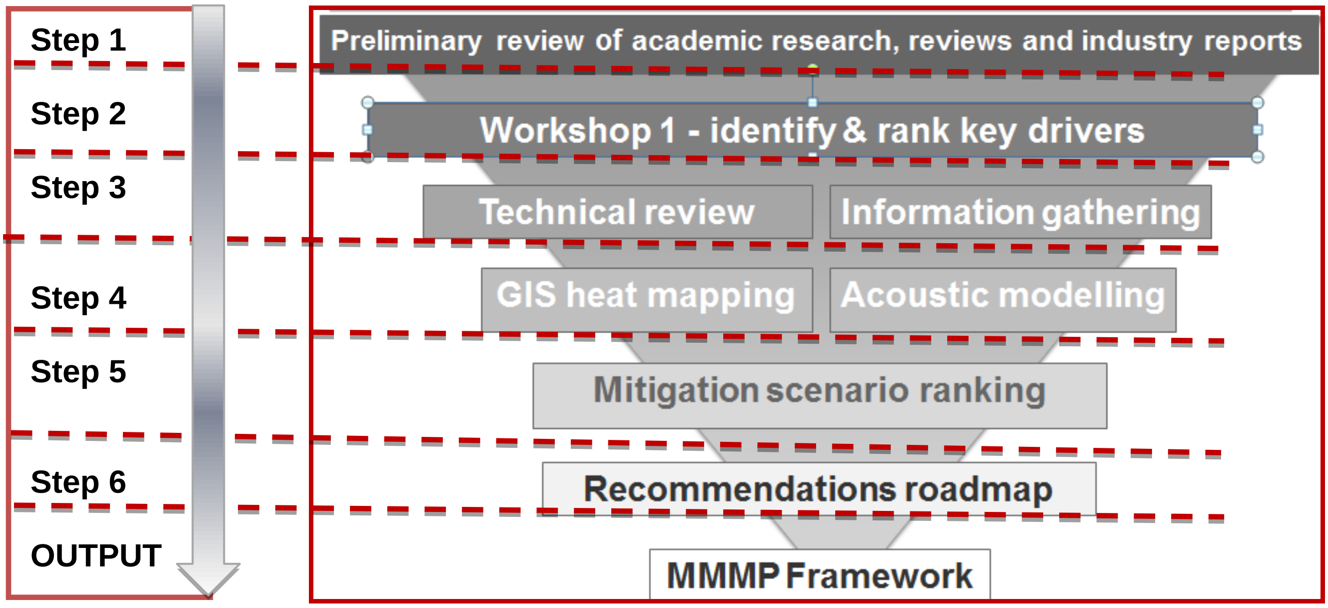
Country	OWF	Soft start	ADD	Notes	Source
Belgium	C-Power/ Thornton Bank	No indication of a standardised procedure.	Lofitech seal scarer.	No indication of soft start in report, but guidance and interviews indicate it is likely to have been implemented. ADD deployed in the immediate vicinity of the piling event.	(Haelters *et al.*, 2012)
Belgium	Northwind	Yes.	Yes – 1 hour before piling.	Also required to conduct observations around piles in a zone of 200 m between 1st June and 1st April.	Personal communication, *anon.*
Denmark	Horns Rev I	Yes, but no standardised procedure, so soft start duration only as long as necessary for engineering purposes.	Aquamark100 porpoise pinger and Lofitech seal scarer.	Acoustic pingers were deployed from all anchors of the piling rig. Lofitech seal scarer was lowered into the water every time the rig was moved.	(Tougaard *et al.*, 2009)
Denmark	Horns Rev II	Report indicates no standardised soft start procedure.	Aquamark100 porpoise pinger and Lofitech seal scarer.	Pinger and seal scarer deployed 2 – 3 hours before piling commenced.	(Brandt *et al.*, 2009)
Denmark	Nysted	No mention of soft start.	Aquamark100 porpoise pinger and Lofitech seal scarer.	Pinger and seal scarer were employed near (< 200 m) the pile for 30 minutes before and up until the end of piling activity.	(Carstensen *et al.*, 2006)
Denmark	Anholt	Yes.	Unknown ADD.	-	Personal communication, *anon.*
Germany	Alpha Ventus	Yes (in addition, vibration piling was used prior to hammer piling).	Unnamed pinger and seal scarer.	Personal communication during interviews suggest ADDs are deployed by installation vessel crew member. A bubble curtain was also employed at this site, and prevailing opinion suggests that such noise abatement techniques will become ubiquitous in German OWF development.	(Dähne *et al.*, 2013)
The Netherlands	Eegmond aan Zee	Yes.	Unknown pinger.	-	Personal communication *anon.*
The Netherlands	Princess Amalia	No requirement beyond	No.	No mammal mitigation required due to location.	Personal communication *anon.*

Country	OWF	Soft start	ADD	Notes	Source
		engineering soft start.			
The Netherlands	LUV	Yes.	Yes – 30 mins before piling.	Also required MMO and PAM during porpoise calving period (1 month). 300 m mitigation zone.	Personal communication *anon.*

APPENDIX H METHODOLOGY

Study methodology

The study followed a multistage process of information gathering, industry engagement and review to produce a recommendations roadmap that will be used to inform the eventual MMMP framework. Contributions from all parties were recorded and coordinated in a public file in order to ensure consistency of approach between contributors and efficient sharing of tasks. The key stages of the study are outlined below.



STEP 1: Initial Information Review

There is a considerable existing body of publically available data on current marine mammal mitigation techniques and Acoustic Deterrent Devices (ADDs) comprising: work funded by COWRIE, on-going academic research, and recent reviews of acoustic deterrents and marine mammal observer reports in parallel sectors (aquaculture and seismic). An up to date independent and concise review of all relevant, publically accessible material including industry reports, studies and research pertinent to the use and impact of soft start, PAM, MMO and ADDs formed the foundation step for discussions in Steps 2 and 3. The scope of the review included the collation of all materials on:

- The use of MMOs, ADDs (and any other deterrent devices) and soft-start procedures in relation to constructed UK and European offshore windfarm projects (OWF) to date (subject to data availability);
- The use of soft-start procedures in piling operations at said European windfarms;
- The status, and feasibility, of available ADDs (and other deterrent devices) for the species of concern for offshore wind developments in UK waters; and
- The comparative aspects of Health and Safety issues related to the range of mitigations, including current measures and the actual and potential use of ADDs.
- The comparative aspects of cost, practicality and installation schedule impact related to the range of mitigations; and
- The legislative implications of the actual and potential use of ADDs.

In parallel to the review of publically available information, the research team explored all opportunities to ascertain the availability of information outside of the public domain including the parallel "Review of Post-Consent Offshore Wind Farm Monitoring Data Associated with Marine Licence Conditions" currently being carried out by SMRU Ltd for Cefas, Defra and the MMO. Because ADDs have not been extensively employed in the UK, a significant proportion of the information obtained was derived from experiences elsewhere in Europe, both at commercially deployed OWFs and from experimental work e.g. BioConsult. The study team also liaised with respective national regulatory authorities and developers to obtain available monitoring reports and supporting documents.

Knowledge gaps identified as part of this initial step were channelled into the later interview and technical analysis phases. This preliminary review was also used to inform the development of the mitigation scenarios, as outlined in the next step. All of the information/ data used to inform this project were consolidated in reference sheets to inform Project 4 Phase 2.

STEP 2: Stakeholder engagement workshops

A collaborative approach to the decisions made during the study was an overarching objective of this study. Every effort was therefore made to capture the opinions and considerations of key stakeholders through a series of workshops, interviews and the on-going involvement of the Project Steering Group (PSG).

Workshop sessions were held on the 26th June 2013 in London and 15th July 2013 in Edinburgh. The objective of these workshops was partially to identify the key criteria or study drivers against which the various marine mammal mitigation scenarios will be evaluated, but mainly to encourage a detailed discussion around what was felt was important to take into consideration during this study and relative importance and implications of the drivers identified. The relative importance of the drivers was derived using a pair-wise comparison or Analytical Hierarchy Process (Saaty, 1980) e.g. as shown in the example table below (where N = Neutral, S = Stronger, W = Weaker).

To ensure that the study reflected the needs and perspectives of the 'end-users' attendees were selected to ensure a mixture of environmental and technical/project development skills and were sought from a mixture of: project developers, Statutory Nature Conservation Bodies (SNCBs), Non – Governmental Organisations (NGOs) and other interested parties. Awareness was raised by advertising the workshops in an ORJIP project update issued by The Crown Estate to a mailing list of interested organisations and individuals. In addition the project team presented the project scope and approach to the wider ORJIP steering group and invited feedback and input to the process.

The research question agreed by the workshop participants was:

Considering the evidence and experience from the application of existing techniques for mitigating the effects of piling noise on marine mammals (MMOs, PAM and soft starts), as well as the potential use of ADDs, what improvements can be made, and what is the best approach to adopt going forward, taking into account the future development of the offshore wind sector?

Following discussion, the key drivers identified during this workshop process were used to inform how the evaluation of mitigation solutions were identified and grouped. These drivers are listed below:

- Efficacy of technique;
- Unintended consequences;
- Practicality;
- Effects on installation schedule;
- Health and safety implications;
- Compliance with regulatory and legislative framework; and
- Cost implications.

Full details of the workshop process and findings are presented in the workshop report included in Appendix I.

STEP 3: Information gathering exercise and technical review

The outputs of the initial information review and stakeholder engagement workshops informed the scope of the information gathering exercise, questionnaire development and parallel detailed technical review. This step provided supplementary information on the use of MMOs, soft starts and ADDs on e.g. project schedules, health and safety and any technical or practical experiences.

The questionnaire was developed to obtain as much supplementary information as possible on the following:

- MMOs, ADDs or other deterrent devices if used, how they were deployed (from buoys, vessels, construction barges), location in respect of piling operation, conditions when deployed (night time, fog etc.), any issues with deployment, time between using ADD and piling;
- The potential for adverse effect on protected species;
- Any PAM undertaken and results;
- Protocol adopted;
- Any information on the effective spatial range of the method used;
- Records kept (including marine mammals seen);
- Any evidence of habituation of target species to the deterrent;
- Any evidence of species specificity;
- Costs of using MMOs/Deploying ADDs or other deterrent devices, including costs of installation, operation and maintenance;
- Any implications of using MMOs/ADDs for the activities being undertaken (time delays, costs); and
- EPS Licensing of activities (whether a licence was required, process to obtain).

Practicality and impacts on H & S, cost and installation schedule were assessed primarily by a series of telephone interviews and working discussions between the study team and various stakeholders including project developers (attempts were made to contact all relevant UK and EU projects), mitigation solution providers (specialist service providers and technology developers), and specialist contractors (e.g. piling contractors). Efficacy and unintended consequences of each option and compliance with the regulatory and legislative framework were researched using a primary literature search and consultation with SNCBs, ADD developers and researchers and interested groups.

Key data sources used in the literature search were:

- Marine mammal observer and mammal mitigation reports from construction phase of Round 1 and Round 2 projects (where available);
- Marine mammal mitigation plans (MMMPs);
- Peer reviewed articles; and
- Industry reviews (in particular work conducted by COWRIE and studies funded by Marine Scotland and the JNCC).

The output of this task was a shortlist of marine mammal mitigation techniques to be assessed. This step drew heavily on the work carried out for the Marine Scotland review (Coram *et al.*, 2013) and the literature sources described therein.

STEP 4: GIS heat mapping and acoustic modelling.

GIS heat mapping

A high level GIS approach was used to frame the current industry issues (siting and status of current UK OWFs, known marine mammal distribution and densities) and to help understand the future issues (increasing size, distance from shore and water depths of Round 3 zones).

The team was also able to use this heat mapping to identify areas that would be suitable for field trials of acoustic devices. Criteria (data layers) used in the selection of potential sites included marine mammal density data for the UK, deployment practicalities (proximity to areas of water with depths characteristic of R3 and STW piling operations), costs and risks associated field trials (e.g. remoteness of the offshore locations and distances from suitable ports etc). GIS was used to create maps overlaying the above criteria to areas where all criteria combined to produce an area conducive to conducting ADD trials (see Section 5.6).

Acoustic modelling

The review of existing Environmental Statements identified that the noise assessments to date had been undertaken using a range of propagation models under a wide range of conditions. They used different criteria for example, many only using peak criteria or single pulse criteria rather than the multiple pulse methods suggested by Southall *et al. (2007)* or criteria from Nedwell *et al.* and very few mentioned more recent work by Lucke *et al.,* as referenced in the JNCC guidance (JNCC, 2010a in press). It was also identified that there was variability in how the source strength was determined. Given the very large variability in assessment criteria, modelling methods and source strength derivation, the project team considered it beneficial to undertake some limited noise modelling under controlled conditions for the following purposes:

- Carry out a sensitivity analysis on assumptions in assessment and modelling;
- Predict a set of "typical" impact ranges under controlled conditions in order to determine the likely efficacy range required for ADDs;
- Assist in quantifying the efficacy of soft start procedures (for comparison against MMO, PAM and ADD); and
- Assess the potential impact of using possible lower threshold criteria (e.g. Lucke *et al.* for harbour porpoise) on the recommendations made as part of this workscope.

The modelling output provided the quantitative data (on a like-for-like basis for different scenarios) to inform the marine mammal mitigation ranking process detailed in step 5. The outputs of the modelling can be seen in Appendix K.

STEP 5: Mitigation scenario ranking

The broad information base gained through the previous steps then informed a scenario ranking exercise, carried out in a workshop setting by the technical specialists within the internal study team. The aim of the exercise was to identify a series of marine mammal mitigation scenarios recommended for consideration by ORJIP during Project 4 and the quantitative "ranking" of these scenarios against the key drivers identified earlier in the study (e.g. efficacy, unintended consequences, practicality). One of the primary objectives of this ranking exercise was to encourage a detailed technical discussion around what was felt was important to take into consideration during the development of viable recommendations to support Project 4 and the relative importance and implications of the mitigation measure scenarios identified. The output of this step was a framework within which various mitigation options can be comparatively assessed using a combination of quantitative and qualitative criteria.

STEP 5: Recommendations roadmap

Finally, through consultation with the steering group and wider stakeholders, the research necessary to move from current to recommended best practise was identified and presented in the form of a 'roadmap', highlighting the key targets for the Project 4 Phase 2 to achieve.

APPENDIX I WORKSHOP REPORT

ORJIP Project 4: Review of Marine Mammal mitigation for OWF

Workshop 1 Summary Report

DECC

Assignment Number: L300100-S00
Document Number: L-300100-S00-TECH-002

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Integrated Services
Asset Support

Workshop 1 Summary Report

L300100-S00

Client: DECC
Document Type: Technical Note
Document Number: L-300100-S00-TECH-002

R02	23.07.2013	Updated following Edinburgh Workshop	CS	JJ	AH	
R01	07.07.2013	Issued for Client Review	AH	CS	AH	
Rev	**Date**	**Description**	**Issued by**	**Checked by**	**Approved by**	**Client Approval**

Table of Contents

1 INTRODUCTION

This report presents a summary of a workshop carried out on the 26th June 2013 in London, and follow up session held on 15th July 2013 in Edinburgh, collectively referred to as 'Workshop 1' for the purpose of this report. The second workshop held in Edinburgh was scheduled to enable those who couldn't make the London workshop the opportunity to provide input and was used to refine and progress the output from the London event.

These workshops formed part of a study into the "Use of Deterrent Devices and Improvements to Standard Mitigation Measures during Piling" as part of a programme of work being carried out through the Offshore Renewables Joint Industry Programme (ORJIP) and coordinated by the Department of Energy and Climate Change (DECC).

The purpose of the workshop was to explore the criteria and key parameters to be considered in evaluating mitigation measures against marine mammal injury during offshore piling for marine renewables developments, including the use of Marine Mammal Observers (MMOs), Passive Acoustic Monitoring (PAM), soft starts and Acoustic Deterrent Devices (ADDs).

The workshop was facilitated and coordinated by Xodus Group, with input from our project partners, SMRU Ltd.

Background

In recent years concern has grown over the effects of underwater development activities on marine mammals, which are particularly sensitive to noise. Uncertainty about such impacts on marine mammals already presents a significant risk to deployment given the requirements of the EU Habitats Directive (transposed via The Conservation of Habitats and Species Regulations) and the "qualitative descriptors for determining good environmental status" as laid out in the Marine Strategy Framework Directive. During the installation of piles offshore developers are required to adhere to a Marine Mammal Mitigation Protocol which is intended to prevent injury to marine mammals.

The current mitigation protocol (JNCC, 2010), which includes such measures as the use of Marine Mammal Observers (MMOs), soft starts, delayed piling and the use of Passive Acoustic Monitoring (PAM) imposes inherent financial, schedule and H&S risks during their implementation. The complexity of such environmental impacts and mitigation will only continue to increase throughout Round 3 as wind farms get larger, more numerous and further offshore.

Xodus Group and SMRU Ltd, have been contracted by DECC to carry out a study, the scope of which is to review the evidence and experience from the deployment of these mitigation measures to date. The study is aiming to draw conclusions as to the effectiveness of current mitigation measures and provide recommendations on improvements, and on the need for additional testing and/or development of ADDs for multiple marine mammal species.

A key aspect of this is a structured process that has been selected to enable the project team to use the views and concerns of the key stakeholders to define the focus of the review. The workshop forms the first stage of the process. The second stage will be to score the selected mitigation options based on the criteria and weighting assigned during the initial workshop, and described in this note. This will identify how well the mitigation solutions, (based on evidence available), meet the criteria identified in the framework, identifying those options that maximise the contribution to achieving the stakeholders drivers.

Workshop Attendees

Members of the Project Steering Group, alongside various key stakeholders including developers, representatives from consenting bodies such Marine Scotland, Statutory Conservation Bodies (SNH), and individuals with direct experience of carrying out mammal mitigation activities (UK and EU) were invited to attend the workshop. The intention was to ensure that all perspectives were represented including environmental, project management, health and safety and offshore construction, as well as industry experts in acoustics and marine mammals. The attendees were as follows:

London Workshop

	Organisation / Interest		Attendee
1	DECC	ORJIP member / Project Manager	Emma Peterson
2	SNH	ORJIP Steering Group / SNCB	Fiona Manson
3	EDPR	ORJIP Steering Group / Developer	Paula Low
4	DEFRA	Government Department	Clare Leech
5	Natural Resources Wales	SNCB	Thomas Stringell
6	SMRU Ltd	Project team / mammal specialist	Carol Sparling
7	SMRU	Mammal / ADD specialist	Alex Coram
8	DONG	Developer	Jennifer Brack
9	RWE	Developer	Fabien Wilkes
10	Forewind Project	Developer	Julie Drew
11	Seamarco	Acoustics / sea mammal specialist	Ron Kastelein
12	CEFAS	DEFRA exec. Agency	Fabrizio Borsani
13	SPR	Developer	Marcus Cross
14	senergy	Consultant - Piling	Leo Causey
15	Xodus	Project Manager / environmental	Alex Herschel
16	Xodus	Offshore / subsea engineering	Christine Sams
17	Xodus	Acoustics specialist	Simon Stevenson
18	Xodus	Facilitator	John Jenkins
19	Xodus	Scribe / environmental	James Monnington

Edinburgh Workshop

	Organisation / Interest		Attendee
1	Source Low Carbon	ORJIP Steering Group	Zoe Crutchfield
2	Marine Scotland	ORJIP Steering Group / Scottish Government Directorate	Ian Davies
3	Scotland Natural Heritage (SNH)	ORJIP Steering Group / SNCB	Karen Hall *
4	The Crown Estate	Chief Scientist / Project Sponsor	Mike Cowling *
5	JNCC	SNCB	Karen Hall
6	Independent	MMO Specialist (including Seismic Experience)	Carolyn Barton
7	Marine Management Organisation	Executive non-departmental public body	Lindsay Booth-Huggins
8	Centrica	Developer	Jennifer Snowball *
9	Whale and Dolphin Society	NGO	Sarah Dolman
10	SMRU Ltd	Project team / mammal specialist	Carol Sparling

11	Xodus	Project Team / Engineering & Offshore Construction	Christine Sams
12	Xodus	Facilitator	John Jenkins

*A teleconference / VC approach was attempted at the Edinburgh Workshop which proved unfeasible / impractical therefore these attendees were forced to drop out.

Workshop Objectives

The workshop was arranged as the means of capturing the views and concerns of the key stakeholders, and to facilitate open debate of the issues. The specific aim was to deliver the first stage of the Xodus option ranking methodology, a process that enables various options to be compared in a structured and auditable fashion, in a rapid timescale, and to produce an output that may be used to inform the decision making process.

The attendees worked through a facilitated process to reach consensus agreement on the following:

- The research question for the review and the range of options and views to be considered
- The full range of potential measures or differentiators that need to be taken into account when evaluating mitigation solutions
- Grouping the potential measures into key drivers for the mitigation solutions e.g. Cost
- The comparative importance of each driver and overall importance in addressing the fundamental question
- The driver definitions, and scoring 'classification of contribution' so that they can be consistently applied by the project team carrying out the review

The process is designed to facilitate discussion and debate, and to enable consideration of multiple qualitative and quantitative criteria. It should be noted that output of the workshop (the evaluation 'framework') is intended to focus the evidence review on the topics which the stakeholders identify as critical, and is intended to inform, not replace, decision making.

The approach was selected because it has been found to be particularly useful for evaluating complex decisions with multiple, conflicting criteria and offers a fully auditable process, with capability for sensitivity analysis of results.

Note: Marine mammal mitigation for the benefit of this workshop was defined as '*all marine mammal mitigation practices currently implemented under the JNCC protocol (i.e. MMOs, PAMs and soft or delayed starts)*'.

Methodology

The VDRM Process

The methodology selected to enable the full range of stakeholder views to be taken into consideration was the Xodus 'VDRM' (Value, Decision and Risk Management) tool, part of a process that Xodus have developed in house to improve decision making on projects; it is a multi-criteria assessment tool based on the Analytical Hierarchy Process developed by Saaty (Saaty, 1980).

VDRM offers a systematic and auditable way of reviewing options and capturing and balancing a variety of perspectives.

The VDRM process will be carried out in 2 stages, the initial workshop(s) (as captured in this report) used to identify project drivers and scoring system, and a second workshop (proposed for later in the study) which will use the evidence gathered to score the mitigation solutions against the project drivers.

The output from the first stage is a framework to focus the team on the topics identified as critical by the project stakeholders.

2 WORKSHOP OUTPUT

Research Question

Following an introduction to the topic and outline of the current approaches to marine mammal mitigation the following research question was proposed and agreed by all attendees:

> *Considering the evidence and experience from the application of existing techniques for mitigating the effects of piling noise on marine mammals (MMOs, PAM and soft starts), as well as the potential use of ADDs, what improvements can be made, and what is the best approach to adopt going forward, taking into account the future development of the offshore wind sector?*

Opinions and Considerations

The full range of potential opinions to be taken into account, as identified by workshop participants, were identified as follows (in no particular order):

- Marine Mammals
- Other species e.g. Fish and Diving Birds
- General Public (e.g. as users of the marine environment / with environmental interests / as electricity consumers)
- Government (including UK, EU and devolved administrations perspectives)
- Government departments – DEFRA & DECC
- Statutory Nature Conservation Bodies (SNCB's)
- Other consenting authorities
- Academic organisations
- NGO's (UK, EU, International)
- Offshore Wind Developers
- Commercial Fisheries Organisations
- Other Maritime and Coastal interests e.g. oil and gas, Ministry of Defence, Shipping
- Installation Contractors… (piling)
- Mitigation Solution Providers / Developers e.g. ADD Manufacturers, Marine Mammal Observers etc.
- Noise elimination / reduction providers
- Research Institutes / Businesses
- Marine Mammal Organisation

Key Drivers

Following on from this the full range of potential measures or differentiators that need to be taken into account when evaluating mitigation solutions were identified and then grouped as shown in the table below:

Key Driver	Parameters to consider	Notes
Efficacy	Species	The efficacy of mitigation techniques can vary between species, e.g. PAM not effective for non-vocalising mammals.
	Spatial effect	The effective area covered by the mitigation technique.
	Temporal effect	The amount of the time that the technique is effective.
	Habituation	The risk that the approach becomes less effective over time.
	Flexibility	The ability to deploy the mitigation technique in a variety of conditions, or locations whilst still delivering expected results.
Unintended consequences	Non-target species	The impact of the mitigation on diving birds or fish.
	Additional disturbance/displacement	The technique deployed causes increased stress/impacts over and above the piling noise.
	Injury	The risk that the mitigation technique itself has the potential to cause marine mammal injury.
	Economic/consenting impacts (other sectors)	In addition to ecological impacts there are potential socio-economic impacts e.g. in relation to the Marine Strategy Framework Directive (cumulative noise from one project prevents another gaining consent).
Practicality	Scale (no. and size)	How the mitigation is used - e.g. multiple devices, teams, vessels?
	Reliability	In terms of engineering (does the equipment perform as required) and also human factors (e.g. availability of adequate MMO's).
	Availability	How readily available are the mitigation solutions?
	Deployability	How easy are the techniques to deploy?
Installation schedule	Programme	What is the impact of the mitigation solution on the overall installation programme?
	Swimming speed	e.g. impact on the delays to piling start up due to variability between swimming speed between different mammals and depending on type of deterrent (e.g. what kind of response is the mitigation seeking).
	Uncertainty	How much uncertainty does the mitigation solution introduce into the overall construction schedule?
	Logistics	e.g. do people and equipment need to be moved / handled, how frequently and what is involved (e.g. crane lifts?).
H & S	Offshore (hu)man hours	How many overall additional hours may be required offshore?
	Location	How may the location of the project site affect the H&S risk of the mitigation activity - i.e. not all offshore hours are equally hazardous (e.g. small vessel, large vessel, platform).
	No. of people	How many additional people are required per technique?
	Additional obstructions	How much equipment is needed and where? (On the piling vessels, in the water, additional vessels in field, navigational hazards?).
Regulatory and legislative	Compliance	Developer compliance consent conditions, Habitats Directive,
	International agreement	UK legislation (reflecting EU Directives), Marine Strategy Framework Directive etc.
	Enforcement	How is the mitigation solution enforced or monitored? Nb: this is an evolving area for e.g. MMO's.
	Acceptability	How acceptable is the solution to the stakeholders?
Cost	Equipment (CAPEX)	Total equipment costs?
	Operational cost of mitigation devices	How much does the mitigation cost to operate on the project?
	Impact on project costs	Overall implications for the project - i.e. LCOE?

The importance of reputational risk to developers, industry and government was discussed extensively as it was not felt to fit easily into the framework or categories as it affects multiple areas including cost and public opinion and legislation. At the 2nd workshop it was decided that reputation was best handled by including the impact on public opinion within regulatory and legislation and the impact on mammals in unintended consequences (e.g. dead beached cetaceans).

The 2nd workshop agreed that reputation would be handled as follows:

> The team will consider reputation within the regulatory driver as an issue of regulatory compliance and public acceptability

> The risk of injury to marine mammals will be evaluated and captured within unintended consequences

Pair-Wise Comparison

The next step in the process was to compare the drivers using a pair-wise comparison; this captures the comparative importance of each driver, and overall importance to the research question. The results are shown below. Appendix 1 shows a matrix capturing the key discussion points associated with each comparison. These results were discussed in the 2nd workshop, and although the attendees felt that they would likely have reached a different score in some areas the results were accepted, provided some sensitivity analysis is performed, as outlined in the paragraphs below.

Legend
Very Much Stronger **(VMS)**
Much Stronger **(MS)**
Stronger **(S)**
Neutral **(N)**
Weaker **(W)**
Much Weaker **(MW)**
Very Much Weaker **(VMW)**

Key Drivers	Efficacy	Unintended consequences	Practicality	Installation schedule	H & S	Regulatory and legislative	Cost
Efficacy	N	S	MS	N	W	MS	MS
Unintended consequences	W	N	W	MW	MW	W	W
Practicality	MW	S	N	MW	VMW	MW	MW
Installation schedule	N	MS	MS	N	W	W	MS
H & S	S	MS	VMS	S	N	S	S
Regulatory and legislative	MW	S	MS	S	W	N	MS
Cost	MW	S	MS	MW	W	MW	N

Figure 1: The pair-wise comparison matrix

The respective weightings derived from this process are presented in the graph below. Appendix A includes a discussion table detailing the rationale behind the pairwise comparison results.

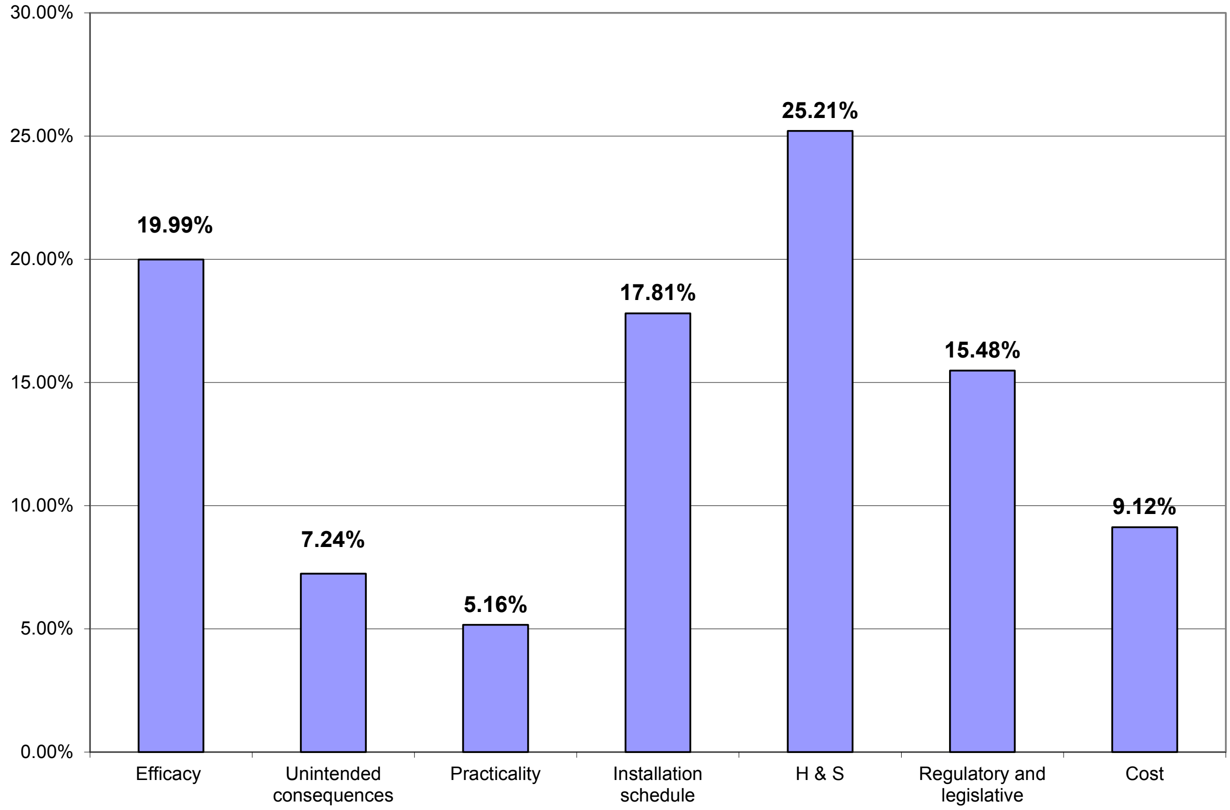

Figure 2: Weighting graph

This graph was discussed by the group. Overall it was agreed that the weighting that had been reached for five out of the seven key drivers was in line with expectation. Two key drivers, Efficacy and Cost were however felt to be potentially skewed. Efficacy originally came out with a lower weighting than had been anticipated. When discussed it was felt that this was because it was the first driver to have been put through the pair-wise comparison. Some of the group felt that the weightings they had assigned were therefore more reserved because they were unfamiliar with the process.

The group partly re-scored cost by drawing out reputation, however, this led to very little change in % and no change in the overall 'order' of the drivers, therefore it was agreed that to handle these concerns by ensuring that cost and efficacy would be subject to a sensitivity analysis later in the process, and that reputation would be handled as outlined previously, explicitly embedded within unintended consequences, and as a regulatory and legislative consideration.

Classification of Contribution

The initial classifications were carried out in workshop 1 and then theses initial descriptions were expanded and finalised at the wash up workshop. The final table is presented below. At this stage of the process the group agreed to place a HOLD on the '0' score, until more information was gathered to inform the review. The key points to note are that:

- -3 and +3 are defined as the realistic worst and best case, respectively, the approach taken is to try to develop a scoring range which can be fully utilised in the process to help differentiate between mitigation solutions
- zero does not necessarily represent a neutral value, but the mid-point on a scale that may be skewed in a negative or positive direction
- this scoring table has been developed to enable a comparison of the solutions versus the impact of piling without any mitigation

In order to handle the difference between the effectiveness of solutions on different species we intend to run the solution scoring seperately for each of the 5 key species of concern (i.e. bottlenose dolphin, harbour porpoise, minke whale, grey seal and harbour seal), and then again to capture all other marine mammals.

Key Driver		Classification of Contribution		
		-3	0	+3
Efficacy	Species Spatial effect Temporal effect Habituation Flexibility	Additional impacts e.g. attraction, increases overall cumulative noise dose (i.e. leading to PTS), only applicable to a single site beyond piling alone		Eliminates all risk of acoustic injury on 100% of marine mammals (i.e. all individuals), removes marine mammals from the minimum area necessary (or ensures required area is clear), without habituation risk, for the minimum time necessary for all species at all sites
Unintended consequences	Non-target species Additional disturbance/displacement Injury Economic/consenting impacts (other sectors)	Major impacts on ecosystem, significant negative impact on other users of the sea, death / injury / significant disturbance to non-target species		No unintended consequences
Practicality	Scale (no. and size) Reliability Availability Deployability	Complex, unreliable, poor track record, untested, only viable in limited sea states / weather conditions / daylight, un-implementable mitigation measures		Harmonius with working environment, easily deployed, readily available, proven reliability to level required (including weather conditions, daylight etc)
Installation schedule	Programme Swimming speed Uncertainty Logistics	Unacceptable and unpredictable levels of downtime		No additional downtime or additional schedule uncertainty due to mitigation
H & S	Offshore (hu)manhours Location No. of people Additional obstructions	Significant high risk activities and increase in no. of people required on site, significant increase in navigational hazards on site		Zero additional persons and manhours required, inherently safe solution
Regulatory and legislative	Compliance International agreement Enforcement Acceptability	Non-compliance, infraction, zero consents to piling projects or development licence revoked, public opposition		Compliant to a higher standard than required by existing legislation, easily enforceable, accepted by all stakeholders (leads global best practice)
Cost	Equipment (CAPEX) Operational cost of mitigation devices Impact on project costs	Mitigation costs are sufficiently high that offshore wind development becomes unviable without increase to CfD		No net additional costs due to mitigation

Discussion points

The VDRM process is designed to provide the opportunity for discussion, to table all views on the research topic and to fully scrutinise the rationale behind people's views. Key discussion topics drawn out during the workshop were recorded to ensure their incorporation into the next steps of the study where appropriate. These are summarised below.

1. Several attendees felt that there was no such thing as a "one solution fits all" for marine mammal mitigation (e.g. a site within the vicinity of a SAC characterised as having significant marine mammal sensitivities may require a different protocol to a site in a location where marine mammal abundance is low).
2. It was felt that there is a definite need to understand the issue before identifying the solution. A robust qualitative and quantitative review of the pros and cons of each type of existing marine mammal mitigation (MMM) option (in particular MMOs) was identified as being critically important to making any recommendations with regard to existing protocols – NOTE this is within the scope of the project already.
3. It was raised that fish and diving birds should also be captured within the study; although care should be taken to ensure that the study does not lose focus or detract from the target marine mammal species – this will be explored within the scoring under non-target species.
4. A comment was raised about how the current mitigation protocols cover the legal framework requirements for injury versus disturbance – it was agreed that the scope of this study is to address injury ranges specifically, but with an appreciation that disturbance cannot be fully de-coupled from the issue.
5. Any mitigation measures implemented will need to balance the development risks facing developers and the need for the UK to comply with EU legislation.
6. As we move into offshore wind farm Round 3 licensing the stakes in terms of cumulative impacts means that more effort is being placed on mitigation rather than just green points. Efficacy will therefore need to be afforded a high priority in the development of any recommendations for improvements to the existing marine mammal mitigation protocol.
7. There was a discussion about the existing MMM protocols and whether piling is permitted at night. There was mixed views about whether piling could be carried out at night. The majority consensus was that piling could be carried out at night as long as piling commenced during daylight hours and PAMs were used during periods of poor visibility (e.g. fog). The fact that PAMs can only detect vocalising species of marine mammals and that it is not presently possible to express range using PAMS was noted.
8. The difference between existing soft start energy ramp up requirements versus normal engineering led start up requirements was discussed.
9. It was noted that in Germany there is a 750 m or 140 dB limit from source for noise. It would be very useful to get a better understanding about the rationale for these guidelines and how the German government ensure compliance with EU Directives.
10. It was acknowledged that the vast majority of the ADDs to date have been designed to deter pinnipeds in nearshore fish cages in very different environments to those that would be encountered by Round 3 offshore wind farm projects.
11. It was noted that there are already two ADDs being used by the OWF sector in Germany that should be investigated .
12. It was raised that there was currently insufficient evidence to reassure regulators to specify, and developers to adopt ADDs as the preferred primary MMM option. Suggested questions that would need to be answered included:
    a. What would need to be the evidence point for moving from one MMM option to another?
    b. What would alternative MMM protocols (e.g. ADDs or other deterrent or detection devices) bring that MMOs couldn't?

c. If ADDs are used, a balance would need to be met between exclusion and the displacement effect and injury versus disturbance.

13. It was noted that project accountants and commercial managers should be included in the questionnaire distribution list.
14. Ron Kastelein highlighted that soft starts are understood to confuse marine mammals, they don't know whether or where to flee from and to. Multiple piles may have serious implications for Round 3 offshore wind farm MMM.
15. It was requested that the order of the drivers be moved around so that they could be grouped together better graphically.
16. The importance of disturbance impacts as well as injury to marine mammals was raised. The point was made that although disturbance has the potential to impact upon marine mammals, the standard mitigation approaches being evaluated in this project are only capable of reducing the risk of injury to marine mammals and it was agreed that the scope of this project was to only examine the effectiveness of the proposed mitigation strategies with respect to the potential for reducing risk to injury rather than disturbance impacts.
17. The role of noise reduction technologies / approaches were raised several times in the workshop, and it was agreed that although assessment of such were outside the scope of the project it would be helpful if the evaluation framework was developed with the flexibility to enable cross-comparison with these approaches at such time that a full review of the effectiveness and practicality of such measures has been carried out with respect to application at UK Round three wind farm sites. The main change that would be necessary to enable this would be changing the definition of the maximum 'Classification of Contribution' score under effectiveness to include disturbance.
18. Following on from comment 2, it was felt that a major part of this understanding the issue is to get a better understanding of the range over which mitigation is required to be effective. This is a challenging task as the effective range required is likely to vary according to the environmental factors driving noise propagation, engineering factors such as pile size, hammer energy and substrate type, the species of concern and the thresholds adopted in the assessment. A review of the modelling carried out to date to predict impact ranges over a range of typical construction scenarios may inform our understanding of this. A robust qualitative and quantitative review of the pros and cons of each type of existing marine mammal mitigation (MMM) option (in particular MMOs) was identified as being critically important to making any recommendations with regard to existing protocols. – NOTE this is within the scope of the project already

Ron Kastelein (Seamarco) provided a summary of his work on ADDs/ pingers on captive marine mammal species and raised several points:

> Certain species of marine mammal have greater sensitivity to disturbance than others. For example harbour porpoises need to feed constantly, and small changes in calorific intake can very quickly lead to health risks, prolonged disturbance would therefore lead to greater levels of stress from not being able to feed than species that feed less frequently.

> The distance that species are influenced by piling noise may be up to 30 km from the noise source.

> If ADDs are to be considered for MMM then robust research is needed to ascertain over what range (in different environments) they will be effective and for what species.

> Regulators in The Netherlands decided that it was preferable to deploy an OWF field as quickly as possible rather than enforce prolonged disturbance to marine mammals from piling noise through delayed soft starts, stop-start procedures.

> Initial results from the research being undertaken indicate that potentially it is not the risk of PTS that poses the biggest risk to marine mammals, but that disturbance can create more profound and significant impacts on certain species – this work has not yet been published.

3 NEXT STEPS

The framework presented in this workshop report has been used to shape the information gathering and next phases of the review. For each of the key drivers and parameters identified the project team are gathering information and assessing the evidence in order to be able to score the mitigation solutions against these factors. It is already anticipated that a number of these parameters will potentially be 'unscore-able' due to e.g. knowledge gaps or insufficient information available. The method for handling these areas will therefore be agreed with the steering group and revisited throughout the iterative review process.

Summary

The workshop based approach was selected to ensure:

- promotion of effective communication between project participants;
- a balanced view of all marine mammal mitigation drivers (legislative, environmental, cost, time, performance etc.);
- an expedient, flexible, robust and auditable decision making process;
- auditability, clarity and consistency in decisions; and
- a mechanism for comparing strategies with diverse strengths and weaknesses.

The audit trail of decisions taken during the study execution will in addition provide a useful basis for review and for the carry-over of learning into subsequent workscopes or phases of the ORJIP project.

ACRONYMS

ADD	Acoustic Deterrent Device
CAPEX	Capital Cost (Expenditure)
CfD	Contract for Difference
H&S	Health & Safety
MMM	Marine Mammal Mitigation
MMO	Marine Mammal Observer
OWF	Offshore Wind Farm
PAM	Passive Acoustic Monitoring
PTS	Permanent Threshold Shift
SNCB	Statutory Nature Conservation Body

REFERENCES

JNCC, (2010), Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise. Available from:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/50006/jncc-pprotocol.pdf

Saaty, TL (1980), The Analytical Hierarchy Process, NY, McGraw Hill.

APPENDIX 1 RECORD OF DISCUSSION

KEY DRIVERS	Unintended consequences	Practicality	Installation schedule	H & S	Regulatory and legislative	Cost
Efficacy	**S –** issues associated with unintended consequences acknowledged as highly important, but reducing piling related injury is priority issue. Injury versus disturbance issue raised, however noted that the current requirement is to prevent injury and therefore efficacy must be evaluated on this basis. . Importance of impacts to non-target species acknowledged, marine mammals are priority for this study. NOTE: A lot of the discussion was around the assumption that these comparisons can only be done under the assumption that a mitigation was effective, otherwise effectiveness would trump every other driver	**MS** – general sentiment was that if a highly efficacious mitigation measure can be identified, practical issues with its implementation would be overcome. Motivation to do so includes the desire for mitigation to be effective, but also because of the knock-on benefits to consenting issues, installation schedule etc.	**N –** felt that they are equally important. Identified that there will be a 'tipping point' at which a highly effective mitigation measure would not be employed due to unacceptable impacts on project schedule.	**W –** unanimous agreement that risks of human injury/death outweigh risks of marine mammal auditory injuries.	**MS –** Legislation is an absolute (Govt. must comply – however it was noted that approach is an interpretation) Group concluded that an effective measure is much more desirable than one that simply complies with legislation. In theory the two factors are unlikely to oppose each other, i.e. an effective mitigation is one which is likely to meet regulatory requirements. Issue of possibility of needing disturbance licences for ADDs also discussed.	**MS –** group decided efficacy should take priority over cost. Attendees that have been in the position to make calls on types of mitigation to be used on behalf of developers explained that they would generally follow recommendations on the most appropriate mitigation, even if more expensive. Some debate over whether the opposite can occur i.e. priority of developer is cutting cost and doing the minimum expected.
Unintended consequences		**W** – important that mitigation is practical, as impractical measures could have implications for efficacy, cost, H & S and installation schedule. Less likely to be used if impractical.	**MW** – installation schedule much more critical to developers, costs associated with construction vessels far outweigh the mitigation costs, and anticipated impact of unintended consequences. Overall risk of mitigation solutions to other socio-economic groups or developers generally seen as low (or very low)	**MW** – risk of human injury/death outweighs risks to non-target species, as well as any potential socio-economic consequences.	**W –** regulatory and legislative compliance essential to project and must, therefore, take priority over unintended consequences, which may range from insignificant to highly undesirable.	**W** – cost may reach a point at which it becomes prohibitive to the project, whereas unintended consequences from mitigation solutions are generally undesirable, but unlikely to pose a major risk to project, through consenting issues or otherwise.
Practicality			**MW** – group felt that minimising impacts to the installation schedule was much more important than the practicalities on implementing mitigation, due in part to the respective costs i.e. delays to schedule are likely to be very significantly more expensive.	**VMW** – felt that it there would be no situation where the practicality of implementing a mitigation measure would take priority over H & S. Furthermore, in general more practical measures would inherently have lower levels of H & S risk.	**MW** – regulatory compliance is of critical importance to a project, whereas practical mitigation is highly desirable, but impracticalities can generally be resolved (e.g. through engineering or technical development).	**MW** – in general, the cost of mitigation was decided to be more important than practicality, but in reality the two factors are unlikely to oppose each other i.e. impractical mitigation is less likely to be cost effective and efficient.
Installation schedule				**W** –as per the above comparisons, agreed that risk of human injury/death takes priority over project scheduling issues.	**W** – regulatory and legislative compliance are essential to the legal progression of a project and therefore take priority over installation schedule by default. Regulatory breach could result in development licences being revoked.	**MS** – the costs imposed by delays during installation are likely to be far greater than those associated with the marine mammal mitigation measures under consideration.
H & S					**S** – It was agreed that H&S legislation takes priority over environmental legislation in UK law	**S –** H & S issues are very high priority, and the group decided that choosing mitigation measure to save money at the expense of safety was an inconceivable scenario.
Regulatory & legislative						**MS** – group came to conclusion that legislative requirements must be met, regardless of cost, if a development is to proceed, making Regulatory and legislative a *de facto* priority.

APPENDIX 2 INITIAL TEST SCORING

In order to 'test' the framework in the 1st workshop a sample scoring run was completed and has been included below for reference.

The scores assigned to the "Current best practice marine mammal mitigation protocol" scenario and supporting Record of Discussion are presented below. These are included as an illustration of the process only and will be revisited and revised following the full evidence review process.

Option	TOTALS (%)	Efficacy	Unintended consequences	Practicality	Installation schedule	H & S	Regulatory and legislative	Cost
		19.99%	7.24%	5.16%	17.81%	25.21%	15.48%	9.12%
Current best practice marine mammal mitigation protocol		-1	0	-1	1	-1.5	0	-1

Figure 3: Example Scoring

Efficacy	Unintended consequences	Practicality	Installation schedule	H & S	Regulatory and legislative	Cost
Record of Discussion						
Discussion around soft start as an engineering practice vs as a mitigation measure – is there a difference? It is difficult to score the efficacy of the existing mmmp without industry wide scrutiny of the available data.	What is the definition of unexpected vs unintended – e.g. if piling stops at night, animals return, when fleeing they don't feed etc. Ref RK's comments on harbour porpoise. Agreed unintended consequence to include fish and other marine life.	Practicality considered based on the existing mmmp in place, although it was noted that the same mitigation options would become increasingly impractical for R3.	The difference between existing soft start energy ramp up requirements versus normal engineering led start up requirements was discussed. No OWF piling experience was not available to inform workshop but wider industry used. Potential for proxy from seismic was considered.	Increasing wind farm size and distance offshore means that it will become increasingly difficult to implement the existing marine mammal mitigation. The more people that are required to work offshore, the greater the HSE risk.	Discussion raised about whether current mitigation protocols cover the legal framework requirements for injury versus disturbance. Risk of infraction on EU regs discussed as well as developer consents.	Reputational risk and costs were removed from the discussion to enable the scoring to more robustly reflect the cost of the mitigation protocols

Figure 4: Discussion associated with example scoring of current mitigation protocols

APPENDIX J INFORMATION GATHERING SUMMARY

Overview of information gathering exercise

In order to capture information not usually presented in primary and grey literature or construction reports, such as hands on experience with different mitigation techniques or participation in the MMMP design and selection process, a series of telephone interviews based on a standard questionnaire were conducted. The invitation to take part in an anonymous interview exercise was extended to approximately 40 individuals from OWF developers, piling contractors, environmental contractors, consultants and advisers. 11 of these invitees were successfully interviewed before the project submission date. Despite the relatively modest sample size, the interviewees spanned a diverse set of disciplines and nationalities. Many had experience from a number of European countries and were therefore able provide a substantial amount of information. As such, the process facilitated knowledge transfer from projects in the UK, Germany, the Netherlands, Denmark and Belgium. The disciplines of the individuals interviewed included:

- Construction management;
- Consents and compliance management;
- Environmental advice; and
- MMMP solution provision and research.

The questionnaire was sent to interviewees at least one week prior to conducting the interview to allow time for consultation with colleagues in case certain question fells out of their particular area of expertise. The questionnaire questions are presented here in Table J.1. Each interview lasted approximately 35-45 minutes and whilst all responses were information rich and insightful, it was rare that individuals were able to provide answers to every question. The interviews also proved to be one of the most effective methods of obtaining reports from developers. To preserve anonymity and prevent excessive repetition, individual responses are not presented here. Instead, the key themes drawn out during the exercise have been summarised in beneath Table J.1. Additionally, anonymous quotes specifically relevant to sections of this review have been inserted and referenced as personal communications.

Table J. 1 Example of questionnaire provided to interviewees

No	Question
1	Does your company use any of the following marine mammal mitigation techniques alone or in combination during piling and why: a. Soft start techniques; b. MMO surveys; c. PAM (or other monitoring devices); d. ADDs (or other deterrent devices); and/or e. Other?
2	Any supporting information on the following related to the above techniques would be very beneficial, namely: a. How they were deployed (from buoys, vessels, construction barges); b. Location in respect of piling operation; c. Conditions when deployed (night time, fog etc.); d. Any issues with deployment; and e. Time between using ADD and piling etc.
3	What is the reason that you have employed the marine mammal mitigation techniques mentioned in the previous question? a. Practicality for deployment; b. Efficacy of the technique(s); c. Ease of deployment; d. Technique(s) used are a specific condition of consent; and/or e. Based on research carried out specifically for your project/ by your company.
4	Have you considered any other MMM options, and if so which and what was the rationale for not taking these techniques forward? a. Practicality for deployment; b. Efficacy of the technique(s); c. Technique(s) used are a specific condition of consent; and/or d. Based on research carried out specifically for your project/ by your company.
5	To understand the internal and external stakeholder communications used in the process of developing a Marine Mammal Monitoring Protocol, please can you provide any information on the decision process you use to develop MMMP & who is involved?
6	If your company/ project has carried out any specific work to understand the efficacy of the options/approaches included or excluded at your development(s), would you be willing to share this information on the work and its results? E.g. > The potential effects on protected species;

No	Question
	> The effective spatial range of the method used; > Records kept (including marine mammal observations); > Any evidence of habituation of target species to the deterrent; and/or > Any evidence of species specificity. (Any information provided can be treated in confidence).
7	What improvements (if any) do you think could be made to the existing JNCC protocol? And does your company complement the existing protocol with any additional internal company guidance?
8	Have the current mitigation techniques you employ had any positive or negative implications on your construction schedule(s)? (e.g. recorded incidences of soft or delayed starts that have had significant implications on the project)?
9	Do you have any available information that you would be willing to contribute on the costs of using MMOs/Deploying ADDs or other deterrent devices, including costs of installation, operation and maintenance? If you cannot contribute specific cost data please see question 10.
10	Do the current mitigation techniques you employ have any positive or negative implications on your costs for the project, either direct (cost of devices or service providers) or indirect such as training, additional vessels etc?
11	Has the current mitigation technique(s) you employ had any positive or negative implications on the H & S risks assigned to the project? (e.g. any recorded incidents). If yes, how has the risks assigned to the protocol techniques been addressed?
12	How significant is your company/ project's reputation with respect to marine mammals and piling? What associated risks have been identified (e.g. cost implications) and what is your company/ project's approach to managing any such risks?
13	Has the current mitigation technique(s) you employ had any positive or negative practical implications during construction and deployment? (e.g. increased obstructions on site due to the deployed ADDs, increased interest from construction crew/awareness)?
14	Is your company involved in ROUNDS OF OW /STW or other offshore wind developments? If yes, are there any specific additional measures (above those implemented for any R1 and R2 sites that you are involved in) to address any identified additional risks to marine mammals during R3 and STW related piling?
15	Do you have any other points/questions/ideas/concerns/thoughts you would like to raise or receive feedback on?

Summary of responses

The responses described below have grouped according to key themes as opposed to the individual questions presented above in Table J.1.

Which mitigation measures does your company use during piling, why were they chosen and how were they deployed?

UK

- In the UK, soft starts, MMOs and PAM have been used extensively, principally because they are usually required in the FEPA/Marine Licence;

- MMOs and PAMs are usually deployed from a dedicated survey vessel. There is some industry experience (three projects) of deploying them from the installation vessel. This approach has shown considerable promise in terms of overcoming logistical and practical issues. Benefits include better communications, reduced collision risk, better quality rest on installation vessel (leading to reduced fatigue), a higher and more stable viewing platform and cost savings;
- Mixed experience with PAM – key point is that efficacy is highly dependent on the skill and experience of the operator. Other developers reported lots of trouble;
- Soft starts, as they are currently prescribed, are not considered onerous by developers, who are generally positive about the technique;
- ADDs have been used more widely in the UK than is immediately apparent from project ESs and interrogation of FEPA/Marine licences. Pingers and ADDs have been used on different projects (but not together). The most common approach in the UK has been to use them at night after 30 minutes of PAM and for 30 minutes before soft start, being deployed from the installation vessel. However, in one instance they have been deployed using buoys, which was subsequently deemed a flawed approach due to significant logistical issues;
- ADDs have been successfully deployed by non-specialists such as installation vessel crew, FLOs and client representatives; and
- One project deployed ADD and PAM on a single palette, which was considered highly practical. This project required an EPS licence for the ADD. It was decided to change ADD model half way through the project, which required a revised EPS licence.

Rest of Europe

- OWFs mitigation plans assessed on case by case basis;
- MMO and PAM used very rarely in Netherlands but not elsewhere;
- Soft starts and ADDs favoured approach, with additional restrictions such as seasonal/spatial closures;
- General opinion of MMOs is that they are not effective, but no work has been conducted to test this assumption;
- Germany are unique in their extensive use of noise abatement techniques such as bubble curtains or IHC sleeves, and strict noise criteria. Looking to develop online PAM network system and potentially link to triggering ADDs;
- Use of ADDs differs from UK – in Europe they are used at every piling event, regardless of visibility. They are also left running during piling to ensure aversive signal continues through any potential breaks in piling;
- In some European countries the only resident species is harbour porpoise, making it a simpler problem than in the UK; and
- Anecdotal evidence from installation vessel crew who have deployed ADDs suggest they work well and easy to implement.

What is the decision process that leads up to certain techniques being taken forward?

- In the UK, process is generally to follow guidance and best practice as stipulated in licence conditions; and
- For certain European projects there has been seemingly more dialogue and room for negotiation.

Is your company involved in any research into the efficacy of marine mammal mitigation measures employed?

- One of the developers has been extensively involved in research into networks of PAM in Europe; and
- Other developers said they will adhere closely to best practice and guidance, but do not seek to exceed it.

What improvements could be made to the existing JNCC (2010b) piling protocol?

- Almost all of the respondents who answered this question stated that a move away from prescriptive 'blanket application' of MMMPs towards plans that are tailored to the specific needs and challenges of individual projects was highly desirable;
- There were concerns voiced regarding the value of MMOs and that potentially they might represent an 'expensive insurance policy';
- Improvements could be made to the start approach; for example, by tailoring the duration/ramp up energy to suit specific species;
- Protocol needs to be a suite of tools/options that can be tailored to project specific requirements; and
- One respondent expressed concern over that fact that the current mitigation protocol does nothing to address disturbance or behavioural effects.

Have the marine mammal mitigation measures used had a significant effect on construction schedules?

- UK developers perception is that MMOs/PAMs have not caused significant delays to any projects, with cumulative delays time in the order of minutes to hours over entire construction period; and
- ADD and soft starts (as they are used currently) are thought to be harmonious with construction schedules.

Have the marine mammal mitigation measures used had a significant effect on project costs?

- In Germany, noise mitigation costs are very small in comparison to the cost of the noise abatement equipment; and
- General comment on UK OWFs was that the cost is not prohibitive, but it is certainly not negligible, and can be 'felt'.

Have the marine mammal mitigation measures used had a significant effect on H & S?

- Developers flagged additional man hours and vessels at sea as an H & S concern that is treated very seriously and highlighted that this is likely to become more significant for Round 3 Developments.

Have the mitigation measures used had any practical implications?

- Not a big problem. Multiple respondents highlighted that vessels towing PAM gear cannot operate close to the piling event because of the potential for entanglement in anchor chains. This compromises the solution somewhat;
- One developer provided details on the phenomena of chalk setup and the implications it has for soft starts after piling breaks i.e. it cannot be done because it puts undue stress and fatigue on the pile; and
- ADDs have certain practicality issues, especially if deployed from buoys. Another issue raised was associated with time limits that may be required when using ADDs. If for example, ADD use beyond 30 minutes is prohibited, but a full 30 minutes is necessary to bring about the desired deterrence

effect, it becomes very difficult to predict when the ADD should triggered so that it seamlessly transitions into the soft start. This is not an issue in Europe, where they run the ADDs throughout piling.

Additional comments:

- A general comment that emerged in multiple interviews was that mitigation plans need to reflect more closely the reality of working offshore and allow for common sense thinking/adaptation when specific issues arise;
- On the subject of developers' reputation, the general response was that its importance is very difficult to quantify, but is considered. Particularly important for knock on effects to other areas of the business;
- One developer representative stated that MMO and PAM were probably unfeasible for Round 3 considering the conditions likely to be encountered that far offshore; and
- Communication between MMM team and construction team was raised in multiple interviews and was highlighted as being of the utmost importance.

APPENDIX K ACOUSTICS REVIEW

Acoustic concepts and terminology

Sound travels through the water as vibrations of the fluid particles in a series of pressure waves. The waves comprise a series of alternating compressions (positive pressure variations) and rarefactions (negative pressure fluctuations). Because sound consists of variations in pressure, the unit for measuring sound is usually referenced to a unit of pressure, the Pascal (Pa). The unit usually used to describe sound is the decibel (dB) and, in the case of underwater sound, the reference unit is taken as 1 μPa, whereas airborne sound is usually referenced to a pressure of 20 μPa. To convert from a sound pressure level referenced to 20 μPa to one referenced to 1 μPa, a factor of 20 log (20/1) i.e. 26 dB has to be added to the former quantity. Thus 60 dB re 20 μPa is the same as 86 dB re 1 μPa, although differences in sound speed and densities mean that the difference in sound intensity is much more than this from air to water. All underwater sound pressure levels in this report are described in dB re 1 μPa. In water the strength of a sound source is usually described by its sound pressure level in dB re 1 μPa, referenced back to a representative distance of 1 m from an assumed (infinitesimally small) point source. This allows calculation of sound levels in the far-field. For large distributed sources, the actual sound pressure level in the near-field will be lower than predicted.

There are several descriptors used to characterise a sound wave. The difference between the lowest pressure variation (rarefaction) and the highest pressure variation (compression) is the peak to peak (or pk-pk) sound pressure level. The difference between the highest variation (either positive or negative) and the mean pressure is called the peak pressure level. Lastly, the root mean square (rms) sound pressure level is used as a description of the average amplitude of the variations in pressure over a specific time window. These descriptions are show graphically in Figure K.1.

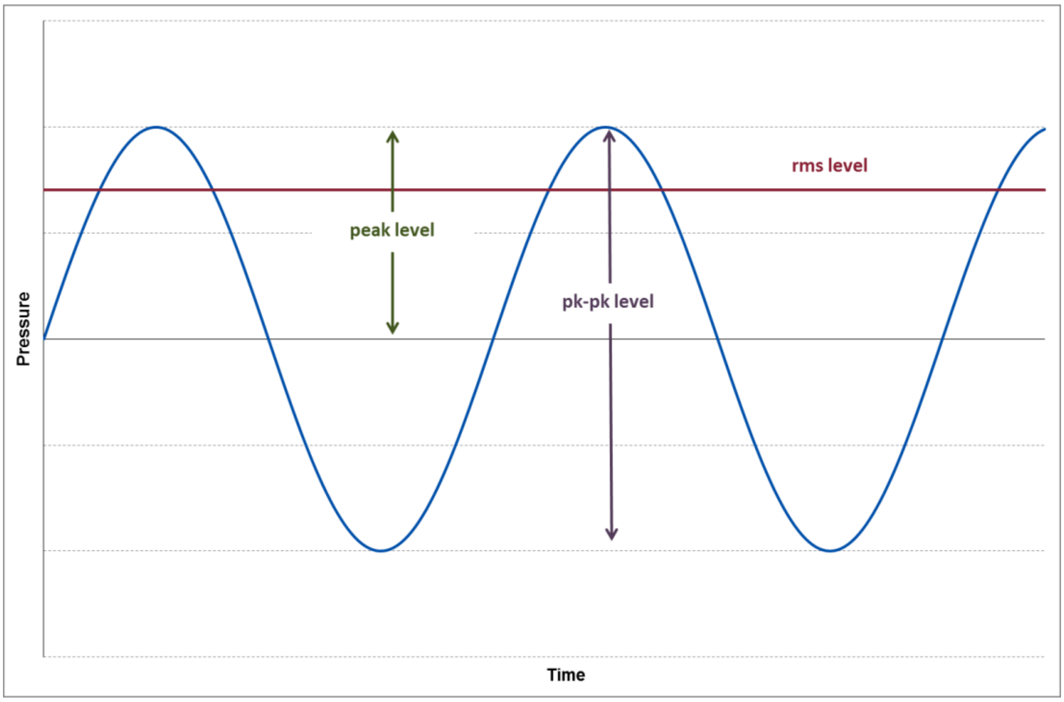

Figure K.1 Graphical representation of acoustic wave descriptors

Another useful measure of sound used in underwater acoustics is the Sound Exposure Level, or SEL. This descriptor is used as a measure of the total sound energy of an event or a number of events (e.g. over the course of a day) and is normalised to one second. This allows the total acoustic energy contained in events lasting a different amount of time to be compared on a like for like basis. Historically, use was primarily made of rms and peak sound pressure level metrics for assessing the potential effects of sound on marine life. However, the SEL is increasingly being used as it allows exposure duration and the effect of exposure to multiple events to be taken into account

The frequency, or pitch, of the sound is the rate at which these oscillations occur and is measured in cycles per second, or Hertz (Hz). When sound is measured in a way which approximates to how a human would perceive it using an A-weighting filter on a sound level meter, the resulting level is described in values of dBA. However, the hearing faculty of marine mammals is not the same as humans, with marine mammals hearing over a wider range of frequencies and with a different sensitivity. It is therefore important to understand how an animal's hearing varies over the entire frequency range in order to assess the effects of sound on marine mammals. Consequently use can be made of frequency weighting scales to determine the level of the sound in comparison with the auditory response of the animal concerned. A comparison between the typical hearing response curves for fish, humans and marine mammals is shown in Figure K.2 (it is worth noting that hearing thresholds are sometimes shown as audiograms with sound level on the y axis rather than sensitivity, resulting in the graph shape being the inverse of the graph shown.)

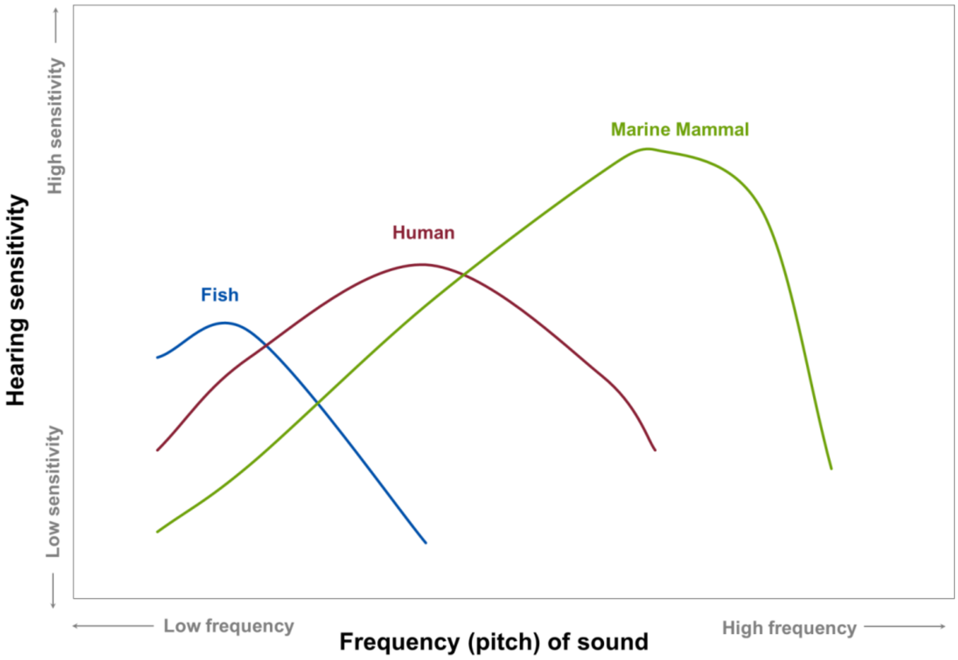

Figure K.2 Comparison between hearing thresholds of different animals

The JNCC guidance (JNCC, 2010a in prep) recommends using the injury criteria proposed by Southall *et al*. (2007), which are based on a combination of linear (i.e. un-weighted) peak pressure levels and mammal hearing weighted (M-weighted) sound exposure levels (SEL). The M-weighting function is designed to represent the bandwidth for each group within which acoustic exposures can have auditory effect. The M-weighting curves are shown graphically in Figure K.3.

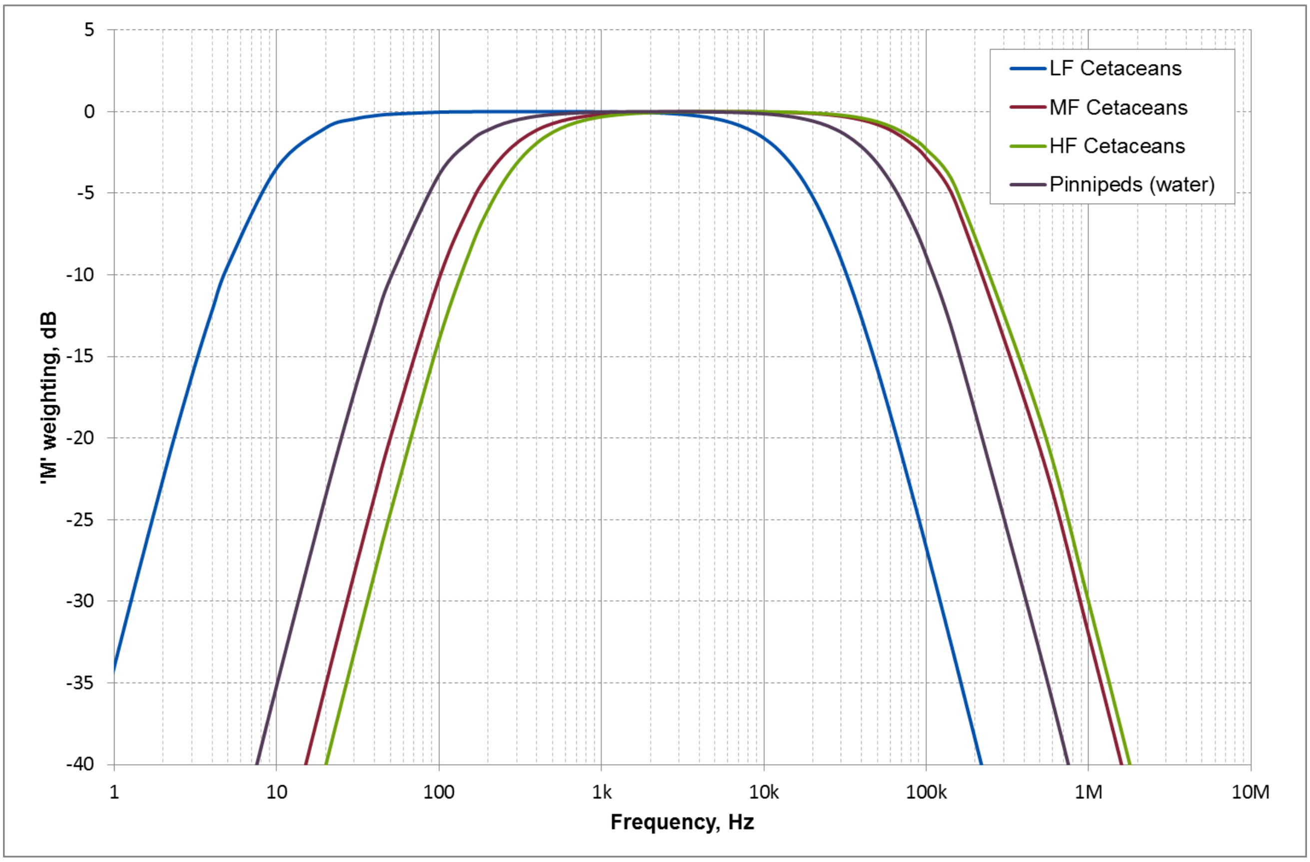

Figure K.3 M-weighting functions for pinnipeds and cetaceans in water (LF = low-frequency, MF = mid-frequency, HF = high-frequency (Southall *et al*., 2007)

Impulsive sound

The indicator used to monitor impulsive noise under the Marine Strategy Framework Directive (MSFD) is defined as "*The proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1µPa2.s) or as peak sound pressure level (in dB re 1µPa peak) at one metre, measured over the frequency band 10 Hz to 10 kHz*." The levels that are likely to entail significant impact on marine animals are not strictly defined but Tasker et al (2012) recommended proportion of days within a calendar year over areas 15 ¢N × 15 ¢E/W in which anthropogenic sound sources exceeded either of 2 levels, 183 dB re 1 mPa^{2}s (i.e., measured as sound exposure level [SEL]) or 224 dB re 1 mPa peak (i.e., measured as peak sound pressure level) when extrapolated to 1 m, measured over the frequency band of 10 Hz to 10 kHz.

Acoustics of offshore piling

In general, reducing the diameter of a pile reduces the required hammer energy to drive the pile which in turn will result in a reduction in emitted noise. Nehls *et al.* (2007) present a comparison of methods for estimating corrections to pile source noise strengths in order to correct for the pile diameter. Although there is no definitive method of making this correction (the actual noise levels depends not only on the pile diameter but also on the properties of the sediment, pile penetration depth, pile driving energy etc.), a quadratic relation between pile diameter and noise emission can be assumed[27].

When a pile is driven it is normal engineering practice to start with a reduced hammer energy and to ramp up the energy until full power is reached. Because the noise emitted by the pile is related to the hammer energy, this ramp up procedure can be used over a longer period of time (gradually building up the energy incrementally) so that the first few hammer strikes produce a lower level of noise and give the marine mammal a chance to leave the area upon hearing the first few strikes. Such a process is known as a "soft start", which is different to a "slow start", in which the time interval between the first few strikes is increased to allow the mammal to vacate the area before a more rapid hammer blow rate is used (slow starts are neither within the scope of this study, not a commonly applied technique in MMMPs). In the UK, the current piling mitigation protocol (JNCC, 2010b) state that the soft start duration should be a period of not less than 20 minutes. It is understood, based on discussions with pile installation engineers during the course of this project, that the ramp up of energy required for engineering reasons is for a shorter period of time (5-15 minutes), and sometimes uses a higher initial hammer blow energy, than the "soft start" protocol required to reduce risk of injury to marine mammals. Although progress has been made on tailoring soft starts, through the development of bespoke detailed soft start procedures at some OWF sites, there is a lack of guidance on exactly what constitutes a soft start. This lack of clear guidance means that there is some uncertainty about the required initial reduction in hammer blow energy and the likely benefits of soft start procedures.

As shown in below soft starts have been used on all OWF projects to date within the UK with the exception of a small number of piles where technical issues have led to non-conformances with MMMP (e.g. due to set up). Although there is also no engineering or practicality evidence to suggest that a 20 minute soft start will not be viable for R3 and STW sites, the larger piles sizes proposed for use in these developments may in fact require soft starts of several hours to work as effective mitigation. Whether it is feasible to soft start for several hours is as yet unclear, and should be further explored.

The effect of soft starts on noise emission has been considered in a number of studies (e.g. Robinson *et al.*, 2009, Robinson *et al.*, 2013, Lepper, 2007, Lepper *et al.*, 2012, Bailey *et al.*, 2010). Example time histories are shown in Figure K.4. The figures show that typical reductions in noise due to soft start are in the range 5 – 10 dB.

[27] *It should be noted that no empirical data is available for piles larger than approximately 5 m diameter to the knowledge of the authors. Therefore, any extrapolation of existing data could result in large scale inaccuracies in estimating the noise emission from very large piles.*

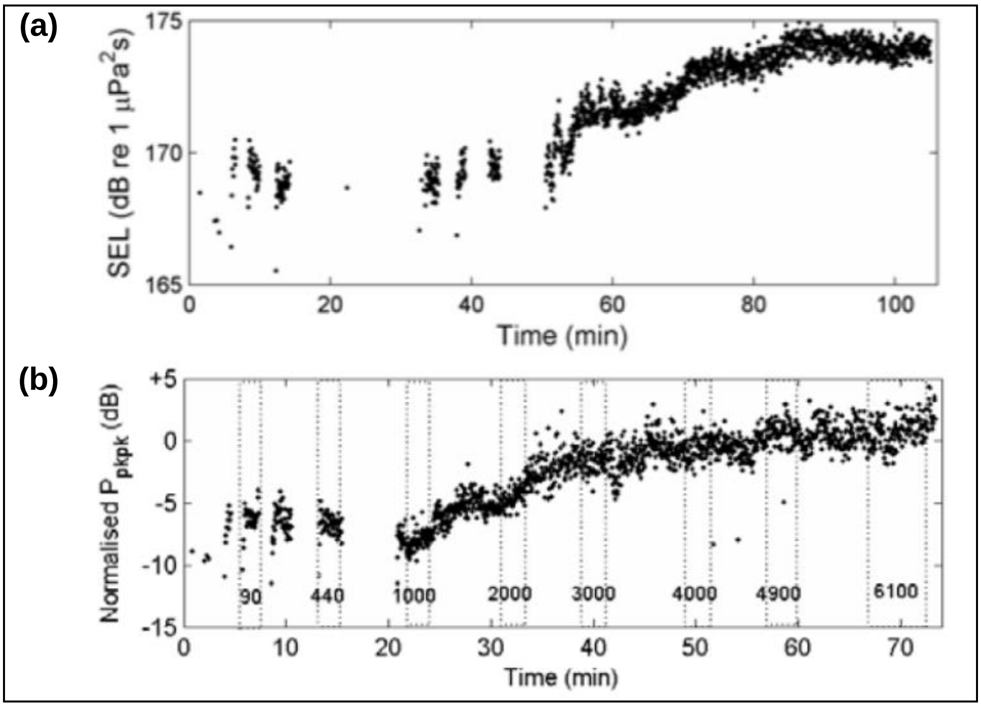

Figure K.4 Measured sound level time histories during soft start (a) SEL by Robinson *et al.*, 2013, (b) Peak to peak by Robinson *et al.*, 2009

As discussed previously the effectiveness of soft start is dependent upon many factors, not least the hammer blow energy. The relationship between hammer blow energy and noise emitted by the pile is shown in K.5. Figure (a) appears to show a much greater reduction in initial hammer energy compared to final hammer energy than (b) and therefore also shows a much larger reduction in sound. As can be seen in Figure (c), the relationship between hammer blow energy and noise appears to be fairly straightforward such that the halving the hammer blow energy results in a 3 dB reduction in sound and a tenfold reduction in energy results in a 10 dB reduction in sound. In order for soft start procedures to be effective in mitigating potential for injury to marine mammals, it is therefore important that piling protocols are designed with as low a hammer energy as possible for as long as possible, preferably starting with at least a tenfold reduction in hammer energy and not increasing the energy too rapidly but instead steadily and gradually over the entire soft start time.

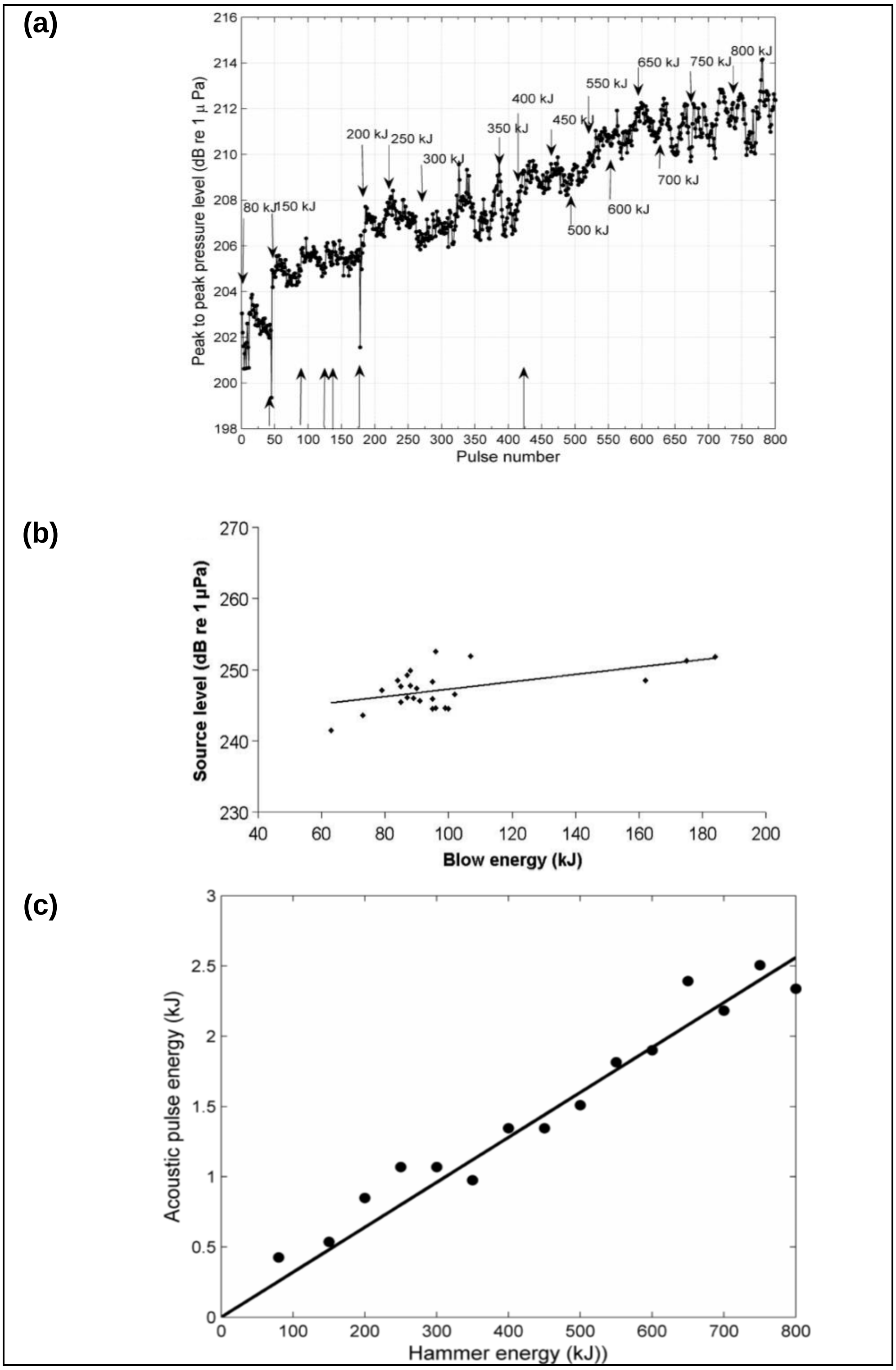

Figure K.5 Relationship between hammer blow energy and sound level measured during soft start (a) Peak to peak by Lepper, 2007, (b) Source level by Bailey *et al.*, 2010 and (c) acoustic pulse energy by Lepper, 2007.

The efficacy of soft start procedures relies heavily on the assumption that a marine mammal will be able to locate the initial sound and will react in the desired way and move away from the source to avoid exposure. This is based on common sense reasoning, but there is no evidence that soft starts always result in the desired effect.

Because using soft start as a mitigation method relies on using the initial sound to "disturb" the marine mammal, it is important to consider whether soft starts constitute acceptable disturbance in accordance with policy requirements. Of course, disturbance would have occurred anyway had no soft start been used so there is no additional impact from soft start, other than perhaps the additional time taken to drive each pile. It is considered that 15 minutes additional piling time (compared to a minimum 5 minutes reduced energy piling for a "standard start") would be of minor consequence in terms of disturbance especially when the potential benefits of reducing the likelihood of injury are taken into account (injury being a more severe impact than disturbance, albeit that disturbance occurs over a much wider area). These same considerations would apply to the use of ADDs (i.e. that the use of ADDs as a mitigation measure for injury relies on the effect of disturbance which would be over a slightly longer period than the piling activities alone).

It should be noted that soft start procedures will not eradicate all possibility of injury occurring. In particular, it is possible that for very large piles and hammer energies injury could occur during the very first hammer blow over a fairly wide area even during soft start. However, soft start will still reduce the injury range compared to no soft start and therefore this "unintended consequence" is not an additional consequence of the soft start, but rather a question of efficacy.

Underwater sound modelling

Injury criteria

It is beyond the scope of this report to advise which criteria should be adopted or are most robust and therefore the various scenarios have been assessed using a range of current criteria in order to understand how the adoption of different criteria could affect the findings of this study. These range from the Southall *et al*. (2007) criteria for onset of PTS in cetaceans and pinnipeds using un-weighted peak pressure level and M-weighted sound exposure level (SEL) to criteria derived from the Lucke *et al*. (2008) values for onset of TTS using un-weighted peak pressure level and M-weighted SEL.

Injury criteria are proposed in Southall *et al.* (2007) for three different types of sound. These sound types include multiple pulsed sound (i.e. sound comprising two or more discrete acoustic events per 24 hour period, such as seismic surveys and impact piling), single pulse sound (i.e. a single acoustic event in any 24 hour period, such as an underwater explosion) and continuous sound (i.e. non-pulsed sound such as continuous running machinery). The relevant criteria proposed by Southall *et al.* (2007) for multiple pulse sounds are considered to be an un-weighted peak pressure level of 230 dB re 1 μPa and an M-weighted SEL of 198 dB re 1 μPa^{2}s for all cetaceans. The criteria for pinnipeds are an un-weighted peak pressure level of 218 dB re 1 μPa and an M-weighted SEL of 186 dB re 1 μPa^{2}s. These injury criteria values are derived from values for onset of Temporary Threshold Shift (TTS) with an additional allowance of +6 dB for peak sound and +15 dB for SEL to estimate the potential onset of Permanent Threshold Shift (PTS). Southall *et al.* (2007) states that these thresholds represent suitable levels for a precautionary approach.

It has recently been reported by Lucke *et al*. (2008) that the onset of TTS in harbour porpoises might have a lower threshold, with the onset of TTS at 200 dB re 1 μPa peak-peak (equivalent to 194 dB re 1 μPa peak) and a sound exposure level of 164.3 dB re 1 μPa^{2}s (un-weighted). This work has been supported by more recent studies (e.g. Kastelein *et al.,* 2012). JNCC guidance (JNCC, 2010a in prep) suggests that these lower thresholds for TTS could be used to provide an estimation of PTS for these mammals. By applying the PTS onset calculation from Southall *et al.* (2007) this results in a peak level injury criterion of 200 dB re 1 μPa (i.e. by adding +6 dB to the peak level for TTS) and a SEL injury criterion of 179.3 dB re 1 μPa^{2}s (i.e. by adding +15 dB to the SEL level for TTS). The SEL value is, however, an un-weighted SEL and it is therefore necessary to apply the HF M-weighting to the received SELs reported by Lucke *et al*. (2008) in order to compare against HF M-weighted SELs due to piling. Based on the frequency spectrum information presented in the Lucke *et al.* (2008) paper, it is estimated that applying the HF M-weighting would result in a correction of

-2.5 dB. An M-weighted SEL criterion of 177 dB re 1 μPa^{2}s has therefore been adopted in order to estimate the potential injury ranges for harbour porpoise.

Sound propagation model

Increasing the distance from the sound source usually results in the level of sound becoming lower, due primarily to the spreading of the sound energy with distance, analogous to the way in which the ripples in a pond spread after a stone has been thrown in, in combination with attenuation due to absorption of sound energy by molecules in the water. This latter mechanism is more important for higher frequency sound than for lower frequencies.

The way that the sound attenuates will depend upon several factors such as water column depth, pressure, temperature gradients, salinity as well as surface and bottom conditions (including the sediment geo-acoustic properties). Thus, even for a given locality, there may be seasonal variations to the way that sound will propagate. However, in simple terms, the sound energy may spread out in a spherical pattern (close to the source) or a cylindrical pattern (much further from the source) depending on several factors (primarily the water depth), or somewhere in between. In shallow waters the propagation mechanism is more complex due to multiple reflections from the seabed and the water surface.

Sound propagation modelling undertaken for this project was based on the semi-empirical model developed by Marsh and Schulkin (1962). The sound propagation model uses several concepts including:

- Refractive cycle, or skip distance;
- Geometric divergence;
- Deflection of energy into the bottom at high angles by scattering from the sea surface;
- A simplified Rayleigh two-fluid model of the bottom for sand or mud sediments; and
- Absorption of sound energy by molecules in the water.

The following inputs are required to the model:

- Third-octave band source sound level data;
- Discrete range (distance from source to receiver);
- Water column depth and sediment layer depth;
- Sediment type (sand/mud) ; and
- Sea state.

The model is based on a combination of acoustic theory and empirical data from around 100,000 measurements and has been found to provide good predictions when applied correctly.

A water column depth of 30 m has been used in this study to be representative of the “typical” water column depth for an offshore wind farm installation. A sediment depth of 1 m has been used and the sediment type has been assumed to be sand, which gives the lowest value of attenuation and is therefore a worst case assessment. The sea state was assumed to be zero which also gives the lowest value of attenuation. Whilst all of these parameters will vary from site to site, the purpose of the acoustic modelling was to assess (in general terms) the sensitivity of an assessment to different criteria and how this affects the efficacy of soft starts.

The acoustic modelling is not intended to represent a site specific assessment but is intended to represent a range of generic cases to demonstrate the hypothetical effectiveness of soft starts, and this should be borne in mind when interpreting the results. A number of worst case assumptions were made in order to demonstrate the possible maximum theoretical range of impacts that might need to be considered when assessing the requirement for the range of effectiveness of ADDs.

It should also be considered that it is not within the scope of this project to comment on the noise modelling methodologies adopted in support of EIAs. Developers are responsible for agreeing EIA approaches with regulators in order to determine their impacts on receptors.

Source Noise Data used in Model

The pile source noise levels were estimated using an empirical scaling law as described previously, based on the methods presented by Thomsen *et al.* (2006), Parvin *et al.* (2006) and Wyatt (2008). The resultant source noise levels are as follows:

Pile diameter, m	Parameter	Sound level
1.6	SEL @ 1 m per blow	206 dB re 1 μPa^{2}s
	Peak pressure level @ 1 m	233 dB re 1 μPa
2.5	SEL @ 1 m per blow	214 dB re 1 μPa^{2}s
	Peak pressure level @ 1 m	241 dB re 1 μPa
5	SEL @ 1 m per blow	226 dB re 1 μPa^{2}s
	Peak pressure level @ 1 m	255 dB re 1 μPa
8.5	SEL @ 1 m per blow	235 dB re 1 μPa^{2}s
	Peak pressure level @ 1 m	266 dB re 1 μPa

It should be reiterated that there is no empirical data of piling noise levels for very large piles and, using this empirically derived scaling law could result in large scale overestimates. Assuming an approximate inverse square relationship, a 6 dB overestimate in source noise level would result in the estimated injury range being doubled. It is important that the reader does not interpret the hypothetical modelling scenarios developed as part of this study as being a definitive prediction of impact for any “real-world” piling schemes.

Exposure calculations

As well as calculating the un-weighted rms and peak sound pressure levels at various distances from the source, it is also necessary to calculate the SEL for a mammal using the relevant M-weightings described above taking into account the number of pulses (individual pile strike sounds) to which it is exposed. The SEL sound data for a single hammer strike was utilised, along with the maximum number of hammer strikes expected to be received by marine mammals in order to calculate cumulative exposure. Modelling was undertaken to represent a mammal moving away from the pile for a range of start distances (initial distance between the animal and pile) in order to calculate cumulative exposure for a range of scenarios. The modelling was repeated for two different swim speeds, 1.5 m/s (representing the swim speed assumed in the majority of offshore wind farm EIAs) and 3 m/s, to determine the sensitivity of the efficacy of soft start to the assumed swim speed. In each case, the pulses to which the mammal is exposed in closest proximity to the pile dominate the sound exposure. This is due to the logarithmic nature of sound energy summation. A hammer blow rate of 60 strikes per minute has been assumed based on a review of offshore piling undertaken to date.

The SEL calculations described above have also been conducted to estimate the benefit of soft start operations. In this case, the individual pulse SELs are reduced in magnitude for a period of time before reverting back to the full source array values. For this assessment, it has been assumed that the each pulse SEL will initially be attenuated by 10 dB re 1 μPa^{2}s (equating to a tenfold reduction in hammer blow energy) and will increase over a period of 20 minutes during the soft start procedures until reaching the full blow energy. The sound modelling is based on a single pile drive event and makes the assumption that the mammal does not re-approach the pile (or another pile) in the same day. For the “no soft start” scenario, it is understood based on discussions during the course of the project that all piling requires an engineering “soft start”, but that the hammer energy is brought up more quickly if there is no requirement for soft start as part of mitigation procedures. This has been modelled by assuming a 3 dB reduction in the first few blows (i.e. assuming the hammer starts at 50%) with energy increasing to full over a 20 minute period, although it is understood that this period can be as short as 5 minutes. Because most of the mammal’s sound exposure occurs during the first few hammer strikes (assuming it flees on hearing the first pulse) this is considered to be a sufficient method of assessing exposure.

It is important to note that the results of the modelling are based on several worst case assumptions, including:

- The assumed source noise levels could be significantly higher than encountered in reality due to errors in extrapolation for the larger pile sizes;
- The cumulative SEL criteria assume an equal energy principal – i.e. that a mammal’s hearing does not recover between successive exposure to each sound pulse;
- The assumed piling rate of 60 bpm is considered very much worst case, actual hammer rates are likely to be lower which would result in lower SEL values;
- The swim speed is low in comparison to maximum swim speeds for the species identified – swimming at a higher speed, especially at onset of piling, would result in a lower SEL dose.

As stated previously, the modelling is based on a range of hypothetical scenarios to demonstrate the potential maximum required range of effectiveness for ADDs and to assess the effectiveness of soft start procedures on reducing the risk of injury to marine mammals.

Acoustic modelling results and the efficacy of soft start

The results of the acoustic modelling are presented in Table K.1 which shows the predicted injury range for different piling scenarios using various different criteria, derived from Southall *et al*. (2007) and Lucke *et al*. (2008). The ranges presented in the table are the range outside of which an animal must be at the beginning of the piling sequence to acquire a cumulative noise dose below the injury threshold, assuming a flee response (i.e. anything starting inside this range will likely be exposed to sufficient noise to cause PTS by the end of the piling sequence).

It should be borne in mind that the ranges for exceeding the various injury criteria have been rounded for ease of reading and to reflect the potential for errors and variability in the predictions. Because piles are a large, distributed, sound source it is difficult to predict likely noise levels very close to the pile (in the near-field). Noise is emitted along the length of the pile as well as through the ground. Because the sound source level used in the modelling is based on a hypothetical sound level at one metre from the pile (typically within tens of metres), assuming that the pile is an infinitesimally small point source, noise levels very close to the pile will be overestimated. Predicted impact ranges (or start distances for marine mammals) of less than 10 m have not therefore been presented.

Table K.1 Estimated radius of injury zones with and without soft-start for different piling scenarios and swim speeds

Soft start	Swim speed	Radius of potential injury zone, m							
		Injury zone based on peak pressure			Injury zone based on M-weighted SEL				
		All cetaceans[28]	Pinnipeds[29]	Harbour porpoise[30]	LF cetacean[31]	MF cetacean[32]	HF cetacean[33]	Pinniped in water[34]	Harbour porpoise[35]
Scenario 1: 1.6 m pin piles, 60 blows per minute									
No soft start	1.5 m/s	<10	11	65	10	<10	<10	100	500
20 minutes soft start	1.5 m/s	<10	<10	38	2.5	<10	<10	20	160
No soft start	3 m/s	<10	11	65	<10	<10	<10	60	150
20 minutes soft start	3 m/s	<10	<10	38	<10	<10	<10	12	60
Scenario 2: 2.5 m piles, 60 blows per minute									
No soft start	1.5 m/s	<10	20	175	50	30	20	650	2.5k
20 minutes soft start	1.5 m/s	<10	10	80	12	<10	<10	220	2k
No soft start	3 m/s	<10	20	175	30	15	12	300	1.5k
20 minutes soft start	3 m/s	<10	10	80	<10	<10	<10	80	550
Scenario 3: 5 m piles, 60 blows per minute									
No soft start	1.5 m/s	25	100	800	800	450	300	6.5k	13.5k
20 minutes soft start	1.5 m/s	12	60	350	300	150	100	6k	12.5k
No soft start	3 m/s	25	100	800	400	200	180	5k	12k
20 minutes soft start	3 m/s	12	60	350	100	50	40	3k	10k
Scenario 4: 8.5 m piles, 60 blows per minute									
No soft start	1.5 m/s	90	400	2k	5k	3k	2.5k	17.5k	25k
20 minutes soft start	1.5 m/s	40	160	1.25k	4.5k	2.5k	2k	16k	23k
No soft start	3 m/s	90	400	2k	4k	2.2k	1.5k	15k	22k
20 minutes soft start	3 m/s	40	160	1.25k	2k	800	500	15k	21k

[28] *Based on un-weighted 0-peak pressure level criterion for PTS in cetaceans from Southall et. al. 2007*
[29] *Based on un-weighted 0-peak pressure level criterion for PTS in pinnipeds from Southall et. al. 2007*
[30] *Based on un-weighted 0-peak pressure level criterion for PTS in harbour porpoise derived from Lucke et. al. 2008*
[31] *Based On M-weighted (LF) SEL criterion for PTS in low frequency hearing group cetaceans from Southall et. al. 2007*
[32] *Based On M-weighted (MF) SEL criterion for PTS in mid frequency hearing group cetaceans from Southall et. al. 2007*
[33] *Based On M-weighted (HF) SEL criterion for PTS in high frequency hearing group cetaceans from Southall et. al. 2007*
[34] *Based On M-weighted (PW) SEL criterion for PTS in pinnipeds (in water) from Southall et. al. 2007*
[35] *Based on M-weighted (HF) SEL criterion for PTS in harbour porpoise derived from Lucke et. al. 2008*

From Table K.1, it can clearly be seen that the efficacy of soft start procedures depends on the size of the potential injury range. This is because soft start procedures rely on a mammal swimming away from the source of noise at the onset of piling. Depending on the assumed swim speed, a mammal will be able to swim a discrete distance within the soft start time. Assuming a mammal can swim at 1.5 m/s, the distance covered during the 20 minute soft start period would be 1.8 km. If the injury zone (i.e. the zone within which the mammal could be injured if it starts swimming as soon as it hears commencement of piling) is much smaller than the potential swim distance, then the mammal has plenty of time to swim outside of the injury zone before the end of the soft start. However, if the potential injury zone is much larger than the distance it can travel, then the soft start will be much less effective. This relationship between the distance a mammal can swim during the soft start and the size of the injury zone with no soft start governs the efficacy of the soft start procedures. This relationship is shown in Figure K.6.

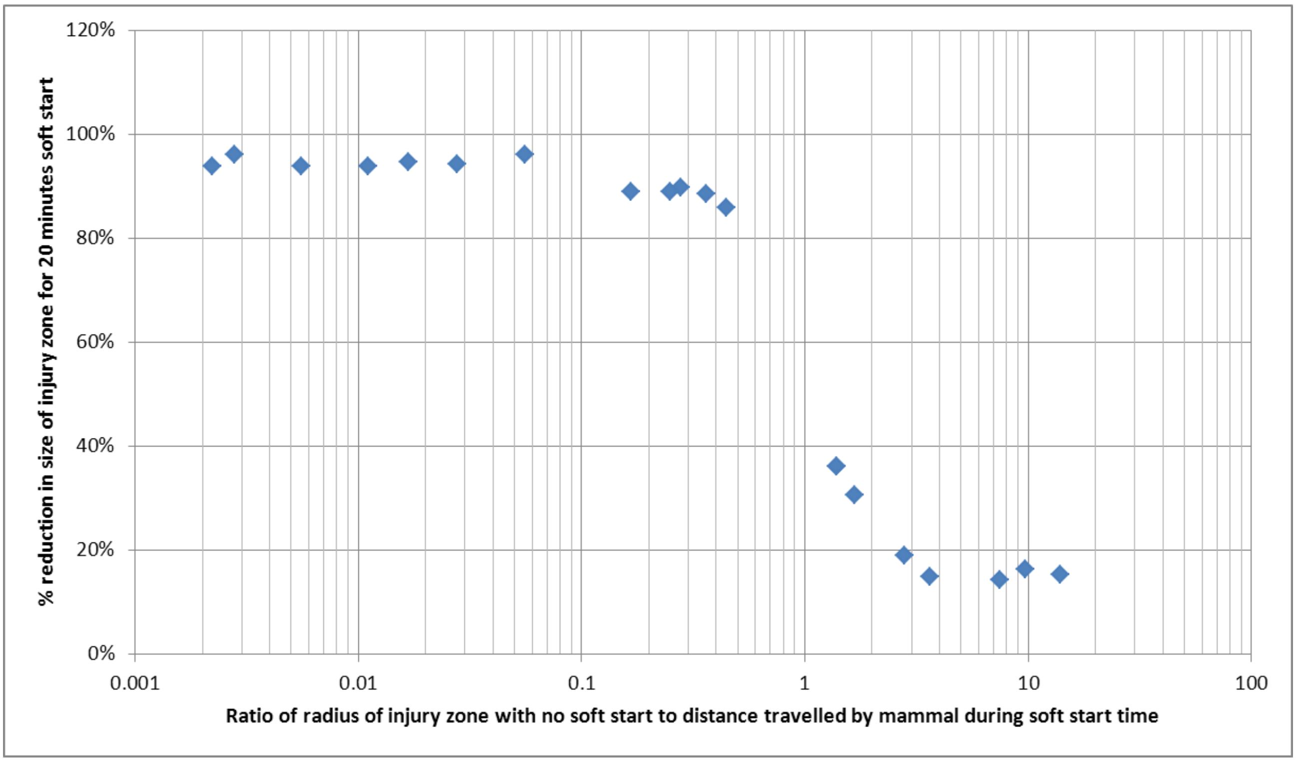

Figure K.6 Relationship between the percentage reduction in size of injury zone as a result of soft start and the ratio between the size of the injury zone with no soft start and the distance a mammal can swim during the soft start period

Figure K.6 shows that the marine mammal needs to travel at least twice the distance of the predicted injury range in order for soft start to be most effective, but increasing/decreasing the injury zone above or below that point doesn't markedly affect the reduction in size of the zone. It can therefore be inferred that a soft start should ideally be tailored to ensure that all animals can swim twice the distance of the injury zone during the soft start time in order to gain significant reductions in the potential for injury, but excessive precaution beyond that (i.e. much longer soft starts) will yield negligible gains in terms of reducing the potential area over which injury may occur.

A comparison between the potential injury zone radius and required soft start time in order for soft start procedures to significantly reduce the injury zone is show in Figure K.7. The figure shows that the JNCC guideline suggested soft start time of 20 minutes will be effective for a potential injury zone radius of up to 1 km. This is sufficient for smaller piles and assuming that the Southall *et al*. (2007) criteria are robust enough to protect all marine mammals from injury. However, for much larger pile sizes and lower injury criteria (e.g. if the Lucke *et al*. (2008) criteria for harbour porpoise were adopted) the graph shows that a longer soft start time could be required.

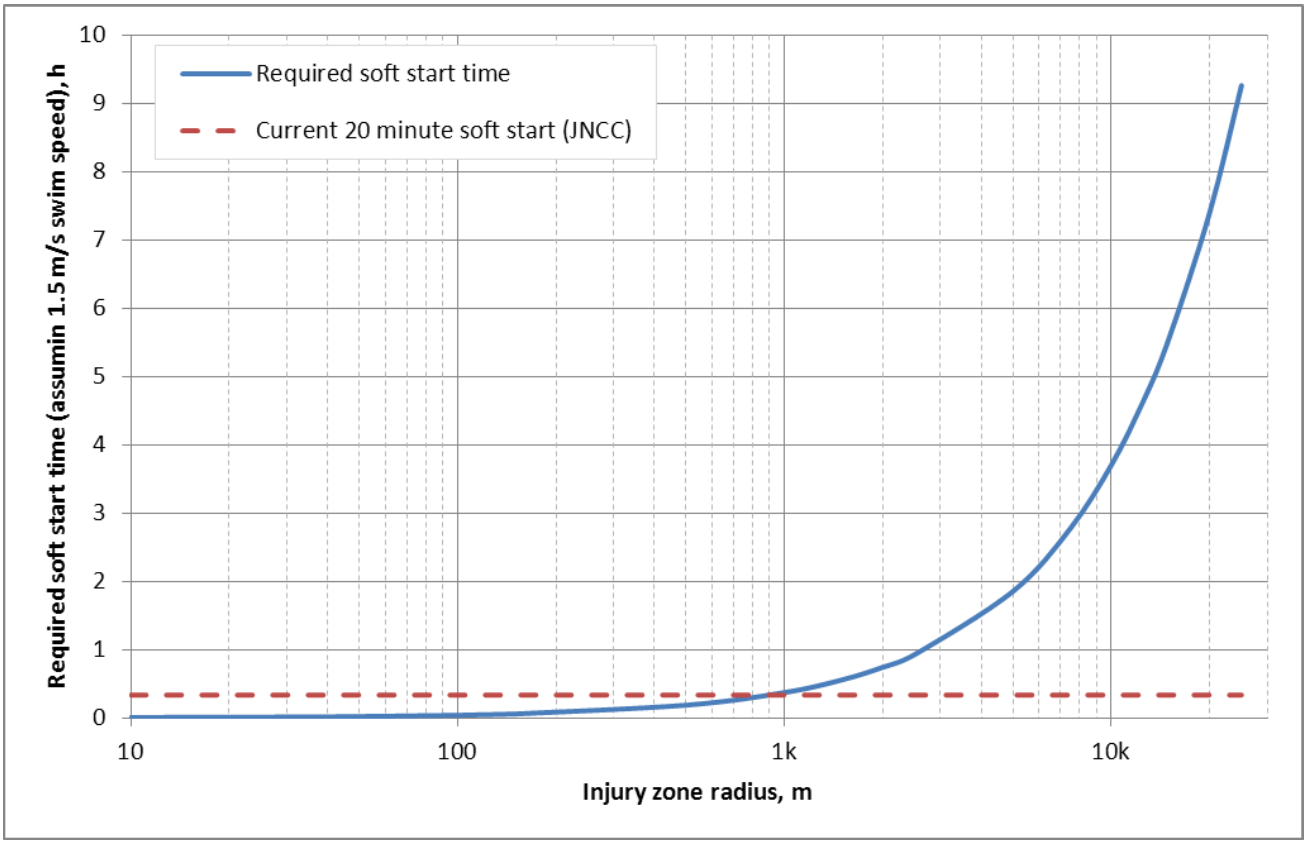

Figure K.7 Relationship between the size of the injury zone with no soft start and required soft start time to be effective (assuming a swim speed of 1.5 m/s)

Negative Impacts of ADDs

An important impact to consider when using ADDs is that their use involves introducing additional noise into the marine environment. ADDs rely on behavioural disturbance to work. There is therefore the possibility that use of the devices could be construed as a disturbance offence.

To consider the possibility of a disturbance offence resulting from the use of ADDs or piling, it is necessary to consider the likelihood that the sound could cause non-trivial disturbance (in an individual animal and therefore a disturbance offence in Scotland or at a population level and therefore an offence in all UK territories), and the likelihood that the sensitive receptors will be exposed to that sound and whether the numbers exposed are likely to be significant at a population level. Assessing this is, however, a very difficult task due to the complex and variable nature of sound propagation, the variability of documented animal responses to similar levels of sound and the availability of population estimates and regional density estimates for all marine mammal species.

Southall *et al*. (2007) recommended that the only currently feasible way to assess whether a specific sound could cause disturbance is to compare the circumstances of the situation with empirical studies. The JNCC guidance (JNCC, 2010a in prep) indicates that a score of 5 or more on the Southall *et al.* (2007) behavioural response severity scale could be significant (see Table K. 2). The more severe the response on the scale, the lower the amount of time that the animals will tolerate it before there could be significant negative effects on life functions, which would constitute a disturbance under the relevant regulations.

Table K.2 Southall et al. (2007) behavioural disturbance scale

Response Score	Corresponding Behaviours in free-ranging subjects
0	> No observable response.
1	> Brief orientation response (investigation/visual orientation).
2	> Moderate or multiple orientation behaviours; > Brief or minor cessation/modification of vocal behaviour; > Brief or minor change in respiration rates.
3	> Prolonged orientation behaviour; > Individual alert behaviour; > Minor changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source; > Moderate change in respiration rate; > Minor cessation or modification of vocal behaviour (duration < Duration of source operation).
4	> Moderate changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source; > Brief, minor shift in group distribution; > Moderate cessation or modification of vocal behaviour (duration more or less equal to the duration of source operation).
5	> Extensive or prolonged changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source; > Moderate shift in group distribution; > Change in inter-animal distance and/or group size (aggregation or separation); > Prolonged cessation or modification of vocal behaviour (duration > duration of source operation).
6	> Minor or moderate individual and/or group avoidance of sound source; > Brief or minor separation of females and dependent offspring; > Aggressive behaviour related to sound exposure (e.g. Tail/flipper slapping, fluke display, jaw clapping/gnashing teeth, abrupt directed movement, bubble clouds); > Extended cessation or modification of vocal behaviour; > Visible startle response; > Brief cessation of reproductive behaviour.
7	> Extensive or prolonged aggressive behaviour; > Moderate separation of females and dependent offspring; > Clear anti-predator response; > Severe and/or sustained avoidance of sound source; > Moderate cessation of reproductive behaviour.
8	> Obvious aversion and/or progressive sensitisation; > Prolonged or significant separation of females and dependent offspring with disruption of acoustic reunion mechanisms; > Long-term avoidance of area (> source operation);

Response Score	Corresponding Behaviours in free-ranging subjects
	> Prolonged cessation of reproductive behaviour.
9	> Outright panic, flight, stampede, attack of conspecifics, or stranding events; > Avoidance behaviour related to predator detection.

Looking at the behaviours described in Table K.2 it is clear that an ADD would have to evoke a response of at least a Response Score 6 or 7 in order to be effective in reducing the likelihood of injury for any mammal within the potential injury zone. This is higher than the Response Score of 5 benchmarked as being potentially significant by JNCC. It is important to understand that exposure to sound levels in excess of the behavioural change threshold does not necessarily imply that the sound will result in significant disturbance as defined in legislation. It is also necessary to understand the likelihood that the mammals will be exposed to that sound and whether the numbers exposed are likely to be significant at the population level. The mammal density in the area as well as the size of the zone over which marine mammals need to be displaced are therefore important considerations.

The ADDs will be operated before piling starts and turned off once the piling soft start commences. Therefore, use of ADDs will result in potentially disturbing sound occurring for a slightly longer period than soft start piling alone. The noise level and potential zone of disturbance due to ADDs is considered unlikely to be as great as the disturbance zone due to piling (particularly for larger piles) so it is not envisaged that there will be any increase in the size of the zone of disturbance (or injury).

Disturbance is unlikely to be considered as severe an impact as injury as it is likely to be a temporary impact, although disturbance is likely to occur over a much wider range than injury[36]. On balance, it is considered that the benefits in terms of reducing the likelihood of injury far outweigh the slight increase in time over which disturbance may occur. However, it would clearly be desirable to minimise the extent of any disturbance introduced as a result of using ADDs and it is therefore recommended that further research be conducted to help understand the levels of sound from ADDs that are required to evoke a flee response and to use this data to fine tune ADD acoustic outputs to strike the right balance between preventing injury and disturbance.

[36] *It should be noted that the assumption that disturbance due to ADDs will be temporary does not mean that the potential impact should be dismissed. The potential for disturbance with and without mitigation measures in place will need to be assessed on a site specific basis as part of each development's impact assessment.*

APPENDIX L ADD DEVELOPMENT (AND OTHER DETERRENTS)

Devices and research on efficacy

The mechanisms by which aversive sounds achieve their effect are generally not well understood. There are two basic mechanisms underlying the concept of acoustic deterrence. Firstly, acoustic stimuli can be presented at a source level that crosses the auditory pain threshold with the assumption being that animals would avoid such stimuli. The second solution relies on the acoustic stimulus itself being aversive without causing pain. Aversive signals can be aversive due to a learned association, for example predator sounds inducing a response on prey species , for example grey and harbour seals in the Baltic responding to playback of killer whale calls (De La Croix, 2010). Generally reaction thresholds are not well understood and vary depending on animal motivation (Götz & Janik 2010). Over the last two decades, a variety of acoustic devices have been designed to reduce interactions between seals and aquaculture and to reduce interactions between marine mammals and capture fisheries (reducing bycatch or reducing depredation). The range of devices available, their acoustic characteristics (where described) and the data relating to their effectiveness in various settings have been reviewed and summarised extensively elsewhere (see Gordon *et al*., 2007; Dawson *et al*., 2013; Coram *et al*., 2013; Götz and Janik, in press).

In a review commissioned by COWRIE, Gordon *et al*. (2007) and more recently Coram *et al*., (2013) in a Scottish Government funded review, provide a detailed background of the principles of using aversive sounds to deter marine mammals from areas of pile driving to reduce the risk of auditory injury and provide an overview of the types of sounds that might be capable of causing marine mammals to move out of an 'exclusion zone'. In another recent COWRIE study, Nedwell at al., (2010) carried out an assessment of acoustic output of a number of different potential Acoustic Mitigation Devices (AMDs). In addition to this, COWRIE commissioned SEAMARCO in the Netherlands to carry out studies on the audibility of three candidate acoustic deterrent devices and their effects on the behaviour of captive harbour seals and harbour porpoises. Although focused more on the tidal energy industry, Wilson and Carter (2013) have recently completed a review of the use of acoustic warning systems in the mitigation of collisions with tidal devices.

The current review builds upon the results presented in these studies and primarily focuses on those systems which have been identified as having potential for use in the mitigation of auditory injury during pile driving. Although there are no devices that have been shown to consistently exclude marine mammals over the distances required to eliminate the risk of auditory injury from pile driving, the devices considered in detail here were selected based on a number of features:

- Features of the acoustic output have been characterised or described and are in the hearing range of the UK species of interest and have source levels at an intensity which could lead to behavioural responses;
- Data from published studies demonstrate a measurable aversive response to the device in one or more of the UK species of interest; and
- The device is currently commercially available or currently in development for commercial application.

The key areas of evidence assessed in the current review for each device were as follows:

1. Evidence for effectiveness in terms of demonstrated deterrence for the different species being considered in this review;
2. The evidence for effective ranges for the different species. Although it is important to note that effective range is unlikely to be constant across different environments, an observed response is likely to be partly a result of a particular effective sound level, and the effective range is simply the range from the device at which this sound level is reached, given local propagation conditions. Responses can also vary between and within individuals for a given received level dependent on context (previous experience, motivational state); and

3. The evidence for any reductions in effectiveness over time.

The characteristics of available devices are summarised below in Table L.1. The GenusWave and Kastelein systems have been omitted from this table because commercial sensitivity issues dictate that data pertaining to their acoustic characteristics cannot yet be released into the public domain. However, these devices are qualitatively discussed in more detail in the following section.

Table L.1 Acoustic characteristics of ADDs detailed in the review (adapted from Götz and Janik, in press))

	Ace-Aquatec	Airmar	Terecos Ldt	Lofitech
	Ace-Aquatec "Silent Scrammer"	**Airmar dB Plus**	**Terecos type DSMS-4**	**Lofitech "universal or seal scarer"**
source level (ref. 1 μ Pa @ 1 m)	193 dB re 1 μPa @ 10 kHz (rms) 192 dB @ 10.3 kHz (rms).	192 dB re 1 μPa @ 10.3 KHz (rms) 198 dB (rms) Side-bands at: 20.5 kHz, 31 kHz, 41 kHz.	178 dB re 1 μPa @ 4.9 kHz (rms) (manufacturer claims 90-100 dB).	191 dB re 1 μPa (unspec) 182 dB re 1 μPa (rms) @ 14.9 kHz [2] 189 dB re 1 μPa (unspec.).
Frequency structure	Pulses centred at 28 different frequencies (pattern of jumping frequencies) arranged in 64 sequences which are randomly chosen.	More or less sinusoidal: 10.3 kHz (2nd harmonic 43 dB weaker).	Complex; randomized sequences: tonal blocks (with harmonics) forming up and down sweeps (fundamental from 1.8 - 3 kHz), sequences of continuous and time-variant multicomponent blocks (2.4 kHz-6 kHz).	15 kHz (narrow-band) 14.9 kHz.
Temporal pattern	3.3 - 14 ms long segments, pulse interval: 33.2 ms – 48.5 ms in 5 s long trains.	1.4 ms long segments at 40 ms intervals in 2.25 s long trains; 4 transducers produce these trains in an alternating pattern.	Depending on operation mode: 8 ms segments in sequences of eight or 16 ms segments in sequences of 5; variation possible due to randomisation software1; trains from 200 ms to 8 s long, some segments follow with no pulse interval.	Approx. 500 ms long pulses; mitted in variable length blocks containing a randomised number of pulses; minimum pulse interval within blocks approx. 0.5 s consecutive blocks separated by 20 – 60 s intervals[2] 550 ms pulse duration.
Emission duty cycle: % time an emission is produced	Activity-dependant; 50% short-term for 5 s period, manufacturers' user manual states between 6x and 72x 5 s long emissions per hour.	50 % almost continuous during typical operation with more than 1 transducer.	Difficult to quantify and user selectable 1,2 , 20x20s emissions per hour: 0.11 %.	20-25 % ~10 % 12 %.
Ultrasonic components	More than 165 dB re 1 μPa at 30 kHz;145 dB re 1 μPa at 70 kHz.	145 dB re 1 μPa up to 103 kHz.	Less than 143 dB re 1 μPa above 27 kHz.	Multiple harmonics, 2nd harmonic at -15 - 40 dB2 or -10 dB.
Reference	Lepper et al. (2004).	Lepper *et al*. (2004)	Lepper *et al*. (2004)	Reeves, Read &

	Ace-Aquatec	Airmar	Terecos Ldt	Lofitech
		Manufacturers 'owners manual' (confirmed by own measurements) Reeves, Read & Nortabartolo di Sciara (2001).	Reeves, Read & Nortabartolo di Sciara (2001).	Nortabartolo di Sciara (2001) Own measurements manufacturers' own specification Brandt *et al.* (2013).

Ace-Aquatec

The Ace-Aquatec Seal Scrammer consists of a large transducer housing assembly connected to a control unit via a cable. The control unit has a touchpad which can be used to select functions and a screen which displays system information. This device is being marketed as a marine mammal deterrent (MMD) for use as a mitigation device to "push marine mammals to a safe distance in preparation for loud underwater operations such as pile driving". This 'offshore' version can be deployed at greater depths than the standard 'aquaculture' model; it has more randomised or controlled sound varieties; manual controls over frequencies, volume and spacing, with AC mains or DC battery operation. The transducer can be operated from the surface control box or by using an optional sonar trigger. It can also be programmed to emit noise on a timed basis and can emit a 5 second burst of noise between 6 and 72 times per hour. According to the manufacture it has a source level of 194 dB re 1 μPa (unknown whether rms or pk or pk-pk), which corresponds well with the value of 193 dB re 1 μPa (rms) reported by Lepper *et al*. (2004) although Nedwell *et al.* (2010) reported at value of 184 dB re 1 μPa (rms). Nedwell *et al*. (2010) characterised the acoustic output and examination of the frequency spectrum shows that the majority of the signal energy is generated between approximately 10 – 30 kHz with a peak in level at around 12 kHz. One complete cycle of transmission lasts approximately 5 s with the signal being composed of many short individual pulses each lasting around 0.01 s. These pulses vary in both amplitude and frequency throughout the duration of the signal. Gotz and Janik (in press) report that the pulses are centred at 28 different frequencies, arranged in 64 random sequences.

Several unpublished documents summarising field research by the manufacturers claim high success rates at deterring seals (Ace-Hopkins, 2002a; Ace-Hopkins, 2002b; Ace-Hopkins, 2002c; Ace-Hopkins, 2004; Ace-Hopkins, 2006) and whilst these demonstrate that useful data can be collected with industry collaboration, ideally research should be conducted and reported by independent researchers.

Götz and Janik, (2010) tested the Ace-Aquatec with grey and harbour seals in captivity and with grey seals around a haul out site at the mouth of the River Tay in East Scotland. Although seals initially responded, captive study subjects habituated rapidly to all sound types in the presence of food motivation. In the field the deterrence range was approximately 60 m, although deterrence was not complete, with 50% of animals remaining within 60 m.

Kastelein *et al*. (2010) investigated the responses of a harbour porpoise and two harbour seals to the Ace Aquatech and found that porpoises swam significantly faster, showed more leaping behaviour and had a greater mean distance from the device at higher broadcast levels. Seals hauled out more and spent more time with their heads above water as sound source as levels increased. Based on the sound levels that caused behavioural effects, Kastelein *et al*. (2010) concluded that the Aquatec would be likely to deter porpoises at ranges between 0.2 and 1.2 km. For seals it should be effective at ranges of between 0.2 and 4.1 km.

There is no information available on the potential deterrence performance of the Ace-Aquatec on any other species of marine mammal. Nedwell *et al.* (2010) calculated the pk-pk and rms dBht values at various ranges from an operating device and for harbour porpoises the dBht re 1 μPa (rms) ranged from 120 dBht at 1 m to 108 dBht at 80 m. This suggests that according to the classification of dBht scale by Nedwell *et al.* (2007), where values of 90 dBht and over may indicate the potential for strong avoidance, deterrence might be expected beyond this range. For harbour seals the equivalent value at 80 m was 91 suggesting that harbour seal deterrence might be expected out to this range. It is important to note that these are theoretical ranges and the dBht metric as a predictor of behavioural response is yet to be fully validated in any marine mammal species. Although an analysis presented in Thompson *et al.* (2013), using data from Brandt *et al.* (2011)

suggests that the pattern of changes in reduced detection rates with distance from a pile driving operation was in reasonable agreement with expectation from predicted avoidance using the dBht scale (i.e. at levels of 90 dBht and above, the reduction in acoustic detections was over 80%).

Lofitech

The Lofitech seal scarer is a high output seal scarer which comprises a transducer connected to a separate control unit via a 25 m long cable. The unit emits 500 ms long pulses in variable length blocks containing a random number of pulses. The minimum pulse interval within blocks is approximately 0.5 s and consecutive blocks are separated by 20-60 s intervals (Gotz and Janik, in press). The signal is comprised of a number of very narrow band emissions with a peak at about 15 kHz.

Brandt *et al.* (2012) and Brandt *et al.* (2013) detail studies that have been carried out in the German North Sea and the Danish Baltic Sea to investigate the effectiveness of the Lofitech seal scarer in deterring harbour porpoises from the area around pile driving. These studies are reviewed in detail in Coram *et al.* (2013) but are briefly summarised here. The effective deterrence of harbour porpoises was achieved over long ranges: during the North Sea study detection rates were close to zero close to the device and were 86% lower than baseline at 750 m and 96% lower at 7500 m. There was no clear evidence of a reduction in the exclusion effect with range and therefore 7500 m should not be considered the maximum effective range. Detection rates recovered after the end of trials and by between 9 and 12 hours after the trial they were no longer significantly reduced.

Brandt *et al.* (2012) reported that porpoise swim speed while responding to the Lofitech was 1.62 m/s when they were within 1.3 - 2.4 km distance and the authors point out that response speed is likely to be faster closer to the device.

There have also been some studies describing the responses of seals to the Lofitech device in the UK and Sweden. Graham *et al*. (2009) tested Lofitech devices in two Scottish Salmon rivers, the North Esk and Conan, to prevent seals from moving upstream. The number of seals upstream of the seal scarer was reduced by about 50%. Harris (2011) tested its effectiveness at fixed near shore salmon nets by grey and harbour seals in Scotland. The number of sightings was significantly reduced, as was the time seals spent in the area. Although the distances at which deterrence was achieved was not reported, in the first year, no seals were seen within 80 m of the device. In the second year there were 7 sightings within 80 m, suggestive of habituation occurring. Photo ID indicated that only a small number of seals were using the site suggesting that some individuals were unaffected by the ADD.

As part of a recent Marine Scotland funded project, trials measuring the behavioural responses of harbour seals to the Lofitech seal scarer were carried out in Kyle Rhea in June 2013. Seals were followed when they moved out of the narrows into open water in the Sound of Sleat or into Loch Alsh. A total of 20 individual trials were performed using both the ADD and killer whale vocalisations. Preliminary observations suggest avoidance responses to the ADD but these remain to be fully analysed (D. Thompson, SMRU pers comm). Further analyses of these data are pending and it is hoped that the results should allow estimation of reaction ranges.

Götz and Janik, (2010) also tested the Lofitech with grey and harbour seals in captivity and with grey seals around a haul out site at the mouth of the Tay in East Scotland. Results were similar to the Ace-Aquatech in that although captive seals initially responded, subjects habituated rapidly in the presence of food motivation. In the field the deterrence range was approximately 60 m, although the sample size from field trials was small. No habituation was evident in the field trials (tested by the relationship between playback number and the count of seals).

Kastelein *et al.* (2010) also tested the Lofitech device and found similar results to that for the Ace-Aquatech (see above).

Nedwell *et al.* (2010) calculated the pk-pk and rms dB_{ht} values at various ranges from an operating device and for harbour porpoises the dB_{ht} (rms) ranged from 127 dB_{ht} at 1 m to 99 dB_{ht} at 80 m. Similar to the Ace-Aquatech, this suggests that according to the classification of dB_{ht} scale by Nedwell *et al.* (2007), deterrence might be expected beyond this range. For harbour seals the equivalent value at 80 m was 99 dB_{ht}, suggesting that harbour seal deterrence might be expected out to this range (Table J.2).

Airmar dB plus II

The Airmar system consists of a multi-transducer array which emits brief pulses which are 1.4 ms long at 40 ms intervals in 2.25 s long trains. Typically four transducers produce these trains in an alternating pattern.

The manufacturer's manual provides a source level of 198 dB re 1 μPa (rms) but field measurements have differed widely. Field measurements reported in the literature range from only 178-179 dB re 1 μPa (peak to peak) (Jacobs and Terhune, 2002), to 192 dB re 1 μPa (rms) (Lepper *et al*., 2004). Most recently Brandt *et al*. (2012) estimated the Airmar source level as 190 dB re 1 μPa (rms), peak pressure level of 206 dB re 1 μPa.

Yurk & Trites (2000) tested the Airmar ADD in an attempt to keep harbour seals from feeding on out-migrating salmon under a bridge. The use of an Airmar dB Plus II device yielded a decrease of predation rate in 7 successive trials, but further trials were not carried out.

Jacobs & Terhune (2002) tested an Airmar dB Plus ADD (consisting of an array of four transducers) on harbour seals around a haul out, but reported no significant responses, similarly there was no effect on harbour seals approaching a haul-out site when deployed as an acoustic barrier.

Götz and Janik, (2010) also tested the Airmar with grey and harbour seals in captivity and with grey seals around a haul out site in the Tay Estuary. The results were similar to those from the Ace-Aquatech and Lofitech in that although captive seals initially responded, subjects habituated rapidly in the presence of food motivation. In the field the deterrence range was approximately 40 m, although the sample size from field trials was small. No habituation was evident in the field trials (tested by the relationship between playback number and the count of seals).

The Airmar ADD is widely used in the Scottish aquaculture industry, Northridge *et al.* (2010) reported that of farms with ADDs in Scotland, 35% were using Airmar. This suggests that many seal populations may have been previously exposed to these signals and therefore some degree of habituation may be expected.

There have been a number of studies examining the effect of Airmar ADDs on harbour porpoises, in Canada and in Scotland. Johnston (2002) and Olesiuk *et al.* (2002) both reported striking results in deterrence of harbour porpoises around devices. Deterrence was achieved up to 3.5 km in British Columbia (Olesiuk *et al*., 2002) with detection rates at that range only 8% of those seen during control periods. On the Canadian east coast Johnson (2002) reported evidence that porpoises left the site soon after the ADD was activated and the mean distance of approach was 991 m on days when the ADD was active (compared to 364 m on control days). No porpoises were observed within 645 m of the device when it was active, according to Johnston (2002) this distance corresponded to a received level of 128 dB re 1 μPa. The dramatic effect of the Airmar device on porpoises is likely because of the sensitivity of odontocetes is higher at the peak frequency of the device (at 10 kHz odontocete hearing is 15–20 dB more sensitive than pinniped hearing).

Static acoustic monitoring devices (PODS) were used to collect data at salmon farm sites on the west coast of Scotland (Northridge *et al*., 2010). Complete exclusion was not evident even at the closest monitoring sites and substantial inter-site differences in detection rates tended to obscure effects of range to ADDs. However, significant increases in detection rates were evident after the ADDs had been turned off. At one site porpoise detections were increased by factors of 7, 4 and 9 times at monitoring stations at distances of 200, 1,100 and 4,000 m respectively.

These results were not as clear cut as those from Olesiuk *et al.* (2002) and Johnston (2002) which Coram *et al.* (2013) have suggested may be indicative of reduced responsiveness as a result of habituation. The authors point out that porpoises in this area are exposed to ADDs from a range of fish farm sites throughout their home range and it is likely that animals will not have been naïve to these signals, particularly because the Airmar is widely used on the west coast of Scotland.

Morton (1997) reported a reduction in the number of sightings of humpback, grey and minke whales in the Broughton Archipelago over the period when salmon farms in the area were using Airmar ADD devices followed by a substantial recovery in sighting rates after ADD use was stopped. Morton and Symonds (2002) reported on changes in killer whale detection rates and residence patterns at two locations over a period of 15 years between 1985 and 2000 in relation to differential ADD use at each site.

Terecos

The Terecos device emits more continuous noise, with different programmes designed to generate a diversity of signals, presumably to minimise habituation. The Terecos has four different programs of different sequences of continuous and time variant tonal blocks. According to Coram *et al.* (2013), the Terecos manufacturers periodically make changes to programs in order to reduce the likelihood of habituation.

The Terecos is one of the least powerful devices used routinely at Scottish aquaculture sites. The manufacturers do not provide a reliable source level, however Olesiuk *et al.* (2010) report the source level of a Terecos DSMS-4 to be 185 dB re 1 μPa (unknown), whereas Lepper et al. (2004) found the same device to have maximum SPL of 178 dB re 1 μPa (rms).

It is also one of the most widely used in Scottish aquaculture, Northridge *et al.* (2010) found that 42% of farms in Scotland that were using ADDs, were using the Terecos. Despite this, there are very few data describing the effectiveness of the device in deterring seals.

The Terecos was also tested by Gotz and Janik, (2010) in field and captive trials. In the field there was no detected deterrence effect on seals around a haul out site. In captive trials, there was an aversive response to the Terecos, but as was the case for all the ADDs tested, this response rapidly diminished in the presence of food (Gotz and Janik, 2010).

Northridge *et al*. (2012) used PODs to investigate porpoise responses to a Terecos device deployed at a fish farm site in Loch Hourn, Scotland. Overall, there was no significant difference in detection rate when the ADD was active. Detection rates were reduced, though not significantly, at the four closest sites, which were all within 1,000 m. As described above, the Terecos ADDs have a lower acoustic power output than the Airmar dB Plus II (Lepper *et al.* 2004; Gotz and Janik, in press) and this is likely that this is the reason for the difference in response between the devices on harbour porpoises.

GenusWave™

This device, currently in development under patent, comprises a control unit, a power source, amplifier and transducer. The approach of this device is based on elicitation of the acoustic startle reflex, a well-known reflex arc in terrestrial mammals. In terrestrial mammals the acoustic startle response (ASR) is an obligatory reflex elicited by short sound stimuli that exceed the hearing threshold by at least 80-90 dB (see Pilz *et al*. (1987) for startle thresholds in rats). For the signal to be effective, the stimulus has to reach a 'startle threshold' amplitude in the first 12 ms regardless of the eventual intensity of the stimulus. The ASR involves the interruption of on-going behaviour patterns and the initiation of protective motor-patterns and has been interpreted as a preparation or pre-cursor of a flight response. The response elicitation itself is very simple and mediated by only a few neurons (Koch & Schnitzler, 1997).

Most importantly the likelihood of eliciting the startle response depends only on a few simple factors like rise-time, bandwidth, intensity and duration. Whether or not animals that are startled actually leave the area thus does not depend on the level of arousal in the animal and on whether or not the sound is perceived as a threat, but on a factor that is independent of these other parameters.

Repeated exposure to the signal reinforces the acoustic startle response reflex therefore increasing aversive responses in the mammals over time (Gotz and Janik, 2011).

This device uses startle stimuli specifically designed for marine mammals and its effectiveness on both harbour and grey seals has been demonstrated in several captive and field trials over ranges of 60-250 m (Götz, 2008; Götz & Janik, 2011) and the long term effectiveness has been demonstrated during trials lasting over a year at a fish farm (Götz, pers comm). The system tested to date does not have an effect on harbour porpoises (Scottish Government work) as this version was developed to be targeted towards seals to ensure that there were not effects on non-target species at aquaculture sites. However the signal can be modified to produce sounds which will elicit startle responses in other species and this is part of the commercial development currently taking place.

The obvious advantages of this system are the fact that the underlying mechanisms responsible for the aversive response are understood. This potentially enables the signal to be modified to alter the effective range and allows the signal to be modified to work for a range of species. There are also advantages in that habituation is unlikely to be a problem as sensitisation to the signal will increase the responsiveness of individuals on repeated exposure. The devices are currently being developed as a commercial product and will be available for sale in 2014.

Table L.2 Recorded levels of underwater noise made at 80 m (maximum measurement range) from each device (Nedwell *et al.*, 2010). Values are presented in a variety of metrics. Values for grey seal likely to be similar to harbour seal. The Airmar dB plus II and Terecos were not tested by Subacoustech during this study.

Device	Species					
	Harbour porpoise RMS dB_{ht}	Harbour seal RMS dB_{ht}	High Frequency Cetaceans SEL (dB re. 1 $\mu Pa^2 s$ (M_{hf}))	Mid Frequency Cetaceans SEL (dB re. 1 $\mu Pa^2 s$ (M_{mf}))	Low Frequency Cetaceans SEL (dB re. 1 $\mu Pa^2 s$ (M_{lf}))	Seals SEL (dB re. 1 $\mu Pa^2 s$ (M_{pw}))
Lofitech	130	99	161	161	160	161
Ace-Aquatech	110	91	163	163	162	163

Kastelein system

Ronald Kastelein of SEAMARCO has developed a modular multispecies acoustic deterrent system, named the Sea Life Guard. Currently only the fish module has been tested in captivity and in the field (although published details of these tests are currently unavailable) but porpoise and seal modules are also in development. Details of the nature of the sound types emitted from these modules is not available and therefore it is difficult to assess the potential effectiveness under field conditions although it is clear that many years of research into the behavioural responses of captive seals and porpoises by Kastelein and colleagues forms the basis for the selection of the sound types.

Other candidate aversive sounds

As well as commercially available devices, it has been proposed that other sounds should be considered as likely candidates for mitigation of pile driving induced auditory injury. Coram *et al.* (2013) suggested that two different classes of sounds should be considered, those that had biological significance (e.g. predator vocalisations), and those which were “inherently aversive”. Loud sounds in the frequency bands that animals have most sensitive hearing and that are currently used in ADDs may be experienced as unpleasant, uncomfortable or painful but there are factors other than intensity that make sound unpleasant or aversive.

Zwicker & Fastl (1990) developed a model to describe what makes sound pleasant or unpleasant for humans. The relevant psychophysical parameters were sharpness, roughness, tonality and loudness. It is possible that perceived pleasantness of a sound is based on general principles of auditory processing in mammals and therefore it could provide a way to influence marine mammal behaviour with moderately loud sounds. Loudness obviously depends on stimulus intensity however; it is important to note that the physical composition of a sound also contributes to perceived loudness (Fletcher & Munson 1933). For instance the perceived loudness of a group of pure tones depends on the bandwidth of the stimulus relative to the cochlea filter bandwidth (critical bandwidth). Furthermore, there is some evidence from experiments with rats which showed preference for musically consonant sound indicating that these features of sound perception might be generic to all mammals (Borchgrevink, 1975). Other general properties of sounds that are “inherently” aversive to humans include unpredictability (such as randomly modulating amplitude) and dissonance.

Dissonant sounds are composed of tones which are not simple ratios of each other. Humans prefer combinations of tones varying by simple ratios, such as whole octaves: called consonant sounds. Attempts to find a similar preference for consonant sounds in another primate, the cotton-top tamarin (*Saguinus oedipus*), were not successful (McDermott and Hauser, 2004). Thus, findings from human research may be difficult to transfer to other species and there is a question over whether these sounds are likely to be sufficiently aversive to induce movements over the ranges required.

Götz and Janik (2010) tested a number of candidate sound types for aversiveness in seals and found evidence that sounds maximised for ‘roughness’ (or dissonance) perceived as unpleasant by humans also caused the strongest avoidance responses in seals, suggesting that sensory pleasantness may be the result of auditory processing that is not restricted to humans. The results of this study highlight the importance of considering the effects of acoustic parameters other than the received level as well as animal motivation and previous experience when assessing the potential for behavioural responses to aversive sounds. Of the psychophysical model sounds tested by Gotz and Janik, (2010), deterrence ranges were similar or greater to those resulting from the commercially available ADD species. The largest deterrent distance measured, 80 m, was from the Square 500/530). Furthermore the PPM sounds were the only sounds which significantly reduced the number of seals in the area during the post-playback phase compared to the pre-playback phase. Although not completely eliminated, responses were significantly diminished in the presence of food while this was not the case for tests with commercial ADDs.

Avoidance threshold levels of harbour porpoises have been determined in captive studies for noise bands and tonal signals around 12 kHz, a continuous 50 kHz tone (SPL of 108 dB re 1µPa (rms)), and continuous and pulsed 70 and 120 kHz tones (Kastelein *et al*., 2005, 2008a,b), although in each of these studies sample sizes were small. Both the spectrum and the received level of an underwater noise appear to determine the effect the sound has on the behaviour of porpoises. There was no habituation to the 50 kHz tone despite a large number of playback sessions, although this was not tested in the presence of food motivation. However higher frequency signals will attenuate more rapidly through the water and therefore will have reduced effective ranges compared to lower frequency aversive signals.

Kastelein *et al.* (2006) reported on a study with harbour seals subjected to four series of tone pulses together spanning a broad frequency range between 8 and 45 kHz. The seals were displaced by all four frequencies throughout the 40 trial days. The seals came to the surface more often when the test tones were produced than in the baseline periods. The initial displacement distances did not change over the 40 test days. This suggests that operating ADDs for only short periods will be more effective and less likely to result in habituation by the seals than operating them continuously. The deterrent effect of these sounds was not tested in the presence of food motivation.

Kastelein *et al.* (2012) reported on a study testing the “sudden flinch” responses of harbour porpoises to low (1-2 kHz) and mid (6-7 kHz) frequency “sweeps” from the perspective of understanding the detectability of, and response to, naval sonar sweeps. While they used the term “startle” in their paper, this is not the same response as the one elicited by the Genuswave device. Kastelein *et al.* used the term “startle” in a more colloquial sense meaning a sudden response. However, scientifically they used the wrong term. We therefore refer to these responses here as a sudden flinch instead. They found that porpoises exhibited such a flinch at similar sound pressure levels for mid frequency signals without harmonics and low frequency signal with harmonics (~35-40 dB above the detection threshold). Low frequency signals with harmonics elicited a flinch response at higher sound pressure levels (~60 dB above the detection threshold).

Using predator sounds to deter marine mammals is sometimes effective but is not advisable as an avenue for deterrence around marine constructions. Harbour seals have been shown to habituate to sounds of killer whales if they don’t pose a threat (Deecke *et al*., 2002). Such a habituation is likely to occur in repeated playbacks. It also poses a threat for the species that do habituate, since it would lead to decreased predator avoidance when under an actual threat from the predator. The likelihood of habituation makes it therefore not advisable to use such sounds in deterrence devices.

Unintended consequences to marine mammals

Additional injury and disturbance

There is a possibility that exposure to the sound emitted by ADDs may themselves cause hearing damage in marine mammals. Table K.3 presents the results of calculation of the various exposure times and distances that would be required for marine mammals to receive a level of sound exposure which puts them at risk of hearing damage (PTS thresholds) from the various devices, sourced from a number of other studies (Lepper *et al*., 2004 and Gotz and Janik, in press). In general, although there is a risk of PTS from short exposures at very close distances, exposure times would need to be relatively long within close range of the devices for a risk of PTS. Whereas this might be considered a concern at aquaculture sites where the motivation to remain close to a fish farm is high, it is less likely to be an issue at offshore wind farm sites, particularly where the presence of vessels and construction activity may also serve to deter animals. Injury is only likely to be a real risk if the devices do not have the desired deterrent effect which emphasises the importance of being confident about efficacy before deployment in a pile driving mitigation scenario.

Given the residence times required at the distances given in K.3. It is unlikely that exposure to the noise of ADDs will significantly increase the risk of auditory injury, comparative to the risk presented by the piling.

In addition there is a risk that using ADDs may add to the degree of disturbance and displacement from important habitats, however the currently predicted displacement ranges for piling driving are well beyond the effective ranges of ADD devices. For example, harbour porpoises are typically displaced by at least 20 km during pile driving whereas the reported displacement range for ADDs for harbour porpoises were between 3.5 and 7.5 km for the Airmar and Lofitech respectively, although it must be noted that these limits reflect the monitoring range rather than the effect limits. It is unlikely that the potential for disturbance presented by the ADD deployment will add significantly to the displacement as a result of the pile driving itself, particularly if the ADD deployment is limited to short periods before the onset of piling and during any breaks in piling. For species where there is less empirical information about the potential for displacement during piling (e.g. seal species), the nature of the balance of risk between pile driving induced displacement and ADD use is less certain.

Table L.3 Predicted injury ranges and exposure times for the ADDs and species that have been presented in the literature

Device	Species			
	Seals (Southall threshold)	**Porpoises (Southall threshold)**	**Porpoises (Lucke threshold)**	**Dolphins (Southall threshold)**
Airmar (Lepper *et al.* 2011)	> 3.3 hours at 100 m (single device); > 24 hours at 400 m (single device); > 1.6 hours at 100 m (2 devices); > 1.1 hours at 100 m (3 devices).	> 5.5 hours at 500 m (single device); > 2.75 hours at 500 m (two devices); > 1.8 hours at 500 m (three devices).	Not calculated .	Not calculated.
Airmar 50% 200% (4 transducers) (Götz and Janik., in press)	> 3h 38 min at 60 m; > 3 mins at 7 m; > 55 min at 60 m; > 45 s at 7 m.	Not calculated.	> 3 hours 38 min at 76m; > 3 min at 9 m; > 55 min at 76 m; > 45s at 9 m.	> 3 hours 38 min at 15 m; > 3 min at 2 m; > 55 min at 15 m 45s at 2 m.
Ace Aquatec (Lepper *et al.*2011)	> 3 hours at 100 m (single device); > 24 hours at 350 m (single device).	> 24 hours at 400 m (single device); > 24 hours at 400 m (single device).	Not calculated.	Not calculated.
Ace-Aquatec 30% duty cycle (3 transducers) (Götz and Janik, in press)	> 3 hours 10 min at 60 m; > 2 mins 37s at 7 m.	Not calculated.	> 3 hours 10 min at 76 m; > 2 mins 37s at 9 m.	> 3 hours 10 min at 15 m; > 2 mins 37s at 2 m.
Lofitech (25% duty cycle) (Götz and Janik., in press)	> 10 hours at 60 m; > 8 mins at 7m.	Not calculated.	> 10 hours at 76 m; > 8 mins at 9 m.	

APPENDIX M TECHNICAL DRIVERS

Practicality

Soft starts

The difference between an engineering soft start and a marine mammal mitigation (MMM) soft start

In order to understand soft start as marine mammal mitigation, it is important to consider the operational requirements associated with starting a piling operation from an engineering and construction perspective. A brief description is included to ensure a common understanding and clarify the difference between an engineering soft start, and a marine mammal mitigation soft start.

A piling operation is a complex offshore construction activity, the complexity of which varies depending in particular on the water depth, substrate type, substrate homogeneity, pile size and installation equipment used. The piling procedure involves a number of offshore lifts, a requirement for precise positioning and, most importantly is not an activity which can be reversed or easily re-attempted. Vertical alignment is a critical parameter which is monitored closely, especially during the initial, low energy hammer blows. Additionally, changes in soil resistance to driving are notoriously difficult to predict accurately and will directly influence the energy and number of hammer blows required for each pile (Jardine, 2009).

From a construction perspective a typical piling start up procedure involves a small number of low-energy blows followed by a pause in activity for alignment checks. This is repeated until the piling operations manager is satisfied the alignment is within the required tolerances, at which point the blow energy will be ramped up to a level sufficient to drive the pile to the requisite depth (but no higher).

The image below shows the Heavy Lift Vessel (HVL) Svanen upending a pile on the Rhyl Flats Project, as an illustration of the type of offshore construction activity involved in piling operations.

Svanen Piling Operations from http://www.bnoffshore.com/content/files/SITE4512/svanen.pdf

An MMM soft start varies in that the length of time that the low energy blows are applied is pre-defined (and in some cases the amount of, or percentage of maximum energy) seeking to enable any unseen marine mammals to swim away from the potential injury zone. This duration is generally longer than the soft start typically performed to meet engineering requirements (JNCC suggest a period of not less than 20 minutes, 30 minutes is a typical time proposed in more recent MMMPs).

A review of MMO construction monitoring reports shows that the overall duration of a monopile driving event has been typically between 30 minutes to 4 hours – usually around the 1 to 3 hours average. Therefore the use of a soft start at the initiation of a piling event is not significantly problematic from a duration and equipment perspective. As a rough approximation it can generally be considered to result in approximately an additional 15 - 20 minutes of piling activity at 'low' energy.

Currently each project is required to develop a site specific soft start procedure, which anecdotal evidence suggests is heavily subject to interpretation and inconsistent understanding across the different disciplines involved.

Practical limitations of a soft start

The JNCC piling mitigation protocol (JNCC, 2010b) states that in the event of a break in piling activity longer than 10 minutes a pre-piling search (if not maintained throughout operations) and soft start should be repeated.

The full soft start in this case is not always viable due to technical issues. In the event of a break, in certain substrate types (chalk is a known example, encountered on UK East Coast projects), the substrate can consolidate around the pile exhibiting a 'grow-in' or 'set-up' effect which results in an increase in the friction or driving resistance. This is a time critical effect, which requires potentially higher blow energies to overcome, requiring in the worst case additional piling remediation works such as drilling to address. There are examples of MMMP non-conformities found in a small number of construction reports due to this phenomenon (CMACS, 2012). This example highlights the need to increase understanding about the challenges associated with the soft start approach between piling engineers and those defining the requirements and licence conditions.

As a general engineering practice a pile will only be driven with the lowest energy required to overcome the soil resistance, this is to reduce the risk of damaging the equipment and to limit the amount of energy transferred to the pile which causes metal fatigue (pile buckling - structural damage from cyclic loading). A pile will be designed to tolerate a certain level of fatigue; however excessively increasing the amount of fatigue during installation through over hammering the pile will directly impact on the operational integrity of the foundation, potentially reducing the available fatigue life of the structure during its operational life.

Practical improvements to soft start

Soft start as a mammal mitigation solution is a technique which has come from mitigation approaches used during offshore seismic work, where different limitations apply. Feedback from industry engagement suggested there is room to develop guidance on soft starts both to clarify the requirements and to aide improvement in understanding of the approach between the different disciplines. Feedback from interviews highlighted the need to recognise that offshore construction is fundamentally a practical environment, which requires mitigations which can be adapted to the operational context. In addition discussions highlighted an uncertainty in requirements.

One interviewee highlighted that common sense and an understanding of the problem can often lead to better solutions than the prescriptive requirements generally set out in the MMMP. For example, having ADDs available (with deployment restrictions that recognise practical realities associated with offshore construction) and an MMO on the construction vessel to deploy during piling breaks, or advise during unpredicted or unplanned events may assist in ensuring best possible mitigation approaches are maintained without causing delays.

For a number of projects consent conditions required the MMOs to monitor and record the soft starts. The challenges associated with such a task, including the inability of the MMOs to remotely detect the changes in blow energy, raised the need for further consideration to be given to the scope of monitoring approach guidelines. Recommendations raised during the consultation phase of this study have included the potential for the development of a reference example to facilitate this process, the data for which is already captured in the piling records held by the piling contractor.

A final issue relates to the importance of communication between the MMOs and the piling contractors. Specifically the need for strong communication between the installation vessel and observation vessel to avoid the potential for soft starts being initiated without warning while PAM operators were still monitoring.

Extending a soft start

The acoustic modelling work presented in Appendix K identified the potential for increasing the efficacy of soft starts as a mitigation solution by extending the duration of the soft starts, i.e. tailoring the approach to address the specific species and noise attenuation characteristics of the site/operations. The practical viability of this is limited. Based on anecdotal experience and considering the installation schedule pressures, vessel day rate costs and the volume of foundations anticipated any significant time extension to the soft start duration may impact on the viability of the installation process. If considered Best Available Technology (BAT) then this will need more detailed consideration in terms of the benefits versus implications in terms of pile fatigue, construction schedule and additional duration of overall disturbance. In addition European discussions on MMM have highlighted that some specialists believe that a faster build may be preferable in terms of overall impacts on marine mammals which would counter the case for extended soft starts.

MMO and PAM

General comments

The majority of projects to date have deployed MMOs and PAM on dedicated survey vessels, mobilised from a local port. Practically this requires significant logistical effort and good communication protocols and protocol implementation between the installation vessel, survey vessel and marine operations co-ordinator. The key driver for developers is to ensure that any risks relating to MMO activities (e.g. delays in arriving on site, survey vessel problems) are mitigated as far as practicable to minimise the risk of delay to piling operations. This requirement may in some cases lead to additional costs for a stand-by 'back-up' vessel and additional stand-by MMOs. Examples of the vessels used for carrying out mitigation work are shown overleaf (Isadale, Sea Badger and Sea Mink used on recent R2 projects).

One of the important practical requirements is ensuring that the weather limits for the piling operations tie-in with the operational capability of the survey vessel used for MMO and PAM deployment, to date this has been managed well with only a single occasion reported where a survey vessel was forced to return to port due to adverse weather while piling continued. This needs careful project specific review for e.g. R3 and STW where sea states in some areas are significantly worse than the early near shore projects.

Section 3.2 discusses the current MMO and PAM approaches in detail, however from a practical perspective the key points to note are:

- MMO efficacy is dependent on a clear field of view, all approaches (whether observers are survey vessel or installation vessel based) suffer some limitations in this respect;
- Ideally PAM hydrophones are towed at a distance of around 200 m from a powered vessel to eliminate electrical and acoustic interference, for practical and safety reasons (risks associated with reduced vessel manoeuvrability and umbilical snag) this distance is reduced to a maximum of 40 m for piling MMM work making it more challenging to obtain reliable data; and
- Both MMO and PAM have been deployed successfully (i.e. to the satisfaction of all parties involved) from piling installation vessels – the benefits and drawbacks of this approach are expanded below, however from a practical perspective reducing the number of vessels involved in the construction operations provides clear benefit.

Based on the UK projects constructed to date, a typical approach has been to permanently charter a suitable survey vessel with the crew living on board, or based locally, and the MMOs staying nearby. The operational protocol is defined in the MMMP but consists of a series of communications to ensure that the crew and vessel mobilise and transit to be on site approximately 2 hours prior to piling. The team will generally consist of 2 MMOs and a PAM operator (sometimes 2) on board who set up the equipment and prepare for the pre-piling watch. PAM monitoring is continued throughout the piling operation, while visual piling searches are only required prior to the soft start, and in the event of an extended piling break.

Selection of MMO/PAM deployment platform

There are mixed perspectives on the optimum ‘platform’ for carrying out mitigation work, with some mitigation solution providers showing a strong preference for utilising the piling installation vessel to perform the required activities.

Limitations of using the survey vessel approach include:

- Navigational issues around moored installation vessels (on one project anchors lines numbered 8 – 10 and extended 200 m from the vessel – impacting the ability of the survey vessel to complete the specified track around the MZ);
- Additional marine co-ordination and logistics/overhead effort to manage additional vessel during construction (note – the survey vessel is working within the installation vessel exclusion zone); and
- Moving ‘blind spot’ - vessels usually follow a 250 m radius track around the piling site at around 4 kts leaving a blind spot behind the installation vessel.

On the upside the survey vessel can be used for other duties whilst not performing MMM. Reported benefits of using the installation vessel for MMM:

- Avoidance of risk that the MMO team are not present for piling event (assuming the team remain offshore and work e.g. a similar shift pattern to the construction team);
- Better opportunity to rest between piling operations (and therefore an ability to be more alert during critical periods);
- Markedly reduced reduction in electrical and acoustic interference to PAM reported;
- Potentially enhanced viewing elevation/vantage point (vessel dependent, assessed on a case by case basis) - it is likely that some blind spots will remain;

- Ability for face to face communications with the construction team, especially useful in the event of unexpected or unplanned events; and
- Ability to directly monitor soft start or carry out ADD deployment and ensure that equipment is operating and maintained (batteries charged etc). It is probable that the MMO would have greater ownership of this than a crew member reducing the risk of inappropriate or missed deployment.

Another subtle but potentially important factor is that by placing the MMO/PAM team on the same vessel as the installation crew they may gain a better understanding of the work and purpose of marine mammal mitigation. One interviewee described an approach taken on a project which involved the provision of a short training course for all project members on mammal recognition and action in the event of finding a distressed or injured animal. This led to heightened awareness and interest across the project, with all operational crew now recording casual sightings contributing to a growing database of mammal activity in the area.

The drawbacks of locating the MMO/PAM team on the the piling vessel include:

- An inability to cover multiple piling operations (although experience suggests that this not likely to be consistently viable with a single survey vessel either);
- Bed space limitations (although this has been successfully overcome on recent projects by ensuring requirements are incorporated into contractual negotiations from the outset – possible because consent conditions known upfront);
- Visual surveillance limitations (as per above, vessel dependent, assessed on a case by case basis) – may require multiple MMOs;
- Additional HSE training requirements (hazards on a construction vessel significantly higher than a survey vessel);
- Need to transfer crew on and off installation vessel (approached on a case by case basis depending on the strategy and logistics on project);
- Need for a more complex and costly PAM array (2 - 3 static arrays versus single towed array);
- Any viewing blind spot will be continuously so (as opposed to the ‘moving’ blind spot for survey vessel based approaches); and
- Initial mobilisation of equipment (PAM, and ADD if used) is more complicated and careful planning is needed to operate safely without conflict with other activities on the installation vessel. Long cable runs may be required along with minor works to establish safe deployment.

The installation vessels shown below are the HLV Svanen, and the Pacific Orca, these are examples of installation vessels which have been used successfully to deploy MMOs and PAM equipment.

Acoustic Deterrent Devices (ADDs)

In order to assess the practicalities of deploying ADDs versus other mitigation options the following considerations have been taken into account:

- What are the key components of an ADD?
- How are the ADDs handled and powered offshore?
- How reliable are the devices?
- Is further development required to improve their deployability and use?

What are the key components of an ADD?

ADDs are simple powered devices which consist of a control unit, a power source, amplifier and transducer, water proof housing and cable connections. They are designed to be manually handled.

The devices contain pulse generators and amplifiers which transmit audio frequency signals to a transducer, where the signal is converted into sound. The devices are powered from AC or chargeable battery sources such as a 12 V car battery. Further details of specific devices are included in Appendix L. To aide understanding of the practical issues images of a selection of devices are included below, showing the Lofitech and Aquamark 848 models.

How are the ADDs handled and powered offshore?

The JNCC guideline (JNCC, 2010*b*) recommends that ADDs if used, are deployed from as close to the piling operation as possible, i.e. from the piling vessel itself, which has been the approach adopted in the majority of cases. It has not been possible to obtain and review any deck plans which detail the locations from which the ADDs have been deployed with respect to the piling operations, however anecdotally there is no evidence to suggest that this has been an issue. The key concern is anticipated to be whether the deployment location is optimal from a efficacy perspective, without compromising operational considerations on the construction site.

From the anecdotal information gathered devices used to date have been battery powered. They are deployed manually by one person, generally with the aid of a small winch. On several projects the devices have been managed by crew on the vessel (e.g. a trained rigger), as is the case widely in Europe. The location of the equipment is vessel specific and dependent on the deck layout/other equipment on deck and access requirements.

How reliable are the devices?

ADDs of the higher power seal scarer type of device are in widespread use for aquaculture, for which they have been specifically designed and developed. Although very little hard evidence is available on device reliability, the requirements for the aquaculture market (low cost, robust, easy to install and operate, designed to operate remotely for extended durations), have significant parallels with the requirements for offshore wind. Anecdotal evidence from technology users suggests that, to date, the devices deployed have been reliable and with the exception of a flat battery, there are no reported incidence of ADDs (of the seal scarer type) not working. The ADD manufacturers who could be contacted reported little feedback from the offshore wind sector on their technology.

Could they be developed to improve their deployability and use?

ADD Intellectual Property is centred on the transmission frequency and sound pattern of the devices. As highlighted in Section 3.3.2, it is this area which is the current focus of development. The equipment housing, handling and power supply equipment is not complex and can be modified to suit specific applications. During the review no specific requirements for improvement from a hardware perspective were identified.

Conclusions

- Although MMO and PAM approaches to date have been managed effectively, they are inherently not a practical solution. Looking ahead to future OWF developments the benefits of locating these MMM's onto the installation vessel (and reducing numbers if possible) may outweigh the potential drawbacks, but this would need to be reviewed on a case by case basis**;**
- ADDs provide a highly practical solution for MMM requiring minimal deployment effort; and
- Soft start provides a relatively practical but not 100% deployable solution. This mitigation technique needs to be carefully assessed on a project-by-project basis (for both technical possibilities/limitations and mitigation efficacy) and would benefit from the development of additional guidance and clarification.

Installation schedule

Piling installation

Figure M.1 below provides an illustrative example, at a high level, of a single offshore piling operation for a monopile foundation from a jack-up barge (not including mobilisation or seafastenings).

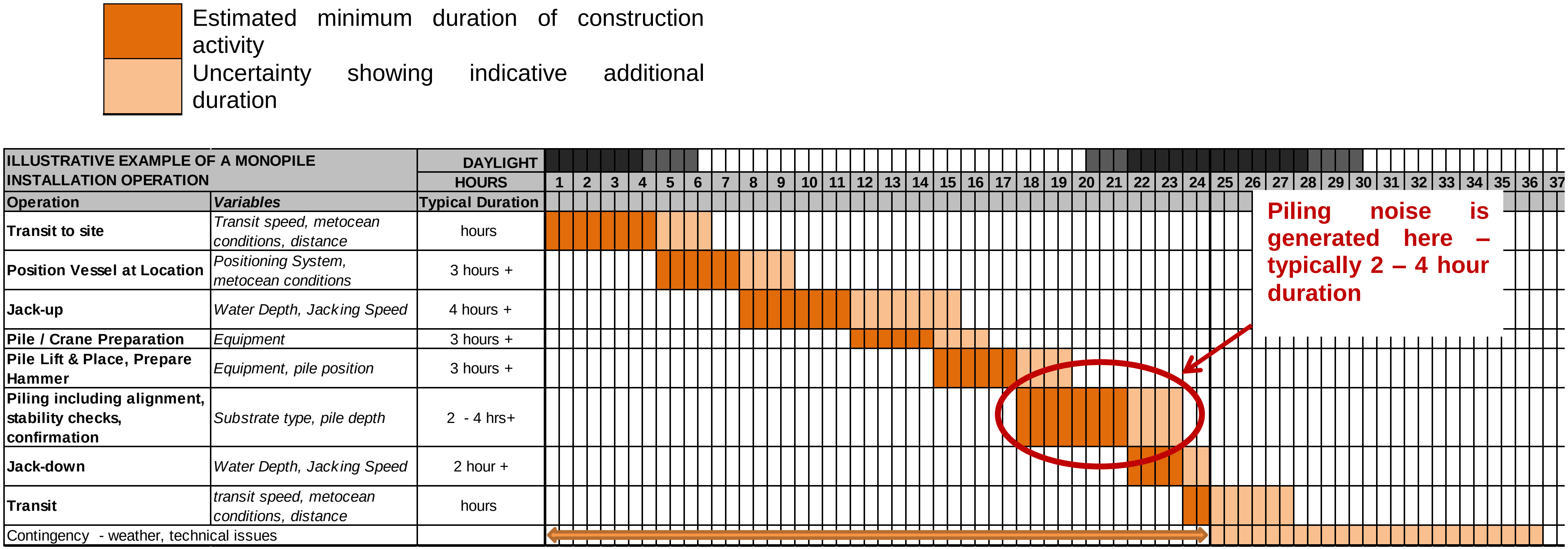

Figure M.1 Illustrative example of the sequence of events that occur during a single offshore piling operation

The impact of mitigation on the installation schedule

Figures M.2 & M.3 (overleaf) below show a piling operation with and without mitigation, highlighting where specific uncertainty and time is added to the construction schedule.

MMO & PAM

MMO and PAM activities are performed in parallel to construction operations, whether carried from a survey vessel or the installation vessel. In the event of a sighting within the MZ, during the pre-piling search the piling start-up will be delayed. A qualitative estimate of the expected frequency of sightings could be made given sufficient data on mammal activity in the area; however there is currently very little evidence on which to base this judgement. This approach therefore remains a significant uncertainty for which developers will need to consider adding additional contingency to the installation programmes.

This type of uncertainty has commercial implications on the contractual arrangements for the installation contract; negotiations will need to resolve which party takes this risk on the project.

Project developers and mitigation solution service providers work hard to ensure that the mitigation measures are decoupled from the installation schedule as far as practicable, i.e. they are independent operations. In practice this means that survey vessels and MMOs are on 24 hour stand-by, with contingency plans in place in case of survey vessel break-downs.

The approach relies on selecting a survey vessel which can operate in the same conditions as the piling operations (as far as practicable), on well written (and followed) operational procedures and on good communications with the installation vessel to ensure that the skipper and MMOs are advised of piling operations in sufficient time to get to site.

A review of the available construction reports has identified a small number of events where soft starts were delayed due to late arrival on site of the MMO survey vessel (due to poor communications) or where soft starts were initiated without warning. These issues have only occurred on one project, and could be avoided through adopting and implementing good practices.

The table below (M.2) shows the project delays due to MMO and PAM sightings/detections, this shows that as far as we have been able to ascertain, there are only 2 projects which have experienced delays due to mammal observations in the 500 m Mitigation Zone (MZ) – these have led to an overall offshore wind farm installation schedule delay of less than 3 hours.

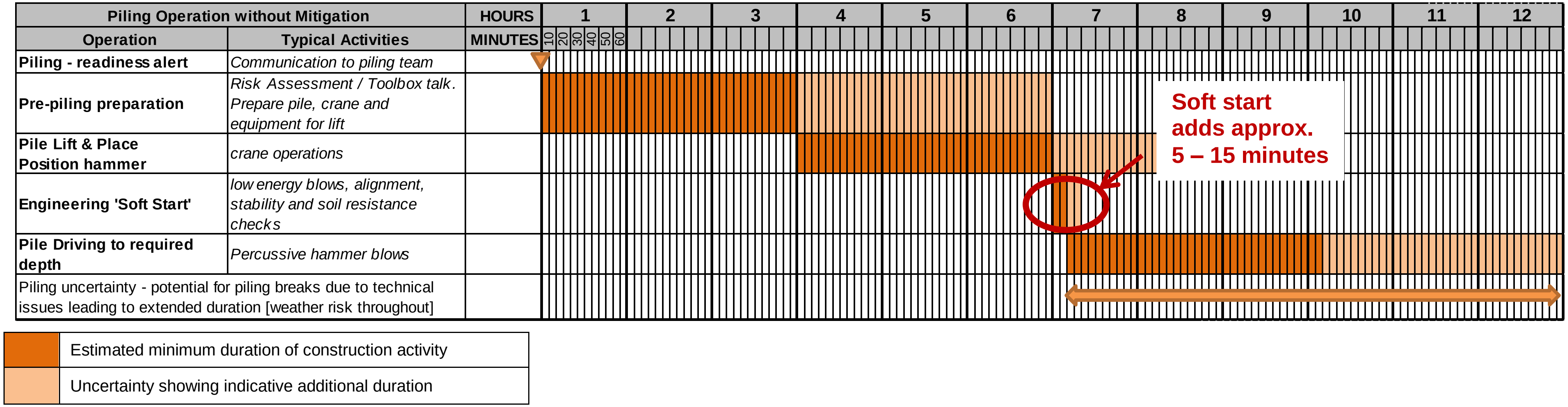

Figure M.2 Piling schedule without MMO/PAM monitoring of mitigation zone

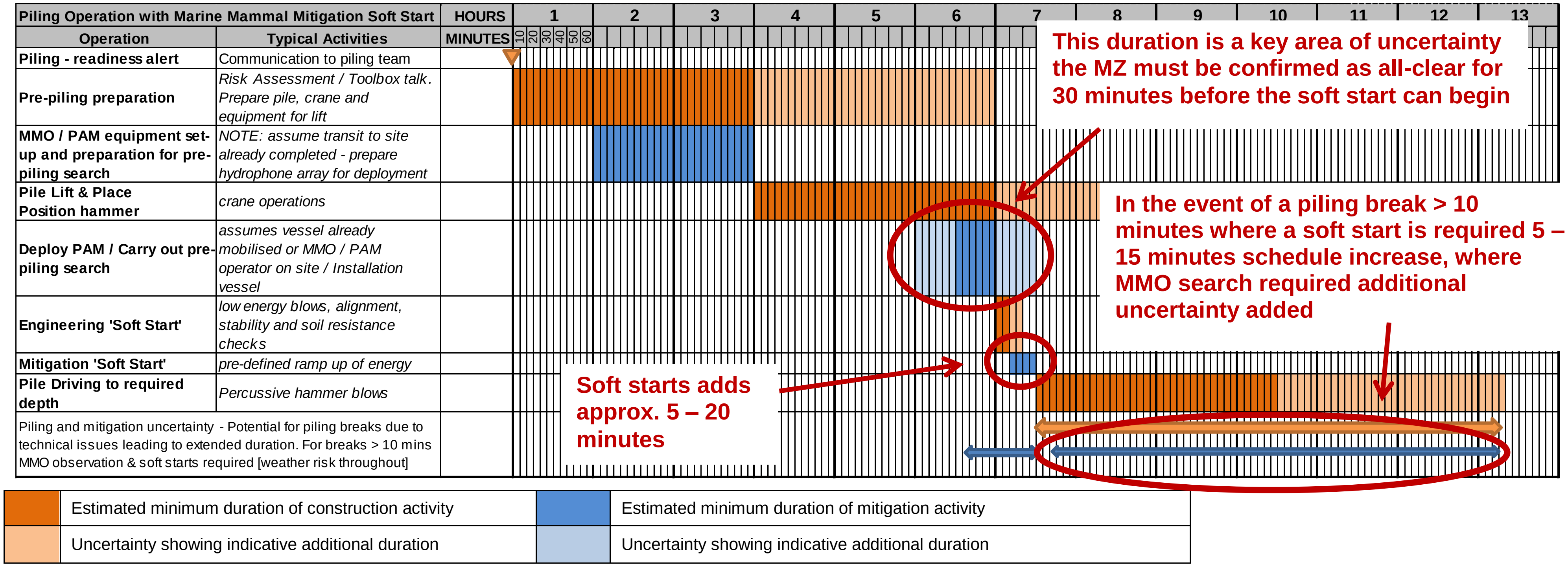

Figure M.3 Piling schedule with MMO/PAM monitoring of mitigation zone

Table M.1 Project delays due to MMO and PAM detections

Project	Sightings per Offshore Manhour of effort (within MZ)	Number of minutes Delay per Piling Event	MMO time (mins)	PAM time (mins)	Mammal sightings outside mitigation zone	Mammal sightings inside mitigation zone during pre-surveillance	No. of times piling delayed	Delay (mins)
Barrow	0	0	unknown	unknown	unknown	0	0	0
Ormonde	0.027	0	17,727	25,344	7	0	0	0
Rhyl flats	0.017	1.68	3,552	4,331	unknown	1	1	42
Walney	0	0	9,840	7,620	unknown	0	0	0
Lynn & Inner Dowsing	0.159	0	4,955	5,155	13	3	0	0
London Array (phase 1)	0.010	0.51	32,789	40,596	5	8	3	90
Gunfleet Sands	0	0	1,963	4,020	6	0	0	0
Gunfleet Sands demo	0	0	unknown	unknown	0	0	0	0
Walney I	0	0	6,720	7,680	3	0	0	0
Walney II	0.002	0	7,620	9,840	3	0	0	0
Gwynt y Mor	0.035	0.67	13,602	28,748	24	8	5	59
Lincs	0.022	0.60	16,744	35,547	0	6	6	45

Table M.1 presents a summary of the results reported in MMO/construction reports from a selection of UK OWF sites (further details in Appendix G). The maximum sighting rate in the mitigation zone per manhour of effort was 0.159, at Lynn and Inner Dowsing, whilst the maximum cumulative piling delay experienced at any one project due mammal detections was 90 minutes at London Array (Phase 1). The reasons why these sightings are relatively low are uncertain, and could relate to e.g. low population densities in the area; hence this situation cannot be extrapolated to future development sites. Anecdotally it has been suggested that marine mammals may be deterred from the construction area due to the high volume of vessel traffic and activity, for example on Walney 1 it was observed that vessel activity was most intense 1 hour prior to piling with up to 8 vessels within the 1 km of the piling site, however there is a lack of evidence or data to support or challenge this hypothesis.

Soft starts

Assuming a 30 min soft start increases each piling operation by 15 minutes in total (see section on practicalities for detailed discussion) over an installation programme lasting a year, with 1 pile installed every 2 days this would equate to roughly 2 additional vessel – days in total. A simple sensitivity on the impact of soft start durations is shown in the table below.

M.1 Impact of soft start durations on installation programme

Soft start additional duration (mins)	Piling rate (per day)	Additional vessel-days assuming a 12 month campaign
15	0.5	1.90
20	0.5	2.53
30	0.5	3.80

The benefit of the soft start approach is that it can be planned, priced and agreed with the installation contractor during the contractual negotiations phase, although some uncertainty will remain (linked into the technical challenges discussed in the section on practicality, and the need for a common understanding of the exact requirements).

Based on the information reviewed the uncertainty and logistical implications on the installation schedule for soft starts performed as per the current MMMP (JNCC, 2010b) are very low, and do not present a major concern for the developers, particularly as the delay (at least for the initial soft start) is known and can be built into contractual requirements and commercial models.

ADD

To date ADDs are being used on offshore wind projects to provide risk mitigation during conditions where MMOs and/or PAM cannot be deployed effectively (e.g. at night or during poor weather). The approach has been to deploy the ADD for 30 min prior to the soft start from the installation vessel itself (either using a rigger or MMO if on board). If unplanned or poorly co-ordinated then there is a risk that the requirement for deploying the device for a specified period could lead to a delay however, from the evidence gathered the operations have been well planned and have taken place in parallel to piling preparation works. There is only one reported incident where an ADD did not work, which was later found to be because it was not charged, this did not however lead to a delay.

ADDs, being an active mitigation measure, therefore provide the highest level of schedule certainty and very little risk of project delay. The logistical implications are also minimal.