Protocol for mitigating the risk of instantaneous death or injury to marine mammals during piling at the BOWL and MORL Wind Farms

Paul Thompson [1] & Tessa McGarry [2]

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1. University of Aberdeen, Institute of Biological & Environmental Sciences, Lighthouse Field Station, Cromarty IV11 8YL
2. RPS Energy, Riverside Court, Beaufort Park, Chepstow, Monmouthshire, NP16 5UH.

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Background: To date the consents issued to offshore wind farms have focused on the current JNCC guidelines to minimise the instantaneous near-field impacts of piling on marine mammals (JNCC, 2010). Nevertheless these guidelines remain untested and a number of studies have criticised the reliance on these guidelines with calls for more effective mitigation (see Annex 3). Recent studies provide evidence that acoustic deterrent devices (ADDs) can result in aversive responses by both seals and cetaceans over ranges which are at least in the order of magnitude greater than predicted zones for instantaneous death and injury (see Annex 2). This indicates that they could be integrated into piling procedures along with soft start to provide more effective mitigation and improve the protection of marine mammals. This document (including Annexes 1-3) provides the proposals for mitigating the risk of instantaneous death or injury to marine mammals during piling at the BOWL and MORL wind farms.

Aim: This document outlines a procedure for mitigating the risk of instantaneous death or injury to marine mammals during piling at the BOWL and MORL wind farms, with the aim of developing the *Best Available Technique* [1] for balancing the highest level of environmental protection against commercial affordability and practicality.

Specific Objectives: To develop mitigation measures that can be integrated into a predictable and efficient engineering process that:

- minimises the risk of instantaneous death or injury (physical or auditory) for marine mammals during piling operations as a result of single noise pulses at close range;
- allows piling to be initiated in darkness, in poor visibility or after breaks in engineering works;
- can be used safely in an offshore environment in all seasons; and
- minimises the duration of the overall construction period.

Approach:

1. ***Optimise hammer energies to balance environmental risk and engineering requirements.*** Use available geotechnical data to predict the hammer energies required through the piling sequence to minimise the risk of pile refusal. Optimise piling sequence at each site to avoid unnecessary activity at full hammer energy (to minimise impact zones for instantaneous death and injury) and optimise hammer energies throughout the piling process (to minimise cumulative noise exposure).

[1] As defined in 2010 JNCC piling mitigation guidance.

2. ***Identify impact zones***. Estimate the size of impact zones for instantaneous death and injury based upon available geotechnical data, final pile sizes and predicted hammer energies at the start of each piling sequence (see Annex 1).

3. ***Develop site specific protocol for initiating the sequence of piling at each turbine location.*** This should involve the key elements outlined in Figure 1 (see page 5). The piling protocol presents the different steps (a to d) throughout the piling sequence with a justification of how the detail has been determined in each step. In addition, the piling protocol presents an illustration of how far an animal may be deterred (indicative cumulative distance) at each step in order to demonstrate that the protocol is sufficiently conservative to allow marine mammals to avoid the injury zone during piling.

   a. Deploy acoustic deterrent device (ADD) at the piling site for a period of 15 minutes (as agreed with the MFRAG-MM Subgroup at the meeting of the 19/06/2015), to allow marine mammals to be displaced out of the impact zones. Duration of ADD use to be based upon estimates of the size of the impact zone and likely swimming speeds. Herschel et al. (2013) recommend that the duration of mitigation should be tailored to allow all animals to swim twice the distance of the injury zone. Selection of ADD to be based upon available evidence on effective displacement of key receptors for each site (see Annex 2).

   b. Soft start commences with positioning the piling hammer and making 5-6 single blows at a low rate (approximately 1 blow per 10 seconds) using as low an energy as practically possible to check hammer operation and embed the pile into the ground. Although the energy level cannot be specified accurately (as this depends on equipment capabilities) the energy will not exceed 300 kJ (threshold set on the basis of 12%[2] of the maximum hammer size[3] of 2,500 kJ that may be employed during construction).

   c. Soft start continues with an increased blow rate of approximately 1 blow per 2 seconds. The minimum duration of soft start will be 20 minutes, consistent with JNCC guidelines. During this time soft start energy will be as low as possible for as long as possible (following recommendations by Herschel et al.

[2] For each halving of hammer energy there is a 3 dB reduction in sound and the ORJIP report on acoustic deterrent devices (Herschel et al. 2014) suggests that a tenfold reduction in hammer energy may be appropriate for initiating soft start as this represents a potential 10 dB reduction in sound. Whilst it may be possible to achieve this in practice, the thresholds here must be set according to the hammer manufacturers' specifications, which for a 2,500 kJ hammer is given as 12% or 300 kJ. This also represents a considerable reduction in sound of >9dB.

[3] Maximum hammer size is to be distinguished from maximum consented hammer energy.

(2013)), starting at an energy no higher than 300 KJ and not exceeding 500 KJ in the latter part of the soft start.

   d. Continue to ramp up hammer energy gradually to the levels required to maintain pile movement at approximately 2.5 cm/blow up to the energy required to drive the pile up to target depth.

4. ***Develop site specific protocol to be used in planned or unplanned breaks in the sequence of piling at each turbine location.*** This should involve the key elements outlined in Figure 2 (see page 6).

   a. In the event of breaks in piling of < 10 minutes no additional mitigation would be required (i.e. the piling may continue from the hammer energy and frequency last used). For breaks in piling > 10 minutes[4] there are two possible outcomes as described in 4b. and 4c. below.

   b. Where duration of break is either unknown, or known to be less than 2.5 hours[5]

      i. deploy ADD for the same pre-determined period (as specified in 3a and as agreed with the MFRAG-MM Subgroup at the meeting of the 19/06/2015) immediately prior to resuming piling,

      ii. initiate piling with approximately 5 - 6 single blows at low energy; and

      iii. continue to ramp up hammer energy to the levels required to maintain pile movement at approximately 2.5 cm/blow.

   c. If the break is greater than 2.5 hours, or if the break occurs during the soft start procedure described under 3 (b. and c.)), re-start procedure as outlined in 3.

5. **Monitoring and Audit.** Establish an agreed monitoring system and an audit trail to demonstrate that:

   a. The ADD is operating according to specifications during all operations.

   b. Hammer energies remain within agreed limits within soft start periods.

The detailed monitoring and reporting procedures can be integrated within each of the projects' Environmental Management Plans (EMPs) and Project Environmental Monitoring Programmes (PEMPs).

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[4] JNCC guidelines state that if there is a pause of greater than 10 minutes, then the pre-piling search and soft-start procedure should be repeated (Section 2.5 in JNCC, 2010).

[5] Based on the deterrence time (total duration that animals are deterred from a disturbed area) of harbour porpoise estimated for the DEPONS model (van Beest et al. 2015) using the life-history parameters and fine-scale movement behaviour as described in model developed by Nabe-Neilson et al., (2014).

6. **Risk assessment.** Recognising that this protocol represents a change in procedures used for piling mitigation, and the efficacy of this protocol cannot be robustly demonstrated within appropriate timescales, undertake a risk assessment to assess the impact on protected marine mammal populations should key receptors not respond to the chosen ADD as expected. This risk-based approach should be used to place any risk from ineffective mitigation in the context of related impacts from piling noise (i.e. cumulative noise exposure and behavioural disturbance) that have previously been considered in the Environmental Statements (ES) and Habitats Regulations Assessment (HRA). A risk assessment has been undertaken for the BOWL and MORL sites, demonstrating that adoption of these new mitigation procedures should present negligible additional risk to the key receptor population in the Moray Firth (see Annex 3).

Figure 1. Schematic providing an example of a piling mitigation procedure based on the general guidelines outlined in section 3.

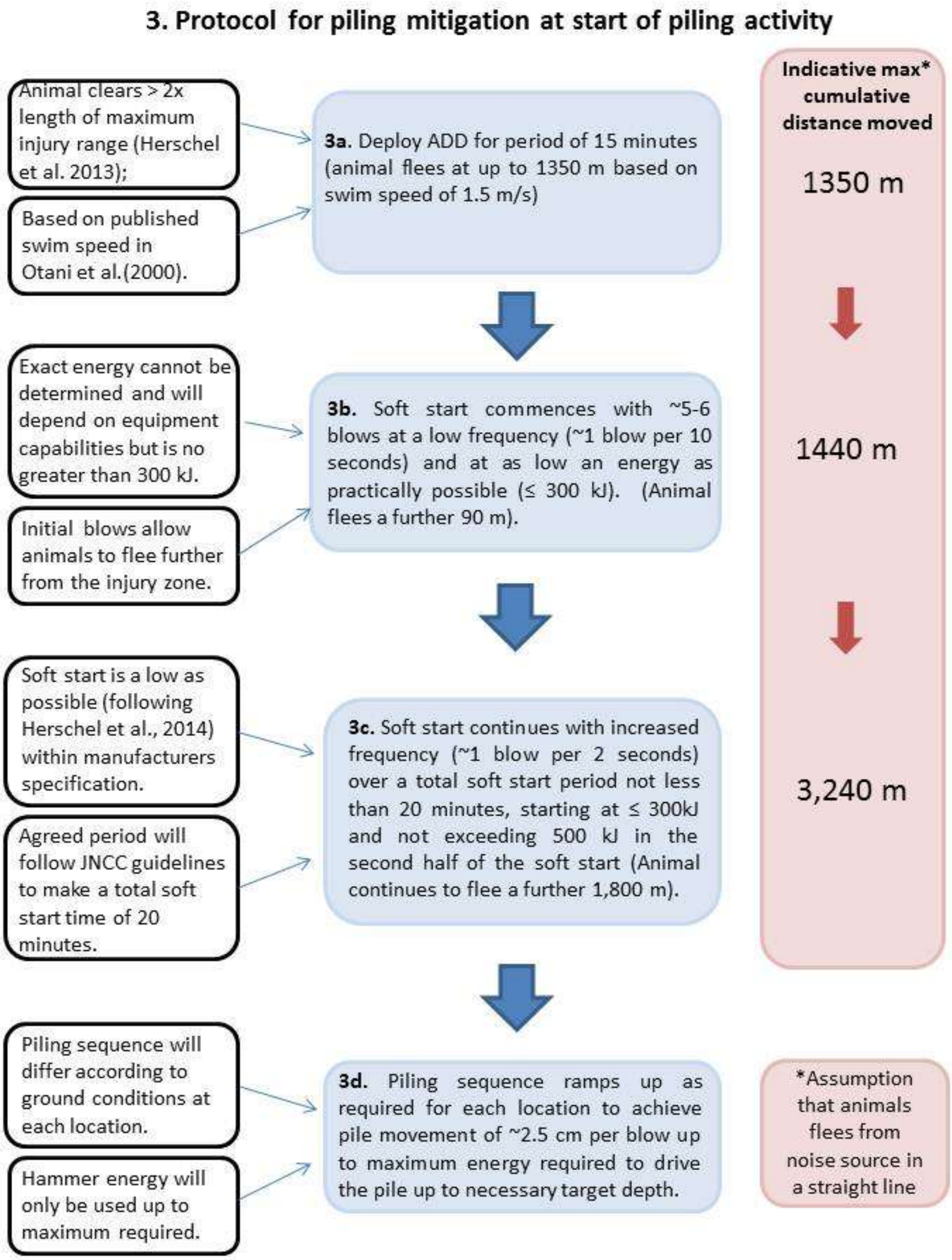
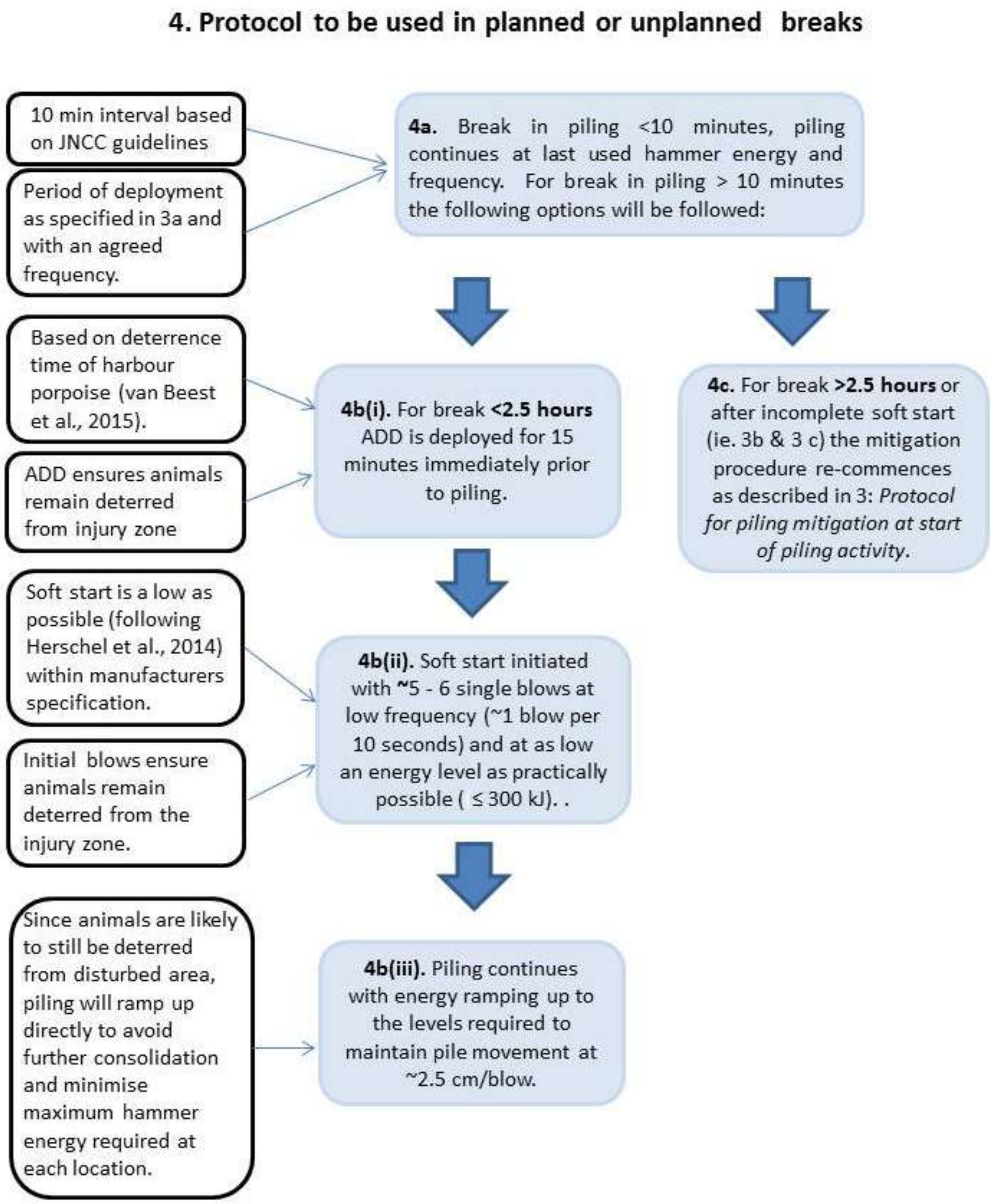


Figure 2. Mitigation protocol to be used in a planned or unplanned break from piling with distinction made between longer breaks and short breaks up to 2.5 hours.



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Herschel, A., Stephenson, S., Sparling, C., Sams, C., Monnington, J. (2013). Use of Deterrent Devices and Improvements to Standard Mitigation during Piling. ORJIP Project 4, Phase 1. Xodus Group Ltd. Document L-300100-S00-REPT-002.

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Annex 1.

Identification of impact zones

The following criteria should be used to identify the noise levels likely to cause instantaneous death or injury around piling operations using different pile sizes and hammer energies (eg. MORL ES Section 4.2.2 Technical Appendix 3.6A).

Death – may occur where peak-peak levels exceed 240 dB re 1 µPa

Injury (physical or auditory) - may occur where peak-peak levels exceed 220 dB re 1 µPa

In addition instantaneous auditory injury thresholds have been defined based upon Southall et al's (2007) single pulse PTS thresholds, expressed either in terms of a peak pressure level or an M weighted sound exposure level (SEL). More recent studies of harbour porpoise TTS thresholds (Lucke et al. 2009) have led to proposals for a revised single pulse PTS threshold for these high frequency cetaceans (ORJIP Project 4 Phase 1 Report p 139).

Species	Single pulse PTS Thresholds	
	SEL	Unweighted peak pressure
High-Frequency Cetacean (Southall et al. 2007)	M-weighted 198 dB re 1 µPa^2s	200 dB re 1 µPa
Mid-Frequency Cetacean (Southall et al. 2007)	M-weighted 198 dB re 1 µPa^2s	230 dB re 1 µPa
Low-Frequency Cetacean (Southall et al. 2007)	M-weighted 198 dB re 1 µPa^2s	230 dB re 1 µPa
High-Frequency Cetacean (based on Lucke et al. 2009)	Unweighted 179 dB re 1 µPa^2s	200 dB re 1 µPa
Pinniped (Southall et al. 2007)	M-weighted 186 dB re 1 µPa^2s	218 dB re 1 µPa

In the BOWL and MORL ES's the risk of instantaneous death was estimated to occur only at extremely short distances and the risk of instantaneous injury at less than 38 m.

For this assessment, CEFAS conducted additional modelling to provide a conservative estimate of impact ranges for a 300 kJ initial hammer energy. This assumed an energy conversion efficiency of 1%, which is at the upper limit of field observations (Ainslie et al. 2012; Dahl et al. (2015). This 300 kJ strike equates to 205.6 dB of acoustic energy as a single pulse SEL (de Jong & Ainslie 2008). A propagation loss of 15*log(R) was assumed due to cyclindrical spreading in these relatively shallow waters, where R is range from the source, and an unweighted threshold of 179 dB re 1 μPa^2s (Lucke et al. 2009) was used to safeguard the most sensitive of marine mammals, including harbour porpoise. This suggests that the maximum range at which instantaneous injury might occur is <60m.

Estimating the time required for marine mammals to be displaced from injury zones

Following recommendations in the ORJIP Project 4 Phase 1 Report (p 142), ADD should be deployed for long enough for animals to swim twice the radius of the appropriate injury zone. The Piling Mitigation Protocol provides for marine mammals to clear an area an order of magnitude greater than this.

Following the approach taken in the ORJIP Project 4 Phase 1 Report (p141) these calculations should assume a minimum swimming speed of 1.5 m/s (Otani et al. 2000).

References:

Ainslie, M. A., de Jong, C. A., Robinson, S. P., & Lepper, P. A. (2012). What is the source level of pile-driving noise in water? In: The Effects of Noise on Aquatic Life (pp. 445-448). Springer New York.

Dahl, P.H., de Jong, C.A.F. & Popper, A. (2015). The underwater sound field from impact pile driving and its potential effects on marine life. Acoustics Today, 11, 18-25.

De Jong, C. A. F., & Ainslie, M. A. (2008). Underwater radiated noise due to the piling for the Q7 Offshore Wind Park. J Acoust Soc Am 123: 2987.

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Otani,S., Naito,Y., Kato,A., Kawamura,A. (2000) Diving behaviour and swimming speed of a free-ranging harbor porpoise, *Phocoena Phocoena*. Marine Mammal Science 16: 811-814.

Lucke K, Siebert U, Lepper PA, Blanchet MA (2009) Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. J Acoust Soc Am 125: 4060–4070

Southall B.L., Bowles A.E., Ellison W.T., Finneran J.J., Gentry R.L., Jr C.R.G., Kastak D., Ketten D.R., Miller J.H., Nachtigall P.E., et al. 2007 Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals 33: 411-521.

Annex 2. Deployment of acoustic deterrent devices.

Choice of ADD. Selection of ADD devices should be based upon the available evidence at the time of procurement given the suite of key receptors at a particular site. Based upon the current literature and the ORJIP review of available devices, it is anticipated that this could be a Lofitech Seal Scarer. A review of available literature on the performance of this device can be found on p 149 of the ORJIP Project 4 Phase 1 Report (Herschel et al. 2013).

In summary, marine mammals with both high frequency (harbour porpoise) and low frequency (harbour seal) have been shown to respond to the Lofitech Seal Scarer. Of particular relevance to the Moray Firth developments are the studies of harbour porpoises in the Danish Baltic Sea, where the use of the Lofitech Seal Scarer decreased sighting rates within 1 km to only 1% of baseline (see Figure 4 and Brandt et al. 2013a). Similarly, in the German North Sea waters, deployment of the Lofitech Seal Scarer resulted in significant decrease in harbour porpoise click activity (recorded using C-PODs) at 750 m and at 3,000 m from the source (Brandt et al. 2013b). Notably, at 750 m recovery was found to be gradual with a significant deterrence effect lasting up to 4 to 6 hours after the Lofitech Seal Scarer was turned off, suggesting that effects are likely to last no longer than 6 hours at this distance (Brandt et al. 2013b).

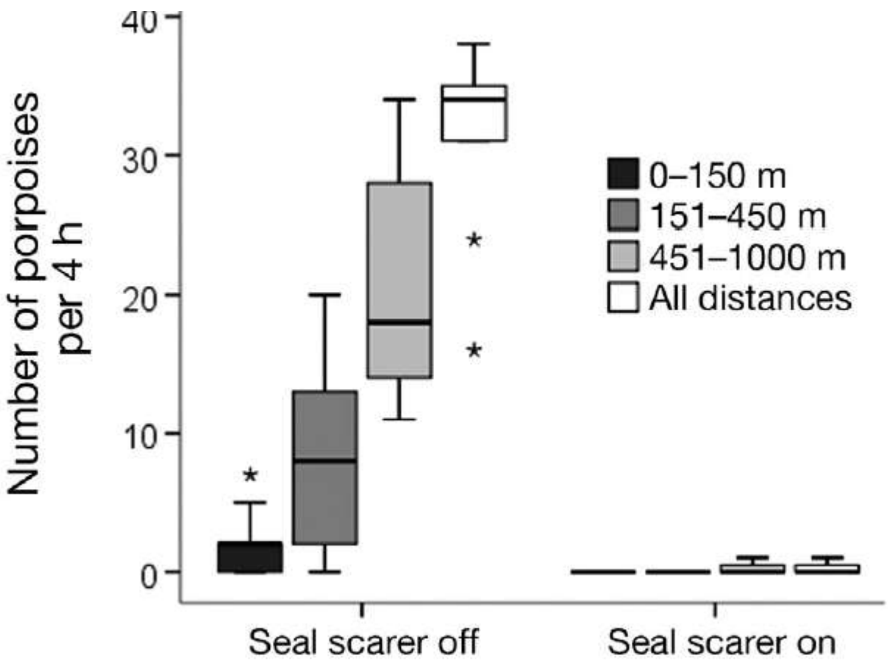

Fig 4 from Brandt et al. (2013) showing variation in sightings rate during observation periods when the Lofitech Seal Scarer was turned on compared to when the Lofitech Seal Scarer was turned off.

Further studies of responses of Moray Firth harbour seals to this device have been conducted both in river systems (Graham et al. 2009) and open water (SMRU Unpublished data). Graham et al's (2009) study showed that use of the device reduced upstream movements of seals by 50%, even though seals are likely to have been strongly motivated to travel upstream to forage on salmonids. Studies conducted for Marine Scotland by SMRU indicate that in open water a behavioural response was observed for all 38 controlled exposure experiments for which a tagged harbour seal was within 1 km of the source, and responses were recorded to a maximum range of > 3km.

Methods for deployment of ADD. A single device should be deployed as close as possible to the piling site, ideally so that the deployment is fully integrated with the engineering process (eg. through remote operation of a device deployed from the piling vessel).

Timing of deployment of ADD. Decisions over the duration of ADD use should seek to balance the key objective of dispersing animals from the injury zone against any risks of habituation to the ADD source, cumulative noise exposure to the ADD source or broader scale disturbance.

Following ORJIP recommendations (Herschel et al. 2013), the duration of deployment at start of piling sequence should be sufficient to allow individuals to travel 2x the distance of the injury zone at a cruising speed of 1.5m/sec.

- Eg. for a 60m injury zone, ADD deployment of just 1.5 minutes would permit animals to swim beyond the required 120 m.

To minimise excessive disturbance and habituation, whilst also ensuring sufficient time for animals to clear the injury zone there should be an agreed duration for each ADD deployment. Following submission of a draft of this Piling Mitigation Protocol, this was discussed with the SNCBs, and the duration for ADD deployment was agreed as 15 minutes.

References:

Brandt, M. J., C. Höschle, A. Diederichs, K. Betke, R. Matuschek, and G. Nehls. 2013a. Seal scarers as a tool to deter harbour porpoises from offshore construction sites. Marine Ecology Progress series 475: 291-302.

Brandt MJ, Höschle C, Diederichs A, Betke K, Nehls G (2013b) Far reaching effects of a seal scarer on harbour porpoises, *Phocoena phocoena*. Aquat Conserv: Mar Freshw Ecosyst 23: 222-232.

Graham, I. M., R. N. Harris, B. Denny, D. Fowden, and D. Pullan. 2009. Testing the effectiveness of an acoustic deterrent device for excluding seals from Atlantic salmon rivers in Scotland. ICES Journal of Marine Science 66: 860-864.

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Annex 3. Framework for a risk-based assessment to underpin the adoption of alternative mitigation measures during piling at the BOWL and MORL Offshore Wind Farms

Paul Thompson, 28th September 2015

Overview

There is widespread interest in the use of Acoustic Deterrent Devices (ADDs) as an alternative to Marine Mammal Observers (MMO) and Passive Acoustic Monitoring (PAM) when mitigating the risk of death or injury to marine mammals during offshore piling. However, decisions on the most appropriate mitigation during construction of the Moray Firth developments remain constrained by stakeholder concerns over the relative efficacy of ADDs and the current JNCC guidelines.

To inform decisions about the potential risk of using these alternative piling mitigation measures, an assessment of the potential risk to different marine mammal species in the absence of ***any*** piling mitigation has been developed. To place this risk in the broader population context considered within the original Environmental Statements (ES) and Habitats Regulations Assessments (HRA), the Moray Firth Harbour Seal Assessment Framework has been used to re-assess the long-term population consequences for this key receptor species. In doing so, the effects of post-consent changes in the project design and construction programme have been explored, comparing the original worst case ES scenarios with new worst case scenarios for BOWL and MORL together based on the current design layout. In addition, the potential risk of injury from scenarios in which piling occurred only within the BOWL or the MORL wind farms were developed to support individual EPS Licence applications.

Current JNCC guidelines are assumed to reduce the potential risk of injury or death to negligible levels. The analyses presented here suggest that, in the absence of any piling mitigation, the risk of marine mammals being within sufficiently close range to result in instantaneous death or injury is also negligible even when considering effects from both BOWL and MORL developments together. Thus, the adoption of alternative mitigation measures using ADD should either equal or exceed the level of protection assumed to result from the current JNCC guidelines.

Background

The key impacts of wind farms on marine mammal populations that are likely to result from pile-driving during construction [1] are:

(1) Instantaneous death or injury (physical or auditory) from single noise pulses at close range
(2) Auditory damage from accumulated noise doses
(3) Behavioural disturbance

In the Environmental Statements (ES) for the Moray Firth developments, the distances at which each of these effects might occur were based upon best available scientific evidence from noise propagation modelling and published marine mammal noise exposure criteria [2]. These data indicated that instantaneous death or traumatic injury should occur only at distances of < 40m (see Table 1). In contrast, behavioural disturbance and the impacts of cumulative noise exposure were predicted to occur at much greater distances. For example, piling noise exposure amongst harbour seals could exceed Southall et al.'s (2007) Permanent Threshold Shift (PTS) threshold for auditory damage [2] at distances of > 10-15km.

In 2010, building on related guidelines for seismic surveys [3], guidance was produced by JNCC to mitigate injuries that might result from pile-driving activity. These require the use of Marine Mammal Observers (MMOs) and Passive Acoustic Monitoring (PAM) to minimise the likelihood that a piling sequence is initiated when marine mammals are within a 500m mitigation zone. When assessing the population consequences of piling activity within the Moray Firth developments, it was assumed that close range impacts resulting in instantaneous death or injury would be avoided through adoption of the 2010 JNCC guidelines [4]. Given that cumulative noise exposure may lead to PTS over ranges in excess of 10km, JNCC guidelines clearly provide negligible protection against the effects of any far field auditory damage resulting from cumulative noise exposure, or indeed for behavioural disturbance. The population effects of these other unmitigated residual impacts were assessed in the ES as resulting in no significant long term effects, and the Habitats Regulations Assessment (HRA) concluded that they did not affect the long term conservation status. Efforts have been made to further reduce any of these longer range impacts through post-consent changes in the design layout. Furthermore, post-consent geotechnical investigations are currently underpinning the development of strategies that aim to minimise the cumulative energy required to drive each pile into the seabed. The requirement for mitigation at the start of each piling process is therefore to reduce the risk of instantaneous death or traumatic injury to negligible levels at the start of each of these piling sequences.

The need for alternative mitigation measures

Although a pragmatic first step towards minimising the impacts of noise on marine mammals, the 2010 JNCC guidelines remain untested. Reliance on the guidelines has subsequently received criticism in the scientific literature, with calls for more effective mitigation [5]. In particular, it is recognised that the probability of visually detecting marine mammals at sea is extremely low [6]. Furthermore, the probability of detection by Passive Acoustic Monitoring (PAM) systems is known to be zero for some key receptors such as harbour seals, and is uncertain for all other species [7].

Recognising these issues, there is widespread agreement over the need for more effective measures to mitigate the risk of instantaneous death or injury at close range. Recent studies provide evidence that at least one commercially available Acoustic Deterrent Device (ADD) can result in behavioural responses by both seals and cetaceans over ranges which are at least an order of magnitude greater than predicted zones for instantaneous death and injury [8, 9]. This suggests that ADDs may be a more effective tool than MMOs and PAM where mitigation aims to maximise the likelihood that animals are outside predicted impact zones at the start of piling.

Consequently, ADDs and soft start piling could be integrated into new procedures for offshore piling that should provide more effective mitigation and improve the protection of marine mammals. This approach would also provide greater certainty in engineering timelines, avoiding delays due to the onset of night time, poor weather and MMO detections. This would have three additional benefits:

1) Greater economic certainty for overall construction plans. This would increase the likelihood of individual developments going forward and contributing to the UK's efforts to meet current climate change targets.
2) Greater certainty in timelines for individual piling events. This would improve the optimisation of piling events within predicted weather windows and reduce HSE risks.
3) Overall reduction in the construction period. This would reduce broader scale disturbance from vessel activity. A shorter construction period would likely also have wider environmental benefits by reducing impacts on other receptors and producing less carbon.

Whilst ADDs have been used in conjunction with MMOs under JNCC guidelines in some regions, discussion within the Offshore Renewables Joint Industry Programme (ORJIP) has highlighted that there are strong stakeholder concerns over the adoption of ADDs as an alternative to the temporal restrictions which would result from the use of MMOs and PAM. Most critically, Statutory Nature Conservation Bodies (SNCBs) are currently requesting scientific evidence that ADDs are more effective than current JNCC guidelines before agreeing to their use as an alternative mitigation measure. This raises two key challenges for regulators and the industry:

1) Given there has been no assessment of the efficacy of current JNCC guidelines, it is unclear how proposed studies might demonstrate that ADDs are more effective than this unknown baseline.
2) Given the global experience of previous behavioural response studies, it is unclear whether a viable experiment can be designed to provide the expected level of confidence in the effectiveness of ADDs as an alternative mitigation measure.

BOWL and MORL are currently developing piling strategies that must be economically viable and accepted by key stakeholders. Critically, project milestones dictated by DECC mean that this process must be completed in Q4 2015. In contrast, even if suitable research projects could be designed and commissioned through ORJIP, results would not be available for at least 2 years, well beyond the timescales required for approval of the projects' piling strategies. Decisions on the potential use of ADDs within the BOWL and MORL piling strategies must therefore be made on the existing evidence base. Currently, however, these decisions are constrained because of SNCB and Regulator concern that the adoption of alternative mitigation measures using ADD may result in unacceptable risks.

Aims

This document develops a framework that aims to allow regulators to assess whether the risk of using ADDs as an alternative form of piling mitigation is acceptable.

Given the challenges outlined above, the proposed approach involves assessing the consequences of a complete failure in the efficacy of ***any*** of the potential mitigation measures.

If it can be demonstrated that there is negligible additional risk to these populations in the absence of any effective mitigation for near-field impacts, then the use of (potentially more effective) alternative mitigation measures using ADDs should either equal or exceed the level of protection assumed to result from the current JNCC guidelines.

Framework overview

The general approach used in this risk assessment was to use site specific density data to estimate the likelihood that randomly distributed individuals may be close enough to a pile to be killed or injured at the start of a single piling sequence. The BOWL Wind Farm layout includes 84 turbines, two offshore transformer modules (OTMs), and two spare locations, each requiring four piles with a maximum diameter of 2.2m. The first phase of the MORL development (Project 1) will not exceed 100 turbines, with a maximum of 4 piles per turbine, and up to 16 piles for each of the up to two Offshore Substation Platforms (OSPs). This information was used to estimate the likelihood of an individual being killed or injured at the start of the resulting maximum number of piling events during the construction period for each scenario. This maximum number was 784 piling events for both projects together, 352 for BOWL only[6] and 432 for MORL Project 1 only scenarios. These calculations were made for all five marine mammal species considered in the ES (Harbour Seal, Grey Seal, Bottlenose Dolphin, Harbour Porpoise & Minke Whale). For harbour seals, the numbers of individuals that might be impacted in the absence of effective mitigation of these close-range impacts were also included in revised scenarios of the Seal Assessment Framework used in the BOWL and MORL ES's. This was then used to compare the long term population consequences of the worst case cumulative construction scenario, with and without mitigation.

Figure 1 provides an overview of the approach used, illustrating where information was drawn from the existing ES's and where new outputs have been generated. More detailed information on the methods used is presented below. As for the Seal Assessment Framework, the approach aimed to be conservative. For example, when generating random distributions of animals, it was assumed that the presence of vessels prior to piling did not disturb any individuals from the immediate vicinity of the piling vessel. Other key assumptions are listed in The Annex.

Potential impact zones were based on ES predictions of the distances at which different species may be killed or physically injured instantaneously from a single loud pulse. The approaches used in the

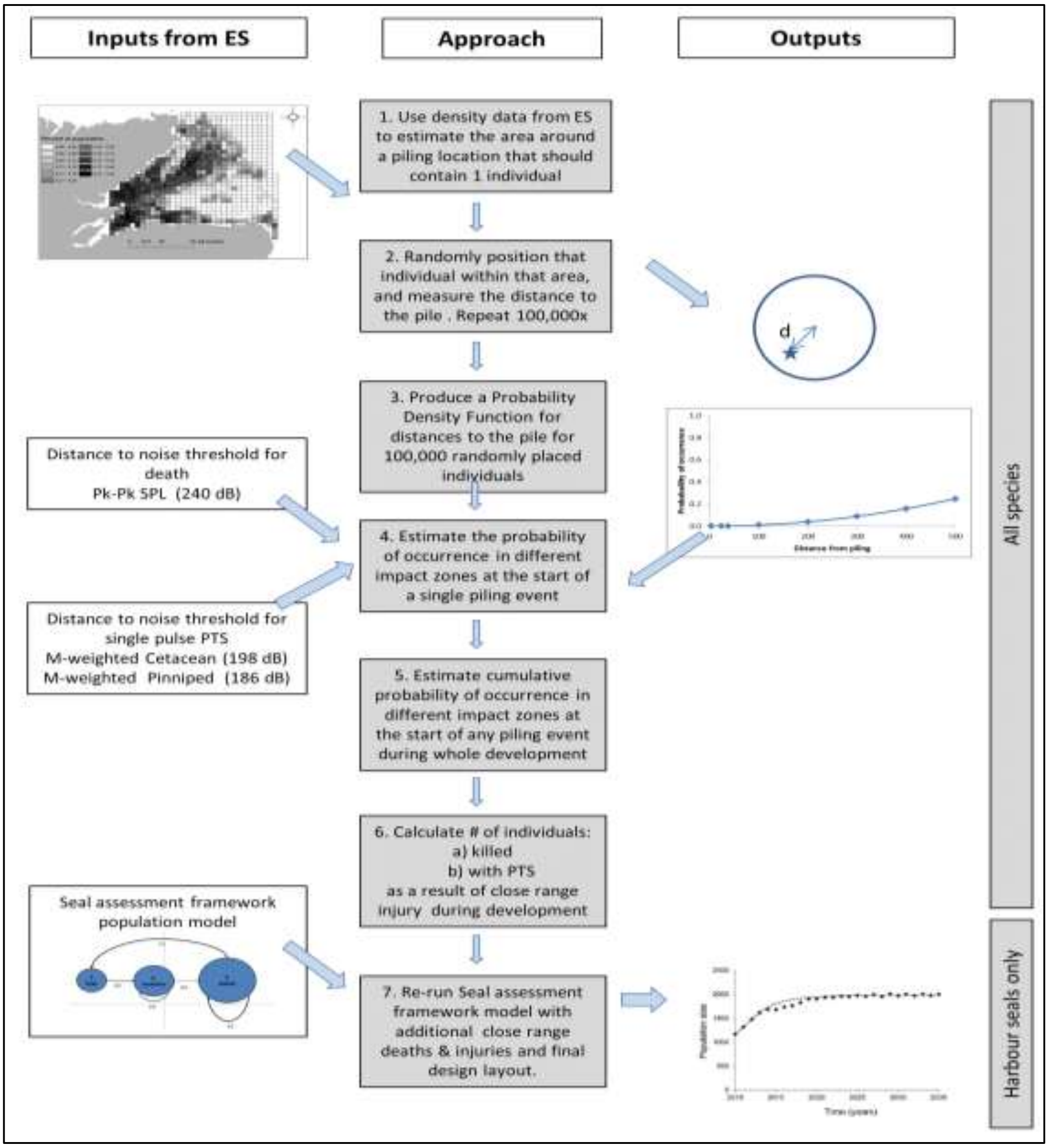
[6] This included 2 spare locations as a worst case scenario

BOWL and MORL ES's varied slightly (Table 1) but, in both cases, risk of death occurred only at extremely short range with risk of instantaneous injury always being <40m. To assess the potential risk of instantaneous injury from a 300 kJ soft start as proposed for the BOWL and MORL Project 1 developments, risk assessments were also used for a more conservative 60m impact zone (see Annex 1 of main document).

Table 1. Distance bands used to estimate close-range impacts of piling

Distance Band	Impact	Species	Criteria	Source
2m	Death	All Marine Mammals	Unweighted pk-pk SPL of 240 dB re. 1μPa (Lethality). Based on a 1200 kJ hammer and a 2.5m pile.	MORL ES Appendix 3.6a, S. 4.2.2.)
4m	Injury	Cetaceans	M weighted single pulse PTS criteria of 198 dB re. 1μPa^2-s. Based on a 360kJ hammer on soft start and a 1.8m pile.	Southall et al (2007) BOWL Supp. noise modelling (unpubl.)
24m	Injury	Pinnipeds	M weighted single pulse PTS criteria of 186 dB re. 1μPa^2-s. Based on a 360kJ hammer on soft start and a 1.8m pile.	Southall et al (2007) BOWL Supp. noise modelling (unpubl.)
38m	Injury	All Marine Mammals	Unweighted pk-pk SPL of 220 dB re. 1μPa (Injury). Based on a 1200 kJ hammer and a 2.5m pile.	MORL ES Appendix 3.6a, S. 4.2.2.)
60m	Injury	All Marine Mammals (based upon harbour porpoise being most sensitive)	Unweighted single pulse PTS criteria of 179 dB re. 1μPa^2-s. Based on a 300kJ hammer energy on soft start.	Annex 1 of main document
500m	N/A	All Marine Mammals	MMO Mitigation Zone	JNCC (2010)

Figure 1. Schematic showing the general approach used to compare the population consequences of variations in the efficacy of mitigation measures used to reduce the impacts of instantaneous death or injury around a piling site.



Methods

Estimating marine mammal occurrence within different impact zones at the start of piling sequences

Predicted distributions were based on the density estimates for each of the marine mammal species that were assessed in the BOWL and MORL ES's. Density estimates for impacts of BOWL and MORL together were based on mean values across all grid cells within the two development zones, whilst density estimates for BOWL and MORL alone were based on the mean values within each individual development site (Table 2). For each species, density data were used to estimate the area and radius of a circle around each piling site that should include one individual (Table 2).

Individuals were then randomly positioned within these circles and their distance from the pile was measured. This was repeated 100,000 times to estimate the probability of individuals being present within different zones at the start of any individual piling sequence.

If each piling event is assumed to be independent (see the Annex to this Risk-based Framework Assessment), the probability of an individual marine mammal occurring within each impact zone during the first piling strike of any of the 784 piles required for construction of the BOWL and MORL Project 1 wind farms can be calculated from the cumulative binomial probability. This approach can also be used to estimate the maximum number of occasions on which an individual is likely to be present in each zone over the sequence of 784 piling events (here estimated using a 95% probability level). These probabilities were also calculated separately for the individual projects, although to simplify the analysis, the focus was on estimating the probability of occurrence within the 60m injury zone only (as this is the most relevant to the Piling Mitigation Protocol), rather than repeating for all the distance bands.

Table 2. Estimates of density within the Moray Firth development areas, with estimated circle radii that would be expected to contain one individual. Separate estimates were produced for BOWL only, MORL only and impacts for BOWL and MORL Project 1 together based upon local densities within each site

	Mean density (individuals per km^2)	Radius of circle containing one individual (m)
BOWL + MORL		
Harbour Seal	0.31	1020.7
Grey Seal	0.15	1456.0
Harbour Porpoise	0.862	607.7
Bottlenose Dolphin	0.00016	44514.4
Minke Whale	0.022	3803.8
BOWL		
Harbour Seal	0.312	1010.2
Grey Seal	0.119	1638.1
Harbour Porpoise	0.926	586.3
Bottlenose Dolphin	0.00006	70711.8
Minke Whale	0.022	3803.8
MORL		
Harbour Seal	0.304	1023.8
Grey Seal	0.159	1413.1
Harbour Porpoise	0.843	614.5
Bottlenose Dolphin	0.00019	41021.3
Minke Whale	0.022	3803.8

Assessing the population consequences of not mitigating instantaneous death and injury

Assessments of population level impacts were only made for one of the Moray Firth's priority species; harbour seals. This was because the estimated density of bottlenose dolphins in the Outer Moray Firth is so low that the cumulative probability of this second priority species occurring even within a 500m mitigation zone around piling events was <0.1 (see results below).

Population trajectories were compared for different construction scenarios with effective mitigation and without any mitigation to prevent instantaneous death or injury. These comparisons were developed using baseline models from the Moray Firth Seal Assessment Framework. Worst case scenarios used in the BOWL and MORL ES's were first adapted to reflect subsequent changes in the scale of each development (see Table 3), and these were used as baseline construction scenarios assuming that effective mitigation was in place.

These baseline construction scenarios already incorporated impacts of wind farm construction through (1) reductions in survival as a result of PTS from cumulative noise exposure (where 25% of animals that suffer injury from PTS will subsequently die) and (2) declines in reproduction as a result of behavioural displacement (where 100% of animals that suffer behavioural displacement will have reproductive failure in that year) [4]. In addition, baseline construction scenarios include the annual shooting of individuals due to licenced killing by fisheries interests. Any additional impacts from unmitigated instantaneous deaths can therefore be incorporated by supplementing the annual removals from shooting. Any additional impacts from unmitigated instantaneous injury can be incorporated by supplementing the number of individuals with PTS. In addition, an extreme worst case scenario was developed for the unmitigated injuries that assumed 100% mortality as a result of those injuries. In each of these cases, the numbers of individuals were based on the cumulative probability of an individual occurring within the different impact zones (see Table 1) during the initiation of piling at any of the 784 piling events during the entire BOWL and MORL Project 1 construction periods.

Table 3. Comparison of key piling parameters used in the ES worst case scenarios and the current design basis layout for the BOWL and MORL developments.

Parameter	BOWL		MORL[7]	
	ES Worst case	Design Basis Layout	ES Worst case	Project 1 Indicative Design
Number of turbines	277 x 3.6 MW	84 x 7 MW	339	< 100
Total piling phase for a single vessel	3 years	1.5 years	5 years	2 years

Overall, seven construction scenarios, with different combinations of mitigation and injury severities were compared as outlined in Table 4. These included one of the original ES worst case scenarios, and three variations for each of two different revised construction scenarios. The first revised construction scenario (Revised A) involved a four year construction period, and the second (Revised B) involved a three year construction period. The three variants of each related to whether or not there was mitigation and the mortality rate resulting from PTS (Table 4; Annex to this Risk-based Framework Assessment). To allow comparison with outputs from the ES, the first year of construction was set at 2014 in all cases. Similarly, to facilitate comparison of the effects of any mitigation, models were run using the best fitting curve for behavioural displacement and a carrying capacity of 2000. For further details see relevant ES sections [4]. The primary difference between these scenarios and those used in the ES relates to the numbers of turbines in the final layout, and the consequences that this has on the number of vessels used and the duration of construction. The main comparisons retain the original ES assumption that displacement leads to 100% failure in reproduction. However, the reduction in turbine numbers at both sites means that most piling is likely to occur in the summer months, and emerging data from DECC SEA funded studies in the Wash further indicate that displacement during piling is more limited in both space and time than predicted in the ES. In one additional scenario, we therefore explore the effects of reducing this conservatism in the impacts of displacement to a more probable worst case of a 50% failure in reproduction (see Annex to this Risk-based Framework Assessment).

[7] MORL has received three Section 36 consents for a maximum total capacity of 1,116 MW generated by not more than 186 turbines. MORL is planning to develop the area through a phased approach. The first phase of development (Project 1) is currently being developed pending announcements of a future Contract for Difference (CfD) allocation round. However, MORL anticipates that Project 1 will not exceed 100 turbines with the balance being developed in a subsequent phase(s).

Table 4. Summary of the different indicative construction scenarios modelled to explore the consequences of not mitigating instantaneous death and injury

Model Scenario		Duration	Construction Scenario (see ES)	Mitigation	Mortality rate from instantaneous injury
1	ES Worst Case Cumulative A	5 yrs	2 piling vessels on BOWL for 2 yrs followed by: 2 piling vessels on MORL for 3 yrs	Yes	-
2	Revised A	4 yrs	1 piling vessel on BOWL for 2 yrs followed by: 1 piling vessel on MORL for 2 yrs	Yes	-
3		4 yrs		No	25%
4		4 yrs		No	100%
5	Revised B	3 yrs	1 piling vessel on BOWL for 1 yr followed by 1 piling vessel on BOWL + 1 piling vessel on MORL for 1 yr followed by 1 piling vessel on MORL for 1 yr	Yes	-
6		3 yrs		No	25%
7		3 yrs		No	100%

Results

Estimating marine mammal occurrence within different impact zones at the start of piling sequences for BOWL and MORL Project 1together.

The probability that individuals of any of the five species of marine mammals were within the instantaneous death or injury zones at the beginning of a single piling event was extremely low in all cases (Table 5a). Probabilities are provided for relevant injury zones (death, PTS from instantaneous M weighted single pulse criteria for seals and cetaceans and physical injury) as shown in Table 1. For instantaneous death (within 2m) this was always ≤ 0.0001, and for instantaneous physical injury (within 60m) this was always < 0.05, even using the most conservative case of a harbour porpoise and a 300KJ hammer. In contrast, the probability that individuals may be present within the 500m mitigation zone at the beginning of a single piling event was sometimes much higher, and only extremely low (<0.01), for bottlenose dolphins. In particular, the probability that an individual may be present within the 500m zone at any single point in time was 0.68, for harbour porpoise, and 0.24 for harbour seals (Table 5a).

The cumulative probability for each of the five species being within the instantaneous death zone during the first strike of any of the 784 piling events was also extremely low (<0.01) for all species (see Table 5b). However, cumulative probabilities suggest that, with the exception of bottlenose dolphin, one cannot have 95% confidence that individuals are likely to be absent from the instantaneous injury zones during all the first piling strikes. Conversely it is almost certain (≥99%

probability) that all species except bottlenose dolphin will be present within the 500m mitigation zone during at least one first piling strike of the 784 piling events.

The cumulative probabilities can also be used to place an upper 95% confidence limit on the number of occasions (from the total of 784 piling events) on which individuals might be present in different zones during the first piling strike as shown in Table 5c. Table 5b indicates that there is a cumulative probability of 0.97 that a harbour seal will be present in the 60m single pulse PTS zone at the start of at least one of the 784 piling events. While Table 5c indicates that there is a 95% probability that this will not occur on more than 7 different occasions.

The data in Table 5c can therefore be used to put an upper limit on the number of individuals that may be affected by these instantaneous injuries during the construction period. These values can subsequently be used to assess population consequences, and assess the relative importance of these impacts compared with previously assessed impacts from cumulative noise exposure or behavioural disturbance. Here, this is explored for harbour seals through the Moray Firth Seal Assessment Framework, but data for other species such as harbour porpoise could be compared, for example, with estimates of Potential Biological Removal (PBR) [10, 11].

Similarly, data in Table 5c can be used to provide an indication of the number of times that different species may be present within the 500m mitigation zone (as detailed within JNCC guidelines as discussed above) during the construction period. These data suggest that harbour seals may be present within the mitigation zone during up to 208 (26%) of the first piling strikes, whereas harbour porpoises may be present during up to552 (70%) of these events.

Table 5. Probabilities for each species occurrence in each distance ban. Estimates are based on the BOWL + MORL Project 1 scenario using average densities across the two sites (see Table 2)

a) Probability of an individual being present in each distance band during the first strike of a single pile

	2m	4m	24m	38m	60m	500m
Harbour Seal	0.00001		0.00056	0.00136	0.0045	0.24109
Grey Seal	<0.00001		0.00038	0.00076	0.00218	0.11772
Harbour Porpoise	<0.00001	0.00003		0.00389	0.01293	0.67604
Bottlenose Dolphin	<0.00001	<0.00001		<0.00001	<0.00001	0.0001
Minke Whale	<0.00001	<0.00001		0.00016	0.0004	0.01697

b) Cumulative probability of an individual being present in each zone during at least one of the 784 first piling strikes

	2m	4m	24m	38m	60m	500m
Harbour Seal	<0.01		0.36	0.66	0.97	<1
Grey Seal	<0.01		0.26	0.45	0.82	<1
Harbour Porpoise	<0.01	<0.03		0.95	<1	<1
Bottlenose Dolphin	<0.01	<0.01		<0.01	<0.01	<0.1
Minke Whale	<0.01	<0.01		0.12	0.27	< 1

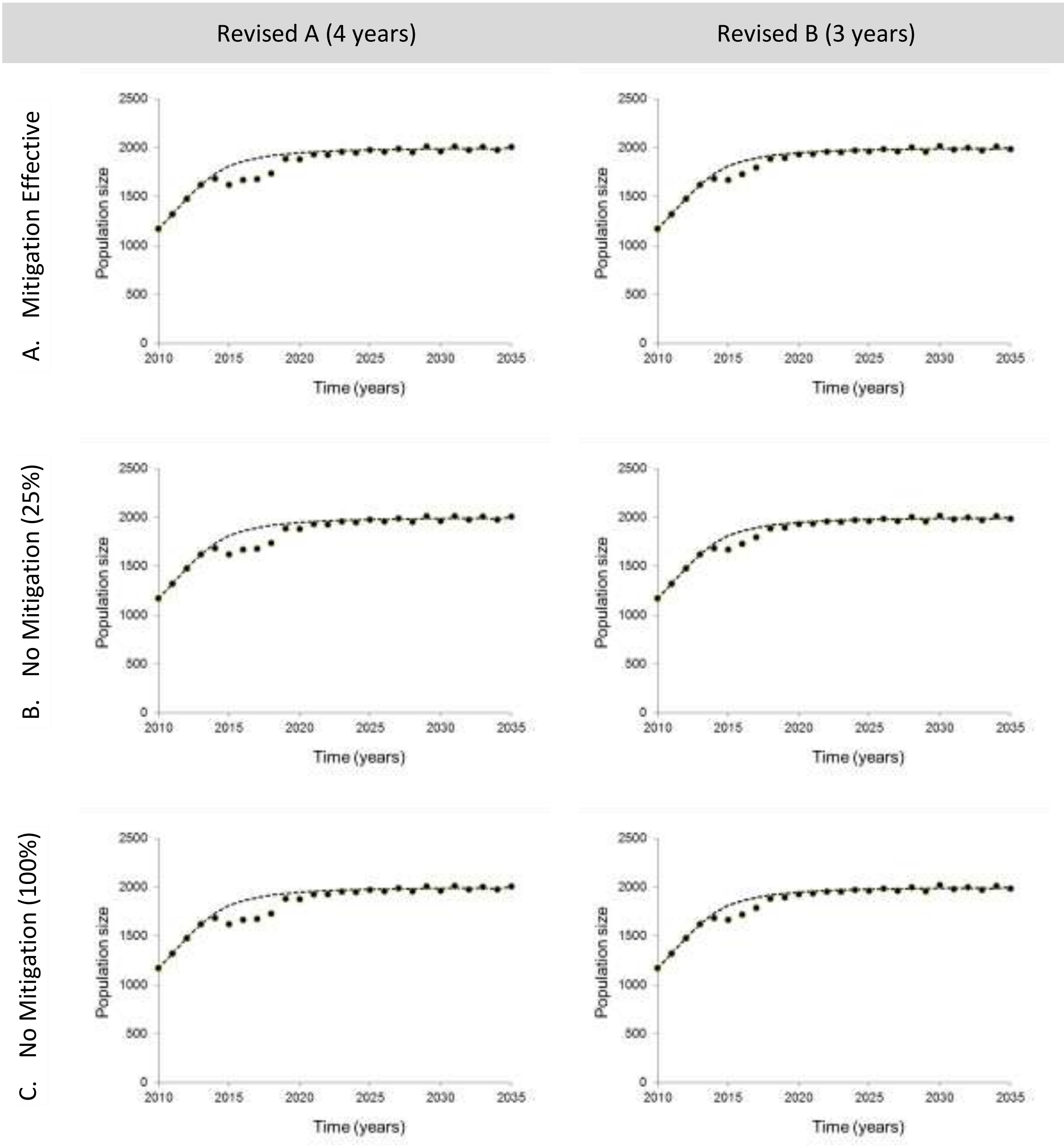
c) Maximum number of first piling strikes in which an individual is likely to be present in each zone (95% Confidence). Data are only presented for those scenarios where the cumulative probability of an individual being present is >0.05 (see Table 5b)

	2m	4m	24m	38m	60m	500m
Harbour Seal	-		2	3	7	208
Grey Seal	-		1	2	4	108
Harbour Porpoise	-	-		6	16	552
Bottlenose Dolphin	-	-		-	-	1
Minke Whale	-	-		1	2	21

Assessing the population consequences of not mitigating instantaneous death and injury for BOWL and MORL Project 1 together

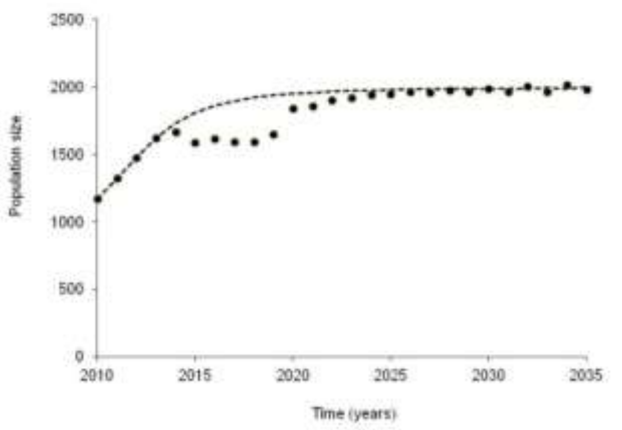
As outlined above, estimates for harbour seals suggest that in the absence of mitigation, there is >99% probability that harbour seals will not be killed during any of the first piling strikes, and a maximum of only seven additional individuals are expected to suffer physical or auditory injury using the larger injury zones (60m) considered in this assessment (Table 1). The impacts of including or not including these additional impacts were explored using the two revised construction scenarios outlined in Table 4, and also by varying the mortality resulting from instantaneous injury between 25% (as used for PTS in the baseline model) and 100% (Figure 2). Inspection of Figure 2 suggests that there is no discernible population level impact from the lack of any mitigation when constructing the BOWL and MORL Project 1 wind farms for either of these construction scenarios, even when all injuries were assumed to result in mortality.

Figure 2. Modelled population trajectories for the two construction scenarios (solid circles) in relation to baseline trends (dashed line) showing patterns with (a) effective mitigation for instantaneous death and injury (b) no mitigation and traumatic injury resulting in 25% mortality and (c) no mitigation and traumatic injury resulting in 100% mortality.

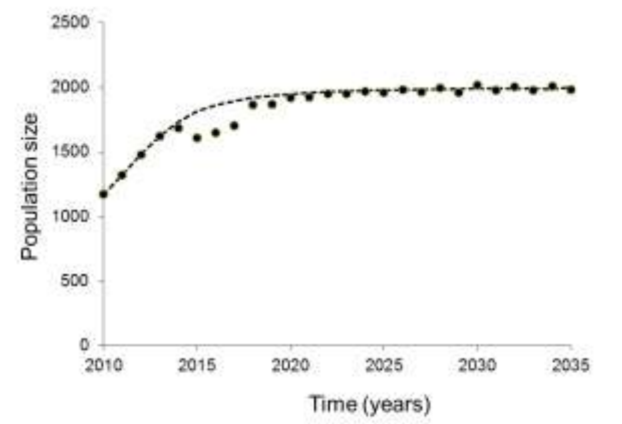


Revised scenario B is presented below in relation to the worst case cumulative assessment from the BOWL and MORL ESs (Figure 3). Assuming 100% reproductive failure and the absence of mitigation for Revised Scenario B, the decrease in population is smaller compared to the worst case scenario assessed in the ESs (Figure 3). Adopting a less conservative assumption for Revised Scenario B, where displacement leads to 50% reproductive failure (a more probable worst case scenario), illustrates that the decrease in population would be smaller again compared to the worst case cumulative scenario presented in the ES (Figure 3).

Figure 3. Comparison of baseline and construction scenarios for the worst case scenario A (from the ES) and Revised Scenario B with no mitigation and 100% mortality from Figure 2. These can also be compared with a further alternative for Revised Scenario B in which the reduction in reproductive success due to displacement is reduced to 50% instead of 100%.

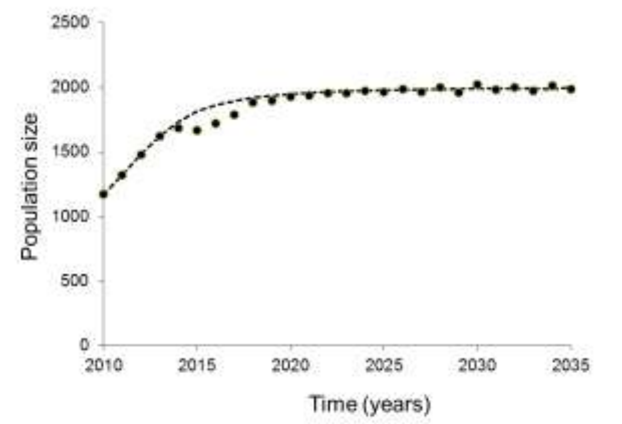


ES Worst Case Cumulative A



Revised Scenario B

100% reproductive failure due to displacement



Revised Scenario B

50% reproductive failure due to displacement

Project specific estimates of marine mammal occurrence within different impact zones at the start of piling sequences

In response to requests from the SNCBs, Table 6 also presents project specific estimates of the risk of different species being present within the 60m instantaneous injury zone, as calculated by Cefas. Here, probabilities are based on the local densities presented in the respective ESs, as summarised in Table 2. The probabilities of occurrence for each species are less than those calculated for the assessment of both projects together (Table 5). On this basis, it can be surmised that there will be no discernible population level impact from the lack of any mitigation when constructing either the BOWL or MORL Project 1 wind farms alone since the construction scenarios for each development alone are considerably less than the scenarios assessed for these two developments together (see Figures 2 and 3). Therefore, even when all injuries are assumed to result in mortality, based on the results of the assessment of both BOWL and MORL Project 1 together, it is considered unlikely that either BOWL or MORL alone would result in a population-level effect.

Table 6. Project specific estimates of the probabilities for each species occurrence within the 60m instantaneous injury zone.

a) Probability of an individual being present within the 60m instantaneous injury zone during the first strike of a single pile		
	BOWL	MORL
Harbour Seal	0.00349	0.00339
Grey Seal	0.00141	0.00195
Harbour Porpoise	0.01014	0.00983
Bottlenose Dolphin	<0.00001	0.00001
Minke Whale	0.0002	0.00022
b) Cumulative probability of an individual being present within the 60m instantaneous injury zone at least one of the first piling strikes for BOWL (n=352) and MORL (n=432)		
	BOWL	MORL
Harbour Seal	0.71	0.77
Grey Seal	0.39	0.57
Harbour Porpoise	0.97	0.99
Bottlenose Dolphin	<0.01	<0.01
Minke Whale	0.07	0.09
c) Maximum number of first piling strikes in which an individual is likely to be present in each zone (95% Confidence). Data are only presented for those scenarios where the cumulative probability of an individual being present (Table 6b) is >0.05.		
	BOWL	MORL
Harbour Seal	3	4
Grey Seal	2	3
Harbour Porpoise	7	8
Bottlenose Dolphin	-	-
Minke Whale	1	1

Conclusions

All stakeholders wish to minimise the likelihood that any marine mammals suffer instantaneous death or injury during offshore piling. Given that these species are expected to move away from loud noise sources, it is accepted that the period of highest risk is likely to be at the beginning of a piling sequence when naïve animals may be close to a piling vessel. Understanding of the noise thresholds that could result in instantaneous death or traumatic injury from a single pulse of this kind is relatively good, and predicted zones in which death or injury may occur (Table 1) are all relatively small for the Moray Firth developments (< 60m). The precautionary nature of the current JNCC guidelines means that MMOs and PAM are required to monitor a much larger 500m mitigation zone around piling activity, with the aim of ensuring that animals are absent from this area before piling can be initiated.

These simulations highlight that, at typical Moray Firth densities, the probability of randomly distributed marine mammals being at risk from instantaneous death or injury at the start of an individual piling event is extremely low (<1%)(see Table 5). In practice, it is likely that the noise coming from vessels during the pile setup would already have displaced individuals out of the immediate danger area, and these values should be even lower. This suggests that, even if mitigation using either JNCC guidelines or ADD failed completely, there are unlikely to be any deaths and a maximum of only 2-16 instantaneous injuries per species during the whole construction programme of the BOWL and MORL Project 1 wind farms. Incorporation of the relevant numbers for seals into the revised scenarios for the Moray Firth Seal Assessment Framework indicate that the absence of mitigation for these near field instantaneous injuries has negligible impact on the resulting population trajectories (Fig. 2).

Notwithstanding these results, it is important to emphasise that they should not be seen as a reason to abandon efforts to mitigate near-field impacts. However, they do provide an evidence base to help balance decisions on the risks of trialling alternative mitigation measures such as ADDs. This framework could also be applied to other developments which have different animal densities or injury zones. Similarly, the approach could be extended for use with other species such as harbour porpoise by considering these injuries as “takes” within a Potential Biological Removal analysis.

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Annex. Summary of key assumptions made within the framework.

1. **The objective of mitigation during the piling process is to minimise the risk of instantaneous death or injury during the initial piling strikes, not to reduce potential impacts from cumulative noise exposure or disturbance**.

2. **Individuals of each species are randomly distributed across the development site at the densities reported within the BOWL and MORL ES's.** This will be a simplification due to spatial variation in habitat quality and, for some species at least, social behaviour. The former should balance out across the sites when considering cumulative probabilities (Table 5b), but assessments could be re-run using minimum and maximum densities to assess how individual probabilities (Table 5b) vary between sites.

3. **Estimates of the cumulative probability of animals occurring in particular impact zones assume that all piling events are independent.** In reality, piling events will be clustered in groups of 4, with longer intervals between events at different turbine sites. Thus, it is more likely that disturbance during the first piling event at each turbine site will reduce the probability of animals being within the injury zone during the next three piling events.

4. **The revised project design for BOWL's construction scenario, as presented in the Piling Strategy, assumes that piling will involve a single vessel working over a maximum 1.5 year period. MORL's development details are still to be finalised, but here it is assumed that MORL Project 1 will also involve a single vessel working over a 2 year period.** Additional piling vessels may be required particularly in case of delays in construction programme, in which case this increase in the intensity of disturbance would result in concurrent reductions in the overall duration of disturbance. Piling at BOWL may be completed within two spring/summer seasons, reducing potential impacts of disturbance on reproductive success.

5. **To model the population consequences of instantaneous death or injury, it was assumed that mortality rates from injury from PTS resulted in either 25% mortality (eg. Fig 2b) or 100% mortality (eg. Fig 2c).** Recent use of Southall et al.'s (2007) M weighted PTS threshold for cumulative noise exposure suggest that ~ 50% of this rapidly increasing harbour seal population may have been at risk of PTS (Hastie et al. 2015). This suggests either that this pinniped PTS threshold is conservative, or that the risk of mortality from PTS is lower than the values used here.

6. **All other assumptions in the population model were the same as those used in the Moray Firth Seal Assessment Framework (Thompson et al. 2013).** The only exception is the final panel in Figure 3, where the impacts of behavioural displacement were reduced to a 50% reduction in reproductive success. This is now likely to represent a more realistic worst case given a) reductions in turbine numbers and the potential to focus piling over the summer season rather than maintain piling intensity throughout the whole annual cycle and b) emerging evidence from DECC SEA funded studies in the Wash that Harbour Seals were not displaced over the whole construction period, and continued to use preferred areas between piling events.

Annex Refs:

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