ORJIP Project 4, Stage 1 of Phase 2:
The use of Acoustic Deterrents for the mitigation of injury to marine mammals during pile driving for offshore wind farm construction.
Final Report

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1 Glossary of Terms, Acronyms and Abbreviations

Term	Description
ADD	Acoustic Deterrent Device
ALARP	As Low As Reasonably Practical – a term used widely in health and safety and risk management
ARGOS	Satellite based tracking system
BRS	Behavioural Response Study
CEE	Controlled Exposure Experiment
CPOD	Passive acoustic monitoring device capable of detecting porpoise and dolphin echolocation clicks
CPUE	Catch Per Unit Effort
CRRU	Cetacean Research and Rescue Unit
dBht	The dBht (Species) provides a measurement of sound that allows the comparison of the effects of noise on a wide range of species. The loudness of a sound to a given species may be assessed by passing the sound through a filter that mimics the hearing ability of that species.
EPS	European Protected Species
FASTLOC®	An approach to the logging of GPS data which is suited to animals which only surface briefly.
GPS	Global positioning system
GSM	Global System for Mobile Communications (network used for mobile/cellular phone)
HWDT	Hebridean Whale and Dolphin Trust
IP	Intellectual Property
MMO	Marine Mammal Observer
MMMPs	Marine Mammal Mitigation Plan
MTTF	Mean Time to Failure

MTTR	Mean Time To Repair
NOAA	National Oceanic and Atmospheric Administration
OEM	Original Equipment Manufacturer
ORJIP	Offshore Renewables Joint Industry Programme
PAM	Passive Acoustic Monitoring
Pinger	Small, low powered devices originally designed to be attached to fishing gear are most frequently referred to as ‘pingers’
PTS	Permanent Threshold Shift
R&D	Research and Development
RTT	Real Time Tracking
RFI	Request For Information
SEL	Sound Exposure Level
SNCBs	Statutory Nature Conservation Bodies (JNCC, Natural England, Scottish Natural Heritage, Natural Resources Wales, Dept. of Environment, Northern Ireland)
SPL	Sound Pressure Level
RMS	Root Mean Squared
UHF	Ultra-High Frequency (radio signals)
VHF	Very High Frequency (radio signals)

2 Introduction

During Rounds One and Two of UK offshore wind farm development, the UK Statutory Nature Conservation Bodies (SNCBs) and wind farm developers agreed methods to minimise the risk of lethal interactions and physical injury to marine mammals from pile driving. These involved using Marine Mammal Observers (MMOs) and/or Passive Acoustic Monitoring (PAM) to ensure an area with a radius of no less than 500 m around the piling location was clear of marine mammals prior to piling commencing in addition to a soft start. This approach is outlined in the Joint Nature Conservation Committee (JNCC) Guidelines '*Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise'* (JNCC, 2010). These protocols have allowed the development of offshore wind farms to proceed. However, the effectiveness of an MMO and PAM based mitigation to adequately protect marine mammals from injury as a result of exposure to underwater noise, particularly in poor weather conditions and at night, has been questioned (e.g. Parsons *et al*., 2009, SMRU Ltd., 2007). These concerns relate to the expected low probability of detection by visual and passive acoustic means, which even in good conditions and considering an observer in a fixed, elevated position, is likely to be considerably lower than 100%. There is no published empirical evidence for the effectiveness of the JNCC (2010) protocol in reducing the risk of injury to marine mammals from pile driving to negligible, however some work has attempted to determine elements of this from seismic surveys (Stone, 2015a and b). A further concern is that calculations suggest that the range at which animals are at risk of suffering injury in the form of permanent threshold shifts may be greater than 500 m for some species (Hastie *et al*., 2015).

In addition, implementation of these measures for UK Round Three (R3) and Scottish Territorial Waters (STW) projects is more difficult owing to the increased scale of projects, the increased distance offshore, challenging, multiyear construction programmes, multiple activities within zones and across sea areas and the health and safety implications of operations offshore. There are also concerns among developers regarding the uncertainty in construction timelines introduced by the need to ensure that the mitigation zone is free of marine mammals by passive means before piling can commence.

The use of acoustic deterrent devices (ADDs) has been suggested as an alternate means to mitigate the risk of lethal and physical direct injury to marine mammals during pile driving (e.g. Gordon *et al*., 2007). There are, however, stakeholder concerns with the proposed use of ADDs as a blanket alternative to adoption of the JNCC protocol and the use of MMOs and PAM at offshore wind farms (OWFs), these concerns primarily relate to the evidence base for ADD effectiveness and uncertainties surrounding the extrapolation of this evidence to a range of different sites and conditions. As a result of these concerns and discussions within the Offshore Renewables Joint Industry Programme (ORJIP), a review was commissioned in 2013 and published by the Department for Energy and Climate Change (Herschel et al., 2013). This review investigated these issues and presented evidence on the effectiveness of available ADD technology for deterring UK marine mammal species at the ranges likely to be required for mitigating physical and auditory injury.

This report is intended to provide an update to the ORJIP Project 4, Phase 1 report (Herschel *et al*., 2013), highlighting any advances relevant to the use of ADDs for mitigation since its publication, in terms of evidence for effectiveness in offshore wind farm mitigation, advances in available ADD technology and advances in methodologies for field tests to improve our understanding of effectiveness. Note that the use of ‘Phase 1’ throughout this report refers to the previous review. This report also provides recommendations to improve the current evidence base for ADD effectiveness and provides a detailed evaluation of methods and field sites for future experimental trials.

The structure of the report is as follows:

- **Section 3:** An introduction to a general framework for assessing the potential for ADD based mitigation on a site by site basis;
- **Section 4:** ADD effectiveness review: an update to the evidence base presented in Herschel et al., (2013) to document research that has been carried out on ADDs for the marine mammal species of concern in relation to injury from pile driving noise during UK OWF construction;
- **Section 5:** Methodology review: A review of the techniques employed to date to measure ADD responses as a high level evaluation of to the various options for field trials. These options are further evaluated in Section 9 in light of the gaps identified in Section 4;
- **Section 6**: A detailed appraisal of the technological status, commercial availability and practicality of use of ADDs in relation to their potential application in the mitigation of the risk of injury from pile driving noise during UK OWF construction;
- **Section 7**: A review of the factors influencing sound propagation with a view to informing how results from a range of trial sites (past and future) would translate to OWF sites with a range of different characteristics;
- **Section 8**: A comparison of the potential costs between different mitigation approaches. To understand the potential value of ADD’s to the UK offshore wind sector by comparing the cost of using ADDs vs other current mitigation techniques such as MMO and PAM;
- **Section 9**: Detailed discussion and evaluation of methodology for field trials as well as a comparison and evaluation of a number of potential field sites for carrying out further ADD trials. This evaluation also includes a power analysis to determine the sample sizes required to allow a robust assessment of ADD effectiveness. This section concludes with recommendations for methods and sites based on this evaluation;
- **Section 10**: Overall conclusions and summary of recommendations.

3 General Framework for the consideration of ADD based mitigation at UK Offshore Wind Farms

During discussions with SNCBs on this project, although there was general agreement that there was a good evidence base for ADD effectiveness for harbour porpoise and harbour seals, it became apparent that a blanket agreement to use an ADD based mitigation (i.e. instead of MMOs and PAM) to reduce the risk of injury to marine mammals as a result of OWF piling noise at all sites was unlikely. In response to this, and in recognition that future research may add to the evidence base for deterrence of a wider range of marine mammal species in a wider range of circumstances, a generic 'decision tree' framework was developed. This framework is intended to guide the consideration of ADD based mitigation on a site by site and species by species basis. Figure 1 outlines the process which should be followed for each species present in appreciable numbers at each wind farm site. While it is difficult to define specific guidance for the inclusion or exclusion of species in this process it is expected that the decision will be made on a case by case basis based on the baseline data collected to inform the impact assessment.

The first stage in the process is to carry out a quantitative risk assessment of the absence of mitigation. Although there is debate about the actual effectiveness of the current methods it has previously been assumed that risk of death, physical injury and instantaneous Permanent Threshold Shift (PTS) will be reduced by the adoption of the current recommended approach to mitigation for piling noise (MMOs and PAM). Here we assume that achieving or exceeding this level of mitigation is the requirement. This risk assessment is therefore simply an extension of the approach used in Environmental Impact Assessments and Habitats Regulations Assessments, i.e. a quantitative assessment of the risk of injury is carried out and an assessment is made as to whether mitigation is required to reduce that risk to negligible. Exactly how this risk assessment is carried out and how the risk of injury is defined is beyond the scope of this report. However, this framework provides the background and context for the development of the evidence base for the effectiveness of ADDs and a method for guiding the decision making on a project by project basis. If a species is deemed to be at risk of injury and there is sufficient evidence of effective deterrence for a particular device with a particular species, the decision tree will recommend the use of ADDs to replace current MMO and PAM based mitigation practice. In each case this decision will be conditional on the results of an assessment of the characteristics of that particular site confirming that noise propagation conditions would not decrease the effectiveness of the ADD mitigation. If this cannot be demonstrated then the next stage in the process is to carry out a quantitative risk assessment of the absence of mitigation. Although there is debate about the actual effectiveness of the current methods it has been previously been assumed that risk of death, physical injury and instantaneous PTS will be reduced by the adoption of the current recommended approach to mitigation for piling noise (MMOs and PAM). Here we assume that achieving or exceeding this level of mitigation is the requirement. This risk assessment is therefore simply an extension of the approach used in Environmental Impact Assessments and Habitats Regulations Assessments, i.e. a quantitative assessment of the risk of injury is carried out and an assessment is made as to whether mitigation is required to reduce that risk to negligible. Exactly how this risk assessment is carried out and how the risk of injury is defined is beyond the scope of this report. However, this framework provides the background and context for the development of the evidence base for the effectiveness of ADDs and a method for guiding the decision making on a project by project basis. Although the detail of this approach requires development and agreement between developers, SNCBs and regulators during implementation, it is hoped that this process will provide a useful starting point for these discussions. Information on the effectiveness of ADD deterrence across a range of species will be required to ensure regulator and SNCB agreement with their adoption in mitigation.

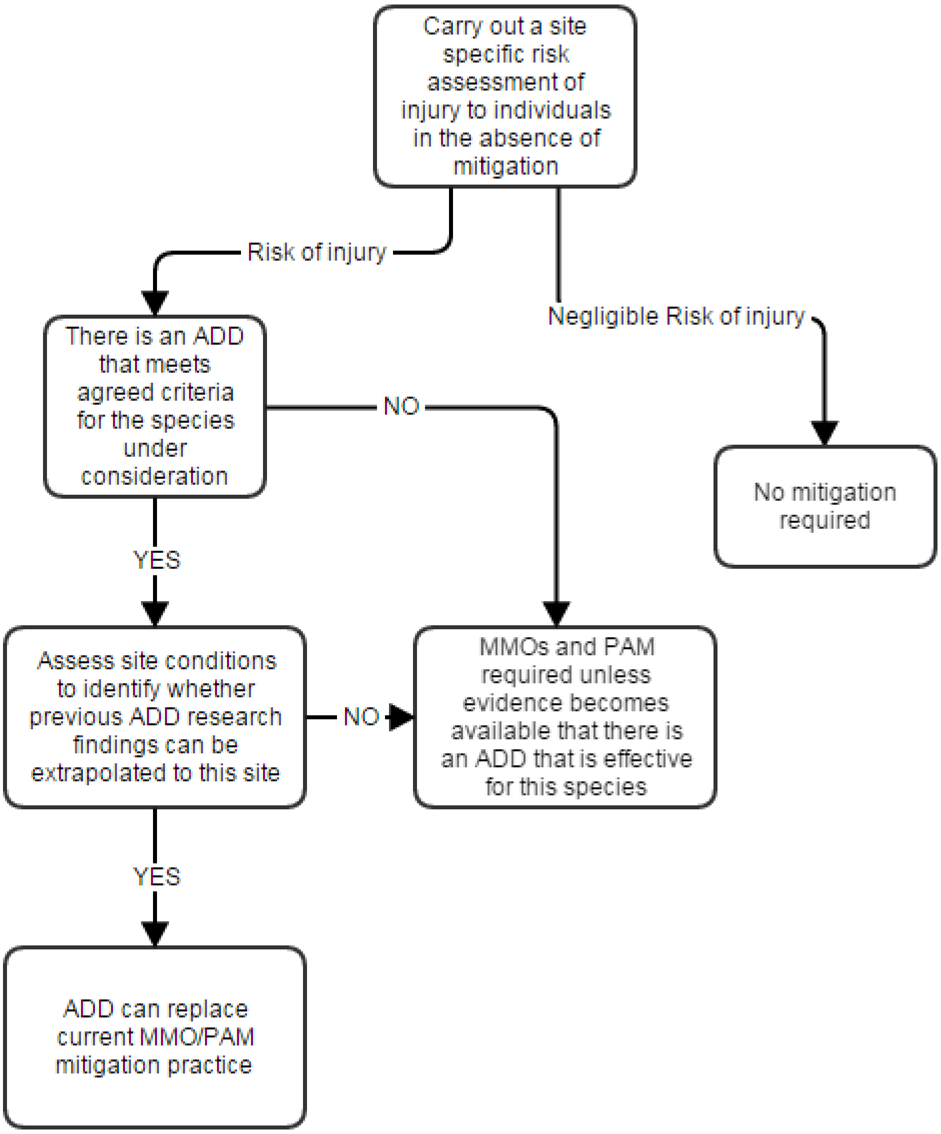

Figure 1. Decision tree process for considering an ADD based mitigation on a site by site basis. This process should be followed for each species deemed to be at risk of injury from pile driving noise as part of the project impact assessment.

4 Review of ADD effectiveness

4.1 Introduction

As discussed in Section 2, this report aims to build upon the findings from Phase 1, using the findings from Herschel *et al.,* (2013) as a basis for an updated review to understand the current level of knowledge in relation to the testing of ADDs conducted to date for the key species and the level of deterrence identified.

4.1.1 What deterrence ranges are required?

In order to assess the potential effectiveness of an ADD for mitigation it is important to have an understanding of the deterrence range required for a particular scenario. Because different projects involve differences in pile size, hammer energy, water depth, bathymetric conditions etc. zones of influence and mitigation ranges are also likely to vary. In addition, different species are believed to have differing thresholds for the onset of auditory injury and the risk of injury will also be affected by the behaviour of individual animals.

All mammalian ears can be damaged by exposure to intense sound. This has been very well studied in humans and in some terrestrial mammals but studies with marine mammals have only been started relatively recently and our scientific understanding in this area is still developing. In the USA, NOAA convened a panel of experts and tasked them with developing a set of criteria and thresholds for exposure to sound. This panel met several times and summarised their findings in an influential paper (Southall *et al*., 2007). The criteria they proposed have been widely adopted by regulatory bodies around the world and new scientific understanding on the effect of sound on the auditory systems of different species have been incorporated into their framework. NOAA is now in the process of updating this document. They have published a draft document dated July 2015 which is now undergoing review. The review and subsequent adoption of NOAA thresholds should be considered when assessing ADD effectiveness in the future.

The approach outlined in Southall *et al*., (2007) recognises that different species groups will have differing sensitivities to sound with differing spectra. This is allowed for by applying an appropriate taxa specific filter to candidate sounds. The approach recognises two general mechanisms resulting in Permanent Threshold Shifts (PTS):

1) A very intense pulse of sound can cause hearing damage after a single short exposure. Southall *et al*. (2007) define a range of thresholds for different species groups. Recognising that any single strike in a series of strike can cause injury, the single pulse and multiple pulse thresholds are identical. For exposure to pulsed noise it is relatively easy to calculate the range within which this threshold is exceeded if source level and propagation conditions are known. This is often termed ‘instantaneous’ PTS in impact assessments. Although it is important to recognise that for pile driving the concept of a single pulse threshold is not really appropriate since by its nature, pile driving is a percussive sound and each pulse is generally followed by another pulse. In the context of pile driving this ‘instantaneous’ impact threshold is used to indicate where the noise level of any strike in a sequence of strikes at that hammer energy would put an animal at risk of auditory injury.

2) Prolonged exposures to sound at lower levels can also result in PTS (often termed 'cumulative' PTS). The cumulative sound exposure level (SEL) over multiple pulses should therefore also be calculated. However, one difficulty in modelling the total acoustic dose for an animal during an extended event such as pile driving is that it depends critically on how the animal moves within the sound field during the event, both horizontally and vertically. In addition, there are a number of uncertainties relating to the potential for recovery between pulses, the effect of 'effective quiet' (when the sound no longer contributes to PTS) and whether the equal energy hypothesis applies (e.g. Kastelein, *et al.*, 2013). The concept of a mitigation zone is more difficult to apply in this case. What has most often been calculated is the minimum safe "starting range" for an animal at the start of a noise event when certain assumptions about animal movement are made. Most risk assessments for pile driving in UK waters have assumed that animals move away consistently at a speed of 1.5 $m.s^{-1}$ for most species, although empirical data to confirm this response is lacking.

The current guidance for pile driving mitigation (JNCC, 2010) recommends a marine mammal exclusion zone of at least 500 m around the piling location and a "soft start" of at least twenty minutes to mitigate the risk of auditory injury. However, the guidance does not specify whether 'instantaneous' or cumulative PTS should form the basis for determining the extent of the mitigation zone. Although the Joint Nature Conservation Committee, Natural England and Natural Resources Wales guidance for the prevention of injury to European Protected Species (EPS) clearly specifies the Southall criteria, and Southall et al., (2007) specify that both peak pressure and cumulative injury thresholds apply and injury risk occurs if either are exceeded.

Table 1 summarises the impact ranges that have been predicted across a range of R2, R3 and STW windfarm sites. Most of these claim to have used the methodology outlined above using the Southall *et al*. (2007) criteria, often updated where appropriate using new scientific findings as they have been published. Some assessments have used alternative criteria such as 130 dBht (Nedwell, *et al.,* 2007) to predict 'traumatic auditory injury'. The dBht metric filters a specific sound by the hearing ability of a species. While the use of the Southall criteria is widely accepted within the regulatory and scientific community, there is less agreement on the dBht criteria for predictions of injury. It can be seen that there is substantial variability in predicted impact ranges. This is partly the result of different site conditions (e.g. water depth) and different piling parameters (e.g. hammer energy and pile diameter) but there are also differences resulting from the use of different criteria for PTS, different assumptions about behaviour etc. Often the assumptions used in these modelling exercises are not made explicit; therefore some caution must be applied when using these different estimates to underpin assessments of ADD effectiveness. It should also be noted that scientific understating of the potential noise exposure risk for different noise types and the effect of intermittent recovery periods is still developing.

Given this uncertainty and variability, it may be helpful to define maximum and minimum ranges at which deterrence may be required for a range of current projects. At a workshop held as part of this project (Project workshop 17 June 15 (minutes of meeting documented in 'ORJIP-ADD study – P2S1-Acceptance workshop – 17June15 MoM FINAL.pdf), this was discussed and although agreement was not reached on which thresholds for auditory injury should be adopted in determining the desired mitigation range, it was felt that a deterrence range of 500 m would provide a pragmatic and achievable range which would reduce the risk of death, physical injury and instantaneous PTS to negligible for most projects. It is important to note that impact ranges of “<500 m" or "<1 km" are not helpful for deciding whether injury zones may in fact be much less than 500 m or 1 km. It should therefore be recognised that these ranges represent a calculated maximum required and it is possible that the injury zones could be considerably smaller than these maximums stated in this way. It is notable that the current mitigation methods (the JNCC protocol) do not always fully mitigate the risk of cumulative PTS (although for some assessments for some species, cumulative PTS ranges, i.e. exposure exceeding Southall’s SEL thresholds are well within the 500 m mitigation zone) and that as part of individual project environmental impact assessments, the magnitude of these unmitigated impacts (i.e. the number of animals likely to receive a noise dose equivalent or greater than cumulative PTS thresholds) are calculated and assessed. Projects will only be consented where the level of predicted impact will not cause any long term significant effects for the populations concerned (it is important to note that injury is not the only impact that is considered as part of the consenting process but this report is focused solely on the mitigation of injury). This process is intended to ensure that neither the Favourable Conservation Status of any species nor conservation objectives of any protected sites will be affected by the level of injury as a result of cumulative exposure to noise from offshore wind farm construction. Site consents and EPS licences can therefore be granted using this logic without recourse to additional mitigation.

Table 1 also indicates that most ranges for ‘instantaneous’ PTS (where peak pressure PTS thresholds are exceeded) for the hammer energies generally employed during the soft start are well within 500 m. Impact ranges for instantaneous PTS at maximum hammer energy range from <100 m to <1 km for cetaceans and <100 m to <500 m for pinnipeds. Given these ranges, an effective deterrent range of between 500m and 1km would provide protection from the majority of instantaneous PTS predictions for all species and all cetacean cumulative PTS predictions based on the adoption of Southall *et al*. (2007) and more recent Lucke *et al*. (2009) thresholds. This gives us a ball park range against which to assess the effectiveness of various candidate ADD devices. If the assumption made in current assessments that animals start to move away as soon as piling starts holds true, at an assumed swim speed of 1.5 m.s^{-1}, animals will be 1800 m away from the piling location after a standard 20 minute soft start. Cumulative PTS impact ranges calculated across a whole piling sequence for cetaceans are generally also within 500 m. However, cumulative PTS impact ranges for seals are often much higher with predicted ranges presented in Table 1 being between 270 m and 16.5 km. It should be noted that there is significant uncertainty around these cumulative PTS impact ranges given uncertainties inherent in predicting exposure and the consequences of that exposure.

It is important to note that should accepted thresholds change (e.g. based on revised NOAA guidelines) then these predictions of impact range may change considerably in the future. For example if draft NOAA guidance is followed, which suggests a lower threshold than Southall *et al.* (2007) for high frequency cetaceans, the impact ranges for harbour porpoises in future will be much larger. The draft NOAA guidance also indicates a higher threshold for seals, and therefore smaller impact ranges.

Table 1. Predicted impact ranges from the Environmental Statements of R2, R3 and Scottish Territorial Waters offshore windfarms for lethal effects, physical and auditory injury. The thresholds used in each prediction are indicated by superscript numbers and other assumptions are detailed in the text.

Site	Hammer energy (kJ)	Pile diameter (m)	Lethal	Physical Injury	PTS (instantaneous thresholds exceeded)	PTS (cumulative, SEL thresholds exceeded)
Triton Knoll	2700	8.5	3 m[4]	53 m[5]	Not given	High frequency cetaceans: **<50 m**[6] Pinniped: **270 m**[6] **9.6 km**[7]
Race Bank	3,000	6.5	7-10 m[4]	80-130 m[5]	Not given	Stationary porpoise: **2 km** Stationary seal: **350 m** Fleeing animal @$1ms^{-1}$: porpoise **300 m**, seal **10 m** (threshold used not stated)
Hornsea Project One	600-2300	3-3.5	Not given	Not given	Low and mid frequency cetacean[6]: **<100 m** Pinniped[7]: **<100 m** for energies ≤2,300 kJ, **<200 m** for 3,000 kJ Porpoise[8]: 600 kJ=**<200 m**, 800 kJ=**<250 m**, 1,400 kJ=**<400 m**, 2,300kJ=**<600 m**	"The modelled estimates of cumulative SEL show that even using the largest hammer energy, at 500 m the received noise dose would not be at a level sufficient to cause PTS in fleeing animals"
Hornsea Project Two	<1,800-3000	Up to 10	Not given	Not given	Pinniped[7], minke whale[6], white-beaked dolphin[6]: **< 500m** Porpoise[8]: **< 500m** for blow energies ≤1,800kJ, **<1 km** for energies up to 3,000 kJ	Not given
East Anglia 1	800 – 900	2-2.5	Not given	Not given	Porpoise[6] and pinnipeds[7]: **50 m**, mid frequency cetaceans[6]: **<50 m**	High frequency cetaceans: <50 m[6] Mid frequency cetaceans: 55 m[6] Pinnipeds[7]: 1.4 km (with soft start), 3.3 km (without soft start)

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[4] threshold peak SPL 240 dB re 1 µPa

[5] threshold peak SPL 220 dB re 1 µPa

[6] Southall *et al*. (2007) injury criteria - M_{mf} weighted SEL 198 dB re 1 $\mu Pa^2 \cdot s$

[7] Southall *et al*. (2007) injury criteria - M_{mf} weighted SEL 186 dB re 1 $\mu Pa^2 \cdot s$

[8] Lucke *et al*. (2009) – 179 dB re 1 $\mu Pa^2 \cdot s$

Site	Hammer energy (kJ)	Pile diameter (m)	Lethal	Physical Injury	PTS (instantaneous thresholds exceeded)	PTS (cumulative, SEL thresholds exceeded)
East Anglia 1	1800	Not given (met mast monopile)	Not given	Not given	Porpoise: **<400 m**[6], mid frequency cetaceans:**<50 m**[6], pinniped: **<100 m**[7]	High frequency cetaceans**: <50 m**[6] Mid frequency cetaceans: **55 m**[6] Pinnipeds[7]: **1.4 km** (with soft start), **3.3km** (without soft start)
Dudgeon		3	NA	Porpoise: 10 m[5]	Porpoise traumatic auditory injury: **300 m**[9]	Not given in ES
Dudgeon		6.5	Porpoise: 10 m[4]	Porpoise: 100 m[5]	Porpoise traumatic auditory injury: **800 m**[9]	Not given in ES
Neart na Gaoithe	1635	3.5	<10 m[1]	<60 m[2]	Threshold based on composite humpback whale audiogram=780 m[6] (Given as maximum across all species but no other species ranges presented)	High, Low and mid frequency cetacean[6]: **<100 m** Pinniped[7]: **7.9 km**
Dogger Bank Teesside A & B	300 – 3,000	Up to 12	"few meters"	Not given	Low and mid frequency cetacean[6]: **<100 m** Pinniped[7]: **<100 m** for energies ≤2,300 kJ, **<200 m** for 3,000 kJ Porpoise[8]: 300 kJ**=<100 m**, 1,900 kJ=**<500 m**, 2,300 kJ=**<600m**, 3,000kJ=**<700 m**	High, low and mid frequency Cetaceans[6]: **<500 m** Pinnipeds[7]: **16.5 km**
Dogger Bank Creyke Beck A & B	300 – 3,000	Up to 10	"few meters"	Not given	Low and mid frequency cetacean[6]: **<50 m** Pinniped[7]: 300 kJ=**<50 m**, 1,900-2,300 kJ=**<100 m**, 3,000 kJ=**<150 m** Porpoise[8]: 300 kJ=**<100 m**, 1,900 kJ=**<550m**, 2,300 kJ=**<600 m**, 3,000 kJ=**<700 m**	High, low and mid frequency Cetaceans[6]: **<500 m** Pinniped[7]: **12.5 km**

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[9] noise level 130 dB_{ht}

4.1.2 Species to be considered

The Phase 1 report identified five proxy species that covered a range of hearing sensitivities for which ADD effectiveness needs to be demonstrated in order to ascertain the effectiveness of ADDs at safely deterring marine mammals from a mitigation zone around UK offshore piling locations. These species were:

- Grey and Harbour seals (interchangeable) – Pinnipeds;
- Harbour porpoise;
- Bottlenose dolphin – As a proxy for other more offshore dolphins (primarily white-beaked dolphins);
- Minke whales.

However during discussions as part of Stage 1 of Phase 2 the adoption of bottlenose dolphins (BND) as a proxy for other species more likely to be found close to OWF construction sites has been revisited and retracted. BND are an inshore species that have rarely been sighted during surveys at wind farm sites. White-beaked dolphins are the species most frequently reported at UK east coast windfarm sites. Given the higher encounter at current planned offshore wind farm projects around the UK, white-beaked dolphins were selected as the preferred target species for ADD behavioural response trials. Further details on dolphin species hearing sensitivities can be found within section 4.3.3.

4.2 **Review by device type**

The Phase 1 report identified six key ADD systems that were further reviewed and detailed. The ‘off-the-shelf’ devices selected to review were the Airmar, Lofitech, Ace Aquatec and Terecos devices. Also considered were the GenusWave system, currently in development by the University of St Andrews and the FaunaGuard system (formally known as the Sea Life Guard system) currently in development by Van Oord and SEAMARCO. These devices were selected because a) 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; b) data from published studies demonstrated a measurable aversive response to the device in one or more of the UK species of interest; and c) the devices were in development for eventual commercial application.

This section aims to update the Phase 1 report by detailing any further testing and data that has become available since the previous report. A summary of data collected for the six key ADD systems can be found in Table 2.

4.2.1 Ace-Aquatec

The Phase 1 report provided information on the sound characteristics of the Ace-Aquatec Seal Scrammer device and outlined the previous work conducted on captive harbour porpoise (Kastelein *et al*., 2010), grey and harbour seals in captivity and field trials with grey seals (Götz & Janik, 2010). Since then, reports have been published providing more information on the acoustic properties of the device and information on animal responses from captive studies on harbour porpoise and harbour seals (see details below). There is no information on the deterrence performance of this device on any dolphin species or minke whales or field trials with wild harbour porpoise and harbour seals.

This device emits a complex signal. Lepper *et al.* (2014) reported that the pulses are centred at 28 different frequencies, arranged in 64 random sequences. Northridge *et al*. (2013) reported an average peak sound pressure level (SPL) of 187 dB re 1 µPa @1m[10] (range 186 – 187 dB re 1 µPa @1m) with a complex array of short tones (around 5 ms) between 7 and 50 kHz (peak at 25 kHz), and harmonics up to 100 kHz.

Lepper *et al.* (2014) reported that 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 with pulse length shortening from 14 ms to 3.3 ms and interpulse intervals between 33.2 ms to 48.5 ms. 'They also showed different source level for different components of this complex signal; with source level, in terms of root mean-square (RMS) sound pressure, of greater than 165 dB re 1 µPa·m at 30 kHz and greater than 145 dB re 1 µPa·m at 70 kHz. The maximum reported source levels were 193 ± 1 dB re 1 µPa·m (RMS) for a ~10 kHz tonal component of the signal.'. Output power was shown to be affected by battery voltage.

Northridge *et al*. (2013) also tested the newer Ace-Aquatec Universal Scrammer (US03) device and found a consistent source level of 185 dB re 1 µPa @1m, but stated that the new model differed from the earlier Ace-Aquatec Seal Scrammer devices. The US03 device showed bursts of tonal noise of around 5 ms between 12 – 22 kHz with non-harmonic noise at higher frequencies up to 65 kHz.

Kastelein *et al*. (2015a, 2015b) observed behavioural responses of a single harbour porpoise and two harbour seals in captivity to broadcasts of recordings of the Ace-Aquatec Seal Scrammer device at different SPLs. The behavioural response experimental sessions were videoed from above and underwater and the animal's distance from the transducer, the number of surfacings and the number of jumps were compared between baseline and test conditions. Playbacks were of 30 minute duration. Results showed that porpoises swam significantly faster, showed more leaping behaviour and maintained a greater mean distance from the device at higher broadcast levels (Kastelein *et al*., 2014a). The seals' behaviour was scored as being either fully below the surface, head above the surface or as hauled out. Results showed that harbour seals hauled out more and spent more time with their heads above water as sound source levels increased (Kastelein *et al*., 2015b). They also measured the threshold for detection of various ADDs using behavioural methods. The 50% hearing threshold levels of the harbour porpoise for the Ace-Aquatec device was an SPL of 55 ± 1.5 dB re 1 µPa for the broadband 100 Hz – 63 kHz third octave bands. The mean hearing threshold level of the two harbour seals for the Ace-Aquatec device was 64 dB re 1 µPa RMS. These levels were in line with the animal's audiogram levels at these frequencies.

Ace-Aquatec recently developed a low frequency signal which is marketed as a mitigation device. It can be programmed to emit frequencies between 1 and 5 kHz however there is no data available describing the effectiveness of this signal in deterring any species.

4.2.2 Airmar dB plus II (now Mohn Aqua MAG seal deterrent)

The Phase 1 report provided information on the sound characteristics of the Airmar dB plus II device and outlined the previous work conducted on wild harbour porpoise (Olesiuk *et al*., 2002) and harbour

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[10] Wherever sound metrics are given throughout this report, care has been taken to specify the correct units. However wherever units are unspecified or unclear this is because the source material did not provide this information.

seals (Mate & Harvey, 1986; Jacobs & Terhune, 2002; Yurk & Trites, 2000; Götz & Janik, 2010). Since then, reports have been published providing more information on the acoustic properties of the device and responses from small scale field tests with harbour seals. There is no information on the deterrence performance of this device on bottlenose dolphins or minke whales or field trials with wild grey seals other than anecdotal reports from aquaculture.

The Airmar system consists of a multi-transducer array which emits brief 1.4 ms pulses at 40 ms intervals in 2.25 s long trains followed by a 2 s quiet phase, resulting in a duty cycle of approximately 50% (Lepper *et al*., 2014). Typically, four transducers produce these trains in an alternating pattern. The start of each pulse shows broadband energy levels with frequencies between 1.5 kHz and 50 kHz with peak frequency at 10.3 kHz. The manufacturers state that acoustic output will vary with device depth due to surface interactions (Lepper *et al*., 2014).

The Airmar device is now being developed by Mohn Aqua and with Airmar's permission Mohn Aqua have redesigned and improved the Control System for what is now the Mohn Aqua Group Seal Deterrent.

Gordon *et al*. (2015) report on a series of controlled exposure experiments (CEEs) to harbour seals specifically designed to assess the suitability of a range of sound sources for this aversive sound mitigation. Most trials were with a Lofitech ADD and killer whale recordings (see details in later sections). However, towards the end of this project an Airmar dB plus II device was made available by Mohn Aqua. Seven CEEs were carried out during which useful exposure data were collected from 12 animals at ranges between 339 m and 3.75 km. ADD exposures lasted 15 minutes. Responses were observed at ranges up to 1,037 m and the shortest range at which no response was observed was 653 m. These results were comparable to those from the Lofitech device, although note that more CEEs were carried out with the Lofitech device which enables more confidence in the results.

4.2.3 Lofitech Seal Scarer

The Phase 1 report presented information on the effective deterrence of harbour porpoise from the Lofitech device during a series of experiments (including some in offshore waters) specifically designed to demonstrate the effectiveness of this device for aversive sound mitigation (Brandt *et al.* 2012, 2013). There is also some evidence of responses for grey seals (Fjalling *et al*., 2006; Götz & Janik, 2010; Harris, 2011) and studies on captive harbour seals (Götz & Janik, 2010). Since then, new data have become available on the effectiveness of the device from field trials with wild harbour seals, captive harbour porpoise and harbour seals, and wild grey seals (see below).

Since the Phase 1 report, a Marine Scotland funded project, specifically designed to assess the effectiveness of aversive sound mitigation by measuring animal movements at appropriate ranges in appropriate habitats has been undertaken . This study involved field trials in Kyle Rhea in 2013 and the Moray Firth in 2014 (Gordon *et al*., 2015). The field tests consisted of 73 controlled exposure experiments (CEEs) with the Lofitech device on 10 harbour seals tagged at Kyle Rhea and 13 harbour seals tagged in the Moray Firth using a new telemetry system developed specifically for this application which combines an ability to track seals at sea in near real time with the capability of recovering a complete archived dataset for more detailed analysis using shore stations. The ADD was active for exactly 15 minutes during each CEE and a towed hydrophone system was used to verify that the signal was working. A behavioural response was observed for all 38 CEEs for which the animal was within ~1 km from the source (predicted received sound level of 132 dB re 1 µPa RMS). Responses recorded out to a maximum range of 3.122 km (predicted received level 120 dB re 1 µPa RMS). Figure 2 displays data from this study, indicating that all exposures where the seals were within 1 km of the source resulted in a behavioural response to the ADD.

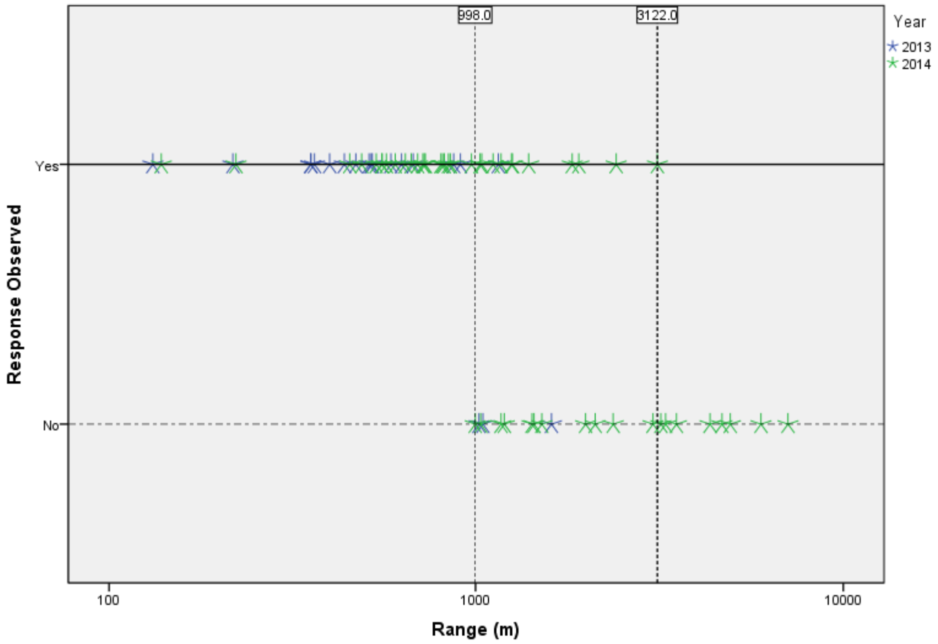

Figure 2. Instances of CEEs with harbour seals using the Lofitech device which elicited responses and CEEs which did not plotted against range for CEEs carried out in 2013 and 2014. The Range of the first closest non-responsive CEE and the most distant responsive CEEs are indicated. Reproduced from Gordon *et al*. (2015).

Often, responses varied with context, in particular with the seals' behaviour and location. Typical behavioural responses for animals thought to be foraging was a change from restricted area movement to directed movement away from the sound source. Animals engaged in "directed movement" at the start of playbacks showed avoidance manoeuvres, ranging from 180 degree reversal of path to "swerving" around the source while continuing in the original general direction. The clearest examples of this latter pattern were instances where the source was activated directly ahead of a seal showing directed movement (for example heading to or from a haul out site). These were termed "cut off" CEEs. Often in these cases animals swerved, diverting from their course but continuing towards their apparent destination, and on occasions passing within a few hundred meters of the active sound source. The minimum approach distance for this type of response was 473 m. There was a reported closer approach of 225 m but this occurred close to the start of the CEE and was not included according to the definition of "cut off" where the ADD playback was positioned at 2 km or more from the animal. Seals close to shore at the start of exposure often moved closer inshore into very shallow waters, which is a known anti-predator response (Laroche *et al.,* 2008 Overall increases in distances travelled between surfacing and in swim speeds were also noted during playbacks. Seals that were assumed to be foraging at the start of exposure (defined as moving in a non-directed manner) would often return towards their original location and appear to resume foraging soon after the exposure ended. This indicates that when used for mitigation there should be no delay between the end of the mitigation broadcast and the start of pile driving. This study clearly showed that while responses showed some variability the use of this ADD should result in low probabilities of animals remaining within exclusion zones of ~1 km. Individuals were repeatedly exposed to signals during trials and probably also heard them at lower levels and greater ranges over the course of the field projects which lasted several weeks. In spite of this there were no indications of habituation or reduced responsiveness. The same approach should be applicable to grey seals and similar work with this species is one obvious next step.

The Lofitech device has been shown to be effective in deterring both harbour and grey seals interactions with salmon bagnet fishery (Harris *et al*., 2014). The catch of salmon per unit effort was significantly higher at nets when the Lofitech device was operating. This study did not state effective ranges or if the seals were deterred from the area or simply from predating.

Kastelein *et al*., (2014a, 2014b) investigated the responses of a single harbour porpoise and two harbour seals in captivity to the Lofitech device, with the same methodology as described above for the Ace-Aquatec device. The 50% hearing threshold levels of the harbour porpoise for the Lofitech device was an SPL of 55 ± 1.7 dB re 1 µPa for the broadband 100 Hz – 63 kHz third octave bands. The number of surfacings, swimming speed and number of jumps increased with increasing mean received SPL (Kastelein *et al*., 2014a). The captive study with two harbour seals (Kastelein *et al*., 2014b) showed mean hearing threshold levels for the Lofitech device were 67 dB re 1 µPa RMS. However, the behavioural response study showed no significant response during exposure trials; though it should be noted that this study used a Subacoustech Ltd recording of the Lofitech device rather than the actual device itself which meant that the maximum source level tested during the study was much lower than the source level of the actual Lofitech device; therefore a behavioural response to higher SPLs cannot be ruled out.

The poor agreement between behavioural responses in these captive trails and field trials for both porpoises (Brandt *et al*., 2013) and harbour seals (Gordon *et al*., 2015) are telling. Both field trials showed responses at received levels far below those predicted from the captive studies. Animal responses in a captive setting are often very different from those observed in the wild and inferring free-living animal responses from captive studies is problematic. It should also be noted that the level of ambient noise should be a consideration for the choice of test sites relative to the sites at which ADDs may be used.

4.2.4 Terecos

Since the Phase 1 report, there has been little additional published information on the Terecos device. The previous review covered the Northridge *et al*., (2012) study, which was further detailed in Northridge *et al*., (2013) in which CPODs were used to investigate porpoise responses to a Terecos device deployed at a fish farm site in Loch Hourn, Scotland. CPODs were deployed at 9 stations with ranges from the ADD between 301 m and 4.5 km. Detection rates were reduced, though not significantly, at the four closest sites, which were all within 1 km and the degree of reduction was proportional to distance from the device out to a range of 1.2 km. The only station that showed a significant decline in porpoise detection positive hours was the one stationed closest to the device (301 m) which showed a decline that was only significant at the 10% level. The study concluded that the Terecos device evoked only a weak or minimal response by harbour porpoise while this suggests that (all other things being equal) it is a good device to use at fish farms; it is clearly unlikely to be useful for aversive sound mitigation and is therefore not considered further in this report.

4.2.5 GenusWave (Genuswave Ltd.)

In the Phase 1 report, the GenusWave device was described as currently in development under patent (Götz & Janik, 2008; 2012). Since then a commercial prototype has been made available on the market, further information has become available on the system and the results from field trials have been updated since Phase 1. The deterrence system consists of independent units in a waterproof housing which are synchronised via radio-link. The transducer covers a wide frequency range (500 Hz to 22 kHz) and deterrence signals can be specifically tailored to a range of target-species. The GenusWave uses the acoustic startle reflex to deter animals, using information on hearing sensitivity to specifically target certain taxa (Götz & Janik, 2015). The source levels reported for the GenusWave are 180 - 182 dB re 1 µPa (RMS) for signals centred at 1 kHz and up to 190 - 192 dB re 1µPa for signals centred at 10 kHz (Götz & Janik, 2015). A noise pulse centred at ~1 kHz is used for deterrence of seals only (This noise pulse was within 10 dB of its maximum output between 700 Hz and 1500 Hz), while a similar pulse centred at ~10 kHz (frequency range 3 - 20 kHz) would be recommended for deterrence of both seals and odontocetes.

Responses to this device from both harbour and grey seals has been demonstrated in several captive and field trials at ranges of 60 - 250 m with received levels of 135 to 145 dB re 1µPa RMS (Götz & Janik, 2011; 2015). The long term effectiveness of the device to reduce predation on fish farms has been demonstrated during trials lasting over a year at a fish farm, although exclusion ranges were not demonstrated (Janik & Götz, 2013). The systems tested to date has been designed to minimise adverse behavioural effects on harbour porpoises (Götz & Janik, 2015) at aquaculture sites where it is desirable to only deter seals. However, experiments on captive odontocetes have been conducted, startle-eliciting signals have been tested and startle thresholds have been determined (Janik & Götz, 2013). Startle responses have been documented down to received levels of 135 dB re 1 µPa RMS at frequencies above 10 kHz. This information has been used to predict deterrence ranges for wild odontocetes. Using a higher-frequency (3 - 20 kHz) and a higher source level signal designed to equally target seals and odontocetes, deterrence ranges could in theory be increased to 1 - 4 km for both taxa (Götz, pers comm).

4.2.6 FaunaGuard (Seamarco /Van Oord)

FaunaGuard has been developed by Van Oord and SEAMARCO. It is a modular system with tailor-made modules for various species including: turtles, fish, seals and porpoise. This device has been designed with the intention of "safely and temporarily deter(ing) various marine fauna species from marine construction sites with specialised underwater acoustics" (Van der Meij *et al*., 2015). The Phase 1 report described this device as the "Kastelein system"; it has also been previously badged as the Sea Life Guard. At the time of the Phase 1 report only the fish module had been tested, but since then the harbour porpoise and dolphin modules have been developed and some tests have been carried out with captive porpoise (see below). There has been no update on the development and/or testing of the dolphin and seal modules and thus far only a report in a non-peer reviewed magazine is available for the harbour porpoise module.

The most recent module added to the FaunaGuard has been designed for harbour porpoise. This model was tested between March and May 2014 on a single captive porpoise. Behavioural parameters used to assess response included the number of respirations and the distance to the transducer. The results showed that the number of respirations was significantly different between control and test sessions at mean received test levels of 104+ dB re 1 µPa. The distance between the porpoise and the transducer significantly increased during test sessions when mean received levels were 86+ dB re 1 µPa (SPL; RMS or peak not specified) (Van der Meij *et al*., 2015). How these behavioural responses relate to deterrence and exclusion is of course not clear. However, the authors report that TNO has calculated a theoretical effective distance of ~1.3 km of the FaunaGuard at the Eneco Luchterduinen wind turbine park based on modelling using the source level, behavioural threshold level, local propagation conditions and ambient noise; which they state is a sufficient distance to prevent PTS from pile driving. However, this remains untested to date.

There is anecdotal information presented in Van der Meij *et al*., (2015) that suggests that the dolphin module has been successful in deterring dolphins during drilling and blasting operations in Brazil, however, data on the deterrence effects on dolphins has not been published. According to Van der Meij *et al*., (2015), the dolphin module emits sounds based on previous harbour porpoise studies as there is a lack of information on the responses of dolphin species to sound. No information was available to assess how the dolphin module differs to the harbour porpoise module.

Van Oord plan to continue developing both the hardware and the signal library in collaboration with SEAMARCO and other collaborators and to conduct further field verification tests. No information was found on the sound characteristics for the various modules of this device and only a summary of the porpoise testing was available.

4.2.7 Predator sounds

Studies have shown high variability in target animal responses to predator sounds. For example, Gordon *et al*., (2015) tested the effects of killer whale sounds on tagged harbour seals but found they were less reliable than the Lofitech device in evoking responses. The killer whale sounds evoked responses out to a maximum range of ~4.6 km where predicted received levels were calculated to be only 109 dB re 1µPa RMS however; the shortest range that did not elicit a response was 198 m with a calculated received level of 141 dB re 1 µPa RMS. Despite this new study, as stated in the previous report, using predator sounds to deter marine mammals is not advisable as an avenue for deterrence around marine constructions. This is due to the potential for habituation from repeated playbacks, which poses a threat to the habituated animals as it could lead to decreased predator avoidance when faced with an actual predator. It has also been shown that the variation in response reflects previous exposure to predator threats. Deecke *et al*., (2002) have shown that seals selectively habituate to killer whale sounds. It would be problematic to habituate seals to sounds from natural predators as this would put them at a higher predation risk. Additionally, killer whales could potentially be exposed to artificial killer whale sounds, which may have unknown consequences. Predator sounds are therefore not considered further in this report.

4.2.8 Cetacean Targeted Pingers

Since the Phase 1 report, several emerging studies have been published on the use of cetacean targeted pingers. Given the absence of trials of the effectiveness of the above ADDs on cetaceans (with the exception of harbour porpoise), these pinger devices have been included in this report.

Kyhn *et al*., (2015) tested an Airmar pinger in field trials in Denmark. The device emitted a signal every 4 s of 300 ms at 10 kHz and had a source level of 132 dB re 1 µPa (RMS). The experimental set up used a grid of periodically activated ADDs placed 100 m apart and responses of harbour porpoise were measured using T-PODs at varying distances from the ADD source to determine if there was a significant change in daily encounter rate during periods when the ADDs were activated. Results showed that over the entire study period there were approximately 2-fold more encounters in the control area than in the impact area. The results showed a 40% decrease in the number of porpoise encounters during exposures out to 2.5 km but no effect between 2.5 and 5 km. The acoustic encounter rate dropped to approximately 20 % of the baseline levels during initial exposures, but this response changed over time with encounter rates stabilising at about 35 % of the baseline level which could suggest gradual habituation. During continuous-exposure scenarios, the detection rate was reduced by 65 % from baseline levels with no sign of habituation.

4.2.8.1 Dolphin Dissuasive Device & Dolphin Interactive Dissuasor

The Dolphin Dissuasive Device (DDD) and Dolphin Interactive Dissuasor (DID) are produced by STM Products (www.stm-products.com). The DDD was developed in conjunction with marine behaviour centres such as Marine and Ambient Research Institute from the CNR and Seamed in order to prevent cetacean entanglement in fishing nets. Nishida & McPherson (2011) described the DDD as a frequency modulated and broadband sonar interference pinger system featuring random and interactive duty cycles. De Carlo *et al*., (2012) described the DDD 03H as having variable emission frequency between 1-500 kHz and a working depth between 10 - 200 m. Kingston and Northridge (2011) identified the DDD as being theoretically loud enough to enable inter-pinger spacing of up to 2 km based on a simple propagation loss calculation based on the source level and spherical spreading, although no direct evidence is presented for this claim. Although deterrence ranges have not been measured, this study showed that nets with DDDs caught statistically significantly fewer porpoise, with an observed reduction in bycatch by 65 - 95%.

Berrow *et al*., (2008) tested the DDD (model DDD02F) on nine occasions with common dolphins off the south coast of Ireland. They describe the sounds produced as having three signal types, a starting sequence, a frequency modulated signal and click trains. The starting sequence is described as a complex of sound patterns including low frequency sounds with a duration of around 30 sec, followed by a frequency modulated signal with random frequencies ranging from 5 - 250 kHz with a ping duration of 0.5 - 9 sec. They report the peak intensity as “174 dB re 1 µPa@ 1m and a pulse of 165 – 170 µPa @ 1m”. This study reported that during the first test with the DDD, observed common dolphin behaviour changed by increasing their distance from the pinger, changing direction and ‘leaps and races’ were recorded, which the authors categorised as a mild change in behaviour. However, this did not occur in all trials, and the authors report only 44 % of the trials eliciting any change in behaviour and none of the trials elicited what the authors describe as evasive behaviour.

4.2.8.2 Save Wave®

The OrcaSaver has been developed by SaveWave BV with the intention of deterring killer whales from longline fisheries. The unit consists of transducers randomly emitting high frequency pulses with an output of 196 ± 2 dB re 1 µPa @ 1m, frequency of 6.5 kHz and pulse duration between 200 ms to 1 sec (Mustad Longline & SeaWave, 2013). The Dolphin Saver was developed to deter bottlenose dolphins and harbour porpoise from fishing nets. The Dolphin Saver has a higher source level of 155 dB re 1 µPa@1m, frequency range of 5 – 160 kHz, randomised pulse duration of 200 – 900 ms and a randomised interpulse interval of 4 – 16 s and is intended to work by jamming echolocation (Dawson *et al*., 2013). No information was found on the impacts of these devices on marine mammals other than anecdotal quotes from fishermen stating an increased catch when the device is used. Critically, there are not any data on deterrence range.

Waples *et al*., (2013) investigated the effectiveness of the SaveWave® device on deterring bottlenose dolphins from gillnets in North Carolina (which SaveWave device used was not stated). The device contains two sound emitting cores, one at 5 - 90 kHz and one at 30 - 160 kHz with a maximum signal energy of 155 dB re 1 µPa @ 1m and produces a randomised transmission interval (4 - 16 sec) and pulse length (0.2 - 0.9 sec) in an effort to reduce the chances of habituation. Their results show that dolphins were significantly less likely to encounter (approach within 500 m), interact and engage with gillnets when the device was active, although it did not completely deter all animals from interacting with the nets. The study also found that dolphins increased their echolocation rates around active devices; while this is good for avoiding entanglement no change in dolphin swimming direction or movement of the dolphins away from the area was detected and so it is unlikely to be of use for the mitigation of impacts from wind farm piling for bottlenose dolphins.

Kyhn *et al*., (2015) tested the SaveWave Black Saver device in Denmark; with the device emitting multiharmonic up-sweeps in the range 30 − 160 kHz with durations from 200 to 900 ms. The source sound pressure level was 155 dB re 1 µPa @ 1m(RMS) and sweeps were emitted every 4 to 16 s. The experimental set-up was the same as described above for the Airmar device, except with SaveWave devices spaced at 200 m apart. Porpoises have good hearing sensitivity in the range in which the SaveWave pinger operates, 50 − 150 kHz (50% detection threshold of 46 − 72 dB re 1 µPa (RMS) with best hearing at ~100 kHz with 44 dB threshold). The study did not attempt to measure deterrence ranges however they showed a 65% decrease in the number of porpoise encounters during exposures where the device was periodically activated. The acoustic encounter rate dropped to approximately 20% of the baseline levels during initial exposures, but this response changed over time with encounter rates stabilising at about 55% of the baseline level which could suggest gradual habituation. During continuous-exposure scenarios, the detection rate was reduced by 65% from baseline levels with no sign of habituation.

4.2.8.3 Porpoise Pinger and AQUAmark300®

Cruz *et al*., (2014) tested the effectiveness of two pingers on their ability to deter Risso’s dolphin depredation at a squid fishery in the Azores. The candidate ADDs were the Future Oceans Porpoise Pinger and the AQUATEC AQUAmark300®. The Future Oceans Porpoise Pinger (previously known as the FumundaMarine®) is designed and produced by Future Oceans (www.futureoceans.com) and produces a sound level of 132 ± 4 dB re 1 µPa @ 1 m at a frequency of 10 kHz with a pulse interval of 4 seconds. The AQUATEC AQUAmark300® is designed and produced by AQUATEC (www.aquatecgroup.com) and produces a sound level of 132 dB re 1 µPa @ 1 m at a frequency of 10 ± 2 kHz. Results from 154 trials showed no significant change in catch per unit effort or the occurrence and severity of depredation across pinger treatments for both models, nor was there any evidence for a movement of animals away from the area. Therefore, this device is unlikely to be effective for the mitigation of impacts from wind farm piling (for Risso’s dolphins at least).

Soto *et al*., (2013) tested the Future Oceans Porpoise Pinger emitting a 300 ms pulse every 4 seconds at a fundamental frequency of 10 kHz and minimum source level of 132 dB re 1 µPa @ 1 m. At the test site in the Rainbow Channel (Queensland, Australia) measurements suggested that the range of audibility of the pinger was approximately 100 m for humpback (*Sousa chinensis*) and snubfin dolphins

(*Orcaella heinsohni*). Humpback dolphins responded to the pinger by significantly decreasing click rates, surfacing rates and percentage of time spent foraging. Snubfin dolphins decreased the percentage of time spent vocalising in response to the pingers. The authors concluded that the pinger evoked only subtle responses in the dolphins, and did not report any movement of the dolphins away from the area when the device was active. Therefore this device is unlikely to be effective for the mitigation of impacts from wind farm piling (for humpback and snubfin dolphins at least). Both humpback and snubfin dolphins are categorised as mid-frequency cetaceans alongside bottlenose dolphins and other UK dolphin species, where their auditory bandwidth is between 150 Hz to 160 kHz (Southall *et al*., 2007). An audiogram for a humpback dolphin (Li *et al*., 2012) overlaps with most bottlenose dolphin audiograms, which could suggest that the study by Soto *et al*., (2013) could represent a proxy for a bottlenose dolphin reaction to the pinger; however, empirical evidence for this would be preferred.

Dawson *et al*., (2013) describe the AQUATEC AQUAmark848® as having a frequency range between 5 - 30 kHz, a source level of 165 dB re 1 µPa @ 1m and a varying ping duration and interval. They describe this device as experimental, intended for the deterrence of whale species, however no data could be found on its deterrence capabilities.

4.2.8.4 Whale Pinger®

Harcourt *et al*.,(2014) tested the effectiveness of the Fumunda (now Future Oceans) F3 3kHz Whale Pinger® at deterring humpback whales from areas of fishing activity in order to reduce the potential for entanglement. Erbe *et al*., (2011) report the F3 Whale Pingers emit an average fundamental frequency of 2.7 kHz with multiple harmonics, tones of 400 ms in duration with an interval of 6 sec and mean source levels of "98 ± 7 to 118 ± 3 dB re 1 μPa^2/ Hz". The manufacturer claims an output level of 135 dB re 1 µPa @1m, but the measurements taken by Erbe *et al*., (2011) were less, reporting broadband levels for three F3 devices over all harmonics of 124 ± 3, 125 ± 5 and 128 ± 3 dB re 1 µPa@ 1 m. The authors reported no effect of the pinger on the humpback whales; they neither changed direction, changed speed nor altered their surfacing behaviour in response to the pinger. Humpback and minke whales are both categorised as low frequency cetaceans with an estimated auditory bandwidth of 7 Hz to 22 kHz (Southall *et al*., 2007). Humpback whale audiograms and estimated hearing abilities are widely used in offshore wind farm noise impact assessments as a proxy for minke whales. For example, the Subacoustech noise modelling for the Neart na Gaoithe offshore wind farm in the Firth of Forth used an approximated humpback whale audiogram based on Erbe (2002) as a surrogate for minke whales (Nedwell & Mason, 2012). Based on the results of the Harcourt *et al*., (2014) study, this device may not be of any effective use for wind farm piling mitigation for humpback whales or minke whales.

4.2.8.5 Banana Pinger

Crosby *et al*., (2013) investigated the responses of porpoise and dolphins to the Fishtek Marine Banana Pinger off Cornwall. Their report describes the pinger as producing pings of 0.3 sec at random intervals between 4 and 12 sec. Each ping contains a random set of frequencies ranging between 50 - 120 kHz above the level of seal hearing, with each frequency set lasting 20+ ms. Their study reported that the number of porpoise and dolphin click detections were reduced when the pinger was active. At the CPOD adjacent to the pinger, the number of porpoise clicks per minute was 47 when the pinger was off, but only 12.6 when the pinger was on. At the CPOD 150 m from the pinger, the number of porpoise clicks per minutes was 72.6 when the pinger was off and 45.2 when the pinger was on; and the number of dolphin clicks per minutes was 6.6 when the pinger was off and 4.9 when the pinger was on. The effect of the pinger varied over time, with the number of clicks detected when the pinger was active being between 15 - ~53% of the clicks detected when the pinger was off. The furthest CPOD was 150 m from the pinger and so there is no data presented in this study (nor could any others be found) on the effects of the pinger at any distances greater than this.

4.2.8.6 Marexi Pinger

The Marexi pinger is manufactured by Marexi Marine Technology. The V2.2 pinger is described by the manufactures as having a frequency of 10 kHz ±2kHz tonal, a source level of 132 ± 4 dB re 1µPa@1m, a pulse duration of 300 ± 15 ms and a pulse interval of 4 ± 0.2 sec (www.marexi.com). Morizur *et al*., (2009) (as referenced in Dawson *et al*., 2013) investigated the effects of this pinger on harbour porpoise but showed no significant reduction in bycatch. No further published data could be found on the effectiveness of this device.

4.2.8.7 Cetasaver

Dawson *et al*., (2013) describe the Ifremer / Ixtrawl Cetasaver V03 as having a frequency modulated range between 30-150 kHz, a source level of 190 dB, ping duration of 1 sec and a ping interval between 2 and 5.5 sec. They describe this device as experimental, intended for the deterrence at trawl nets. The only study that could be found to report on the deterrence of this device was Berrow *et al*., (2008) which gives a description of the sounds produced as having a peak intensity of 190 dB re 1µPa@1m and a pulse of 178 µPa@1m. They describe a second signal produced by the device as a click train at 90 kHz with a duration of 0.1 sec. Their study states that no major changes in dolphin behaviour were observed during the five trails.

Given the results discussed above it is unlikely that any of the ‘fisheries’ pingers described in this section will prove useful for the deterrence in the context of pile driving noise and therefore are not considered further in this report.

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4.3 Summary by species

Table 2. Summary of data collected for the six key ADD systems identified in Phase 1 and updated in this report.

Black text refers to information that was present in the Phase 1 report, blue text is new information presented in this current report. The term ‘effective’, as stated in this table, denotes that animals were deterred to a certain distance by the device.

Device	Harbour Porpoise	Harbour Seal	Grey Seal	Dolphins	Minke whale
Airmar dB plus II **Efficacy: deterrence range and effective RL**	Effective to 3.5 km (Olesiuk *et al.*, 2002) Effective to 2.5 km (Kyhn *et al.*, 2015)	No observable response (Jacobs & Terhune, 2002) Deterrence to 50 m (Yurk & Trites, 2000) Responses out to 1037m (Gordon *et al.*, 2015)	Anecdotally initially effective at reducing predation Avoidance responses shown down to RL of ~144 dB re 1µPa RMS	No information	Limited evidence in grey literature
Airmar dB plus II **Habituation**	No evidence for habituation but only over 3 weeks (Olesiuk 2002) Results suggest gradual habituation when periodically activated but not when continually active (Kyhn *et al.*, 2015)	Mate & Harvey (1986) found seals swimming with head above the water -possible behavioural adaptation The lack of response found by Jacobs & 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 1µPa RMS (Götz & Janik, 2010)	Authors describe, usually anecdotally, the habituation at aquaculture installations (Schotte and Pemberton 2002, Mate and Harvey 1986, Iwama *et al.*,1997) Aquaculture managers have reported reduced effectiveness over time in surveys (Northridge *et al.*, 2010) Rapid habituation (after a few exposures) shown at received levels of 146 dB re 1µPa RMS (Götz & Janik, 2010)	No information	No information

Lofitech **Efficacy and Range**	Effective to 7.5 km (Brandt *et al.* 2012; 2013) Captive behavioural responses such as increased surfacing, swimming speed and jumps (Kastelein *et al.*, 2014a)	All seals showed a behavioural change out to a range of ~1km. The greatest range at which a response was recorded was 3,122 m (Gordon *et al.*, 2015) Harris *et al.* (2014) reported reduced predation at a salmon bagnet fishery Captive study showed no significant response during exposure – though a recording of the Lofitech device was used rather than the actual device (Kastelein *et al.*, 2014b) Responses demonstrated in captive harbour seals although range not determined (Götz & Janik, 2010)	Harris *et al.* (2014) reported reduced predation at a salmon bagnet fishery Fjalling *et al.* (2006) reported reduced predation at fish traps Götz & Janik (2011) reported deterrence up to 60m using synthesised signal (Same SPL would be found at 140 m normally) Harris (2011) reported reduced number of seals upriver of device Some animals showed avoidance responses down to RL of ~140 dB re 1µPa RMS (Götz & Janik, 2010)	No information	No information
Lofitech **Habituation**	No but trials only over 3 months (Brandt *et al.*, 2012; 2013)	Rapid habituation shown at received levels of 146 dB re 1µPa (Götz & Janik, 2010) No reduction in responsiveness observed in the course of field trains extending over several weeks involving multiple exposures to individuals (Gordon *et al.*, 2015)	No – but trial short (NESFC, 2008) Yes – although effective throughout and 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 Rapid habituation at received levels of 146 dB re 1µPa RMS (Götz & Janik, 2010)	No information	No information

Ace Aquatech **Efficacy and Range**	Kastelein *et al*. (2010) likely to deter porpoises at ranges between 0.2 and 1.2 km Captive behavioural responses such as increased surfacing, swimming speed and jumps (Kastelein *et al*., 2014a)	Responses demonstrated in captive harbour seals although range not determined (Götz & Janik, 2010) Captive seals responded by hauling out and lifting head out of water (Kastelein *et al*., 2014b).	~50% of animals showed avoidance responses shown down to RL of ~138-140 dB re 1µPa RMS (low sample size); several animals remained within 40 m of device (RL>144 dB re 1µPa RMS)	No information	No information
Ace Aquatech **Habituation**	No information	Rapid habituation at received levels of 146 dB re 1µPa (Götz & Janik, 2010)	Rapid habituation at received levels of 146 dB re 1µPa (Götz & Janik, 2010)	No information	No information
Terecos **Efficacy and Range**	Northridge *et al*. (2011) suggested possible reduction in acoustic behaviour up to around 1 km. Northridge *et al.* (2013) showed no significant effect on porpoise distribution	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
Terecos **Habituation**	No information	Rapid habituation shown at received levels of 146 dB re 1µPa (Götz & Janik, 2010)	Rapid habituation shown at received levels of 146 dB re 1µPa (Götz & Janik, 2010)	No information	No information
Genuswave **Efficacy and Range**	At frequency tested, shown to not affect porpoises (Götz & Janik, 2015), same theory could be applied to cause porpoise specific startle response but as yet untested. No field data available but if porpoise respond similar to bottlenose dolphins, assuming responses down to 135 dB re 1µPa, deterrence ranges could in	Yes – fish farm trials up to 250 m from loudspeaker (Götz & Janik, 2015); received levels of 135 dB re 1µPa Pilot trial at sea indicates responses occur up to at least 300 m (Götz, pers com) Assuming responses down to 135 dB re 1µPa deterrence ranges can be extended up to >4 km using the 190 dB re 1µPa high-	Visual observations at haul out (60-70 m); avoidance responses down to RL of 145 dB re 1µPa (Götz, 2008) - Likely to be larger at sea Assuming responses down to 145 dB µPa ranges can be extended up to at least 1 km using the 190 dB re 1µPa, high-frequency signal (assuming TL=15*log (distance)).	No field data available but startle responses shown at RL down to ~ 135 dB re 1 µPa (Janik & Götz, 2013). Assuming responses down to 135 dB re 1 µPa, deterrence ranges can be extended up to >4 km using the 190 dB re 1 µPa, high-frequency signal	Götz & Janik (2015) measured closest approach of 1,109 m but does not mean animal responded at that distance. Sample size too small to analyse

	theory be extended up to >4 km using the 190 dB re 1µPa, high-frequency signal (assuming TL=15*log (distance)).	frequency signal (assuming TL=15*log (distance))			
Genuswave **Habituation**	No porpoise data but based on grey seal study sensitisation should lead to increased responsiveness	Based on grey seal study, sensitisation should lead to increased responsiveness (Götz & Janik 2011)	Sensitisation leads to increased responsiveness (Götz & Janik 2011)	No dolphin data but based on grey seal study sensitisation should lead to increased responsiveness (Götz & Janik 2011)	No porpoise data but based on grey seal study sensitisation should lead to increased responsiveness (Götz & Janik 2011)
FaunaGuard **Efficacy and Range**	Captive porpoise showed increased distance from the device during test sessions when mean RL were 86+ dB re 1µPa (Van der Meij *et al.*, 2015) TNO has calculated an effective distance of ~1.3 km (Van der Meij *et al.*, 2015)	No information	No information	Anecdotal information from applications in Brazil (Van der Meij *et al.*, 2015)	No information
FaunaGuard **Habituation**	No information	No information	No information	No information	No information

The current evidence base suggests that both harbour porpoises and harbour seals are excluded by Lofitech Seal Scarer (Brandt *et al*., 2013a; Brandt *et al*., 2013b; Harris *et al*., 2014; Gordon *et al*., in review) at ranges which would be useful for the mitigation of physical and auditory injury from pile driving from the projects reviewed in Table 2.

The following sections provide a summary of the most recent evidence base for ADD deterrence for each species.

4.3.1 Harbour porpoise

There is increasing evidence to support the adoption of some ADDs to reduce the risk of auditory injury to harbour porpoise during piling by deterring the animals from the zone of auditory injury, with a large degree of deterrence evident up to 7.5 km (Brandt *et al.,* 2012; 2013). Although porpoise activity is not significantly reduced at 1.5 and 5 km, porpoise activity prior to activation of the device was already very low at these distances. There was no evidence of reduced responsiveness during the Brandt *et al.,* (2012; 2013) trials which extended over a period of approximately 4 - 6 months. It should also be noted that Brandt *et al.,*'s offshore trial in habitat similar to that of a wind farm site, involved relatively long exposures with the device being active for 4 hours during exposures. Uncertainties had therefore been raised in relation to the timing of the ADD signals and the immediacy of responses at the Project workshop 17 June 15 (minutes of meeting documented in 'ORJIP-ADD study – P2S1- Acceptance workshop – 17June15 MoM FINAL.pdf). However, in the case of the shore based observations, in six out of seven observations, there was an immediate response to the device as soon as it was activated and porpoises immediately disappeared, probably diving and resurfacing out of visual range (Brandt *et al*., (2012)).

4.3.1.1 Harbour porpoise data from offshore windfarm construction sites

There is a body of evidence beginning to emerge from monitoring at a number of European offshore wind farm sites on the effectiveness of ADDs in deterring harbour porpoises around piling locations prior to piling commencing. Höschle *et al.,* (2015) report on ADD use at four offshore wind farms in the German North Sea from 2013 until 2015. All wind farms are situated in an area where harbour porpoises are abundant and occur all year at any location in the area. During all installations of the wind farms the presence of harbour porpoises was documented during by CPODs to evaluate the deterrence measures. CPODs record harbour porpoise echolocation activity and were deployed at 750 m and 1500 m from the construction site. The ADDs that were in use were the Lofitech Universal Scarer and the Airmar dB Plus II Sealscarer. ADDs were activated 30 minutes before the commencement of piling (after 10 minutes of 'pinger' activation. The comparison of porpoise detections between reference periods prior to and during ADD activation demonstrated that the detections were significantly less during ADD activation than during reference periods. The authors concluded that as a result of the combined disturbance from vessel noise and ADDs the overall reduction in porpoise presence in the vicinity of a construction site will strongly exceed 75%. In addition the available data provided evidence that the response of harbour porpoise to the ADD is apparently immediate and any porpoise detections made during sealscarer use could be understood as individual tolerances rather than a delayed response. The data therefore indicates that there might be scope to reduce the ADD time below the 30 minutes applied here (Höschle *et al.,* 2015).

Furthermore, data collected as part of the DEPONS project during construction of the Dan Tysk offshore wind farm also demonstrates an immediate response of porpoises to ADD activation out to several kilometres prior to piling (Jakob Tougaard, pers comm). In addition, although the data were not specifically analysed to address this, there was no obvious evidence of any reduced effectiveness over the whole construction period.

4.3.2 Grey and harbour seals

The recent study by Gordon *et al.,* (2015) provided data necessary to assess the effectiveness of ADDs for aversive sound mitigation for harbour seals at offshore wind farms. Results are encouraging; particularly for the Lofitech ADD demonstrating deterrent responses out to around 1 km, therefore providing confidence that an ADD based mitigation approach would be more effective than current practice for harbour seals. Whilst we acknowledge that the Gordon *et al.,* (2015) report does state that one seal did transit past the ADD at a distance of 225m – a closer inspection of the data after publication of the Gordon *et al.,* (2015) report revealed that this instance did not meet the criteria for what the authors had defined as a 'tolerance range'. Even if this is included, only two out of 73 (2.7%) CEEs resulted in seals approaching within 500m. Although directly equivalent empirical data are lacking to make a quantitative comparison it is unlikely that given the detection probability reported from visual surveys, the effectiveness of visual monitoring for mitigation is unlikely to be as high as 97.3%. Although there remains the possibility that harbour seals may approach within a 500 m radius, the likely level of ADD mitigation effectiveness indicated by this study is higher than the likely level of effectiveness achieved by visual monitoring (noting that PAM is not effective for seals). Testing the responses of seals to arrays of ADDs to reduce the likelihood of approach within 500 m was discussed but ruled out for the following reasons: 1) They were not necessary as available data suggested that the tested ADD was at least as effective as current MMO-based mitigation, 2) there was concern that animals could get 'trapped' between multiple ADDs and thereby be exposed to higher risks, and 3) feedback from the offshore wind farm developers was that deploying multiple ADDs around piling operations would not be achievable in light of operational and H&S concerns.

Most other field ADD studies for both seal species have focused on measuring reduction in predatory interactions at fish farms or fishing nets (i.e. Yurk & Trites, 2000; Götz, 2008). Responses of ADDs have also been made in captivity but the ability to make reliable quantitative predictions of field behaviour from these is extremely limited. Although there is evidence for basic deterrence for grey seals from other studies (Harris, 2011; Götz & Janik, 2010), similar studies showing the extent of animal movements and deterrence ranges at offshore sites have not been conducted with grey seals though it is likely that a similar approach could be used and of course the methodology could be used to test other types of ADD if necessary. In consultation between the ORJIP Discretionary Project Steering Group and SNCBs on this issue, agreement has been reached that for the purposes of this study, harbour seals could be considered as a proxy for grey seals and that evidence gathered for each species would be assumed to apply for the other.

4.3.3 Bottlenose dolphins

For bottlenose dolphins, and any other dolphin species, there is still very little data on the response to ADDs so even a very basic level of deterrence still needs to be demonstrated. Various studies have been conducted to investigate the effects of cetacean targeted pingers but have demonstrated no movement of animals away from the device area and so would be ineffective at deterring dolphins from piling activities. The Gordon *et al*., (2015) Lofitech study specifically did not activate the device if bottlenose dolphins were sighted in the area and so direct measures of the responses to dolphins to all of the six candidate ADDs still remains untested.

Captive studies have shown startle responses in bottlenose dolphins down to a RL of ~135 dB re 1 µPa RMS (Janik & Götz, 2013). Assuming responses down to this RL, deterrence ranges can be estimated to greater than 4 km using the 190 dB 1µPa high-frequency signal of the GenusWave device, however, this remains untested.

Bottlenose dolphins were initially proposed as a representative for all UK dolphin species. This decision was reassessed as in the UK most well-studied bottlenose dolphin populations have a predominantly inshore distribution and this means that it will be very difficult to carry out experiments in areas which are topographically similar to typical wind farm sites. Bottlenose dolphins have rarely been sighted on surveys at offshore wind farm sites and white-beaked and white-sided dolphins have been more commonly sighted during surveys. In addition, there may be differences in hearing sensitivities between bottlenose dolphins and other species of UK dolphin. For example, as Berrow *et al.*, (2008) discuss, short-beaked common dolphin echolocation clicks are between 23 - 67 kHz (Ansmann *et al.*, 2007) while bottlenose dolphin clicks are between 110 - 130 kHz (Richardson, 1995). If their hearing sensitivities were to reflect the frequencies of their echolocation clicks then there is no overlap between the two species. There are few published data available for the hearing sensitivities of dolphin species with the exception of bottlenose dolphins; an examination of the literature could find only one audiogram for a common dolphin (Popov & Klishin, 1998) and one audiogram for a white-beaked dolphin (Nachtigal *et al.*, 2008); both of which suggest that these two species may be more sensitive than bottlenose dolphins. However these audiograms are based on trials with only one common or white-beaked dolphin and on captive bottlenose dolphins. Given this uncertainty around dolphin species hearing sensitivity, caution should be taken in extrapolating findings from one dolphin species to another.

4.3.4 Minke whales

There is still very little information on the responses of minke whales to ADDs. Götz and Janik (2015) reported minke whales at a closest approach of 1,109 m during sound exposure with the GenusWave device however, this is only limited data and the RL at that distance was low (125 dB re 1µPa). It cannot be ruled out that minke whales would be affected at closer distances but this remains untested.

4.3.5 General habituation

The question of the potential for habituation or tolerance has been raised as a concern because there are many cases in which the effectiveness of aversive sounds for management, in keeping terrestrial animals and birds away from crops for example, decreases substantially once devices come into widespread use and animals are repeatedly exposed to signals without any negative reinforcement. In this case however, the ADD signals would be active for only limited periods and would immediately be followed by aversive pile driving noise, which will provide additional reinforcement to any deterrence; it seems unlikely that habituation will be a problem in this context. Gordon *et al.*, (2015) found no evidence of reduced responsiveness in animals exposed multiple times over several weeks and Brandt *et al.*, (2012 & 2013) found no evidence of reduced response over trials carried out over several months. However, in areas particularly important for foraging, a positive motivation to remain in that area cannot be ruled out, although Gordon *et al.,* (2015) did demonstrate that seals thought to be foraging were deterred, they resumed foraging once the exposure was ended. Responses to signals which elicit physiological responses through the startle reflex or which are reinforced (e.g. by subsequent piling noise) are likely to be more consistent.

4.4 **Conclusions**

This review concludes that there is evidence that currently available ADD devices will actively displace the majority of harbour seals and harbour porpoises beyond a 500 m exclusion zone prior to the onset of piling. Adopted as mitigation, this will be equal to, or be better than, the current best practice mitigation methodology of visual observers and passive acoustic monitoring in ensuring that animals are not present in a 500 m exclusion zone at the onset of piling. The inclusion of evidence from OWF construction sites in German waters provides evidence of some ADD models' (Lofitech and Airmar) effectiveness in deterring harbour porpoise from active piling sites.

The Lofitech device has been used in the most field studies and has shown effective deterrence ranges out to 7.5 km for harbour porpoise and 1 km for harbour seals (Brandt *et al.,* 2012, 2013; Harris *et al.,* 2014; Gordon *et al.,* 2015).

There are uncertainties over the effectiveness of ADDs for the other priority marine mammal species and testing with these other species should be a priority – appropriate methodologies and field sites will be considered in detail in Section 8.

5 Methodology review

5.1 Introduction

Studies that measured a change in depredation at fisheries/aquaculture provide little indication of the extent to which animals were deterred from an area and thus are not considered further in this review.

Those methods that measure deterrence can be further divided into those that measure animal movement in response to the ADD and those that measure the deterrence by observing a change in abundance or index of abundance. Direct measures of responsive movement include methodologies such as visual focal follows and telemetry (tagging) studies.

Methods to measure changes in absolute or relative density can include visual sightings and surveys of the change in acoustic detections at a site before and during active ADD periods. Comparisons are usually made between baseline controls and periods with active ADDs. The methods applied here are often species dependent, for example passive acoustic monitoring is only appropriate for vocalising cetaceans.

Table 3. Summary of the methods used in published studies on ADD effectiveness on marine mammals.

Telemetry tracking of movement responses	Visual tracking of movement responses	Change in visual detections around stimuli	Change in acoustic detections around stimuli	Depredation.	Behavioural responses in captive studies
Gordon *et al.*, 2015	Olesiuk *et al.*, 2006	Olesiuk *et al.*, 2006	Kyhn *et al.*, 2015	Harris *et al.*, 2014	Kastelein *et al.*, 2006; 2010; 2014a; 2014b
	Soto *et al.*, 2013	Yurk & Trites, 2000	Soto *et al.*, 2013	Fjalling *et al.*, 2006	Van der Meij *et al.*, 2015
	Tixer *et al.*, 2014	Götz & Janik, 2010	Northridge *et al.*, 2010; 2013	Cruz *et al.*, 2014	Götz & Janik, 2010
	Brandt *et al.*, 2012; 2013		Brandt *et al.*, 2012; 2013	Nishida & McPherson, 2011	
	Waples *et al.*, 2013				
	De Carol *et al.*, 2012				
	Jacobs & Terhune, 2002				
	Harcourt *et al.*, 2014				
	Götz & Janik, 2015				
	Berrow *et al.*, 2009				

5.2 Direct measures of response

5.2.1 Telemetry tracking

To date, telemetry tracking to measure marine mammal responses to ADDs has only been used in one study by Gordon *et al*. (2015). In this study, harbour seals were tagged with specifically developed tags that provided near real-time at sea positioning, data storage and transmission abilities. Real time maps of up to date information on the tagged seal locations helped the field team to follow individual seals and to manoeuvre the vessel into appropriate locations before initiating controlled exposure experiments. To conduct an exposure experiment, the vessel was positioned near the animal as quietly as possible to minimise the risk of disturbance. The sound source was not activated if there was any indication in the animal's track that it was aware of and responding to the vessel or if alternative potential sources of disturbance, such as shipping, were detected in the area. The data were analysed ashore after the fieldwork by viewing animations of the vessel and tag tracks, measuring ranges between the tagged seal and the device and assessing the animals' behaviour based upon their movement patterns.

Telemetry studies are effective for seals as they are relatively simple to catch and tag at haul out sites; however, the use of telemetry tags for cetaceans is somewhat more limited. Some studies investigating porpoise movement and dive behaviour (unrelated to ADDs) have successfully attached tags to harbour porpoise after they had become captured in fish traps (e.g. Westgate *et al*., 1995; Read *et al*., 1997; Edren *et al*., 2010; Akamatsu *et al*., 2010; Sveegaard, *et al*., 2011; Linnenschmidt *et al*., 2013 etc). Minke whales have been successfully tagged by pole-deployment, crossbow launched and air rocket launched methods (ie: Heide-Jørgensen *et al*., 2001; Víkingsson & Heide-Jørgensen., 2005, Víkingsson & Heide-Jørgensen, 2015). Both long term implantable tags and short term suction cup attachments have been used. The latter are probably preferred for these studies for ethical reasons and also because they should allow a larger sample of individuals to be sampled. Attaching tags to dolphins and smaller cetaceans remains difficult as they are a) not easily caught or b) not easy to get near for other attachments methods. Some studies have successfully attached tags to dolphins, (e.g. Mate *et al*., 1995; Chivers & Scott, 2002; Balmer *et al*., 2010); however, the impacts of the tags themselves need to be considered as a recent study has shown that DTAGs have a metabolic impact on dolphins which the dolphins reduce by modifying their behaviour (van der Hoop *et al*., 2014).

While there is a lack of telemetry studies for cetaceans to observe responses to ADDs, there have been many behavioural response studies (BRS) conducted on marine mammals during controlled exposure experiments for a range of other sound types, including sonar. For example, the SOCAL-BRS (Southern California Behavioral Response Study, http://sea-inc.net/socal-brs/) 2010 - 2015 study aims to understand the behavioural response of marine mammals to sound, including military sonar systems. For example, Goldbogen *et al*. (2014) present data from two fin whales tagged with DTAGs in 2012 and 2013 where the tagged animals were exposed to controlled sounds and accelerometer data were collected to determine response movements alongside concurrent recording of received sound levels. Another BRS is the Sea mammal, Sonar, Safety (3S) project which investigates behavioural reactions of cetaceans to naval sonar signals (Miller *et al*., 2011). The first 3S study included killer whales, sperm whales and long-finned pilot whales that were tagged with DTAGs; the second 3S study in 2011 - 2014 ($3S^2$) included minke whales. The

2011 3S^2 field survey reported four minke whales tagged with DTAGs and one with a CTAG during dose-escalation experiments (Kvadsheim *et al*., 2011). They do report that the minke whale "quite clearly responded to the tagging" which highlights that a behavioural response to the tagging itself needs to be considered. They also state that they had difficulties attaching the DTAGs as a) it was very difficult to get close enough to the whales to tag, b) the tags fell off when the animal dived and c) suction cups did not attach well. Therefore they switched to using a CTAG which has an anchor attachment instead of suction cup (Kvadsheim *et al*., 2011) but only managed to tag one animal. The BRAHSS study (Behavioural Response of Australian Humpback whales to Seismic Surveys) is another example of a BRS involving baleen whales tagged with DTAGs to observe any behavioural changes when exposed to a seismic air gun array (http://www.brahss.org.au/; Dunlop *et al*., 2013). These studies all demonstrate that it is challenging, although possible to conduct telemetry studies on baleen whales during sound exposure experiments and so could be a suitable methodology for testing the responses of baleen whales, such as minke whales, to ADD sound exposure experiments.

There are however, some issues that need to be highlighted for cetacean telemetry studies. Attaching tags to minke whales has been described as a difficult task. Joyce *et al*. (1990) state that it is difficult to tag minke whales as they are solitary, difficult to locate and follow, they swim quickly, have short surfacings and show avoidance behaviour. As such, this is likely to result in small sample sizes. Víkingsson and Heide-Jørgensen (2015) have presented data on 17 tagged minke whales in Iceland between 2001 and 2011, of which only eight tags successfully provided position data. They state that tagging minke whales is more difficult than other baleen whales as it is difficult to get close enough to the whale to deploy the tag and that it is difficult to position the tag on the whale correctly. They conclude that "considerable investment in the development of better methods will be needed before large-scale tagging and long-term tracking of minke whales becomes feasible". Kvadsheim *et al*. (2011), as part of the 3S^2, studies state that the failed tagging attempts were "due to the nature of Minke whale skin" which prompted them to develop a scraper tag method for attachment, which removes the 'film' present on the whale skin thought to be responsible for preventing attachment, though this has not yet been tested on live minke whales.

It is clear that tagging cetaceans is difficult and such studies often end up with rather low sample sizes. This leads to difficulties in analysing the resulting data to determine whether responses took place. A recent project at the University of St Andrews has been developing methods for the analysis of behavioural responses studies, particularly with challenging datasets of low sample size and high individual variability (MOCHA, Multi-study Ocean Acoustics Human Effects Analysis, http://www.creem.st-and.ac.uk/mocha/). It is recommended that the analysis techniques developed by MOCHA are considered for ADD field trials.

5.2.2 Visual and acoustic tracking

Responses to ADDs have been measured by conducting visual tracking surveys of focal animals/groups either from land (e.g. Harris *et al*., 2014; Harcourt *et al*., 2014; Götz & Janik, 2015) or from vessels (e.g. Soto *et al*., 2013; Tixier *et al*., 2014). For example, animals can be tracked from land with a theodolite which enables the surveyor to obtain animal position as well as surface behavioural information (Harcourt *et al*., 2014). The data can be assessed to determine if animals changed track heading/course and surface behaviour in response to active ADDs. Focal follows from vessels also allow for position and behavioural information to be recorded, and have the added advantage of being able to deploy a hydrophone to record any changes in vocalisation rates in response to the ADD and also to provide real time information on ADD received levels. Any visual observations at sea require very good weather conditions, especially if the animals of interest are small and difficult to spot (porpoises, seals and dolphins for example). It is also possible to track movements of some animals acoustically by localising their vocalisations using hydrophone arrays. However, if animals cease vocalising when disturbed, tracking while the device is on will be impossible. Brandt *et al.* (2013) report on observations of porpoises made from the shore. In many cases the response on the animals was so dramatic that they simply "disappeared" so that additional tracking data could not be collected. There is also a strong potential for confounding data if the presence of the vessel itself, engine noise or an active echo sounder disturbs the animals and elicits a response, although measures can be taken to avoid such effects.

5.2.3 Captive studies

Captive studies provide a controlled environment in which to study hearing thresholds and observe an animal's response to ADDs. Captive studies vary in their methodology and in how the animals are trained, but one key factor that varies between studies is whether or not food motivation is used in the trials. For example, Götz and Janik (2010) employed a methodology that involved food presentation; their results found different responses from the captive seals in comparison to their wild seal studies, which they attributed to the animal being motivated to approach the feeder, with food acting as a reinforcing stimulus overriding any deterrence. In contrast, studies on harbour seals by Kastelein *et al*. (2006a; 2006b; 2010; 2014a; 2014b) did not present food during the sound playbacks and observed no evidence for habituation over several playback sessions, even when using lower received levels than used by Götz and Janik (2010). The difference in results could be used as an analogy for how seals would react in the wild in areas that are or aren't foraging sites, where it could be predicted that ADDs used at foraging sites would be less successful at deterring the seals and would experience higher levels of habituation in comparison to non-foraging sites.

However, as stated in the Phase 1 report, 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 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.

5.2.4 Change in abundance measured by visual survey

Measures of the temporal changes in relative abundance at a site before, during and after ADD use can provide an indirect measure of marine mammal response. This method assumes that any change in numbers of animals in the area is as a response to the ADD and not due to any other potential sources such as environmental variability, vessel activity etc., and therefore it may be more difficult to tease out a response to the ADD exposure independent of these other factors. The study conducted by Yurk and Trites (2000) counted the number of seals at two stations, one at the ADD installation site and one further away.

They noted that when the ADD was active, the number of seals present at the nearest site significantly reduced while the number of seals at the further site significantly increased. Brandt *et al.* (2012) planned to conduct aerial surveys to record porpoise density in the area before and after the ADD was deployed, however, due to very low sighting and re-sighting rates the authors concluded that they could not achieve meaningful density estimates and therefore would have had very limited power to test for a reduction in porpoise numbers.

5.2.5 Change in abundance measured by Passive Acoustic Monitoring (PAM)

A commonly used method of measuring abundance for some vocal species is to use PAM detections of their vocalisations. Change in detection rates at varying distances from the ADD once it is activated provide an indication of reduced densities within the areas covered by PAM devices. An advantage of surveys using static detection devices like this is that survey effort can be prolonged and very cost effective. However, this approach is only suitable for reliably vocalising marine mammals and so is not suitable for minke whale or seals for example. This method is based on the assumption that a reduction in vocalisations means a reduction in the number of animals present and therefore effective deterrence. It assumes that a reduction in vocalisations indicates that the animals have moved out of the area, however, it is possible that animals remain in the area but reduce or cease vocalisations in response to the ADD.

While these methods (visual and acoustic survey) provide the required information there are practical difficulties in collecting these data. Marine mammal densities are often low and they are difficult animals to detect. Thus, during any short unit of survey effort (similar to the duration over which ADDs might be used for mitigation for example) the number of detections will be low. To obtain an appropriate sample during ‘traditional’ surveys to have the required power to detect changes in marine mammal density effort can be extended (large survey areas, over long periods of time). In this case however we are specifically interested in how densities change over a relatively short time period, <1 hour and at a relatively small spatial scale (hundreds of meters). Consequently, to obtain an adequate sample many replicate control and treatment surveys would need to be carried out. These are likely to be expensive, but there is an additional concern in this case because the experiments involve the broadcast of loud sounds which are intended to be disruptive. Sites where local densities are high and there is a higher likelihood of detecting a change over a short period of time would be more suitable for ADD trials.

5.3 **Conclusions**

Certain methodologies are more suited to different species of marine mammal than others (Table 4). For example, acoustic monitoring is only suitable for marine mammals that vocalise regularly, which excludes both seal species; and telemetry tracking is only easily deployed on seals, though it has the potential to be used for cetaceans with the right equipment and skills and licenses (see above and in Section 9 where the requirements for field trials will be explored in detail).

Table 4. Summary of potential methodologies to examine the responses of marine mammals to ADDs.

	Harbour Porpoise	Harbour Seal	Grey Seal	Dolphin sp	Minke Whale
Telemetry tracking	Potential – possible attachment, sample size and licencing issues	Yes	Yes	Potential – possible attachment, sample size and licencing issues	Potential – possible attachment, sample size and licencing issues
Visual tracking (vessel)	Potential but hard to track visually	Potential but hard to track visually	Potential but hard to track visually	Potential but requires very good conditions	Potential but requires very good conditions
Visual tracking (land)	Potential but hard to track individuals visually and – range issues	Potential but hard to track individuals visually and – range issues	Potential but hard to track individuals visually and – range issues	Potential –range issues	Potential –range issues
Change in abundance	Potential – power issues	Potential – power issues	Potential – power issues	Potential – power issues	Potential – power issues
Acoustic survey	Yes	No	No	Yes	No

Tracking of marine mammals whether by telemetry or by visual observations from land or vessel surveys could be applied to any marine mammal species and these types of direct surveys to observe the effectiveness of ADDs on marine mammals are the most likely to yield information on deterrent range and effectiveness for minke whales and white-beaked dolphins. The specific methodologies adopted for recommended field trials will be fully explored in Section 9 but Table 4 provides an indication of the survey methods which may be possible for each species.

6 ADD technology readiness review

6.1 Introduction

The aim of this section to review the availability of acoustic deterrent devices (ADDs) suitable (or potentially suitable) for use during offshore wind farm (OWF) construction. This assessment considers each device's maturity and potential to be deployed effectively to mitigate the risk of injury to multiple species during OWF construction and does not consider the issue of effectiveness.

As outlined in Section 4.2 there are a range of devices commercially available or currently in development which vary according to the purpose and species for which they were designed. Of the range of devices available only those which have been identified in Section 4.2 as having the potential to be an effective deterrent for the species of interest, or devices specifically being marketed or developed for the OWF sector have been shortlisted for this review. These devices are shown in Table 5 below.

Table 5. Shortlist of devices reviewed here

Manufacturer	Device
Ace Aquatec	Marine Mammal Mitigation device (MMD)
Aquatec Group Ltd	AQUAmark 848
Genuswave Ltd	Genuswave
Lofitech	Seal Scarer
Mohn Aqua	MAG Seal Deterrent (based on the Airmar db II)
Seamarco / Van Oord	Faunaguard (now the APD-01 & ASD-01)
STM products	DDD, Dolphin Dissuasive Device (DDD 03)

6.2 Factors influencing the suitability of a device for use during OWF construction

In order for the use of ADDs to be accepted as a suitable solution by Statutory Nature Conservation Bodies (SNCBs), developers and other stakeholders there are a number of minimum technical and operational requirements which will need to be satisfied. Additionally from a pile-driving operations perspective, there are considerations that if taken into account during project planning and procurement phases will influence the likelihood of successful ADD operations. These considerations are additional to the fundamental requirement that ADD devices are effective at deterring the species of concern.

Assuming that efficacy is a prerequisite, a successful ADD operation can be defined as one in which:

- The ADD is deployed and used according to the methodology defined in the Marine Mammal Mitigation Plan (MMMP) and;
- The ADD operation is carried out within the budget and schedule estimates defined in the project plan, and without any health and safety accident, incident or near miss.
- The principal criteria which will influence a successful ADD deployment, in the context of OWF piling are listed in

- Table 6, along with the types of information available to enable an assessment of existing devices for their potential to be used to the satisfaction of stakeholders.

Table 6. ADD requirements

Criteria or requirement	Types of evidence to consider
Reliability / maturity of the technology or device (where reliability is defined as the ability of the ADD to operate on demand according to the manufacturers specification)	- Manufacturer test data - Independent tests/ validation of devices - Field performance data e.g. Mean Time to Failure (MTTF), Mean Time To Repair, (MTTR), operational records from deployment, user feedback - Track record e.g. number of devices in use, and duration
Safe, practical and robust for offshore use	- Method of transportation (including weight / size / robustness) - Ability to withstand environmental conditions on vessel and in transit - Method of deployment and recovery - number required and positioning of units - Power source and method of operation - Risks associated with ADD use have been considered by original equipment manager (OEM) and made 'ALARP' (As Low As Reasonably Practical) e.g. electrical, auditory and manual handling hazards - Device is 'failsafe'
Commercial readiness / Cost	- Ability of the OEM to manufacture high quality product, provide warranties and post sales or operational support (including spare parts and servicing) - System purchase / rental price - Lead times for equipment - Operator skill and level of training required - System 'add on' costs (e.g. cases, power cables, handling equipment)

6.3 **Information gathering methodology**

As part of the previous phase of the ADD ORJIP project (Herschel *et al.,* 2013), an interview process was used to gather information on ADD use, with more than 40 individuals contacted and 11 interviews carried out. The decision was taken not to repeat this process due to the limited additional information expected to be available. Instead, for this update, a request for information (RFI) process was used to obtain information directly from the ADD OEM's or European Union (EU) sales agents. The RFI is included in Appendix A and contact list in Appendix B.

In addition, the ORJIP partners were invited to provide details or contact information relating to any relevant experience of ADD use, and the Marine Management Organisation (MMO) were asked if they could provide a summary list of the sites where ADDs have previously been used or included in MMMPs.

Responses were received from RWE Innogy and DONG Energy. RWE Innogy supplied information in relation to Gwynt Y Mor where an Airmar dB II device was used during construction (note this deployment was carried out by the company CMACS who were interviewed and contributed substantially to the Phase 1 report). DONG Energy responded that an Airmar dB II device was used during construction at Arnholt and a Lofitech seal scarer is being used during construction at Gode Wind 1 and 2. No new information was provided on direct practical experience of ADDs during piling operations.

In addition to the formal approaches to gathering information detailed above a number of informal conversations were held with researchers and technicians that have direct experience of using ADD's for trials and for research projects.

6.4 **RFI response summary**

This section provide a summary of the responses received from the device OEM's and comments on suitability considering the requirements defined in Table 6, above.

6.4.1 Ace Aquatec - Marine Mammal Mitigation device (MMD)

The Ace Aquatec MMD has been designed specifically for use in offshore applications. Although only eight units have been delivered for offshore wind/offshore ordnance projects, it appears to be a robust and practical ADD system, sold and supported by an established company keen to supply the OWF sector.

Ace Aquatec has produced acoustic deterrents since 2001 for the aquaculture industry. The device is based on the Ferranti Thompson seal scarer system for which Ace Aquatec bought the rights. It was developed further by John Ace-Hopkins into the US2. In 2011 the development and build was contracted to Neptune Sonar, although the design rights remain with Ace Aquatec. The product has since been differentiated into the MMD (for pile driving and other offshore applications) and the US3 (for aquaculture use).

A review of the information provided by Ace Aquatec suggests that the MMD is one of the most offshore 'friendly' devices available on the market and is not, as far as can be determined, in need of any further development to make it suitable for use on OWF construction projects.

The key points noted from the RFI response are detailed below, followed by a number of images of the device.

Table 7. Ace Aquatec - Marine Mammal Mitigation device (MMD)

Criteria / requirement	Summary
Reliability / maturity of device	- Eight MMD devices stated to be in operation on pile driving and ordnance projects (it is also relevant that approximately 400 US3 units are in operation on fish farms, evidence that the company has experience with supplying and supporting the technology). - Devices are tested in water at Neptune Sonar's lake facility in Yorkshire to ensure that all equipment meets the specification. Subcontractors in aquaculture installations are equipped with a hydrophone to check outputs in the water; hydrophone test kits are available. - The MMD has a real time clock allowing all operational history to be logged throughout the period of use. A full report of operational use can be transmitted to a laptop. Fault lights and warning messages alert the user to any self-diagnosed issues within the system or components. - The system can run automatic sounds randomized from 1-2Khz, 10-20kz or in other ranges depending on the supplied transducer. The user can elect the system to run single, dual tone, or multi tone sound patterns. Duty cycle can be decreased or increased. Soft start is used as standard at switch on.
Safe, practical and robust for offshore use	-Device is packaged to facilitate easy handling consisting of: 1. Standard pod for underwater deployment. 2. Transportation amazon case 3. 100m Underwater cable (system is suitable for water depths up to 100m) 4. Top box with automatic and user defined settings 5. Harsh shell for 2x 12 volt batteries 6. Mains cable and plugs for universal power - The unit can be powered from universal mains supplies or from two 12V batteries or gel batteries. When connected to mains the system automatically recharges the batteries. - The top box has an optional radio transmitter port allowing it to operate remotely. This allows the system to be set up on a barge, boat or buoy, and activated from a radio controller in another location. - The system should be cleaned regularly, either by hand with a cloth or with a pressure washer to ensure that any build-up of detritus is removed. The transducer must be kept clean for optimal effectiveness; it is recommended that cleaning occurs every two weeks.
Commercial readiness / Cost	- The product can be either purchased or rented. The MMD system can be purchase for £9500 and comes with 1 year warranty or alternatively it can be rented at £99 per day.

	- All repairs are carried out by Neptune Sonar, immediate replacement is offered if there is a problem during rental. Contact is available 24/7 via phone. - The device is designed to be 'plug and play' and does not require specialist training.

Figure 3: Images of the Ace Aquatec MMD

6.4.2 Aquatec Group Ltd – AQUAmark 848

Following a conversation with the Aquatec office contact by phone, an outline of this study was forwarded to Aquatec via the enquiries email address on the website. This was later followed up with the RFI. No acknowledgement or response has been received. The findings from WP1-1 describe this device as experimental and no data could be found on its deterrence capabilities. As no response could be obtained to the RFI this device has not been further reviewed and due the lack of information and evidence of efficacy the device is not considered to be suitable for OWF construction at this time.

6.4.3 *Genuswave Ltd – Genuswave*

The Salmonsafe ADD was developed by marine scientists at St. Andrews University (St. Andrews University also owns the IP). GenusWave is the sole entity that owns, leases and provides sales support and maintenance for the Salmon Safe System. The device is manufactured by SA Instrumentation Limited, who are wholly owned by the University of St Andrews.

The device has not yet been deployed commercially, Genuswave state that they are in the later stages of prototyping and have a number of improvements planned to make the system more robust for deployment. The device has been designed for a range of different applications and can be operated with various signal types at different source levels. Signal type, frequency band and source levels can be tailored to the specific application depending on what species need to be deterred. The research foundations of the device and experience of the team in deploying and testing alternatives suggest that this is one to monitor and if the commercial and manufacturing risks associated with a start-up are managed effectively then this could be a good candidate for testing.

Table 8. Genuswave - Salmonsafe ADD

Criteria / requirement	Summary
Reliability / maturity of device	Genuswave are in the process of completing the prototyping stage for the salmonsafe device – modifications are planned to increase system reliability, to make the device more user friendly and to improve the communication system. 10 units have been in operation on an aquaculture facility with a salmon company in the Shetland Islands to verify commercial viability. There are plans to roll out another 20 units (two more sites) with the same company in the near future. The new units will be improved planned features are: • Enhanced external structural integrity • IP67 Standards and IP68 for some connectors • Longer battery life • Manual controls and indicator lights added to each unit
Safe, practical and robust for offshore use	System design and number of transducers: • Independent units with internal battery which can be recharged from main or solar power. • Units are synchronized via radio link • Sound emission protocol can updated and monitored via mobile or satellite phone link • Number of transducers depend on application (up to a maximum of 10 have been tested) • Effective radius of 250 meters per unit for seals but using a higher frequency and higher source level designed to target both seals and odontocete cetaceans, deterrence ranges could be increased to 1-4 km for both taxa

Commercial readiness / Cost	Current pricing is £500 per month per individual unit Maintenance is provided by GenusWave as part of the contract In the event of the system gets damaged or malfunctions, GenusWave state that they will repair or replace the unit GenusWave will be responsible for routine maintenance and repair of the product operating in its normal operating environment

Figure 4: Salmonsafe Device

6.4.4 Lofitech AS - Seal Scarer

The seal scarer device was developed and is manufactured and sold by Lofitech AS, an established company, operating since 1988, based in Norway. The seal scarer has been used for a number of OWF construction projects in Europe. The device is a simple design, and although bespoke systems are available (and have been used in the UK), the same basic device marketed for aquaculture is also sold for offshore construction projects.

A recent modification of the Lofitech seal scarer includes a waterproof enclosure containing a battery and built in intelligent battery charger which provides an indication if the batteries are faulty. From the information provided the seal scarer appears to lack the control functionality of Ace Aquatec's MMD (Section 6.4.2) or the Seamarco (Section 6.4.6), which have, for example, the ability to log operational history, self-diagnose system failures, and have been 'packaged' to specifically target the OWF sector. However, it should be noted that the simplicity of the device (and associated low cost), coupled with a reasonable track record of use suggest that the design has merit. Furthermore there are examples of bespoke seal scarer designs that have been developed and deployed for ordnance projects, this involved devices that were placed into waterproof buoys and controlled by radio communication from a vessel. It is clear that with some investment it would be quite possible to develop a standard OWF friendly model; modifications might include control functionality, power supply options, longer cables and a transport case.

Table 9. Lofitech AS - Seal Scarer

Criteria / requirement	Summary
Reliability / maturity of device	- Exact number sold to the OWF sector unknown. There are more than 950 units in operation in aquaculture applications. - No data provided on device reliability or performance in the field; however widespread use in aquaculture and informal feedback from research community suggests that the device is simple and robust. - The device output has been characterised in an independent (confidential) report delivered by Subacoustech in 2010. Once on, the unit emits bursts of noise at random intervals unless the test switch is activated, forcing a signal to be emitted. - There are no standard integrated means provided for verifying the output during operation although there is an indication of battery fault.
Safe, practical and robust for offshore use	- The device itself consists of a transducer connected to a separate control unit via a 25m long cable. - The device is powered with a 12V battery. - The device controller unit is placed in a waterproof enclosure which contains an ordinary Auto-Marine 12V battery with 90 -120 Ah with an integrated charging unit.
Commercial readiness / Cost	- Device cost is c. £4,480 depending on currency variation (55.600 NOK).

Figure 5: Lofitech Seal Scarer

6.4.5 *Mohn Aqua - MAG Seal Deterrent*

Mohn Aqua Group is an ADD device developer and manufacturer, with IP ownership. The group was formed in 2011 and is based in Forres, Scotland (R&D and production) and Bergen, Norway (servicing and technical support). Their core business is the provision of technology and control systems for aquaculture, of which ADD’s are one product line.

The MAG Seal Deterrent is an Airmar DB II device with an enhanced control system. The Airmar DB II has been used on both European and UK OWF’s, and is one of the most widely used in Scottish waters for aquaculture applications (Lepper et al. 2014). The device differs from the other models reviewed in that it features a multi-transducer array, with up to 6 transducers per device.

Mohn Aqua redesigned the Airmar control system and now markets the device as the MAG Seal Deterrent. The new control box is designed and built fully in the UK but has been built in consultation with, approved and tested by Airmar in the USA.

The device has not been specifically developed for the offshore wind sector, and the stated effective range of 40m per projector (transducer) seems to conflict with the evidence gathered in field trials and presented in WP1-1 where deterrence ranges for porpoises were shown to be between 2 and 3.5 km. For seals the deterrence range from studies was more variable between no response and some evidence of responses at a range of ~1km. In response to a request for clarification from Mohn Aqua, they were asked to present a solution suitable to protect an area of 500m radius from a piling operation and responded and priced a solution based on an array of 6 devices, each connected to 6 transducers mounted on a series of buoys circling the piling site. The solution as presented, in comparison to a system which can be deployed directly from the piling vessel itself is a less practical and cost effective solution for OWF construction operations and would not be recommended in this configuration. However, because there is evidence of efficacy for this device for some species and the company have a track record in providing systems with relatively sophisticated control systems, and an interest in further development, follow up discussions on potential OWF tailored solutions are recommended.

Table 10. Mohn Aqua - MAG Seal Deterrent

Criteria / requirement	Summary
Reliability / maturity of device	- Mohn Aqua are not aware of any MAG devices that have been used for OWF however previous reports noted that the Airmar DB II has been used on UK and EU projects (including Gwynt Y Mor in the UK and Anholt in Denmark). - There are more than 200 MAG devices deployed on aquaculture sites in Scotland, plus more than 50 in Chile and a similar number in Canada / US. Other applications include FPSO's and power station inlets. - The RFI response noted that the company is actively developing the technology, an important positive point to note for potential OWF customers.
Safe, practical and robust for offshore use	- Devices run on mains power or 24/48V battery with back-up charging. - Current deployment equipment is designed for aquaculture purposes where the equipment is fixed to the cages and has cables running from the control unit to the acoustic projectors and to the power source. - Control features include the ability to control the acoustic characteristics of the device (e.g. pulse length), LED fault detection, soft start and improvements to lower the power consumption. The transmitter and transducers are the same as the Airmar model. The system is designed to have up to 6 transducers connected to a single transmitter. - The device has fault and battery protection, if a fault develops in the cable or projector the effected channel instantly closes down and a fault light identifies which projector is off. It is also possible to programme automatic alerts to a mobile phone. - For marine sites servicing is normally every six months (details not provided). - No specialist training required - devices are 'user friendly and intuitive'
Commercial readiness / Cost	- Devices are available to purchase and to rent.

	- The cost for a 6 device array suitable to cover an area of 500m radius from a piling operation was quoted as £75,000, this equates to £12,500 per device with cables and chargers. - Standard warranty is one year covering operating faults, manufacturing defects and faulty workmanship by either repair or replacement.

Figure 6: Mohn Aqua - MAG Seal Deterrent

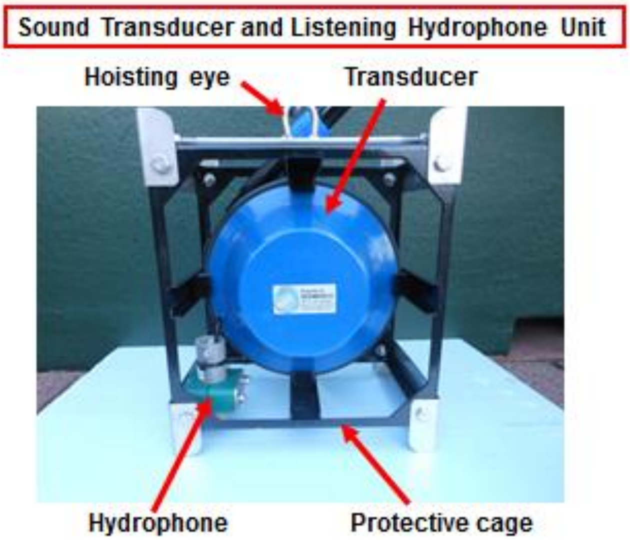
6.4.6 Seamarco / Van Oord – Faunaguard

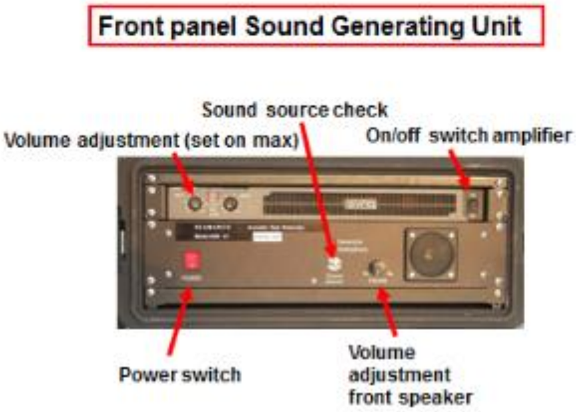
SEAMARCO are a developer of ADDs coming from a scientific research background. The company was originally involved in the testing of pingers to reduce bycatch of harbour porpoises in gillnets, before expanding into research into the hearing and behaviour of marine mammals. As a result of this work and testing of alternative ADD devices they have developed their own range of devices, with input from Van Oord. They produce two relevant models, a seal deterrent referred to as the Acoustic Seal Deterrent (ASD) Model 01, and a porpoise deterrent, known as the Acoustic Porpoise Deterrent (APD) Model 01. The systems are well designed, and differentiated from the other models reviewed in that they require a dry environment from which to house the control unit / operator. This in itself is not necessarily a drawback but would need to be taken into account during planning and a suitable area provided on the vessel or platform they are deployed from. The overall set up seems to be very robust and is specifically aimed at the OWF and marine construction sector. As far as can be ascertained without testing or experience in handling the devices, they are not in need of any further development to make them suitable for OWF construction projects.

Table 11. Seamarco – ASD 01 / APD 01

Criteria / requirement	Summary
Reliability / maturity of device	- Only a small number of devices have so far been deployed / sold to Van Oord and TAQA - When starting the unit, the sound level is slowly ramped up (automatic soft start). - The unit has a build-in underwater sound detection system which allows the operator to check acoustically if the system functions properly.
Safe, practical and robust for offshore use	The ASD consists of the following components: 1. Sound Generating section (for generating and amplifying sounds). 2. Sound Listening section (for listening to the outgoing electrical signal and the actual sounds underwater). 3. A transducer (underwater loudspeaker) in a protective cage. 4. A hydrophone (underwater microphone; fixed in the protective cage). 5. Electrical cable (length specified by customer) - All of SEAMARCO's Acoustic Deterrent systems can be deployed from a piling platform and run on 240 V mains supply (this is compatible with construction vessels) - The SEAMARCO systems are designed to be rugged, however the electronic part (Sound Generating and Listening Unit) needs to be placed in a dry room, and the equipment which goes into the seawater, needs to be rinsed with fresh water before being stored in the transport boxes. When the Sound Generating and Listening Unit of the ADD is stored in its transport box, the entire ADD is waterproof for transport.
Commercial readiness / **Cost**	- The equipment is mainly for sale with a 1 year warranty, but SEAMARCO also has a few rental units. - The basic APD-01 (porpoise) with a 25 m cable costs Euro 11,500 + VAT - The basic ASD-01 (seal) with a 25 m cable costs Euro 31,000 + VAT - There are additional costs for longer cables - Device is plug and play design requiring no specialist operational training.

Figure 7: Seamarco ADD devices (APD-01)





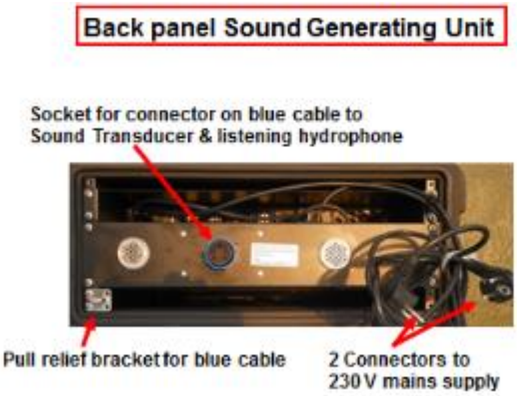


Figure 8: Additional images of the Seamarco ADD devices (APD-01)

6.4.7 STM products - DDD, Dolphin Dissuasive Device (DDD 03)

In response to the RFI, STM sent the operating manual for their device, the key points from which have been summarised below. The device itself has been designed to keep dolphins from nets or gear for fishing and aquaculture, and is simply attached to a net or deployed into the water when required. The control system is a simple inbuilt system which activates the device when in contact with water, and changes the sound when the power is low. The device is very much packaged for the fishing and aquaculture sectors and lacks the sophistication required for OWF applications; in particular there is no ability to manually or remotely activate the device.

Figure 9: Dolphin Dissuasive Device (DDD 03)

Table 12. STM DDD O3

Criteria / requirement	Summary
Reliability / maturity of device	- No information was provided.
Safe, practical and robust for offshore use	- The device has a power amplifier, a broadband transducer and a 16 bit microprocessor which controls these functions: • power amplifier driver • signal generation system randomising all parameters • automatic switch-on when sunk in water • power / low battery signal - These are all packaged within the device itself, which is small, light and easy to transport (less than 1kg, 210mm height x 61mm dia.). A method for deployment and recovery is not included and would need to be procured separately. - The device is battery powered. - When the sensors touch the water the device performs a series of sounds. These may indicate: • that the batteries are low (short sounds at regular intervals each 2 seconds) • that the DDD03 has started its normal activity under the current emission strategy (variable length modulated signals) - Recharge: when the DDD03 produces the low batteries signal, or even when there is no signal at all, it means that the batteries need to be charged. The charge level of a DDD03 can be checked precisely with a voltmeter or charger.
Commercial readiness / Cost	- The device is available commercially. No cost information was provided.

6.5 User Experience

Drawing on the material gathered during Phase 1 (Herschel *et al.,* 2013) informal feedback from users (mainly the research community) and the technology review conducted for this study, ADD devices can be considered as relatively straightforward to deploy and use with no requirement for extensive training or particular qualification or operator certification. Deployment of these devices from a piling or drilling vessel does not pose any real challenge provided that protocols are established and executed, including following operating procedures and carrying out due care and maintenance of the systems.

From an offshore engineering and offshore operational perspective, the following should be considered:

- Advising the installation contractor and vessel operator (if different) of the deployment requirements as early in the planning phase as possible

- Conducting a vessel survey once the piling vessel (s) have been selected with an operational lead, an electrical supervisor and a rigger to agree the best location and method of providing power supply and communications to the device or operator, including a trial run and test deployment if feasible.
- Ensuring that the operating and maintenance procedures, communication protocol (on the vessel) and reporting requirements are agreed, and are readily available to the vessel crew and project team.
- Consideration of a signal verification system during deployment. This can either be as part of the device design (e.g. FaunaGuard and Ace Aquatech MMD) or using a separate hydrophone system.
- Managing the procurement of the devices to ensure that they are fabricated to a high standard and operate as per the specification under the anticipated operating conditions.

6.6 Conclusions and recommendations

There are two devices which, from an OWF construction procurement and operational perspective are clear forerunners; these are the Ace Aquatec MMD and the Seamarco Faunagaurd. These are closely followed by the Lofitech Seal Scarer which has more of a track record than the other devices but has been ranked behind simply because it has not been 'packaged' into a bespoke OWF model (note that the device has been re-packaged since the RFI response was received). All of these models should be considered ready for procurement and use on a project from a technology perspective. Although the solution proposed by Mohn Aqua for this study is more complex than the alternatives, it is recommended that further engagement is conducted with the company. The Genuswave salmonsafe is still under development but is another ADD option which should be monitored.

One of the key points that the RFI has raised is that the device OEM's have had very limited direct engagement and feedback from the OWF community and therefore their understanding of user requirements is also limited. Better engagement would undoubtedly enhance the solutions proposed.

It should be noted that the evidence presented in this report is based on information available on the web and in short responses to an RFI. It is strongly recommended that any decisions to select devices for field trial or deployment should be preceded by a face to face meeting with the device suppliers, preferably at their offices or manufacturing facilities to discuss the details of the devices and handle and inspect the equipment directly. Furthermore, as noted above, an initiative to outline expectations and requirements for ADD use in OWF applications to the OEM's is advised.

The table below summarises the findings from the technology readiness review. The recommended options are differentiated by:

- Recognition of the importance of operational control measures such as verification of signal, recording / feedback of ADD output (potentially important for MMMP records)
- Consideration of deployment methods and safe transportation of the devices. To some extent the deployment method will depend on the vessel specifics and it is reasonable to assume that a system would be set up for a specific vessel for each piling campaign

- Robust transport case to protect devices (critical offshore)
- Power and deployment systems (e.g. cable lengths, mains supply) that suit offshore construction vessels and operating water depths.
- Ability to purchase additional units as spares.

Table 13. Summary of findings. Shading indicates a positive recommendation

Manufacturer	Device	Recommendation
Ace Aquatec	Marine Mammal Mitigation Device (MMD)	Suitable - recommended
Aquatec Group Ltd	AQUAmark 848	No Information available – due to lack of response this is not recommended solution
Genuswave Ltd	Genuswave	Promising potential deterrence range although remains to be demonstrated. Needs commercial development but one to watch.
Lofitech	Seal Scarer	Recommended as is usable in current form but note that improvements could be made and an OWF specific model developed
Mohn Aqua	MAG Seal Deterrent (based on the Airmar db II)	Not suitable in current configuration due to limited stated range by manufacturer (40m) and therefore practicalities of deploying a suitable system to achieve adequate deterrence - however recommendation is to take forward further discussion and provide the opportunity for Mohn Aqua to provide potential alternative solutions
Seamarco / Van Oord	Faunaguard (now the APD-01 & ASD-01)	Suitable - recommended
STN products	DDD, Dolphin Dissuasive Device (DDD 03)	Not designed to have the control functions necessary for OWF applications therefore not suitable in current configuration

7 Sound Propagation Review

There are uncertainties regarding the degree to which data collected at a test field site on the effectiveness of Acoustic Deterrent Devices (ADDs) can be directly transferred to the offshore wind farm sites where ADDs may be deployed to mitigate the risk of auditory injury to marine mammals as a result of pile driving. This is because the sites might differ in the way in which the ADD signals travel through the water as a result of differences in water depth, seabed substrate, degree of shelter etc. This section is intended to provide a review of the factors which are likely to affect the sound propagation between sites and to assess the variation in these conditions between the sites where ADDs have been trialled to date, the proposed field trial sites explored in Section 9.4 and the range of UK offshore wind farm sites where the ADDs will be deployed. A number of recommendations are made to ensure that the results from test sites can be successfully translated to OWF sites.

7.1 Factors affecting sound propagation

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). In water the sound source strength is usually defined by its sound pressure level in dB re 1µPa, 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.

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 the square root of the mean squared sound pressure over a specific time window. These descriptions are shown graphically in Figure 10.

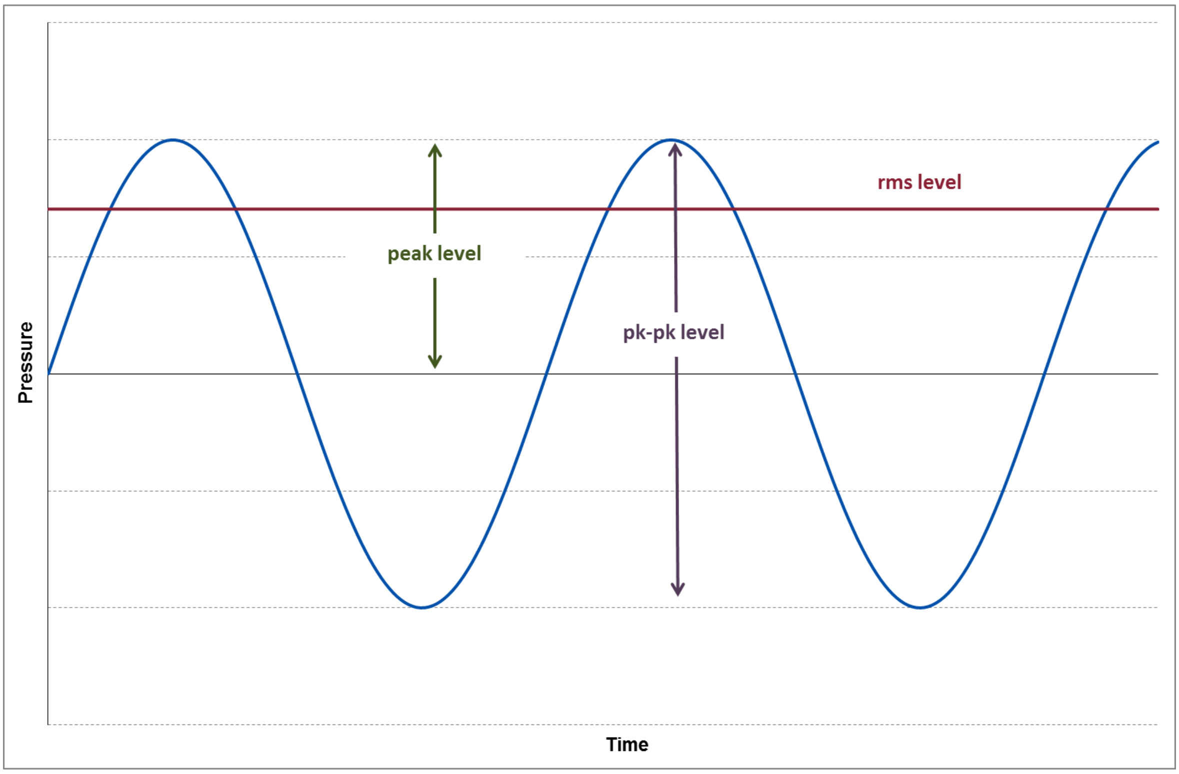


Figure 10. Graphical representation of acoustic wave descriptors

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 faculties of marine mammals and fish are not the same as humans, with marine mammals hearing over a wider range of frequencies, fish over a typically smaller range of frequencies and both with different sensitivities. It is therefore important to understand how a species' hearing varies over the entire frequency range in order to assess the effects of sound on marine life. 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.

Increasing the distance from the noise source usually results in the level of noise getting 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.

The way that the noise spreads will depend upon several factors such as water column depth, pressure, and temperature gradients, salinity as well as water surface and bottom (i.e. seabed) conditions. Thus, even for a given locality, there are temporal 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), although other factors mean that decay in sound energy may be somewhere between these two simplistic cases.

In acoustically shallow waters[11] in particular, the propagation mechanism is coloured by multiple interactions with the seabed and the water surface (Lurton 2002; Etter 2013; Urick 1983; Brekhovskikh and Lysanov 2014; Kinsler et al. 1999). Whereas in deeper waters, the sound will propagate further without encountering the surface or bottom of the sea, in shallower waters the sound may be reflected from either or both boundaries (potentially more than once).

At the sea surface, the majority of sound is reflected back in to the water due to the difference in acoustic impedance (i.e. sound speed and density) between air and water. However, scattering of sound at the surface of the sea could be an important factor with respect to the propagation of sound from ADDs. In an ideal case (i.e. for a perfectly smooth sea surface), the majority of sound wave energy will be reflected back into the sea. However, for rough seas, much of the sound energy is scattered (e.g. Eckart 1953; Fortuin 1970; Marsh, Schulkin, and Kneale 1961; Urick and Hoover 1956). Scattering can also occur due to bubbles near the surface such as those generated by wind or fish or due to suspended solids in the water such as particulates and marine life. Scattering is more pronounced for higher frequencies than for low frequencies and is dependent on the sea state (i.e. wave height). It is possible therefore that ADDs could be effective over a shorter range in sites with rough seas compared to otherwise similar sites with calm seas. However, the various factors affecting this mechanism are complex.

Because surface scattering results in differences in reflected sound, its effect will be more important at longer ranges from the source sound and in acoustically shallow water (i.e. where there are multiple reflections between the source and receiver). The degree of scattering will depend upon the sea state/wind speed, water depth, frequency of the sound, temperature gradient, grazing angle and range from source. Depending upon variations in the aforementioned factors, significant scattering could occur at sea state 3 or more for source frequencies of 15 kHz or more. It should be noted that variations in propagation due to scattering will vary temporally within each site (primarily due to different sea-states / wind speeds at different times) as well between sites. It is possible that more sheltered sites (which are more likely to experience calmer waters) could experience surface scattering to a lesser extent and less frequently than an offshore site which is likely to encounter rougher seas. However, over shorter ranges (e.g. a few hundred meters or less) the sound will experience fewer reflections and so the effect of scattering should not be significant.

When sound waves encounter the bottom, the amount of sound reflected will depend on the geoacoustic properties of the bottom (e.g. grain size, porosity, density, sound speed, absorption coefficient and roughness) as well as the grazing angle and frequency of the sound (Cole 1965; Hamilton 1970; Mackenzie 1960; McKinney and Anderson 1964; Etter 2013; Lurton 2002; Urick 1983). Thus, bottoms comprising primarily mud or other acoustically soft sediment will reflect less sound than acoustically harder bottoms such as rock or sand. This will also depend on the profile of the bottom (e.g. the depth of the sediment layer and how the geoacoustic properties vary with depth below the sea floor). The effect is less pronounced at

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[11] Acoustically, shallow water conditions exist whenever the propagation is characterised by multiple reflections with both the sea surface and bottom (Etter 2013). Consequently, the depth at which water can be classified as acoustically deep or shallow depends upon numerous factors including the sound speed gradient, water depth, frequency of the sound and distance between the source and receiver.

low frequencies (a few kHz and below) and so could be a significant factor to take into account with respect to ADDs (all of which considered here are approximately 10-15 kHz or more). A scattering effect (similar to that which occurs at the surface) also occurs at the bottom (Essen 1994; Greaves and Stephen 2003; McKinney and Anderson 1964; Kuo 1992), particularly on rough substrates (e.g. pebbles).

Another phenomenon is the waveguide effect, which means that shallow water columns do not allow the propagation of low frequency sound (Urick 1983; Etter 2013). The cut-off frequency of the lowest mode in a channel can be calculated based on the water depth and knowledge of the sediment geoacoustic properties. Any sound below this frequency will not propagate far due to energy losses through multiple reflections. ADDs typically operate at frequencies of several kilohertz or more, meaning that this low-frequency cut-off effect is unlikely to have significant bearing on the propagation of sound from ADDs.

Another important factor will be the sound speed gradient. Changes in temperature and pressure with depth mean that the speed of sound varies throughout the water column. This can lead to significant variations in sound propagation and can also lead to sound channels, particularly for high frequency sound. Sound can propagate in a duct-like manner within these channels, effectively focussing the sound, and conversely they can also lead to shadow zones. The frequency at which this occurs depends on the characteristics of the sound channel but, for example, a 25 m thick layer would not act as a duct for frequencies below 1.5 kHz. The temperature gradient can vary throughout the year and thus there will be potential variation in sound propagation depending on the season.

Sound energy can also be absorbed due to interactions at the molecular level converting the acoustic energy into heat. This is another frequency dependent effect with higher frequencies experiencing much higher losses than lower frequencies. This is shown in Figure 11. Although the effect of this absorption will be higher in cold water and with higher levels of MgSO4, these variations are relatively insignificant. In any case, because most ADDs work in the frequency range of the low tens of kilohertz, this effect is likely to only result in a few decibels per kilometre of propagation distance at the most.

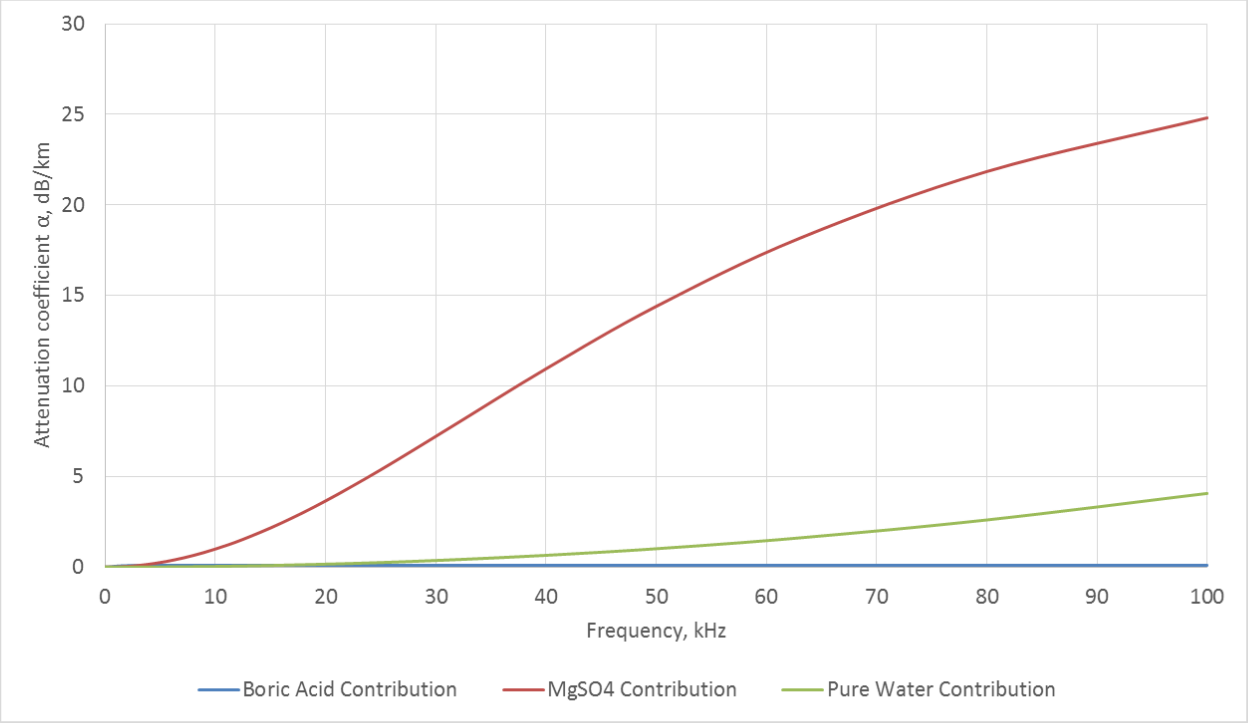


Figure 11. Absorption loss coefficient (α), dB/km (pH 8, 5 ºC, salinity 35 ppt)

Another factor that could significantly affect propagation of sound from the ADDs is the mounting arrangements. For example, if the ADD is mounted underneath a vessel it is likely that the reflecting plane at the surface will be affected due to the vessel's hull. It is also possible that this could lead to shadow zones, depending on depth. Furthermore, the height at which the ADD is mounted below the surface could also significantly affect propagation. Therefore, it will be important to ensure that each ADD is mounted in a controlled and consistent manner at each of the test sites.

The deterrence effectiveness of an ADD might not just be related to the "loudness" of the received sound level. Other factors, including the character and temporal variation (e.g. rise time and repetition) in the sound signal may play as important (or more important) role. Consequently, any propagation effects that change the temporal characteristics of the sound could play an important part in understanding the range of effectiveness of ADDs. Different signal paths including those reflected and scattered from the surface and bottom could arrive at different times and with different characteristics. Frequency dependent propagation effects as previously discussed in addition to reverberation effects will lead to an elongation of the signal combined with a change in frequency content. This effect may not be as important for continuous sounds but may be important with time varying signals. However, quantifying the effect may be difficult as it requires an understanding of how the character and temporal characteristics of sound affect marine mammal response which is not well understood for most devices.

7.2 Review of the acoustic characteristics of R3 and STW OWF sites

An outline review has been performed taking into account the differences in bathymetry and seabed for the various ADD test sites, potential trial sites and R3 and STW OWF sites. This review is intended to highlight potential differences in propagation characteristics (to determine how transferable results from test sites might be to OWF construction sites), as opposed to undertaking a detailed assessment of propagation.

Of the various factors discussed in the preceding section, it is likely that the water depth and bottom type will be the most important factors to influence sound propagation. Notwithstanding this, it will be important to ensure that any differences between the test sites and R3 and STW OWF sites are fully understood and if possible quantified during the study, albeit that this level of analysis is not warranted at this stage. It is likely that this will require a combination of modelling and measurement / analysis of data. It is also reiterated that aspects relating to character of sound and in particular the temporal signal profile are not discussed as part of this review, not least because of the current lack in understanding in relation to how marine mammals' reactions to ADDs vary accordingly. Consequently, it is recommended that any future acoustic measurements of operating or trial ADDs include a measure of the temporal characteristics. This should include an analysis of T90 (i.e. the interval over which the cumulative energy curve rises from 5% to 95% of the total energy) and rise time for the sounds, and how this varies with distance, as a minimum.

A review of the water depth and bottom substrate for each of the previous and potential test sites is shown in Table 14. In general, it is not expected that results will differ significantly in terms of sound propagation in the relatively flat shallow areas over the ranges of interest (a few hundred metres), although care will need to be taken in particularly shallow areas, especially those with soft substrate (e.g. Fyns Hoved), or in areas with steep bathymetry and deep channels (e.g. West Finnmark and Vestfjorden). Differences in propagation could also occur in areas with bedrock or gravel/pebbles due to differences in acoustic properties and the potential for scattering from the bottom. With respect to sea state and surface scattering, this is likely to vary over time within each area and so it is recommended that a record is kept of sea conditions over the monitoring period. Even in cases where sound propagation does differ between sites (or within the same site due to variation in tides, sea state and sound speed gradient), it is expected that a correction can be applied for this based on a combination of measurements and modelling. To some extent, this relies on measurements of sound level being undertaken at various ranges from each device at each test site in order to verify the propagation of sound from source. Variations in sound propagation will be most important at longer distances from the ADD. Thus, it is expected that propagation of sound will be fairly consistent within a few hundred meters of the ADD for most sites and it is only at ranges greater than 1 km or so that significant variations are likely to occur for the range of water depths and bottom conditions identified. Because the mitigation zone agreed with stakeholders is 500 m, it is therefore considered unlikely that significant variations will occur over the ranges of effect required for this study. Consequently, the results would be transferable between different offshore sites as long as the required range of effectiveness is no more than 500 m to 1 km. However, it is anticipated that even at greater ranges (greater than 1 km) the data can be extrapolated to other sites thanks to the study including an analysis of sound measurements to quantify the site specific propagation factors.

Table 14. Comparison of acoustic characteristics of ADD test sites (past and proposed) and Round Three and Scottish Territorial Waters (STW) Offshore Wind Farms

Site	Water depth / bathymetry	Bottom	Comments
ADD test sites to date			
Bioconsult - Fyns Hoved (Danish Baltic sea)	Very shallow water depths of about 6 - 10 m	Muddy sea bottom. In places rocky.	The level decrease with distance is significantly stronger than for spherical wave propagation without absorption or other losses, which at Fyns Hoved corresponds to a transmission loss of 27 log R. High TL probably due to muddy sea bottom, very shallow water depth, and numerous stones and rocks that cause a scattering of sound in many directions.
Bioconsult - German North sea north of Langeoog Island	Approx. 25 m water depth	Hard sand substrate	The measured sound level decrease with distance was close to spherical spreading (20 log R)
SMRU - Kyle Rhea / Upper Sound of Sleat	Kyle Rhea seabed slopes steeply from the foreshore to a depth of about 35 m Upper Sound of Sleat seabed slopes steeply from the foreshore up to approx. 110 m	Mostly bedrock	Measured spreading approximated to 20 log R (probably more like 22 log R) but data at >1km shows high TL rate – possibly due to high frequency losses from absorption and scattering.
SMRU - Moray Firth	Water depths up to 57 m	Variable – mostly sand and mud with some rock	Measured spreading approximated to 20 log R
Potential future study trial sites			

Site	Water depth / bathymetry	Bottom	Comments
Mingan Archipelago, North Shore of Gulf of St Lawrence, Quebec	The area comprises approximately 40 coastal islands and has a complex bottom topography including canyons, dunes, and rock outcrops. The maximum depth within the islands is 130 m, up to 10 km from shore. The Strait of Jacques Cartier lies to the south of the archipelago and reaches depths of up to 300 m between the north shore and Anticosti Island. The strait presents a channel-like bathymetry, reaching maximum depths of 200m	Rock outcrops with a substrate primarily composed of sand and mud (Naud et al. 2003).	Due to the complex bathymetry of this area, care will need to be taken to ensure that propagation effects are taken into account. Particular consideration should be given to areas with steep bathymetry and deep canyons if tests are carried out in such areas as these differ from the round three and STW offshore wind farm sites. Care also needs to be taken when analysing results to take the vertical position of animals relative to the ADD into account as opposed to simply analysing the "aerial" range, since the depth of the deeper areas could be similar to the range of effectiveness of some ADDs. However, it is currently anticipated that tests will be conducted in the area landward of the islands between the mainland and Anticosti Island. This area is approximately 4-5 wide and 25 km long. The water depths in this area are likely to be relatively shallow compared to areas further offshore in the main Jaques Cartier passage. Consequently, it is likely that results of studies in this more inshore area are likely to be comparable to the round three and STW offshore wind farm sites.
Faxaflói Bay, Iceland	The water in Faxaflói Bay is mainly 35 to 37 m deep and in the inner and coastal parts of Faxaflói Bay water depths are around 40 to 50 m deep (Rasmussen et al., 2013).	The seabed substrate is predominantly sand or basalt (Rasmussen & Miller, 2002).	The water depths at this site are similar to the round three and STW offshore wind farm sites, but consideration should be given to potential differences in propagation due to temperature gradients. There is also potential for scattering depending on the roughness of the basalt layer.
West Finnmark, Norway	The depths of the waters around Finnmark rapidly drop off to over 200 m, even within	The sediment in the more coastal areas is mostly gravelly sand, sandy gravel and sand gravel and cobbles, while areas further	Both Norwegian sites have significantly different bathymetry to round three and STW offshore wind farm sites, with depths of potentially several hundred meters. (Because the R3 and STW OWF sites are in water depths of typically tens of meters, it is unlikely

Site	Water depth / bathymetry	Bottom	Comments
	the inner fjord systems, with depths in the near shore regions reaching 300 m or more.	offshore are predominantly sandy mud, mud and gravelly sandy mud.	that any marine mammals will be exposed to ADD sounds at such depths for UK OWF sites.) Care will need to be taken to ensure that any differences in propagation are taken into account when applying results from these sites to UK offshore wind farm sites. Another consideration for deep waters is that the required range of effectiveness of some devices (say a few hundred meters) is similar in magnitude to the depth of the water. Care therefore needs to be taken when analysing results to take the vertical position of animals relative to the ADD into account as opposed to simply analysing the “aerial” zone of effectiveness. Consequently, it might be important to take measurements of sound at fairly deep hydrophone depths at these two sites. Potential scattering from the substrate also needs to be considered, particularly in areas with gravel and pebble substrates, because this could cause higher levels of attenuation at higher frequencies.
Vestfjorden, Norway	The water depths in Vestfjorden vary greatly – sloping rapidly to depths of between 100 to 700 m, with deep channels reaching up to 700 m deep	Mesozoic and Cenozoic rocks with a fine layer of glacial sediment (Otteson et al., 2005).	
R3 & STW OWF Sites			
Moray Firth	35 – 55 m	Gravel, sands and mud	All of the round three and STW offshore wind farm sites are in water depths within the range of tens of meters. Although there will be some variations in propagation between sites, it is not expected that there will be significant differences within the range of interest (say 500 m to 1 km). Differences in propagation for the OWF sites compared to the ADD trial sites can be estimated based on existing information.
Firth of Forth	40 – 70 m	Mixed clay, silt, sand and gravel	
Inch Cape	33 - 63 m (99% of area between 40 – 57 m)	Predominately sand, muddy sand, gravelly sand, clay and gravel.	
Neart na Gaoithe	40 - 58 m	Sand, gravelly sand and sandy gravel	

Site	Water depth / bathymetry	Bottom	Comments
Dogger Bank	20 – 40 m	Variable – sand, mixed sediments, stiff clay with frequent cobbles and boulders	
Hornsea	25 – 40 m – relatively flat bathymetry	Primarily sand with some areas of mixed sand, gravel and mud	
Rampion	18 – 59 m	Sands and gravels	
East Anglia	30 – 53 m	gravelly sand, sand and sandy gravel	

7.3 Recommendations

Based on the findings of the acoustic review, it is recommended that:

- Acoustic measurements should be carried out during all of the ADD trials;
- Sea conditions should be recorded during ADD trials;
- Measurements should follow the guidelines in the NPL (2014) Good Practice Guide;
- Measurements should be made over the full range of water depths covering the trial area, especially in areas with large changes in bathymetry over the study area or particularly deep channels;
- Multiple hydrophone distances should be used, ideally along a given transect in order to determine the transmission loss and to provide a good reference against which the propagation model can be validated;
- It would also be preferable to undertake measurements at varying hydrophone depths;
- As well as measuring sound pressure level and frequency content, the acoustic measurements should include an analysis of the temporal character of the ADD and how this varies with distance. It is recommended that, as a minimum, the following parameters are recorded:
    - Rms sound pressure level;
    - Peak sound pressure level;
    - Sound exposure level (SEL);
    - Frequency content (e.g. FFT, PSD or third-octave band data);
    - Temporal characteristics (in particular rise time, T90 time and time-frequency distribution or spectrogram);
    - If possible, it would also be advantageous to record time history profiles for more detailed analysis;
- An attempt should be made to analyse the data collected to determine the site specific propagation characteristics. This should include a more detailed analysis than simply attempting to fit to an N log R curve. If possible, this should be done using a suitable sound propagation model taking into account the various factors described in this section (and not a curve fitting approach);
- Once the various factors leading to effectiveness of ADDs has been identified (i.e. sound pressure level, frequency content and temporal characteristics) it is recommended that the site specific characteristics of the R3 OWF sites is reviewed to determine potential ranges of effectiveness for the devices. This could include an exercise in determining whether increasing the power output of devices would be beneficial given the practical difficulties of multiple deployments around piling –although higher source levels would need to be assessed for the potential to cause auditory injury.

8 ADD mitigation business case

8.1 **Introduction**

This section of the report reviews the business case for the use of ADD devices as an active approach to marine mammal injury mitigation versus the passive techniques currently accepted in the UK.

8.1.1 Objectives

The primary aim of this study is to understand the potential value of ADDs to the UK offshore wind sector by comparing the estimated cost of using an ADD based approach versus other current mitigation techniques such as MMO and PAM. In addition consideration is given to the wider business case for developers and other offshore wind stakeholders. This study builds on the analysis completed for ORJIP Phase 1 (Herschel *et al.,* 2013).

8.2 **Methodology**

The following steps were taken to compile this section:

- Review of the Phase 1 report;
- Data gathering (an information request was sent to ORJIP partners and to the study execution team for details of mitigation costs and pile installation data);
- Development of a working editable spreadsheet to estimate the current and expected costs of mitigation including a series of working assumptions, documented in this section;
- Analysis including assessment of the business case from a developer and stakeholder perspective using a 'case study' project type approach to illustrate the cost –benefit of an ADD based approach to mitigation.

8.2.1 Cost Assumptions and Data

This section outlines the assumptions used to develop the accompanying spreadsheet, used to quantify the financial benefit of using ADDs in place of MMO/PAM mitigation measures.

Actual costs for pile installation and for contracting marine mammal injury mitigation services will vary widely depending on project location, seabed type, installation strategy and market conditions at the time of placing contracts. The approach taken in this study has been to establish a set of assumptions around ADD, MMO and PAM operations and then to build a spreadsheet with the functionality to modify input data and evaluate the impact of different cost bases (low, 'best estimate' and high).

Assumptions for piling rates are based on the data gathered for phase 1, i.e. a piling rate of 1 pile every 12 hours of which pile driving operations last between approximately 30 minutes and 2.5hrs. The piling rate has been included as a user modifiable variable in the accompanying spreadsheet.

The following assumptions are relevant to all cost estimates:

- 24 hour working used as baseline
- MMO and PAM deployed from a dedicated vessel

- ADD deployed from the piling vessel

The following assumptions have been made about passive mitigation approaches (MMO and PAM):

- Mitigation team consists of a minimum of 1 MMO and 1 PAM operator per 12hr shift
- Vessel costs include skipper/1st mate plus fuel and berthing fees
- MMO and/or PAM activities start a minimum of 30 minutes prior to piling operation and team remain on standby during entire pile drive operation (as far as reasonably practicable)
- MMO/PAM operators are based onshore, and an allowance has been made for accommodation
- Transit time is included within the day rates for the vessel and personnel. It is assumed that if a development is further from shore then a faster vessel would be utilized or a switch to offshore accommodation (on the MMO/PAM vessel, not the piling vessel) which would reduce onshore expenses but increase vessel day rates.

The following assumptions have been made about active mitigation approaches (ADDs):

- As a base case 3 devices required, 2 for deployment (1 on each side of the vessel) and 1 spare. The use of 2 devices has been selected as a base case for the analysis based on the risk that there may be a need to compensate for acoustic shielding from the vessel hull, this is uncertain and hence has been set up as a user modifiable value in the accompanying spreadsheet.
- ADD will be deployed and handled by a dedicated resource on the piling vessel - this may be feasible using only 1 person (working on a variable shift pattern to coincide with the pile driving operation) but for the analysis in this report it is assumed that 2 operators will be required.

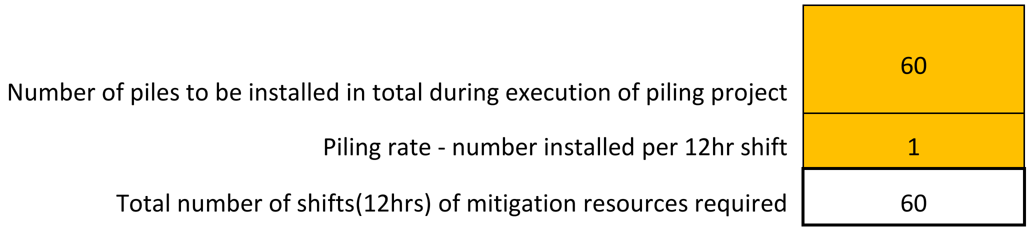
8.2.2 Spreadsheet design

The accompanying spreadsheet has three working tabs:

1. Cost inputs
2. Cost Calculations MMO PAM ADD
3. Impact on schedule

The cost inputs tab contains a table with all cost data used for the analysis; the orange highlighted cells can be modified.

The cost calculations tab uses a simple formula to calculate the mitigation costs based on number of piles to be installed and an assumed average piling rate, as shown below (orange cells can be modified).



Number of piles to be installed in total during execution of piling project	60
Piling rate - number installed per 12hr shift	1
Total number of shifts(12hrs) of mitigation resources required	60

Passive mitigation costs are calculated based on the sum of variable costs (people, vessel, equipment) and fixed costs (mobilisation fees and expenses).

To estimate the full cost of ADD deployment it has been assumed that the devices are purchased (not rented), that 24hr operator cover is required, and that there are some additional costs associated with setting up for safe deployment of the devices on the installation vessel (e.g. winch / small A-frame and additional cable).

The impact on schedule tab contains a simple calculation that quantifies the impact of downtime on the baseline piling cost using percentages between 0% and 50%. These delays could be due to weather, mammal sightings during or prior to piling, poor visibility or technical problems. Regardless of the cause of the delay the impact will be the same from a financial perspective i.e. it will cause operational downtime and directly increase the installation duration. The costs are therefore quantified using vessel day rate as the proxy, which should be considered as a minimum estimated cost. In reality any delay to the project will also incur costs arising from onshore support and any additional vessels associated with the piling operations.

8.3 Results

There are two clear findings from the analysis, illustrated using the graphs below.

Figure 12 illustrates that the cost of using ADDs does not scale linearly with the number of piles installed, unlike MMO and PAM mitigation techniques. This is because of the fixed cost associated with purchasing the ADD units and the relatively lower resources required to deploy the devices offshore. Figure 12 is based on the 'best estimate' costs shown in the cost inputs tab. The difference between ADD cost and MMO/PAM cost for a development requiring installation of 250 piles has been estimated as £834,448.

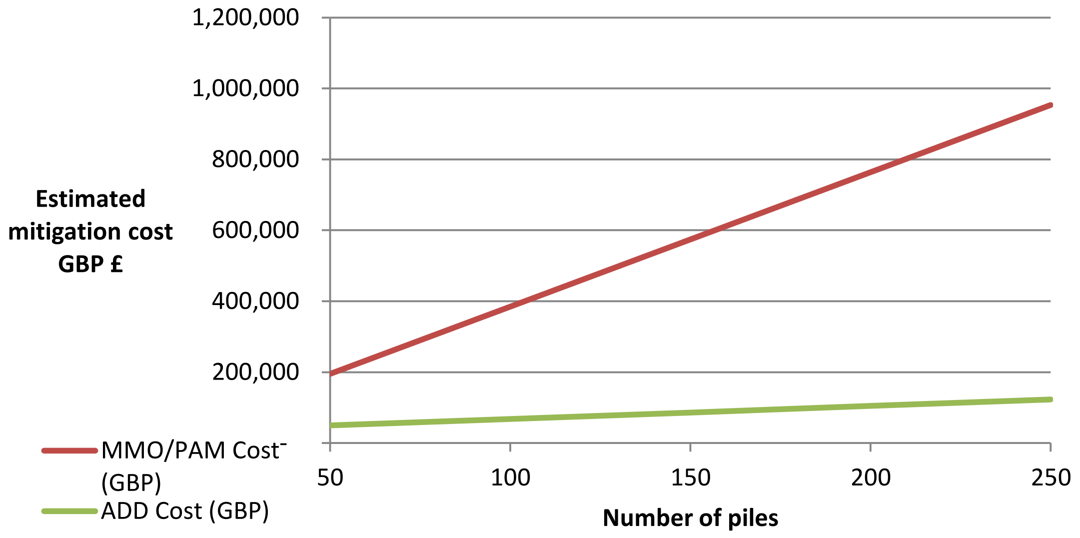


Figure 12: The relationship between estimated (direct) costs of the mitigation solutions versus the number of piles installed

The second finding relates to downtime and the additional costs that could be incurred due to delays arising from MMO or PAM limitations (reduced efficacy during poor visibility and high sea states). ADDs do not have the same limitations and it has been assumed that any technical risks associated with the reliability of the devices would be managed through normal procurement / QA processes.

Figure 13 illustrates the cost increase associated with different percentage downtimes, this is based on a baseline piling rate of 1 pile every 12hrs (for a 150 pile project). At 50% downtime the piling rate is reduced to 1 pile every 24hrs. Figure 14 shows the same information for 0% to 10% downtime, highlighting the additional vessel day rate costs incurred.

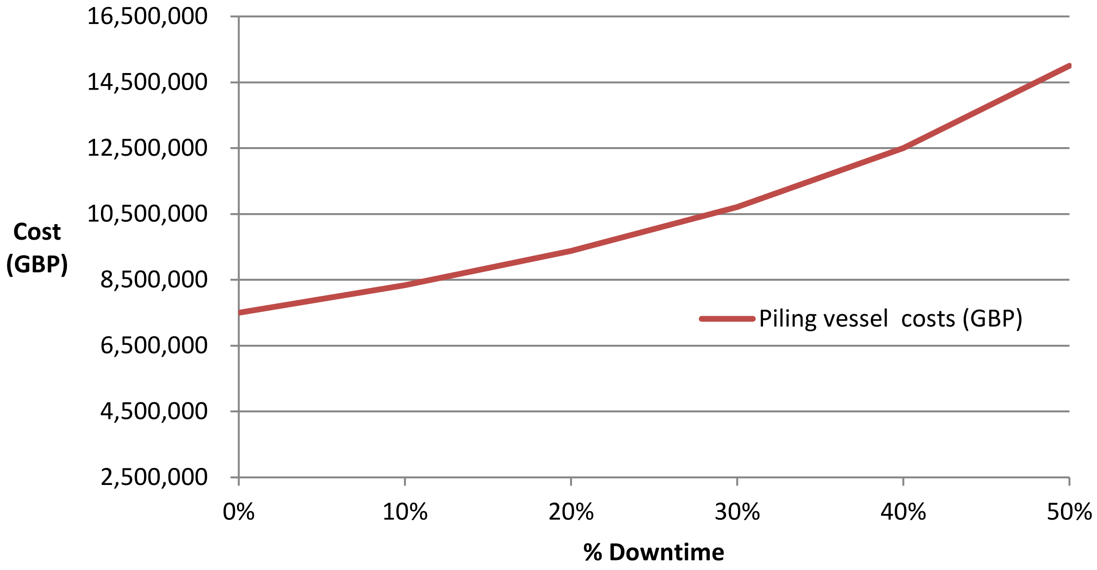
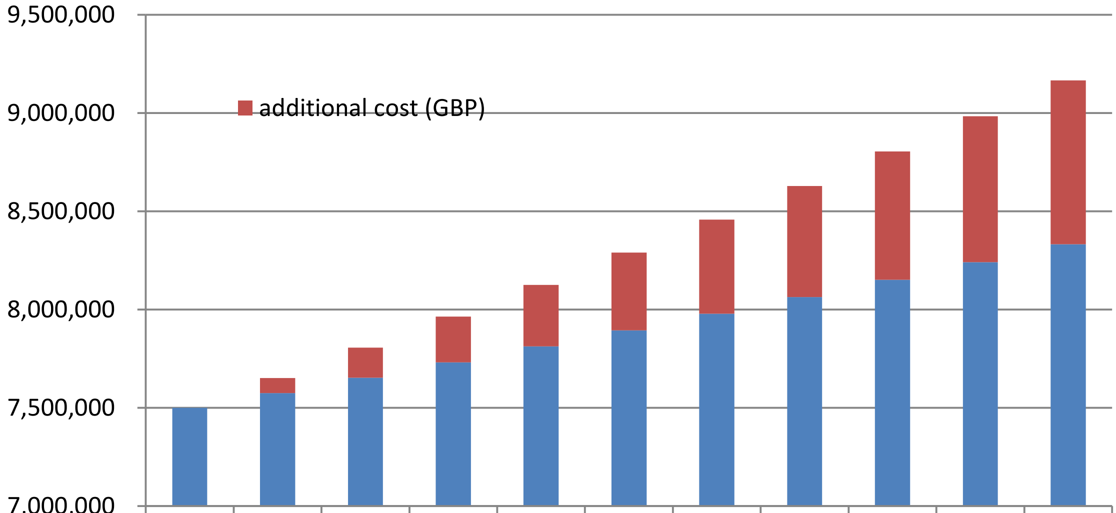


Figure 13: The impact of downtime on piling vessel cost



	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
additional cost (GBP)	-	75,758	153,061	231,959	312,500	394,737	478,723	564,516	652,174	741,758	833,333
Piling vessel costs (GBP)	7,500,00	7,575,75	7,653,06	7,731,95	7,812,50	7,894,73	7,978,72	8,064,51	8,152,17	8,241,75	8,333,33

Figure 14: The impact on vessel cost for downtime over the range 0% to 10%

8.4 Conclusion

The analysis carried out for this study has shown that the use of active mitigation using ADDs in place of MMO/PAM will have a direct financial impact on offshore wind farm pile installation costs. For a single OWF development of 150 monopiles this has been estimated as approximately £500,000. The table below shows how these costs change according to the number of piles installed (using a day rate of £100,000 and a piling rate of 1 pile every 12hrs). Should piling rate be higher than this – the relative benefit of using ADDs will decrease, and conversely should the piling rate decrease, the relative benefit of using ADDs will increase.

Table 15. Cost comparison of MMO/PAM versus ADD according to the number of piles installed

Number of piles installed	MMO/PAM Cost (GBP)	ADD Cost (GBP)	Cost Difference
50	194,598	49,750	144,848
100	384,248	68,000	316,248
150	573,898	86,250	487,648
200	763,548	104,500	659,048
250	953,198	122,750	830,448

The analysis carried out, as noted in section 2, is based on an assumption that MMO/PAM is deployed from a dedicated vessel whereas ADD's are deployed from the piling vessel. Where MMO/PAM is deployed from the piling vessel the difference in costs is reduced as shown in Table 16. Cost comparison of MMO/PAM versus ADD according to the number of piles installed, assuming MMO/PAM are deployed from the piling vessel below. It is noted that for wind farms constructed further offshore the deployment of MMOs and PAMs from the piling vessel may be used more frequently than standalone vessels.

Table 16. Cost comparison of MMO/PAM versus ADD according to the number of piles installed, assuming MMO/PAM are deployed from the piling vessel

Number of piles installed	MMO/PAM Cost (GBP)	ADD Cost (GBP)	Cost Difference
50	70,098	49,750	20,348
100	135,248	68,000	67,248
150	200,398	86,250	114,148
200	265,548	104,500	161,048
250	330,698	122,750	207,948

In addition to these direct savings the ‘active’ characteristic of ADD approaches have the potential to reduce uncertainty associated with passive approaches which are limited in efficacy during higher sea states and reduced visibility. Clearly the financial value of effective ADDs as a mitigation option which could enable piling operations during poor visibility is dependent on the site location and will vary due to metocean differences, propensity to fog and seasonal daylight hour variations. However a straightforward calculation based on the impact of downtime on overall pile installation schedule has been used to provide indicative results. For an installation campaign of 150 piles for a vessel costing £100,000 per day, installing piles at a rate of 1 every 12 hours, this has been valued at £830,000 for 10% downtime and £3.2 million for 30% downtime.

From a broader business case perspective the use of ADDs will also significantly reduce health and safety risks through the reduction of offshore man-hours; this is detailed in the phase 1 report (Herschel *et al.,* 2013).

9 Recommendations for future field studies: power analysis, methodologies and site evaluation

9.1 Background

Section 2 delivered a review of the available evidence for key UK marine mammal species for the potential effectiveness of ADDs for deterrence from injury impact zones around piling operations at offshore wind farms. In summary, the review concluded that there was a sufficient evidence base to be confident that the adoption of an ADD based approach to mitigation for harbour porpoises and seals would be at least as effective as, and probably better than the current practice of employing visual and acoustic MMOs. However, the review also concluded that there was limited evidence for minke whales and dolphin species. Therefore it was recommended that the feasibility of field trials be explored to investigate the effectiveness of ADDs for deterring minke whales and dolphin species from potential injury zones around piling.

This section is also informed by discussions held at the Discretionary Project Steering Committee (DPSC) and expert panel on the 6th August 2015 and presents an evaluation of different potential options for field testing of ADDs that can be carried forward to the next phase of this ORJIP project. A key question is whether ADDs are effective at excluding minke whales and/or dolphins from an agreed mitigation zone around the piling location. This evaluation is informed by a statistical power analysis, presented herein, carried out to understand the sample sizes required to ensure a robust field study has been designed.

Section 4 highlighted that the priorities for future ADD trials were an investigation into the effectiveness of ADDs for minke whale and dolphin species. In each section below, our recommended approaches for these studies is presented. In practice, conducting behavioural response studies can be an expensive and complicated operation, work at sea is challenging and several replicates may be required to capture and describe variable behaviours over a range of contexts and scenarios. Thus, it is essential to come up with an efficient and cost effective working method and to choose study sites where logistics are favourable, there is a good chance of finding sheltered waters and the appropriate animals are available in reasonable numbers. As minke whales and dolphins are less abundant and tractable than the species which have been the focus of previous ADD studies (e.g. seals and harbour porpoise) research may take longer.

Three elements of the potential field trials are explored in the following sections of the report: 1) A statistical power analysis to evaluate the likely sample size required (Section 8.2); an evaluation of the methodology that should be employed to carry out behavioural response trials (Section 8.3); and, 3), an evaluation of the potential field sites for each species (Section 8.4).

9.2 Power Analysis

9.2.1 Approach

Statistical power analysis is an important aspect of experimental design. It allows the determination of the sample size required to detect an effect of a given size with a given degree of confidence. Conversely, it allows us to determine the probability of detecting an effect of a given size with a given level of confidence, under sample size constraints. This is a particularly important step in advance of experimental studies of marine mammals as they are resource intensive. For example, conducting behavioural response studies can be an expensive and complicated operation; work at sea is always challenging and marine mammals not always predictably encountered. Therefore an understanding of the required scale of a project in advance of project commissioning is advantageous.

In the context of an experimental design to evaluate the effectiveness of ADDs, there are a number of interrelated considerations; these are:

1) The Sample Size (the number of control and treatment (ADD) trials that are required),
2) The Effect Size, i.e. the magnitude of the treatment (ADD) effect. In this context this is the level of ADD effectiveness which is a combination of the required distance that animals are required to be deterred to but also the proportion of animals responding to this degree. Traditionally in response studies, this is the most difficult part. Previous studies of the behavioural effect of ADDs have often measured several different aspects of the animal's behaviour to maximize the chance that a behavioural response is observed if it is present. This has involved measuring changes in direction of movement, respiration rates, directivity index, swim speed, etc. However, for this study, we are most interested in whether animals are excluded from a given area by the ADD. This can be distilled down to whether or not an avoidance response occurs at an agreed distance, which is a binomial measure (i.e. either a zero or a one). Focusing on this binomial measure simplifies the power analysis. A range of potential responses, e.g. animal within desired deterrence range moving out of it, animal within desired deterrence range stays within it; animal out with range moving into it, etc. can all be scored as a zero or one in the context of this question.
3) The Significance Level (P, the probability of falsely finding an ADD effect that is not present), and,
4) The Power - the probability of finding a significant effect from the ADDs that is real.

Recognising that defining the effect size is a regulatory issue, the power analysis was carried out across a range of estimates for effect sizes.

There are also two alternative study designs for behavioural response trials – 1) 'Independent': in which treatment (exposure to ADDs) and controls (no exposure) are carried out on two separate, independent groups of animals or 2) 'Crossover': in which each trial is conducted twice on the same animal (or group of animals) so that each two trials are carried out on each animal or group, a treatment and a control. A power analysis for both these designs was carried out. For clarity, the treatment involves moving the ADD into place, lowering it into the water and conducting a playback of the ADD. The control also involves moving the ADD into place at the same range, lowering it into the water, but not playing the ADD signal. This design acts as a control by allowing the response rate of animals to be measured for other parts of the experimental design. For example, the animals might respond to the presence of the boat that is lowering the ADD into the water.

Under a set of assumptions listed below, these power analyses suggest a minimum number of field trials to ensure that the experimental design has sufficient power to detect a positive deterrent effect of ADDs.

The assumptions were as follows:

- The animal either responds to the ADD playback or it doesn't – this involves setting a desired deterrence distance to enable us to determine experimentally whether an avoidance response occurred or not;
- The measured response is measured accurately – i.e. there are no false positives or false negatives;
- The power analyses assumes that successive trials are run in comparable spatial areas at comparable times of the day and year, such that there are no sample size considerations for variations in response related to covariates;
- The first power analysis is carried out for a crossover, or repeated measures design in which trials of both the treatment and control are applied to each animal/group. The second power analysis is carried out for trials applied singly to individual cetaceans/groups and assumed independent with no inter-trial correlations.

If these assumptions are violated, there may be less power than needed to detect the positive effect of the ADD, and the required sample size may be larger. Therefore it is recommended that methods are selected that can measure the defined response with certainty and that trials are carried out in similar conditions. It should be noted that additional trials to understand the effects of covariates such as environmental conditions would require larger sample sizes.

9.2.2 Results

The results determine the minimum sample size required to detect an effect of a given size with a given degree of confidence (power). The power analysis approach is shown through two figures; Figure 15 translates the control response rate and the treatment response rate into an Effect Size (which we later translate to a sample size). For example, where the treatment response rate is 0.7 (i.e. 70% of animals exposed to a playback respond) and the control response rate is 0 (no animals leave the area during the control playback) then the effect size is shown on the y-axis as 1.98. If a relatively small number of animals respond to the control (perhaps as a response to the presence of the vessel itself) and the control response rate is 0.25 (a quarter of all control animals respond) then the effect size reduces to 0.94.

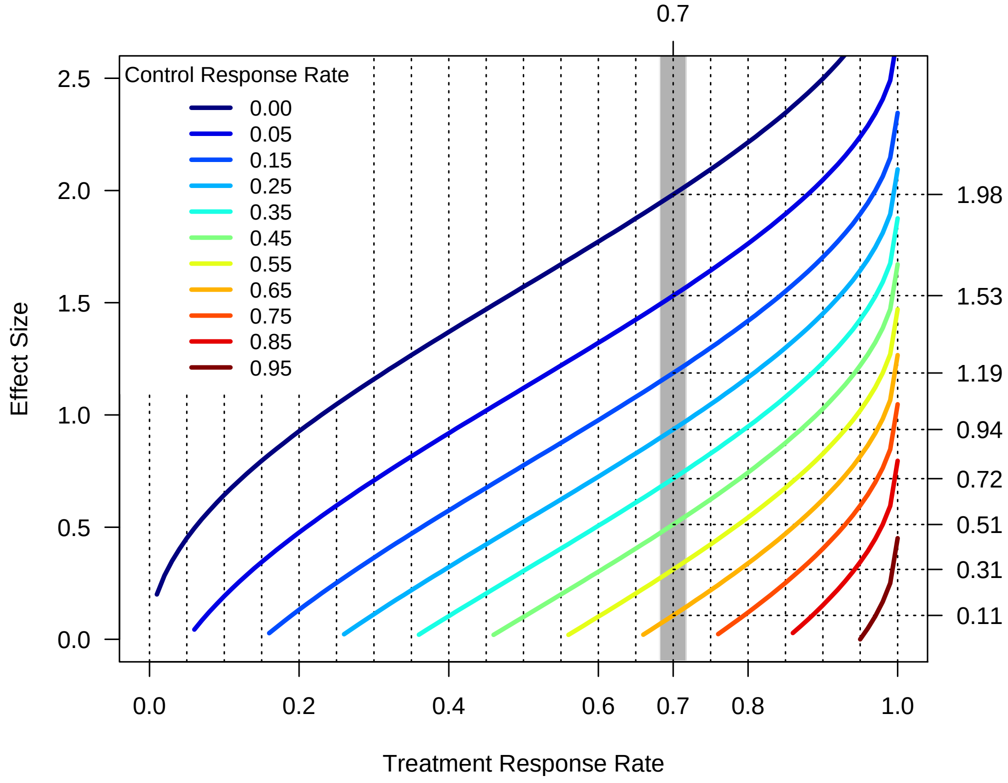


Figure 15. Effect size in relation to treatment and control response rates. The x-axis corresponds to the proportion of trials that respond to the ADD (Treatment Response Rate). Each coloured line corresponds to a range of response rates in the control trials. The y-axis corresponds to the calculated effect size.

Figure 16 translates these Effect Sizes to Sample Sizes for the crossover design and provides, as an example, sample sizes for a statistical power of 0.8 (the trial has an 80% chance of detecting a statistical effect, by convention, 80% is an acceptable level of power (Parry, 2004). Here we have used a one-sided hypothesis that tests if the proportion of positive trials in the treatment group is “greater than” the proportion observed in the control group. We have assumed a statistical significance of 0.05 (there is only a 5% probability that the results could have happened by chance, rather than a treatment effect), and a statistical power of 0.8. Trials in this figure are the total number of playbacks (control and treatment) that are needed. Since this figure deals with a crossover design where each animal or group of animals serves as its own control, the actual number of animals or groups of animals needed for the study is the number of trials divided by two (rounded up to a whole number). Although it is important to note that the number of trials may be a better indicator of the amount of work that needs to be done or the amount of time that it will take.

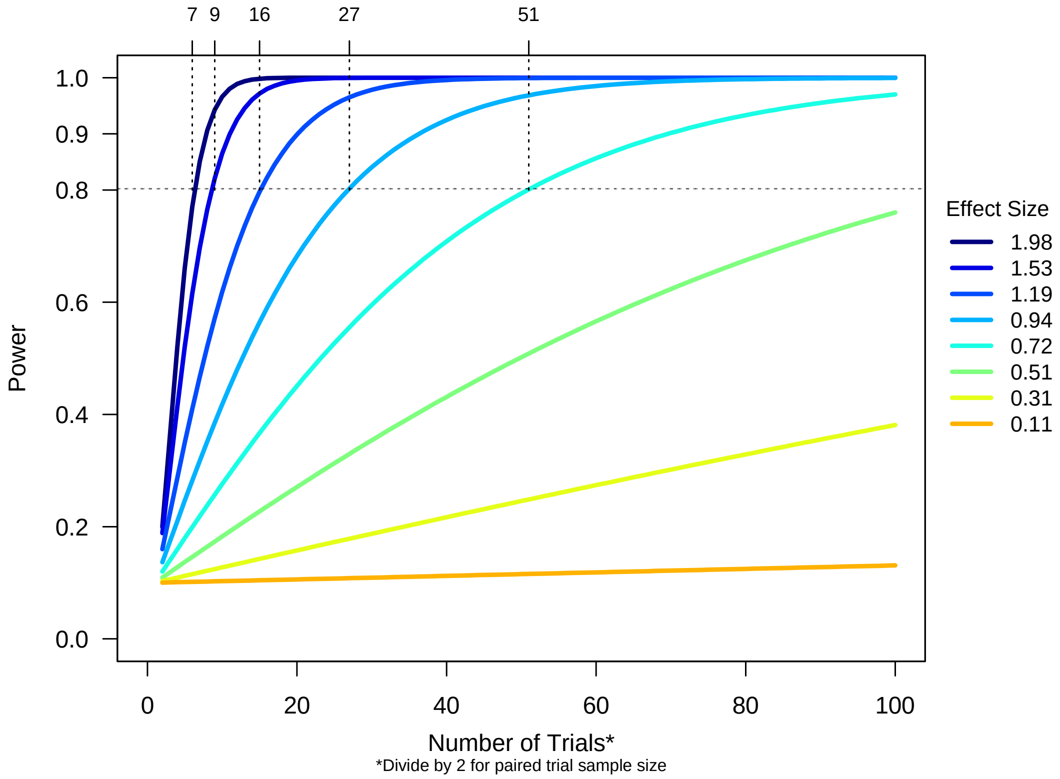


Figure 16. Minimum sample Sizes for a one-sided hypothesis testing if positive response probabilities are greater in the treatment group verses the control groups (Chow *et al*., 2003). The horizontal line for 80% power is drawn, and sample sizes for 80% appear along the top axis. To determine the number of animals / groups needed, divide the number of trials by two and round up any non-integers.

So for example, suppose the treatment response rate is 0.7 (70% of animals exposed show a response), and the control response rate is 0.0 (i.e. under control scenarios the animals show no response). The effect size is 1.98, and the minimum sample size is 7 trials, since 7 trials can't be divided by 2, the sample size rounds up to 8, giving a minimum sample size of 4 paired trials (Table 17). Or suppose the treatment response rate remains 0.7, but the control response rate is higher, at 0.35. This corresponds to an effect size of 0.72, and the minimum sample size is then 51 trials or 26 paired trials on different animals / groups of animals.

Table 17 presents sample sizes for a crossover design, where each animal acts as its own control and is exposed to both treatment and control field trials in a random order. Table 18 presents sample sizes for a design where treatment and control trials are carried out with two different groups of animals.

Table 17. Minimum sample sizes (i.e. number of animals / groups of animals) for a repeated measures design in which each animal is exposed to both treatment and control field trials in random order (i.e., a 2-sequence, 2-period, 2-treatment crossover design, or 2 × 2 crossover design; McNemar Test, (Connor, 1987). This power analysis is based on a design that tests if within-subject positive response probabilities are greater for treatment vs control trials.

Treatment Response Rate	Control Response Rate	Effect Size	# of animals / groups with 80% Power	# of animals / groups with 90% Power	# of animals / groups with 95% Power
0.5	0	1.57	6	7	8
0.5	0.05	1.12	8	10	12
0.5	0.15	0.78	16	21	26
0.5	0.25	0.52	37	50	63
0.5	0.35	0.3	116	160	202
0.5	0.45	0.1	1174	1626	2054
0.6	0	1.77	4	6	7
0.6	0.05	1.32	6	8	9
0.6	0.15	0.98	11	14	18
0.6	0.25	0.72	21	28	35
0.6	0.35	0.51	46	64	80
0.6	0.45	0.3	144	198	250
0.6	0.55	0.1	1421	1968	2487
0.7	0	1.98	4	4	5
0.7	0.05	1.53	5	6	7
0.7	0.15	1.19	8	11	13
0.7	0.25	0.94	14	19	23
0.7	0.35	0.72	26	35	44
0.7	0.45	0.51	56	77	97
0.7	0.55	0.31	171	237	298
0.7	0.65	0.11	1669	2311	2920
0.8	0	2.21	3	4	4
0.8	0.05	1.76	4	5	6
0.8	0.15	1.42	6	8	10
0.8	0.25	1.17	10	13	16
0.8	0.35	0.95	17	23	28
0.8	0.45	0.74	31	42	53
0.8	0.55	0.54	66	91	115
0.8	0.65	0.34	199	275	347
0.8	0.75	0.12	1916	2653	3353
0.9	0	2.5	3	3	3
0.9	0.05	2.05	3	4	4
0.9	0.15	1.7	5	6	8
0.9	0.25	1.45	8	10	12
0.9	0.35	1.23	12	16	20
0.9	0.45	1.03	20	27	34
0.9	0.55	0.83	36	49	62
0.9	0.65	0.62	76	105	132
0.9	0.75	0.4	226	313	395
0.9	0.85	0.15	2163	2996	3786

Table 18. Minimum sample sizes (i.e. number of animals / groups of animals) for design with separate groups for control and treatment response trials. The number of trials corresponds to the total number of trials of Treatment and Control groups (i.e., assuming equal trials for each of treatment and control groups). This power analysis is based on a design that tests if positive response probabilities are greater in treatment compared to control groups (Chow *et al*., 2003).

Treatment Response Rate	Control Response Rate	Effect Size	# of animals / groups with 80% Power	# of animals / groups with 90% Power	# of animals / groups with 95% Power
0.5	0	1.57	12	14	18
0.5	0.05	1.12	20	28	36
0.5	0.15	0.78	42	58	72
0.5	0.25	0.52	92	126	158
0.5	0.35	0.3	268	370	468
0.5	0.45	0.1	2466	3416	4316
0.6	0	1.77	8	12	14
0.6	0.05	1.32	16	20	26
0.6	0.15	0.98	26	36	46
0.6	0.25	0.72	48	66	84
0.6	0.35	0.51	98	134	170
0.6	0.45	0.3	274	378	478
0.6	0.55	0.1	2416	3346	4228
0.7	0	1.98	8	10	12
0.7	0.05	1.53	12	16	20
0.7	0.15	1.19	18	26	32
0.7	0.25	0.94	30	40	50
0.7	0.35	0.72	50	68	86
0.7	0.45	0.51	96	132	166
0.7	0.55	0.31	256	354	448
0.7	0.65	0.11	2168	3002	3794
0.8	0	2.21	6	8	10
0.8	0.05	1.76	8	12	14
0.8	0.15	1.42	14	18	22
0.8	0.25	1.17	20	26	32
0.8	0.35	0.95	28	40	50
0.8	0.45	0.74	46	62	80
0.8	0.55	0.54	84	118	148
0.8	0.65	0.34	216	300	378
0.8	0.75	0.12	1722	2384	3012
0.9	0	2.5	4	6	8
0.9	0.05	2.05	6	10	12
0.9	0.15	1.7	10	12	16
0.9	0.25	1.45	12	18	22
0.9	0.35	1.23	18	24	30
0.9	0.45	1.03	24	34	42
0.9	0.55	0.83	38	52	64
0.9	0.65	0.62	64	90	112
0.9	0.75	0.4	152	212	266
0.9	0.85	0.15	1072	1486	1878

9.2.3 Conclusions

The minimum sample size (animals or groups) required to have an adequate amount of statistical power, and therefore to provide a robust set of trials, clearly depends on several factors. In this context the main factors driving the sample size requirements are the experimental design and the difference between the treatment response rate and the control response rate. The crossover design requires a lower sample size (fewer number of animals) than the independent groups design, however as discussed above the number of trials may be the most relevant measure as in the field the ability to repeat a 2nd trial on the same individual may be as high as acquiring a new animal at random.

While a desired size of treatment effect may be simple to define, and for this context it is more likely that response rates at the upper end of the range are desirable (likely upwards of 70%), it is more difficult to predict what the control response rates might be. In an ideal world these should be zero but we cannot rule out that a response might occur to the presence of the vessels used for playback or tracking, or to the methods used for tracking (e.g. tagging). The results presented here clearly highlight the need for the choice of methodologies to take this into account – i.e. methods should be chosen which minimise the chance of control responses.

Although site dependent, it is most likely that data collection and ADD playbacks will need to occur from one or more research vessels. The chance of a control response will vary based on the location, context, previous experience and species of animal studied, but it may be illustrative to consider published behavioural effects of whale watch boats on marine mammals. Cetaceans have been shown to react to whale watch boats. For example, bottlenose dolphins changed their behaviour and were more likely to exhibit 'side flops' when whale watch boats were intrusively interacting (e.g. following closely) (Lusseau, 2006). Interestingly, that study was not able to find an effect on the dolphins from the research vessel itself, suggesting that there are ways to effectively minimize control effects from research vessels. In killer whales, 'surface active behaviour' is highest when whale watch boats are less than 150 m (Noren *et al*., 2009) from the animal. In minke whales, whale watch boats decreased the amount of time individuals spent foraging (Christiansen *et al*., 2013). Whale watch boats during that study were on average 350 m away from the whales.

In all these studies, distance makes a difference on the level of the effect, and the effects in these cases were changes of behavioural state or increases in specific behaviours, but not an exclusion of animals from a given area. Given that the trials will focus on avoidance distance from the ADD, and that whale watching boats generally approach much closer than is required for this work, it is unlikely that the control response will be very high. Therefore, if we take a 'worst case' scenario where treatment response is at the lowest end of what is likely an acceptable response rate (70% response), and control response is on the higher end of what is likely given the distances needed between the observation vessel and the animal and the care of experience researchers in approaching animals (25%), and the fact that only a relatively large response (i.e. movement away from the device to at least 500 m) will be considered a response, then under this scenario a minimum of 14 animals or groups of animals would be needed as to conduct the ADD experiments with a power of 80%.

Given the extent of the response required to be considered a suitable response to ADDs is actually a large degree of responsive movement (greater than 500m) and given the ability of the researchers to minimise the effect of the research vessel (described above), we could consider a design where no controls are carried out. However, even under this assumption that control rates will be zero, it would be a conservative approach in that instance to assume the same sample sizes are required. Therefore a suitable sample size to demonstrate a response rate of 0.7 and above would be a total of 14 trials using the crossover approach. If the independent groups approach was undertaken the sample size required would be 30 trials (see section 2.1 for details of the two approaches).

Although it is important to note that the work carried out by Gordon *et al.,* with tagged harbour seals did not involve controls, yet still adequately identified the degree and range of responses. In this study in the Moray Firth the sample size was higher, with a total of 51 CEEs with 13 tagged individual seals. However given the possibility that minke whales and dolphins may respond to vessels, we would recommend an adaptive approach whereby the data are incrementally analysed to assess the need for further controls. The design could be tiered to include controls in the first 5 or 6 trials and then the data re-evaluated. If the controls are consistently zero or near zero, the controls could be stopped in future trials. If they are not, then controls are continued.

9.3 **Methodology Review and evaluation**

9.3.1 Introduction

Section 4 concluded that there was sufficient evidence from studies on harbour seals and harbour porpoises that an ADD based approach to mitigation would be at least as effective, if not more so, than current standard mitigation methods for those species but that data were lacking for efficacy in displacing minke whale and dolphin species. This was discussed by the Discretionary Project Steering Committee and Expert Panel at a meeting on the 6th August 2015 (ORJIP-ADD study – P2S1-Acceptance and methodology workshop – 06Aug15 MoM FINAL.pdf). Section 5 provided a high-level review of the potential methods that could be used to measure animal responses to ADD playbacks. These included captive studies; measuring changes in abundance; telemetry tracking (i.e. animal borne tags); and visual tracking. As the least is known about the efficacy of ADDs in excluding offshore dolphin species and minke whales from a given area, this section focuses on these two groups of animals. While it is potentially possible to conduct captive studies on representative dolphin species, this is clearly not possible for minke whales. In addition, it has proven difficult to infer behavioural reactions of wild animals from captive animals. Therefore captive studies are not further considered in this report.

Changes in abundance can be measured by visual surveys or by Passive Acoustic Monitoring (PAM). Visual surveys of offshore species are conducted by shipboard or aerial transects. However, these are typically designed to cover large areas efficiently, and, due to the low densities of most marine mammal species, large amounts of effort are required to achieve sufficient power to detect change in densities. It takes long periods of time to make a sufficient number of detections in a relatively small area. There is therefore a mismatch between the spatial and temporal scales needed to detect change in abundance for an ADD playback (small spatial and temporal scales) and those of an offshore visual survey (large spatial and temporal scales). It has been considered that in order to better match the spatial scales of the ADD playback with that of the abundance survey, one could utilise stationary PAM which uses fixed hydrophones which monitor over relatively small areas. Unfortunately, there are several limitations in this approach to understanding the efficacy of ADDs. The first is a similar temporal scale mismatch between the study designs as discussed for visual surveys. PAM deployments need to be long-term in order to collect sufficient data for low density species while ADD for pile driving mitigation would be used only over short time scales. Additionally, observed changes in the acoustic detections of the study species could be caused by the animals moving away or alternatively because they reduced their vocalisation rates. Thus additional work would be required to clarify how ADDs affect vocalisation rates. Although harbour porpoise are expected to vocalise more or less continuously, this is not the case with other dolphin species and therefore static PAM deployments are less suitable for detecting responses in dolphins. Minke whales in the North Sea do not vocalise at a high rate and it’s probable that call rates are seasonal and vary between sexes. Furthermore, static PAM as a means of detecting responses to ADD rely on reasonable baseline detection rates characterised over a sufficient period to ensure enough statistical power to detect a reduction in vocal activity, however we lack knowledge of areas of predictable encounter of dolphins at a sufficiently fine scale. For these reasons, research to measure changes in abundance directly (either visually or by PAM) will not be considered further in this report.

This methods section will, as a result, focus on telemetry and visual (video) tracking methods for ADD playback studies to measure behavioural changes and movements in response to ADDs.

9.3.1.1 Telemetry tracking

Telemetry tracking involves attaching a sensor tag to an individual animal. There is an extensive literature base that documents the different species-specific approaches. In summary, this can be achieved via adhesive, an anchored attachment, or a suction cup. Tagging of dolphin species has been done both by capturing the animals (e.g. Rasmussen *et al*., 2013) or by using a pole (e.g. Sakai et al., 2011,) Both barbed and suction cup tags have been attached to minke whales (Heide-Jørgensen *et al*., 2001; Víkingsson & Heide-Jørgensen, 2005, Víkingsson & Heide-Jørgensen, 2015), but tags are very difficult to attach to minke whales (animals are difficult to get close enough to tag and suction cup type tags are reported to easily detach (Kvadsheim *et al.,* 2011)) similar concerns apply to small cetaceans.

It should be noted that attaching tags to animals can also cause behavioural responses (Kvadsheim *et al*., 2011) which complicates the determination of responses, and tags may have metabolic costs for the tagged animal (van der Hoop *et al.,* 2014).

A range of different sensors can be incorporated into different types of tags. Tags can record the surface location of animals (e.g. SMRU GPS/GSM Phone tags and Pathtrack GPS/UHF tags), their depth while submerged (e.g. Wildlife Computers' Mk5 and SMRU GPS/GSM tags), relative three dimensional movement with accelerometers (e.g. Wildlife Computers' TDR10, DTags) and acoustic exposure and vocalizations (e.g. DTAGs, Acousonde). Many tags combine several different sensors. Tags can generate a great deal of information about the behaviour of the tagged animal.

An effective series of behavioural response trials with any ADD requires that a significant number of trials can be conducted at the ranges of interest. Studies of the movements of tagged seals suggest that the likelihood of a tagged study animal approaching a fixed ADD test site is small. Given the sample size constraints in telemetry based studies it is unlikely that sufficient trials could be carried out with a stationary source, even where animal movements are reasonably predictable. Therefore, in order to conduct sufficient behavioural response trials with tagged animals it would be essential that the ADD source is mobile and can be positioned close to or in the path of tagged study animals. This further requires that we are able to locate and observe the recent tracks of study animals in near real-time. This severely limits the choice of telemetry system. In the past, real time tracking systems based on a combination of VHF radio and acoustic pinger tags or using ARGOS satellite transmitters with boat based direction finding systems have been used to conduct behavioural response trials (e.g. Kvadsheim *et al.,* 2011). However, the former are labour intensive and require a dedicated vessel in continuous contact with the tracked animals and the latter has suffered from low spatial and temporal resolution. In response to this requirement there have been two major tracking system developments. High resolution GPS locations are now available from marine mammals during their short surface periods through the development of the FASTLOC® GPS system. These sensors have been incorporated into both ARGOS tags and purpose built GSM phone tags and UHF radio tags.

In a recent study for Scottish Government a purpose-built UHF tracking system was developed for conducting behavioural response trials with ADDs. The system allows long-term remote monitoring of marine mammal movements from land based recording stations but more importantly also allows for boat-based real time tracking. The system comprises GPS logging UHF transmitters and a boat based (computer based) receiver and GPS decoder. Data from the receiver/decoder is fed directly to a mapping package that displays locations of all tagged animals in line of sight and the positions of the tracking vessel and playback system. This has proven effective in facilitating ADD trials with harbour seals. A similar system based on modified GPS/GSM transmitters could be developed for tags that could be attached to minke whales and dolphins. More remote tracking involving more widely ranging species would require the addition of a satellite transmitter to facilitate relocation of animals out of line of sight range. This is considered to be achievable with the currently available technology. For example this would involve the addition of a small satellite transmitter such as the Wildlife Computers SPLASH tag.

Existing transmitters capable of delivering this real time tracking (RTT) capability are similar in size to devices currently deployed with suction cup attachments on cetaceans. Incorporating small satellite transmitters to provide a wide/long-range capability is expected to be relatively simple and have little effect on the package size. The timelines and costs involved in such development would require detailed investigation.

9.3.1.2 Visual tracking

Visual tracking involves the measurement of an animal's surface location using a theodolite, binoculars, video or still camera. Typically these measurements have been made from an elevated location, on a number of different platforms. All visual based methods are weather dependent as sea state, glare and other factors will reduce the ability of observers to see animals at the surface. The risk of interfering with the observed animal's behaviour will be influenced by the type of platform is being used. The main drawback of visual tracking methods (whether drone, land or vessel based) is that marine mammals are only observable at or near the surface and capturing reliable tracks of animals depends on the ability to detect and link series of surfacings. Consideration must be given to the potential dive durations of the animals and the possibility that animals can move relatively long distances when submerged. There is a great deal of variability in reported surfacing intervals for minke whales (Stockin *et al.,* 2001; Dorsey *et al.,* 1989). Surfacing intervals of minke whales on the west coast of Scotland were 66 secs on average. This is similar to average dive durations of Icelandic minke whales (Gunnlaugsson, 1989; Joyce *et al.,* 1990). Baumgarter (2008) presented estimates of surfacing intervals of minke whales in the Moray Firth, Scotland which varied depending on activity. Surfacing intervals of minke whales off the coast of Norway were longer with a mean of 85.7 seconds (Øien *et al.,* 1990). In the study by Stockin *et al.,* 2001 surfacing rates were highly variable ranging from 1-806 seconds. This upper end of the range corresponds to 13.4 minutes. Given a reported average horizontal speed of 2.7 km/hr (Heide-Jorgensen *et al.,* 2001), a whale could move 600 m during this time, i.e. completely out of a 500m deterrence zone. This puts particular emphasis on being able to track animals prior to exposure to be able to differentiate between responses to the ADD and normal travelling behaviour.

9.3.1.3 Land based

Land based visual tracking has been used successfully to track a range of marine mammals from large baleen whales (e.g. humpbacks; Harcourt *et al.,* 2014) to small harbour porpoise (e.g. Kyhn *et al.,* 2012) using theodolites which measure the vertical and horizontal angle to the object of interest (in this case the marine mammal) from an observation point at known height. A similar approach can be taken with reticule binoculars, but with a lower accuracy. Video and still cameras can also be used to accurately estimate the location of surfacing animals from a vantage point (e.g. Hoekendijk *et al.,* 2015). Reticule binoculars will have a very low accuracy.

Land based visual techniques have the benefit of being relatively cost effective and safe since observers remain on land and there is no possibility of the observer influencing the behaviour of the animal. The downside of land based observations are that the near shore environment will not be greatly representative of the offshore environment in which Round Three and Scottish Territorial Waters offshore wind farms will be installed. In addition, the density of offshore species within visual sight of land may be lower than areas which can be targeted offshore thus reducing potential sample size. The range within which reliable observations can be made from land is also limited to a kilometre or so and there is no scope for moving to find concentrations of animals or sheltered weather conditions.

9.3.1.4 Vessel based

Like land-based visual tracking, theodolite, reticule binoculars, video or still cameras can be used to track animals from vessels. Although theodolites have been used (e.g. Holt *et al.,*2011), other methods, such as photogrammetry using video images showing the horizon, are better suited for moving platforms (e.g. Gordon, 2001; Soto *et al*., 2013; Tixier *et al*., 2014). Boat movement can reduce the accuracy of location estimates as can the relatively lower elevation of observation points; however reported accuracies are certainly adequate for this application. One advantage of this approach is that the observers can typically be closer to the animal which reduces the error in position estimates (error increases with range from the animal). Vessel based tracking does have the advantage of being able to follow the animals that are being tracked. A closer proximity can improve the accuracy of location estimates, but comes at an increased risk of causing disturbance or behaviour change in the subject animals. Vessel based observers are also in a better position to assess received sound levels at the target animal.

9.3.1.5 Vessel based with drones

Consumer grade drone technology has recently seen huge developments in their sophistication and reliability and reduction in costs. Current models can be launched and retrieved vertically from small vessels (i.e. like helicopters), are easy to fly, can be programmed to hover over certain locations, and can carry high resolution video cameras. They are currently being used on a number of marine mammal projects. For example, they are being used to assess the nutritional health of killer whales by measuring the girth of different animals over time[12]:

The minimum flight height above the whales used in that study was 100 feet (30 m). The view of marine mammals from a drone is surprisingly good and animals can be seen even when submerged at shallow depths which is not possible when visual observations are made from an oblique angle. While drones could cause a change in behaviour, this likelihood should be small from the higher altitudes needed to monitor 500 m exclusion zones and due to the small size of current drones. For example, drone monitoring of humpback whales from typical heights of 125 to 150 feet (38 – 46 m) and even as low as 10 feet (3 m) have not shown disturbance to the animal being monitored[13]:

A fairly standard video system used on drones is a GoPro Hero 3 which can record video at three different angles of view (90, 127, 170 degrees). To monitor a 500 m exclusion zone, and using the widest video option available (170 degrees) would require the drone to hover at a minimum of 44 m. For the medium angle, the minimum height would be 250 m. At either of these heights, any effect on the study subject is likely to be minimal.

Measurement accuracy from drones can be high; drones are used to measure length/girth/etc. of killer whales by using parallel lasers on the video camera that allow for a scale reference. This technique probably allows 1 cm accuracy, which is much higher than required for this application. In this case there will be a small boat deploying the ADD in the frame. The length of the boat is known and can be measured in the image and thus have a reference scale in each video frame. The height of the drone can also be monitored. However, a GoPro set to the medium angle of view uses a barrel distortion to achieve the wider angle. This means that the accuracy of this type of visual calibration will reduce at the outer edge of images. It will be possible to correct this distortion by using a calibration in OpenCV[14] or in Matlab[15]. It will be possible to pre-calibrate camera units over land with marked chess squares to determine a) how best to calibrate, b) determine actual calibrations for each camera, c) calculate what the actual measurement errors are likely to be, and d) what is the best combination of camera angle and height to achieve the goals of the study.

Drones do however suffer from relatively short flight durations. Most consumer grade models on the market today report flight times of 15 to 20 minutes. Ideally the monitoring time of the drone should match the time over which ADDs are planned to be used before pile driving ramp up commences, as well as for a short period afterwards to continue to track the animal once the exposure ends. If the period of ADD deployment is 15 minutes, then single drones will be on the outer limits of their capability, especially if time required before the ADD exposure to set up the correct positioning for the CEE.

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[12] http://www.fisheries.noaa.gov/podcasts/2014/10/aerial_vehicle_killer_whale.html#.VefA2xHBzGc

[13](http://www.takepart.com/article/2015/08/07/drones-for-good-tiny-flyers-may-help-save-rarest-humpback-right-whales.

[14] http://docs.opencv.org/doc/tutorials/calib3d/camera_calibration/camera_calibration.html

[15] http://www.vision.caltech.edu/bouguetj/calib_doc/

Many drones have a simple plug and play battery system so that can be swapped in less than 30 sec by a trained operator. The time consuming aspect would be flying the drone back to the boat for battery swap (which needs to be done with care to avoid injury to the drone or people on the boat) and then flying back to being ‘on scene’. This would miss too much monitoring in the middle of the trial. A solution to this could be to use two drones that operate in a staggered ‘tag team’ manner to ensure complete coverage. Therefore three drones in total with one spare would be the recommended approach.

An alternative aerial based system would be a heli-kite (http://www.allsopp.co.uk/) which is tethered like a kite, but the lift is provided by a helium balloon. This allows it to hover for much longer periods than a drone, and can equally be fitted with high resolution cameras. They are also likely to work more reliably in higher wind situations than drones, but would need to be tethered to the research vessel. This will mean the vessel will need to keep its distance from the animals to avoid disturbance but also stay upwind of the whales to keep the heli-kite loosely overhead the animals.

9.3.2 Recommended ADD playback methodology

The feedback from the SNCBs and the expert meeting was that the minimum objective of these ADD playbacks is to test the effectiveness of ADDs in deterring minke whales and dolphins out of a 500 m zone around the active ADD in an offshore setting similar to those that will be experienced by UK Round Three and Scottish Territorial Waters offshore wind farms. It would be best to work in offshore locations or locations that are most similar. A stationary study site may not be feasible for a short term study (i.e. a single summer season) and the study will need to occur from a mobile vessel to ensure that the ADD sound source can be located at appropriate ranges and locations around marine mammals.

To minimize disturbance the observation boat should be as quiet as possible, in previous studies motor sailing yachts have been used to good effect (e.g. Gordon *et al.*, 2015); for practical reasons it is suggested that an additional smaller vessel (e.g. a RIB) should be used for moving and playing back the ADD sound source. To control for the potential disturbance from the observation and playback vessels, the study design could incorporate ‘controls’ where the playback and observation vessels are moved to the location where a playback would occur, and the ADD is lowered into the water but no sound is played back. This will allow for the comparison of behavioural response between ‘control’ and ‘treatment’ (i.e. active playback) trials. These control and treatment trials could be done on different animals/groups or applied to each animal/group in a random order if animals could be identified and tracked. Preferably, this would be done in a ‘double blind’ fashion, such that both those in the playback boat and those measuring the response do not know which trials are controls and which are treatments.

However as also stated above, if the likelihood of any control response is very low then a more pragmatic approach will be to carry out treatment trials without associated controls. In section 2 we recommended an adaptive approach with a tiered design which includes controls in the first 5 or 6 trials. If the controls are consistently zero or near zero, the controls could be stopped in future trials. If they are not, then controls are continued.

Previous studies of the behavioural effect of anthropogenic sounds have often measured many different aspects of the animal's behaviour to maximize the chance that a behavioural response is observed if it is present. This has involved measuring a whole suite of behavioural variables. However, for this study, as discussed in section 2, we are most interested in whether animals are likely to be excluded from a given area by the ADD. This can be distilled down to whether or not the animal responded at a distance that would be considered required for effective mitigation which is a binomial measure (i.e. either a zero or a one). An animal that is outside of this desired range at the start of an ADD playback that moves away would still be considered a response but a lack of a response at this range, while still noted, would be neither be considered a response or otherwise. Focusing on this response/no response metric has a number of advantages. It tests the effectiveness of the ADD directly while keeping the measurement of the behavioural response as simple as possible and thus shifts questions of efficacy from something potential like "how much of a change in direction is needed to be considered effective" to "what proportion of animals need to respond at an appropriate distance to be considered effective". It also simplifies the power analysis and improves the power of the statistical tests. In practical terms it may not be straightforward to simply measure exclusion from a 500m zone around the animal due to the difficulty in positioning the ADD close to the animal. In reality the range of distances achieved in field trials are likely to be variable and as such, the question turns more into one of "what is the probability of response at a range of distances?" and the test is whether or not the probability of response is high enough within the agreed mitigation distance. Box 1 provides a protocol for a "Controlled Exposure Experiment".

Box 1: Protocol for Controlled Exposure Experiments

- Carefully manoeuvre the observation platform into a location in which data can be collected without disturbing the subjects
- Collect pre-exposure data (locations, tracks, surface cue rates). Identify individuals if possible.
- Bring the playback vessel to an appropriate location to conduct the CEE.
- Activate the ADD for an appropriate length of time (suggest 15 minutes).
- Collect data on position of animal during the exposure.
- Continue to track animal and collect data after the exposure.
- During post trial analysis (quite possibly ashore after the field season) calculate and plot animated tracks of animals, observation platform and playback vessel.
- Determine and record range from ADD and predicted received levels at start and end of ADD exposure.
- Make an assessment of whether there was an avoidance response or not. Do this as objectively as possible, ideally compare results from more than one independent assessment team. Possible results- Avoidance, No Avoidance or Missing data i.e. trial not considered adequate for making this assessment e.g. animal already heading away at start of ADD playback.

- An assessment could be made from these data as to whether the trial provides evidence that animals would be deterred beyond a specified range R. The trial would be assumed to be positive if:
- An avoidance response was scored at a range greater than R, or if:
- An avoidance response scored and at the end of the ADD exposure animals are further from it than R.

Note: animals that do not show a clear response but end up further away than R are fails.

The simplest way to measure the reactions of marine mammals to the ADD would be using visual observers from an elevated position on-board a survey vessel, capable of conducting focal follows and tracking animals using video or still camera tracking methods. Drones or Heli-kites could be used off the same platforms without compromising the more traditional tracking approach to explore whether they could provide additional and more detailed data.

Once located, the animal (or group of animals) can be tracked over a period of time to get an understanding of the behaviour of the animal; if the animal is travelling in a discernible direction the aim will be to manoeuvre the ADD source in front of the animal directly in its path, and continuing visual tracking will determine if the path of the animal changes. If the animal is not engaging in directed movement the aim will be to manoeuvre the ADD source to within 500 m of it. As discussed above, the main drawback of visual tracking methods (whether drone land or vessel based) is that marine mammals are only observable at or near the surface and there is a possibility that animals can move relatively long distances when submerged. Minke whales may be able to travel greater than 500m during a long dive and therefore it is recommended that an area greater than 500 m around the source is monitored for subsequent surfacings. It is important to be able to distinguish between real deterrence (animal has left the area in response to the ADD) and an inability to detect subsequent surfacings because they are out of range.

Tagging data could be very useful in this respect. Tagging studies will be challenging however. For example, despite some considerable effort, researchers working on the 3S study in Norway and Iceland achieved only limited success with tagging minke whales due to a combination of animals being difficult to approach and poor suction cup attachment (generally believed to be as a result of the properties of the whales' skin) (Kvadsheim *et al.*, 2012 and Patrick Miller, pers comm). Previous attempts to tag minke whales in UK waters were also unsuccessful for similar reasons (Simone Panigada, pers comm). It is unlikely that the required sample sizes suggested by the power analysis presented above will be achieved using tagging alone however, even a modest contribution to compliment and support a larger sample of visual only tracking data might be very informative.

In summary, the recommended ADD playback methodology would involve a primary vessel with an elevated platform and visual observers and trackers, a secondary smaller vessel and aerial video cameras. The primary vessel would be to locate and track the subject animals. Towed hydrophones will be useful for locating dolphin groups. An aerial camera could also be deployed. The secondary vessel would be used to move and deploy the ADD device to set up CEE scenarios.

The aerial video cameras could be flown by a drone or a heli-kite. Consumer grade drones cost roughly £1,000 while a heli-kite with radio controlled video pan-tilt costs roughly £2,000. Although there is likely to be a need to buy several drones so as to have them operating in tandem to ensure adequate survey coverage, this equipment would only make up a small percentage of the research budget (which would largely be vessel hire and staff time), the decision on which to use could be put off until closer to commencement of the study, were it to move forward. By then, prices of drones and their battery capacity might have changed. Some feasibility investigations would be required before we could fully recommend the drone approach but it shows considerable promise. Visual observations from an elevated platform on the research vessel using binoculars and video cameras will always remain the principal methodology should the drone approach not be practical.

9.4 **Field Site Evaluation**

A number of considerations informed the assessment of field sites, and these were generally related to the likelihood of a sufficient sample size being reached at each site. These were:

- Expected abundance of target species in the area/time of year;
- Weather conditions, particularly wind in area/time of year;
- Number of daylight hours in area/time of year;
- Expected logistical support and feasibility of operating at site (distance from port, availability of harbour facilities for support, etc.).

In addition to power and sample size considerations, other factors informed the assessment of each site as suitable for effective ADD trials. These included the similarity of sites to OWF sites (particularly in terms of the factors affecting sound propagation and therefore likely effective ranges of ADDs), the likelihood of being successful in getting a licence to carry out trials at each site, and for non UK sites, whether there were potential local collaborators to support the work.

9.4.1 Determination of suitable species and review features

The objective of trials should be determining the response ranges of animals and how these relate to the agreed mitigation exclusion zone (currently a radius of approximately 500 m around the ADD source). As discussed in Section 4.1.2, previous suggestions of trials with bottlenose dolphins as a proxy for other species more likely to be found close to OWF construction sites have been revisited and revised in discussion with the DPSG, expert panel and SNCBs. Bottlenose dolphins have rarely been sighted during surveys at OWF sites. Given the higher encounter at current planned offshore wind farm projects around the UK, white-beaked dolphins were selected as the preferred target species for ADD behavioural response trials. This species is also likely to be a reasonable proxy for the other dolphin species most likely to be encountered at R3 and STW sites. These are likely to be common dolphin, white-sided dolphin, Risso's dolphin. All of these species are considered mid-frequency cetaceans and are grouped by Southall *et al.,* (2007) for the purposes of agreeing criteria for noise exposure related to injury and behavioural effects. Although there is a lack of reliable audiogram data that is directly comparable across these species to directly compare hearing sensitivities, audiograms from delphinids with broad band clicks indicate a degree of broad similarity.

Each of these issues was explored for each species using the following approach:

- A review of readily available data on abundance from a number of sites was selected through an initial literature review. Where data were available, an assessment was made of the encounter rate per unit time, the variability in encounter rate and therefore the potential future predictability of encounter of a sufficient sample size for a future field campaign.

- A review of available weather data for each site was carried out to predict the likely number of days throughout a field season where conditions are likely to be suitable for detecting, tracking (and possibly tagging) animals. It is likely that in the winter that daylight hours and weather conditions will become critical factors (note that the species concerned have seasonal pattern of occurrence).

In addition to the review of UK information, a number of non UK sites were also explored as potentially good sites for white-beaked dolphin whale and minke whale encounters:

- Norway: particularly the area around the Lofoten Archipelago and Vestforden
- Iceland: Faxaflói Bay and Skjálfandi Bay
- Canada: St Lawrence Estuary and Gulf of St. Lawrence (Mingan, Quebec)

Additional considerations included logistical considerations the comparability with the site environment (e.g. bathymetry, bottom sediment type etc.) for OWFs in the UK, and for non-UK sites, the potential for local collaborators and logistic support and an assessment of the licencing and permitting processes.

9.4.2 Review of animal density / abundance / site use - dolphin species

9.4.2.1 UK

White-beaked dolphins are only found in the temperate and sub-Arctic seas of the North Atlantic (Reid *et al*., 2003). Around the UK the species is recorded frequently in the western sector of the central and northern North Sea across to western Scotland and south to western Ireland. A number of data sources were examined to explore white-beaked dolphin abundance and identify potential areas of high expected encounter rates around the UK. These were:

- SNH commissioned report "Statistical approaches to aid the identification of Marine Protected Areas for minke whale, Risso's dolphin, white-beaked dolphin and basking shark" (all Scottish coastal waters).
- Hebridean Whale and Dolphin Trust (HWDT) surveys (primarily the Hebrides)
- Aberdeenshire land and vessel visual surveys (Weir *et al.*, 2007)
- Marine Scotland ECOMMAS study (East coast of Scotland)
- University of Aberdeen data (Moray Firth) (Thompson *et al.,* 2015)
- Cetacean Research and Rescue Unit surveys (southern coast of outer Moray Firth)
- Seawatch data (All UK coast)

SNH commissioned statistical analysis of Joint Cetacean Protocol data

A recent analysis commissioned by Scottish Natural Heritage (Paxton *et al*., 2014) used survey data (1994 – 2012) from a variety of sources and combined them into a single, spatially indexed density data set that was then modelled with the intention of predicting density surfaces so areas of persistent higher relative density could be identified to support SNH's advice on Marine Protected Areas. This analysis highlighted areas of persistent 'greater than average' abundance of white-beaked dolphins in the following areas: north of Lewis and Harris, east of Aberdeenshire and off the north coast of Sutherland. Figure 17 displays the adjusted densities across the entire period covered by the dataset. Observed adjusted densities were highest between north Lewis and Harris and mainland Scotland, where the densities per grid cell ranged between a minimum of 0 and a maximum of 98 animals per km^2 with an average density of approximately 5 animals per km^2. Observed adjusted densities off the Aberdeenshire coast ranged between 0 and 47 animals per km^2 with an average density of approximately 2.5 animals per km^2.

Figure 18 presents the adjusted densities for summer 2012 along with the predicted density surface alongside upper and lower confidence estimates. It should be highlighted that while the observed adjusted densities off the north of Lewis and Harris and Aberdeenshire can be high, the summer 2012 predicted density values indicate that the 2.5th percentile is only 0-0.1 animals per km and the 97.5th percentile is 0.1-0.5 animals per km^2.

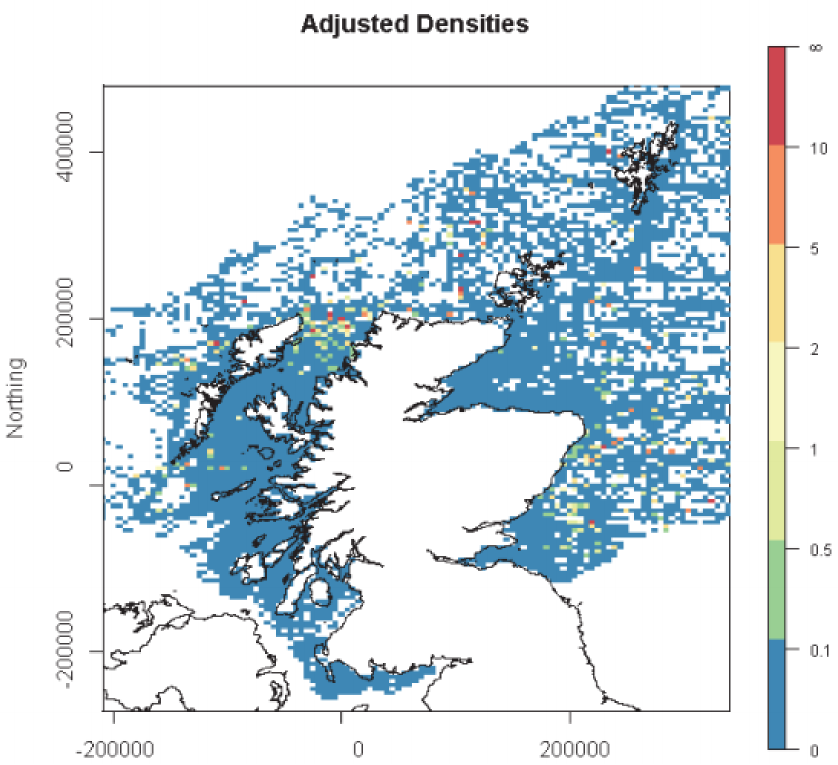
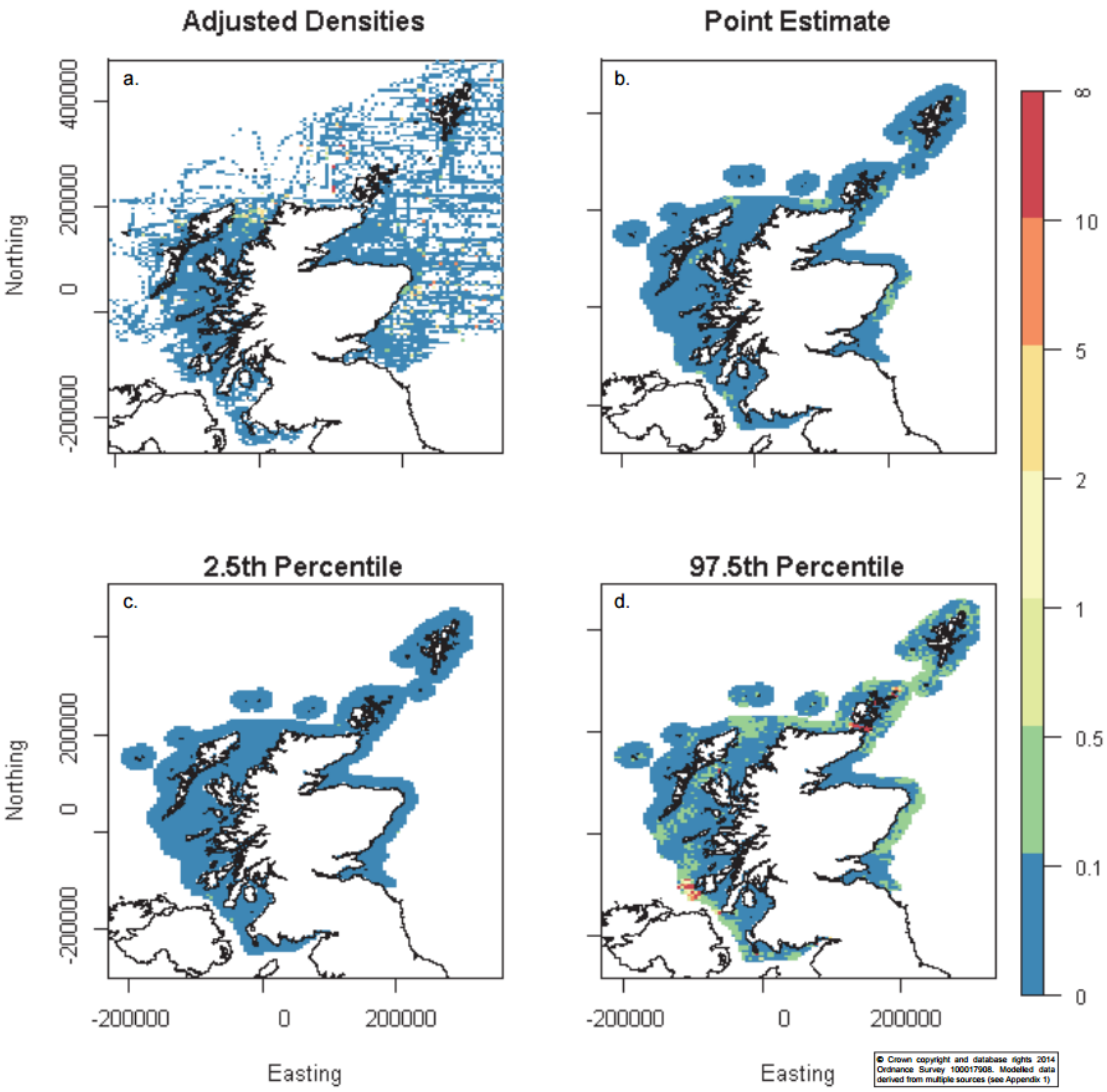


Figure 17. Observed adjusted white-beaked dolphin densities 1994-2012. All Seasons. Colour scale indicates animals per km^2. Each cell is 5 by 5km. From Paxton *et al*., (2014).



© Crown copyright and database rights 2014 Ordnance Survey 100017908. Modelled data derived from multiple sources (see Appendix 1)

Figure 18. White-beaked dolphin, summer 2012: a) adjusted summer densities (1994-2012) b) estimated density summer 2012, c) and d) estimated upper and lower bound confidence surfaces. Colour scale indicates animals per km^2. Each cell is 5 by 5km. From Paxton *et al*., (2014).

The Minch: Hebridean Whale and Dolphin Trust data

The Minch is located in the Inner Hebrides between the Isle of Lewis and the west coast of mainland Scotland. This area was surveyed by the Hebridean Whale and Dolphin Trust in August 2007 (Weir *et al*., 2009) where vessel based visual surveys were conducted providing a total effort of 793 km equating to 66.3 hours of effort. A total of ten white- beaked dolphin sightings were recorded during these surveys, comprising of approximately 70 individuals. This equates to a sightings rate of 0.15 groups per hour of effort and 1.06 individuals per hour effort and an encounter rate of 0.09 individuals per km across the Minch study site. The group sizes ranged from 2 to 12 animals with a mean group size of 7 animals. All white- beaked dolphin sightings were concentrated in the upper parts of Minch, between the top of the Isle of Lewis and mainland Scotland (Figure 19).

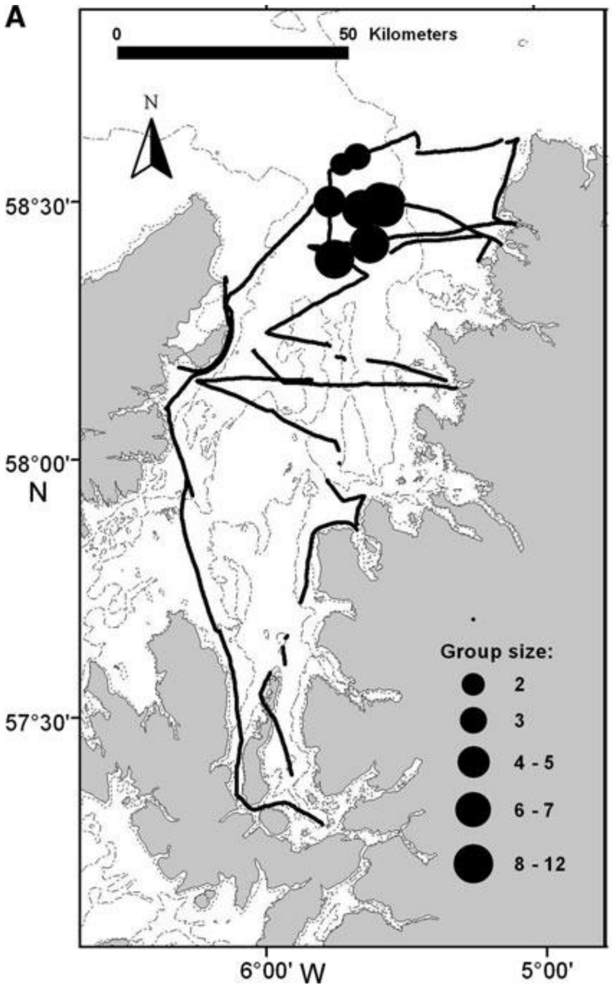


Figure 19 Location of survey effort and white-beaked dolphin sightings in the Minch in August 2007 (Weir *et al*., 2009).

The data presented in Weir *et al*., (2009) were collected in conditions all less than or equal to Beaufort Sea state 4. The mean water depth that dolphins were sighted in was 122.5 m (range 106.5-134.5 m) with a mean sea surface temperature of 13.4°C. Although these data represent a reasonably high encounter rate, they are only from a single period of survey effort and there are no data to assess how predictable these sightings rates are between years. However, this area coincides with the high density area located by Paxton *et al.,* (2014), although this is probably largely due to the inclusion of these data in the analysis.

Aberdeenshire Land and vessel visual surveys

Weir *et al*., (2007) present white-beaked dolphin data collected along the Aberdeenshire coast between March 1999 and October 2001. These consisted of both land based surveys (213 hour effort) and vessel surveys (101 hours effort). In the area between Aberdeen and Stonehaven the land based surveys provided a rate of 0.31 sightings per hour and 2.05 individuals per hour while the vessel surveys provided a rate of 0.15 sightings per hour and 0.69 individuals per hour. In the area between Stonehaven and St Cyrus the land based surveys provided a rate of 0.13 sightings per hour and 0.83

individuals per hour while the vessel surveys provided a rate of 0.20 sightings per hour and 0.91. White-beaked dolphin group sizes ranged between 1 and 32 animals, with a mean of 5.7 individuals. In both areas, despite surveys being conducted between March and October, white- beaked dolphins were only sighted in June and August. Over the whole survey area, the monthly sightings rate was highest in July with 2.5 individuals per hour, with 1.34 and 2.3 individuals per hour in June and August respectively. No between year variation in sightings rates were presented. The environmental characteristics were described at this study site. Between Aberdeen and Stonehaven the water depths extend to 50 m deep at 3.5 km from the shore. Between Stonehaven and St Cyrus there is a shallower descent in water depths to 50 m deep at 8 km from the shore.

While the range at which animals can be tracked from the shore for carrying out CEEs is very limited, shored based effort using powerful binoculars can be a very effective means of locating animals for boat based trials. The good sightings rates from the shore reported here using relatively low power binoculars is encouraging in this respect.

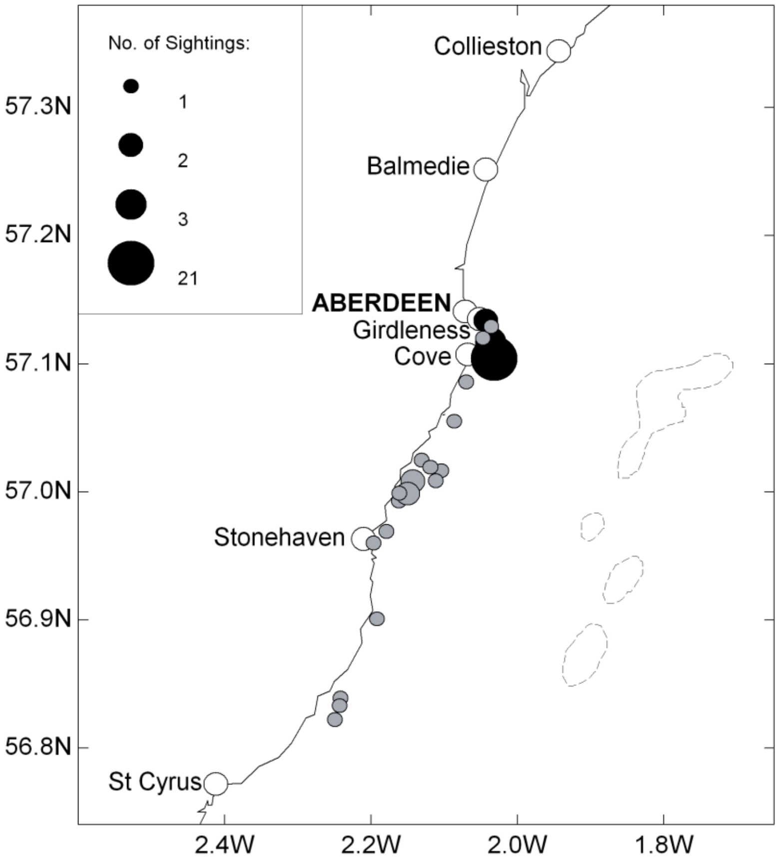


Figure 20 White-beaked dolphin sightings along the Aberdeenshire coast made during land-based (black symbols) and vessel-based (grey symbols) surveys (Weir *et al*., 2007).

East Coast of Scotland Marine Mammal Mammal Acoustic Study

The East COast Marine Mammal Mammal Acoustic Study (ECOMMAS) is currently in progress to quantify the presence and absence of harbour porpoise and dolphin species along the East coast of Scotland. This involves the deployment of CPODs to detect echolocation clicks of dolphins and porpoises and SM2Ms to collect ambient noise data and to distinguish between dolphin species. This project has collected data over three field seasons to date, 2013-2015 from 30 CPOD, 10 SM2M and 2 PAMBuoy mooring stations along the coastline (Figure 21). To date, only data from the 2013 and 2014 CPOD surveys have been analysed.

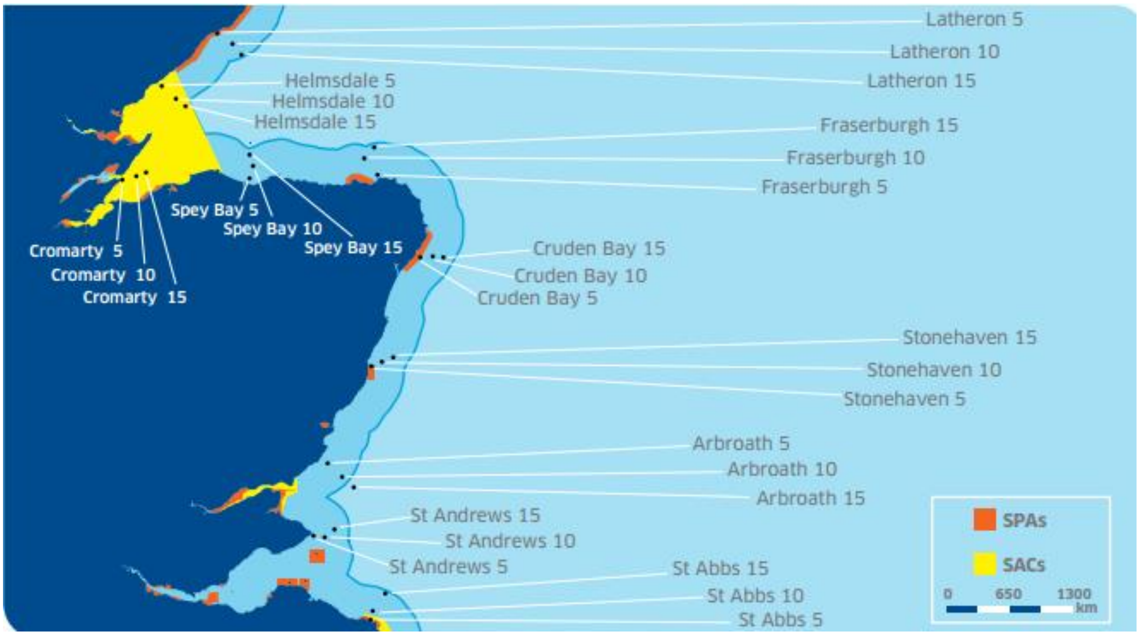


Figure 21. Positions of acoustic monitoring devices on east coast of Scotland as part of Marine Scotland Science's ECOMMAS study.

This available CPOD data demonstrates relatively low numbers of dolphin positive days over the two year period analysed to date. Other than the sites in the Cromarty Firth, the percentage of dolphin positive days at the other monitoring stations were generally less than 30% (Figure 22). Unfortunately, the data have not yet been analysed at a finer temporal resolution and so there is no current information on how these levels of dolphin detections change by month or season throughout the available two-year study period. Although it must be noted that we currently don't know how reliably CPODs detect white-beaked dolphins. Nor do these data differentiate between dolphin species, so it is unknown what proportion of these detections are from white-beaked dolphins or from other dolphin species such as bottlenose dolphins. It is difficult to translate from dolphin positive days to encounter rate from a survey vessel.

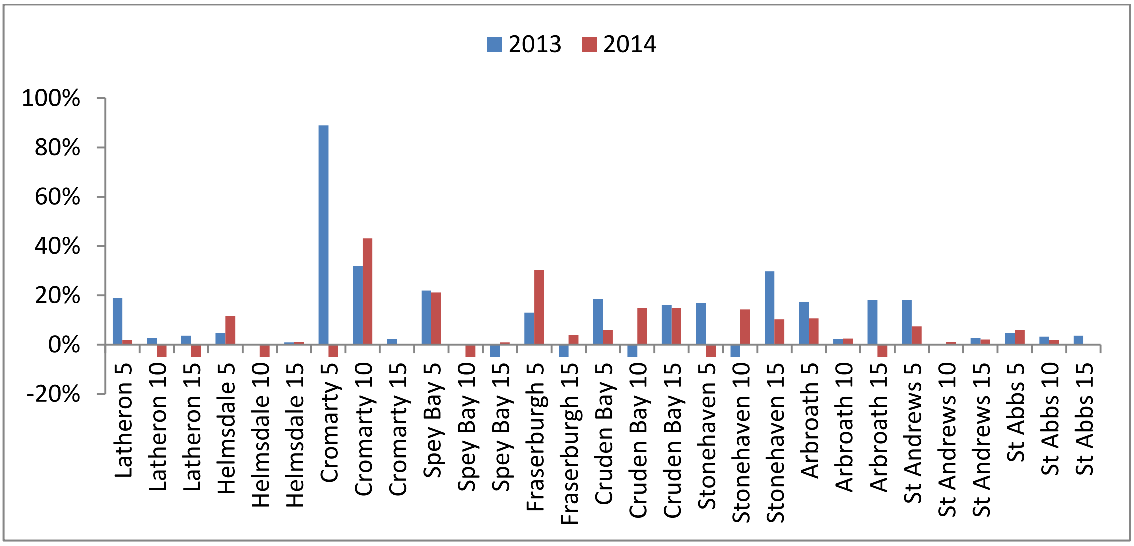


Figure 22. Percentage dolphin positive days from the acoustic recorders deployed as part of the ECOMMAS study. A negative value indicates there were no usable data for that site from that year. Data from Kate Brookes, Marine Scotland Science.

Moray Firth

An analysis conducted by Thompson *et al*., (2015) involved the combination of both visual and PAM data to investigate the abundance and distribution of dolphin species throughout the Moray Firth. The visual data were obtained from a number of sources between 1980 and 2010. The visual sightings resulted in a total of 983 dolphin sightings comprising of 7,870 individual dolphins. Of these, there were a total of 50 white-beaked dolphin sightings comprising a total of 168 individuals (5% of all sightings). The white-beaked dolphin sightings were between 1980 and 2010 and were concentrated in the offshore areas of the Moray Firth, with very few sightings in coastal areas (Figure 23). The areas in which white-beaked dolphins were sighted correspond to areas that recorded only 0-20% Dolphin Detection Positive Days from the 2009-2011 CPOD data (Figure 23). The average group size was between six and ten animals (90%) with a maximum group size recoded of 20 individuals during one sighting. Unfortunately, effort data were not available for the visual surveys and so it is not possible to calculate white-beaked dolphin encounter rates within the Moray Firth.

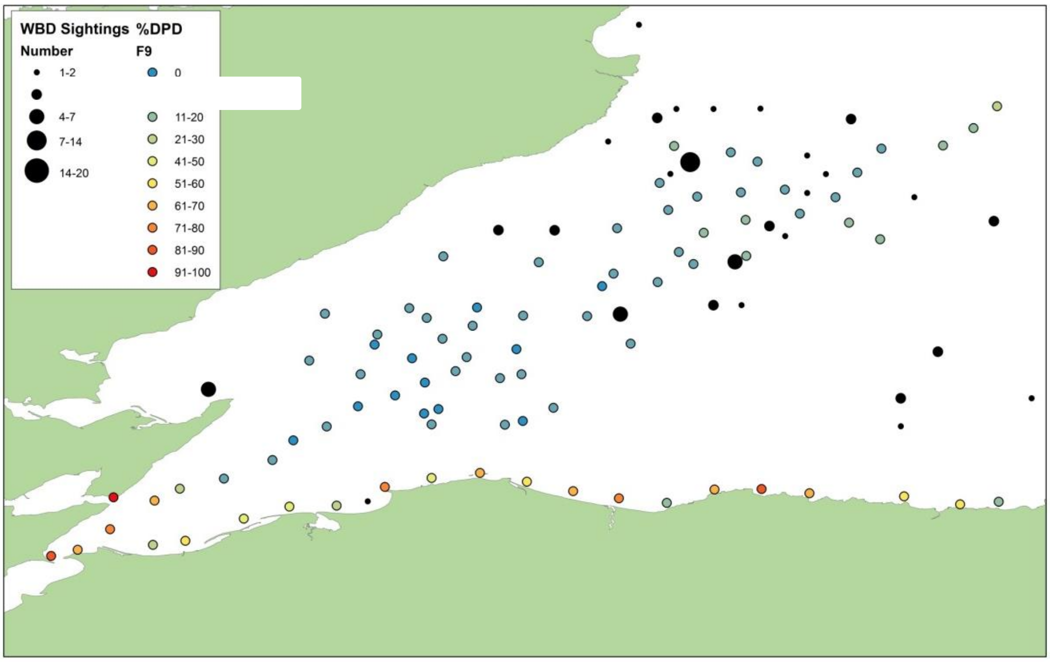


Figure 23. White-beaked Dolphin sightings across the Moray Firth recorded between 1980 and 2010 (black circles) and % Detection Positive Days of any dolphin species from CPOD deployments between 2009 and 2011 (colour circles) (data obtained from Thompson *et al*., 2015).

Other UK sites have been mentioned as a possibility for high white-beaked dolphin encounter rates, for example, the Northumberland coast has been highlighted as a potential hotspot and records from local skippers and wildlife operators indicate that white beaked dolphins are regularly sighted in the area, particularly in the summer. However despite extensive anecdotal information records, there are very few sources of systematic survey or effort-corrected sightings data with which to evaluate this.

9.4.2.2 Non UK sites

There are a number of non UK sites where white-beaked dolphins are encountered in reasonably high numbers. These include Canada, Norway and Iceland.

Canada

Mingan Archipelago: Mingan Island Cetacean Study (MICS)

The Mingan Archipelago is a National Park Reserve located on the north shore of the Gulf of St. Lawrence, in Quebec, Canada. The area comprises approximately 40 coastal islands and has a complex bottom topography including canyons, dunes, and rock outcrops with a substrate primarily composed of sand and mud (Naud *et al*., 2003). The maximum depth within the islands is 130 m, up to 10 km from shore. The Strait of Jacques Cartier lies to the south of the archipelago and reaches depths of up to 300 m between the north shore and Anticosti Island.

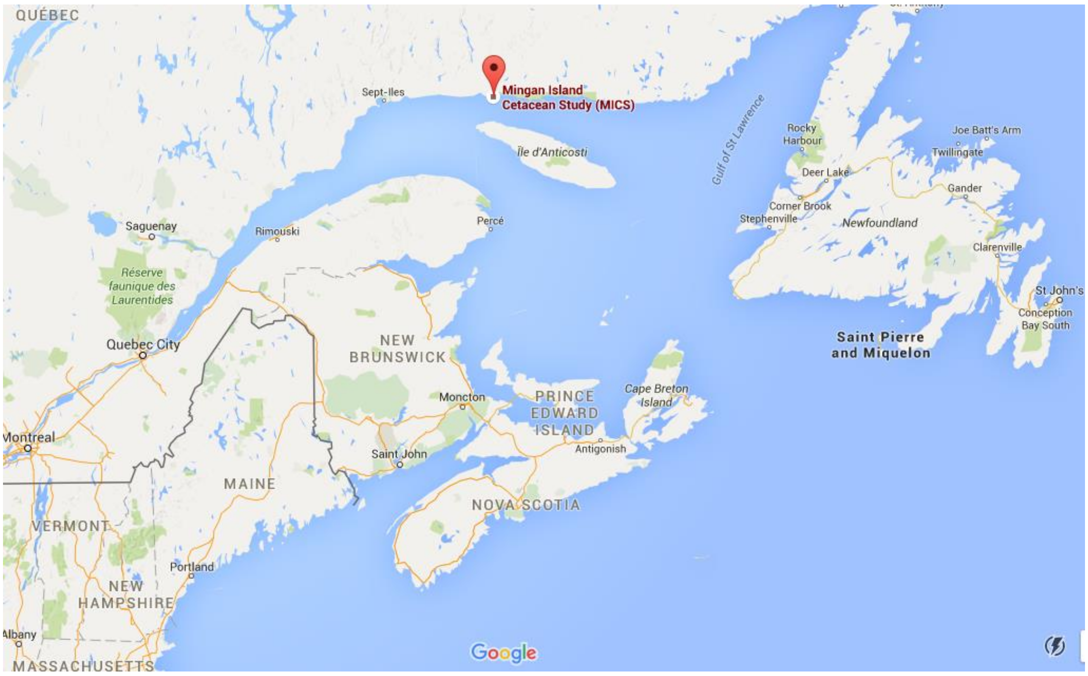


Figure 24. Location of the Mingan Island Cetacean Study Site, Quebec, Canada.

White-beaked and white-sided dolphins are found within the Mingan islands and in the Jacques Cartier Strait, and directly overlap with the local distribution of minke whales. Sightings are sporadic and typically occur from a few days to a few weeks per summer field season, although white-sided dolphins are more common (pers. comm. Christian Ramp). White-beaked dolphins have not been sighted within the proposed study area within the last two years; however they have been documented further east along the North shore.

The Mingan Island Cetacean Study (MICS; http://www.rorqual.com) is a non-profit research organization based out of Longue-Pointe-de-Mingan situated at the eastern end of the Mingan Archipelago. MICS is a remote field station with the closest airport located 2.5 hours west in Baie Comeau, Quebec. MICS is however, completely fitted out for marine mammal surveys including full-time summer staff (May through October) and a fleet of four rigid inflatable hulled boats with a dedicated marine repair workshop. The research station is accessible to the proposed study area, and is located a ten minute drive from the boat launch site. Discussions with this group have indicated that due to the remoteness of the location, there is very little vessel traffic and no local whale watching fleets that might confound a Behavioural Response Study (BRS). Multiple locations are also available within the study site for the BRS study depending on the method chosen to measure animal responses to ADD playbacks. For example, a within-islands location might be prioritized for land based visual observations, as there are a large number of suitable vantage points, including a lighthouse with an observation deck on l'île aux perroquets, which directly overlooks the large unobstructed area in front of Longue-Pointe-de-Mingan where animals can be observed from shore. On the other hand, several offshore locations are also accessible where animals are free to move in any direction as opposed to being restricted to a channel between the mainland and Islands within the national park reserve (the sound propagation implications between these options is considered in Section 7). This could also facilitate vessel-based telemetry or drone tracking while better representing the locations of OWF developments and the conditions expected to be encountered by the animals in their vicinity.

Based on both minimum and the average daily wind speeds for Longue-Pointe-de-Mingan, the proposed Mingan study site has 100% of summer days (June – Aug) equal to or less than Beaufort Sea state 3. Based on the maximum daily wind speeds, this site has 97% of summer days equal to or less than Beaufort Sea state 3. Combined with a relatively low daily 57% chance of rain, occasional patches of fog, and nearly 16 hours of summer daylight hours, the Mingan archipelago is extremely well suited to conducting small cetacean surveys. A marine mammal research licence (permitting photo-identification and rorqual whale biopsy sampling) is already in place for MICS through the Department of Fisheries and Oceans (DFO) Canada and approval for a BRS is likely if the study is covered under the MICS Animal Welfare and Ethics Committee (AWEC) approval, especially since white-beaked and white-sided dolphins are not listed species under SARA. MICS has agreed to be a local partner if required.

Norway

From discussions with local scientists, West Finnmark has been identified as an area suitable for white-beaked dolphin studies between May and August (Lars Kleivane[16], pers comm). West Finnmark is located at the most Northern parts of mainland Norway, shown in Figure 25. White-beaked dolphins are known to be year round residents in the Barents Sea with an estimated population size of 60-70,000 found throughout the Barents Sea (Kovacs *et al*., 2009).

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[16] FFI Forsvarets forskningsinstitutt – Norwegian Defence Research Establishment

Figure 25 Location of West Finnmark in Norway (highlighted in red).

Fall *et al*. (2014) investigated the distribution of white-beaked dolphins in the Barents Sea using vessel based visual marine mammal sightings data from the Joint Ecosystem Surveys of the Barents Sea in August to September between 2003 and 2009 and reported a total of 2738 white-beaked dolphin observations (Figure 26). Dolphin density peaked around 150–200 m water depths.

It was not possible to find any data on the sediment types found in the inner fjord systems of the Finnmark area, however, data are available for the general near shore and offshore waters (Aivo *et al*., 2014). This categorises the sediment in the more coastal areas as being comprised mostly of gravelly sand, sandy gravel and sand gravel and cobbles, while those further offshore are predominantly sandy mud, mud and gravelly sandy mud. The depths of the waters around Finnmark rapidly drop off to depths of over 200 m, even within the inner fjord systems, with depths in the near shore regions reaching 300+ m depths.

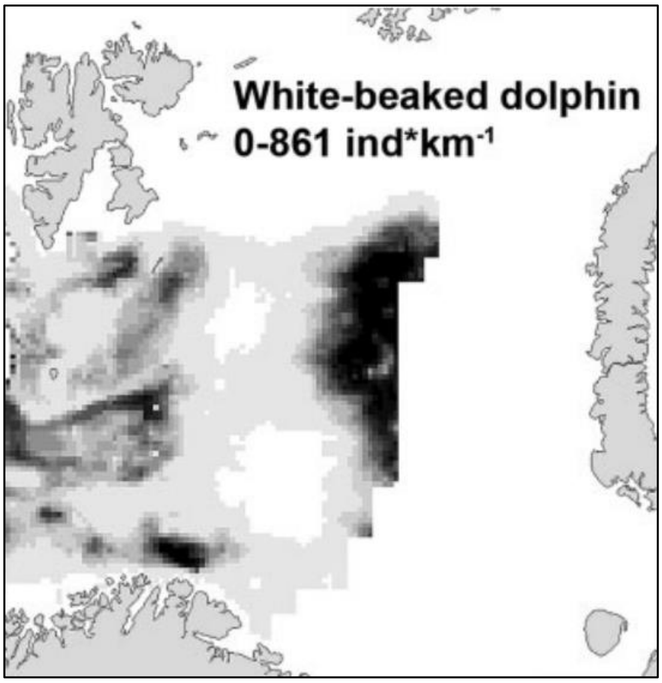

Figure 26 GAM predicted distributions of white-beaked dolphins from 2003 to 2009. Darker colour indicates a higher density with the value range 0-861 individuals per km (Fall, *et al*., 2014).

Iceland

White-beaked dolphins are the most common delphinid species in Icelandic waters (e.g. Pike *et al.,* 2009; Rasmussen & Miller, 2002; Víkingsson & Ólafsdóttir, 2004; Rasmussen *et al.,* 2013). Surveys for cetacean species were conducted around Iceland, usually in July, between 1986 and 2001 during the North Atlantic Sightings Surveys (NASS). These are presented in Pike *et al.* (2009). During these surveys, a total of 437 dolphins were sighted, 400 of which were white-beaked dolphins (92%) and 11 were white sided dolphins (2.5%). The sightings rates ranged from 0.01 to 0.015 animals per km over the four survey years (Table 19). White-beaked dolphins were the most commonly sighted species after minke whales and were present in all survey blocks. They were most commonly sighted in Southeast (Faxaflói Bay) and Northeast of Iceland (north of Skjálfandi Bay) across all years (Figure 27). White-beaked dolphins have also been recorded in Faxaflói bay during the winter months which confirms that they are present year round (Magnúsdóttir, 2007). The total uncorrected abundance calculated for dolphin species ranged from 11,717 (95% CI 8,874 – 15,471) in 1995 to 18,706 (95% CI 13,912 – 25,152) in 2001 but was not significantly different between all four survey years. Following an estimation of g(0), the corrected total dolphin abundance in 2001 was estimated as 31,653 (95% CI 17,679 – 56,672) (Pike *et al.,* 2009).

Table 19. Effort and sightings rates of dolphin species around Iceland during the NASS surveys between 1986 and 2001 (Pike *et al*., 2009).

	Effort (nm)	Effort (km)	Dolphin sightings	Sightings/nm	Sightings/km
1986	5298	9812	107	0.020	0.011
1987	3548	6571	68	0.019	0.010
1995	5399	9999	146	0.027	0.015
2001	4998	9256	116	0.023	0.013

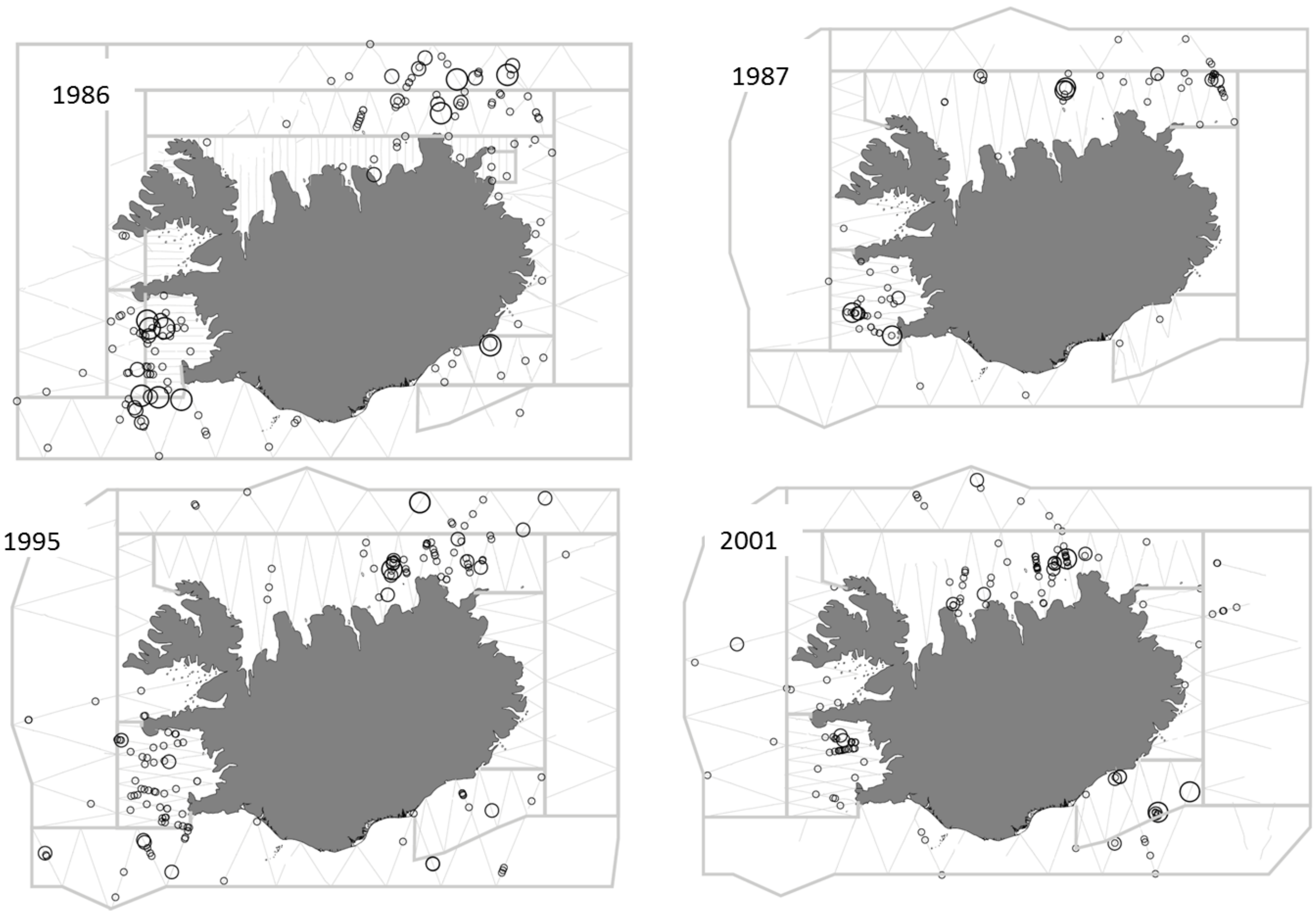

Figure 27 White-beaked dolphin sightings during NASS aerial surveys in 1986, 1987, 1995 and 2001 (Pike *et al*., 2009). Group size: Smallest circle = 1-10, medium circle = 11-20, largest circle = 21+.

Within Faxaflói Bay, white-beaked dolphins are most commonly found between one and three nautical miles from the shore, where they have been described as being socially active, feeding, resting and travelling (Rasmussen & Miller, 2002). Various studies have been conducted on the white-beaked dolphins in Faxaflói Bay, including acoustic studies (Rasmussen & Miller, 2002), photo ID studies between 1997 and 2010 (e.g. Rasmussen & Jacobsen, 2003; Bertulli, 2010) and tagging studies with acoustic and TDR VHF tags (Rasmussen *et al.*, 2013). While telemetry data is only available for one tagged dolphin, this data showed that the dolphin stayed close to shore within the 200 m depth contour and spent 44% of its time within the Faxaflói Bay area. Rasmussen *et al*., (2013) suggest that the high number of white-beaked dolphin sightings within Faxaflói Bay is likely due to high concentrations of sand eels in the bay. There are not any more recent published data sources on sightings rates but it was reported to us that during surveys carried out in conjunction with whale watching boats in the summer of 2015, white-beaked dolphins were encountered on 86 out of 112 days of effort (Marianne Rassmussen, pers comm).

Proxy species

In addition it was suggested at the Discretionary Project Steering Committee (DPS) and expert panel on the 6th August 2015 that there are several sites around the world where other species of *Lagenoryhynchus* dolphins are found reliably in high numbers and that these sites should be considered as potential field sites. These include: dusky dolphins in New Zealand and South America and Peale's dolphins in South America. Although likely to be more expensive and logistically challenging than UK based fieldwork, the pay off in terms of guaranteed encounters and larger sample sizes might be worth it. Subsequent investigations have ruled out Peale's dolphins as a proxy for white sided dolphins due to the difference in their acoustic capabilities. Peale's dolphins produce narrow band high frequency (NBHF) clicks while white-sided dolphins produce broadband sounds, therefore it is likely that their hearing thresholds differ which will likely affect their responses to acoustic disturbance. Dusky dolphins were ruled out as a result of conservation concerns.

Summary of White-beaked dolphin evaluation

Table 20 presents a summary of the available data in encounter rate/abundance of white-beaked dolphins at the sites discussed in the previous sections. The variety of survey methods, the reporting of sightings in very different metrics and a lack of detail provided on survey effort makes it very difficult to compare measures of abundance between sites in a strictly quantitative way. In addition it is the degree to which sightings are predictable which is also a key factor in the feasibility of future ADD studies. Based on the data presented above it is likely that the sites with the most predictable encounters of white-beaked dolphins are the hotspots around the UK coast – Aberdeenshire and The Minch, and Iceland (Faxafloi Bay) and Norway (West Finnmark).

Table 20. Summary of available data on encounter rate/abundance of dolphins at selected sites. Species is white-beaked dolphin unless otherwise specified.

Site	Method	Period covered	Encounter rate
East coast Scotland[17]	Acoustic	July-	Generally <30% DPD
Aberdeenshire coast[18]	Variety	1994-2012	2.5/km^2
Aberdeenshire coast[19]	Visual land and vessel		0-to 2.5 individuals/hour
Offshore Moray Firth[20]	Visual and PAM	2009-2011	0-20% DPD
The Minch[21]	Visual vessel	August 2007	0.09/km
The Minch[22]	Variety	1994-2012	5/km^2
Iceland[23]	Aerial	1986-2001	0.01-0.015 animals/km
Norway (Finnmark and Barents Sea)[24]	Visual vessel	Aug-Sept 2003-2009	0-861 individuals/ km
Mingan Islands, Quebec[25]	No data available, anecdotal evidence only	Recent	White-beaked dolphins not present in past 2 years. White-sided dolphins seen every year, can appear for few days up to several weeks

9.4.3 *Review of animal density / abundance / site use - minke whale*

Minke whales are distributed across the northern hemisphere tropical, temperate and polar seas. In the North Atlantic it occurs from Baffin Bay in the west, Greenland and Barents Sea in the east, south to the Lesser Antilles in the west and south to the Iberian Peninsula and Mediterranean in the east (Reid *et al.,* 2003). Around the UK the species is recorded frequently along the Atlantic seaboard of the UK and also throughout the central and northern North Sea (Reid *et al.,* 2003).

A number of data sources were examined to explore minke whale abundance and identify potential areas of high expected encounter rates. These were:

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[17] ECOMMAS study, summary data provided by Kate Brookes, Marine Scotland Science

[18] Paxton *et al.,* 2014

[19] Weir *et al.,* 2007

[20] Thompson *et al.,* 2015

[21] Weir *et al.,* 2009

[22] Paxton *et al.,* 2014

[23] Pike *et al.,* 2009

[24] Fall *et al.* 2014

[25] Christian Ramp (Mingan Island Cetacean Study), pers comm

- SNH commissioned report “Statistical approaches to aid the identification of Marine Protected Areas for minke whale, Risso’s dolphin, white-beaked dolphin and basking shark” (all Scottish coastal waters).
- Hebridean Whale and Dolphin Trust (HWDT) surveys (primarily the Hebrides) and whale watching data
- Cetacean Research and Rescue Unit surveys (southern coast of outer Moray Firth)

A number of non UK sites were also suggested as potentially good sites for minke whale encounters:

- Norway: particularly the area around the Lofoten Archipelago and Vestforden.
- Iceland: Faxaflói Bay
- Canada: St Lawrence Estuary (Quebec), Mingan archipelago (Quebec).

SNH commissioned statistical analysis of Joint Cetacean Protocol data

This analysis highlighted areas of persistent ‘greater than average’ abundance in the Moray Firth and in parts of the Inner Hebrides. Figure 28 displays the adjusted densities across the entire period covered by the dataset. Observed adjusted densities along the outer Moray Firth coast per 5 km by 5km grid cell were between 0 and 124 animals per km^2 with an average of 4 minke whales per km^2.

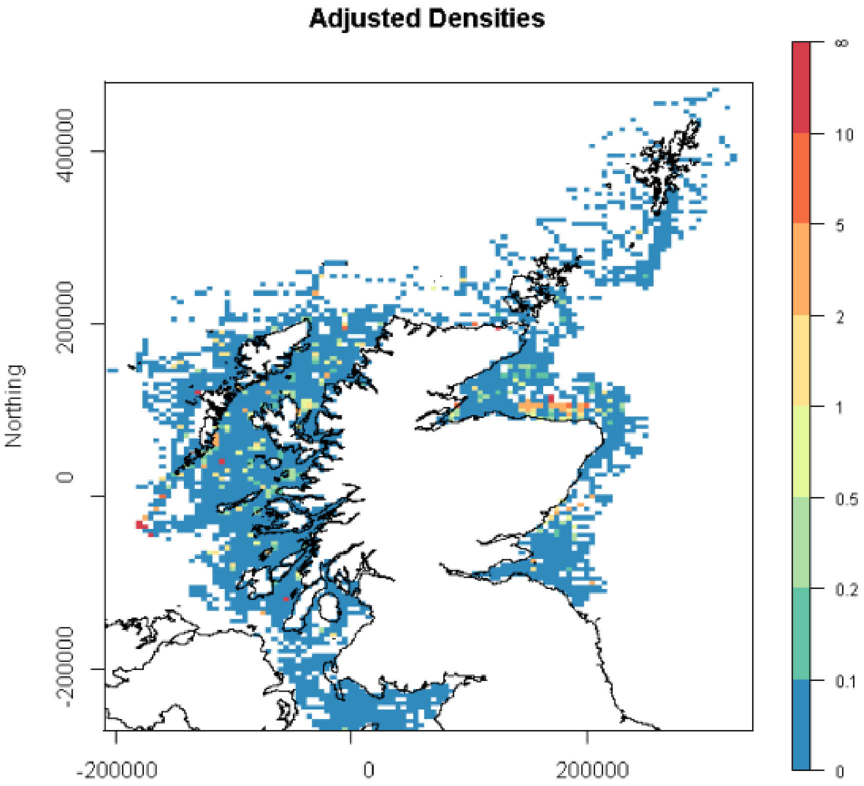
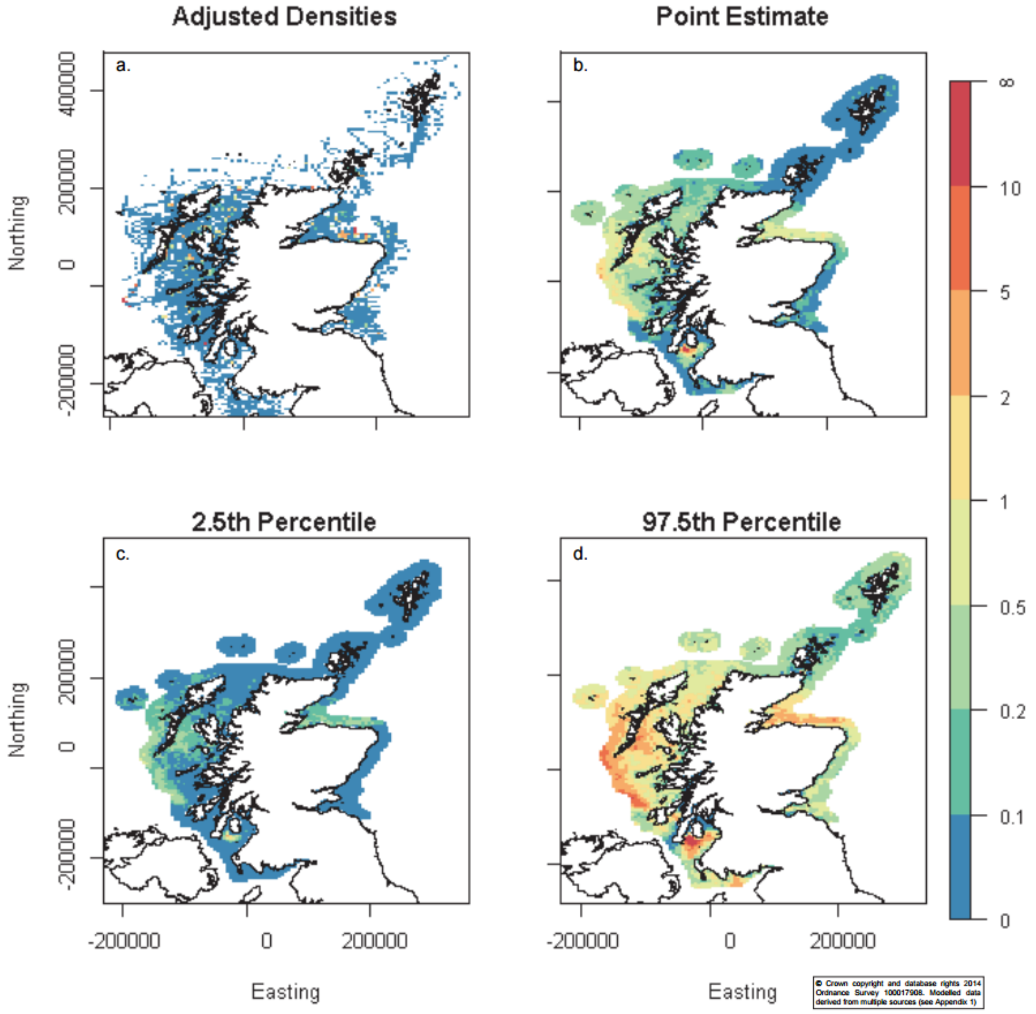


Figure 28. Observed adjusted minke whale densities 1994-2012. All Seasons. Colour scale indicates animals per km^2. Each cell is 5 by 5km. From Paxton *et al*., (2014).

Figure 29 presents the adjusted densities for summer 2012 along with the predicted density surface alongside upper and lower confidence estimates. This clearly shows that the 2.5th and 97.5th confidence estimates for minke whale densities were between 0.1 and 10 animals per km^2 in the southern outer Moray Firth and for most of the Sea of the Hebrides. These figures highlight that the highest area of minke whale density in the Hebrides are the waters between the Isle of Skye, South Uist and Rum, and to the South and West of the Isle of Uist. There is also a concentration of high minke whale densities around the south of the Isle of Arran.



© Crown copyright and database rights 2014 Ordnance Survey 100017908. Modelled data derived from multiple sources (see Appendix 1)

Figure 29 Minke whale summer 2012: a) adjusted summer densities (1994-2012) b) estimated density summer 2012, c) and d) estimated upper and lower bound confidence surfaces. Colour scale indicates animals per km^2. Each cell is 5 by 5km. From Paxton *et al*. (2014).

Based on the above data, two areas in the UK were identified by SNH as having persistent above mean densities of minke whales between 2001 and 2012, these were the Sea of the Hebrides and the southern outer Moray Firth (Figure 30; SNH, 2014).

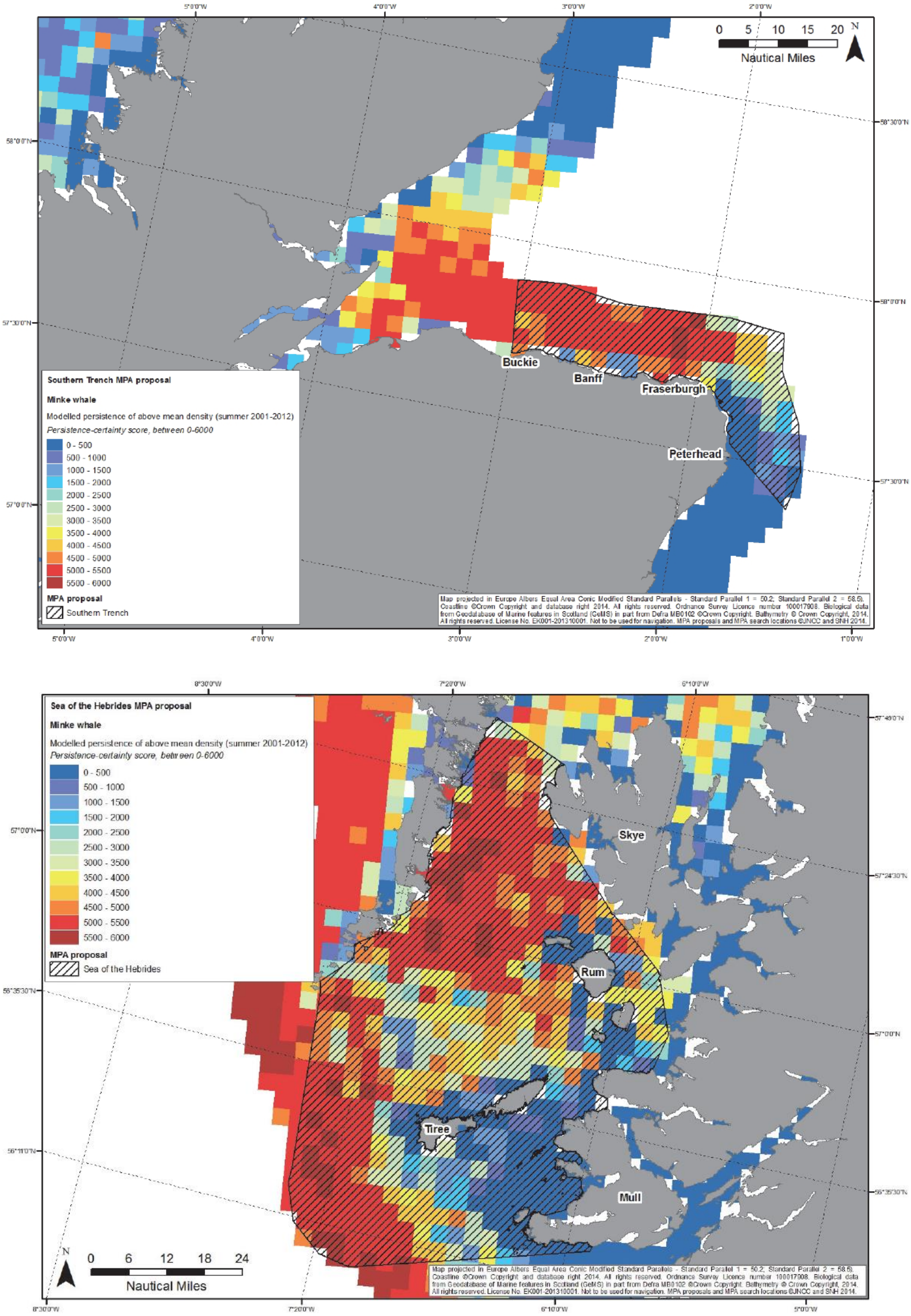


Figure 30 Results of habitat modelling showing areas that are persistently above average density for minke whales (top= Southern Trench Moray Firth, bottom = Sea of the Hebrides) (SNH, 2014).

Hebridean Whale and Dolphin Trust Data

The Hebridean Whale and Dolphin Trust (HWDT) have been carrying out cetacean surveys throughout in the Hebrides with consistent methodology since 2003 and have collected a valuable set of data to monitor cetacean populations in the Hebrides. Sightings data from the HWDT are included in the SNH analysis presented above. Data presented in Macleod *et al.,* 2004 from surveys carried out off the Isle of Mull, the Small Isles and Coll between 1992 to 1999 suggested seasonal changes in distribution in relation to prey. Overall sightings rates were 0.022 per km of survey effort, however these data are now over fifteen years old so have limited usefulness for study site evaluation. More recently annual HWDT surveys have included photo ID for minke whales – there were 37 minke whale photo-id encounters in 2014 compared to 17 in 2013 (HDWT, 2014). The photo ID catalogue contained 125 animals in 2010 and the database is currently being updated to carry out a reassessment on the number of minke whales in the local population (HWDT, 2013). An ability to identify individual animals is useful for analysing data from ADD CEEs and long term histories of some know individuals could be very helpful when interpreting results. During all 2013 survey effort there were a total of 63 minke whale sightings comprising of 76 individuals.

In addition there are several successful whale watching operations targeting minke whales in the Hebrides. This provides at least a qualitative indication that regular encounters with this species in this area are possible. One company, Seal Life Survey, have been collecting computerised data consistently since 1992 mainly in the waters around Mull, Coll and Tiree. Several analyses of these data have been made. Leaper *et al.,* (1997) reported that minke whales were encountered on 64% of trips. They were also able to identify two restricted areas of consistent high densities (between and within years): one around Muck and the other to the north east of Coll. In a later analysis of a larger data set Macleod *et al.,* 2004 demonstrated a good ability to predict distributions based on spawning habitats of sand eel and herring (in the spring and summer respectively). Anderwald *et al.,* (2012) analysed minke whale datasets collected from whale watching and other platforms around the small Isles (just to the North of the Sea Life Survey surveyed area). They found that depth and topography as well as sea surface temperature and chlorophyll provided good predictions of seasonal distribution patterns while fine scale foraging behaviour was influenced by the strength and direction of tidal currents.

Predictability in animal densities and distributions and a capacity to predict it will greatly increase encounter rates and research effectiveness. Sea Life surveys have also collected a considerable amount of focal follow and individual tracking data somewhat similar to that which would form part of CEE studies (e.g. Stockin *et al.,* (2001);

While these data provide some indication that reasonable encounter rates can be achieved in this region they also highlight the need for research in this area to be carried out in consultation with local stakeholders.

The HDWT have indicated that they would be willing to discuss the use of recent time series of sightings data to inform the evaluation of particular areas in the Hebrides as a study site for further ADD trials but it has not been possible to progress this within the timeframe for this study.

CRRU data Southern outer Moray Firth

The Cetacean Research and Rescue Unit have been collecting minke whale sightings data since 2001, and track line effort associated minke whale sightings data since 2009. These data are not publicly available to include in this report, however, a subset of these data are described in Tetley *et al*., (2008). This presents data collected between May and September from 2000 to 2004 from an 880 km^2 area in the southern outer Moray Firth in Beaufort Sea states 3 or less. The sightings rate varies between 0 and 2.27 minke whales per hour of effort (Table 21), with whales only observed between June and September across all years. It is important to note that there was quite a high degree of variability between years with no sightings at all in 2004, however, no data were presented on the amount of effort in each month and each year and so it is unknown if low sightings rates are as a result of low effort or a true lower number of whales. More recent data are available but could not be obtained for this study to ascertain whether this pattern still holds. These data, in combination with the analysis carried out by Paxton *et al.,* (2014) suggests wide confidence intervals around density estimates which makes it difficult to predict the probability of encounter for any given year in the future.

Table 21. Minke whale sightings per unit effort (hour) encountered in the Southern outer Moray Firth between 2000 and 2004 (data from Tetley *et al*., 2008). Total effort not given.

	May	June	July	August	September
2000	0	0.00	0.00	0.00	1.15
2001	0	0.56	2.19	2.20	1.10
2002	0	0.00	0.00	0.40	1.62
2003	0	0.08	2.27	0.97	1.13
2004	0	0.00	0.00	0.00	0.00

9.4.3.1 Non UK sites

There are a number of non UK sites where minke whales are encountered in reasonably high numbers and predictably between years. As described above in the dolphin section, although these studies may be more expensive and logistically challenging than UK based fieldwork, the pay off in terms of guaranteed encounters and larger sample sizes might be worth it. In addition the possibility of targeting sites where there is a high probability of encounter of both minke whale and white-beaked dolphins should be seriously considered. Important non UK North Atlantic minke whale feeding grounds where minke whales are reliably sighted include: Canada, Iceland, Greenland and Norway.

Canada

There have been many studies on minke whales in Canada, including twenty years of behavioural data collected in St. Lawrence estuary which is a well-established minke whale summer feeding ground. Vessel based continuous individual focal follows were used to record minke whale behaviour between June and October 1990 to 2009 which resulted in 324 days of data with 489 focal follows totalling 298 hours of focal follow data and 24,579 recorded surfacings (no precise effort and encounter rate data was provided; Christiansen *et al*., 2015). Vessel focal follow data were also collected in the Saguenay Fjord (tributary to the St. Lawrence Estuary) between June and October 2003 where 162 trips resulted in 32.8 hours of minke whale surface feeding data (no precise effort and encounter rate data was provided; Kuker *et al*., 2005). However this site is within a protected area, the Sagueny-St Lawrence Marine Park and is protected habitat for Beluga whales, therefore getting a permit to carry out ADD playbacks at this site could be challenging.

Other studies include those conducted in the Mingan Islands in the Gulf of St Lawrence where valley depths reach 130m, with valley sediments varying between sandy fine sediments, rocky sea beds and large sub marine sand dunes where currents reach 1 m/s (Naud *et al*., 2003). Naud *et al*., (2003) present vessel based sightings data between June and October from 1988 to 1999 where minke whales were most frequently sighted in shallow depths between 20-40m where encounter rates were 7.1 per km. Minke whales were also most frequently sighted in sub marine sand dune areas where the mean number of minke whales per km^2 was 13.8 and in areas where there was a complex bottom topography (rather than flat areas) where the mean number of observations of minke whales per km^2 was 8.6. From discussions with local scientists, the Mingan/Anticosti region has been identified as an area very suitable for minke studies (Christian Ramp[26], pers comm). The long term photo ID mark recapture work conducted by the Mingan Island Cetacean Study Research Station indicates over 1,000 minke whales in the Mingan/Anticosti region with encounters being very predictable throughout the summer field season. For further details on the feasibility of conducting field trials in the Mingan area, please see the section “Mingan Archipelago: Mingan Island Cetacean Study (MICS)” within paragraph 9.4.2.2 section. Additional considerations included logistical considerations the comparability with the site environment (e.g. bathymetry, bottom sediment type etc.) for OWFs in the UK, and for non-UK sites, the potential for local collaborators and logistic support and an assessment of the licencing and permitting processes.

Review of animal density / abundance / site use - dolphin species presented above.

Iceland

Surveys for cetacean species were conducted around Iceland between 1986 and 2001 during the North Atlantic Sightings Surveys (NASS). These are presented in Pike et al., (2009). During these surveys, a total of 702 minke whales were sighted. They were most commonly sighted in the Southeast (Faxaflói Bay), Southwest and North of Iceland across all years (

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[26] Mingan Island Cetacean Study Research Station

Figure 31).

In this survey area the sightings per km was fairly consistent between years, ranging from 0.04 to 0.057 sightings per km (Table 22). This equated to a total corrected density of between 0.0383 to 0.0595 animals per km^2, with densities being higher in the latter two years of surveys (Table 22). Overall these sightings rates are rather low. However, one might expect higher rates if consistent areas of high density could be identified.

Table 22. Effort and sightings rates of minke whales in survey area 1 of the Icelandic coastal shelf during the NASS surveys between 1986 and 2001 (Pike *et al*., 2009).

	Effort (nm)	Effort (km)	Sightings	Sightings /nm	Sightings /km	Total corrected Density (animals/nm^2)	Total corrected Density (animals/km^2)
1986	737	1365	55	0.075	0.040	0.132	0.0383
1987	663	1228	70	0.106	0.057	0.143	0.0418
1995	765	1417	78	0.102	0.055	0.204	0.0595
2001	819	1517	73	0.089	0.048	0.202	0.0588

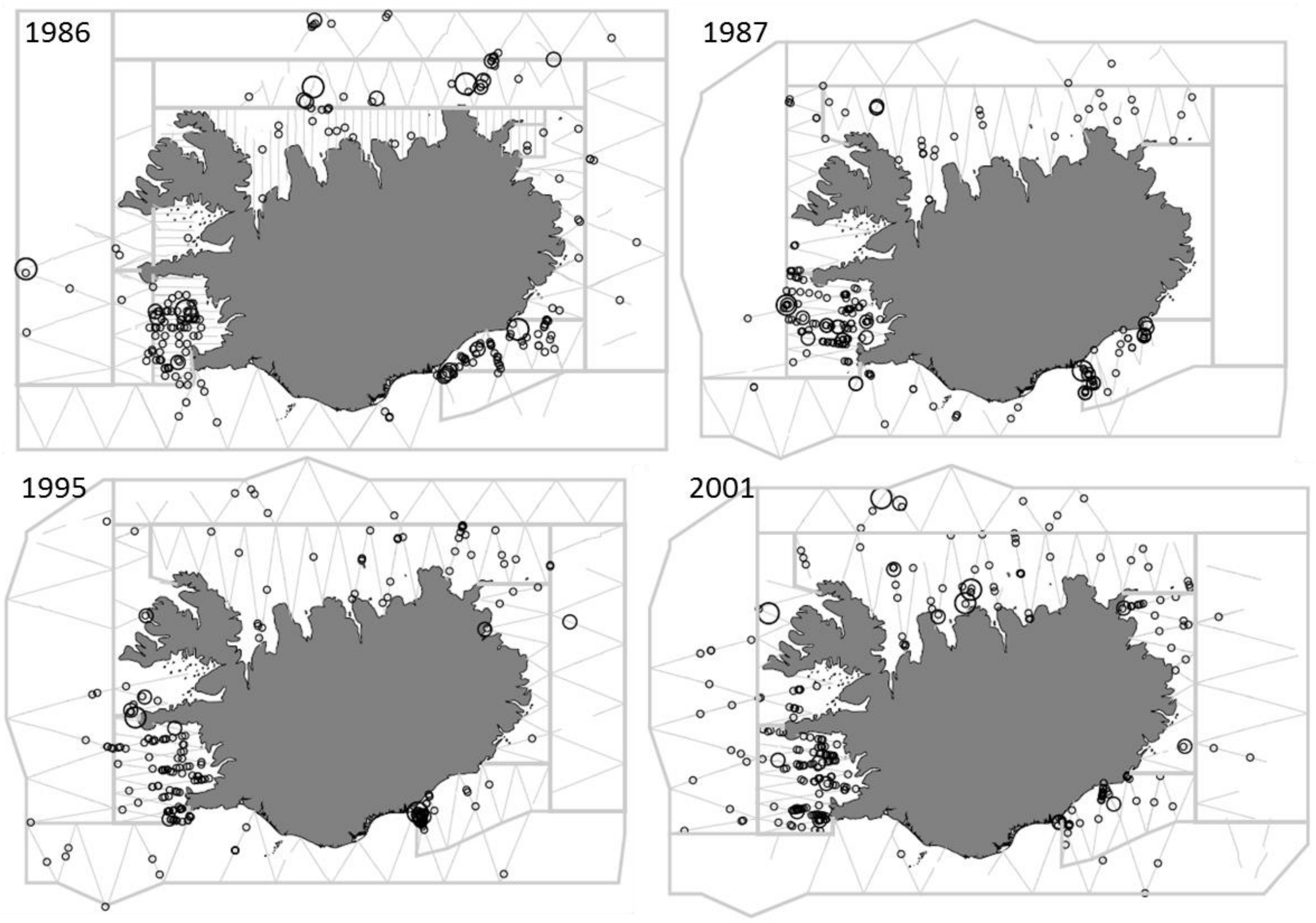

Figure 31 Minke whale sightings during NASS aerial surveys in 1986, 1987, 1995 and 2001 (Pike *et al*., 2009). Group size: Smallest circle = 1, medium circle = 2, largest circle = 3+.

As identified above, Faxaflói Bay has high minke whale encounter rates during all years of the NASS surveys. This area has been highlighted as an important minke whale feeding ground in the north Atlantic where minke whales are present all year, but are most common between mid-April to mid-October (Christiansen *et al.*, 2013). Faxaflói Bay has been targeted by other researchers for observation studies such as Christiansen *et al*., (2014) where whales were tracked from land using a theodolite and tracked from vessels during focal follows to assess surfacing rates in response to whale watching vessel activity. This study collected 118 days of data between June and September in 2010 and 2011 providing 164 hours of minke whale observations and 1358 minke whale tracks (no precise effort and encounter rate data was provided).

As identified in the Iceland section above, Faxaflói Bay was also highlighted as an area with high white-beaked dolphin encounters. The water in Faxaflói Bay is mainly 35 to 37 m deep and the seabed substrate is predominantly sand or basalt (Rasmussen & Miller, 2002). The water depths in the inner and coastal parts of Faxaflói Bay are around 40 to 50 m deep (Rasmussen et al., 2013).

Norway

From discussions with local scientists, Vestfjorden has been identified as an area suitable for minke studies between May and August (Lars Kleivane[27], pers comm.). Tagging studies on minke whales have been conducted in this area, such as is presented in Heide-jørgensen *et al*., (2001). This study presents telemetry data on two tagged minke whales, one tagged south of Lofoten (67°38'N, 13°21'E) on 5 September 1994 (tracked for 31 days) the other tagged north of Vesterålen (69°31'N, 15°52'E) on 2nd August 1999 (tracked for 38 days). Both minke whales remained in the Vestfjorden area for over a month (August to September), clearly demonstrating a preference for this area. This area has previously been identified as an important herring feeding ground for minke whales between August and September (e.g. Haug *et al.*, 1996). It was not possible to obtain any encounter rate information for the Vestfjorden area.

The water depths in Vestfjorden vary greatly, with deep channels reaching up to 700 m deep, making it far deeper than any of the ADD test sites to date, and significantly deeper than R3 and STW offshore wind farm development sites. The depths at this site may influence the sound propagation of the ADD and could influence the minke whale deterrence ranges.

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[27] FFI Forsvarets forskningsinstitutt – Norwegian Defence Research Establishment

Figure 32 Location of Vestfjorden in Norway (red marker).

Summary of Minke whale evaluation

Table 23 presents a summary of the available data in encounter rate/abundance of minke whales at the sites discussed in the previous sections. The variety of survey methods, the reporting of sightings in very different metrics and a lack of detail provided on survey effort makes it very difficult to compare measures of abundance between sites in a strictly quantitative way. In addition it is the degree to which sightings are predictable which is also a key factor in the feasibility of future ADD studies. Based on the data presented above it is likely that the sites with the most predictable encounters of minke whales are the Small Isles in the Hebrides, the Mingan Islands and Faxaflói Bay in Iceland. If more recent, extensive data from the CRRU in the Moray Firth could be examined, this would allow further evaluation of the Moray Firth as a suitable site.

Table 23. Summary of encounter rate data reviewed for identification of field sites for minke whale ADD trials

Site	Method	Period covered	Encounter rate
The Minch[28]	Land based visual	May 2009, April 2010, April 2011, October 2009, October 2010, October 2011	0.34 (ind per hour) 0 0.5 0.15 0.08 Total 45indiv/165 hours
Moray Firth coast[29]	various	1994-2012	4/km^2
Southern outer Moray Firth[30]	Vessel based visual	May-Sept 2000-2004	Up to 2.27/hour – average 1/hr
Southern outer Moray Firth[31]	Vessel based visual	May-Oct 2007-2007	0.299/hour or 0.022/km
Iceland (Faxaflói Bay) Error! Bookmark not defined.	Aerial visual	1986-2001	up to 0.0595 animals/km^2
Iceland (Faxaflói Bay)[32]	Vessel and land based visual	June-September 2010 and 2011	118 days of Fieldwork - 164 hours minke whale obs
Canada (St Lawrence Estuary)[33]	Vessel based visual	June-October 1990 to 2009	324 days of data - 489 focal follows
Canada (St Lawrence Estuary)[34]	Vessel based visual	June-October 2003	162 trips - 32.8 hours of feeding data
Canada (Mingan Islands, Gulf of St Lawrence)[35]	Vessel based visual	June-October 1988 and 1999	Up to 13.8/km^2
Canada (Nova Scotia)[36]	Vessel based visual	April-Oct 1997-2008	Sighted 61% of survey days

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[28] Dolman *et al.,* 2014
[29] Paxton *et al.,* 2014
[30] Tetley *et al.,* 2008
[31] Baumgartner, 2008
[32] Christiansen *et al.,* 2014
[33] Christiansen *et al.,* 2015
[34] Kuker *et al.,* 2005
[35] Naud *et al.,* 2003
[36] Bartha *et al.,* 2011

9.4.4 Weather and daylight

Sea state, wind and visibility are limiting factors in marine mammal behavioural observation studies, regardless of the methodologies used. Weather data from the sites considered in the above section were explored to understand the typical conditions at a site, particularly how often conditions suitable for carrying out trials reliant on visual observation and tracking of animals occurred (i.e. in sea states of Beaufort 3 or less).

None of the sites were limited in terms of daylight as long as field work takes place in the summer months. Most of the sites considered are high latitude and therefore benefit from upwards of 19 hours of daylight in summer. Weather varies, typically by how sheltered or how far offshore a site was. The best conditions are encountered in the Mingan Islands in Canada where 97% of days have a maximum sea state of 3 or less , followed by Aberdeenshire, the St Lawrence Estuary and then Norway and Iceland. The remaining UK sites had the worst average conditions with the Minch experiencing only 54% of days with an average sea state of 3 or less.

Table 24. Weather conditions at a range of selected dolphin field study sites. Max and average wind value given are the percentage of days during summer (Jun/Jul/Aug for sites in the northern hemisphere, Dec/Jan/Feb in the southern hemisphere) where maximum and average wind values are at or below Beaufort Sea state 3. The numbers of hours of daylight are based on July in the Northern Hemisphere and December in the Southern Hemisphere.

Site	Species	Max wind % Days BSS ≤ 3	Average wind % Days BSS ≤ 3	#hours daylight (July)
UK: Aberdeenshire coast	White-beaked dolphin	31.5	88.8	16
UK: The Minch	White-beaked dolphin	13.4	54.7	17
Iceland: Faxaflói Bay	White-beaked dolphin and Minke whale	25.4	83.3	20
Norway: Vestforden	Minke whale and white-beaked dolphin	28.5	83.2	24
UK: Southern coast of outer Moray Firth	Minke whale	16.3	77.2	17
UK: Inner Hebrides	Minke whale	19.9	80.0	17
Canada: Mingan Archipelago	Minke whale and primarily white-sided dolphin although some white-beaked dolphin	97	100	16

9.4.5 Logistics and local collaborators

Most UK sites are logistically straightforward and all the required expertise exists within existing research groups, although it would be recommended to recruit a full time post-doctoral researcher to lead these studies and additional field support will need to be employed on a temporary basis. Progressing studies at non UK sites will be much easier with local collaborators involved. Local researchers will have knowledge about local boat availability, they will have local knowledge of the study sites and know where and when best to target to maximise sample sizes. They will understand the politics involved with other users of an area and will have previous experience of the licencing process in their country. We have identified potential local collaborators at most of the suggested non UK sites (Norway, Iceland and Canadian sites). While involving local collaborators is clearly desirable from a logistics point of view, this will add additional cost and time onto requirements.

9.4.6 The influence of sound propagation conditions

There is a need to ensure that data collected at test sites will be directly applicable to the offshore wind farm sites where the mitigation will be employed. A review of the factors which could significantly affect the sound propagation conditions, and thus effective distances, of ADDs is provided in Section 7. It has been highlighted that across most of the sites considered in this section, differences in these factors are unlikely to influence propagation conditions to the extent that they would alter the effective range of devices within the range of concern here (500 m to 1 km). However it was highlighted that caution should be applied in areas with steep bathymetry and deep channels such as the Norwegian sites. This suggests that it might be more difficult to extrapolate between these sites and UK OWF sites although regardless of the conditions at the trial sites it is recommended to carry out acoustic measurements of the ADDs at varying ranges so that site specific conditions can be verified and predictions generalised to other sites with different conditions.

9.4.7 Previous noise exposure

The degree of previous exposure to potentially disturbing sound could have an influence on the likelihood of animals in a given area to be deterred by ADD signals. It is therefore recommended that field trials are not carried out in areas that have experienced significant previous use of ADDs in aquaculture. The degree of ambient noise (from for example, shipping, other marine activities such as dredging) may also influence the likelihood of response with animals with previous prior experience to noise may be more likely to respond than animals from ‘noisy’ environments, although there is limited empirical data to support this for ADD responses. Given this uncertainty, to rule out the possibility that responses to ADDs may vary between sites as a result of differences in previous exposure to anthropogenic noise underwater, it would be recommended to carryout trials in areas with similar levels of exposure to ambient noise.

9.4.8 Licencing

In the UK an EPS licence will be required to carry out trials on cetaceans and also for trials on seals where there is potential for incidental exposure to cetaceans. There are also additional home licence requirements if tags with anchoring systems are used. Outside of the UK the requirements vary between countries. On the information gathered to date and the conversations with local researchers in each of the countries selected, it is likely that it would be possible to gain the appropriate licences for this work at most of the sites explored. The exceptions to this are the site in the St Lawrence Estuary in Canada which is in protected Beluga habitat and is a designated marine park (Sagueny-St Lawrence Marine Park). Any licence application for any work in the Mingan Island area will need to consider the potential disturbance of non-target species, especially those which are SARA protected (Species At Risk Act) such as fin whales, blue whales and right whales. All of which have been encountered at the Mingan study site. It is likely that mitigation can be adopted to ensure no significant risk of disturbance to these species.

Table 25. Summary of licencing requirements in various countries where field trials have been considered.

Country	Licence(s) required	Timeline	Cost	Comments
UK	EPS licence	Within 40 working days	No fee	For EPS licencing SNCBs have stated that they are willing to comment on draft generic licence prior to full application for quicker processing
UK	Home office licence (required for invasive tagging and possibly for playback experiments[37])	Likely to be a lengthy process (several months) for a new application. Additions to existing licences to cover these activities will be quicker.	Fees are charged to institutions holding licences: there is an annual fee for the establishment licence and for each personal licence held. Training for personal licence cost £150-£175 per person (plus VAT)	Need an establishment licence as well as a project and personal licences for those carrying out the activities. Only likely to be granted to Research Institutions with Animal Care and Welfare arrangements.
Norway	Permit from the Norwegian Animal Research Authority	Guidance states approximately 40 working days but experience limited	None	Application must be approved by institution with an approved unit for

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[37] Each project needs to be assessed on a case by case basis and will need to be discussed at the earliest opportunity with the Institution's home office liaison officer.

Country	Licence(s) required	Timeline	Cost	Comments
		due to recent change in administration of permits		animal welfare. Discussions with local collaborators indicate high likelihood of licence being granted
Iceland	Permit from the Environment Agency of Iceland	Unknown but would be possible to put in place by next summer (Marianne Rasmussen, pers comm)	None if study done in collaboration with Icelandic researchers	Discussions with local collaborators indicate high likelihood of licence being granted
Canada	Marine mammal research licence required from the Department of Fisheries and Oceans (DFO)	Up to 90 days	None	Application must have approval from an AWEC (Animal Welfare Ethics Committee) from an established University or Research Institution. Licence application will need to consider effects on non-target SARA species

9.4.9 Conclusions – Overall suitability of field sites

This report has evaluated a range of possible field sites based on information on animal abundance, weather conditions, similarity to UK offshore wind farm sites, licencing requirements and the co-operation of local collaborators. Unfortunately the information available from all sites to describe animal encounter rates / density / abundance differ enormously in extent and quality between sites and therefore a robust quantitative comparison based on potential effort corrected encounter rates between sites was not possible. The review had to rely on a combination of published data from surveys (of varying methodologies) and on anecdotal information from a network of researchers with experience working in these areas.

One site has been ruled out on the basis that it will be difficult to obtain permits for this work. The St Lawrence Estuary was ruled out because the proposed site is in a protected marine park and is in protected beluga habitat.

The UK sites in general had variable sightings rates, but data were suggestive of quite high potential encounter rates in some areas and times. The Hebrides around the Small Isles and the Moray Firth are potential sites for minke whales and the Aberdeenshire coastline is a potential hotspot for white-beaked dolphins, although concerns regarding previous exposure to ADDs may result in a degree of caution in the selection of sites on the West coast of Scotland where ADD use in aquaculture is widespread. The Northumberland coast has also been identified as a potential hotspot for white beaked dolphins although it has proven difficult to access reports and data to fully assess this region within the timeline for this report. The advantages of UK based fieldwork include the overall lower costs, the project's links with researchers familiar with these sites, existing relationships with SNCBs and those involved in licencing, the availability of sheltered waters and ability to demobilise in times of bad weather and the flexibility to move rapidly between areas to encounter different species.

The Mingan Islands in Quebec had very high and consistent encounter rates of minke whales and the local research station has indicated a willingness to collaborate and provide logistical support. However this site doesn't have reliable encounters of white-beaked dolphins. White-sided dolphins are more common and if targeting minke whales at this site there is a chance that opportunistic trials could be carried out but dolphin encounters are not reliable enough numbers to focus dolphin effort at this site. There are sites further up the coast where white-beaked dolphins are more likely to be encountered (Christian Ramp, pers comm) but this would require effort to be separated to two distinct sites. These areas are quite remote and consideration will need to be given to the possibility that animals here may have experienced very different ambient noise conditions to those at typical UK OWF sites and therefore animals here may be more sensitive to noise.

Norway has areas where, according to local researchers, minke whale and white-beaked dolphin are present in high numbers, although there are limited published survey data to quantify this. The two species don't necessarily overlap in the same areas therefore it has been suggested that a field season could be spread over two sites, targeting West Finnmark early in the season (May/June) for white-beaked dolphins and then moving to Vestfjorden later in the summer, after the whaling season to target minke whales. There is a good chance that minke whale will be encountered opportunistically at West Finnmark but Vestfjorden has higher, more reliable numbers of minke whales. The Norwegian sites are characterised by deep water, Vestjorden is up to 700 m deep in places and West Finnmark bathymetry slopes rapidly away from the coast to depths of over 200 m which means that they are significantly deeper than Round three and STW offshore wind farm development sites. The depth is likely to influence the sound propagation of the ADD and could influence the deterrence range, although this can be understood by carrying out concurrent sound propagation measurements at the site and modelling propagation to allow a prediction of how results might apply to shallower sites (the separate Sound Propagation Report examines this in more detail). We have identified local researchers who would be willing to collaborate and provide logistical support and help with permit applications.

Faxaflói Bay, Iceland has high and predictable encounter rates of both species and is characterised by bathymetry which is more similar to the North Sea than the Norwegian or Canadian sites. We have identified willing local collaborators and been assured that obtaining the necessary licences and setting up field logistics would be possible to allow field work to commence in summer 2016. Whale watching boats do operate in this area but not exclusively over the whole bay. Furthermore the long hours of daylight in the summer months means that there is potential to work outside of the time that the boats are operating. The potential local collaborator we have been discussing this site with has established a good relationship with these boats and has a long history of collaboration and co-operation.

There is the possibility that in areas where whaling takes place or has taken place relatively recently, such as Iceland and Norway, whales may be more likely to respond to boats and therefore rates of control response may be higher potentially leading to a requirement for higher sample size.

Table 26. Summary of shortlisted non-UK sites

Site	Species	Abundance	Water depth	Bottom substrate	Local collaborators?	**Other users**	**Historical ADD use?**
Iceland	Minke Whale and white-beaked dolphin	High and predictable in Summer season	35-37 m	Predominantly sand or basalt	University of Iceland/ Marianne Rassmussen	Whale watching but there areas/times where whale watchers don't operate. History of whaling.	Unknown
Norway	Minke whale in Vestfjorden, white-beaked dolphin in West Finnmark		Vestfjorden = 100-700m deep West Finnmark = depths rapidly drop off to >200m	Vestfjorden = bedrock West Finnmark: Near coast gravelly sand and cobbles, sandy mud and gravelly sandy mud further offshore	Martin Biuw, Lars Kleivane	Whalers – would restrict activities to before or after whale watching season (May or Sept)	ADD use associated with aquaculture recorded in Vestfjorden

Site	Species	Abundance	Water depth	Bottom substrate	Local collaborators?	**Other users**	**Historical ADD use?**
Canada (Mingan)	Minke whale and possible white sided dolphin (WBDs not reliable)	High minke whale	channel-like bathymetry, reaching maximum depths of 200m	rock outcrops with a substrate primarily composed of sand and mud	Mingan Island Cetacean Study – Christian Ramp	Resident research team and visitors	Unknown

9.5 Choice of device

One device, the Lofitech seal scarer, now has a strong body of field evidence supporting its efficacy for a species of small cetacean and a species of pinniped. Trials of the Airmar dB plus II and trials using predator sounds with seals suggested they are probably less effective. Given the need to provide a system which provides the basic mitigation needs of regulators and industry as quickly as possible and in a very limited timeframe we suggest that initial research should focus on the Lofitech device unless it is shown not to be effective with either species or until equally strong evidence has been put forward to show that an alternative device is more effective. If time allowed, then tests could be carried out on a range of commercially ready devices and alternative signal types.

9.6 Costs

We have attempted to provide an estimate of the costs of a single field season of ADD playbacks on minke whales and white-beaked dolphins, assuming working at a single site for a three month field season. Staff costs are calculated based on an 18 month full time Post-Doctoral researcher, primarily responsible for data collection, analysis and reporting, plus a Principal Investigator at 5% of FTE across this period. Additional costs have been applied for field based research assistance and for overall project and contract management within the organisation. Costs are included for charter of a large research vessel or yacht capable of accommodating several researchers (a team of 6-8) at sea for days at a time plus a smaller rigid hulled inflatable (RIB) for carrying out playbacks. Costs have been included for visual tracking equipment, including drones with cameras.

Other than staff costs, the biggest single costs are vessel costs, a large survey vessel capable of accommodating several researchers at sea for a period of days is expensive, however a live-aboard vessel provides maximum flexibility and reduces the requirement to also secure land based accommodation for the team. Experience has shown that this can be provided by a relatively modest motor sailor.

It has been difficult to obtain information to accurately estimate the costs of field trials in the various countries evaluated and so far country specific costs for vessels and collaborators are only available from Norway and Canada. Additional costs for non UK fieldwork have been added to cover additional travel and subsistence costs, additional costs for local researcher involvement and costs for licences where appropriate. It has been difficult to specify exact costs for these aspects without much more extensive discussion of protocols, logistics and programme, which has not been possible to carry out within the timeline for this report.

Table 27. Estimated costs for a single field season of ADD field trials on minke whales and dolphins and associated analysis and reporting.

Country	Estimated costs
UK	£582,000
Norway	£748,000
Iceland	£718,000
Canada	£726,000

10 Conclusions and summary of recommendations

10.1 Overall approach to decisions regarding ADD based mitigation at OWF sites

The decision tree approach presented in Section 3 presents a methodology for a generic framework to be applied on a site by site basis. Although the detail of this approach requires development and agreement between developers, SNCBs and regulators, it is hoped that this process will provide a useful starting point for these discussions. It is clear from this process and from the ongoing discussions during this project that information on the effectiveness of ADD deterrence across a range of species is required to ensure regulator and SNCB agreement with their adoption in mitigation.

10.2 Evidence base for ADD effectiveness

SNCBs and regulators accept that there is evidence of effective deterrence of harbour porpoise and harbour seals for at least one device. It is likely that a similar degree of evidence will be required to provide confidence that this device can be adopted in mitigation for other species and/or that alternative devices can be adopted for mitigation for these species. The technology readiness review suggested that there are several devices capable of being used in this application with little or no modification. A combination of empirical data demonstrating effectiveness in the species of concern and a high degree of technological readiness are a pre-requisite for the adoption of a specific device in the mitigation of injury as a result of piling noise.

Despite agreement in earlier discussions, there is still debate over whether grey seals are likely to respond in a similar manner to harbour seals. Anecdotal comments from fish farmers suggest that grey seals are harder to deter from fish farms than harbour seals (Götz, pers comm) although there is no empirical evidence on which to base the conclusion that grey seals will respond any differently. Caution must also be taken in comparing OWF construction sites with fish farm sites where the motivation to remain is very different and the ADD signal is not backed up with additional aversive stimulus such as pile driving.

Uncertainties remain regarding ADD mitigation at OWF sites for species other than harbour porpoise and seals – primarily minke whale and offshore dolphin species (white-beaked dolphin being sighted most commonly at OWF sites in the UK). A key recommendation from this study is therefore that further research should aim to determine the effectiveness of the chosen ADD system on these species. The next section summarises what this research should entail.

10.3 Recommendations for further research

The use of telemetry tracking methods provides the most effective way of accurately measuring behavioural responses to experimental ADD playbacks; however tagging is unlikely to yield large sample sizes. The power analysis presented in Section 9.2 suggests that a sample size of 14 would provide an acceptable degree of power (80%) for a response rate of 70% and a control response rate of 25%. It is unlikely that 14 animals of each species of interest (minke whale and white-beaked dolphin) could be tagged over a single field season. Visual tracking methods provide a much better chance of achieving this sample size, and thus a vessel based approach is recommended to ensure that the research team can be sufficiently mobile to actively seek encounters and to carry out trials in an environment similar to OWF sites. Although there is a trade off in that visual tracking methods may be less likely than telemetry to detect a response; drones equipped with video cameras may prove useful in improving the ability to visually track animals and determine their movements in response to ADD playbacks.

Based on the detailed information provided in Section 9.4, sites in the UK, Iceland, Canada (Quebec) and Norway all present promising locations for field trials. The advantages of UK based fieldwork include the overall lower costs, the project's links with researchers familiar with these sites, existing relationships with SNCBs and those involved in licencing, the availability of sheltered waters and the flexibility to move rapidly between areas to encounter different species. Local collaborations will be essential to ensuring the success of non UK fieldwork and local collaborators have been identified for each potential study site. Detailed costs for comparison between these sites have proven difficult to obtain but based on the information gathered to date the relative order of costs are UK<Iceland <Canada <Norway.

Norwegian site conditions are least similar to OWF sites in terms of depth, topography and substrate and minke whale and white-beaked dolphin encounters are more likely in different regions rather than in the same location. Although minke whale encounter rates are high and predictable at the Quebec site, minke whales and dolphins are not found reliably in the same spot and this would necessitate moving to other sites to target white-beaked dolphins.

Variation in sound propagation conditions across UK OWF sites are unlikely to result in major differences in the predicted effectiveness of ADDs however it is recommended that any field trials are accompanied by empirical measurements of ADD transmission loss so that effects can be predicted at other sites. It is also recommended to measure how the temporal characteristics of sounds vary with distance from the source given evidence that temporal characteristics might be important in eliciting avoidance behaviour.

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Appendix A - Request for Information (RFI)

The following RFI was issued to the contacts listed in Appendix B.

Acoustic Deterrent Devices - Request for Information (RFI)

The use of acoustic deterrent devices (ADDs) have been suggested as an alternate means to mitigate the risk of lethal and physical direct injury to marine mammals during pile driving operations associated with the construction of offshore wind farms (OWF's) in the UK. This proposal (to use ADDs as an alternative to adoption of the JNCC protocol and the use of MMOs and PAM) in response to stakeholder concerns led to a 2013 review commissioned by the Offshore Renewables Joint Industry Programme (ORJIP), published by the Department for Energy and Climate Change.

The review can be accessed here: http://www.carbontrust.com/orjip

An update to this review is underway to identify any advances in ADD technology and experience gained from their use since its publication. The purpose of this RFI is to gather information and evidence from ADD technology providers. The questions below outline the information we are hoping to gather. Your assistance is much appreciated.

The information provided will be used to prepare a short report to the ORJIP commenting on device maturity and readiness for deployment on an OWF project. A review of the evidence available on device efficacy for specific species of concern is being completed by SMRU, however if you have any information on this aspect of the ADD's that is not already published then please let us know. If you have any pictures of your device that you could provide that would be helpful, especially in deployed configuration, please indicate whether these can be included in the report.

RFI issued 1st July by Christine Sams

Please direct any questions to Christine.sams@xodussubsea.com or +44 7747 848920 (please note I am currently travelling so better to email and set up a call if possible)

Responses requested by 10th July latest

1. Context - Company background and involvement in ADD's

Please include a brief introduction to the company and outline your involvement with ADD's. (i.e. device developer / owner of IP, if you manufacture, sell / rent etc. and whether alone or in partnership)

2. ADD device(s) – specification

Please provide an overview of the device itself and the system currently available (e.g. power, deployment equipment and cables etc.).

Please provide details of method of operation and any safeguards in place to ensure that the device is functioning according the specification. Please outline the recommended maintenance for the system.

3. ADD device(s) – deployments

Please provide details of the number of units in operation (and for what application) and any on-going device development. Please highlight in particular, if known, any OWF deployments of your ADD (including field trials).

If you have experience of OWF deployment, or deployment from construction vessels please provide details if possible of recommended system set up (e.g. deployment / recovery and power supply), or proposed system set up.

4. Commercial

A later stage of this study will look at the potential cost savings of using ADDs, please provide an indicative specification / cost for an ADD system suitable for deployment from a piling vessel if possible.

We are interested in device reliability and performance; please provide information if available and details of after sales support / warranties provided.

If you have details of any OWF clients that may be willing to provide detail of their experience with your device then please provide details and I will follow up (or pass on my contact info).

Appendix B - ADD supplier contact information

Manufacturer	Device	Contact
Ace Aquatec	Marine Mammal Mitigation device (MMD)	Nathan Pyne-Carter Managing Director Ace Aquatec Tel: 0044 (0) 7862217320 Email: nathan@aceaquatec.com Website: www.aceaquatec.com
Aquatec Group Ltd	AQUAmark 848	Email sent to inquiry@aquatecgroup.com following telephone conversation with the office (details on the website) – No response received
Genuswave Ltd	Genuswave	Dr Thomas Goetz Scottish Oceans Institute Sea Mammal Research Unit University of St Andrews KY16 8LB, St Andrews Scotland/UK 01334 463459 Enquiry was passed by Thomas onto Steven Alevy of Genuswave Ltd. RFI response received from Jason Brandler, jjbrandler@bankersllc.comsalevy@bankersllc.com
Lofitech	Seal Scarer	Dag Hansen – CEO Phone: +4795781303 www: lofitech.no
Mohn Aqua	MAG Seal Deterrent	David M Adam Technical Sales Engineer MOHN AQUA (UK) LTD Direct Line +44 (0) 1309 678274 Mobile +44 (0) 7876 040609 Email david.adam@mohnaqua.com
Seamarco / Van Oord	Faunaguard	Dr. ir. R. A. Kastelein Director & owner SEAMARCO (Sea Mammal Research Company) Julianalaan 46, 3843 CC Harderwijk The Netherlands Tel (Office): +31-(0)341-456252 Tel (Mobile): +31- (0)6-46-11-38-72 E-mail: researchteam@zonnet.nl
STM Products s.r.l.	DDD, Dolphin Dissuasive Device (DDD 03)	Martín Ipuche martin.ipuche@stm-products.com Mktg & Sales Manager Via Morgagni 14 37135 Verona, Italy Tel. +39 045 585700 www.stm-products.com