MORAY OFFSHORE WINDFARM (WEST) LIMITED

Offshore Transmission Infrastructure Piling Strategy (Addendum to Piling Strategy)

Document Name: 8460005-DBHA04-MWW-PLN-000002

Revision: 3

Status: Final

Date: 08-12-2022

Version Control				
Revision	Date	Status	Revision Description	Distribution List
0	13/05/2022	Draft	Moray West Review	Moray West
1	31/05/2022	Final	Submission to MS-LOT (8460005-DBHA04-MWW-000001)	MS-LOT
2	10/11/2022	Final	Second submission to MS-LOT OfTI Piling Strategy (Addendum to original Moray West Piling Strategy)	MS-LOT
3	08/12/2022	Final	Third submission to MS-LOT Appendix E included	MS-LOT

Document Approval				
Prepared by:	ECoW Review by:	Legal Review by:	Approved by:	Approved by:
Moray West				

Plan Overview

Purpose and Objectives of the Plan

The Moray West Piling Strategy (PS) (hereafter referred as the original Moray West PS) was prepared to address the specific requirements of the relevant conditions attached to the Section 36 (S36) consent and Marine Licences (collectively referred to as 'offshore consent conditions') issued to Moray Offshore Windfarm (West) Limited. The original Moray West PS was submitted to Marine Scotland Licensing and Operations Team (MS-LOT) on 31 May 2022.

Following on the consultation of the original Moray West PS, a new underwater noise modelling has been undertaken in order to present a realistic worst-case scenario.

This Offshore Transmission Infrastructure (OfTI) PS has been prepared as a revision of the original Moray West PS (8460005-DBHA04-MWW-PLN-000001, dated 31 May 2022) to address the specific requirements of the relevant conditions attached to the OfTI Marine Licence and to address the comments received from the consultation of the original Moray West PS.

A Wind Farm PS will be prepared to address the specific requirements of the relevant conditions attached to the S36 consent and Wind Farm Marine Licence and submitted to MS-LOT for its written approval.

The overall aim and objective of this OfTI PS is to provide detailed information on the piling activities for installation of the offshore substation platforms (OSPs) monopile foundations, including setting out the anticipated timing, location, duration and maximum pile driving hammer energy to be used.

The OfTI PS also provides information on the mitigation measures which will be applied during the piling process and the monitoring proposed in relation to underwater noise from piling.

All Moray West personnel and Contractors involved in the Development (piling related activities) must comply, as a minimum, with this OfTI PS.

Scope of the Plan

In line with the requirements of the OfTI Marine Licence condition 3.2.2.7, and in line with industry standards and good practice, the OfTI PS provides details of the following:

- details of expected noise levels from pile driving in order to inform mitigation;
- Proposed methods and anticipated duration of the OSPs pile installation;
- Anticipated maximum pile driving hammer energy required;
- Soft start piling procedures; and
- Mitigation and monitoring to be employed during the OSPs pile driving operations.

Structure of the Plan

The OfTI PS is structured as follows:

Section 1 provides an overview of the Development, specifies the scope and objectives of the OfTI PS, and describes the approach to the development of the OfTI PS.

Section 2 describes the key piling parameters including OSPs pile dimensions, hammer energies and anticipated piling durations and installation methodology.

Section 3, 4 and 5 provide a summary of the underwater noise modelling and an overview of the marine mammal and fish impact assessment.

Section 6 provides a summary of the proposed mitigation measures

Section 7 sets out the approach to marine mammal monitoring.

Section 8 provides a summary of the parameters considered in this OfTI PS compared with the parameters assessed in the Moray West EIA 2018.

The accompanying Appendices present a detailed description of the Development, details of the relevant conditions set out in the Marine Licence and Moray West's commitment to sustainable construction. The Addendum to Appendix C presents the updated underwater noise impact assessment and Addendum to Appendix D sets out the piling mitigation protocol. Appendix E present the Appendix C underwater noise impact assessment of the original Moray West PS.

Plan Audience

The OfTI PS is intended to be referred to by personnel involved in the construction of the Development (piling related activities), including Moray West personnel and Contractors.

Compliance with this OfTI PS will be monitored by the Moray West Development Team, Moray West's Environmental Clerk of Works (ECoW), and Marine Scotland Licensing Operations Team (MS-LOT).

Plan Locations

The latest version of this OfTI PS can be obtained from Moray West's document management system, *Viewpoint For Projects,* and from Marine Scotland website[1]. In addition, copies of this document are to be held in the following locations:

- Moray West's main project office in Edinburgh; and
- with the ECoW(s).

[1] https://marine.gov.scot/ml/moray-west-offshore-windfarm

Table of Contents

1 Introduction 9
1.1 Background 9
1.2 Objectives of the Plan 9
1.3 Linkages with other Consent Plans 10
1.4 Document Structure and Control 11
1.4.1 Document Control 12
2 OfTI Piling Strategy 13
2.1 Introduction 13
2.2 Installation Considerations 13
2.2.1 Geotechnical and Geophysical Survey Interpretation 13
2.3 OSP Pile Foundation Design Parameters 14
2.4 Pile Installation Methodology 16
2.4.1 Vessel requirements 16
2.4.2 Pile installation sequence 17
2.4.3 Pile Driving 19
2.4.4 Piling Locations 21
2.5 Pile Installation Programme 23
2.5.1 Individual pile installation timescales 23
2.5.2 Consecutive pile installation 23
3 Underwater Noise Modelling 24
4 Marine Mammal Impact Assessment 26
4.1 Permanent Threshold Shift (PTS) Assessment 26
4.1.1 Instantaneous PTS 27
4.1.2 Cumulative PTS 28
4.2 Disturbance Assessment 30
4.3 Comparison with EIA Report 2018 30
5 Fish Impact Assessment 31
5.1 Impact Ranges and Assessment Results 31
5.2 Comparison with EIA Report 2018 32
6 Piling Mitigation Protocol 33

6.1 Marine Mammals Mitigation 33
6.1.1 Optimization of pilling sequencing 33
6.1.2 ADD protocol 33
6.1.3 Soft start and ramp-up 33
6.2 Fish mitigation 33
7 Marine Mammal Monitoring Programme 34
7.1 Reporting 34
8 Compliance with the Application 35
9 References 36
Appendix A – Defined Terms 37
Appendix B – Development Background Information 39
B.1 Development Description 39
B.2 Legal Context 41
Addendum to Appendix C – Underwater noise impact assessment 43
Addendum to Appendix D – Piling mitigation protocol 44
Appendix E – Appendix C of the original Piling Strategy – Underwater noise impact assessment 45

Abbreviations and Acronyms

Acronym / Abbreviation	Description
ADDs	Acoustic Deterrent Devices
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CF	Conversion Factor
CMS	Construction Method Statement
CoP	Construction Programme
CPT	Cone Penetration Testing
ECoW	Environmental Clerk of Works
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EPS	European Protected Species
FIA	Fish Impact Assessment
IDP	Intermediate Delivery Port
iPCoD	interim Population Consequences of Disturbance
MBES	Multibeam Echo Sounder
MFRAG	Moray Firth Regional Advisory Group
MMO	Marine Mammal Observer
MS-LOT	Marine Scotland - Licensing Operations Team
MSS	Marine Scotland Science
MU	Management Unit
OfTI	Offshore Transmission Infrastructure
OSP	Offshore Substation Platform
OWF	Offshore Wind Farm
PAM	Passive Acoustic Monitoring
PEMP	Project Environmental Monitoring Plan
PMP	Piling Mitigation Protocol
PS	Piling Strategy
PTS	Permanent Threshold Shift
RA	Risk Assessment
RIAA	Report to Inform Appropriate Assessment
SAC	Special Area of Conservation
SBP	Sub-Bottom Profiler
S36	Section 36
SEL_{cum}	Cumulative Sound Exposure Level
SLE	Source Level Energy
SPL	Sound Pressure Level
SPL_{peak}	Peak Sound Pressure Level
TTS	Temporary Threshold Shift
VMP	Vessel Management Plan

Acronym / Abbreviation	Description
WTG	Wind Turbine Generators

1 Introduction

1.1 Background

The Moray West Offshore Wind Farm and associated Offshore Transmission Infrastructure (OfTI) (referred to as 'the Development') is being developed by Moray Offshore Windfarm (West) Limited (known as 'Moray West'; see Appendix A for defined terms). Consent for the Development was granted on 14 June 2019 under Section 36 (S36) of the Electricity Act 1989 (as amended), Part 4 of the Marine (Scotland) Act 2010 and the Marine and Coastal Access Act 2009 from Scottish Ministers. One S36 consent was granted by Scottish Ministers for the Wind Farm (012/OW/MORLW-8) and two Marine Licenses were granted by Scottish Ministers, one for the Wind Farm and another for the OfTI.

Variations of the S36 consent and Wind Farm Marine Licence were granted by the Scottish Ministers on 7 March 2022, and further variations of the Wind Farm Marine Licence (licence number: MS-00009774) and OfTI Marine Licence (licence number: MS-00009813) were granted on 11 April 2022. The revised S36 consent and associated Marine Licences are referred to collectively as 'offshore consents'.

Further details of Moray West and the Development can be found in Appendix B.

1.2 Objectives of the Plan

The S36 and Marine Licences conditions (referred to as 'offshore consent conditions') require the production of a Piling Strategy (PS; Condition 11 of S36 and Marine Licences MS-00009774 and MS-00009813 conditions 3.2.2.8 and 3.2.2.7 respectively). The original Moray West PS was prepared to address the specific requirements of the offshore consents conditions and was submitted to Marine Scotland - Licensing Operations Team (MS-LOT) for its written approval on 31 May 2022.

Following on the consultation of the original Moray West PS (8460005-DBHA04-MWW-PLN-000001), a new underwater noise modelling has been undertaken with the aim to present more realistic pile installation scenarios, as requested, and updates have been made to the marine mammal and fish impact assessment accordingly. This OfTI PS has been prepared as a revision of the original Moray West PS (8460005-DBHA04-MWW-PLN-000001, dated 31 May 2022) to address the specific requirements of the relevant conditions attached to the OfTI Marine Licence and to address the comments received from the consultation of the original Moray West PS.

The purpose of the OfTI PS, is to set out the key Offshore Substation Platforms (OSPs) pile installation parameters, provide details of the installation methodologies and anticipated duration of pile driving and maximum hammer energies to be used. The OfTI PS also presents the new underwater noise modelling results undertaken for the OSPs monopile locations and provides information on the mitigation strategy that will be implemented during the OSPs monopile installation to mitigate the effects of underwater noise. The relevant conditions setting out the requirement for a PS and which are to be discharged by this OfTI PS, are presented in full in Appendix B (Table B.1).

In addition to the specific consent requirements for a PS and the requirements thereof, this document also includes information in respect of a number of other consents conditions which are linked to the matter of environmental management; these are set out in Appendix B, Table B.2.

1.3 Linkages with other Consent Plans

The OfTI PS is part of a group of approved documents that provide the framework for the construction process works – namely the other Consent Plans required under the consents. The other plans named in the relevant consents have a link to the PS document in so far as they either provide additional details on the construction methodology or provide details on the control of construction to mitigate or manage potential environmental impacts and impacts on other marine users.

The OfTI PS will, so far as is reasonably practicable, be consistent with the Environmental Management Plan (EMP; 8460005-DBHA06-MWW-PLN-000001), Project Environmental Monitoring Programme (PEMP; 8460005-DBHA13-MWW-PLN-000001) and Construction Method Statement (CMS; 8460005-DBHA03-MWW-PLN-000001) consent documents.

Table 1-1 lists the Consent Plans with linkages to this OfTI PS.

Table 1-1 OfTI PS linkage with other Consent Plans

Other Consent Plans	Linkage with OfTI PS
Construction Programme and Construction Method Statement (CoP & CMS)	Specifies the Development's construction methods, setting out good practice construction measures and provides an overview of pile installation methodologies and programme; as described in this OfTI PS.
Environmental Management Plan (EMP)	Provides the framework for environmental management during construction phase. It sets out the roles and responsibilities of personnel and contractors in relation to environmental management measures, to prevent significant adverse impacts on the environment as identified in the Moray West Environmental Impact Assessment (EIA), during the construction of the Development.
Project Environmental Monitoring Plan (PEMP)	Outlines the monitoring strategy for proposed monitoring to be undertaken pre-construction, during construction and post construction for marine mammals.
Development Specification and Layout Plan (DSLP)	The DSLP provides information about the Moray West Site including a detailed plan of WTG and OSP layout, seabed information, details on monopile foundations dimensions; as described in this OfTI PS.
Vessel Management & Navigational Safety Plan (VMNSP)	Provides details of vessels and management measures for the Development, including those involved in pile installation.
Wind Farm Piling Strategy (Wind Farm PS)	Provides detailed information on the piling activities for installation of the WTGs monopile foundations.

1.4 Document Structure and Control

The structure of this PS is provided in Table 1-2.

Table 1-2 PS document structure

Section	Title	Summary of Content
1	Introduction	An overview of the Development and its associated consent requirements.
2	OfTI Piling Strategy	Provides detail on the design constraints considered in finalising the pile design, installation methodology and programme, sets out key steps during the two OSP pile installation for the Development. Confirms the key piling parameters including OSP pile dimensions, hammer energies and anticipated piling durations.
3	Underwater Noise Modelling	Provides a summary of the noise modelling approach taken to develop this OfTI PS.
4	Marine Mammal Impact Assessment	Provides a summary of the revised marine mammal impact assessment.
5	Fish Impact Assessment	Provides a summary of the revised fish impact assessment.
6	Piling Mitigation Protocol	Provides a summary of the proposed mitigation measures.
7	Marine Mammal Monitoring Programme	Approach to marine mammal monitoring and noise monitoring during the monopile installation works.
Appendix A	Defined Terms	Defines the terms to be used throughout this document.
Appendix B	Development Background Information	Detailed information of the Development. Including the construction programme, key stakeholders and legal context associated with the Development.
Addendum to Appendix C	Underwater Noise Modelling and Impact Assessment	Presents the results of the updated noise modelling and assessment to inform the design of the mitigation measures to be employed during piling at the two OSPs monopile foundation locations. Also included is a comparison between the Moray West EIA 2018 to ensure accordance with the Application and no change in impact significance.
Addendum to Appendix D	Piling Mitigation Protocol	Presents the recommended procedure for mitigating the risk of instantaneous and cumulative auditory injury to marine mammals during piling at the Moray West Site.

Table 1-2 PS document structure		
Section	**Title**	**Summary of Content**
Appendix E	Appendix C of the Original Moray West Piling Strategy – Underwater noise impact assessment	Presents the results of the original noise modelling and assessment to inform the design of the mitigation measures to be employed during piling.

1.4.1 Document Control

This OfTI PS will be reviewed and revised as relevant to ensure the information is kept up to date, with any revisions being notified to the Scottish Ministers/Licensing Authority as soon as practicable and any proposed material revisions being subject to prior approval by the Scottish Ministers/Licensing Authority.

Linkages exist between a number of offshore Consent Plans as highlighted in Section 1.3 within Table 1-1. As plans are updated, there will be a review of inter-linkages with other Consent Plans to ensure these are also updated as relevant. The document is controlled via Viewpoint For Projects, an electronic document management system.

2 OfTI Piling Strategy

2.1 Introduction

This section provides details of the Moray West Site ground conditions, OSPs pile foundation design parameters, installation methodologies and anticipated duration of pile driving, including details of soft-start and ramp up procedures and the anticipated maximum hammer energies for pile driving required at the OSPs monopile installation locations within the Moray West Site.

2.2 Installation Considerations

A series of site investigation surveys (geophysical and geotechnical) have been commissioned by Moray West to understand the seabed conditions at the Moray West Site to initially define, and then refine the WTG and OSP layout, monopile foundation design as well as to identify the requirements for monopile installation. A summary of the surveys that have already been carried out is provided in Table 2-1.

Table 2-1 Site investigation surveys (completed surveys and anticipated surveys)

Survey type	Description	Date
Geophysical	High-resolution swath bathymetric survey, side scan sonar survey, and sub-bottom seismic profiling survey used to inform site development and Environmental Impact Assessment (EIA).	2010
Geophysical	Geophysical site investigation comprised of an Multibeam Echo Sounder (MBES) coverage of Moray West Site with line spacing of 100m and 6 cross lines.	2019
Geophysical	Seismic coverage with Sub-Bottom Profiler (SBP) and Sparker of the grid used to determine WTG locations with spacing of 1400 m (E-W) x 1100 m (N-S) and 4 diagonal lines across the Moray West Site.	2019
Geotechnical	Moray West Site geotechnical investigation comprised of 42 composite boreholes to a depth of 40 m, 6 composite boreholes to a depth of 60 m and 52 Seismic CPTs with target depth of 25 m	2019
Geophysical	Moray West Site investigation with high-resolution swath bathymetric survey, side scan sonar survey, magnetometry, vibrocore, and sub-bottom seismic profiling	2021
Geotechnical	32 Drilling seismic Cone Penetration Tests (CPTs) to a depth of 40 m carried out in Moray West Site positions not previously investigated or in positions where the soil profile was originally interpreted with difficulty.	2021

2.2.1 Geotechnical and Geophysical Survey Interpretation

In order to assess the seabed conditions within the Moray West Site, 102 geotechnical locations have been investigated between 2018 and 2021. These samples coupled with geophysical seismic surveys have been used to create a detailed “ground model” which has been used to characterise and predict subsurface soil conditions across the Moray West Site.

In general, below a thin cover of Holocene sands, the seabed within the area is composed of Quaternary sands and clays in very variable thickness, from about 5-10 m up to 25 m, followed to Lower Cretaceous sands and clays to the end of the available borehole data.

The layering of the Lower Cretaceous series as well as the lower part of the Quaternary series is quite complex, due to extensive glacial deformation of the series, and seabed conditions may therefore vary considerably from one location to the next.

2.3 OSP Pile Foundation Design Parameters

The two OSPs will be supported by monopile foundations.

Details of the OSP monopile foundations are listed in Table 2-2 and presented in Figure 2-1.

Table 2-2 Summary of OSP monopile foundation to be installed

Component	Number	Key Dimensions
OSP monopile foundation	2	Pile dimensions vary depending on location specific water depth and soil characteristics: • Pile diameter: 9.5 m • Pile Length: up to 88.5 m

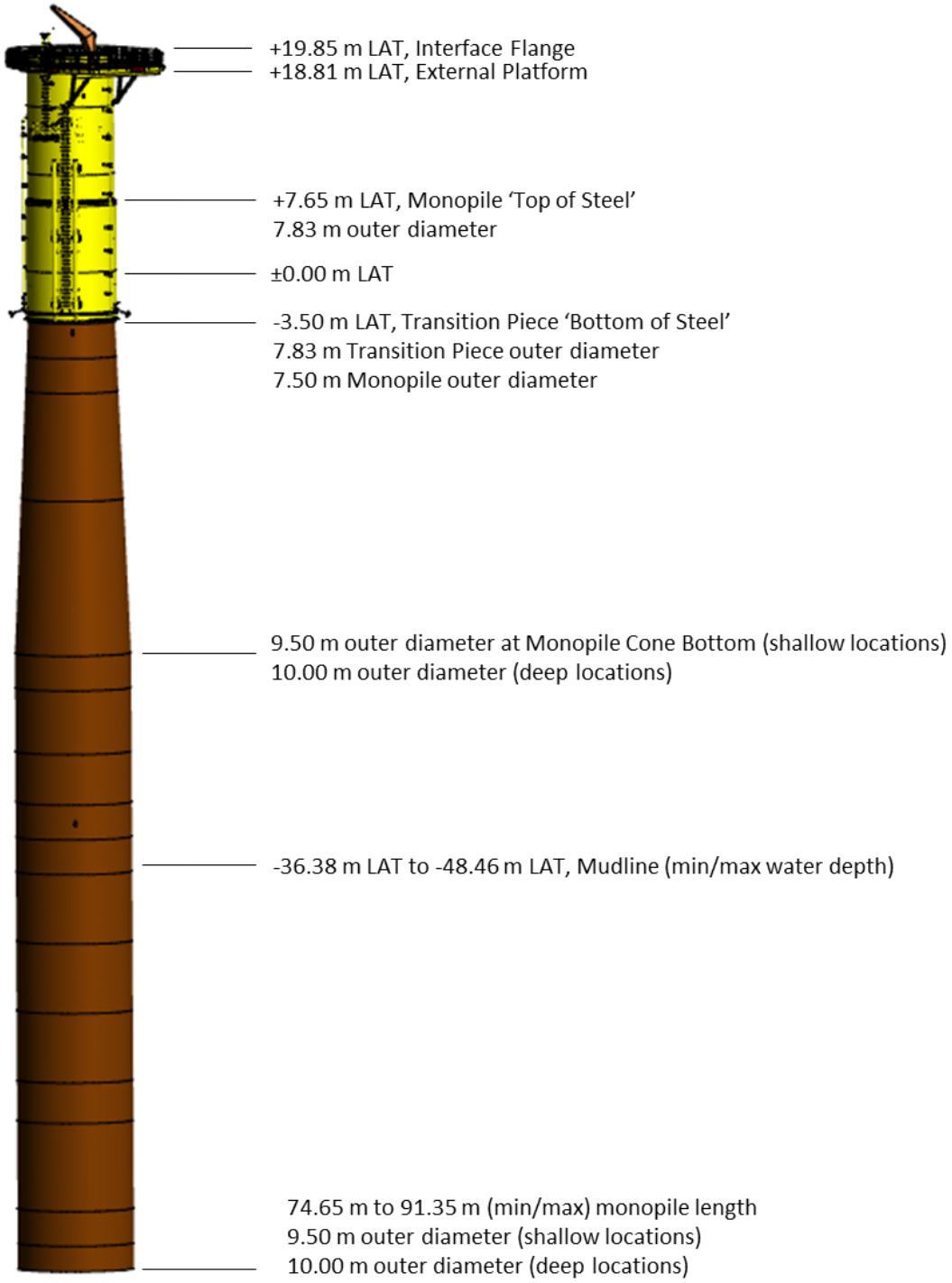


Figure 2-1 Example of Moray West monopile foundation

2.4 Pile Installation Methodology

2.4.1 Vessel requirements

Piling will be undertaken from a jack-up vessel (JUV) or a heavy lift vessel (HLV). Dynamic positioning will be used to ensure the installation vessel is in the correct position prior to commencing pile installation operations. Examples of pile installation vessels are shown in Figure 2-2.



Figure 2-2: Example of pile installation vessels.

Further details on the vessels to be used during construction phase of the Development will be provided within the Vessel Management Plan and Navigation Safety Plan (VMNSP; 8460005-DBHA07-MWW-PLN-000001).

2.4.2 Pile installation sequence

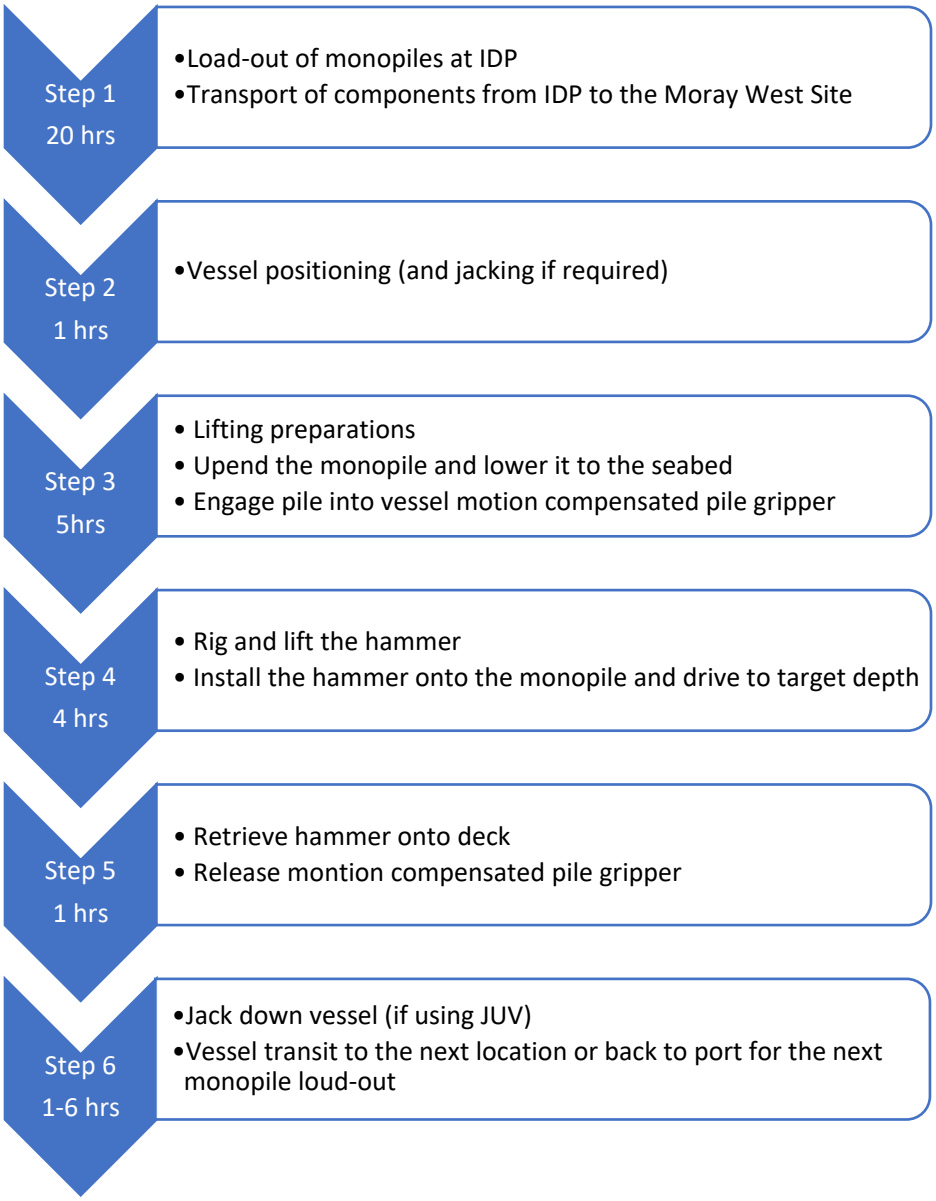


Figure 2-3: Overview of the monopile foundation transport and installation sequence

An overview of the pile installation sequence is presented in Figure 2-3. The OSP monopile foundations shall be delivered from their port of origin to the selected Intermediate Delivery Port (IDP) ready to be shipped out to the Moray West Site as required.

The installation contractor will load up the foundation components at the IDP using a suitable vessel, which will either be a JUV or an HLV.



Figure 2-4: Example of a monopile being loaded up onto the installation vessel.

Once the vessel has reached the target location, the vessel will position itself using dynamic positioning in readiness for the pile installation works. If vessel a JUV the vessel will execute jacking operations.

The monopile will then be upended (as shown in Figure 2-4) and lowered to the proposed location by means of the vessel crane in combination with a monopile upending frame, designed in such a way so as to prevent the monopile from sliding during the upending process. Once the monopile is vertical, the pile will be located using the vessel crane into the vessel motion compensated pile gripper tool, designed to hold the pile in position and maintain verticality during the piling operation. The monopile will be lowered and stabbed onto the seabed. Rollers found in the gripper will guide the monopile, thus allowing for a degree of freedom when lowering to ensure the correct location is targeted.

After the monopile has been positioned vertically on the seabed, the crane will release the monopile and lift the hydraulic pile driving hammer from the vessel deck and onto the top of the monopile. Figure 2-5 shows a typical example of the hydraulic pile driving hammer being installed on top of the monopile and the gripper in action. The use of a vibro-hammer for intermediate driving may be required in some locations where identified by further engineering.



Figure 2-5: Example of the hammer being installed onto the top of the monopile.

Once the self-penetration and vertical positioning of the monopile are checked, the piling process can begin.

Once the monopile installation is complete, the vessel will move to the next location and repeat the above steps for the installation of the next foundation or sail back to port to load the vessel with the next set of monopiles.

2.4.3 Pile Driving

2.4.3.1 Hammer Energy and Drivability

Moray West Site conditions and geotechnical information have been used to undertake pile driveability assessments, designed to provide a forecast of the anticipated hammer energies for pile driving required at each of the OSPs monopile installation locations within the Moray West Site (Table 2-3).

The pile drivability assessment predicts the hammer energies required through each individual piling sequence. These assessments reflect the variation in blow energy during the driving operation, where only sufficient energy is used to maintain steady rate of penetration, and is usually characterised by progressively increasing energy, or “ramp–up”, as the pile is driven deeper into the seabed before reaching a maximum energy level required at each piling location to reach target penetration depth.

It should be noted that although hammer energies can be predicted with a moderately high level of confidence there are site specific characteristics (such as boulders) which may affect the piling energy levels required at each location, the effects of which cannot be predicted prior to piling commencing. As the precise hammer energies required will not be known until piling is underway this document considers

the likely maximum (i.e. highest expected) requirements to account for all eventualities. The pile driving methodology proposed, with the associated piling hammer energies, is designed to minimise risk to environmental receptors whilst satisfying the engineering requirements necessary to successfully complete the installation of monopile foundations and reduce the potential risk of pile refusal.

The maximum hammer energy permitted under the Moray West offshore consents is 5,000 kJ as set out in the Moray West Application. However, hammer energies will be optimized at each location to minimize hammer energies as far as possible to avoid fatigue on the pile and hammer.

The outcomes of the pile driveability assessment have indicated that most of the pile foundations can be driven to the target penetration depth using pile driving hammer energies up to 4,000 kJ, which can be achieved by using a 4,000 or 4,400 kJ hammer (for example hammer models IHC S-4000 or MHU4400S) at maximum hammer efficiency reduced to 95%. There is the potential for maximum hammer energies of up to 4,400 kJ to be required for those locations with harder ground conditions.

The maximum hammer energy required at the OSPs monopile foundation locations within the Moray West Site will not exceed 4,400 kJ.

Table 2-3 provides the anticipated hammer energies required to drive the OSPs monopile foundations to target depth.

Table 2-3 Anticipated hammer energies

Parameter	Modelling Locations (Section 3 and Addendum to Appendix C)	
	OSP 1 (E06)	OSP 2 (M11)
Minimum hammer energy (kJ)	432	432
Maximum hammer energy (kJ)	2,050	2,158

2.4.3.2 Soft start and Ramp-up

At commencement of pile driving at each location, the hammer may operate in single blows mode for technical purposes. The installation of each OSP monopile foundation will involve a minimum of a 17-minute soft-start[2] procedure where a maximum hammer energy of 432 kJ[3] will be used at a strike rate of approximately 28 – 32 blows/min unless there are technical reasons prohibiting this.

[2] JNCC Guidance describes the soft-start as the gradual ramp up of piling power until full operational power is achieved. The soft-start duration should be a period of not less than 20 minutes.

In this PS, ramp-up of the hammer energy will follow the soft-start procedure (minimum of 15 min). Overall, the soft-start and ramp up procedures will be longer than the 20 minutes recommended by JNCC Guidance.

[3] 10% of the Menck MHU 4400Shammer energy capability used in the Moray West Underwater Noise Modelling (Addendum to Appendix C).

Following the completion of the soft-start procedure, hammer energy will ramp-up gradually until a suitable energy level is reached, to maintain a steady rate of pile penetration. Hammer energy will not be increased above that required to complete each installation – i.e., if ground conditions are such that a lower than maximum hammer energy is sufficient to complete installation, then hammer energy will not be unnecessarily ramped up to the maximum permitted. Further details on the soft-start procedure are described in the Addendum to Appendix D.

Table 2-4 provides a summary of the piling profiles obtained from the underwater noise modelling and used for the impact assessment.

Table 2-4 Summary statistics of the piling profiles used for the marine mammal impact assessment.

Parameter	Modelling Locations	
	OSP 1 (E06)	OSP 2 (M11)
Refusal risk	low	low
Duration of soft start (min)	47.4	16.9
Duration of ramp-up (min)	128.9	181.5
Total piling duration (min)	176.3	198.4
Total number of blows	5,337	5,978

Further installation engineering may identify the requirement on OSP locations to use a vibro-hammer, a specialist pile driving hammer which can drive the pile through soft sediments during the initial pile driving operations. The pile driving hammer(s) identified above will be required to complete driving operations. Impact energies using a vibro-hammer are significantly lower than those foreseen during soft start driving with the hydraulic piling hammer. Detailed engineering is ongoing at the time of writing this OfTI PS, however it is currently estimated that the vibro-hammer will be used to reach approximately 50% of the 36 m full penetration of OSP 1 (E06). It is not anticipated that the vibro-hammer will be required to install OSP 2 (M11).

2.4.4 Piling Locations

The locations where the two OSPs monopiles will be installed is shown on Figure 2-6.

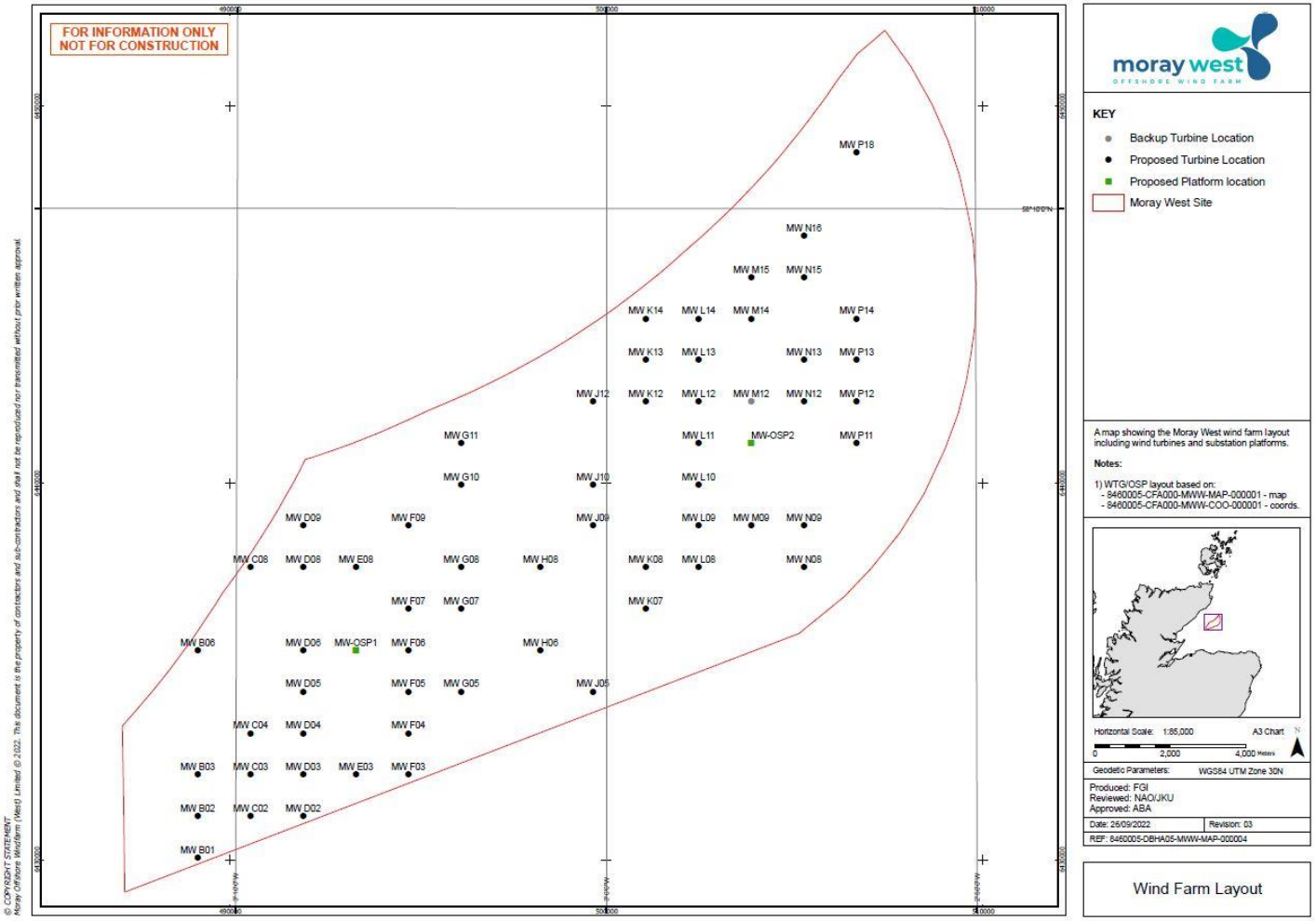


Figure 2-6: Moray West DSLP Wind Farm layout and OSP monopile locations (green dots).

2.5 Pile Installation Programme

The installation of the two OSP monopile foundations is anticipated to commence in August 2023 and is planned to be completed by December 2022. The monopile installation campaign at Moray West Site (including the installation of the WTG monopile foundations) is planned to be completed by March 2024.

During the OSPs monopile installation period there will be an aggerated duration of approximately 8 hours of actual pile driving (noise generation) activity for two monopiles, based on up to 4 hours of pile driving at each location. The additional time in the programme is conservative and allows for:

- Sequencing and seasonal work scheduling;
- The time for pile installation activities other than the pile driving operation (vessel positioning and setup for the pile installation works);
- Vessel transit to port for the next monopile load-out;
- Operational downtime as a result of weather, equipment failures, and other unforeseen issues; and
- Time to implement mitigation measures.
- Installation of the 60 WTGs monopile foundations.

Further detail on the timing and the overall construction programme is provided in the CoP and CMS.

2.5.1 Individual pile installation timescales

Piling duration (noise generation) at each OSP location will generally only vary depending on ground conditions. In addition to predicting hammer energies, the pile driveability analysis provides an estimate for the duration of pile driving required for a pile in each of the modelled locations based on Moray West Site soil conditions. Table 2-4 provides an estimated pile driving durations for the OSP 1 (E06) and OSP 2 (M11) noise modelling locations presented in the Addendum to Appendix C.

Indicative average operational timescales for the pile installation works are presented in Figure 2-3. It is anticipated that the maximum aggregated timescale for pile driving at a single pile location in a given 24-hour period is not likely to exceed four hours.

2.5.2 Consecutive pile installation

Based on the indicative duration of the piling installation sequence (Figure 3-2), it is anticipated that up to two piles could be installed within a 24-hour period. In the event that the overall duration of piling installation activities in a single location allows for the post-piling activities and the installation vessel to transit to the next location, piling operation would re-commence in the next location within the same 24-hour period.

The ability to pile consecutively in two locations within a 24-hour period would reduce the overall pile installation programme. Underwater noise modelling has also been conducted assuming that two monopiles could be installed consecutively within a 24-hour period.

3 Underwater Noise Modelling

In light of refinement of piling parameters since the Moray West EIA Report 2018, noise modelling was undertaken based on the worst-case pile driving parameters determined as a result of the pile driveability assessments A new underwater noise modelling has been undertaken to inform this OfTI PS, and the Addendum to Appendix C provide details of expected noise levels resulting from pile-driving at the OSPs monopile installation locations, OSP 1 (E06) and OSP 2 (M11), and the revised impact of assessment on marine mammal and fish species.

Figure 3-2 displays the piling locations used for the new noise modelling to inform this OfTI PS in relation to the original noise modelling locations (shown in black).

As described in section 2.4.3, the pile driveability assessment undertaken to refine the final Moray West layout has indicated the maximum hammer energy that will be required for pile driving across Moray West Site will not exceed 4,400 kJ, which is lower than the maximum consented hammer energy (5,000 kJ). The final Moray West layout excludes all locations where moderate or high refusal risk had been identified or those locations that would need hammer energies higher than 4,400 kJ to reach target penetration.

Underwater noise modelling has been undertaken by Cefas using their propagation model (Farcas et al. 2016) and an energy conversion source model (constant conversion factor (CF) of 4% and 10%). The Addendum to Appendix C presents the results of the new noise modelling and assessment criteria applied for fish and marine mammals to inform the design of the mitigation measures to be implemented during piling driving operations at the OSPs locations within the Moray West Site.

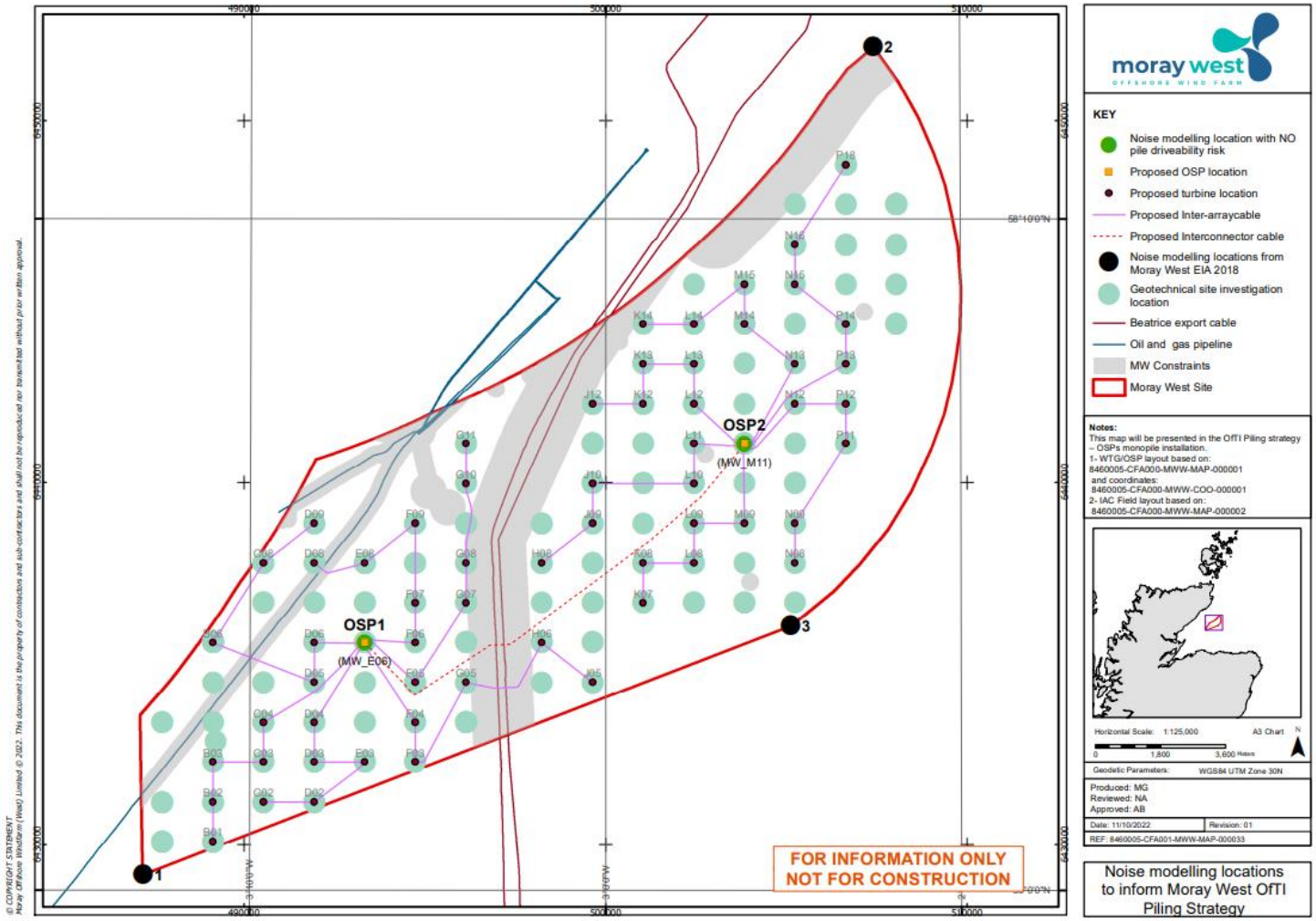


Figure 3-1: Noise modelling locations to inform this OfTI PS

4 Marine Mammal Impact Assessment

The Addendum to Appendix C Underwater Noise Impact Assessment presents the results of the new underwater noise modelling based on a more realistic worst-case scenario piling parameters than those presented in the original Moray West PS and assessment to inform the design of the mitigation measures to be implemented during piling operations at the two OSPs monopile installation locations.

To address consultation comments, the below scenarios have been reassessed based on the new underwater noise modelling results from the installation of the two OSPs monopiles:

- Auditory injury (instantaneous PTS and cumulative PTS) for harbour porpoise and minke whale;
- Disturbance for bottlenose dolphin and minke whale.

Modelling the risk of auditory injury (instantaneous PTS and cumulative PTS) for bottlenose dolphins and seals, and disturbance for harbour porpoise and seals has not been repeated, as impacts resulting from the worst-case scenario of pile driving at Moray West Site for these species were concluded to be negligible in the original Moray West PS (Table 4-1).

Table 4-1 Summary of the marine mammal impact assessment presented in the OfTI PS Addendum to Appendix C Underwater Noise Impact Assessment

Species	Instantaneous PTS	Cumulative PTS	Disturbance
Harbour porpoise	Re-modelled. New results presented in the Addendum to Appendix C		Conclusions of the assessment presented in the original Moray West PS remain valid
Minke whale	Re-modelled. New results presented in the Addendum to Appendix C		
Bottlenose dolphin	Conclusions of the assessment presented in the original Moray West PS remain valid		Re-modelled. New results presented in the Addendum to Appendix C
Harbour seal	Conclusions of the assessment presented in the original Moray West PS remain valid		
Grey Seal	Conclusions of the assessment presented in the original Moray West PS remain valid		

A comparison has been made between the results of the Moray West EIA Report 2018, the results of the assessment presented in the original Moray West PS, and the OfTI PS. Overall, the results presented in this OfTI PS and in the Addendum to Appendix C are generally the same as those presented in the Moray West EIA Report 2018 and the original Moray West PS.A summary of the updated marine mammal impact assessment is provided in the sections below.

4.1 Permanent Threshold Shift (PTS) Assessment

For marine mammals, the risk of PTS has been assessed using the Southall criteria (Southall et al. 2019).

4.1.1 Instantaneous PTS

In the original Moray West PS, the impact of instantaneous PTS-onset from the soft-start and for the maximum hammer energy consented (5,000 kJ) was assessed as being of negligible magnitude for all species.

The revised impact assessment for harbour porpoise and minke whale, indicates that the maximum instantaneous PTS-onset impact range at soft-start (432 kJ) is 579 m and 75 m, respectively. These impact ranges for the OSPs monopile installation locations are smaller than those modelled in the original Moray West PS. Based on empirical evidence, it is expected that harbour porpoise detections will decline due to the increasing vessel presence within Moray West Site, reducing the probability of a harbour porpoise being present within 579 m of the OSPs monopile installation locations prior to the commencement of pile driving operations.

The instantaneous PTS-onset at full hammer energy modelled with a CF of 10% is 1,595 m for harbour porpoise and 183 m for minke whales.

Table 4-2 provides a summary of the maximum instantaneous PTS onset impact ranges for harbour porpoise an minke whale.

Table 4-2 Maximum instantaneous PTS onset impact ranges (based on a constant 10% CF) for worst case locations and species considered in the new noise modelling.

Species	Location	Max PTS-onset range 432 kJ (soft start)	Max PTS-onset range 2,158 kJ (full hammer energy)
Harbour porpoise	OSP 2 (M11)	579 m	1,595 m
Minke whale	OSP 2 (M11)	39 m	183 m

As described in section 3.1.1 of the underwater noise impact assessment (Addendum to Appendix C), and table 4-3 below, the likelihood of an animal being in the PTS-onset impact ranges is negligible, assuming the animals will not be stationary and given that they will have already been displaced by presence of installation vessels, the pre-piling Acoustic Deterrent Device (ADD) deployment, the soft-start and the ramp-up before the first strike at full hammer energy is reached.

Table 4-3 Probability of an animal being present with the instantaneous PTS-onset impact zone at full hammer energy.					
Species	**Instantaneous PTS-onset range (km)**	**Density (#/km^2)**	**Area of circle containing 1 individual (km^2)**	**Radius of circle containing 1 individual (km)**	**Probability of animal being present**
Harbour porpoise	*1.595*	*1.46875**	*0.7*	*0.47*	*1*
Minke Whale	*0.183*	*0.00950ł*	*105.3*	*5.79*	*<0.00105*
*Maximum density cell within the Moray West array area, łSCANS III density estimate					

The impact of instantaneous PTS at soft-start and for full hammer energy is assessed as being of **negligible** magnitude for harbour porpoise and minke whale.

4.1.2 Cumulative PTS

The modelling of cumulative PTS-onset impact ranges is based on a series of highly conservative assumptions that result in highly over-precautionary estimates of impact ranges and impact areas.

In the original Moray West PS, the risk of cumulative PTS-onset was assessed as being of negligible magnitude for all species. Both the Moray West EIA Report 2018 and the original Moray West PS assessment concluded no significant effect of instantaneous or cumulative PTS-onset for any marine mammal species when considering impacts against the entire Management Unit (MU).

1 piling installation event per day

The conservative estimates for harbour porpoise cumulative PTS-onset impact ranges for OSP 1 (E06) ranges from <500 m at 4% CF with less than one animal potentially within the impact area to over 2.4 km at 10% CF with 11 animals potentially within the impact area

The conservative estimates for minke whale cumulative PTS-onset impact ranges for OSP 1 (E06) ranges from <5 km at 4% CF with less than one animal potentially within the impact area to over 28.5 km at 10% CF with a maximum of 4 animals potentially within the impact area

Due to the conservative assumptions used to calculate the cumulative PTS onset ranges, these predicted impacts ranges are considered unrealistically high and the animals likely to be at risk of experiencing cumulative PTS will be considerably fewer.

The risk of cumulative PTS on harbour porpoise would be of **negligible** magnitude and **not significant** in EIA terms, considering the implementation of mitigation measures and assuming a displacement of the animals due to the presence of construction vessels prior piling operation commences (Benhemma-Le Gall et al. 2021).

The risk of cumulative PTS on minke whales is assessed as being of **negligible** magnitude **not significant** in EIA terms, given that the effect is on such a small proportion of the population (0.02% MU, 0.04% UK portion) that there is expected to be no change to the population size or trajectory.

2 piling installation events per day

Assessment of cumulative PTS for consecutive (or sequential) piling was not presented in the Moray West EIA and was only presented in the original Moray West PS with a 10% CF. For both harbour porpoise and minke whale (Table 3-6 and 3-7 respectively of the original Moray West PS), the maximum cumulative PTS impact ranges are slightly larger at 10% CF in the OfTI PS compared to those in Appendix C of the PS, but the numbers of animals impacted is the same for minke whale and lower for harbour porpoise.

The conservative cumulative PTS-onset impact ranges for the installation of two consecutive monopiles for harbour porpoise reach 3.827 km, with 18 animals potentially within the impact area. As stated previously, it is likely that harbour porpoise would have already been displaced by the presence of construction vessels before piling commences (Benhemma-Le Gall et al. 2021). Considering the conservatism bult into the assessment and the mitigation measures that will be implemented prior piling operation commencing (ADD activation), the impact of cumulative PTS on harbour porpoise is therefore of **negligible magnitude** and **not significant** in EIA terms.

For minke whale, the conservative cumulative PTS-onset impact ranges for the installation of two consecutive monopiles reach 48.065 km, with 6 animals (summer density) or less than one animal (non-summer density) potentially within the impact area (a maximum of 0.03 % MU, 0.06 % UK portion). The impact of cumulative PTS on minke whale is therefore of **negligible** magnitude and **not significant** in EIA terms, as the effect is on such a small proportion of the population (even without considering a reduction of conservatism) that there is expected to be no change to the population size or trajectory.

Table 4-4 provides a summary of the maximum cumulative PTS onset impact ranges for harbour porpoise and minke whales, and maximum number of animals within these impact ranges, for 1 piling installation event and 2 piling installation events.

Table 4-4. Maximum cumulative PTS onset impact ranges (based on a constant 10% CF) for minke whale and harbour porpoise at OSP 2 (M11), and OSP 2 (M11) followed by OSP 1 (E06) and number of animals within the impact area based on species density distribution maps. (S – summer, NS – non-summer).

Species	Location	Refusal Risk	Max cumulative PTS-onset range (m)	Number of animals within the cumulative PTS-onset impact area
Harbour porpoise	OSP 2 (M11)	low	2,329	11
	OSP 2 (M11) followed by OSP 1 (E06)	low	3,827	18
Minke whale	OSP 2 (M11)	low	28,500	S: 4, NS: <1
	OSP 2 (M11) followed by OSP 1 (E06)	low	48,065	S: 6, NS: <1

In summary, the Moray West EIA Report 2018, the original Moray West PS and this OfTI PS conclude no significant effect of instantaneous or cumulative PTS onset for any marine mammal species when considering impacts against the entire Management Unit (MU).

4.2 Disturbance Assessment

As presented in the original Moray West PS, the magnitude of impact of disturbance from pile driving for harbour porpoise and bottlenose dolphins was assessed as low, whereby the impact is short-term and temporary behavioural effects are expected in only a small proportion of the populations, resulting in potential impacts to individual vital rates but only over the short-term, such that the population trajectory would not be altered. The magnitude of impact of disturbance from pile driving for minke whales, harbour seals and grey seals was assessed as negligible since there was predicted to be no change to the population size or trajectory.

Both the Moray West EIA Report 2018 and the original Moray West PS assessment concluded no significant effect of behavioural disturbance to any marine mammal species.

The disturbance assessment has been remodelled for bottlenose dolphin and minke whale as recommended by the comments received from the original Moray West PS consultation. The updated estimate of the disturbance impacts on these two species are provided in the Addendum of the Appendix C.

4.3 Comparison with EIA Report 2018

The results presented in the original Moray West PS were generally the same as those presented in the Moray West EIA Report 2018. Both the Moray West EIA Report 2018 and the original Moray West PS assessment concluded no significant effect of instantaneous or cumulative PTS-onset and no significant effect of behavioural disturbance to any marine mammal species.

The results presented in the Addendum to Appendix C (revised assessment for the Moray West OfTI PS) are generally the same as those presented in the Moray West EIA Report 2018 and the Appendix C of the original Moray West PS. All three concluded no significant effect of instantaneous or cumulative PTS-onset to any of the marine mammal species assessed when considering impacts against the entire MU and including the activation of an ADD.

It is therefore concluded that the potential for injury and behavioural effect would be of negligible significance for all marine mammal species, and therefore not significant in EIA terms.

5 Fish Impact Assessment

The criteria used for the fish assessment are those contained in the recent Sound Exposure Guidelines for Fishes and Sea Turtles (Popper et al. 2014).

For impulsive noise from impact piling sources, the guidelines specify dual metric criteria for recoverable injury and mortality (SPL_{peak}), and an cumulative exposure (SEL_{cum}) criterion for Temporary Threshold Shift (TTS).

The noise model applied the thresholds for Group 2 (fish species with swim bladder but the swim bladder does not play a role in hearing; i.e. salmonids) under both cumulative exposure and recoverable injury and mortality metrics in the assessment. The SPL_{peak} was modelled for both the soft-start hammer energy and the maximum hammer energy of the piling scenarios considered in the assessment. For the SEL_{cum}, the modelling adopted a highly conservative approach by assuming that fish are stationary and do not flee away from the noise source. This approach, since it is precautionary, is considered likely to lead to an overestimate of the ranges of effect. For the stationary fish receptors the cumulative exposure is determined only by the total energy of the piling profile (the sum of all the strike energies within the profile.

Baseline characterisation of Coull et. al (1998) spawning areas indicates the Moray West Offshore Wind Farm (the Development Site), is not within key (high intensity) spawning grounds for cod, herring or sandeel and that these spawning grounds are located in more suitable areas out with the Development Site.

Research has shown that spawning adults are unlikely to show displacement as their spawning activity takes precedence over any other behaviour due to the amount of energy put into the spawning process and its importance in successful recruitment (Moray West, 2018).

Herring spawning activity occurs further to the north around the Orkney and Shetland islands (Coull et al., 1998; Moray Offshore Renewables Ltd, 2018), meaning spawning activity for herring will not be affected by piling activity, as this is beyond the ranges found for TTS at a threshold of 186 dB SEL_{cum}.

For this reason, the Fish Impact Assessment (FIA) considers the remaining sensitive receptors that have the potential to be affected by piling, namely the diadromous species that may be migrating through the Moray Firth during piling activity, in particular the salmonids: Atlantic salmon and sea trout. For detailed information on the FIA, please see Section 4 of the Addendum to Appendix C Fish Impact Assessment.

5.1 Impact Ranges and Assessment Results

SPLpeak Assessment of Mortality and Recoverable Injury in Fish

The maximum effect range for mortality or recoverable injury according to the Popper et al., (2014) criteria (which have the same threshold of 207 dB re 1 µPa) was 950 m, for the BE50 blow count scenarios at 2,158 kJ and 10% energy CF. The corresponding effect range for the 4% energy conversion factor was 510 m.

Cumulative SEL Assessment of TTS, Recoverable Injury, and Mortality Effect Zones for Fish

The greatest mortality range predicted for Atlantic salmon and sea trout was 1,133 m at location OSP 2 (M11) for the blow count profile BE50 and the energy conversion factor of 10%. The corresponding maximum range for the 4% conversion factor, also at location OSP 2 (M11), was 647 m. The greatest recoverable injury range was 3,203 m, and the greatest TTS range was 43,270 m, both at the same location OSP 2 (M11), blow count profile (BE50) and conversion factor (10%). For the 4% conversion factor, these ranges were reduced to 1,793 m for recoverable injury and to 19,324 m for TTS.
Effect areas for mortality, recoverable injury, and TTS according to the Popper et al., (2014) SEL_{cum} criterion for the Atlantic salmon and the sea trout are presented in the Addendum to Appendix C.

5.2 Comparison with EIA Report 2018

Based on noise modelling presented in the Moray West EIA Report 2018, any impacts on fish species as a result of piling noise at Moray West Site were considered to be of low magnitude, with the significance of the effect assessed as minor, even for more sensitive species such as salmonids. Although there is some potential for mortality, injury and behavioural effects in the ranges summarised above, piling (noise generation) is predicted to occur over a short duration (up to 8 hours in total) and overlap with sensitive locations and time periods for the fish species considered is limited.

In light of the low potential for any barrier effects to natal rivers as a result of the noise contours, the assessment of potential noise related effects is not expected to exceed that previously assessed within the Moray West EIA Report 2018.It is therefore concluded that the potential for mortality, impairment and behavioural effects would be of negligible significance for Atlantic salmon and sea trout, and therefore not significant in EIA terms.

A full explanation of the differences in effect ranges between the Moray West EIA Report 2018 and the current modelling, and the high levels of conservatism built into both model outputs is presented in the Addendum to Appendix C Underwater noise impact assessment.

6 Piling Mitigation Protocol

6.1 Marine Mammals Mitigation

Moray West piling mitigation protocol (PMP) for mitigating the risk of instantaneous and cumulative auditory injury to marine mammals during piling at the two OSPs monopile location within Moray West Site is presented in Addendum to Appendix D. The mitigation measures will aim to successfully:

- Minimise the risk of instantaneous auditory injury for marine mammals during piling;
- Allow piling to be conducted during periods of poor visibility e.g., darkness and adverse weather conditions and restarted following breaks in piling;
- Allow the mitigation measure process to be conducted safely; and
- Conduct construction activities in an efficient manner to minimize the overall duration of the period of potential risk to marine mammals.

Moray West proposes the following mitigation measures to reduce the risk of injury to negligible:

6.1.1 Optimization of pilling sequencing

The installation programme has been designed to focus pile driving activity in those locations with harder ground conditions where hammer energies will likely reach 4,400 kJ to drive the pile to target penetration in non-summer months (from October) to reduce worst case impacts upon minke whales.

6.1.2 ADD protocol

An ADD protocol will require the deployment of an ADD prior to piling operations commencing at each of the two OSPs piling locations to allow marine mammals to be displaced out of the impact ranges.

6.1.3 Soft start and ramp-up

Pile driving operations will commence with a soft-start procedure with a maximum hammer energy of 432 kJ and minimum duration of 15 minutes. Following the 15-minutes soft start, hammer energy will ramp-up gradually until a suitable energy level is reached, to maintain a steady rate of pile penetration.

6.2 Fish mitigation

The mitigation soft-start and use of ADDs proposed to reduce the risk of injury to marine mammals may also deter hearing-sensitive fish species from the impact ranges. The effectiveness of ADDs as a method to deter fish has not been studied and therefore their appropriateness as a mitigation tool for noise related impacts for fish is currently undetermined.

It is expected that fish will not stay stationary and will move away from the source on commencement of soft start piling and will continue to do so as piling ramps up. Whilst the ADD appropriateness as a mitigation tool is current undetermined, the implementation of soft-start procedure represents an effective method of preventing sensitive fish species from being exposed to the to the highest hammer energies.

7 Marine Mammal Monitoring Programme

Moray West have committed to undertake marine mammal monitoring during pre-construction, construction and post-construction to better understand the distribution of marine mammals within the vicinity of the Development, to validate assumptions made within the Moray West EIA Report and RIAA and to inform the PS.

Marine mammal pre-construction monitoring commenced in spring 2021 and will continue during 2022.

The key objectives of the construction monitoring are to compare marine mammal distribution and activity against the pre-construction baseline and monitor for any changes to disturbance or noise generated during the construction phase.

The approach to monitoring for marine mammals (Moray Firth Marine Mammal Monitoring Programme (MMMP) Addendum, 2022) has been discussed and agreed with MFRAG-marine mammals (MFRAG-MM) subgroup, and it is outlined in the Moray West Project Environment Monitoring Programme (PEMP, 8460005-DBHA13-MWW-PLN-000001).

Moray West will be undertaking noise monitoring during the monopile installation works with the aim to reduce uncertainty over levels of piling noise generated during the installation of large monopile foundations and how these vary with hammer energy.

To make field measurements during the installation of monopile foundations, work carried out at Beatrice and Moray East offshore wind farms will be replicated at a subset of sites within Moray West Site. In addition, independent nearfield measurements will be made at 750 meters to enable comparison with data collected from other wind farm sites. Measurements of received levels will be based upon calibrated Soundtrap recordings, and these data related to engineering records to assess how received levels vary in relation to changes in hammer energy. Additionally, CPODS will be deployed during installation of monopiles to assess changes in occurrence and feeding activity of harbour porpoises in response to piling noise at Moray West. Soundtraps will be deployed during construction.

Deployment locations within Moray West Site will be discussed and agreed with MFRAG-MM in advance prior the pile installation works commencing.

7.1 Reporting

Results of the construction monitoring programme will be reported and presented at MFRAG-MM meetings within an agreed timescale after the field measurements and the completed collection of the data results, and through yearly reports submitted to MFRAG-MM and MS-LOT.

8 Compliance with the Application

Table 8-1 provides a summary of the parameters considered in this OfTI PS compared with the parameters assessed in the Moray West EIA 2018.

Table 8-1 Comparison of the parameters used in the Moray West EIA 2018 and in the assessment to inform this OfTI PS

Parameter	Moray West EIA 2018	Moray West OfTI PS	Difference
Maximum number of OSP monopile foundations	2	2	0
Maximum hammer energy (kJ)	5,000 kJ	2,158 kJ	<2,842 kJ
Maximum installation time	8 hours per foundation	4 hours per foundation	<4 hours
Pile installation programme	10 months	4 months, as a worst-case scenario	<2 months
Total number of piling days (single vessel)	87	two (assuming installation of 1 pile/day)	<85
Maximum number of piles per 24 hours (assuming simultaneous piling events)	2	0 simultaneous piling events 2 consecutive piling events	No simultaneous piling events is proposed in this OfTI PS.

The refined Development's design, the reduction of the total number of pile foundations and overall pile installation programme and duration of pile driving at each location results in a notable decrease in potential temporal and spatial disturbance to sensitive marine species resulting from pile driving noise at Moray West Site when compared to the consented design envelope assessed and presented in the Moray West EIA Report 2018.

9 References

Coull, K.A., Johnstone, R., and Rogers, S.I (1998). Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd.

Popper, A. N. and Hawkins, A. D. (2016). The Effects of Noise on Aquatic Life, II. Springer Science+Business Media. New York, NY.

Southall, B. 2021. Evolutions in Marine Mammal Noise Exposure Criteria. Acoustics Today **17**.

Southall, B., J. J. Finneran, C. Reichmuth, P. E. Nachtigall, D. R. Ketten, A. E. Bowles, W. T. Ellison, D. Nowacek, and P. Tyack. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals **45**:125-232.

Moray West (2018) Moray West Offshore Windfarm Offshore Environmental Impact AssessmentReport. Available at http://marine.gov.scot/data/moray-west-offshore-windfarm-environmental-impact-assessment-reportaccessed 18/01/2022

Appendix A – Defined Terms

Term	Description
Conversion Factor	The proportion of hammer energy that is converted into acoustic energy (%) is referred as the conversion factor
Design Envelope	The range of design parameters used to inform the assessment of impacts.
Marine Licence for the Generating Station	Marine Licence for the Moray West Offshore Wind Farm - Licence Number: MS-00008731 - granted under the Marine and Coastal Access Act 2009, Part 4 Marine Licensing for marine renewables construction works and deposits of substances or objects in the Scottish Marine Area and the UK Marine Licensing Area granted to Moray West on 14 June 2019, varied on 7 March 2022 and on 11 April 2022.
Marine Licence for the Transmission Works	Marine Licence for the Offshore Transmission Infrastructure – Licence Number MS-06764/19/0 – granted under the Marine and Coastal Access Act 2009, & Marine (Scotland) Act 2010, Part 4 Marine Licensing for marine renewables construction works and deposits of substances or objects in the Scottish Marine Area and the UK Marine Licensing Area (referred to as the "OfTI Marine Licence"), granted to Moray West on 14 June 2019 and varied on 11 April 2022.
Moray Offshore Windfarm (West) Limited	The legal entity submitting this Piling Strategy (PS).
Moray West EIA Report	The Environmental Impact Assessment Report for the Moray West Offshore Wind Farm and Associated Transmission Infrastructure, submitted July 2018. Additional information was provided in the Moray West Report to Inform an Appropriate Assessment (RIAA) July 2018 and Moray West Application Addendum Document November 2018.
Moray West Offshore Wind Farm	The wind farm to be developed in the Moray West site (also referred as the Wind Farm).
Offshore Consents	Collective term for the two Marine Licences and the Section 36 consent
Offshore Consent Conditions	Collective term for the conditions attached to the Section 36 Consent and Marine Licences
Offshore Transmission Infrastructure (OfTI)	The offshore elements of the transmission infrastructure.
OfTI Corridor	The export cable route corridor, i.e., the OfTI area excluding the Moray West site.
Section 36 Consent	Section 36 consent under Section 36 of the Electricity Act 1989 for the construction and operation of the Moray West Offshore Wind Farm was granted on 14 June 2019 and varied on 7 March 2022.
The Development	The Moray West Offshore Wind Farm and OfTI.
The Development Site	The area outlined in Figure 1 attached to the Section 36 Consent Annex 1, Figure 1 attached to the two Marine Licences, and Figure B.1 of this PS.

The Moray West Site	The area in which the Moray West Offshore Wind Farm will be located. Section 36 Consents and associated Marine Licence to construct and operate generating stations on the Moray West site were granted in June 2019 and varied in March 2022.
The Works	The construction and O&M activities undertaken for the Development.
Transmission Infrastructure (TI)	Includes both offshore and onshore electricity transmission infrastructure for the consented wind farm. Includes connection to the national electricity transmission system near Broad Craig in Aberdeenshire encompassing Alternating Current (AC) Offshore Substation Platforms (OSPs), AC export cables offshore to landfall point at Broad Craig, near Sandend in Aberdeenshire continuing onshore to the AC collector station (onshore substation) at Whitehillock and the additional regional Transmission Operator substation at Blackhillock near Keith. A Marine Licence for the OfTI was granted in June 2019 and varied on 11 April 2022.

Appendix B – Development Background Information

B.1 Development Description

Moray West Offshore Wind Farm is being developed by Moray Offshore Windfarm (West) Limited (Moray West; Company Number 10515140) which is registered at Octagon Point, 5 Cheapside, London, England, EC2V 6AA. Moray Offshore Windfarm (West) Limited is a wholly owned subsidiary of Moray West Holdings Limited which in turn is owned by Moray Offshore Renewable Power Limited, Delphis Holdings Limited, EDP Renewables Europe, S.L.U and UAB Ignitis Renewables.

The Moray West Site covers an area of approximately 225 km^2 on the Smith Bank in the Outer Moray Firth approximately 22 km from the Caithness coastline.

The Moray West Offshore Wind Farm will comprise 60 wind turbine generators (WTGs), associated substructures and seabed foundations, inter-array cables, one OSP inter-connector cable and any scour protection around substructures or cable protection. The OfTI comprises two offshore substation platforms (OSPs) which will be located within the Moray West Site, and two offshore export cable circuits which will be located within the OfTI Corridor and will be used to transmit the electricity generated by the offshore wind farm to shore.

The offshore export cable circuits will come ashore at Sandend Bay, which is located on the Aberdeenshire Coast at Broad Craig, approximately 65 km south of the Moray West Site. There will be two underground circuits from landfall at Sandend Bay to Whitehillock where the onshore substation will be located. There will also be further underground cabling between Whitehillock substation and Blackhillock substation. Moray West will transfer ownership of the transmission asset to an Offshore Transmission Owner (OFTO) who will manage the transmission infrastructure.

Figure B.1 displays a map of the Moray West Site and OfTI Corridor.

The development is aiming to be fully operational in 2024/25 with an operational life of 25 years from the date of final commissioning of the Development.

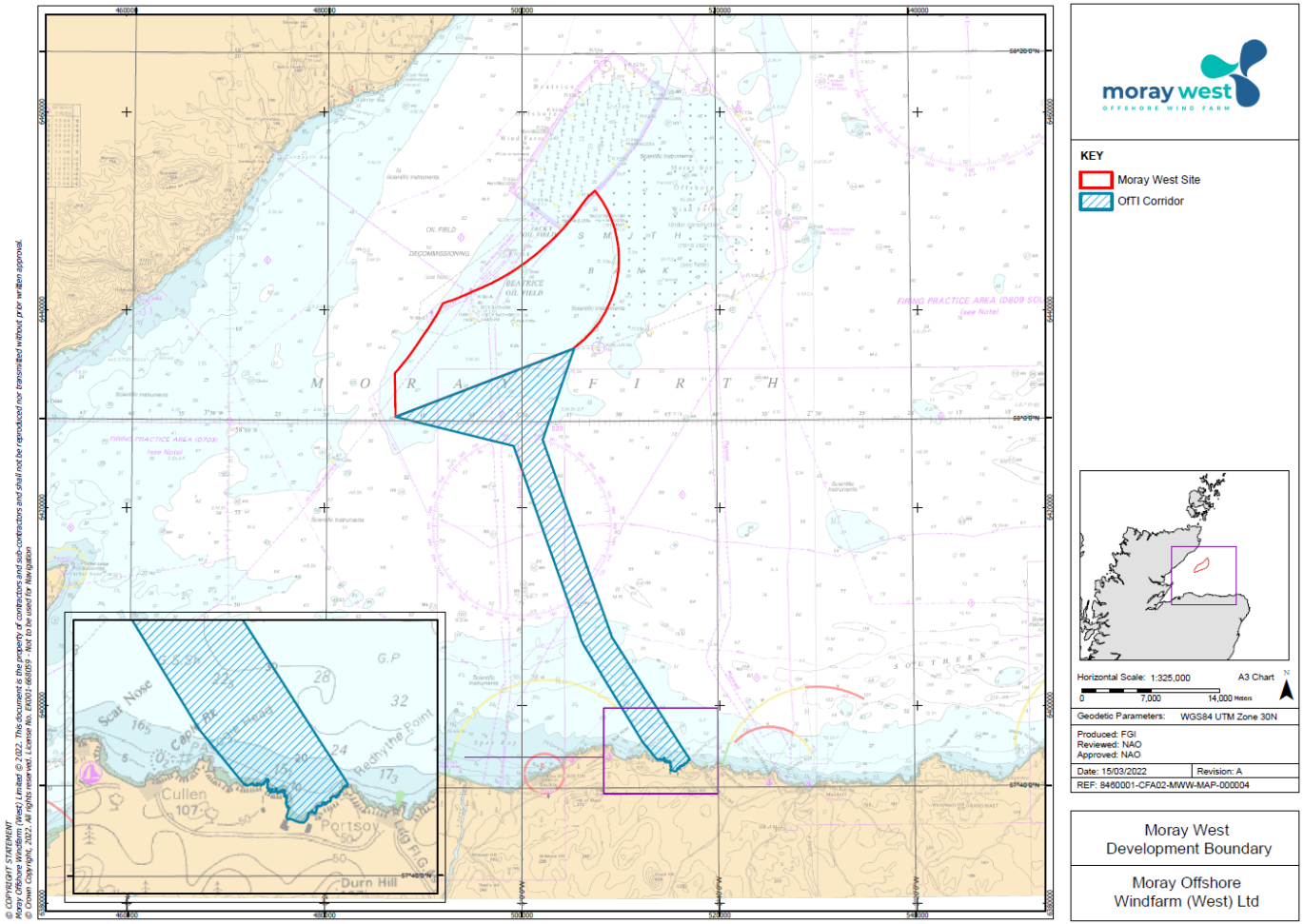


Figure B.1 Geographical location of the Moray West Site and OfTI Corridor.

B.2 Legal Context

Table B.1 provides a list of marine licence consent conditions relevant to this OfTI PS and how they are addressed within it.

Table B.1. Consent conditions to be discharged by this OfTI PS		
Consent Condition Reference	**Condition**	**Addressed**
OfTI Marine Licence Condition 3.2.2.7	Where construction of OSP involves piling, the Licensee must, no later than six months prior to the Commencement of the Works, submit a PS, in writing, to the Licensing Authority for its written approval.	This document sets out the PS for approval by the Scottish Ministers.
	Such approval may only be granted following consultation by the Scottish Ministers with SNH[4] and any such other advisors or organisations as may be required at the discretion of the Scottish Ministers. Commencement of the Development cannot take place until such approval is granted	Consultation to be undertaken by the Scottish Ministers.
	The PS must include, but not limited to: a) Details of expected noise levels from pile-drilling/driving in order to inform point d below;	Addendum to Appendix C
	b) Full details of the proposed method and anticipated duration of piling to be carried out at all locations;	Section 2.4 and 2.5
	c) Details of soft start piling procedures and anticipated maximum piling energy required at each pile location;	Section 2.4.3 and 2.4.4 Addendum to Appendix D
	d) Details of any mitigation such as PAM, MMO, use of ADD and monitoring to be employed during pile-driving, as agreed by the Licensing Authority.	Section 6 and Addendum to Appendix D
	The PS must be in accordance with the Application and must also reflect any relevant monitoring or data collection carried out after submission of the Application.	Section 7 and 8
	The PS must demonstrate the means by which the exposure to and/or the effects of underwater noise have been mitigated in respect to harbour porpoise, minke whale, bottlenose dolphin, harbour seal, grey seal and Atlantic salmon and sea trout.	Addendum to Appendix D
	The PS must, so far as is reasonably practicable, consistent with the EMP, the PEMP and the CMS	Section 1.3

[4] Scottish Natural Heritage (SNH) currently known as NatureScot since May 2020

B.3 Sustainable Construction

The Institute of Environmental Management and Assessment (IEMA) state "Sustainable Construction" as "*application of sustainable development to the construction industry, whereby the construction and management of a development is based on principles of resource efficiency and the protection/enhancement of natural and built heritage. Sustainable construction comprises such matters as site planning and design, material selection, resource and energy use, recycling and waste minimisation". (Institute of Environmental Management and Assessment, Environmental Management Plans Practitioner, Volume 12, December 2008).*

Moray West is fully committed to ensuring that the Development staff and stakeholder needs and expectations are met and exceeded, achieving the ultimate goal of delivering the Development to the highest standard of quality, with a Zero Harm approach to the health and safety of individuals and to the environment as a whole. Moray West have developed an overarching QHSE Policy, which includes the following objectives:

- To reduce our carbon footprint by conserving natural resources and reducing energy use and waste generated by our operations; and
- To support and maintain our commitment to the protection of the environment, including prevention of pollution and other specific commitment(s) relevant to the context of the organisation's undertakings.

The Moray West EMP provides a framework, supported by Moray West's QSHE Policy, the organisational context, the EIA and associated documents, the Consent Plans (including the WMP and MPCP) and the output of hazard identification processes, to aid Moray West in achieving its own environmental objectives:

- Zero spills to sea.
- Zero high potential incidents.
- All personnel working on the Development shall have a risk assessment for every task, which also addresses environmental impact.
- Responsible construction and compliance with all applicable legislation, licences and conditions and best practice guidance.
- Consideration of local supply chain and use of sustainable materials where possible.
- Use of the waste hierarchy of reduce, reuse and recycle wherever possible.
- Incorporation of 'lessons learnt' into ongoing works for continued HSE improvement.

Addendum to Appendix C – Underwater noise impact assessment

MORAY OFFSHORE WINDFARM (WEST) LIMITED

Piling Strategy
Addendum to Appendix C: Underwater Noise Impact Assessment
Offshore Transmission Infrastructure (OfTI) Piling Strategy

Document Name: 8460005-DBHA04-MWW-REP-000003

Revision: 2

Status: Final

Date: 10/11/2022

Version Control				
Revision	Date	Status	Revision Description	Distribution List
0	21/10/2022	Draft	Moray West Review	Moray West
1	31/05/2022	Final	Submission to MS-LOT Moray West Piling Strategy Appendix C (8460005-DBHA04-MWW-REP-000001)	MS-LOT
2	10/11/2022	Final	Second Submission to MS-LOT Moray West OfTI Piling Strategy Addendum to Appendix C (8460005-DBHA04-MWW-REP-000003)	MS-LOT

Table of Contents

Table of Contents 3
Figures 4
Tables 6
Abbreviations and Acronyms 8
1 Introduction 11
2 Assessment Methodology 11
2.1 Piling locations and scenarios 11
2.2 Source model 14
2.3 Propagation model 14
2.4 Input data 14
2.5 Piling profiles 15
2.6 Metrics modelled and assessment criteria 17
2.6.1 Metrics 17
2.6.2 Marine Mammal Assessment Criteria 17
2.6.3 Assessment of potential effects 21
2.6.4 Population modelling 21
2.6.5 Analysis of potential impacts to the Southern Trench Marine Protected Area (MPA) 21
2.6.6 Comparison with EIA Report 2018 and Appendix C of the Original Moray West PS 23
2.6.7 Comparison with 2018 RIAA 26
3 Marine Mammal Assessment Results 27
3.1 Auditory injury 27
3.1.1 Instantaneous PTS 27
3.1.2 Cumulative PTS 29
3.2 Disturbance 39
3.2.1 Bottlenose dolphin 39
3.2.2 Minke whale 43
3.2.3 Limitations of disturbance assessment 44
3.3 Analysis of potential impacts to the Southern Trench MPA 47
3.3.1 Number of animals within the MPA 47

3.3.2 Auditory injury 47
3.3.3 Disturbance 47
3.3.4 Prey availability 50
3.3.5 Conclusions 50
3.4 Proposed mitigation measures 50
3.5 Comparison to 2018 EIA and original Piling Strategy 50
3.6 Comparison to 2018 RIAA 53
4 Fish Impact Assessment 54
4.1 Introduction 54
4.1.1 Background 54
4.1.2 NatureScot Response on Piling Strategy 54
4.1.3 Scope of Fish Impact Assessment 54
4.2 Underwater Noise Modelling 55
4.3 Salmonid Ecology and Underwater Noise 56
4.4 Fish Impact Assessment Results 57
4.4.1 Injury Criteria 59
4.4.2 Impact Assessment (Adult Salmonids and Smolts) 60
4.4.3 Consideration of Other Fish Species 69
4.4.4 Comparative Developments 71
4.4.5 Comparison with 2018 EIA 71
4.4.6 Fish mitigation 73
5 4References 74

Figures

Figure 2-1 Noise modelling locations of OSP 1 (E06) and OSP 2 (M11) – yellow dots. Black dots numbered 1-3 on the edge of the wind farm boundary (red line) represent the modelling locations from the 2018 EIA 13
Figure 2-2 Piling profiles for the two OSPs monopile foundation locations OSP 2 (M11) and OSP 1 (E06), showing hammer energy (red) and blow rate (black) over time. 16

Figure 2-3 Dose-response relationship for harbour porpoise developed by Graham et al. (2017) used for all cetacean in this assessment. 20
Figure 3-1 Harbour porpoise cumulative PTS-onset impact ranges for OSP 2 (M11), featuring different conversion factor scenarios. 32
Figure 3-2 Minke whale cumulative PTS impact ranges for OSP 2 (M11), featuring different conversion factor scenarios. 33
Figure 3-3 Harbour porpoise cumulative PTS-onset ranges for sequential piling at OSP 2 (M11) followed by OSP 1 (E06), given different conversion factor scenarios. 36
Figure 3-4 Minke whale cumulative PTS-onset impact ranges for sequential piling at OSP 2 (M11) followed by OSP 1 (E06) given 4% and 10% conversion factor scenarios. 37
Figure 3-5 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location OSP 1 (E06) overlain the bottlenose dolphin distribution. CF = 10%, hammer energy = 2,050 kJ. 41
Figure 3-6 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location OSP 1 (E06) overlain the bottlenose dolphin distribution. CF = 4%, hammer energy = 2,050 kJ. 42
Figure 3-7 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location OSP 2 (M11) overlain the minke whale distribution. CF = 10%, hammer energy = 2,158 kJ. 45
Figure 3-8 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location OSP 2 (M11) overlain the minke whale distribution. CF = 4%, hammer energy = 2,158 kJ. 46
Figure 3-9 Simulated minke whale MPA population sizes for both the un-impacted and the impacted populations. 49
Figure 4-1 Cumulative exposure effect zones for salmonid species exposed to piling at location OSP 1 (E06), for the blow count profile BE50 and the energy conversion factor C.F.=4%. 62
Figure 4-2 Cumulative exposure effect zones for salmonid species exposed to piling at location OSP 2 (M11), for the blow count profile BE50 and the energy conversion factor C.F.=4%. 63
Figure 4-3 Cumulative exposure effect zones for salmonid species exposed to concurrent piling (within 24hours) at locations E06 and M11, for the blow count profile BE50 and the energy conversion factor C.F.=4%. 64
Figure 4-4 Cumulative exposure effect zones for salmonid species exposed to piling at location OSP 1 (E06), for the blow count profile BE50 and the energy conversion factor C.F.=10%. 65
Figure 4-5 Cumulative exposure effect zones for salmonid species exposed to piling at location OSP 2 (M11), for the blow count profile BE50 and the energy conversion factor C.F.=10%. 66
Figure 4-6 Cumulative exposure effect zones forsalmonid species exposed to concurrent piling (within 24hours) at locations OSP 1 (E06) and OSP 2 (M11), for the blow count profile BE50 and the energy conversion factor C.F.=10%. 67

Tables

Table 2-1 Summary of the marine mammal impact assessment carried out and re-assessed scenarios presented in this Addendum to Appendix C 12
Table 2-2 Summary statistics of the piling profiles used for the marine mammal impact assessment. 16
Table 2-3 PTS-onset thresholds for impulsive noise for harbour porpoise and minke whale (Southall et al. 2019). 17
Table 2-4 Comparison of the parameters and assumptions used for the assessments from the 2018 EIA and Appendix C of the original Moray West PS. For the OfTI PS the same parameters and assumptions apply unless given in brackets and italics. 24
Table 2-5 Comparison of the iPCoD parameters for bottlenose dolphin population modelling in the EIA and Appendix C of the PS. 26
Table 3-1 Harbour porpoise: Instantaneous PTS impact ranges (m) for soft start and full hammer energy compared across the three assessments conducted to date. 27
Table 3-2 Minke whale: Instantaneous PTS impact ranges (m) for soft start and full hammer energy compared across the three assessments conducted to date. 28
Table 3-3 Probability of an animal being present with the instantaneous PTS-onset impact zone at full hammer energy. 29
Table 3-4 Comparison of cumulative PTS impact ranges for harbour porpoise in a single piling scenario among the three assessments conducted to date. 30
Table 3-5 Comparison of cumulative PTS impact ranges for minke whale in a single piling scenario among the three assessments conducted to date. (S – summer and NS – non-summer). 31
Table 3-6 Comparison of cumulative PTS impact ranges for consecutive piling scenarios for harbour porpoise among the three assessments conducted to date. 35
Table 3-7 Comparison of cumulative PTS impact ranges for consecutive piling scenarios for minke whale among the three assessments conducted to date. (S – summer and NS – non-summer). 35
Table 3-8 Maximum cumulative PTS impact ranges (m) for harbour porpoise based on the piling profiles shown in Table 2-2 and a constant CF of 10% for OSP 2(M11) and when followed consecutively by OSP 1 (E06) with ADD mitigation measures and threshold changes included. 38
Table 3-9 Comparison of the potential disturbance to bottlenose dolphins resulting from worst case scenarios in the EIA, original piling strategy, and current OfTI addendum impact assessments. 43
Table 3-10 Comparison of the potential disturbance to minke whales resulting from worst case scenarios in the EIA, original PS, and current OfTI PS impact assessments. 44
Table 3-11 Calculation of the % MPA within which minke whale are potentially disturbed using the Graham et al. (2017) dose-response function for location OSP 2 (M11) and a 4% CF. 47
Table 3-12 Calculation of the % MPA within which minke whale are potentially disturbed using the Graham et al. (2017) dose-response function for location OSP 2 (M11) and a 10% CF. 48
Table 3-13 Results of the iPCoD modelling, giving the mean MPA population size of minke whale for years up to 2042 for impacted and un-impacted populations, and the mean and median ratio between their annual growth rates. 49

Table 3-14 Comparison of the evaluation of sensitivity, magnitude, and impact of Instantaneous PTS on marine mammal species in the 2018 ES, Appendix C of the original Piling Strategy and this OfTI Addendum. 51
Table 3-15 Comparison of the evaluation of sensitivity, magnitude, and impact of cumulative PTS on marine mammal species in the 2018 EIA and this OfTI Piling Strategy. S = summer, NS = non-summer. . 52
Table 3-16 Comparison of the evaluation of sensitivity, magnitude, and impact of disturbance on marine mammal species in the 2018 EIA and this OfTI Piling Strategy. S = summer, NS = non-summer..... 52
Table 4-1 Criteria for onset of injury to fish due to impulsive piling (Popper et al., 2014) 59
Table 4-2 Effect ranges for mortality and recoverable injury according to the Popper peak SPL criterion for Atlantic salmon and the sea trout. 60
Table 4-3 Effect areas for mortality, recoverable injury, and TTS according to the Popper SELcum criterion for the Atlantic salmon and the sea trout. Thresholds for these effects are 210, 203, and 186 dB re 1 µPa2 s, respectively. 61
Table 4-4 Estimated potential distances and timings for salmonids based on assumed swim speeds based on Drenner et al., (2012) 69

Abbreviations and Acronyms

Acronym / Abbreviation	Description
ADD	Acoustic Deterrent Device
ASA	Acoustical Society of America
BE	Best Estimate
Cefas	Centre for Environment, Fisheries and Aquaculture
CF	Conversion factor
EIA	Environmental Impact Assessment
ES	Environmental Statement
FIS	Fish Impact Assessment
iPCoD	interim Population Consequences of Disturbance framework
MORL	Moray Offshore Renewables Ltd.
MPA	Marine Protected Area
MS	Marine Scotland
MU	Management Unit
NMFS	National Marine Fisheries Service
OSP	Offshore Substation Platforms
OfTI	Offshore Transmission Infrastructure
OWF	Offshore Wind Farm
PS	Piling Strategy
PTS	Permanent Threshold Shift
RIAA	Report to Inform Appropriate Assessment
SAC	Special Area of Conservation
SEL	Sound Exposure Level
SEL_{ss}	Single Strike Sound Exposure Level
SEL_{cum}	Cumulative Sound Exposure Level
SNH	Scottish Natural Heritage
SPL	Sound Pressure Level
SPL_{peak}	Peak Sound Pressure Level
TTS	Temporary Threshold Shift
UK	United Kingdom
WTGs	Wind Turbine Generators

Consultation Log

Consultation Comment	Moray West Response
NatureScot 11/08/22 Response to: Piling Strategy Appendix C: underwater noise impact assessment	
The conversion factor used in the modelling appears to be a key factor in predicting the impact, and it remains uncertain as to which % may be most appropriate. The PS considers noise levels recorded at other offshore wind farms (pg. 23 of 103), and states that only at two of them were the noise levels reflective of 8% CF. There is no information as to the size of the monopiles that this information is based on, and therefore whether or not it is transferable to this project.	The pile diameters of those windfarms are between 7 and 8.5 m and therefore comparable (i.e., the expected difference in sound levels due to pile diameter should be small). Water depth is another influencing factor on the sound level, and the water depth of these wind farms ranges from 16 to 30 m, while for Moray West this is 33 m. Moray West will add a table and a short discussion on the comparability to the **Wind Farm PS Addendum** which includes the updated noise impact assessment.
Before we can confirm that we agree the conclusions of the existing 2018 ES and the 2019 Appropriate Assessment still hold, we would like the following further information: Marine mammals · To aid our consideration of the relative conservatisms used for both assessments, we request the following is supplied; o Tabulated comparison of the parameters and assumptions used for the assessments from the 2018 EAS and this PS;	Table 2-3 in Section 2.4.6.
o Tabulated comparison of ranges and predicted impacted individuals from both assessments; and,	Tables 3-1 to 3-10 in Sections 3.1 and 3.2
o Tabulated comparison of the iPCoD modelling versions used, and parameters/assumptions done in both cases;	Tables 2-3 and 2-4 in Section 2.4.6
· Likely proportion of vibropiling to be used (as this will reduce cumulative injury risk);	This will be addressed in the Wind Farm PS Addendum
· Clarity on when (which month/season) the piling is due to occur. S.3.2.3 suggests that piling will only occur between Oct and Jan, but elsewhere it is suggested that only the most difficult locations will be piled outwith the sensitive MW season; · Following on from the above, please provide the likely number of low medium and high refusal locations, and likely maximum hammer energy for each one;	These points will be addressed in the Wind Farm PS Addendum
· We recommend that cumulative PTS risk is re-modelled using the realistic worst case hammer energy,	This will be addressed in the Wind Farm PS Addendum and is addressed in Sections 2.4.2.1 and

Consultation Comment	Moray West Response
based on the CF of 10% for minke and harbour porpoise. As the mitigation protocol stipulates ADD use, we recommend that this is included in the modelling as this may refine some of the conservatism within the modelling. This should focus both on the piling timetabled for the summer season and the piling in the non- summer season	3.1 of this OfTI PS Addendum
· iPCoD modelling should be done for minke whale. We are aware that the expert elicitation was not updated for the lasted version; however, this was done in the 2018 EIA report;	This will be addressed in the Wind Farm PS Addendum
· We recommend that the disturbance is re-modelled for bottlenose dolphin, using the realistic worst case scenario;	This will be addressed in the Wind Farm PS Addendum and is addressed in Section 2.4.22 and 3.2 of this OfTI PS Addendum
· We would like to see an assessment on potential impact on the Southern Trench MPA, and whether the disturbance has any impact on the site other than insignificantly; and,	Addressed in Sections 2.4.5 and 3.3, and will be addressed in the Wind Farm PS Addendum
· We request that more clarity on the point re. seal and disturbance contour, i.e. not stretching as far as the threshold used, and so “an unknown portion of the true impact area not accounted for”, and why this is ultimately not important for our consideration of disturbance to seal species (as was suggested in the meeting on the 4th August).	This will be addressed in the Wind Farm PS Addendum
We advise that the ADD operator should be dedicated to this role throughout the mitigation period, and as a good practice measure, should also scan the mitigation zone for marine fauna when visibility allows.	This is addressed in the Piling Strategy Addendum to Appendix D: Piling Mitigation Protocol

1 Introduction

To address and fulfil specific requirements of Condition 11 of the Moray West Section 36 consent, Condition 3.2.2.8 of the Wind Farm Marine Licence, Condition 3.2.2.7 of the Offshore Transmission Infrastructure (OfTI) Marine Licence, and in light of refinement of piling parameters since the 2018 application, noise modelling has been undertaken to provide details of expected noise levels resulting from pile-driving and the potential impact of underwater noise on marine mammal species.

This OfTI Piling Strategy (PS) Addendum to Appendix C of the original Moray West PS[1] presents the results of the noise modelling and assessment to confirm the design of the mitigation measures to be employed during installation of the Offshore Substation Platform (OSP) monopile foundations.

To ensure accordance with the Moray West Application and no change in impact significance, this addendum also includes a comparison among the assessments done for:

- the OfTI PS;
- the original Moray West PS (Appendix C); and
- the Moray West Environmental Impact Assessment (EIA) Report 2018 – Volume 2, Chapter 92 and its Addendum Volume 1, Part 1 Chapter 43 (for impact assessment using a 1% Conversion Factor (CF)). These two assessments are hereafter referred to collectively as the EIA.

2 Assessment Methodology

Underwater noise modelling has been undertaken by the Centre for Environment, Fisheries and Aquaculture (Cefas) using their propagation model (Farcas et al., 2016) and an energy conversion source model. Details of the assessment methodology and criteria applied for marine mammals and fish, are provided in the sections below.

2.1 Piling locations and scenarios

Two OSPs monopile foundations will be installed, resulting in two monopile installations events. This Addendum to Appendix C Underwater Noise Impact Assessment presents the underwater noise impact assessment for the two OSPs monopile foundation locations (Figure 2-1).

Impacts resulting from pile driving at the Moray West Site have already been assessed for selected piling locations and piling scenarios, to inform the marine mammal and fish impact assessment, which is presented in the original Moray West PS (Appendix C). This Addendum presents the results of the new underwater noise modelling based on a more realistic worst-case scenario piling parameters than those

[1] MORAY OFFSHORE WINDFARM (WEST) LIMITED, Piling Strategy Appendix C: Underwater Noise Impact Assessment, Document Name: 8460005-DBHA04-MWW-REP-000001, Revision: 1, Status: Final, Date: 31-05-2022

[2] https://marine.gov.scot/sites/default/files/00538033.pdf

[3] https://www.moraywest.com/download_file/force/630/219

presented in the original Moray West PS (Table 2-1). To address consultation comments on the original Moray West PS, the below scenarios have been re-assessed based on the new underwater noise modelling results from the installation of the two OSPs monopiles monopile foundation locations (OSP 1 (E06) and OSP 2 (M11)):

- Auditory injury for harbour porpoise and minke whale;
- Disturbance for bottlenose dolphin and minke whale.

OSP1 (E06) has been selected for modelling impacts resulting from a single installation event on bottlenose dolphin due to its proximity to location 1, which was used in the EIA for the assessment of impact on bottlenose dolphin. OSP2 (M11) has been selected for modelling impacts resulting from a single installation event on harbour porpoise and minke whale due to its proximity to location 2 and location 3, used in the EIA for the assessment of impacts on harbour porpoise and minke whale, respectively. Modelling was also conducted to assess the risk of auditory impact when installing the two OSPs monopiles consecutively within a 24-hour period.

Modelling the risk of auditory injury (instantaneous PTS and cumulative PTS) for bottlenose dolphins and seals, and disturbance for harbour porpoise and seals has not been carried out, as impacts for these species were concluded to be negligible in the Appendix C of the original Moray West PS. Additionally, the maximum hammer energies required to drive the OSPs monopile locations to target penetration are lower than those maximum hammer energies considered in the original Moray West PS.

Table 2-1 Summary of the marine mammal impact assessment carried out and re-assessed scenarios presented in this Addendum to Appendix C

Species	Instantaneous PTS	Cumulative PTS	Disturbance
Harbour porpoise	Re-modelled. New results presented in this Addendum to Appendix C		Conclusions of the assessment presented in the original Moray West PS remain valid
Minke whale	Re-modelled. New results presented in this Addendum to Appendix C		
Bottlenose dolphin	Conclusions of the assessment presented in the original Moray West PS remain valid		Re-modelled. New results presented in this Addendum to Appendix C
Harbour seal	Conclusions of the assessment presented in the original Moray West PS remain valid		
Grey Seal	Conclusions of the assessment presented in the original Moray West PS remain valid		

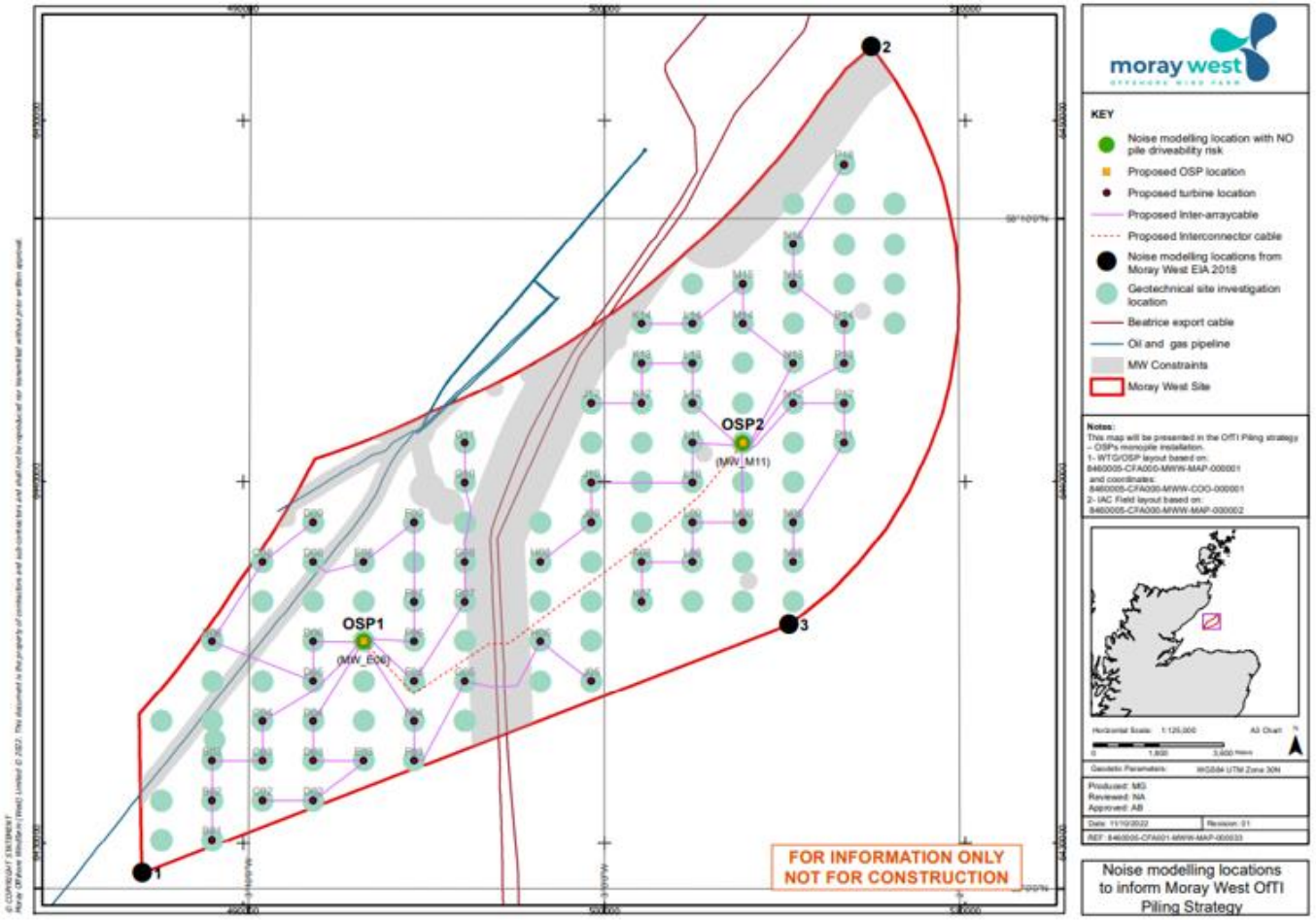


Figure 2-1 Noise modelling locations of OSP 1 (E06) and OSP 2 (M11) – yellow dots. Black dots numbered 1-3 on the edge of the wind farm boundary (red line) represent the modelling locations from the 2018 EIA

2.2 Source model

In the model, the source level estimate for piling was calculated using an energy conversion model (De Jong and Ainslie 2008), whereby a proportion of the expected hammer energy is converted to acoustic energy:

$$\boldsymbol{SLE} = \mathbf{120} + \mathbf{10}\boldsymbol{log}\mathbf{10}\ (\boldsymbol{\beta Ec0\rho}\ \mathbf{4}\boldsymbol{\pi}) \qquad (1)$$

where E is the hammer energy in joules, SLE is the source level energy for a single strike at hammer energy E, $\boldsymbol{\beta}$ is the acoustic energy conversion efficiency (aka conversion factor, CF), $c0$ is the speed of sound in seawater in ms^{-1}, and ρ is the density of seawater in kgm^{-3}.

This yields an estimate of the source level in units of sound exposure level (SEL; dB re 1 μPa^2s). This energy is then distributed across the frequency spectrum based on previous measurements of impact piling (Ainslie et al. 2012). Hammer energy profiles for the piling scenarios (see Section 2.5) formed the basis of the source level estimates. At the request of Marine Scotland and NatureScot, the acoustic energy conversion efficiencies used to compute the source level energies in Equation (1) were taken as either 4% or 10%, respectively, which represent a significant increase over the 0.5% and 1% values used for the modelling in the Moray West EIA Report 2018 and its appendix. The higher values reflect uncertainty when modelling source levels for large monopiles. The use of the two conversion efficiency values illustrates the sensitivity of modelling predictions to this input parameter.

Equation (1) gives the source level energy for a single strike. The field values of the single strike SEL (SEL_{ss}), as well as the cumulative SEL (the total SEL generated during a specified period), SEL_{cum}, were computed using a propagation model, as detailed in Section 2-3. The peak sound pressure level (SPL_{peak}) was calculated from the SEL_{ss} using the empirical linear equations linking peak sound pressure levels and sound exposure levels for piling sources found by Lippert et al. (2015).

2.3 Propagation model

Cefas's propagation model (Farcas et al. 2016) is based on a parabolic equation solution to the wave equation (RAM; Collins (1993)). This model considers the bathymetry, sediment properties, water column properties, and tidal cycle. The model is a quasi-3D model consisting of 360 2D transects extending away from the source at intervals of one degree. Sound propagation is modelled at each discrete frequency in the source spectrum (10 frequencies per 1/3 octave band). Transects are then resampled and integrated over frequency (using the appropriate auditory weightings where needed). Finally, the resulting levels are averaged over depth to produce noise maps.

2.4 Input data

Aside from estimated source levels of pile driving, the main model inputs for the noise propagation model were bathymetry, water temperature and salinity (used to compute sound speed), and the acoustic properties of the seabed sediments.

Bathymetric data in UTM30N projection at 90 m resolution was provided to Cefas by Moray West. These data show that through the Moray West Site the water depth varies from a minimum of approximately

35 m near the northern boundary with Moray East to a maximum of 54 m near the southern limit of the Site.

Typical seawater temperatures in the Moray West Site are between about 6°C in February and 14°C in August. A balanced choice of 8°C was used for the modelling, which is the water temperature used for modelling in the EIA.

The acoustic properties of the seabed sediments were used to construct a geoacoustic model of the seafloor. These properties were derived from the seabed core data by correlating the core sediment information with published acoustic properties of various sediment types (Hamilton 1980).

2.5 Piling profiles

A drivability assessment and driving-induced fatigue analyses at the OSPs monopile locations has been undertaken to inform the hammer selection and identification of location-specific installation risk and fatigue damage. Pile driving profiles have been determined for characteristic best estimate (BE) soil parameters, using a Menck MHU 4400S hammer with a constant blow count and a hammer energy ramp-up. Table 2-2 presents summary statistics of the expected piling profiles: minimum and maximum hammer energies used, duration of soft-start (piling with ~10% of the maximum hammer energy), duration of the ramp-up (increase in hammer energy up to maximum hammer energy used in the profile) and duration of the whole sequence, as well as number of blows used. Piling profiles for the two locations used for modelling are illustrated graphically in Figure 2-2.

A blow count of 50 blows per 25 cm was used to simplify the modelling to a worst-case scenario as a higher maximum hammer energy is generally needed than with 80 blows per 25 cm, despite both locations having a low refusal risk. For modelling, blow rate was set to 28 blows per minute up to 20 m penetration depth, and then changed to 32 blows per minute up to the final penetration depth.

Modelling was also conducted with the two OSPs being installed consecutively within a 24-hour period. The highest impact resulted from the scenario of pile driving at location OSP 2 (M11) first followed by pile driving at OSP 1 (E06) and therefore this scenario has been used for the impact assessment.

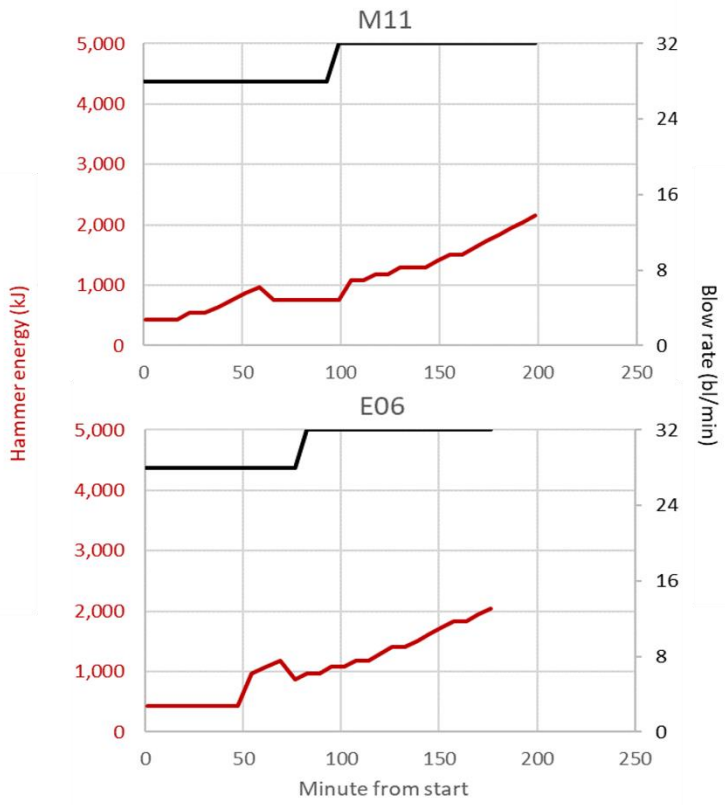


Figure 2-2 Piling profiles for the two OSPs monopile foundation locations OSP 2 (M11) and OSP 1 (E06), showing hammer energy (red) and blow rate (black) over time.

Table 2-2 Summary statistics of the piling profiles used for the marine mammal impact assessment.

Parameter	Locations	
	OSP 1 (E06)	OSP 2 (M11)
Refusal risk	low	low
Minimum hammer energy (kJ)	432	432
Maximum hammer energy (kJ)	2,050	2,158
Duration of soft start (min)	47.4	16.9
Duration of ramp-up (min)	128.9	181.5
Total piling duration (min)	176.3	198.4
Total number of blows	5,337	5,978

2.6 Metrics modelled and assessment criteria

2.6.1 Metrics

Three noise metrics were modelled for assessing auditory injury and disturbance ranges:

1. Peak sound pressure level (SPL_{peak}): SPL_{peak} was estimated for the initial and maximum hammer energies to assess instantaneous permanent threshold shift (PTS) risk at the start of piling and during piling;
2. Cumulative sound exposure level (SEL_{cum}): SEL_{cum} was considered over a 24-hour period based on the piling profiles presented in Table 2-1 and Figure 2-2, assuming one or both OSP monopile foundations are installed during the 24 hour period to assess risk of cumulative PTS for harbour porpoise and minke whale;
3. Single strike sound exposure level (SEL_{ss}): SEL_{ss} was based on the maximum hammer energy of the respective piling sequence to inform assessment of risk of disturbance in bottlenose dolphin and minke whale.

2.6.2 Marine Mammal Assessment Criteria

2.6.2.1 Permanent Threshold Shift (PTS) Assessment

For marine mammals, the risk of PTS was assessed using the updated Southall criteria (Southall et al. 2019). The Southall thresholds are based on a dual criteria approach to assess instantaneous and cumulative PTS.

Permanent Threshold Shift (PTS) has been assessed for harbour porpoise and minke whale considering both instantaneous and cumulative PTS. See Section 2.6.2.1.1.1 (Instantaneous PTS) and section 2.6.2.1.1.2 (Cumulative PTS) in Appendix C of the original Moray West PS for details on the thresholds, methods, sensitivities, and assumptions used. The impulsive noise PTS-onset thresholds for harbour porpoise and minke whale are given in Table 2-3.

Table 2-3 PTS-onset thresholds for impulsive noise for harbour porpoise and minke whale (Southall et al. 2019).

Species	Functional hearing group	Instantaneous PTS threshold Unweighted SPL_{peak} (dB re 1 µPa)	Cumulative PTS thresholds Weighted SEL_{cum} (dB re 1 μPa^2s)
Harbour porpoise	Very high frequency cetacean	202	155
Minke whale	Low frequency cetacean	219	183

2.6.2.1.1 Precaution in PTS assessment with emphasis on cumulative PTS

The use of the current PTS-onset thresholds to determine PTS impact ranges is a conservative approach for both the instantaneous as well as the cumulative PTS. There is considerable uncertainty associated with the estimation of PTS impact ranges, especially for cumulative PTS impact ranges. The precaution inherited in the PTS assessment is discussed in detail in section 2.6.2.1.2 of Appendix C of the original Moray West PS. To demonstrate the conservatism of the cumulative PTS impact assessment and the magnitude of the conservatism, a worked example is provided in section 3.1.3 of Appendix C of the original Moray West PS. This demonstration has been repeated for the OSPs monopile foundations and presented in this Addendum to Appendix C.

To estimate the magnitude of the conservatism, one or more of the following four assumptions have been considered (as also described in Appendix C of the original Moray West PS).

2.6.2.1.1.1 Conservatism A: PTS-threshold is based on PTS-onset level (PTS of 6 dB)

Scientific evidence: PTS-onset (a PTS of 6 dB) is predicted to cause only a very small predicted effect on survival or fertility in relation to piling noise (Booth and Heinis 2018). For harbour porpoise, the expert elicitation predicted a similar small effect on survival or fertility for a PTS of 18 dB in adult females (Booth and Heinis 2018).

Assumption applied: It is still conservative if the PTS-threshold will be increased by 1 dB.

2.6.2.1.1.2 Conservatism B: Adoption of the Equal Energy Hypothesis.

Scientific evidence: Experiments of Kastelein et al. (2021) with California sea lions showed that a reduction of the duty cycle from 100% to 90% reduced their temporary threshold shift (TTS) to an amount that allows for an increase in PTS-threshold of 2 to 5 dB.

Experiments of Kastelein et al. (2014) with a harbour porpoise exposed to 1-second-long sonar pulses showed at a duty cycle of 25% (3 second silent period) a reduced TTS compared to a 100% duty cycle that allows for an increase in PTS-threshold of 3 to 5 dB. At a duty cycle of 50% (1 second silent period) the resulting TTS reduction would allow for a 2 to 3 dB increase in PTS-threshold. While these experiments were done with non-impulsive sound, a duty cycle of 25% and a silent period of 1.5 second is comparable to what is expected during piling at Moray West (using a blow rate of 28 and 32 blows per minute and assuming a 0.5-second-long pile strike).

Assumption applied: The PTS-threshold can be increased at least by 2-3 dB to account for the evidence that the equal energy hypothesis is false.

2.6.2.1.1.3 Conservatism C: Piling sound received by an animal is impulsive throughout the exposure

Scientific evidence: Impulsive sound loses its impulsive character with increasing distance to the sound source (Hastie et al. 2019, Martin et al. 2020). Impulsive sound becomes increasingly less harmful in terms of auditory injury as impulsive characteristics of the signal are reduced (Hamerick et al. 2007, in Martin et al. 2020). The PTS-onset threshold must therefore lie between the PTS-onset for impulsive sound and non-impulsive sound if an animal is exposed to sound with decreasing impulsiveness. In this worked

example, such impact range will consequently lie between the maximum cumulative PTS impact range (assessed with noise thresholds for impulsive sound) and the impact range assessed with noise thresholds for non-impulsive sound (which, for Minke whale, is an LF-weighted SEL of 199 dB re 1 µPa²s). The non-impulsive threshold is not reached in the worst-case scenario for Minke whale, and therefore 0 km.

Assumptions applied: Impulsive sound becomes fully non-impulsive in the Moray Firth at 25 km (following a conservative estimate proposed in Southall 2021). This estimate is based on calculations done for Appendix C of the PS.

A minke whale swimming away from the pile site will experience TTS with a growth rate of impulsive sound while at distances shorter than 25 km (which is still a conservative assumption given that the impulsive sound becomes increasingly less harmful), and experience a growth rate of non-impulsive sound at distances longer than 25 km.

A TTS of 40 dB leads to PTS-onset, and the sound levels leading to a 40 dB TTS are considered the PTS-onset threshold (following the methodology as applied by Southall et al. (2019).

PTS-onset thresholds increase with increasing distance to the sound source once the animal starts to cross the 25 km contour while being exposed to piling sound.

The threshold obtained for the direction away from the pile location with the maximum impact range is valid for all directions away from the sound source (which is a conservative approach).

2.6.2.1.1.4 Conservatism D: Piling profiles are modelled with a constant conversion factor.

Scientific evidence: Noise monitoring during the installation of monopiles at offshore wind farms in UK waters showed a relationship between hammer energy and sound exposure level that can only be explained with a varying conversion factor (CF; see Appendix C of the original Moray West PS for more detail). Were the same levels to be modelled at Moray West, conversion factors of 0.5 to 10 and above were to be used.

Since the conversion factor is variable, modelling with a constant 10% is considered unrealistic, leading to an overly precautionary estimate in most, if not all cases. It is not yet known for monopiles which factors influence the conversion factor, while for pin piles, the length of the pile in the water column seems to be the major influencing factor (Thompson et al. 2020).

Assumption: For illustration purposes, the assumption in this worked example is that the results of a constant 4% are likely more realistic than those of a constant 10%, resulting in a 4 dB difference between the modelled sound exposure levels (Note that there is a 10 dB difference between conversion factors 1% and 10%, and a 13 dB difference between 0.5% and 10%).

2.6.2.2 Behavioural Disturbance Assessment

The methodology used to assess behavioural disturbance impacts resulting from the installation of the OSPs monopiles followed the same methodology applied in Appendix C of the original Moray West PS (including the sensitivities for each species) and was based on the current best practice methodology

which incorporates the application of a dose-response approach rather than a fixed behavioural threshold approach as used in earlier assessments.

The dose-response relationship adopted in this assessment was developed by Graham et al. (2017) using data on harbour porpoises collected during Phase 1 of piling at the Beatrice Offshore Wind Farm (Figure 2-3). Using the dose-response relationship derived from the initial piling events for all piling events in this impact assessment is considered to be precautionary, as evidence obtained during construction of the Beatrice Offshore Wind Farm showed that porpoise responses are likely to diminish over the construction period (Graham et al. 2019). A detailed discussion and explanation on this dose-response relationship is given in the MORL (Moray Offshore Renewables Ltd.) ES (Environmental Statement): Technical Appendix 7.3 D[4].

In the absence of species-specific data on bottlenose dolphins or minke whales, the harbour porpoise dose-response function has been adopted for all cetaceans. This is likely to be highly precautionary as porpoise are considered to be particularly responsive to anthropogenic disturbance (e.g. Brandt et al. 2013, Thompson et al. 2013, Tougaard et al. 2013, Brandt et al. 2018, Sarnocinska et al. 2019, Thompson et al. 2020, Benhemma-Le Gall et al. 2021). Therefore, the number of individuals of these other species predicted to experience behavioural disturbance is considered to be an over-estimate.

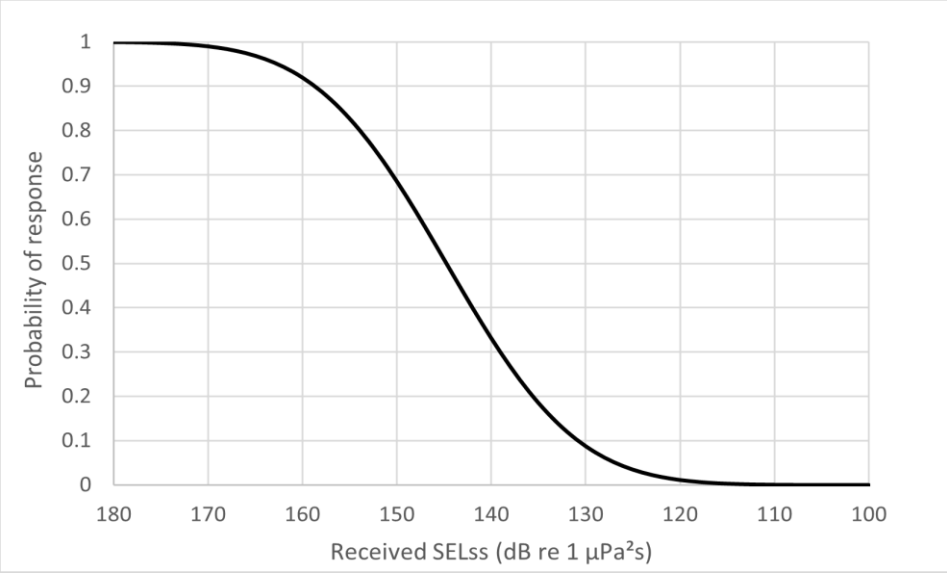


Figure 2-3 Dose-response relationship for harbour porpoise developed by Graham et al. (2017) used for all cetacean in this assessment.

[4] https://www.morayeast.com/application/files/3915/8014/0965/Appendix-7-3-D-Behavioural-Responses-to-Noise.pdf

2.6.2.3 Density and Management Unit Data

Since the Moray West EIA was submitted in 2018, there have been updates to marine mammal management unit (MU) abundance estimates as well as species-specific density surfaces. However, there have not been any changes since the PS Appendix C and this addendum. The changes since the EIA submission for all species are detailed in Appendix C of the original Moray West PS (section 2.6.2.3) and the numbers relevant for the species assessed in this addendum are summarized in Table 2-4.

2.6.3 Assessment of potential effects

The criteria for determining the significance of effects is a two-stage process that involves defining the sensitivity of the receptors and the magnitude of the impacts. This addendum uses the same criteria used in the original Moray West PS (Appendix C section 2.6.4) and also follows the criteria used in the Moray West EIA Report 2018 – Volume 2, Chapters 8 and 9.

2.6.4 Population modelling

Population modelling has been conducted previously for bottlenose dolphin, harbour porpoise, harbour and grey seal (See Appendix C section 3.2 of the original Moray West PS for details on iPCoD and a summary of those results and section 2.4.6.1 below for a comparison of iPCoD parameters used for bottlenose dolphin impact assessments). The interim Population Consequences of Disturbance (iPCoD) framework (Harwood et al. 2014, King et al. 2015) has been used to estimate the potential population consequences of the predicted amount of disturbance and auditory injury resulting from piling at Moray West.

While iPCoD modelling has been used to understand the potential impact of piling on the Southern Trench Marine Protected Area (MPA) (see section 2.6.5), no population modelling has been conducted to understand the population consequences of piling at the OSPs monopile locations as part of this addendum. As piling will occur over one or two days only, with low hammer energies, and with the implementation of mitigation measures, it is highly unlikely to result in any significant population level impacts. iPCoD modelling will be used to assess potential impacts to all marine mammal species once the piling scenarios and schedule is available for the wind farm.

2.6.5 Analysis of potential impacts to the Southern Trench Marine Protected Area (MPA)

The Conservation and Management Advice “Southern Trench MPA” from December 2020 (NatureScot 2020) details how the Conservation Objectives of the site may be furthered, or their achievement hindered, covering a range of activities including pile driving.

According to Annex 1 of the Conservation and Management Advice “Southern Trench MPA”, the site-specific advice for minke whales is as follows:

> 1) Minke whale in the Southern Trench MPA are not at significant risk from injury or killing.
>
> Any activities that take place within or outside the MPA that could kill or injure minke whale in the MPA should be considered in an assessment. An important consideration is whether any killing or

injury would result in reduced densities within the site, from which recovery to above average densities cannot be expected.

2) Conserve the access to resources (e.g., for feeding) provided by the MPA for various stages of the minke whale life cycle and conserve the distribution of minke whale within the site by avoiding significant disturbance.

Significant disturbance is defined as resulting in:

- the contribution to long term decline in the use of the MPA
- changes to the distribution on a continuing or sustained basis
- changes to the behaviour such that it reduces the ability of the species to feed efficiently, breed or survive.

3) Conserve the extent and distribution of any supporting feature upon which minke whale is dependent (i.e., their prey) and conserve the structure and function of supporting features, including processes to ensure minke whale are healthy and not deteriorating.

For any assessment the advice highlights that the type of disturbance, its timing, duration, and the area over which minke whales are likely to be impacted are important to be considered. "Significant disturbance" should be interpreted as disturbance that leads to a non-recoverable change in distribution. Effects of activities lasting beyond the average generation time are more likely to constitute significant disturbance.

To assess whether there is likely to be a significant effect on the Conservation Objectives of the MPA, potential impacts were assessed as follows:

1) Auditory injury:

The number of minke whales potentially at risk of auditory injury (PTS) within the MPA was estimated by determining the overlap between the MPA area and the auditory injury impact area with the maximum overlap with the MPA (section 3.1) and calculating the number of animals within the overlap. A qualitative assessment on whether the risk of auditory injury will reduce the absolute densities within the site, from which recovery to above average densities cannot be expected, is provided.

2) Significant disturbance:

A quantitative assessment of the area over which minke whales are likely to be disturbed was conducted. The MPA area within which disturbance is expected was estimated with the help of the dose-response relationships from Graham et al. (2017) and single strike SEL contours decreasing in 5 dB steps from 180 to 120 dB re 1 μPa^2s, following the method as used for the assessment of disturbance (Section 2.6.2.2 in Appendix C of the original Moray West PS). As there is no fixed noise limit at which significant disturbance of minke whale will occur, the size of the area affected within the MPA was weighted with the probability of response expected by an animal within that area based on the Graham et al. (2017) dose-response function. Therefore, an area within which sound levels lead to a higher probability of response makes a

proportionally larger contribution to the "effective disturbance area" than an area with lower sound levels leading to a lower probability of response. The use of a fixed noise threshold approach, by contrast, would assume that the whole area encircled by the threshold is considered as the area where all animals will be disturbed, although not all animals within that area may be disturbed. Outside the disturbance area, no animal is considered to be disturbed, which may also be unrealistic. The use of a dose-response approach is, therefore, considered to be a more realistic approach.

The assessment of the significance of this disturbance was conducted qualitatively, considering the effective disturbance area as well as the timing and duration over which minke whales are likely to be impacted, and whether this may lead to a long-term decline in the use of the MPA or a non-recoverable change in distribution. An evaluation was made on whether the effects will last beyond the average generation time of minke whale.

To assess whether behavioural changes will result in reduced ability of the species to feed, breed and survive, a highly conservative iPCoD model, assuming a closed population within the MPA was conducted. The size of the closed population was determined by intersecting the MPA boundaries with the summer density distribution map as used for the assessment of disturbance (Section 2.6.2.2 in Appendix C of the PS).

3) Potential impacts to minke whale prey:

Minke whales are known to take a wide range of pelagic shoaling small fish species, and the main prey species are the lesser sandeel (*Ammodytes marinus*), sprat (*Sprattus sprattus*), herring (*Clupea harengus*) and mackerel (*Scomber scombrus*) (Anderwald et al. 2007). Potential impacts of noise on prey because of piling the OSPs is discussed in the Fish Impact Assessment for the OSPs[5]. Impacts to the physical benthic substrate (and any associated impacts to the prey) within the MPA is not a factor when considering impacts of piling at the wind farm site.

2.6.6 Comparison with EIA Report 2018 and Appendix C of the Original Moray West PS

Throughout this addendum, results of the current assessment are compared with those of the Moray West EIA Report 2018 and Appendix C of the original Moray West PS. Each assessment is based on different piling scenarios and schedules, using the most recent assessment methodologies. Any changes to the assessment in Appendix C of the original Moray West PS compared to the EIA are clearly explained in Appendix C and not repeated in this addendum. Comparisons between the 2018 EIA, Appendix C of the original Moray West PS and this Addendum to Appendix C are shown in Table 2-4. The table also includes an indication if the differences reflect improvement in the realism of the assessment scenarios and what the effect was on the conservatism in the assessment.

[5] Moray Offshore Windfarm (West) Limited, Piling Strategy: Fish Impact Assessment for the Offshore Substation Platforms, 12/10/2022

Table 2-4 Comparison of the parameters and assumptions used for the assessments from the 2018 EIA and Appendix C of the original Moray West PS. For the OfTI PS the same parameters and assumptions apply unless given in brackets and italics.

(↑: increase, ↓: decrease, : ↔ (most likely) similar, ?: effect unknown).

Parameter/Assumption	2018 EIA	Original Moray West PS (*OfTI PS*)	Realism	Conservatism
OWF parameters				
Piling or Modelling locations	Located within Moray West site boundary	Actual piling locations	↑	↔
Foundations	Jacket, pin-pile, or monopile	Monopile only	↑	?
Maximum piling period	10 months	8 months (*2 days*)	↑	↓
Maximum hammer energy	5,000 kJ	5,000 kJ (*2,158 kJ*)	↔	↔
Soft-start hammer energy	1,000 kJ	550 kJ (*432 kJ*)	↑	↓
Concurrent piling	Yes	No	↑	↓
Consecutive piling	No	Yes	↑	↑
Number of piling days	87 (assuming 1 vessel) 44 (assuming 2 vessels)	62 (assuming 1 vessel) (*1-2*)	↑	↓
Noise modelling				
Source model	CF=0.5% and 1%	CF=4% and 10%	↑	↑
Propagation model	CEFAS		no change	
Input data	CEFAS		no change	
Piling profiles	Hypothetical	Based on drivability assessment	↑	↓
Auditory injury noise thresholds	NMFS 2016	Southall et al. 2019	no change	
Swim speeds for SELcum modelling	Species specific		no change	

Table 2-4 Comparison of the parameters and assumptions used for the assessments from the 2018 EIA and Appendix C of the original Moray West PS. For the OfTI PS the same parameters and assumptions apply unless given in brackets and italics.

(↑: increase, ↓: decrease, : ↔ (most likely) similar, ?: effect unknown).

Parameter/Assumption	2018 EIA	Original Moray West PS (*OfTI PS*)	Realism	Conservatism
Swim speed restrictions	Stop swimming after 25 km	Continue swimming after 25 km	↑	↓
Disturbance thresholds	Dose-response relationships		no change	
Assessment criteria				
Significance criteria	Impact magnitude and receptor sensitivity matrix		no change	
Management Units				
Harbour seal	1,304 Moray Firth MU	3,447 Moray Firth & North Coast and Orkney MUs combined	↑	↓
Grey seal	3,534 Moray Firth MU	58,322 Moray Firth & North Coast and Orkney MUs combined	↑	↓
Bottlenose dolphin	195	224	↑	↔
Harbour porpoise	345,373	346,601 159,632 (UK portion)	↑	↔
Minke whale	23,528	20,118 10,288 (UK portion)	↑	↔
Density surfaces				
Harbour seal	Bailey (2017)	Carter et al. (2020)	↑	↔
Grey seal	Russell et al. (2017)	Carter et al. (2020)	↑	↔
Bottlenose dolphin	Revised from Moray Offshore Renewables Ltd (2012)		no change	
Harbour porpoise	Moray Offshore Renewables Ltd (2012)		no change	
Minke whale	Paxton et al. (2014) & SCANS III, Paxton et al. (2016)	Paxton et al. (2014) scaled to SCANS III density, SCANS III	↑	↔

Table 2-4 Comparison of the parameters and assumptions used for the assessments from the 2018 EIA and Appendix C of the original Moray West PS. For the OfTI PS the same parameters and assumptions apply unless given in brackets and italics.

(↑: increase, ↓: decrease, : ↔ (most likely) similar, ?: effect unknown).

Parameter/Assumption	2018 EIA	Original Moray West PS (*OfTI PS*)	Realism	Conservatism
iPCOD modelling (full example of updated numbers for bottlenose dolphin given in Table 2-5)				
Model version	4.1	5	↑	?
Transfer function version	4.1 for all species but 3 for minke whale	5 for harbour porpoise & seal species 4.1 for bottlenose dolphins 3 for minke whale	↑ for harbour porpoise & seal species	↓for harbour porpoise & seal species
Population vital rates	Default recommendations	Revised based on Sinclair et al. (2020)	↑	?

Table 2-5 Comparison of the iPCoD parameters for bottlenose dolphin population modelling in the EIA and Appendix C of the PS.

Assessment	Model version	Transfer function version	# of days piling	Max # animals disturbed	Population size estimate	Population vital rates					
						Calf survival	Juvenile survival	Adult survival	Fecundity	Age of independence	Age of first reproduction
EIA	4.1	4.1	44	22	195	0.9	0.94	0.9497	0.3	2	9
Appendix C of the PS	5	4.1	62	55	224	0.925	0.962	0.98	0.24	3	9

2.6.7 Comparison with 2018 RIAA

Harbour seal and bottlenose dolphin were the focal species in the Report to Inform Appropriate Assessment (RIAA) conducted in 2018. iPCoD modelling results from the 2018 RIAA were compared with those obtained in the original Moray West PS assessment, and presented in the Appendix C of the original Moray West PS (section 3.5). As described in section xx, the seal impact assessment has not been updated

in the current assessment, and iPCoD modelling for bottlenose dolphin will be updated and presented in the Wind Farm PS Addendum. Therefore no further updates are required in this section.

3 Marine Mammal Assessment Results

3.1 Auditory injury

3.1.1 Instantaneous PTS

The instantaneous PTS impact ranges for harbour porpoise for the soft-start and full hammer energy at OSP 2 (M11) are presented in Table 3-1 and compared to results from the EIA and Appendix C of the original Moray West PS. For the EIA, instantaneous impact ranges were not calculated at 1% CF for soft start and full hammer energies. Therefore, results of the assessment with a 0.5% CF are presented. At 4% CF and 10% CF, the impact ranges for the OSPs monopile locations are smaller than those modelled in the original Moray West PS, but larger than those assessed in the EIA.

Given lower hammer energies required for the installation of the OSPs monopiles and resulting smaller impact zones compared with the original Moray West PS, the assessment of a **negligible** magnitude and **minor adverse** impact for harbour porpoise made in Appendix C of the original Moray West PS remains valid for the installation of the OSPs monopiles.

Table 3-1 Harbour porpoise: Instantaneous PTS impact ranges (m) for soft start and full hammer energy compared across the three assessments conducted to date.

Assessment	Hammer Energy (kJ)		Instantaneous PTS impact ranges (m)					
			0.5% CF		4% CF		10% CF	
Monopile	soft start	full hammer energy	soft start	full hammer energy	soft start	full hammer energy	soft start	full hammer energy
EIA	…	5,000	….	335	….	….	….	….
Appendix C of the PS	550	5,000	….	….	300	1,503	672	2,595
Addendum to Appendix C	432	2,158	….	….	240	897	579	1,595

The instantaneous PTS impact ranges for minke whale for the soft-start and full hammer energy at OSP 2 (M11) are presented in Table 3-2 and compared to results from the EIA and Appendix C of the original Moray West PS. As mentioned above, for the EIA, instantaneous impact ranges were not calculated at 1% CF for soft start and full hammer energies. Therefore, results of the assessment with a 0.5% CF are

presented. At 4% CF and 10% CF, the impact ranges for the OSPs locations are smaller than those modelled in the original Moray West PS, but larger than those assessed in the EIA.

Given lower hammer energies required for the installation of the OSPs monopiles and resulting smaller impact zones compared with the original Moray West PS, the assessment of a **negligible** magnitude and **minor adverse** impact for minke whale made in Appendix C of the original Moray West PS remains valid for the OSP piling.

Table 3-2 Minke whale: Instantaneous PTS impact ranges (m) for soft start and full hammer energy compared across the three assessments conducted to date.

Assessment	Hammer Energy (kJ)		Instantaneous PTS impact ranges (m)					
			0.5% CF		4% CF		10% CF	
	soft start	full hammer energy	soft start	full hammer energy	soft start	full hammer energy	soft start	full hammer energy
EIA	…	5,000	….	<50	….	….	….	….
Appendix C of the PS	550	5,000	….	….	29	46	144	354
Addendum to Appendix C	432	2,158	….	….	24	39	75	183

For harbour porpoise, in the absence of any mitigation or any response to the presence of construction activities prior to the first strike at full hammer energy, the probability of an individual being within the instantaneous PTS-onset zone at full hammer energy is 1 (100%) (Table 3-3). This likelihood is reduced to zero assuming the deployment and activation of an Acoustic Deterrent Device (ADD) for a minimum of 8 minutes. Assuming a swimming speed of 1.4 m/s and the animal swimming directly away from the pile location, an animal starting at the piling location will exit the impact zone after 19 minutes, long before the end of the soft start preceded by the ADD activation period, which combined last >24 minutes.

The probability of a single individual minke whale being within the 183 m impact radius for instantaneous PTS-onset at full hammer energy is negligible (~0.1%) (Table 3-3). This probability estimate is considered to be an overestimate since it assumes that animals have not moved out of the impact radius in response to the presence of construction vessel and during the soft start period, which is extremely unlikely.

The likelihood of an animal actually being in these PTS-onset impact ranges is therefore negligible, given that in reality they will have already been displaced by the presence of construction vessels, the ADD mitigation, the soft-start and the ramp-up before the first strike at full hammer energy is reached.

In summary, the impact of instantaneous PTS at soft-start and for full hammer energy is assessed as being of **negligible** magnitude for both species.

Table 3-3 Probability of an animal being present with the instantaneous PTS-onset impact zone at full hammer energy.

Species	Instantaneous PTS-onset range (km)	Density (#/km^2)	Area of circle containing 1 individual (km^2)	Radius of circle containing 1 individual (km)	Probability of animal being present
Harbour porpoise	*1.595*	*1.46875**	*0.7*	*0.47*	*1*
Minke Whale	*0.183*	*0.00950ł*	*105.3*	*5.79*	*<0.00105*
*Maximum density cell within the Moray West array area, łSCANS III density estimate					

3.1.2 Cumulative PTS

3.1.2.1 1 pile per day

Table 3-4 and Table 3-5 present the maximum cumulative PTS-onset impact ranges (i.e. the distance at which an animal is safe to start fleeing at the start of piling without the risk of experiencing PTS) and numbers of animals within the impact area for harbour porpoise and minke whale at the OSP 2 (M11). As outlined in Section 2.6.2.1.1, these are based upon a series of highly conservative assumptions.

In the EIA, cumulative PTS ranges were calculated with a 1% CF for both single and concurrent installation of pin-piles and monopiles. Impact ranges and numbers of animals at both 4% and 10% CF are lower for this assessment than those presented in the Appendix C of the original Moray West PS for single piling for harbour porpoise (Table 3-4) and lower or equal for minke whales (Table 3-5) with the exception of the maximum impact range at 10% CF which is slightly larger than the low refusal risk location modelled in the original Moray West PS. However, the numbers of animals impacted remained the same.

The conservative estimates for harbour porpoise cumulative PTS-onset impact ranges for OSP 1 (E06) ranges from <500 m at 4% CF with less than one animal potentially within the impact area to over 2.4 km at 10% CF (Figure 3-1) with 11 animals potentially within the impact area (Table 3-4).

Assuming a displacement of the animals out of a 2 km radius due to construction vessel noise before installation, an 8-minute period of ADD activation would be sufficient to displace them out of the maximum impact range (see section 3.1.2.3).

It is important to note that a series of pulses is likely to elicit a smaller threshold shift in mammals compared to a single pulse of the same cumulative SEL, and considering the blow rate required for the installation of monopiles at the Moray West Site, the cumulative PTS-onset threshold for harbour porpoise is expected to be 2-3 dB higher than the Southall et al. (2019) threshold (see conservatism B, Section

2.6.2.1.1.2 for more detail). This would lead to a considerably lower impact range and reduced number of animals within the impact area.

Considering the implementation of mitigation measures as outlined in section 3.1.2.3 alone, the impact of cumulative PTS on harbour porpoise can be judged to be of **negligible magnitude** and **not significant** in EIA terms.

A maximum of 4 minke whales are expected to be within the worst-case cumulative PTS impact zone (0.02% MU, 0.04% UK portion) as shown in Figure 3-2. Reducing conservatism A and B alone (see section 2.6.2.1.1.2 for more detail) leads to the use of an increased noise threshold of 3-4 dB, which results in smaller impact areas with less than 1 animal within it, not even considering conservatism C and D. This impact is assessed as of **negligible** magnitude **not significant** in EIA terms, as the effect is on such a small proportion of the population (even without considering a reduction of conservatism) that there is expected to be no change to the population size or trajectory.

Table 3-4 Comparison of cumulative PTS impact ranges for harbour porpoise in a single piling scenario among the three assessments conducted to date.

Assessment	1% CF		4% CF		10% CF	
	Impact range (m)	# animals	Impact range (m)	# animals	Impact range (m)	# animals
EIA – single pin pile	<200	….	….	….	….	….
EIA – single monopile	289	….	….	….	….	….
EIA – concurrent pin piles	<200	….	….	….	….	….
EIA – concurrent monopiles	324	….	….	….	….	….
Original Moray West PS – low risk monopile modelling locations	….	….	965	3	2,792	25
Original Moray West PS – high risk monopile modelling locations	….	….	1,986	10	4,825	72
OfTI PS – OSPs monopile locations	**….**	**….**	**448**	**<1**	**2,429**	**11**

Table 3-5 Comparison of cumulative PTS impact ranges for minke whale in a single piling scenario among the three assessments conducted to date. (S – summer and NS – non-summer).

Assessment	1% CF		4% CF		10% CF	
	Impact range (m)	# animals	Impact range (m)	# animals	Impact range (m)	# animals
EIA – single pin pile	28,000	S: 10, NS: 1	….	….	….	….
EIA – single monopile	2,000	<1	….	….	….	….
EIA – concurrent pin piles	38,000	S: 88, NS: 11	….	….	….	….
EIA – concurrent monopiles	32,000	S: 6, NS< 1	….	….	….	….
Original Moray West PS – low risk monopile modelling locations	….	….	4,972	S<1, NS<1	15,162	S: 4, NS<1
Original Moray West PS – high risk monopile modelling locations	….	….	29,922	S: 10, NS<1	33,606	S: 39, NS: 4
OfTI PS – OSPs monopile locations	**….**	**….**	**4,759**	**S<1, NS<1**	**28,500**	**S: 4, NS<1**

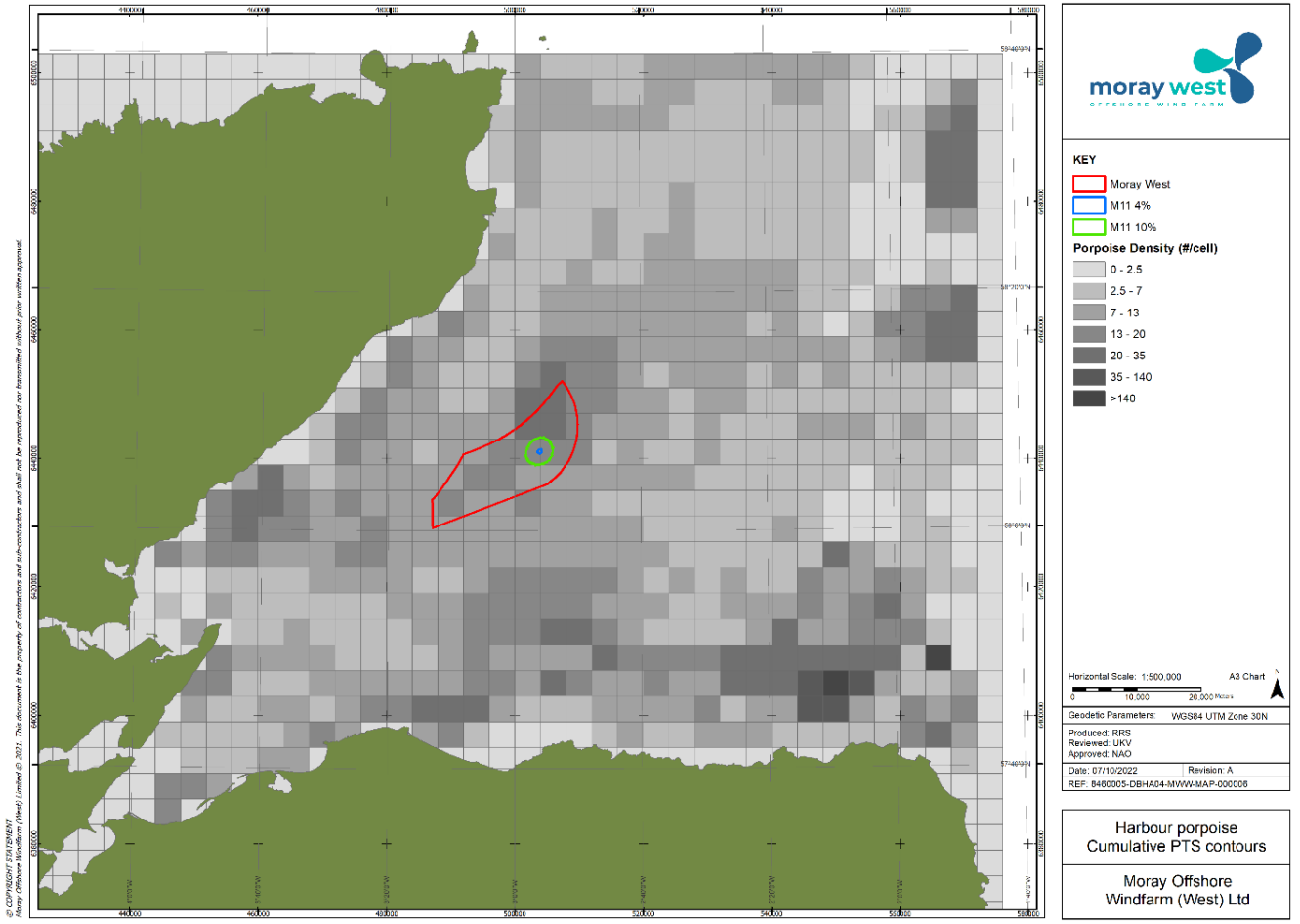


Figure 3-1 Harbour porpoise cumulative PTS-onset impact ranges for OSP 2 (M11), featuring different conversion factor scenarios.

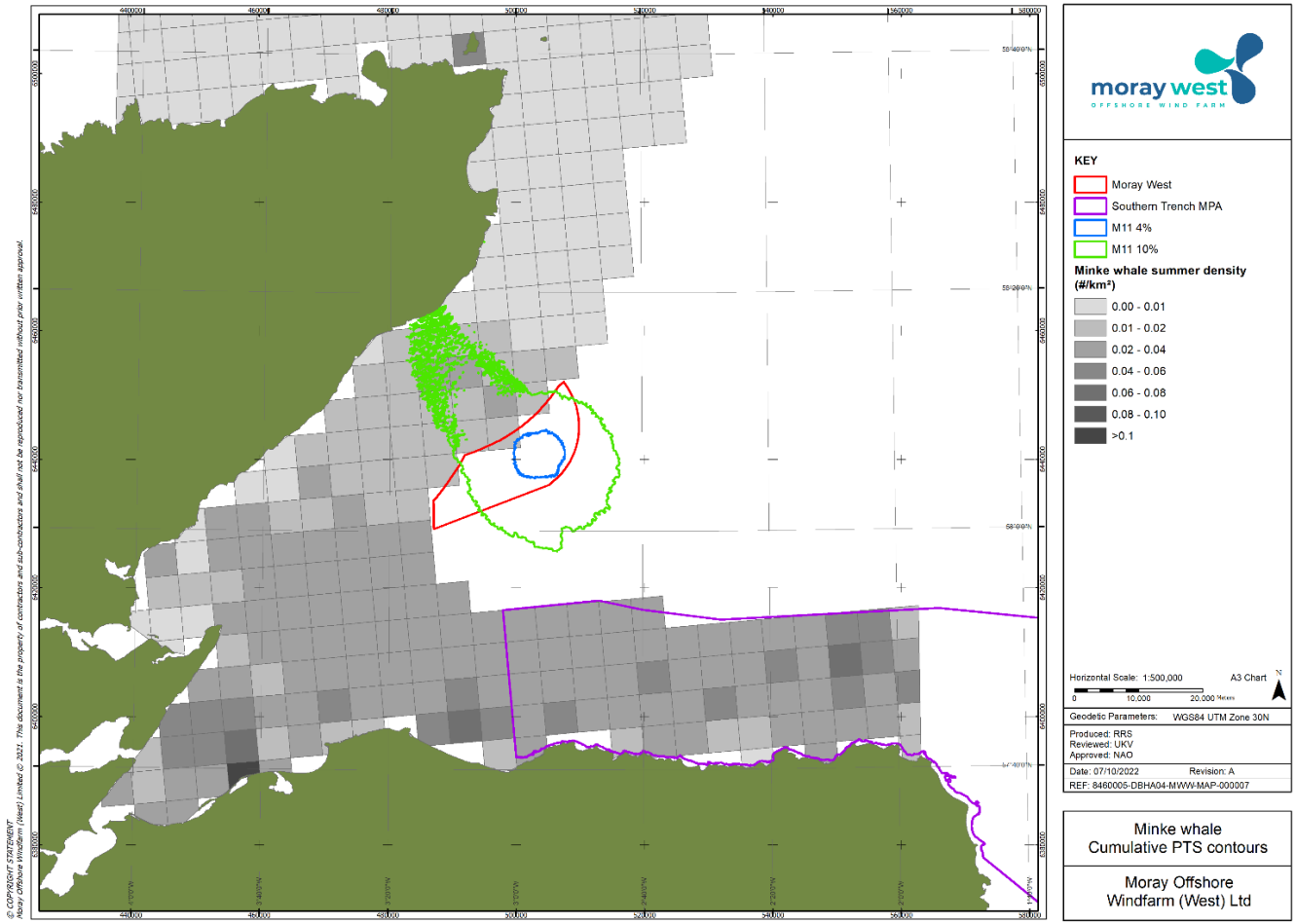


Figure 3-2 Minke whale cumulative PTS impact ranges for OSP 2 (M11), featuring different conversion factor scenarios.

3.1.2.2 2 piles per day

Assessment of cumulative PTS for consecutive (or sequential) piling was not presented in the EIA and was only presented in the original Moray West PS with a 10% CF. For both harbour porpoise (Table 3-6) and minke whale (Table 3-7), the maximum cumulative PTS impact ranges are slightly larger at 10% CF in the Addendum to Appendix C compared to those presented in Appendix C of the original Moray West PS, but the numbers of animals impacted is the same for minke whales (Table 3-7) and lower for harbour porpoise (Table 3-6).

The conservative cumulative PTS-onset impact ranges for the installation of two consecutive monopiles for harbour porpoise reach 3,827 m (Figure 3-3), equating to 18 harbour porpoise (Table 3-6). As stated previously, it is likely that harbour porpoise would have already been displaced by the presence of construction vessels before piling commences (Benhemma-Le Gall et al. 2021). Therefore, assuming a displacement of the animals out of a 2 km radius prior to the start of piling, a 13 minute ADD activation period would be sufficient to displace them out of the maximum SEL_{cum} impact range (see Section 3.1.2.3).

Considering conservatism B (Section 2.6.2.1.1.2), leading to a considerably lower impact range and number of animals within the impact area as well as a minimum of 13 minutes of ADD activation period as mitigation measures (see Section 3.1.2.3 for further explanations), the impact of cumulative PTS on harbour porpoise is therefore of **negligible magnitude** and **not significant** in EIA terms.

For minke whale, the conservative cumulative PTS-onset impact ranges for the installation of two consecutive monopiles reach 48,065 m (Figure 3-4), equating to either 6 whales (summer density) or <1 whale (non-summer density) (Table 3-7), (a maximum of 0.03 % MU, 0.06 % UK portion).

Reducing the conservatism A and B alone (see Section 2.6.2.1.1.2 for more detail), leads to the use of an increased noise threshold of 3-4 dB, which results in smaller impact areas with <2 whales (3 dB) / <1 whale (4 dB) impacted in the summer, not even considering conservatism C and D, and less than 1 animal in non-summer months. The impact as assessed is considered of **negligible** magnitude and **not significant** in EIA terms, as the effect is on such a small proportion of the population (even without considering a reduction of conservatism) that there is expected to be no change to the population size or trajectory.

Although these maximum worst-case cumulative PTS-onset impact ranges for minke whales are large, these occur very directionally to the South-West and North-West (Figure 3-4). Most impact ranges range between 10 and 25 km. The impact as assessed is considered as **negligible** magnitude and **not significant** in EIA terms, as the effect is on such a small proportion of the population when considering the conservative cumulative PTS estimates (6 animals is 0.06% of the UK portion and 0.03% of the MU), that there is expected to be no change to the population size or trajectory.

Table 3-6 Comparison of cumulative PTS impact ranges for consecutive piling scenarios for harbour porpoise among the three assessments conducted to date.

Assessment	1% CF		4% CF		10% CF	
	Impact range (m)	# animals	Impact range (m)	# animals	Impact range (m)	# animals
EIA	….	….	….	….	….	….
Appendix C of the original Moray West PS	….	….	….	….	3,552	28
Addendum to Appendix C	**….**	**….**	**1,165**	**2**	**3,827**	**18**

Table 3-7 Comparison of cumulative PTS impact ranges for consecutive piling scenarios for minke whale among the three assessments conducted to date. (S – summer and NS – non-summer).

Assessment	1% CF		4% CF		10% CF	
	Impact range (m)	# animals	Impact range (m)	# animals	Impact range (m)	# animals
EIA	….	….	….	….	….	….
Appendix C of the original Moray West PS	….	….	….	…	34,743	S: 6, NS< 1
Addendum to Appendix C	**….**	**….**	**21,557**	**S<1, NS<1**	**48,065**	**S: 6, NS< 1**

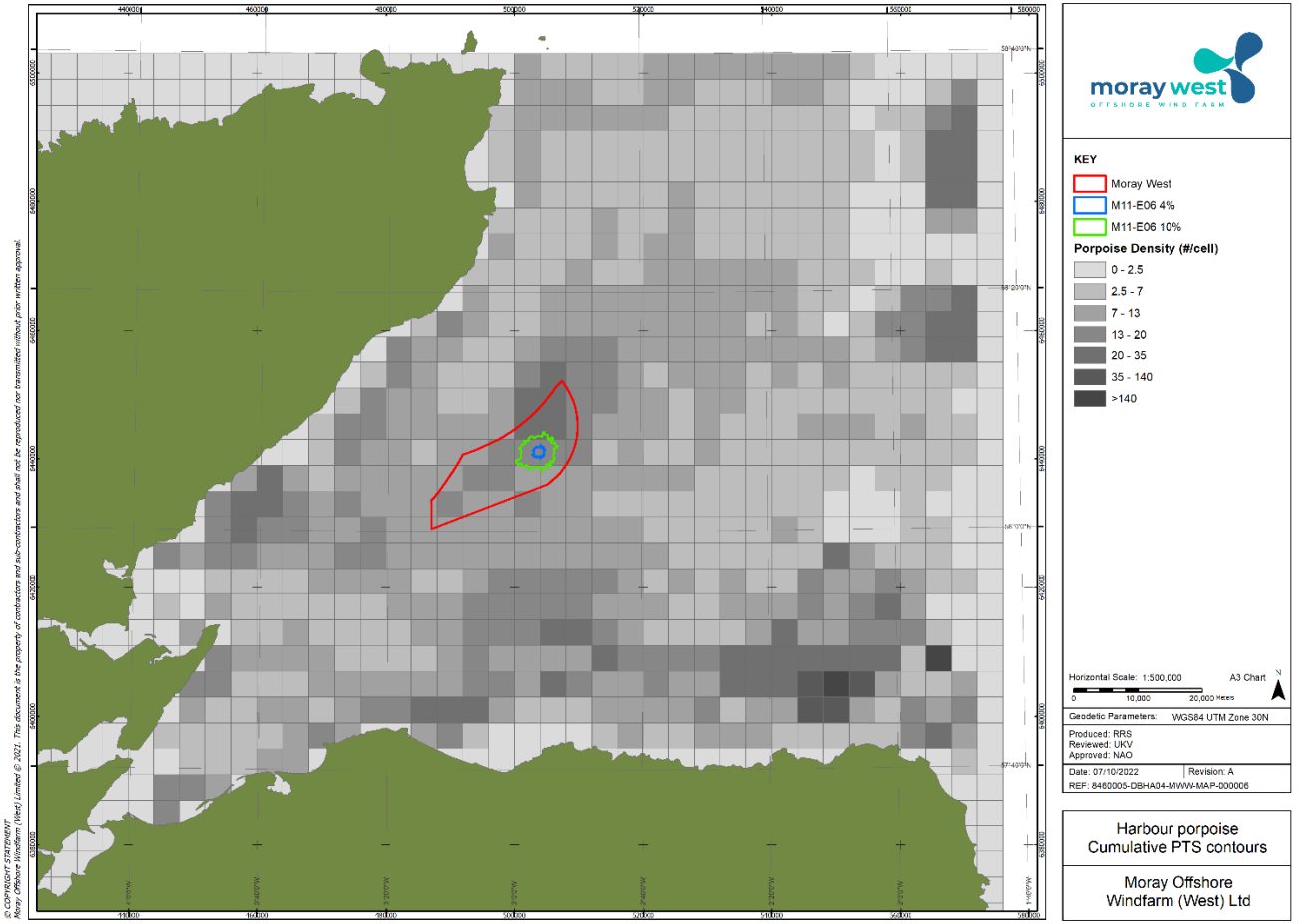


Figure 3-3 Harbour porpoise cumulative PTS-onset ranges for sequential piling at OSP 2 (M11) followed by OSP 1 (E06), given different conversion factor scenarios.

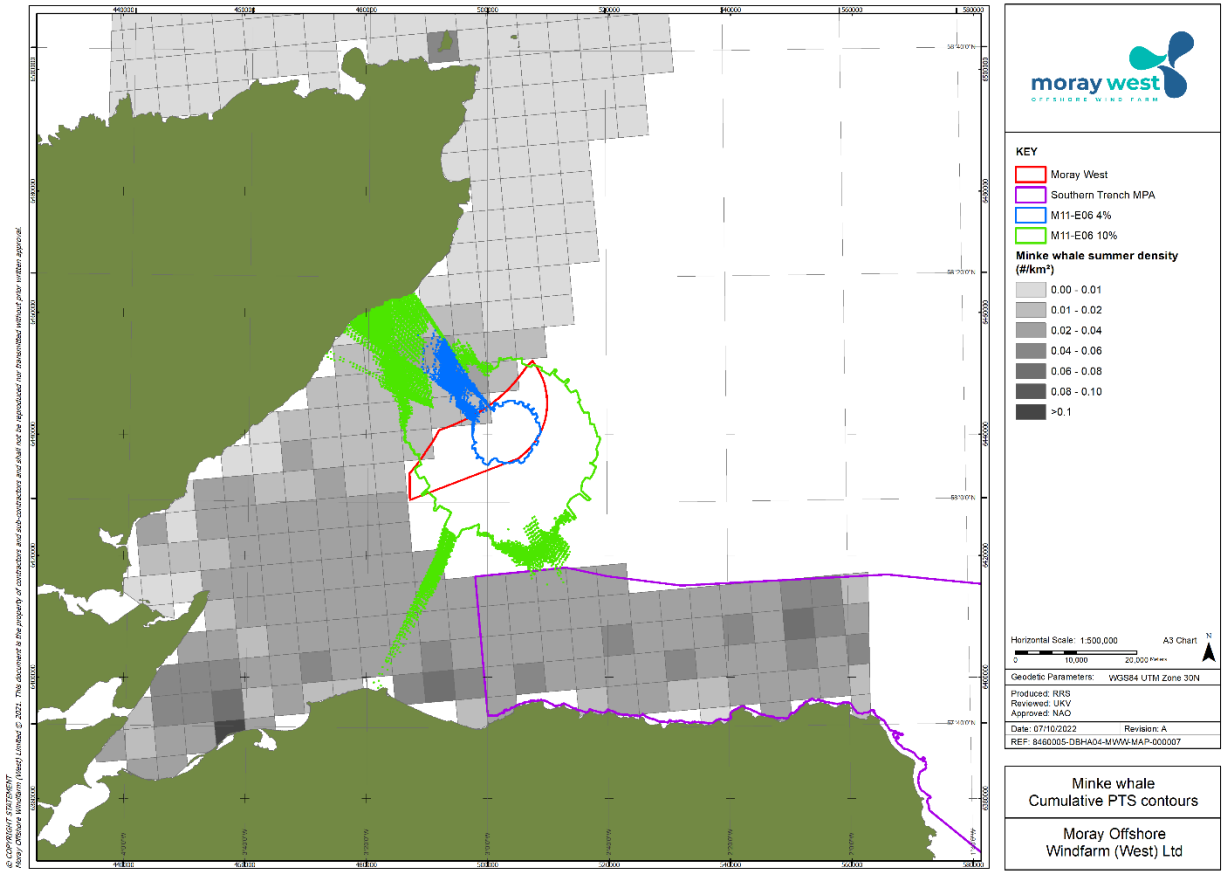


Figure 3-4 Minke whale cumulative PTS-onset impact ranges for sequential piling at OSP 2 (M11) followed by OSP 1 (E06) given 4% and 10% conversion factor scenarios.

3.1.2.3 ADD deployment and activation

For harbour porpoise, the deployment and activation of an ADD is considered a viable mitigation measure to reduce the risk of PTS to negligible. In this addendum, we modelled the effect on the cumulative PTS impact ranges of the ADD activation for a period of 8 and 13 minutes before piling started

Table 3-8 illustrates the results (assuming a swimming speed of 1.4 m/s) on the PTS-onset impact ranges for OSP monopile foundations piling scenarios. For a single piling event, an 8 minute ADD activation is considered sufficient to mitigate the risk of PTS, considering that most harbour porpoises would have already been displaced out of a 2 km radius by the presence of construction vessels (Benhemma-Le Gall et al. 2021). For consecutive piling events, a 13 minute ADD activation would result in a 2.8 km impact radius, which is outside the 2 km radius the animals are displaced from by the presence of construction vessel. However, considering the conservatism inherent in the cumulative PTS impact range calculations (see Section 2.6.2.1.1), the application of a less conservative noise threshold, raised by 1 to 4 dB, excluding conservatism A and B, lead to minimal impact ranges. Alone, a 1 dB rise in the noise threshold leads to an impact range of 1.9 km, i.e., below the 2 km construction vessel displacement range (Table 3-8).

Using an ADD activation period of a minimum of 8 minutes for single piling events and a minimum of 13 minutes for concurrent piling events as mitigation measures, will reduce the impact of cumulative PTS to **negligible** magnitude for harbour porpoise.

Table 3-8 Maximum cumulative PTS impact ranges (m) for harbour porpoise based on the piling profiles shown in Table 2-2 and a constant CF of 10% for OSP 2(M11) and when followed consecutively by OSP 1 (E06) with ADD mitigation measures and threshold changes included.

Location	Unmitigated	8 min ADD	13 min ADD	13 min ADD and 1dB threshold increase	13 min ADD and 2dB threshold increase	13 min ADD and 3dB threshold increase	13 min ADD and 4dB threshold increase
OSP 2 (M11)	2,329	1,702	1,344	…	…	…	…
OSP 2 (M11) then OSP 1 (E06)	3,827	3,326	2,846	1,900	1,323	601	<45

3.2 Disturbance

The original Moray West PS considered potential impacts from disturbance for harbour porpoise, minke whale, bottlenose dolphin, and grey and harbour seals given a piling schedule for the full wind farm and included population modelling with iPCoD to assess impacts (See Appendix C section 3.2 of the original Moray West PS). The results of that overall assessment indicated impacts of **minor adverse magnitude** for all species from disturbance which, when considering species-specific sensitivities to disturbance, were determined to be not significant in EIA terms. Given the much lower number of monopiles and hammer energies to be used for the OSPs monopile installation (Table 2-2) no change to the overall assessment is anticipated. However, one of the comments received from the consultation of the original Moray West PS recommended remodelling the disturbance assessment for bottlenose dolphin and minke whale; therefore, these have been remodelled and revised estimates of disturbance impacts are provided in this addendum (see Consultation Log). iPCoD modelling was not conducted for any species as part of this addendum as a revised piling schedule for the wind farm is not available at the time of writing the OfTI PS and the number of animals impacted for the worst-case scenario at this time and using the piling schedule for the OSPs monopiles alone is unrealistic and highly unlikely to reveal significant impacts.

3.2.1 Bottlenose dolphin

Impact assessment results for the maximum levels of disturbance to bottlenose dolphins expected for the installation of a monopile for the location OSP 1 (E06) are given in Table 3-9and shown in Figure 3-5. The impact resulted in a prediction of 41 bottlenose dolphins being disturbed on a single day of piling (this represents 18.44% of the East Coast Scotland MU). Figure 3-6 shows the isopleths modelled for a CF of 4% at location OSP 1 (E06) for the behavioural impact assessment for completeness.

Although iPCoD modelling has not been conducted for this part of the assessment, in the original PS Moray West PS, with a piling schedule for the full wind farm, only a slight discernible impact was estimated (see Appendix C of the original Moray West PS section 3.2.2).

Impacts of disturbance on bottlenose dolphins from piling at OSP 1 (E06) at 4% CF are similar to those for the 2018 EIA (Table 3-9). At 10% CF, the impacts are closer to those presented in the original Moray West PS. There are several places where a conservative approach is adopted in the impact assessment (such as the use of a harbour porpoise dose-response relationship to assess the number of dolphins being disturbed (see section Behavioural Disturbance Assessment), and the use of a 10% CF and maximum hammer energy for determining the dose-response contours). iPCoD models of the disturbance impacts in both the 2018 EIA and the original Moray West PS showed no significant population impacts. Given the impacts of disturbance from piling at the OSPs monopile locations are intermediate to these other two assessments, there is no reason to change the magnitude or overall impact assessment for disturbance to bottlenose dolphins at this time, and therefore it remains **minor adverse** (Table 3-16).

The magnitude of impact of disturbance from pile driving for bottlenose dolphins is assessed as **low**, whereby the impact is short-term and temporary behavioural effects are expected in only a small

proportion of the population, resulting in potential impacts to individual vital rates but only over the short-term, such that the population trajectory would not be altered.

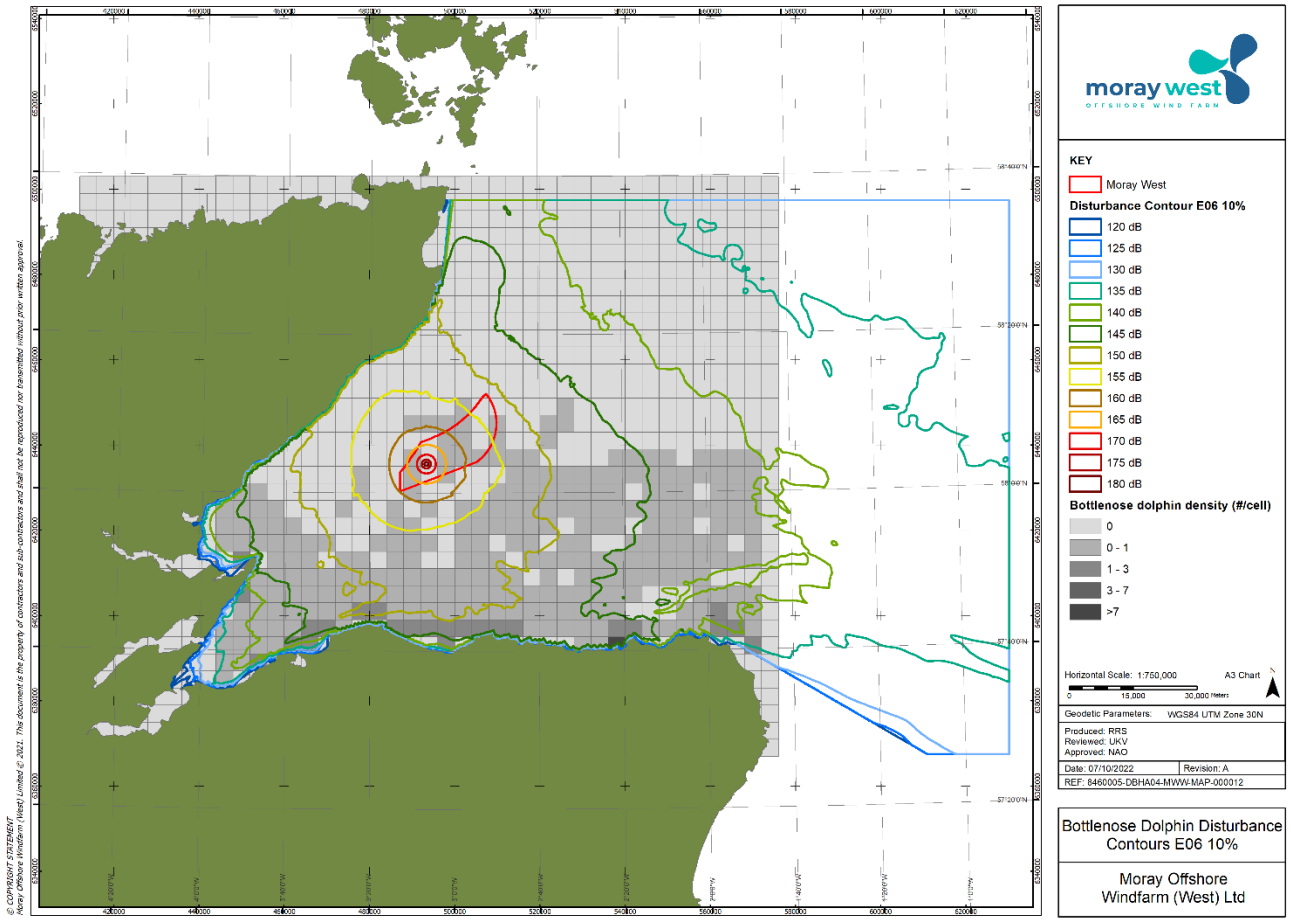


Figure 3-5 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location OSP 1 (E06) overlain the bottlenose dolphin distribution. CF = 10%, hammer energy = 2,050 kJ.

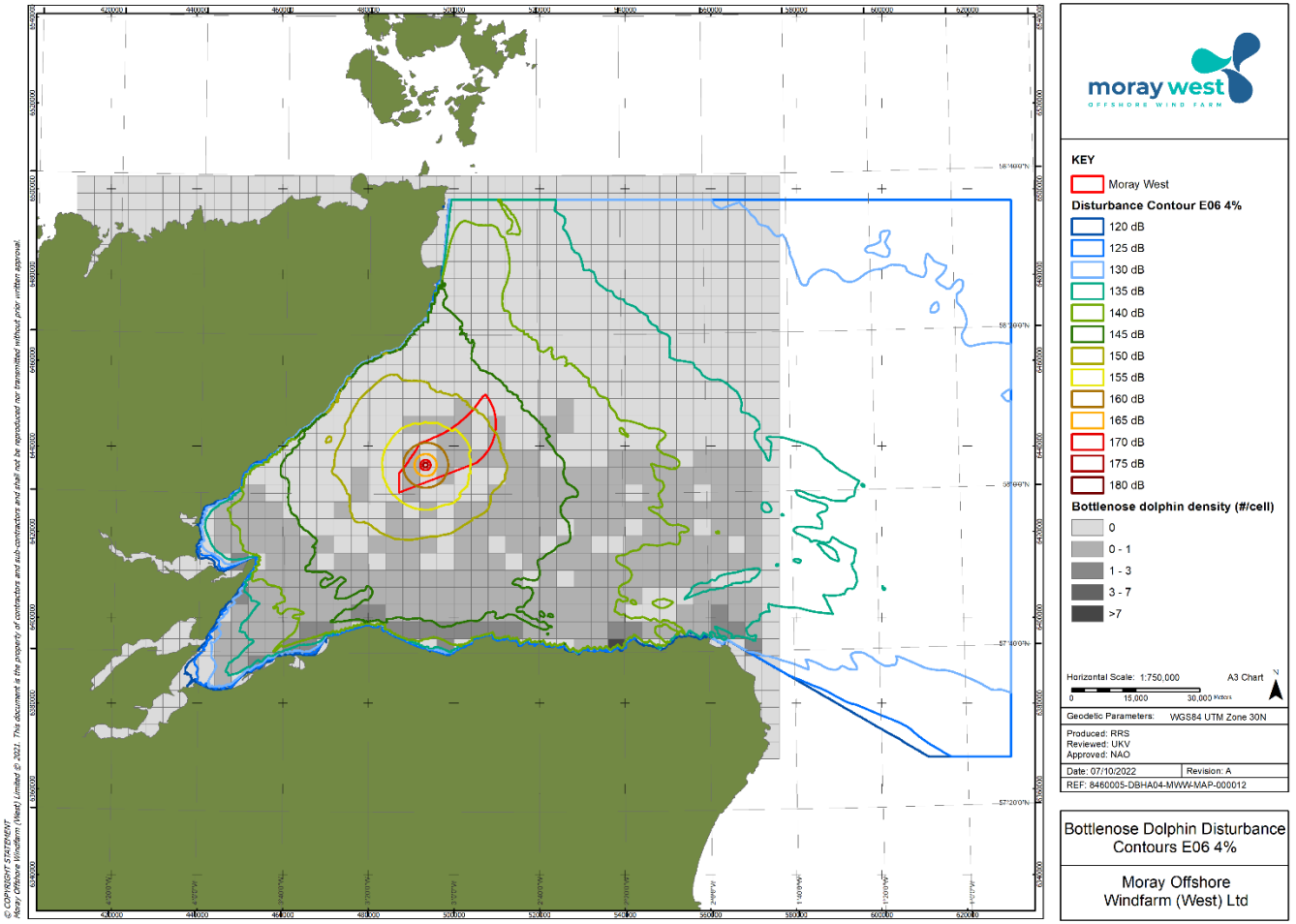


Figure 3-6 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location OSP 1 (E06) overlain the bottlenose dolphin distribution. CF = 4%, hammer energy = 2,050 kJ.

Table 3-9 Comparison of the potential disturbance to bottlenose dolphins resulting from worst case scenarios in the EIA, original piling strategy, and current OfTI addendum impact assessments.

Assessment	Hammer Energy (kJ)	1% CF		4% CF		10% CF	
		# Dolphins	% MU	# Dolphins	% MU	# Dolphins	% MU
EIA - concurrent monopiles installation	5,000	22	11.28%	….	….	….	….
Appendix C of the original Moray West PS	5,000	….	….	40	17.99%	55	24.60%
Addendum to Appendix C	2,050	….	….	27	11.80%	41	18.40%

3.2.2 Minke whale

The maximum level of disturbance to minke whales was predicted to occur for a 10 % CF when installing the OSP 2 (M11) with a maximum hammer energy of 2,158 kJ (Figure3-7) (see CF of 4 % for comparison in Figure 3-8). This resulted in a prediction of 84 minke whales being disturbed on a single day of piling, if the piling took place in summer (Jul, Aug, Sep) (0.82% of the UK portion of the MU) (Table 3-10).

Given the very low proportion of the entire MU predicted to be impacted, and the short duration of piling at the OSPs monopile locations (Table 2-2), the magnitude of impact of disturbance from pile driving for minke whales is assessed as **negligible** for the entire MU, since there is expected to be no change to the population size or trajectory. When considering the non-summer density estimates, a maximum of 5 minke whales are predicted to be disturbed on a single day of piling (0.05 % UK portion). This is also of **negligible** magnitude for the entire MU, since there is expected to be no change to the population size or trajectory. iPCoD modelling will be conducted to assess potential disturbance effects in the Wind Farm Piling Strategy Addendum once the full piling schedule is available.

Disturbance of minke whales from piling at OSP 2 (M11) in this assessment is lower than the 2018 EIA assessed impact as well as the original PS at both high and low refusal risk locations modelled and both 4% and 10% CFs (Table 3-10). iPCoD model has not been undertaken for this assessment as the 2 days of piling are highly unlikely to result in a significant population-level impact. However, iPCoD modelling will be included for minke whale in the Wind Farm PS Addendum, to better assess the significance of potential disturbance from piling. The overall impact assessment for minke whales from piling at the two OSPs monopile locations remains unchanged from the original PS (Table 3-16).

Table 3-10 Comparison of the potential disturbance to minke whales resulting from worst case scenarios in the EIA, original PS, and current OfTI PS impact assessments.							
Assessment	**Hammer Energy (kJ)**	**1% CF**		**4% CF**		**10% CF**	
		# Animals	**% MU**	**# Animals**	**% UK MU**	**# Animals**	**% UK MU**
EIA - concurrent monopiles installation	5,000	S: 111 (Paxton et al. 2016)	0.47%	….	….	….	….
Appendix C of the original Moray West PS	5,000 (high refusal risk)	….	….	S: 135 NS: 11	S: 1.31% NS: 0.11%	S: 186 NS: 14	S: 1.81% NS: 0.14%
	2,432 (low refusal risk)	….	….	S: 95 NS: 8	S: 0.93% NS:0.08%	S: 141 NS: 11	S: 1.37% NS: 0.11%
Addendum to Appendix C	2,158	….	….	S: 53 NS: 3	S: 0.51% NS:0.03%	S: 84 NS: 5	S: 0.82% NS: 0.05%

3.2.3 Limitations of disturbance assessment

The limitations of the assessment of disturbances remain the same as presented in Appendix C of the original Moray West PS, Section 3.2.6.

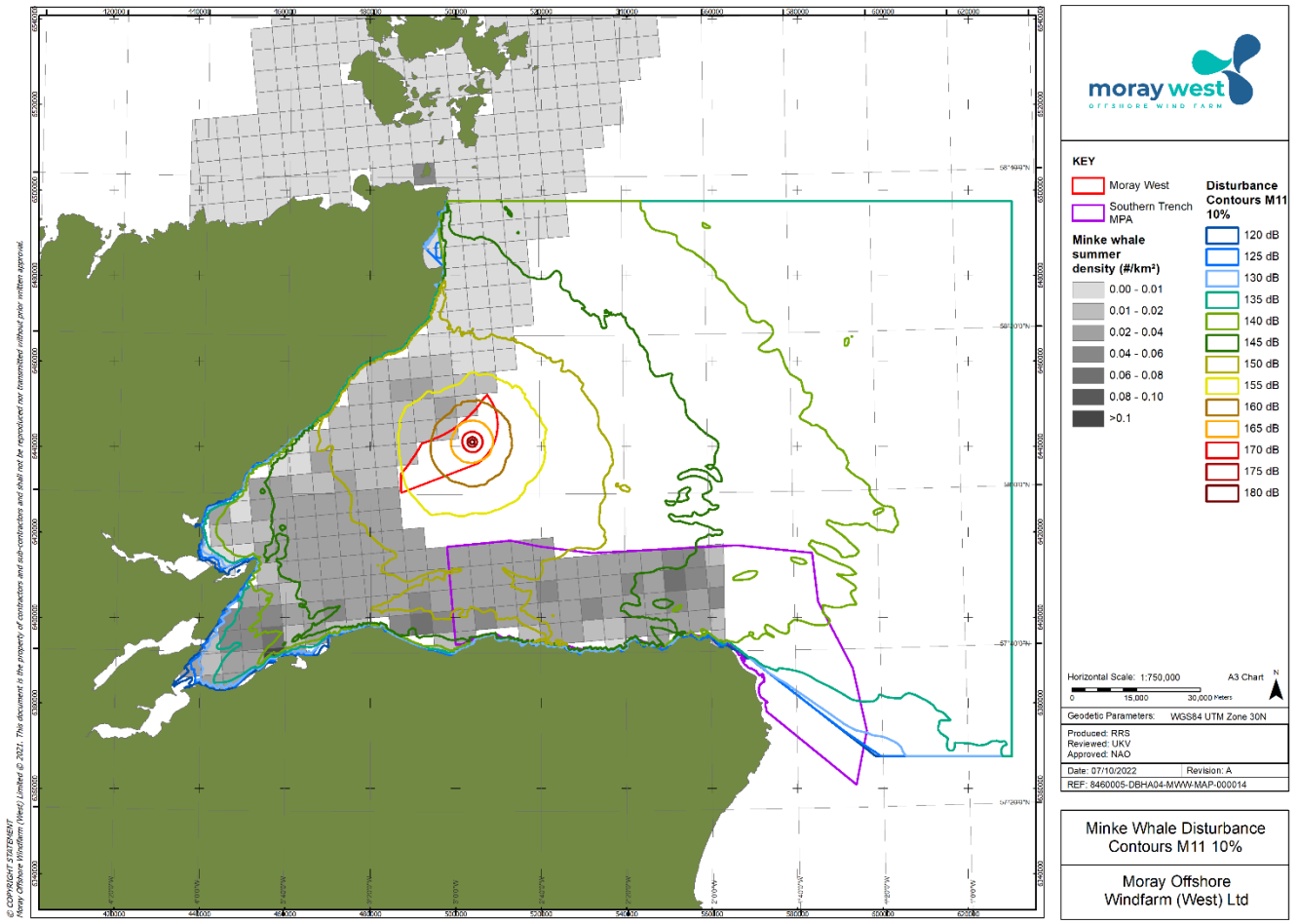


Figure 3-7 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location OSP 2 (M11) overlain the minke whale distribution. CF = 10%, hammer energy = 2,158 kJ.

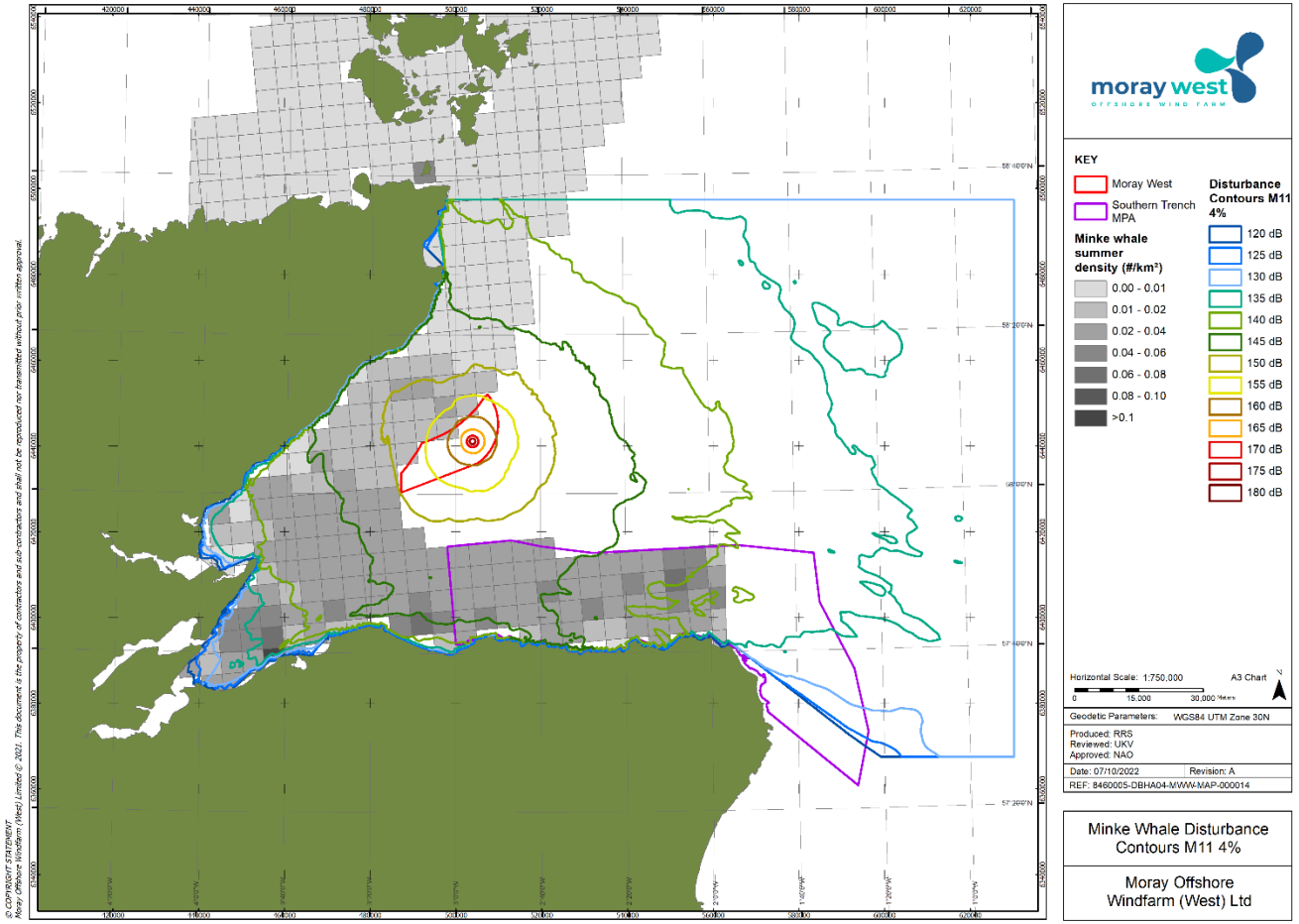


Figure 3-8 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location OSP 2 (M11) overlain the minke whale distribution. CF = 4%, hammer energy = 2,158 kJ.

3.3 Analysis of potential impacts to the Southern Trench MPA

3.3.1 Number of animals within the MPA

Based on the most recent densities derived for this assessment (Table 2-4), 41 animals are estimated to use the MPA in the summer and 1 animal in non-summer months.

3.3.2 Auditory injury

The only overlap between the Southern Trench MPA and predicted impacts for auditory injury relate to the cumulative PTS impact assessment for consecutive piling events with a CF of 10% (Table 3-7), where just 0.06 km^2 of the maximum impact area from piling at the OSPs locations overlaps with the MPA (green contour in Figure 3-4). This overlap results in <1 minke whale within the MPA boundary being at risk of PTS. Even without accounting for the conservatisms in this impact assessment (see section 2.6.2.1.1), this can be considered as no significant risk of auditory injury for animals within the MPA and is not expected to reduce the absolute density of animals within the site.

3.3.3 Disturbance

There was no overlap between the MPA and SEL_{SS} contours above 145 dB at 4 % CF and above 150 dB at 10% CF. The MPA area within which disturbance is expected totalled 26% with a 4% CF (Table 3-1 and Figure 3-8) and 37% with a 10% CF (Table 3-12 and Figure 3-7).

Table 3-11 Calculation of the % MPA within which minke whale are potentially disturbed using the Graham et al. (2017) dose-response function for location OSP 2 (M11) and a 4% CF.

dB level	DR	Size of contour area overlapping with MPA (km^2)	Size of area between successive contours overlapping with MPA (km^2)	Effective disturbance area (km^2)
145	0.5090	521.1	521.1	265
140	0.3312	1,183.5	662.4	219
135	0.1852	1,874.3	690.8	128
130	0.0878	2,125.0	250.7	22
125	0.0349	2,229.6	104.6	4
120	0.0115	2,254.7	25.1	0
	Total		**2,254.7**	**639**
			% of MPA	**26%**

Table 3-12 Calculation of the % MPA within which minke whale are potentially disturbed using the Graham et al. (2017) dose-response function for location OSP 2 (M11) and a 10% CF.

dB level	DR	Size of contour area overlapping with MPA (km²)	Size of area between successive contours overlapping with MPA (km²)	effective disturbance area (km²)
150	0.6849	344.9	344.9	236
145	0.5090	1,052.7	707.8	360
140	0.3312	1,808.9	756.2	250
135	0.1852	2,095.3	286.4	53
130	0.0878	2,218.3	122.9	11
125	0.0349	2,252.6	34.3	1
120	0.0115	2,257.7	5.1	0
	Total		**2,257.7**	**912**
			% of MPA	**37%**

Despite using a conservative 10% CF and the dose-response function for harbour porpoise (in the absence of empirical data for minke whales) less than 40% of the MPA is expected to be disturbed on a given piling day. This equates to 8 animals being disturbed on a given day in summer or approximately 20% of the animals expected to be in the MPA in those months. For the maximum 2 days of piling, this would result in a non-significant (a recoverable change in distribution) impact, especially when considering the generation time of minke whale is 22.1 years (Taylor et al. 2007).

Although no significant impact is likely to occur as result of two days of piling at the OSPs monopile location foundations, as 37% of the MPA area may be impacted, an initial analysis was conducted to assess the possible impacts of a worst-case scenario. A highly conservative iPCoD model has been conducted, assuming a closed population of 41 animals present in the MPA year-round with 8 animals disturbed on each of 62 piling days - the piling schedule presented in the original Moray West PS (Table 2-3). Despite using a conservative 10% CF, the dose-response function for harbour porpoise, and the unrealistic scenario of a closed-population of animals present in the MPA year round, the iPCoD model reveal no significant long-term changes to the population (Table 3-13 and Figure 3-9). Although the model returns an initial population size of 36 animals rather than the 41 input, the key result is the lack of change in population size over the subsequent 25 years. Additional scenarios were run (e.g., with zero disturbance effects) to confirm that this change in initial population size is a quirk in the model when considering extremely small population sizes rather than a result of any disturbance to the population. Further

examination of the model will be conducted in case it might be applied to similar analyses of the Southern Trench MPA in the Wind Farm PS Addendum.

Table 3-13 Results of the iPCoD modelling, giving the mean MPA population size of minke whale for years up to 2042 for impacted and un-impacted populations, and the mean and median ratio between their annual growth rates.

Year	un-impacted pop mean	Impacted pop mean	Impacted as % un-impacted	Mean ratio of impacted:un-impacted annual growth rate	Median ratio of impacted:un-impacted annual growth rate
Start	36	36	100%	1	1
End 2028	36	36	100%	1	1
End 2033	36	36	100%	1	1
End 2038	36	36	100%	1	1
End 2043	36	36	100%	1	1

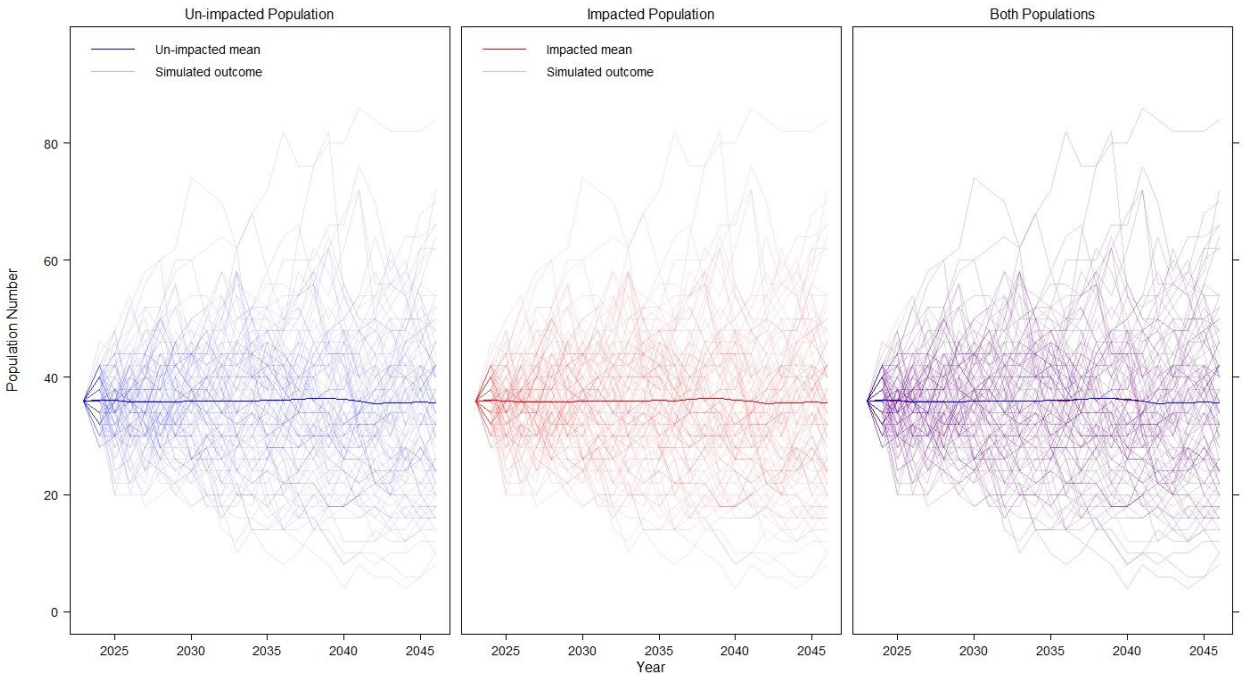


Figure 3-9 Simulated minke whale MPA population sizes for both the un-impacted and the impacted populations.

3.3.4 Prey availability

Piling at the OSPs monopile locations within the Moray West Site was assessed to have no impacts to the sandeel and herring prey of minke whales[6] and therefore is not expected to have any direct effects at the more remote MPA. No impacts within the MPA are expected to the structure and function of supporting features, i.e., the benthic substrate on which prey species rely, due to the piling at the Moray West Site.

3.3.5 Conclusions

We conclude that piling at the two OSPs monopile locations does not constitute a significant risk of auditory injury to minke whales and will not reduce absolute densities. Piling for the OSP installation will not result in significant disturbance as it will not contribute to a long-term decline in the use of the MPA by minke whale, or to changes in their distribution within the MPA on a continuing or sustained basis, nor to changes in behaviour that may reduce the ability of the species to feed efficiently, breed or survive. No significant impacts to prey are expected directly from piling or indirectly to the benthic substrate. Thus, OSP piling will not have a significant impact on the Southern Trench MPA.

3.4 Proposed mitigation measures

Based on the results of the marine mammal assessment detailed above, the following mitigation measures are proposed for the installation of the OSPs monopiles to reduce the risk of injury to negligible.

1. ADD deployment. An ADD-activation period prior to commencement of pile driving (soft start) of a minimum of 8 minutes for single piling events and 13 minutes for consecutive piling events, to reduce worst case impacts upon harbour porpoise.
2. Soft-start procedure with a maximum hammer energy of 432 kJ for a minimum of 17 minutes.
3. Ramp-up gradually until a suitable energy level is reached, to maintain a steady rate of pile penetration.

Details of the mitigation measures are provided within Addendum to Appendix D: Piling Mitigation Protocol..

3.5 Comparison to 2018 EIA and original Piling Strategy

The results presented in Appendix C of the original Moray West PS and this addendum are generally the same as those presented in the Moray West EIA Report 2018. All three concluded no significant effect of instantaneous or cumulative PTS-onset to any of the marine mammal species assessed when considering impacts against the entire MU and including the activation of an ADD (Table 3-14 and Table 3-15).

The proportion of the population impacted increases when considering only the UK portion of the population; however, as stated in Appendix C Section 2.6.2.3 of the original Moray West PS, there is no

[6] Moray Offshore Windfarm (West) Limited, OfTI Piling Strategy: Fish Impact Assessment.

biological reason to present the UK portion of the MU separately, and this was not done in the Moray West EIA Report 2018.

Despite changes to the MUs sizes, and some density surfaces between the Moray West EIA Report 2018 assessment and the assessments done for the original Moray West PS, the conclusion of no significant effect of behavioural disturbance to any marine mammal species is therefore still valid (Table 3-16).

Table 3-14 Comparison of the evaluation of sensitivity, magnitude, and impact of Instantaneous PTS on marine mammal species in the 2018 ES, Appendix C of the original Piling Strategy and this OfTI Addendum.

	2018 ES			Original Piling Strategy/OfTI Piling Strategy		
Species	**Sensitivity**	**Magnitude**	**Impact**	**Sensitivity**	**Magnitude**	**Impact**
Harbour porpoise	High	Negligible	Minor Adverse	High	Negligible	Minor Adverse
Bottlenose dolphin*	High	Negligible	Minor Adverse	High	Negligible	Minor Adverse
Minke whale	High	Negligible	Minor Adverse	High	Negligible	Minor Adverse
Grey seal*	Medium	Negligible	Negligible	Medium	Negligible	Negligible
Harbour seal*	Medium	Negligible	Negligible	Medium	Negligible	Negligible
*Species not re-assessed in the OfTI PS; original Moray West PS results apply.						

Table 3-15 Comparison of the evaluation of sensitivity, magnitude, and impact of cumulative PTS on marine mammal species in the 2018 EIA and this OfTI Piling Strategy. S = summer, NS = non-summer.						
	2018 ES			Original Piling Strategy/OfTI Piling Strategy		
Species	**Sensitivity**	**Magnitude**	**Impact**	**Sensitivity**	**Magnitude**	**Impact**
Harbour porpoise	High	Negligible	Minor Adverse	High	Negligible	Minor Adverse
Bottlenose dolphin*	High	Negligible	Minor Adverse	High	Negligible	Minor Adverse
Minke whale	High	Negligible	Minor Adverse	High	S: Negligible NS: Negligible	S: Minor adverse NS: Minor Adverse
Grey seal*	Medium	Negligible	Negligible	Medium	Negligible	Negligible
Harbour seal*	Medium	Negligible	Negligible	Medium	Negligible	Negligible
*Species not re-assessed in the OfTI PS, original Moray West PS results apply.						

Table 3-16 Comparison of the evaluation of sensitivity, magnitude, and impact of disturbance on marine mammal species in the 2018 EIA and this OfTI Piling Strategy. S = summer, NS = non-summer.						
	2018 EIA			Original Piling Strategy/OfTI Piling Strategy		
Species	**Sensitivity**	**Magnitude**	**Impact**	**Sensitivity**	**Magnitude**	**Impact**
Harbour porpoise*	Medium	Low	Minor Adverse	Medium	Low	Minor Adverse
Bottlenose dolphin	Medium	Low	Minor Adverse	Medium	Low	Minor Adverse
Minke whale	Medium	Negligible	Minor Adverse	Medium	S: Low NS: Negligible	Minor Adverse
Grey seal*	Low	Low	Minor Adverse	Low	Negligible	Minor Adverse
Harbour seal*	Medium	Low	Minor Adverse	Medium	Negligible	Minor Adverse
*Species not re-assessed in the OfTI PS; original Moray West PS results apply.						

3.6 Comparison to 2018 RIAA

iPCoD modelling for bottlenose dolphin will be updated with the full Wind Farm PS Addendum and results will be presented and discussed therein.

4 Fish Impact Assessment

4.1 Introduction

4.1.1 Background

The original Moray West PS was reviewed by NatureScot on the 11th of August 2022 who provided advice on the PS. Since consent was granted for the Moray West (in June 2019), there have been a number of changes to the design and assessment parameters / methods. Therefore, the advice by NatureScot considered specifically whether the conclusions regarding the Fish Impact Assessment (FIA) from the original Moray West PS agreed with the conclusions from the 2018 EIA and the Habitats Regulations Assessment (HRA) which were prepared in 2018 for the Moray West Offshore Wind Farm.

As such, this section provides an updated FIA for the Moray West OfTI PS which takes into consideration the advice provided by NatureScot (see Section 4.1.2 below). The FIA has also been summarised in Section 5 and Section 6.3 of the OfTI PS.

4.1.2 NatureScot Response on Piling Strategy

The following responses have been provided by NatureScot on the original Moray West PS, in particular the existing fish impact assessment:

- Underwater noise modelling has been conducted for fish impacts using Popper et al., (2014). We are content with this approach as in the absence of an alternative this remains the best framework currently. We note that for fish species, including Atlantic salmon, that it is likely to be the partical velocity (motion) component of the noise that has the greatest impact as opposed to the particle pressure (as used in Popper et al, 2014). Using pressure metrics, the PS highlights that for salmon and sea trout, that mortality impact range is 1.7 km; and the recoverable injury range is 5 km. These predictions cover a greater distance than might be expected.

- We request further supporting information on the predicted ranges of mortality and recoverable injury for Atlantic salmon and sea trout (collectively termed salmonids) to enable consideration if these considerable distances are realistic. Are there examples of similar monopile installation in other areas that can provide any insight, or are there examples from other industries?

- We request that the new predictions are compared to those in the 2018 Environmental Statement (ES) together with clarity on methods and assumptions in both models.

- There was only modelling presented for salmonid; we request clarification on this rationale, and detail on why herring and sandeels were not included. We also need assurance that the conclusions in the 2018 ES remain valid for these species and the updated piling and model parameters.

4.1.3 Scope of Fish Impact Assessment

As such the scope of works undertaken to update the FIA in line with advice provided by NatureScot as presented in **Section 1.2** above included the following:

- A review of the Moray West OSP Piling Strategy, in particular the number of the piles, size and seasonality to which piling will take place.
- A review of other OWF projects which have had a similar Piling Strategy and how this could be applied to the updated fish impact assessment for the Piling Strategy.
- A review of the Moray West Site and freshwater rivers entering the onshore area of the Development Site.
- A review of salmonid swim speeds and underwater noise impacts, in particular ranges of mortality and recoverable injury.
- A review of recent underwater noise modelling for the Piling Strategy undertaken by Cefas dated 22nd of September 2022. (see section below).
- Determining the updated noise thresholds / buffer zone predictions based on the above Cefas modelling report and Popper et al (2014) for the Piling Strategy.
- Applying salmonid swim speed behavior within the threshold buffer zones to specifically determine the amount of time salmonids are subject to the identified noise thresholds.
- Applying the ecological characteristics of salmonids to better understand the potential impacts of the identified noise thresholds upon salmonid mortality.
- Comparison of the updated fish impact assessment based on the above information with those stated in the 2018 EIA.
- Clarification on the rationale and detail on why herring and sandeels were not included in the underwater noise modelling and the conclusions in the 2018 EIA remain valid for these species and the updated piling and model parameters.
- Appropriate mitigation measures identified if needed to ensure minimal impacts upon salmonids in response to piling.

4.2 Underwater Noise Modelling

The approach to the updated underwater noise modelling which was carried out by the Centre for Environment Fisheries and Aquaculture Science (Cefas) using their propagation model (Farcas et al. 2016) and an energy conversion source model (constant CF of 4% and 10%). The 2018 EIA presented the noise modelling using 0.5% and 1% conversion factor, although it is assumed by Cefas that 4% may be more realistic; however, to date it remains uncertain what the most appropriate CF may be for underwater noise modelling for monopiles.

For the two OSPs (location E06 and M11), a 'best estimate' blow count scenario of BE50 (50 blows/25 cm) for a CF of 4% and 10% was modelled by Cefas in September 2022 to predict mortality, recoverable injury and TTS underwater sound exposure level profiles. The BE50 piling profiles use high strike energies (up to

5,000 kJ). The profiles considered a single pile at OSP 1 (E06) and OSP 2(M11) locations, in addition to two piles in 24h (i.e. one pile at each of these locations), with the conservative assumption that fish remain stationary for the duration of the piling.

Underwater noise and risk posed to fish can be characterised by a number of metrics. Peak sound pressure (SPL_{peak}) (or particle motion) is the maximum absolute value of the instantaneous sound pressure (or motion) during a specified time interval. SEL is an index of the total energy in a sound event (e.g. a single piling pulse). SEL is usually expressed in dB 1 µPa2 s. The accumulation of sound energy is considered as the metric, SELcum, the linear summation of the individual sound events over the time period of interest (Popper et al., 2014).

Underwater noise for the FIA is considered in two ways. Firstly, in terms of instantaneous effects of piling, using mortality and recoverable injury SPL_{peak} thresholds. Secondly, in terms of cumulative effects, which are effects where a receptor is exposed to repeated sounds, such as multiple pile strikes, with resultant effects related to the total energy in all the sound events accumulated over time. Cumulative effects are modelled for a 24-hour period and the SEL_{cum} metric is used to assess for mortality, recoverable injury and TTS.

The installation of the monopile foundations (for both generation and transmission assets, including the two OSPs is anticipated to commence in August 2023 and be completed by March 2024.

4.3 Salmonid Ecology and Underwater Noise

Spawning for Atlantic salmon in the UK generally takes place from November to January, although may occur earlier or later depending on factors such as the size of the fish, latitude and geomorphology of the river and/or estuary (transitional water body) (Milner et al., 2012). Salmon spawn in freshwater and salmon fry (later parr) remain in freshwater for two or three years before moving to deeper water and beginning considerable physiological changes (smoltification) in preparation for their return to the marine environment as smolts. Smolt movements through the estuary or harbour to the sea would be expected to take place between April and June and tend to be during the hours of darkness. In a study on the River Utsjoki, submerged video footage recorded adult salmon preferring to ascend the river between the hours of 21.00 and 03.00 (Orell et al., 2007).

Adult sea trout generally begin to spawn in numbers in early summer in the UK, with numbers building up during July into August, with most larger sea trout, on most rivers, tending to spawn early in the season during May and June. Smolts (young sea trout) will shoal together to migrate to sea, usually around late March/April to May/June (Finstad et al.,2005). Migration also occurs predominately at night for all life stages of sea trout.

Salmonids are unlikely to detect sounds originating in air, they are sensitive to substrate borne sounds and vibration. However, compared with cod, the hearing of the salmon is very poor, and more like that of the plaice (medium to low hearing sensitivity). For example, Nedwell et al (2006), concluded for salmon and brown trout, no obvious signs of trauma could be attributed to sound exposure from vibro and impact piling associated with these fish species which were caged between 30 m – 400 m from the source of

noise. The specific piles used were 508 mm and 914 mm. The unweighted Source Level of the impact piling of the 508 mm diameter pile was 193 dB re1 _Pa@1 m, with a linear Transmission Loss rate of 0.13 dB per metre, and for the 914 mm diameter pile the Source Level was 201 dB re1 _Pa@1 m and the Transmission Loss 0.13 dB per metre.

Overall, the presence and type of swim bladder (physoclistous or physostomous) is expected to determine the vulnerability for sound pressure exposure (see Section 4.4 below). Least susceptible to sound pressure induced injuries are fish with no swim bladder and most susceptible are fish with a physoclistous swim bladder. In the recently published sound exposure guidelines (Popper et al., 2014), a distinction was made between no swim bladder, swim bladder involved in hearing and swim bladder not involved in hearing, each with different thresholds for mortal and potential mortal injuries. Fish with a swim bladder involved in hearing are expected to be most susceptible for mortal and potential mortal injuries.

4.4 Fish Impact Assessment Results

Underwater noise (both sound pressure and particle motion) generated during the installation of OSPs monopile foundations (pile driving) can potentially affect fish species via physical injury (temporary or permanent), mortality or behavioral effects (such as avoidance or displacement).

Recent peer reviewed guidelines have been published by the Acoustical Society of America (ASA) and provide directions and recommendations for setting criteria (including injury and behavioural criteria) for fish. For the purposes of this assessment, the Sound Exposure Guidelines for Fishes and Sea Turtles (Popper et al., 2014) were considered to be most relevant. The Popper et al. (2014) guidelines broadly group fish into the following categories based on their anatomy and the available information on hearing of other fish species with comparable anatomies:

- **Group 1**: Fishes lacking swim bladders that are sensitive only to sound particle motion and show sensitivity to a narrow band of frequencies (includes flatfishes and elasmobranchs).
- **Group 2**: Fishes with a swim bladder where the organ does not appear to play a role in hearing. These fish are sensitive only to particle motion and show sensitivity to a narrow band of frequencies (includes salmonids and some tuna).
- **Group 3**: Fishes with swim bladders that are close, but not intimately connected to the ear. These fishes are sensitive to both particle motion and sound pressure and show a more extended frequency range than groups 1 and 2, extending to about 500 Hz (includes gadoids and eels).
- **Group 4**: Fishes that have special structures mechanically linking the swim bladder to the ear. These fishes are sensitive primarily to sound pressure, although they also detect particle motion. These species have a wider frequency range, extending to several kHz and generally show higher sensitivity to sound pressure than fishes in Groups 1, 2 and 3 (includes clupeids such as herring, sprat and shads).

Baseline characterisation of Coull et al. (1998) spawning areas indicates the Moray West Offshore Wind Farm (Moray West Site), is not within key (high intensity) spawning grounds for cod, herring or sandeel and that these spawning grounds are located in more suitable areas out with the Development Site.

Research has shown that spawning adults are unlikely to show displacement as their spawning activity takes precedence over any other behaviour due to the amount of energy put into the spawning process and its importance in successful recruitment (Moray West, 2018).

Herring spawning activity occurs further to the north around the Orkney and Shetland islands (Coull et al., 1998; Moray Offshore Renewables Ltd, 2018), meaning spawning activity for herring will not be affected by piling activity, as this is beyond the ranges found for TTS at a threshold of 186 dB SEL_{cum} (see **Table 4-1**).

For this reason, **this PS FIA considers the remaining sensitive receptors that have the potential to be affected by piling, namely the diadromous species** that may be migrating through the Moray Firth during piling activity, in particular the salmonids: Atlantic salmon and sea trout.

Freshwater riverine habitats along the east coast of Scotland and England support a number of migratory species that may pass through the wind farm area during the ocean-going phase of their lifecycle (Malcolm et al., 2010). Migratory species include Atlantic salmon, sea trout, European eel, and lamprey species. It should be noted that of the diadromous fish species listed above, Atlantic salmon and sea lamprey are of conservation interest in a number of Special Area of Conservation (SAC) rivers in the Moray Firth area. In general, Atlantic salmon are of greatest concern due to the large distances they travel during their life cycles, their conservation status, and their sensitivity to sound. Migration activity takes place throughout the year with smolt activity from rivers occurring between April and June, peaking in the latter half of April and in May.

4.4.1 Injury Criteria

The injury criteria used in this noise assessment for impulsive piling are given in Table 4-1. Physiological effects relating to injury criteria are described below (Popper et al., 2014):

- **Mortality and potential mortal injury**: Either immediate mortality or tissue and/or physiological damage that is sufficiently severe (e.g. a barotrauma) that death occurs sometime later due to decreased fitness. Mortality has a direct effect upon animal populations, especially if it affects individuals close to maturity.
- **Recoverable injury**: Tissue and other physical damage or physiological effects, that are recoverable but which may place animals at lower levels of fitness, may render them more open to predation, impaired feeding and growth, or lack of breeding success, until recovery takes place.
- **TTS**: Short term changes in hearing sensitivity may, or may not, reduce fitness and survival. Impairment of hearing may affect the ability of animals to capture prey and avoid predators, and also cause deterioration in communication between individuals; affecting growth, survival, and reproductive success. After termination of a sound that causes TTS, normal hearing ability returns over a period that is variable, depending on many factors, including the intensity and duration of sound exposure.

Table 4-1 Criteria for onset of injury to fish due to impulsive piling (Popper et al., 2014)

Type of Animal	Parameter	Mortality and Potential Mortal Injury	Recoverable Injury	TTS
Group 1 Fish: no swim bladder (particle motion detection)	SEL, dB re 1 µPa^{2}s	>219	>216	>186
	Peak, dB re 1 µPa	>213	>213	-
Group 2 Fish: where swim bladder is not involved in hearing (particle motion detection)	SEL, dB re 1 µPa^{2}s	210	203	>186
	Peak, dB re 1 µPa	>207	>207	-
Group 3 and Group4 Fish: where swim bladder is	SEL, dB re 1 µPa^{2}s	207	203	186
	Peak, dB re 1 µPa	>207	>207	-

involved in hearing (primarily pressure detection)				
Eggs and larvae	SEL, dB re 1 µPa^{2}s	>210	(Near) Moderate (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Low (Far) Low
	Peak, dB re 1 µPa	>207		

4.4.2 Impact Assessment (Adult Salmonids and Smolts)

4.4.2.1 SPL_{peak} Assessment of Mortality and Recoverable Injury in Fish

The maximum effect range for mortality or recoverable injury according to the Popper (2014) criteria (which have the same threshold of 207 dB re 1 µPa) was 950 m, for the BE50 blow count scenarios at 2,158 kJ (OSP2, M11) and 10% energy CF. The corresponding effect range for the 4% energy conversion factor was 510 m (**Table 4-2**).

Table 4-2 Effect ranges for mortality and recoverable injury according to the Popper peak SPL criterion for Atlantic salmon and the sea trout.

Location(s)	Blow count	Hammer energy (kJ)	Threshold (dB re 1 µPa)	Maximum effect range (m) at 4% C.F.	Maximum effect range (m) at 10% C.F.
OSP 1 (E06)	BE50	2050	207	420	900
OSP 2 (M11)	BE50	2158	207	510	950

4.4.2.2 Cumulative SEL Assessment of TTS, Recoverable Injury, and Mortality Effect Zones for Fish

The greatest mortality range predicted for Atlantic salmon and sea trout was 1133 m at location OSP 2 (M11) for the blow count profile BE50 and the energy conversion factor of 10%. The corresponding maximum range for the 4% conversion factor, also at location OSP 2 (M11), was 647 m. The greatest recoverable injury range was 3,203 m, and the greatest TTS range was 43,270 m, both at the same location (OSP 2 (M11)), blow count profile (BE50) and conversion factor (10%). For the 4% conversion factor, these ranges were reduced to 1,793 m for recoverable injury and to 19,324 m for TTS (Table 4-3). The effect areas are shown from Figure 4-1 to Figure 4-6.

Table 4-3 Effect areas for mortality, recoverable injury, and TTS according to the Popper SELcum criterion for the Atlantic salmon and the sea trout. Thresholds for these effects are 210, 203, and 186 dB re 1 µPa2 s, respectively.

Location(s)	Blow count	Conversion factor (%)	TTS area (km^2); *range (m)*	Recoverable injury area (km^2); *range (m)*	Mortality area (km^2); *range (m)*	Figure number
OSP 1 (E06)	BE50	4	827.16; *18,092*	7.67; *1569*	0.91; *546*	**Figure 4-1**
OSP 2 (M11)	BE50	4	878.36; *19,324*	9.97; *1793*	1.29; *647*	**Figure 4-2**
OSP 1(E06) and OSP 2 (M11)	BE50	4	3,672.92; *n/a*	47.75; *n/a*	5.27; *n/a*	**Figure 4-3**
OSP 1 (E06)	BE50	10	2,236.91; *37,505*	25.17; *2961*	3.09; *1003*	**Figure 4-4**
OSP 2 (M11)	BE50	10	2,616.49; *43,270*	31.14; *3203*	4.03; *1133*	**Figure 4-5**
OSP 1(E06) and OSP 2 (M11)	BE50	10	6,127.54; *n/a*	186.78; *n/a*	18.52; *n/a*	**Figure 4-6**

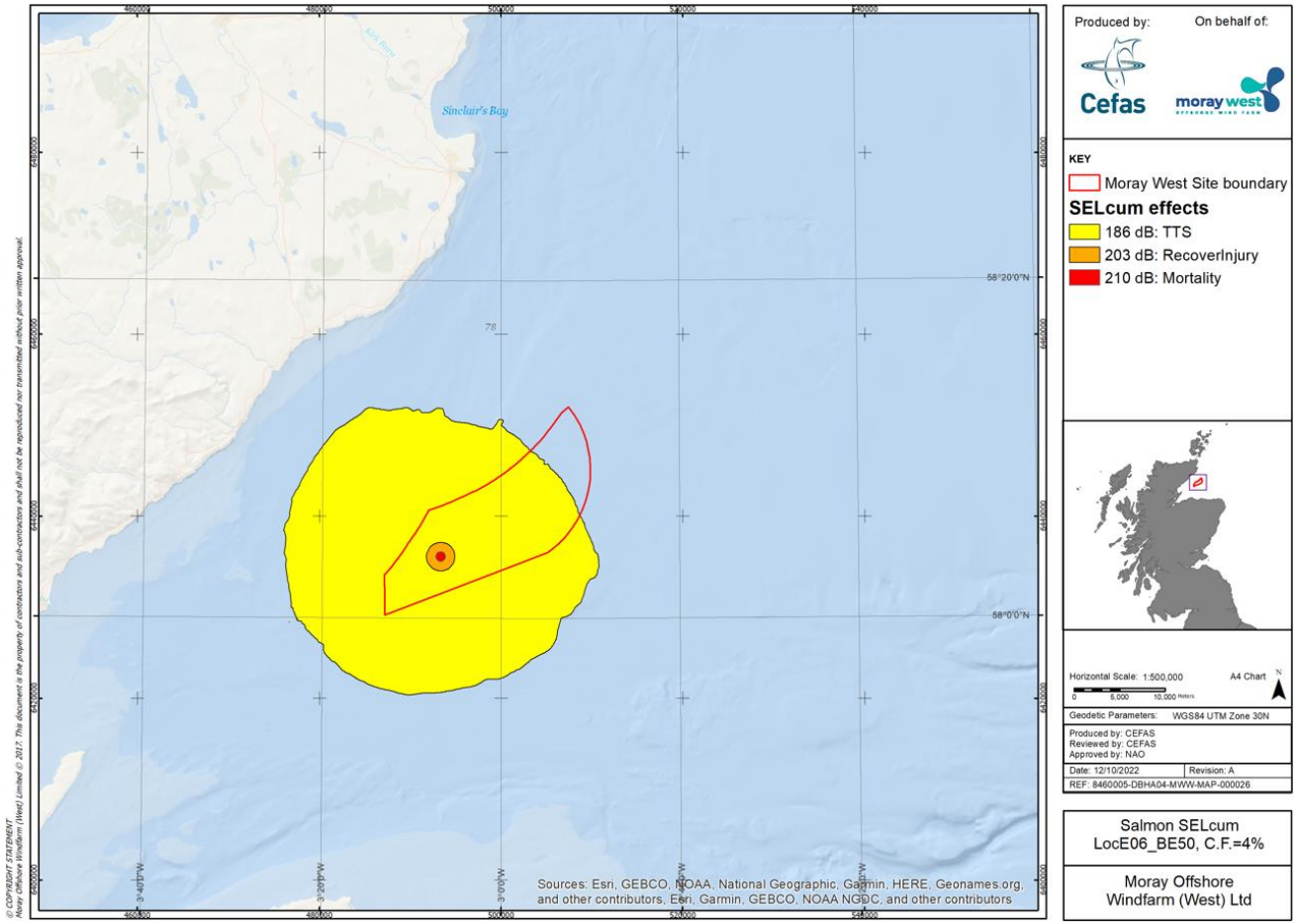


Figure 4-1 Cumulative exposure effect zones for salmonid species exposed to piling at location OSP 1 (E06), for the blow count profile BE50 and the energy conversion factor C.F.=4%.

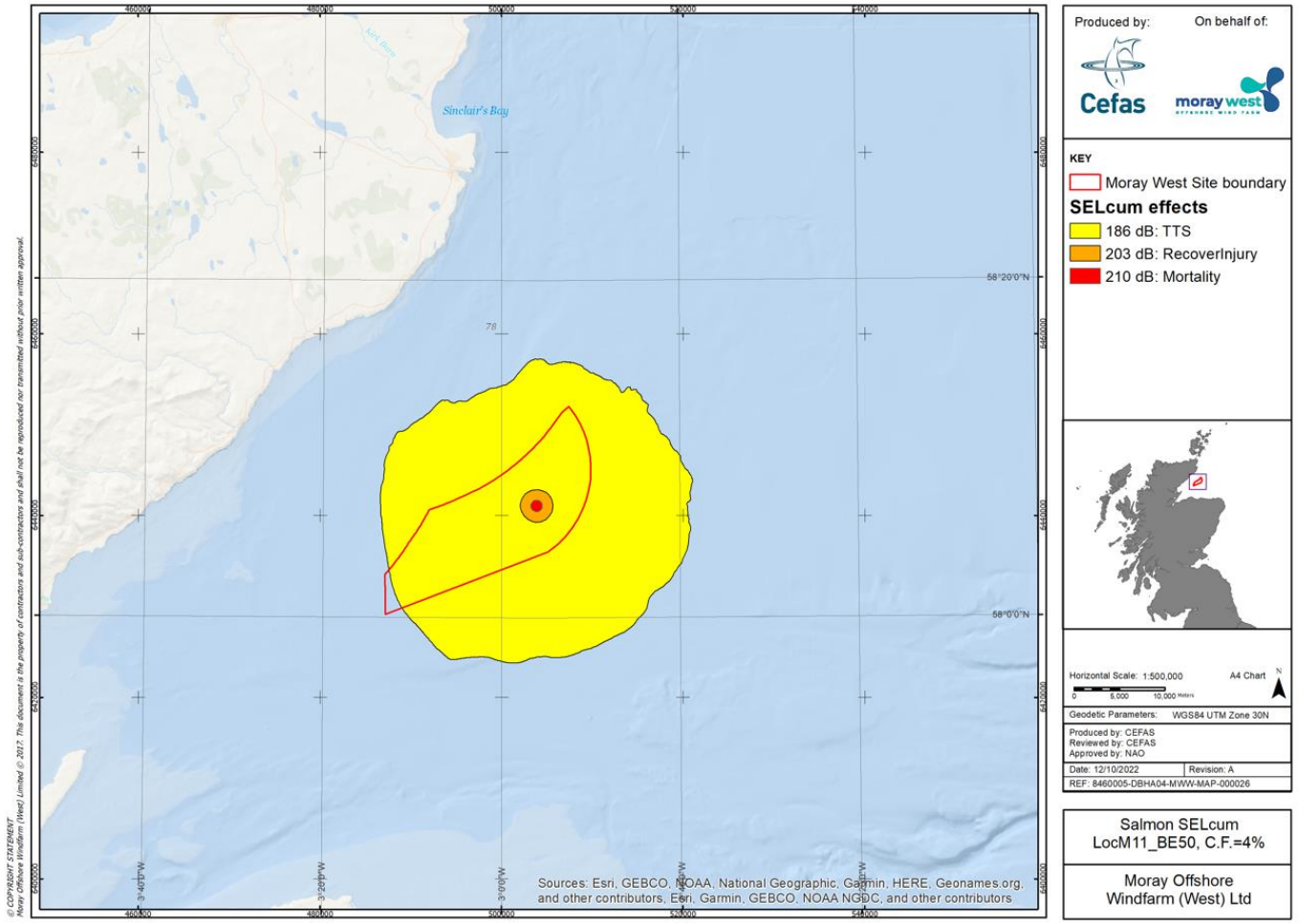


Figure 4-2 Cumulative exposure effect zones for salmonid species exposed to piling at location OSP 2 (M11), for the blow count profile BE50 and the energy conversion factor C.F.=4%.

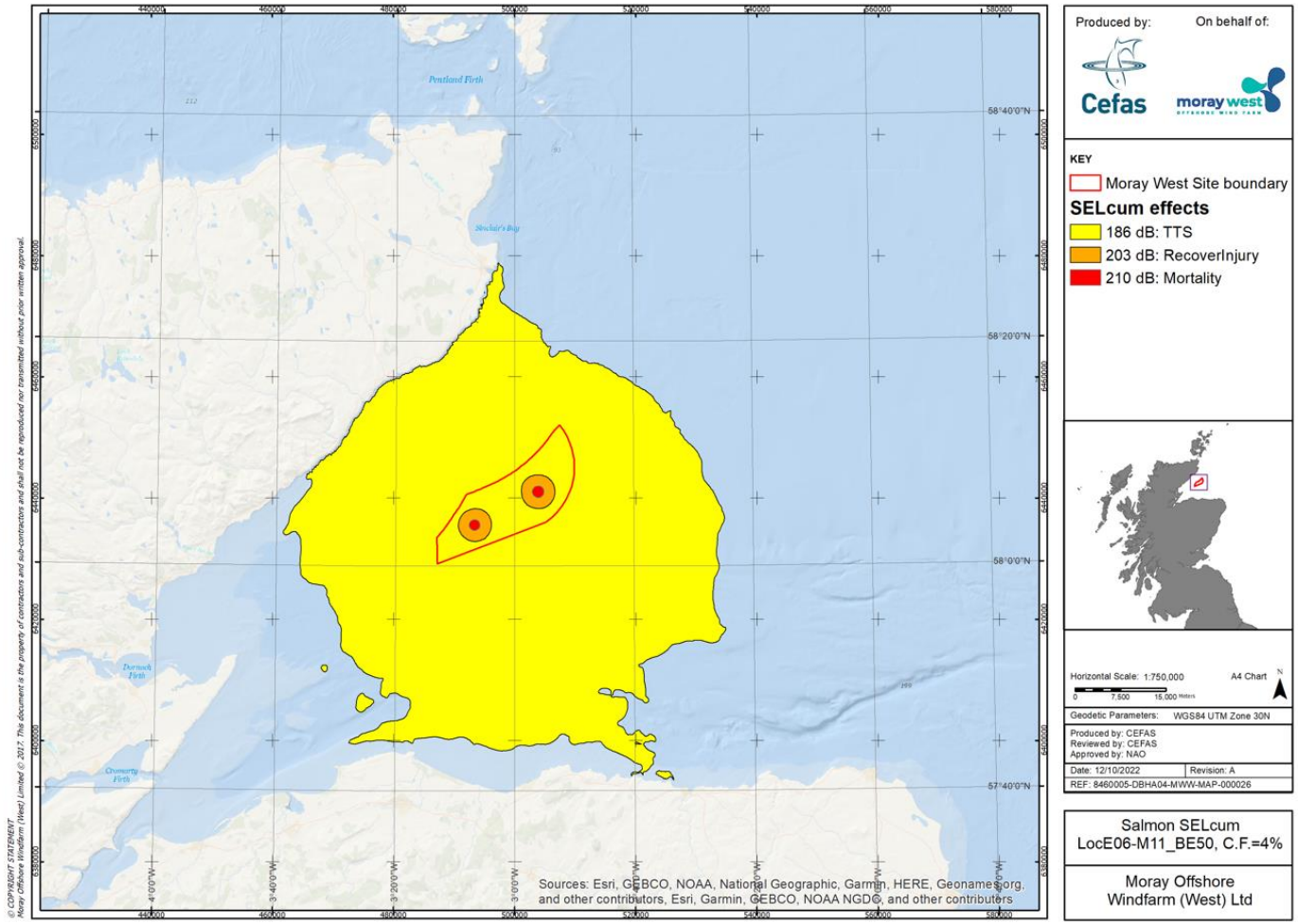


Figure 4-3 Cumulative exposure effect zones for salmonid species exposed to concurrent piling (within 24hours) at locations E06 and M11, for the blow count profile BE50 and the energy conversion factor C.F.=4%.

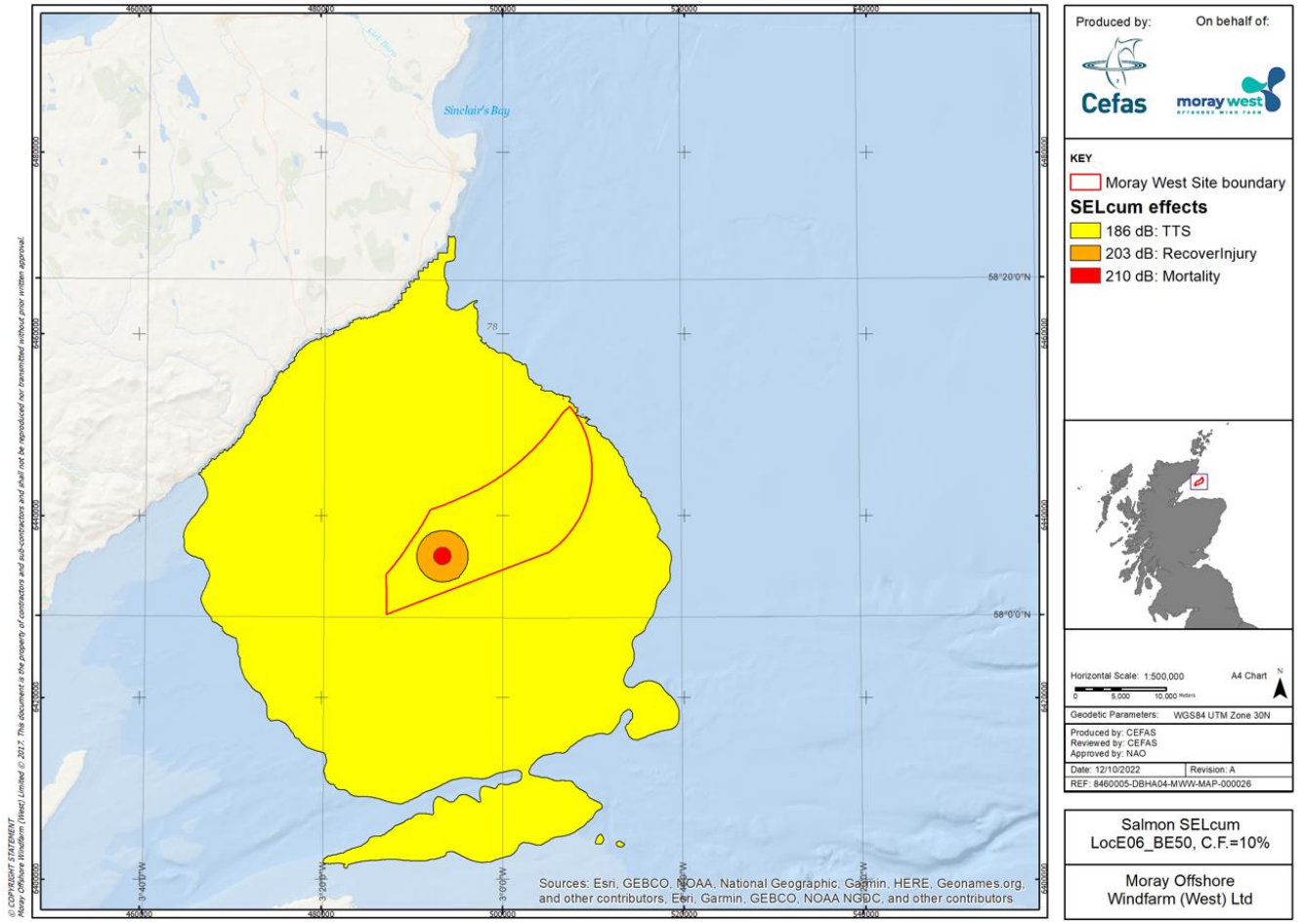


Figure 4-4 Cumulative exposure effect zones for salmonid species exposed to piling at location OSP 1 (E06), for the blow count profile BE50 and the energy conversion factor C.F.=10%.

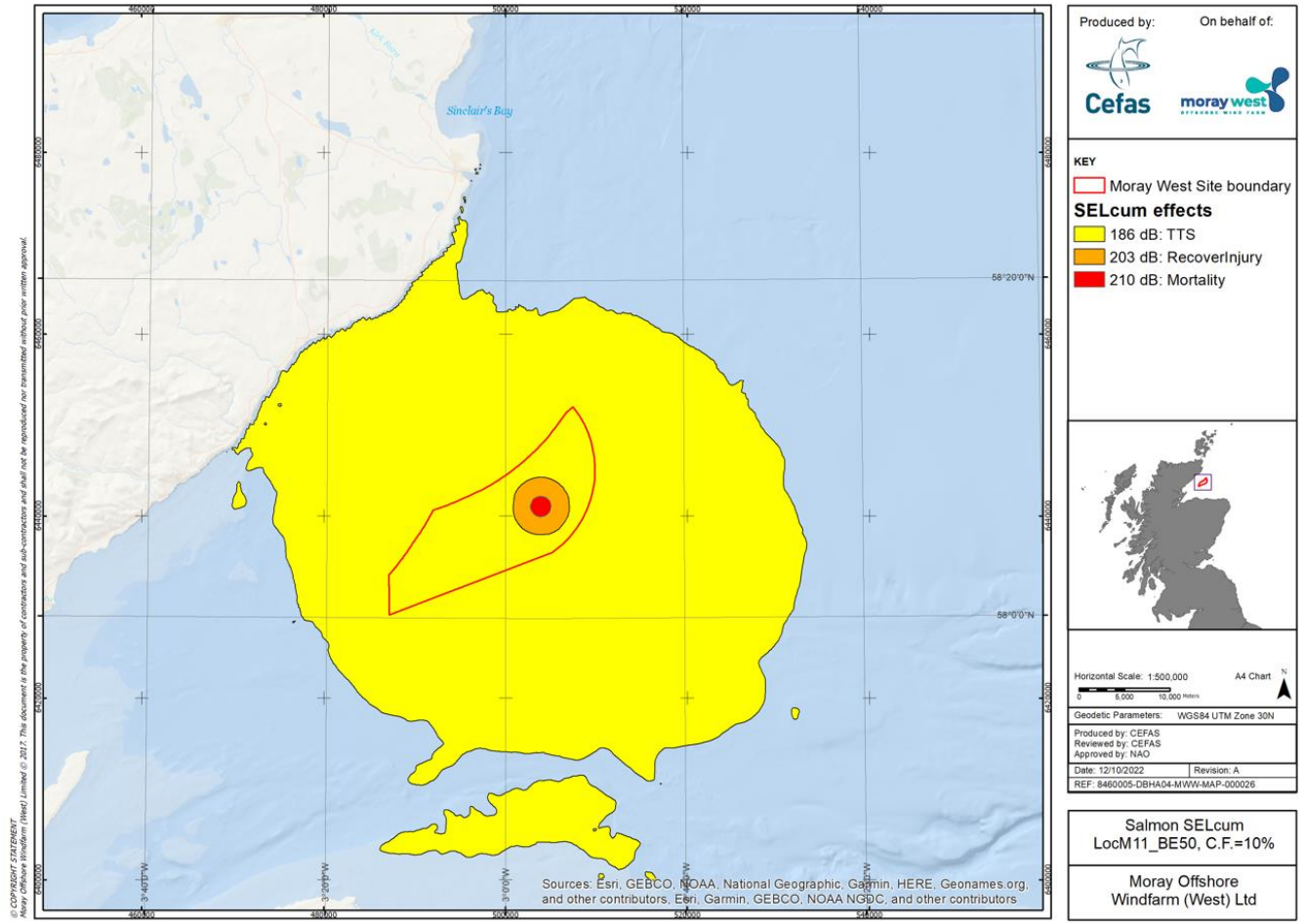


Figure 4-5 Cumulative exposure effect zones for salmonid species exposed to piling at location OSP 2 (M11), for the blow count profile BE50 and the energy conversion factor C.F.=10%.

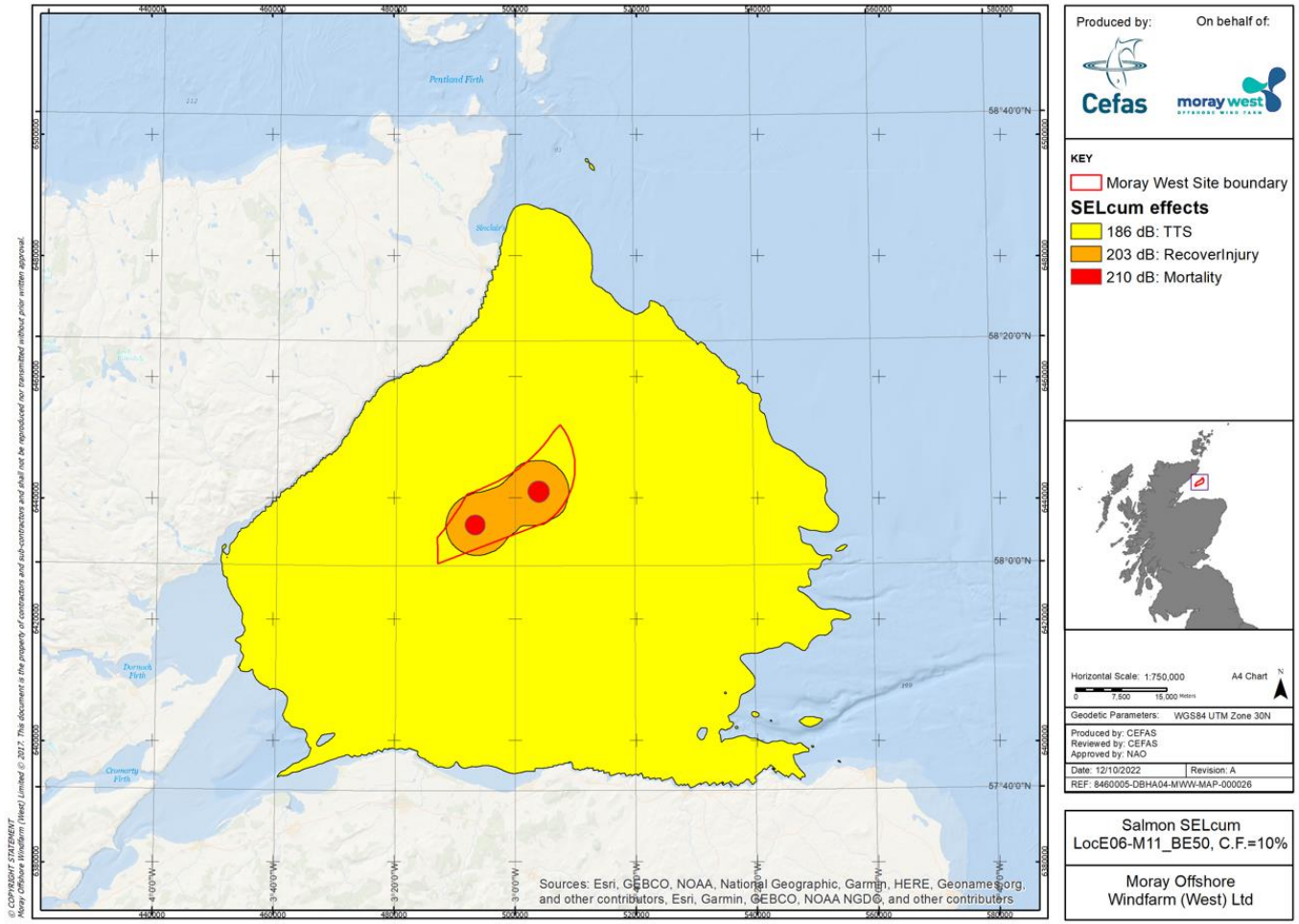


Figure 4-6 Cumulative exposure effect zones forsalmonid species exposed to concurrent piling (within 24hours) at locations OSP 1 (E06) and OSP 2 (M11), for the blow count profile BE50 and the energy conversion factor C.F.=10%.

4.4.2.3 Conservatism in the Model

It should be noted that the modelling has adopted a highly conservative approach by making a number of assumptions – see Section 3.1.3.1 of Appendix C of the original Moray West PS for details of all conservatisms. The assumption that has the greatest bearing on impact ranges for salmonids, is the assumption of a constant conversion factor. Noise monitoring during the installation of monopiles at UK offshore wind farms showed a relationship between hammer energy and sound exposure level that can only be explained with a varying conversion factor. Since the conversion factor is variable, modelling with a constant 10% is considered unrealistic, leading to an over precautionary estimate in most, if not all cases. It is not yet known for monopiles, which factors influence the conversion factor, while for pin piles, the length of the pile in the water column seems to be the major influencing factor (Thompson et al. 2020). The use of a constant conversion factor has a large bearing on impact ranges for fish as a stationary receptor model has been used, meaning that the entirety of the increased energy output produced by increasing the conversion factor is transferred to the fish receptor (minus transmission loss). So whilst a conversion factor of 4% would be considered more realistic than 10% (as previously mentioned), the resulting impact ranges can still be considered highly conservative, given the assumption of a stationary receptor. In summary, the impact ranges for a 4% conversion factor reported here are considered likely to lead to an overestimate of the ranges of effect, due to the assumption of a stationary receptor.

For a 2,158 kJ (OSP 2 (M11)) hammer energy (monopile), recoverable injury ranges may be expected within a maximum of 510 m (at 4% conversion factor) for all fish groups, based on SPL_{peak}, and a maximum of 1,793m based on SEL_{cum}, assuming a stationary animal.

These ranges are for recoverable injury, and therefore any effects are reversible, however fitness may be reduced during the recovery period as fish may be more susceptible to predation or disease during this time (Popper et al., 2014).

When assuming a stationary receptor, as a worst case (10% CF), there is a potential for mortality and recoverable injury within a distance of 1,133m and 3,203m from piling respectively. When a more realistic conversion factor of 4% is used, these ranges reduce to 647m and 1,793m for mortality and recoverable injury respectively. Permanent injury may occur in extreme proximity to the pile (or within 647m assuming a conversion factor of 4% and a stationary animal), although the risk of this will be reduced by the use of soft start techniques at the start of the piling sequence, thereby allowing fish to move away from the impact range before cumulative noise exposure reaches lethal thresholds.

4.4.2.4 Barrier Impacts to Migration

The noise modelling that informs this assessment has precautionarily assumed that receptors are stationary with respect to the piling noise source. However, for salmonids in the Moray Firth area during piling works for the OSPs, a more realistic scenario is that rather than remaining stationary, they will be swimming to or from their natal river systems. Laboratory work on brown trout has shown that repeated sine sweeps (up to 2kHz), and, more relevant to piling, intermittent 140 Hz tones do not affect swimming behaviour (Jesus et al., 2019). Further, high intensity (114 dB above the hearing threshold) low frequency sound at 150 Hz has no effect on downstream smolt migration (Knudsen et al., 2005). At high intensities,

very low frequency infrasound of 10Hz does deter smolt movement, but the vast majority of sound energy in a pile frequency spectrum is contained at frequencies above 20Hz (Gil et al., 2012).

Overall, the evidence suggests that changes to salmonid swimming behaviour during migration may occur in extreme proximity to the piles, but this will not be significant in EIA terms.

If it is assumed that rather than remaining stationary, migrating salmonids will travel through the derived areas for mortality, recoverable injury, and TTS, as determined by SEL_{cum} thresholds, then the time taken for salmonids to pass through these areas is presented in Table 4-4.

Table 4-4 Estimated potential distances and timings for salmonids based on assumed swim speeds based on Drenner et al., (2012)

Species	Swim speed ($m\ s^{-1}$)	Distance travelled over a 4 hour period (km)	Worst case range (SEL_{cum} over 4 hour piling period with 10% conversion factor) (km)			Time taken to travel through range (minutes)		
			Mortality	Recoverable Injury	TTS	Mortality	Recoverable Injury	TTS
Salmonid (adult)	0.6	8.64	1.1	3.2	43.3	31	89	1203
Salmonid smolt (maximum speed)	0.59	8.50				31	90	1223
Salmonid smolt (minimum speed)	0.22	3.17				83	242	3208

4.4.3 Consideration of Other Fish Species

Herring spawning activity occurs further to the north around the Orkney and Shetland islands (Coull et al., 1998; Moray Offshore Renewables Ltd, 2018) meaning spawning activity for herring will not be affected by piling activity, as this is beyond the maximum ranges found for TTS at a threshold of 186 dB SEL_{cum}.

Grab sample surveys carried out for Moray West and the nearby Beatrice Offshore Wind Farm, suggest that there are not extensive sandeel populations in the Moray Firth area surrounding the proposed piling works (Moray West, 2018). In addition, sandeel have no swim bladder and are therefore considered to have low sensitivity to noise, detecting particle motion only (Popper et al., 2014).

Similarly, other migratory species such as Sea lamprey have lower sensitivity to sound than salmonids, so will be impacted to a lesser extent than has been modelled here for group 2 fish. The only site designated for sea lamprey in the Moray Firth is the River Spey, located approximately 37 km from the proposed works. It should be noted that impulsive noise impacts beyond 10 km are unlikely, for the reasons outlined in **Section 4.4.5**.

For the reasons outlined above, Atlantic salmon are the greatest species of concern in relation to piling noise in the Moray Firth, and the noise modelling has focused on impact thresholds for hearing group 2 fish accordingly.

4.4.4 Comparative Developments

Very little information on the sound propagation and appropriate conversion factors for the large diameter (9.5m in this case) monopiles exists, hence the adoption of conservative modelling parameters (i.e. the constant 4% and 10% conversion factors and the stationary fish receptors).

4.4.5 Comparison with 2018 EIA

Based on noise modelling presented in the Moray West EIA Report 2018, any impacts on fish species as a result of piling noise at Moray West Site were considered to be of low magnitude, with the significance of the effect assessed as minor, even for more sensitive species such as salmonids. Although there is some potential for mortality, injury and behavioral effects in the ranges summarised above, piling (noise generation) is predicted to occur over a short duration (up to 8 hours in total) and overlap with sensitive locations and time periods for the fish species considered is limited.

In light of the low potential for any barrier effects to natal rivers as a result of the noise contours, the assessment of potential noise related effects is not expected to exceed that previously assessed within the Moray West EIA Report 2018. It is therefore concluded that the potential for mortality, impairment and behavioural effects would be of negligible significance for Atlantic salmon and sea trout, and therefore not significant in EIA terms.

The differences in effect ranges between the 2018 EIA and the current modelling can be explained largely through the change in the conversion factors used in the piling source model from 0.5% and 1% in 2018, to 4% and 10% in the modelling reported here (See Section 2.2 of Appendix C of the original Moray West PS for an explanation of the source model). The 0.5% conversion factor used in 2018 was based on the scientific literature which back-calculated conversion factors from real world piling measurements taken in the field; this literature was converging towards a consensus of 0.5% (for a review, see Dahl et al., 2015). The inclusion of a 1% conversion factor in 2018 was at the request of Scottish Natural Heritage (SNH, now NatureScot) through Marine Scotland (MS) and served as a conservative comparison. The substantially higher conversion factors of 4% and 10% used in the current modelling are included at the request of SNH and MS due to the uncertainty around the appropriate conversion factors for larger diameter monopiles.

There is considerable uncertainty associated with the estimation of mortality, recoverable injury and TTS for fish and this is particularly true for impact ranges based on cumulative noise exposure (SEL_{cum}). The drivers of this uncertainty are detailed in original Moray West PS Appendix C Section 2.6.2.1.2. To repeat briefly, as discussed in Southall et al., (2019), there are two assumptions implicit in the SEL_{cum} impact thresholds:

a) the amount of sound energy that an animal is exposed to within 24 hours will have the same effect on its auditory system, regardless of whether it is received all at once (e.g. as a single loud pulse) or in several smaller doses spread over a longer period (such as a series of pile strikes). This is called the equal-energy hypothesis; and,

b) the sound from pile-driving keeps its impulsive character, regardless of the distance between the exposed animal and the sound source.

There is growing scientific consensus that neither of these assumptions hold true, leading to high levels of conservatism in assessments:

a) There is growing evidence (for both marine mammals and fish) that there is a recovery of a sound-induced threshold shift if the dose is applied in several smaller doses (Finneran, 2015; Halvorsen et al., 2012).

b) The latest evidence suggests that piling sound loses its impulsive character as it propagates away from the source. Taking into account the recent data, Southall (2021) notes that "*it should be recognized that the use of impulsive exposure criteria for receivers at greater ranges (tens of kilometers) is almost certainly an overly precautionary interpretation of existing criteria*".

In combination with the above conservative assumptions, the use of constant conversion factors (4% and 10%) can also be considered conservative, as evidence demonstrates that conversion factors vary over the course of a piling event. It has been observed at BOWL wind farm, when driving 2.2 m diameter piles, that conversion factor can be as high as ~10% at the onset of the piling soft-start, and then decreasing towards 2% after 40 minutes and 1% after 60 minutes. In other words, as the hammer energy increases, and the pile penetration depth increases, the conversion factor decreases (Thompson et al., 2020).

Where uncertainty exists, following the precautionary principle, it is understandable that regulators may wish to see conservative values used for all parameters used in the modelling. However, when conservatism is built into the sound source level, propagation model assumptions, piling regime, impact threshold criteria, and fish mobility (i.e. stationary assumed), then it is clear that these conservatisms will compound, particularly over the course of hours of pile driving. Highly precautionary impact ranges are the result.

In terms of mortality and recoverable injury, no studies to date have been carried out with respect to Atlantic salmon and pile driving in the field. Laboratory studies, using pile-driving playbacks on juvenile Chinook salmon, suggest that injuries that bear physiological cost begin to occur at SEL_{cum} = 210 dB re 1 μPa^2s (Halvorsen et al., 2012). It should be noted that no injuries produced at 217 or 210 dB re 1μPa^2s SEL_{cum} resulted in mortality, at least 10 days post-exposure in laboratory conditions (Casper et al., 2012). This highlights once again the conservatism built into this assessment, which uses a mortality threshold of SEL_{cum} = 210 dB re 1 μPa^2s as per Popper et al., (2014) best practice.

Taken together, it can be seen that despite the increase in reported impact threshold ranges since the 2018 EIA (as a result of the requested precautionary increase in conversion factors from 0.5% and 1%, to 4% and 10%), there is enough conservatism built into every aspect of the assessment undertaken in 2018 that it's findings remain precautionary. This assessment has increased levels of precaution; whilst this does provide an indication of extreme worst-case scenarios, some of the parameters used are not in line with current scientific understanding and if requirements for their use remain, risk constraining efforts to identify more likely scenarios that can be used to balance the costs and benefits of potential mitigation measures (see Thompson et al. 2020).

4.4.6 Fish mitigation

The potential for mortality, impairment and behavioural effects without mitigation are considered to be of negligible significance for Atlantic salmon and sea trout, and therefore not significant in EIA terms, with no mitigation required. However, mitigation measures have been proposed for marine mammals, and that mitigation will further reduce the already low risk to salmonid species.

Details of the mitigation measures are provided in the Addendum to Appendix D: Piling Mitigation Strategy.

5 4References

Anderwald, P., P. Evans, K. Robinson, P. Stevick, and C. MacLeod. 2007. Minke whale populations in the North Atlantic: an overview with special reference to UK waters. An Integrated Approach to Non-lethal Research on Minke Whales in European Waters European Cetacean Society Spec Public Series **47**:8-13.

Benhemma-Le Gall, A., I. Graham, N. Merchant, and P. Thompson. 2021. Broad-scale responses of harbor porpoises to pile-driving and vessel activities during offshore windfarm construction. Frontiers in Marine Science **8**:664724.

Booth, C., and F. Heinis. 2018. Updating the Interim PCoD Model: Workshop Report - New transfer functions for the effects of permanent threshold shifts on vital rates in marine mammal species. Report Code SMRUC-UOA-2018-006, submitted to the University of Aberdeen and Department for Business, Energy and Industrial Strategy (BEIS), June 2018 (unpublished).

Brandt, M. J., A.-C. Dragon, A. Diederichs, M. A. Bellmann, V. Wahl, W. Piper, J. Nabe-Nielsen, and G. Nehls. 2018. Disturbance of harbour porpoises during construction of the first seven offshore wind farms in Germany. Marine Ecology Progress Series **596**:213-232.

Brandt, M. J., C. Hoeschle, A. Diederichs, K. Betke, R. Matuschek, S. Witte, and G. Nehls. 2013. Far-reaching effects of a seal scarer on harbour porpoises, *Phocoena phocoena*. Aquatic Conservation-Marine and Freshwater Ecosystems **23**:222-232.

Casper, B., Popper, A., Matthews, F., Carlson, T., & Halvorsen, M. (2012). Recovery of Barotrauma Injuries in Chinook Salmon, Oncorhynchus tshawytscha from Exposure to Pile Driving Sound. PloS One, 7, e39593. https://doi.org/10.1371/journal.pone.0039593

Coull, K.A., Johnstone, R., and Rogers, S.I (1998). Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd.

Dahl, P. H., de Jong, C. A. F., & Popper, A. N. (2015). The Underwater Sound Field from Impact Pile Driving and Its Potential Effects on Marine Life. The Journal of the Acoustical Society of America, 11(2), 18–25.

Drenner, S. M. , Clark, T. D. , Whitney, C. K. , Martins, E. G. , Cooke, S. J. , & Hinch, S. G. (2012). A synthesis of tagging studies examining the behaviour and survival of anadromous salmonids in marine environments. PLoS One, 7. https://doi.org/10.1371/journal.pone.0031311

Farcas, A., P. M. Thompson, and N. D. Merchant. 2016. Underwater noise modelling for environmental impact assessment. Environmental Impact Assessment Review 57:114-122.

Finneran, J. J. (2015). Noise-induced hearing loss in marine mammals: A review of temporary threshold shift studies from 1996 to 2015. The Journal of the Acoustical Society of America, 138(3), 1702–1726. https://doi.org/10.1121/1.4927418

Finstad, A.G., Økland, F., Thorstad, E.B., and Heggberget, T.G (2005). Comparing upriver spawning migration of Atlantic salmon Salmo salar and sea trout Salmo trutta. J. Fish Biol. 67: 919‑930.

Gill, A. B., Bartlett, M., & Thomsen, F. (2012). Potential interactions between diadromous fishes of U.K. conservation importance and the electromagnetic fields and subsea noise from marine renewable energy developments. *Journal of Fish Biology*, 81(2), 664–695. https://doi.org/10.1111/j.1095-8649.2012.03374.x

Graham, I. M., A. Farcas, N. D. Merchant, and P. Thompson. 2017. Beatrice Offshore Wind Farm: An interim estimate of the probability of porpoise displacement at different unweighted single-pulse sound exposure levels. Prepared by the University of Aberdeen for Beatrice Offshore Windfarm Ltd.

Graham, I. M., N. D. Merchant, A. Farcas, T. R. C. Barton, B. Cheney, S. Bono, and P. M. Thompson. 2019. Harbour porpoise responses to pile-driving diminish over time. Royal Society Open Science 6:190335.

Halvorsen, M. B., Casper, B. M., Woodley, C. M., Carlson, T. J., & Popper, A. N. (2012). Threshold for Onset of Injury in Chinook Salmon from Exposure to Impulsive Pile Driving Sounds. PLOS ONE, 7(6), e38968. https://doi.org/10.1371/journal.pone.0038968

Harwood, J., S. L. King, R. S. Schick, C. Donovan, and C. G. Booth. 2014. A protocol for implementing the interim population consequences of disturbance (PCoD) approach: Quantifying and assessing the effects of UK offshore renewable energy developments on marine mammal populations. Page 33 Scottish Marine and Freshwater Science.

Hastie, G., N. D. Merchant, T. Götz, D. J. Russell, P. Thompson, and V. M. Janik. 2019. Effects of impulsive noise on marine mammals: investigating range-dependent risk. Ecological Applications 29:e01906.

Jesus, J., Amorim, M. C. P., Fonseca, P. J., Teixeira, A., Natário, S., Carrola, J., Varandas, S., Torres Pereira, L., & Cortes, R. M. V. (2019). Acoustic barriers as an acoustic deterrent for native potamodromous migratory fish species. Journal of Fish Biology, 95(1), 247–255. https://doi.org/10.1111/jfb.13769

Kastelein, R. A., L. Helder-Hoek, L. N. Defillet, L. A. Huijser, J. M. Terhune, and R. Gransier. 2021. Temporary Hearing Threshold Shift in California Sea Lions (Zalophus californianus) Due to One-Sixth-Octave Noise Bands Centered at 2 and 4 kHz: Effect of Duty Cycle and Testing the Equal-Energy Hypothesis. Aquatic Mammals 47.

Kastelein, R. A., L. Hoek, R. Gransier, M. Rambags, and N. Claeys. 2014. Effect of level, duration, and inter-pulse interval of 1-2 kHz sonar signal exposures on harbor porpoise hearing. The Journal of the Acoustical Society of America 136:412-422.

King, S. L., R. S. Schick, C. Donovan, C. G. Booth, M. Burgman, L. Thomas, and J. Harwood. 2015. An interim framework for assessing the population consequences of disturbance. Methods in Ecology and Evolution 6:1150-1158.

Knudsen, F., Enger, P., & Sand, O. (2005). Avoidance responses to low frequency sound in downstream migrating Atlantic salmon smolt, Salmo salar. Journal of Fish Biology, 45, 227–233. https://doi.org/10.1111/j.1095-8649.1994.tb01302.x

Malcolm, I., Godfrey, J., & Youngson, A. (2010). Review of migratory routes and behaviour of Atlantic salmon, Sea trout and European eel in Scotland's coastal environment: Implications for the development of marine renewables. In Marine Scotland Science (Vol. 1).

Martin, B., K. Lucke, and D. Barclay. 2020. Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals. The Journal of the Acoustical Society of America 147:2159-2176.

Milner, N.J., Solomon, D.J. and Smith, G.W (2012). The role of river flow in the migration of adult Atlantic salmon, Salmo salar, through estuaries and rivers. Fisheries Management and Ecology, 19, 537‐547.

NatureScot. 2020. Conservation and Management Advice - Southern Trench MPA. NatureScot.

Paxton, C., L. Scott-Hayward, M. Mackenzie, E. Rexstad, and L. Thomas. 2016. Revised Phase III Data Analysis of Joint Cetacean Protocol Data Resources.

Nedwell, J R., Turnpenny, A. W. H., Lovell, J and Edwards, B (2006). An investigation into the effects of underwater piling noise on salmonids. J. Acoust. Soc. Am. 120 (5).

Orell P. , Erkinaro J. , Svenning M. , Davidsen J. , Niemelä E. (2007). Synchrony in the downstream migration of smolts and upstream migration of adult Atlantic salmon in the subarctic River Utsjoki. Journal of Fish Biology, 71: 1735‐1750.

Popper, A.N., Hawkins, A.D., Fay, R.R, Mann D.A., Bartol S, Carlson T.J, Coombs S, Ellison, W.T., Gentry R.L, Halvorsen M.B., Lokkeborg S., Rogers P.H., Southall B.L, Zeddies D.G. and Tavolga W.N (2014). Sound Exposure Guildeines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI, ASA S3/SC1.4 TR-2014.

Popper, A. N. and Hawkins, A. D. (2016). The Effects of Noise on Aquatic Life, II. Springer Science+Business Media. New York, NY.

Sarnocinska, J., J. Teilmann, J. B. Dalgaard, F. v. Beest, M. Delefosse, and J. Tougaard. 2019. Harbour porpoise (*Phocoena phocoena*) reaction to a 3D seismic airgun survey in the North Sea. Frontiers in Marine Science **6**:824.

Sinclair, R. R., C. E. Sparling, and J. Harwood. 2020. Review Of Demographic Parameters And Sensitivity Analysis To Inform Inputs And Outputs Of Population Consequences Of Disturbance Assessments For Marine Mammals. Scottish Marine and Freshwater Science **11**:6--74.

Southall, B. 2021. Evolutions in Marine Mammal Noise Exposure Criteria. Acoustics Today **17**.

Southall, B., J. J. Finneran, C. Reichmuth, P. E. Nachtigall, D. R. Ketten, A. E. Bowles, W. T. Ellison, D. Nowacek, and P. Tyack. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals **45**:125-232.

Taylor, B., S. Chivers, J. Larese, and W. Perrin. 2007. Generation length and percent mature estimates for IUCN assessments of cetaceans. Administrative Report LJ-07-01National Marine Fisheries Service, Southwest Fisheries Science Center.

Thompson, P. M., K. L. Brookes, I. M. Graham, T. R. Barton, K. Needham, G. Bradbury, and N. D. Merchant. 2013. Short-term disturbance by a commercial two-dimensional seismic survey does not lead to long-term displacement of harbour porpoises. Proceedings of the Royal Society B-Biological Sciences **280**:1-8.

Thompson, P. M., I. M. Graham, B. Cheney, T. R. Barton, A. Farcas, and N. D. Merchant. 2020. Balancing risks of injury and disturbance to marine mammals when pile driving at offshore windfarms. Ecological Solutions and Evidence **1**.

Tougaard, J., S. Buckland, S. Robinson, and B. Southall. 2013. An analysis of potential broad-scale impacts on harbour porpoise from proposed pile driving activities in the North Sea. Report of an expert group convened under the Habitats and Wild Birds Directive - Marine Evidence Group MB0138. 38pp.

Addendum to Appendix D – Piling mitigation protocol

MORAY OFFSHORE WINDFARM (WEST) LIMITED

Piling Strategy
Addendum to Appendix D: Piling Mitigation Protocol
Offshore Transmission Infrastructure (OfTI) Piling Strategy

Document Name: 8460005-DBHA04-MWW-REP-000004

Revision: 2

Status: Final

Date: 10-11-2022

Version Control				
Revision	Date	Status	Revision Description	Distribution List
0	31-03-2022	Draft	Moray West review	Moray West
1	31-05-2022	Final	Moray West Piling Strategy Appendix D Submission to MS-LOT	MS-LOT
2	10-11-2022	Final	Second Submission to MS-LOT Moray West OfTI Piling Strategy Addendum to Appendix D (8460005-DBHA04-MWW-REP-000004)	MS-LOT

Table of Contents

Figures 4
Tables 4
Abbreviations and Acronyms 5
1 Introduction 6
1.1 Background 6
1.2 Objectives of the PMP 6
2 Marine mammal impact ranges for auditory injury 7
3 Piling mitigation approach 9
3.1 Use of ADD 9
3.1.1 ADD protocol 10
3.2 Soft-start and ramp-up 13
3.2.1 Protocol for planned or unplanned breaks in piling 14
3.3 Optimization of piling sequencing 15
3.4 Monitoring and Audit 15
4 Piling procedure 16
5 Roles and responsibilities 17
5.1 Project Manager 17
5.2 Marine Installation Manager 17
5.3 Construction Contractor 17
5.4 Environmental Clerk of Works (ECoW) 17
5.5 ADD Operator 18
6 Communications 18
7 Reporting 19
8 References 20
Appendix 1. ADD effectiveness evidence base 22
1. Harbour porpoise 22
2. Minke whale 24
3. Seals 25
4. Dolphin species 26

Figures

Figure 8-1 Percentage of porpoise positive minutes recorded before and during Lofitech trials at various distances. Figure taken from Brandt et al. (2013b). 22
Figure 8-2 Harbour porpoise aerial sightings before (left) and during (right) Lofitech activation. Figure taken from Brandt et al. (2013b). 23
Figure 8-3 Number of harbour porpoises seen during scans when the Lofitech device was active and inactive. Figure taken from Brandt et al. (2013a). 24
Figure 8-4 Harbour porpoises sightings rates when the Lofitech device was active and inactive over a range of distances. Figure taken from Brandt et al. (2013a). 24
Figure 8-5 Distance of focal whales from the ADD deployment site during treatment and post treatment phases of the experiment. The red dashed line indicates the end of the treatment phase. Figure taken from McGarry et al. (2017). 25
Figure 8-6 Controlled exposure experiments with harbour seals and the Lofitech device which did and did not elicit responses plotted against range. The range of the first closest non-responsive CEE and the most distant responsive CEEs are indicated by the dotted vertical lines. Figure taken from Gordon et al. (2015). 26
Figure 8-7 Percentage of controlled exposure experiments with harbour seals and the Lofitech device eliciting a response ranked by range. Figure taken from Gordon et al. (2015). 26

Tables

Table 2-1 Maximum instantaneous PTS-onset impact ranges (based on a constant 10% CF) for worst case locations for bottlenose dolphin and seals, as presented in the original Moray West PS. 7
Table 2-2 Maximum instantaneous PTS onset impact ranges (based on a constant 10% CF) for worst case locations for harbour porpoise and minke whale considered in OSPs monopile locations noise modelling. 7
Table 2-3 Maximum cumulative PTS-onset impact ranges (based on a constant 10% CF) for worst case locations for bottlenose dolphin and seals, and number of animals within the impact area based on species density distribution maps, as presented in the original Moray West PS, ... 8
Table 2-4 Maximum cumulative PTS onset impact ranges (based on a constant 10% CF) for minke whale and harbour porpoise at OSP 2 (M11), and OSP 2 (M11) followed by OSP 1 (E06) and number of animals within the impact area based on species density distribution maps. (S – summer, NS – non-summer). 8
Table 3-1 Estimated time for bottlenose dolphin and seals to exit the maximum instantaneous PTS-onset range (based on a 10% CF) for a soft start (550 kJ), as presented in the original Moray West PS. 11
Table 3-2 Estimated time for harbour porpoise and minke whale to exit the maximum instantaneous PTS-onset range (based on a 10% CF) for a soft start (432 kJ) considered in the OSP monopile locations noise modelling. 11
Table 3-3 Estimated time for bottlenose dolphin and seals to exit the maximum instantaneous PTS-onset range (based on a 10% CF) for full hammer energy (5,000kJ, as presented in the original Moray West PS. 12

Table 3-4Estimated time for harbour porpoise and minke whale to exit the maximum instantaneous PTS-onset range (based on a 10% CF) for full hammer energy (2,158 kJ). 12
Table 3-5Estimated time for an animal to exit the maximum cumulative PTS onset range (based on a constant 10% CF) for bottlenose dolphin and seals, starting at the pile location and at 2 km distance from the pile location, respectively, as presented in the original Moray West PS. 13
Table 3-6Maximum cumulative PTS impact ranges (m) for harbour porpoise with a constant CF of 10% for OSP location M11 and when followed consecutively by OSP 1 (E06) with ADD mitigation measures and threshold changes included. 13

Abbreviations and Acronyms

Acronym / Abbreviation	Description
ADD	Acoustic Deterrent Device
BOWL	Beatrice Offshore Windfarm Limited
CF	Conversion Factor
ECoW	Environmental Clerk of Works
EMP	Environmental Management Plan
JNCC	Joint Nature Conservation Committee
MMO	Marine Mammal Observer
MS-LOT	Marine Scotland - Licensing Operations Team
NS	Non-summer (Oct – Jun inclusive)
OSP	Offshore Substation Platform
OWF	Offshore Wind Farm
PAMS	Passive Acoustic Monitoring System
PEMP	Project Environmental Monitoring Programme
PMP	Piling Mitigation Protocol
PS	Piling Strategy
PTS	Permanent Threshold Shift
S	Summer (Jul – Sep inclusive)
SNCB	Statutory Nature Conservation Bodies
WTG	Wind Turbine Generator

1 Introduction

This document presents the Moray West Piling Mitigation Protocol (PMP) and has been prepared to address the specific requirements of the relevant conditions attached to the OfTI Marine Licence issued to Moray Offshore Windfarm (West) Limited (Moray West).

This PMP will be adhered to during pile driving operations for the installations of two offshore substation platforms (OSP) monopile foundations within the Moray West Offshore Wind Farm Site (referred to as Moray West Site).

The primary purpose of this PMP is to outline the procedure to mitigate the risk of injury (death or permanent hearing loss) to marine mammals within the immediate vicinity of pile driving operations at the OSPs monopile foundation location within the Moray West Site.

1.1 Background

Since the implementation of the Joint Nature Conservation Committee (JNCC) (2010) guidelines for minimising the risk of injury to marine mammals from piling noise, consents issued for offshore wind farms have focused on minimising the instantaneous near-field impacts of piling on marine mammals. However, as these guidelines have not been updated since, they do not take into consideration more recent developments in our understanding of the effects of underwater noise on marine mammals and, therefore, different mitigation measures may now be more appropriate. For example, recent studies (e.g., Brandt et al. 2013a, Brandt et al. 2013b, Gordon et al. 2015, McGarry et al. 2017, Boisseau et al. 2021, Graham et al. Submitted) have provided evidence that acoustic deterrent devices (ADDs) can be effective at producing aversive responses from cetaceans and seals over ranges which are greater than predicted zones for instantaneous injury (see Appendix 1). This suggests that, whilst not recognised as a primary tool for mitigation in the current JNCC (2010) piling guidelines, the use of ADDs could be successfully integrated into piling procedures to provide mitigation for marine mammals prior to the soft-start in a manner that would be more effective and provide more protection to marine mammals than the currently recommended methods (Thompson and McGarry 2015). This document presents the proposed approach for mitigating the risk of instantaneous and cumulative auditory injury to marine mammals during piling at the Moray West Site using ADDs. The approach presented here is based on the protocol recommended by Thompson and McGarry (2015) during piling at the Beatrice Offshore Windfarm Limited (BOWL) and Moray Offshore Windfarm (East) Limited (Moray East) that was successfully implemented during the construction of those offshore wind farms (OWF).

Impacts were assessed for selected WTGs monopile installation locations and piling scenarios, to inform the marine mammal impact assessment (Appendix C of the original Moray West PS) and the piling mitigation protocol (PMP) presented in Appendix D of the original Moray West PS. For the OSPs monopile installation locations, auditory injury for harbour porpoise and minke whale have been reassessed, following which this PMP version has been updated (Addendum to Appendix D).

1.2 Objectives of the PMP

The purpose of this document is to outline the recommended procedure for mitigating the risk of instantaneous and cumulative auditory injury to marine mammals during pile driving operations at the

OSPs monopile foundation location within the Moray West Site.. The project aims to develop the '*Best Available Technique'* as defined in the JNCC (2010) piling mitigation guidance to ensure the highest possible level of environmental protection for marine mammals whilst also considering the commercial affordability and feasibility during piling.

The mitigation measures developed as part of the Moray West OfTI PS will aim to successfully:

- Minimise the risk of instantaneous auditory injury for marine mammals during piling;
- Allow piling to be conducted during periods of poor visibility e.g., darkness and adverse weather conditions and restarted following breaks in piling;
- Allow the mitigation measure process to be conducted safely; and
- Conduct construction activities in an efficient manner to minimise the overall duration of the period of potential risk to marine mammals.

2 Marine mammal impact ranges for auditory injury

Table 2-1 summarises the maximum instantaneous PTS-onset impact ranges for the maximum hammer energy during the soft-start and at full hammer energy at the Moray West Site for bottlenose dolphins and seals, as presented in the original Moray West PS (Appendix D).

Table 2-2 summarises the re-assessed maximum instantaneous PTS-onset impact ranges for harbour porpoises and minke whale for the maximum hammer energy during soft-start and at full hammer energy during the installation of OSP 1 (M11) monopile foundation location.

Table 2-1 Maximum instantaneous PTS-onset impact ranges (based on a constant 10% CF) for worst case locations for bottlenose dolphin and seals, as presented in the original Moray West PS.

Species	Location	Max PTS-onset range 550 kJ (soft start)	Max PTS-onset range 5000 kJ (full hammer energy)
Bottlenose dolphin	A02	18 m	54 m
Seals	A02	48 m	396 m

Table 2-2 Maximum instantaneous PTS onset impact ranges (based on a constant 10% CF) for worst case locations for harbour porpoise and minke whale considered in OSPs monopile locations noise modelling.

Species	Location	Max PTS-onset range 432 kJ (soft start)	Max PTS-onset range 2,158 kJ (full hammer energy)
Harbour porpoise	OSP 2 (M11)	579 m	1,595 m
Minke whale	OSP 2 (M11)	39 m	183 m

Table 2-3 summarises the cumulative PTS-onset impact ranges for bottlenose dolphin and seals, as presented in the original Moray West PS (Appendix D).

Table 2-4 summarises the re-assessed cumulative PTS-onset impact ranges for harbour porpoise and minke whale for a single piling event at OSP location OSP 2 (M11) and for consecutive piling at OSP 2 (M11) followed by OSP 1 (E06) as well as the number of animals within the impact area.

The modelling of cumulative PTS-onset impact ranges is based on a series of highly conservative assumptions that result in highly over-precautionary estimates of impact ranges and impact areas Therefore, estimates given in Table 2-3 and Table 2-4 are considered as overly conservative and unrealistic.

Table 2-3 Maximum cumulative PTS-onset impact ranges (based on a constant 10% CF) for worst case locations for bottlenose dolphin and seals, and number of animals within the impact area based on species density distribution maps, as presented in the original Moray West PS.

Species	Location	Refusal Risk	Max cumulative PTS-onset range (m)	Number of animals within the cumulative PTS-onset impact area
Bottlenose dolphin	A02	high	<45	<1
Seals	A02	high	127	<1

Table 2-4 Maximum cumulative PTS onset impact ranges (based on a constant 10% CF) for minke whale and harbour porpoise at OSP 2 (M11), and OSP 2 (M11) followed by OSP 1 (E06) and number of animals within the impact area based on species density distribution maps. (S – summer, NS – non-summer).

Species	Location	Refusal Risk	Max cumulative PTS-onset range (m)	Number of animals within the cumulative PTS-onset impact area
Harbour porpoise	OSP 2 (M11)	low	2,329	11
	OSP 2 (M11) then OSP 1 (E06)	low	3,827	18
Minke whale	OSP 2 (M11)	low	28,500	S: 4, NS: <1
	OSP 2 (M11) then OSP 1 (E06)	low	48,065	S: 6, NS: <1

3 Piling mitigation approach

The following sections outline various aspects taken into consideration to ensure an effective and efficient approach to mitigation during piling.

3.1 Use of ADD

This PMP recommends that the most suitable mitigation method is the use of pre-piling ADDs. This represents a deviation from the standard procedures used for piling mitigation as recommended by JNCC (2010). The JNCC (2010) guidelines recommend the use of Marine Mammal Observers (MMOs) to provide mitigation during daylight hours/periods of good visibility and Passive Acoustic Monitoring System (PAMS) operatives during hours of darkness/poor visibility to conduct pre-piling searches of a 1 km mitigation zone for 60 minutes prior to the commencement of the soft-start. Under the JNCC (2010) recommendations, ADDs should only be used in conjunction with visual and/or acoustic monitoring and were not considered sufficient for sole mitigation purposes due to the limited evidence on their efficacy at the time of writing (JNCC 2010). However, since 2010, numerous studies have been conducted into the efficacy of ADDs in deterring marine mammals (e.g., Brandt et al. 2013a, Brandt et al. 2013b, Gordon et al. 2015, McGarry et al. 2017, Boisseau et al. 2021, Graham et al. Submitted). Further details of such studies are presented in Appendix 1 of this PMP. These data present sufficient evidence that the Lofitech AS seal scarer device is capable of deterring animals out of the maximum predicted instantaneous PTS-onset impact range of 1,595 m at full hammer energy (OSP 2 (M11) (See Table 2-2).

In addition, there is now evidence that porpoises are displaced by construction vessel activity (Benhemma-Le Gall et al., 2021), ADDs and piling noise (Graham et al., 2019, Graham et al. Submitted), and thus the likelihood of an animal being with the impact zone at the start of pile driving is extremely low.

More recently, JNCC et al. (2016) have stated that “the SNCBs consider that certain types of ADDs have the potential to be used as an alternative to the mitigation provided by MMOs and PAM for harbour porpoise, harbour seals and potentially for grey seals. SNCB advice on cases applying to use ADDs as an alternative to MMOs/PAM will be considered on a case-by-case basis”. Visual monitoring is limited in that it is not suitable during periods of poor visibility (including darkness and adverse weather conditions) and the JNCC (2010) guidelines recognise that the alternative of using a PAMS is also limited in that it is only particularly effective within a 500 m mitigation zone and can only detect marine mammal species when they are vocalising. As such, this PMP does not include the use of visual or PAM methods and recommends the use of ADDs instead.

A similar mitigation protocol to that recommended in this PMP has previously been implemented during pile driving operations at BOWL and Moray East and, therefore, the efficacy of this protocol has been demonstrated. A risk assessment was undertaken previously for the BOWL and Moray East offshore wind farms, demonstrating that the use of such mitigation procedures should present negligible additional risk to key marine mammal species that occur in the Moray Firth (Thompson and McGarry 2015). As Moray West is planning to implement a very similar methodology, it is likely that the risk of this PMP would also present a negligible additional risk from following the standard procedure previously recommended by

the JNCC (2010). As an addition to the mitigation measures proposed above, the ADD operator will visually monitor the mitigation zone for marine fauna, when visibility allows, throughout the mitigation period.

3.1.1 ADD protocol

The protocol will require the deployment and activation of an ADD at each OSP piling location to allow marine mammals to be displaced out of the injury impact ranges. In the case of piling two foundations within 24 hours, the ADD activation period should follow the recommendation for consecutive piling for the first pile, whilst for the second pile, the ADD activation period can be reduced to the time recommended for single piling or can be omitted in the case that the break in piling is less than 6 hours. An ADD will be deployed from the deck of the installation vessel, with the control unit and power supply on board the installation vessel in a suitable, safe position on deck. The exact deployment procedure will be agreed once the piling contractor is in place and will follow safe, standard working practices using an experienced/trained ADD operator.

The ADD operator will be responsible for deploying and testing the ADD prior to the commencement of pilling operations to ensure it is functioning as required prior to each use. The ADD will be tested by deploying a calibrated hydrophone near the ADD, which will be connected to a computer with a suitable sound card and software e.g., PAMGuard, used to verify the signal. Following testing and prior to the soft-start, the ADD operator will then activate the ADD and notify the installation manager that the ADD is active. The ADD operator will visually monitor the mitigation zone for marine fauna, when visibility allows, throughout the mitigation period (see Figure 4-1). The ADD operator will maintain a log of all ADD deployments so that reports from each monopile installation can be provided (see section 7).

3.1.1.1 ADD duration

The use of an ADD for mitigation purposes needs to be balanced against known far-field disturbance resulting from ADD use (Thompson et al., 2020) to ensure it is activated for the optimum amount of time to achieve the desired aversive effect. The proposed duration of ADD activation is obtained by the time taken for an animal to exit the PTS-onset impact zone before impact, based on the likely swimming speed of an animal (Table 3-1).

3.1.1.1.1 Instantaneous PTS

With the largest soft-start instantaneous PTS-onset impact range of 579 m and slowest swimming speed of 1.4 m/s, harbour porpoise will take the longest time to exit their PTS-onset impact range (less than 7 minutes) (Table 3-1 and Table 3-2). For all other species, the time required is less than 1 minute. Therefore, the minimum ADD activation period is recommended as 8 minutes to allow all animals sufficient time to exit the instantaneous PTS-onset impact range prior to the first blow of the soft-start. The installation of each OSP monopile foundations will involve a soft-start procedure of a minimum of 17 minutes[1] where a maximum hammer energy of 432 kJ will be used. It is anticipated that, following the commencement of

[1] JNCC Guidance describes the soft-start as the gradual ramp up of piling power until full operational power is achieved. The soft-start duration should be a period of not less than 20 minutes. In this PS, ramp-up of the hammer energy will follow the soft-start procedure (minimum of 15 min). Overall, the soft-start and ramp-up procedures will be longer than the 20 minutes recommended by JNCC Guidance.

the soft-start, animals will continue to move away from the noise source. Therefore, by the end of the minimum soft-start period (including the 8 minute ADD activation followed by a 17 minute soft-start), it is estimated that animals would be at least 2,100 m from the noise source before the hammer energy will be increased further.

Table 3-1 Estimated time for bottlenose dolphin and seals to exit the maximum instantaneous PTS-onset range (based on a 10% CF) for a soft start (550 kJ), as presented in the original Moray West PS.

Species	Maximum instantaneous PTS-onset range at soft-start	Swim speed	Time required to exit soft-start instantaneous PTS-onset impact range
Bottlenose dolphin	18 m	1.52 m/s	<1 minute
Seals	48 m	1.8 m/s	<1 minute

Table 3-2 Estimated time for harbour porpoise and minke whale to exit the maximum instantaneous PTS-onset range (based on a 10% CF) for a soft start (432 kJ) considered in the OSP monopile locations noise modelling.

Species	Maximum instantaneous PTS-onset range at soft-start	Swim speed	Time required to exit soft-start instantaneous PTS-onset impact range
Harbour porpoise	579 m	1.4 m/s	<7 minutes
Minke whale	39 m	2.1 m/s	<1 minute

As presented in the original Moray West PS, at 5,000 kJ hammer energy (Table 3-3), the time required for bottlenose dolphins and seals to exit the instantaneous PTS-onset range remains shorter than the initial 8 minute ADD activation.

Harbour porpoise (Table 3-4) have the largest instantaneous PTS-onset impact range at full hammer energy (1,595 m) and slowest swimming speed (1.4 m/s). It will, therefore, take 18.9 minutes for harbour porpoise to exit the instantaneous PTS-onset impact range at full hammer energy (2,158 kJ).

For the smaller impact areas at the OSPs monopile foundation locations (Table 2-2), 8 minutes of ADD activation will be sufficient for harbour porpoise and minke whale to exit the PTS-onset impact range at full hammer energy (2,158 kJ).

Table 3-3 Estimated time for bottlenose dolphin and seals to exit the maximum instantaneous PTS-onset range (based on a 10% CF) for full hammer energy (5,000 kJ), as presented in the original Moray West PS.			
Species	**Maximum instantaneous PTS-onset range at full hammer energy (10% CF)**	**Swim speed**	**Time required to exit instantaneous PTS-onset impact range at full hammer energy**
Bottlenose dolphin	54 m	1.52 m/s	<1 minute
Seals	396 m	1.8 m/s	3.7 minute

Table 3-4 Estimated time for harbour porpoise and minke whale to exit the maximum instantaneous PTS-onset range (based on a 10% CF) for full hammer energy (2,158 kJ).			
Species	**Maximum instantaneous PTS-onset range at full hammer energy (10% CF)**	**Swim speed**	**Time required to exit instantaneous PTS-onset impact range at full hammer energy**
Harbour porpoise	1,595 m	1.4 m/s	18.9 minutes
Minke whale	183 m	2.1 m/s	1.4 minutes

It is anticipated that displacement of animals will likely begin prior to the ADD activation, as a result of installation vessel activity. Studies at both Beatrice and Moray East offshore wind farms sites in the Moray Firth (Benhemma-Le Gall et al. 2021) and other North Sea sites (Brandt et al. 2018) have shown that harbour porpoises are displaced from the immediate vicinity of the piling location prior to the commencement of ADD mitigation and pile driving, likely due to increased vessel traffic. For example, during the construction of the BOWL and Moray East, harbour porpoise occurrence decreased with increasing vessel presence up to 3 km, with the magnitude of decrease depending on the distance to the vessel (Benhemma-Le Gall et al. 2021).

3.1.1.1.2 Cumulative PTS

A longer ADD activation would be needed in order for a harbour porpoise starting at the pile location to exit the (overly precautionary and unrealistic) cumulative PTS-onset impact ranges (Table 3-6). Considering that high vessel noise reduces harbour porpoise occurrence to near zero up to 2 km from the pile site (Benhemma-Le Gall et al., 2021), it can be assumed that prior to piling commencing, animals would already be 2 km from the pile.

Cumulative PTS-onset impact ranges for harbour porpoise from the OSP location OSP 2 (M11) and consecutive piling of OSP 2 (M11) followed by OSP 1 (E06) can be reduced below 2 km with 13 minutes of ADD use, if some of the conservatism is accounted for by increasing the cumulative PTS-onset threshold by 1 dB (Table 3-6).

For minke whale, ADD activation is not considered an appropriate measure for mitigating cumulative PTS. For this species, a different mitigation approach is considered as outlined in Section3.3.

Table 3-5 Estimated time for an animal to exit the maximum cumulative PTS onset range (based on a constant 10% CF) for bottlenose dolphin and seals, starting at the pile location and at 2 km distance from the pile location, respectively, as presented in the original Moray West PS.

Species	Refusal Risk	Max cumulative PTS-onset range (m) (10% CF)	Swim speed	Time required (min) to exit the cumulative PTS-onset impact range starting at	
				Pile location	2 km distance
Bottlenose dolphin	high	<45	1.52 m/s	<1	<1
Seals	high	127	1.8 m/s	<2	<1

Table 3-6 Maximum cumulative PTS impact ranges (m) for harbour porpoise with a constant CF of 10% for OSP location OSP 2 (M11) and when followed consecutively by OSP 1 (E06) with ADD mitigation measures and threshold changes included.

Location	Unmitigated	8 min ADD	13 min ADD	13 min ADD and a threshold increase of			
				1 dB	2 dB	3 dB	4 dB
OSP 2 (M11)	2,329	1,702	1,344	...	...	...	...
OSP 2 (M11) then OSP 1 (E06)	3,827	3,326	2,846	1,900	1,323	601	<45

3.1.1.1.3 ADD duration conclusion

For the low refusal risk OSPs monopile foundation locations (both OSP locations are low refusal), the ADD should be activated for a minimum period of 8 minutes for a single piling event (recommended ADD activation interval between 8-13 minutes) and for a minimum period of 13 minutes for consecutive piling event (recommended ADD activation interval between 13-18 minutes). This will ensure all marine mammals (except minke whales) are outside of both the instantaneous and cumulative PTS impact ranges.

For minke whale, ADD activation is not considered an appropriate measure for mitigating cumulative PTS. For this species, a different mitigation approach is outlined in Section 3.3.

3.2 Soft-start and ramp-up

Following the pre-piling deployment of the ADDs, a soft-start procedure will commence. The installation of each OSP monopile foundation will involve a minimum of a 17-minute soft-start procedure where a maximum hammer energy of 432 kJ will be used at a strike rate of 28 blows/min.

Following the completion of the soft-start procedure, hammer energy will ramp-up gradually until a suitable energy level is reached, to maintain a steady rate of pile penetration For OSPs monopile

foundation locations, the modelling presented in the OfTI PS (Table 2-1 in Section 2.3) assumed the ramp-up varies between 130 minutes and 182 minutes. Hammer energy will not be increased above that required to complete each installation – i.e., if ground conditions are such that a lower than maximum hammer energy is sufficient to complete installation, then hammer energy will not be unnecessarily ramped up to the maximum permitted.

3.2.1 Protocol for planned or unplanned breaks in piling

3.2.1.1 Delay to the commencement of piling

If a delay to the commencement of piling occurs, there is a risk that animals may move back into the predicted impact range if the ADD is switched off. However, if the ADD is left on, there is a risk of animals being displaced to a much greater distance than necessary to mitigate PTS (resulting in unnecessary behavioural disturbance). There is also a risk of habituation to the noise source as a result of no aversive piling noise following the ADD activation. To avoid this issue, the ADD operator will be informed as soon as practicable of any delay to the commencement of piling so that it can be turned off. The ADD will not be reactivated until it is communicated to the ADD operator that piling is ready to commence. The ADD will then be reactivated as per the procedure stated in Section 3.1.1.

3.2.1.2 Break in piling

In order to minimise ADD use and, therefore, reduce any unnecessary disturbance to marine mammals, the ADD will not be re-deployed for breaks in piling that are less than 6 hours. This follows advice provided by NatureScot and MS-LOT on the Moray East Marine Mammal Mitigation Protocol (December 2018). Studies that have shown that harbour porpoise detections remain significantly reduced from the baseline up to 6 hours after ADD activation (Brandt et al. 2013b), and further studies in Germany showed reduced porpoise detection rates for 28-48 hours after the end of pile driving (Brandt et al. 2013a, Rose et al. 2019).

The required procedure for restarting operations following a break in piling is dependent on the length of the break (see Figure 4-1 for summary):

- In the event of breaks in piling of <10 minutes, no mitigation is required. The pile driving can continue from the last hammer energy and strike rate (or lower) used without the need for another ADD deployment.
- For breaks in piling >10 minutes but <6 hours, pile driving will recommence with a full soft-start and ramp-up in hammer energy, wherever this is safe to do so, but without the need for pre-piling ADD deployment.
- If the break in piling is >6 hours, then the full pilling mitigation procedure of pre-piling ADD deployment, soft-start and ramp-up will be conducted.

3.3 Optimization of piling sequencing

Low refusal risk locations are planned to be installed throughout the installation period, i.e., potentially also in summer months. Considering more realistic cumulative PTS impact ranges, the risk of a minke whale experiencing cumulative PTS from the installation of the OSPs monopiles during summer is low, with less than one animal being expected to experience PTS from a single piling event and consecutive piling events. For the WTGs monopile locations this estimate will be revisited and included in the Wind Farm PS.

3.4 Monitoring and Audit

Moray West will establish an agreed monitoring system and an audit trail to demonstrate that:

- The ADD was functioning according to specifications during all operations,
- The ADD was activated for the required time period prior to the soft-start,
- Hammer energies remained within agreed upon limits within soft-start periods, and
- Soft-start durations were conducted as specified.

The detailed monitoring and reporting procedures can be integrated within the Moray West Environmental Management Plan (EMP; 8460005-DBHA06-MWW-PLN-000001) and Project Environmental Monitoring Programme (PEMP; 8460005-DBHA13-MWW-PLN-000001).

4 Piling procedure

A schematic diagram of the steps in the piling procedure with the application of this mitigation protocol is provided in Figure 4-1.

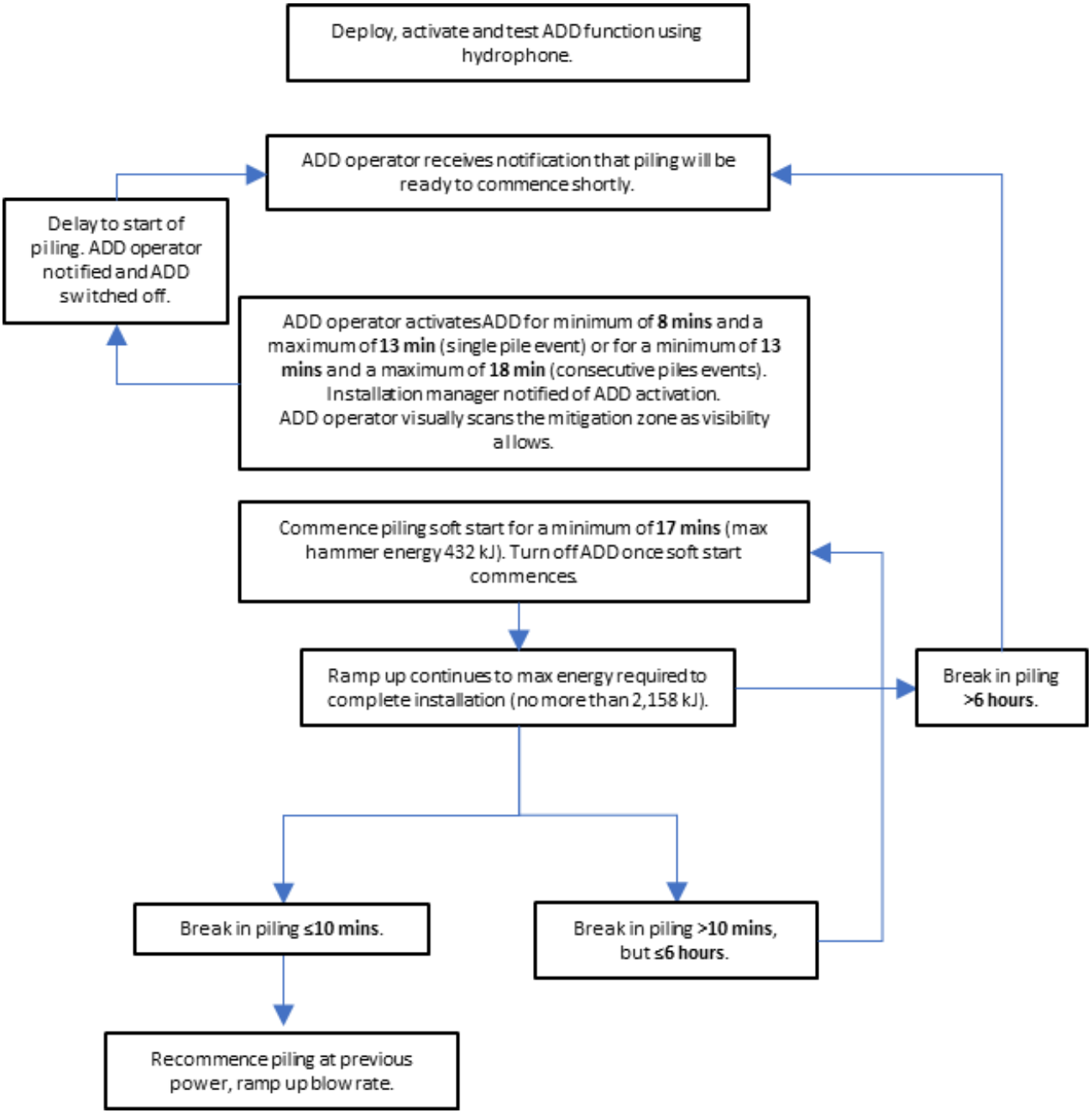


Figure 4-1 Schematic providing an example of a piling mitigation procedure for the OSPs.

5 Roles and responsibilities

The following section details the roles and responsibilities necessary for implementing this PMP and details how communications will be managed between parties involved in piling operations.

5.1 Project Manager

The Project Manager will ensure that contractual obligations are established for all contractors in relation to the OfTI PS and PMP. This will require that all contractors involved in construction activities assist and support the Ecological Clerk of Works (ECoW) to deliver the commitments in this PMP. They will ensure that the purpose of this PMP (to prevent injury to marine mammals) is made clear to all personnel and contractors involved in construction activities.

5.2 Marine Installation Manager

The Marine Installation Manager will be responsible for the piling operations. They will have the following responsibilities:

- Ensuring that resources and processes are put in place across the Marine Installation package to deliver/comply with this PMP;
- Ensuring that matters relating to the delivery of this PMP are part of the construction progress meetings and Project inductions;
- Ensuring that all personnel and contractors involved in construction activities support both the ADD operator and ECoW to deliver/comply with this PMP, as well as supporting monitoring and auditing compliance with the PS;
- Establishing contractual obligations for Key Contractors and Subcontractors in relation to the PS and PMP;
- Reporting to the Project Manager on matters related to the OfTI PS and PMP; and
- Where necessary, addressing Key Contractor and Subcontractor non-compliance in relation to the PS and PMP.

5.3 Construction Contractor

The Construction Contractor will be required to ensure implementation of and compliance with the PS and PMP during construction and will need to liaise with both the ADD Operator and the Moray West Development team and the ECoW.

5.4 Environmental Clerk of Works (ECoW)

The ECoW will provide quality assurance of the PS (as required under the S36 Consent and Marine Licences) and will provide advice to Moray West on compliance with the OfTI PS. The ECoW is responsible for communicating the requirements of the OfTI PS and ensuring this PMP is implemented. The ECoW will work with the ADD Operator and all other personnel and contractors involved in construction activities to ensure that the requirements of the OfTI PS are understood. The ECoW will undertake site inductions with

regard to this PMP, and ensure that this PMP is implemented. The ECoW will also be responsible for reporting on compliance to the Licensing Authority.

5.5 ADD Operator

A trained and dedicated ADD operator will be responsible for ADD maintenance, operation and reporting. The ADD operator duties will be to:

- Identify an appropriate location for the ADD deployment locations (with assistance of the vessel crew) and input to any health and safety risk assessments required;
- Deploy the ADD from the installation platform or vessel;
- Verify the operation of the ADD before piling operations commence;
- Operate the ADD throughout the pre-piling period (and be available in the case of piling breaks to reactivate the ADD);
- Ensure batteries are charged and that spare equipment is available in case of any issues;
- Visually monitor the mitigation zone for marine fauna, when visibility allows, throughout the mitigation period; and,
- Record and report on all ADD and piling activity, as well as marine fauna sightings.

6 Communications

A PMP communications protocol will be prepared by Moray West prior commencement of pile driving campaign and provided to installation contractor and ADD operator for implementation on the installation vessel. The communications protocol will include, but not be limited to:

- Procedure to notify ADD operator to set-up equipment and test the ADD;
- Procedure to deploy and activate the ADD for a minimum of 8 minutes and a maximum of 13 minutes (for single piling events) and for a minimum of 13 minutes and a maximum of 18 minutes (for consecutive piling events) prior to soft-start commencing;
- Procedure to notify the installation manager that deployment of ADDs and activation for the required time has been successful and soft-start can commence, or if deployment of ADDs and activation has not been successful that soft-start will be delayed;
- Procedure for the installation manager to notify ADD operator that there has been a delay in the onset of the soft-start and that ADD should be turned off;
- Procedure for the installation manager to notify ADD operator that soft-start is successfully underway and the ADDs can be deactivated; and

- Procedure for the installation manager to notify ADD operator that there is a break in piling (planned or unplanned) requiring re-deployment and activation of the ADDs (break in piling over 6 hours).

7 Reporting

A record of all piling operations and ADD deployments will be maintained by the ADD operator. Reports will include:

- A mobilisation report of the ADD equipment detailing deployment locations and verification of equipment testing;
- Record of all piling operations detailing date, soft-start duration, piling duration, hammer energy during soft-start and piling and any operational issues for each pile;
- Record of ADD deployment, including start and end times of all periods of ADD activation, any problems with ADD deployment;
- Record of all sightings of marine mammals in the mitigation zone during the mitigation period, when visibility allows for visual monitoring;
- Details of any problems encountered during the piling process including instances of non-compliance with the agreed piling protocol;
- Record of all incidental sightings of marine mammals around the piling vessel (species, activity and distance/bearing from the vessel recorded); and
- Any recommendations for amendment of the protocol.

Reports (interim and final) will be provided to the Licensing Authority and any other relevant parties.

8 References

Benhemma-Le Gall, A., I. Graham, N. Merchant, and P. Thompson. 2021. Broad-scale responses of harbor porpoises to pile-driving and vessel activities during offshore windfarm construction. Frontiers in Marine Science **8**:664724.

Boisseau, O., T. McGarry, S. Stephenson, R. Compton, A. C. Cucknell, C. Ryan, R. McLanaghan, and A. Moscrop. 2021. Minke whales Balaenoptera acutorostrata avoid a 15 kHz acoustic deterrent device (ADD). Marine Ecology Progress Series **667**:191-206.

Brandt, M. J., A. Diederichs, K. Betke, and G. Nehls. 2011. Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Marine Ecology Progress Series **421**:205-216.

Brandt, M. J., A. Diederichs, and G. Nehls. 2009. Harbour porpoise responses to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea.

Brandt, M. J., A.-C. Dragon, A. Diederichs, M. A. Bellmann, V. Wahl, W. Piper, J. Nabe-Nielsen, and G. Nehls. 2018. Disturbance of harbour porpoises during construction of the first seven offshore wind farms in Germany. Marine Ecology Progress Series **596**:213-232.

Brandt, M. J., C. Hoeschle, 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, M. J., C. Hoeschle, A. Diederichs, K. Betke, R. Matuschek, S. Witte, and G. Nehls. 2013b. Far-reaching effects of a seal scarer on harbour porpoises, *Phocoena phocoena*. Aquatic Conservation-Marine and Freshwater Ecosystems **23**:222-232.

Carstensen, J., O. D. Henriksen, and J. Teilmann. 2006. Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODS). Marine Ecology Progress Series **321**:295-308.

Gordon, J., C. Blight, E. Bryant, and D. Thompson. 2015. Tests of acoustic signals for aversive sound mitigation with harbour seals. Sea Mammal Research Unit report to Scottish Government. MR 8.1 Report. Marine Mammal Scientific Support Research Programme MMSS/001/11.

Graham, I., D. Gillespie, K. Gkikopoulou, G. Hastie, and P. Thompson. Submitted. Directional hydrophone clusters reveal evasive responses of small cetaceans to disturbance at offshore windfarms. Biology Letters.

Graham, I. M., N. D. Merchant, A. Farcas, T. R. C. Barton, B. Cheney, S. Bono, and P. M. Thompson. 2019. Harbour porpoise responses to pile-driving diminish over time. Royal Society Open Science **6**:190335.

Haelters, J., W. Van Roy, L. Vigin, and S. Degraer. 2012. The effect of pile driving on harbour porpoise in Belgian waters. Pages 127-144 *in* S. Degraer, R. Brabant, and B. Rumes, editors. Offshore wind farms in the Belgian part of the North Sea: Heading for an understanding of environmental impacts.

JNCC. 2010. Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise.

JNCC, NE, SNH, and NRW. 2016. Joint Statutory Nature Conservation Bodies Position Statement: ORJIP Project 4, Stage1 of Phase 2 “The use of Acoustic Deterrents for the mitigation of injury to marine mammals during pile driving for offshore wind farm construction”.

McGarry, T., O. Boisseau, S. Stephenson, and R. Compton. 2017. Understanding the Effectiveness of Acoustic Deterrent Devices (ADDs) on Minke Whale (*Balaenoptera acutorostrata*), a Low

Frequency Cetacean. Report for the Offshore Renewables Joint Industry Programme (ORJIP) Project 4, Phase 2. Prepared on behalf of the Carbon Trust.

Ramboll. 2021. Moray West foundation feed engineering report: Driveability Assessment.

Rose, A., M. J. Brandt, R. Vilela, A. Diederichs, A. Schubert, V. Kosarev, G. Nehls, M. Volkenandt, V. Wahl, A. Michalik, H. Wendeln, A. Freund, C. Ketzer, B. Limmer, M. Laczny, and W. Piper. 2019. Effects of noise-mitigated offshore pile driving on harbour porpoise abundance in the German Bight 2014-2016 (Gescha 2). IBL Umweltplanung GmbH, Institut für Angewandte Ökosystemforschung Gmb, BioConsult SH GmbH & Co KG, Husum.

Southall, B., J. J. Finneran, C. Reichmuth, P. E. Nachtigall, D. R. Ketten, A. E. Bowles, W. T. Ellison, D. Nowacek, and P. Tyack. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals **45**:125-232.

Thompson, P., and T. McGarry. 2015. Protocol for mitigating the risk of instantaneous death or injury to marine mammals during piling at the BOWL and MORL Wind Farms.

Thompson, P. M., I. M. Graham, B. Cheney, T. R. Barton, A. Farcas, and N. D. Merchant. 2020. Balancing risks of injury and disturbance to marine mammals when pile driving at offshore windfarms. Ecological Solutions and Evidence **1**.

Appendix 1. ADD effectiveness evidence base

As the Lofitech AS seal scarer has been successfully used for marine mammal mitigation purposes at a number of offshore wind farm construction projects in Europe, it is anticipated this device will be used for mitigation during the construction of Moray West. For example, in UK waters, the Lofitech device has recently been successfully used for marine mammal mitigation purposes for harbour porpoise, harbour seal and grey seal during piling construction activities at several offshore wind farms and, elsewhere in Europe, it has been successfully used during construction at the C-Power Thornton Bank offshore wind farm in Belgium (Haelters et al. 2012), the Horns Rev II, Nysted and Dan Tysk offshore wind farms in Denmark (Carstensen et al. 2006, Brandt et al. 2009, Brandt et al. 2011, Brandt et al. 2013a, Brandt et al. 2013b) and on various German sites (Georg Nehls, pers comm). Based on the evidence below, the Lofitech ADD is capable of mitigating the small instantaneous PTS-onset ranges for Moray West pile driving activities.

1. Harbour porpoise

In the German North Sea, an array of CPODs was used to test the effectiveness of Lofitech devices for deterring harbour porpoise (Brandt et al. 2013b). The extent of deterrence was measured by recording porpoise vocalisations up to 7.5 km from the Lofitech deployment site. Ten trials were conducted, where each trial collected four hours of acoustic detections, in conjunction with an active ADD. During the 40 hours of collected data, there was a significant decline in porpoise detections. Within 750 m, detections of porpoise declined by 86% when the ADD was active. Furthermore, declines in porpoise detections were significant up to 7.5 km from the ADD source (Figure 8-1).

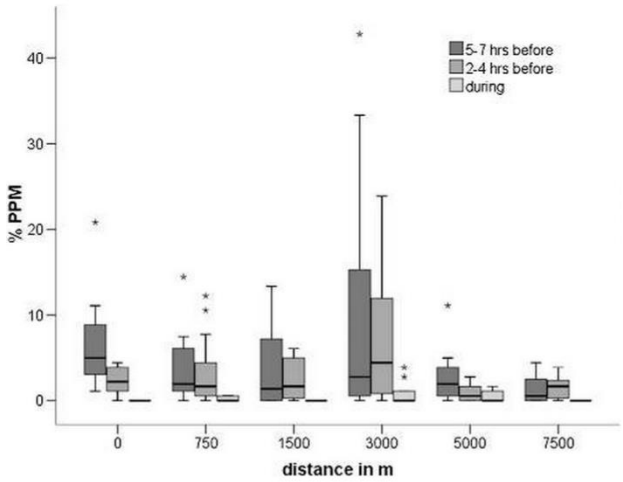


Figure 8-1 Percentage of porpoise positive minutes recorded before and during Lofitech trials at various distances. Figure taken from Brandt et al. (2013b).

In addition to acoustic monitoring, visual aerial surveys were conducted to identify changes in harbour porpoise presence during ADD activation. The average density fell to 0.3 porpoise/km^2 when the Lofitech device was activated, where baseline density estimates were 2.4 porpoise/km^2, over the 990 km^2 study area (Figure 8-2). To determine the duration of deterrence caused by ADDs, Brandt et al. (2013b)

compared harbour porpoise detections before Lofitech activation, and after the device was switched off. Porpoise detection rates were significantly lower up to six hours after devices were switched off, and after 7-9 hours, no significant difference was detected.

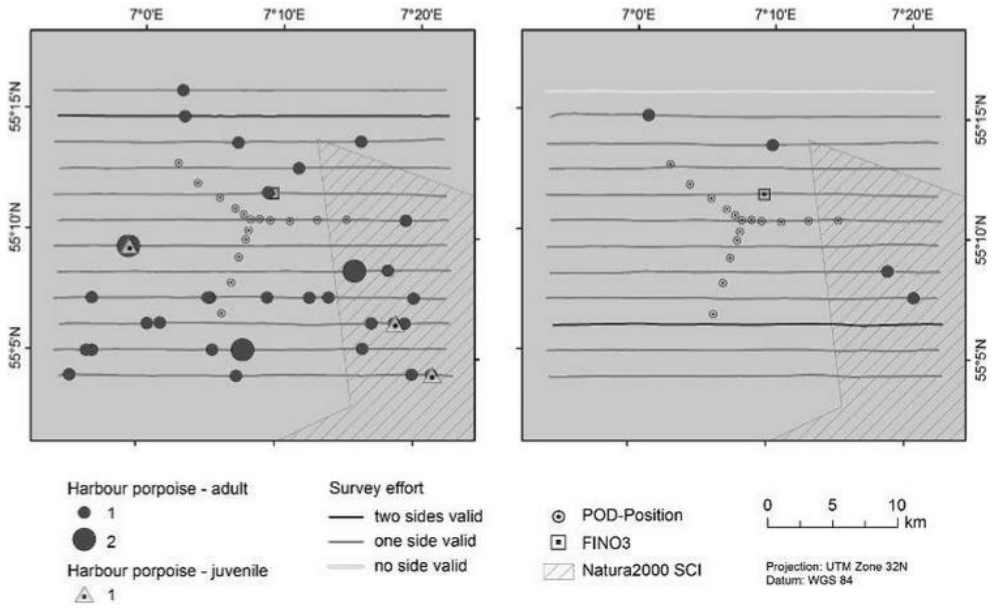


Figure 8-2 Harbour porpoise aerial sightings before (left) and during (right) Lofitech activation. Figure taken from Brandt et al. (2013b).

Brandt et al. (2013a) conducted visual surveys to determine the responses of harbour porpoises to Lofitech ADDs (Figure 8-3 and Figure 8-4). In Danish waters, devices were active for 4 continuous hours, with 7 trials in total, leading to 28 hours of collected data. Sighting rates of harbour porpoise significantly declined up to 1 km from the active Lofitech device, which was associated with a minimum sound level of 129 db re 1 µPa RMS. Upon activation of the ADD, the mean number of porpoises detected during a scan decreased from 0.86 to 0.01. While Lofitech trials in German waters observed avoidance up to 7.5 km from the device, in Danish waters avoidance was detected at a maximum of 2.4 km from the ADD. However, due to differences in water depth, the sound level at the offshore German site (119 dB re 1 µPa) and the more coastal Danish site were comparable. Porpoise avoidance behaviour occurred immediately upon device activation, with average swim speeds recorded at 1.6 m/s. Visual observations confirmed porpoises within a 1 km radius of the device, on average 51 minutes after the device was deactivated.

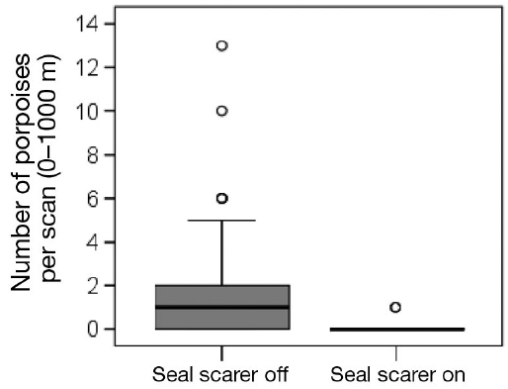


Figure 8-3 Number of harbour porpoises seen during scans when the Lofitech device was active and inactive. Figure taken from Brandt et al. (2013a).

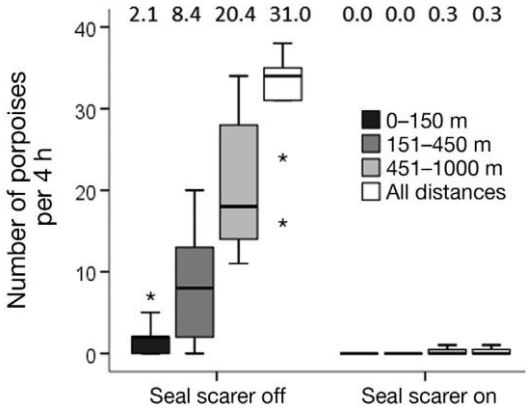


Figure 8-4 Harbour porpoises sightings rates when the Lofitech device was active and inactive over a range of distances. Figure taken from Brandt et al. (2013a).

2. Minke whale

During a study commissioned by ORJIP, the playback of Lofitech ADDs resulted in behavioural modifications of minke whales (McGarry et al. 2017, Boisseau et al. 2021). A significant increase in swim speed and direct movement away from the ADD source implied avoidance of the Lofitech device (Figure 8-5). It was therefore suggested that Lofitech seal scarers may be used as a deterrent of minke whales from mitigation zones in the future. One limitation of this study was the ability to follow the focal whale after it had been exposed to the ADD. The ADD was activated 1 km from the focal animal, and remained active for 15 minutes; all animals responded, which demonstrates an effective deterrence zone of at least 1 km. No measurements were made with ADDs activated at initial distances > 1 km from the focal animal, and the visual limit of observations limited how far animals could be observed responding to, so it is not known what the maximum effective deterrence range is. However, several animals were observed continuing to swim further away to a distance of between c. 3 km and 4.5 km following exposure.

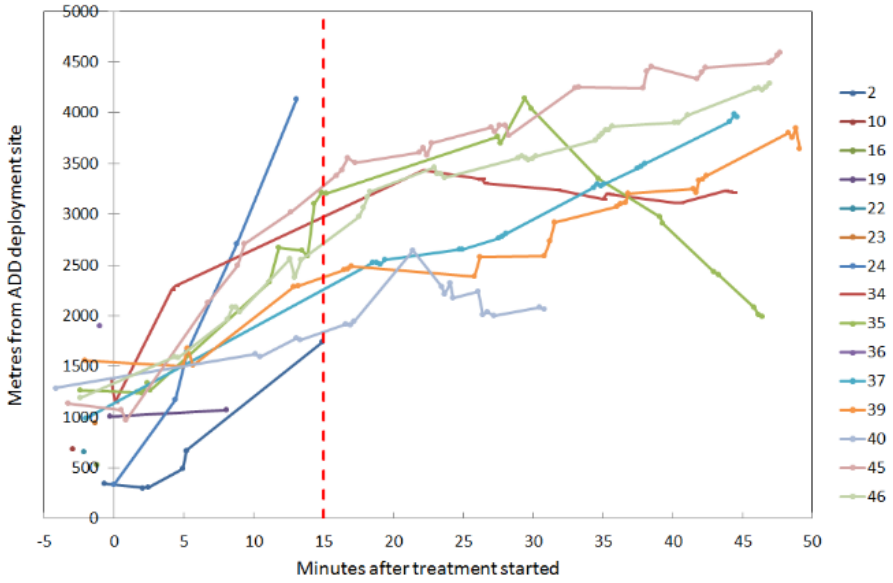


Figure 8-5 Distance of focal whales from the ADD deployment site during treatment and post treatment phases of the experiment. The red dashed line indicates the end of the treatment phase. Figure taken from McGarry et al. (2017).

3. Seals

In 2015, Marine Scotland funded a project to assess the effectiveness of Lofitech devices as harbour seal deterrents (Gordon et al. 2015). In Kyle Rhea in 2013, 10 seals were tagged, and in the Moray Firth in 2014, 13 tags were deployed. In total, 73 controlled exposure experiments were conducted, and responses monitored using a novel telemetry tracking system. All animals within ~1 km of the source exhibited a behavioural response during CEEs (n=38) (Figure 8-6 and Figure 8-7). A lack of response to the CEE was first observed 998 m from the device, with a predicted received sound level of 132 dB re 1 µPa RMS (Figure8-6). Conversely, responses were detected up to 3.112 km from the ADD, where the predicted received level was 120 dB re 1 µPa RMS. However, distances further than 1 km device were characterised by lower response rates, for example, at 4.1 km from the source, only 20% of seals responded to the CEE (Figure 8-7). Overall, it was concluded that the use the Lofitech device would deter seals up to ~1 km from the source.

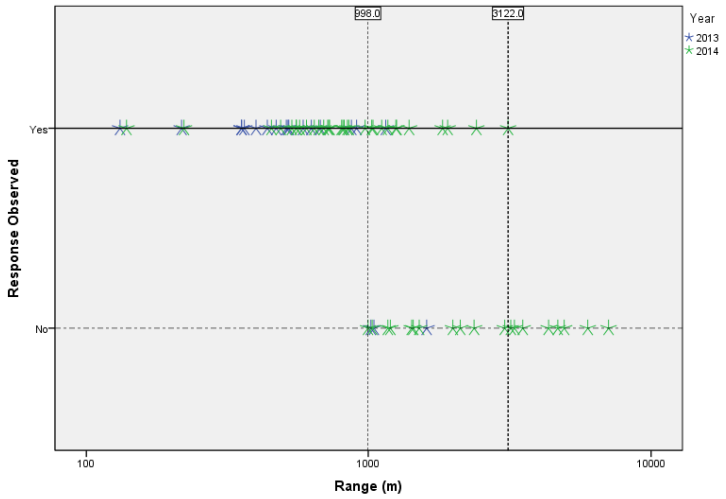


Figure 8-6 Controlled exposure experiments with harbour seals and the Lofitech device which did and did not elicit responses plotted against range. The range of the first closest non-responsive CEE and the most distant responsive CEEs are indicated by the dotted vertical lines. Figure taken from Gordon et al. (2015).

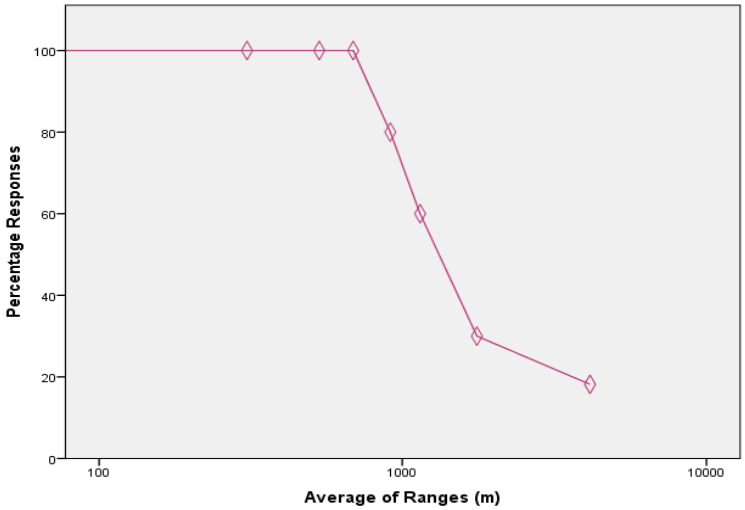


Figure 8-7 Percentage of controlled exposure experiments with harbour seals and the Lofitech device eliciting a response ranked by range. Figure taken from Gordon et al. (2015).

4. Dolphin species

For dolphin species, there has been little/ no research on deterrence using Lofitech device. Given that the maximum modelled PTS-onset range for bottlenose dolphins is 54 m (see PS Appendix C: Underwater Noise Impact Assessment), it is considered that the pre-construction vessel activity and the ADD activation period will be suitable to mitigate this range.

Appendix E – Appendix C of the original Piling Strategy – Underwater noise impact assessment

MORAY OFFSHORE WINDFARM (WEST) LIMITED

Piling Strategy
Appendix C: Underwater Noise Impact Assessment

Document Name: 8460005-DBHA04-MWW-REP-000001

Revision: 1

Status: Final

Date: 31-05-2022

Version Control				
Revision	Date	Status	Revision Description	Distribution List
0	13-05-2022	Draft	Moray West Review	Moray West
1	31-05-2022	Final	Moray West Piling Strategy Appendix C Submission to MS-LOT	MS-LOT

Table of Contents

Table of Contents 3
Figures 4
Tables 6
Abbreviations and Acronyms 9
1 Introduction 13
2 Assessment Methodology 13
2.1 Piling locations and scenarios 13
2.2 Source model 16
2.3 Propagation model 16
2.4 Input data 16
2.5 Piling profiles 17
2.6 Metrics modelled and Assessment Criteria 19
2.6.1 Metrics 19
2.6.2 Marine Mammal Assessment Criteria 20
2.6.3 Fish Assessment Criteria 36
2.6.4 Assessment of potential effects 37
2.6.5 Population modelling 41
2.6.6 Comparison with EIA Report 2018 42
2.6.7 Comparison with 2018 RIAA 44
3 Marine Mammal Assessment Results 44
3.1 Auditory injury 44
3.1.1 Instantaneous PTS 44
3.1.2 Cumulative PTS 47
3.1.3 Worked example: Cumulative PTS impact ranges for minke whale 55
3.2 Disturbance 57
3.2.1 Harbour porpoise 57
3.2.2 Bottlenose dolphin 62
3.2.3 Minke whale 66
3.2.4 Grey seal 70

3.2.5 Harbour seal 73
3.2.6 Limitations of disturbance assessment 78
3.3 Proposed mitigation measures 82
3.4 Comparison to 2018 EIA 82
3.5 Comparison to 2018 RIAA 84
4 Fish Assessment Results 84
4.1 SPL_{peak} Assessment of Mortality and Recoverable Injury in Fish 84
4.2 Cumulative SEL Assessment of TTS, Recoverable Injury, and Mortality Effect Zones for Fish 85
4.3 Comparison to 2018 EIA 86
5 References 99

Figures

Figure 2-1 Noise modelling locations to inform Piling Strategy – turbine locations with moderate (blue) and high (red) risk of pile refusal are indicated; numbered locations are included in the noise modelling for comparison with the original noise modelling locations used in the Application. The final layout is indicated by small black dots connected with cable lines. 15
Figure 2-2 Piling profiles from the six locations considered for modelling, showing hammer energy (red) and blow rate (black) over time. 18
Figure 2-3 Dose-response relationship for harbour porpoise developed by Graham et al. (2017) used for all cetacean in this assessment 25
Figure 2-4 Dose-response data for harbour seal derived from the data collected and analysed by Whyte et al. (2020) used for harbour and grey seals in this assessment 26
Figure 2-5 Minke whale summer density surface based on SCANS III block S density estimate and the relative minke whale distribution as presented in Paxton et al. (2014) 29
Figure 2-6 Minke whale non-summer density surface based on SCANS III block S density estimate and the relative minke whale distribution as presented in Paxton et al. (2014) and the absolute densities given in Paxton et al. (2016). 30
Figure 2-7 Grey seal GPS tracking data from tags deployed during the project of Carter et al. (2020). Tracks are coloured by individual (n=100). White stars denote deployment locations (clockwise from bottom left); Ramsey & Skomer Islands, Bardsey Island, Dee Estuary, Islay & Oronsay (West Scotland), the Monach Isles (Western Isles), Orkney & Pentland Firth (North Scotland & Northern Isles), Dornoch Firth (Moray Firth). Source: Figure 1 of Carter et al. (2020). 32
Figure 2-8 Grey seal density surface map based on Carter et al. 2020. 33
Figure 2-9 Harbour seal density surface map based on Carter et al. (2020). 35
Figure 3-1 Harbour porpoise cumulative PTS-onset impact ranges for locations P18 and N17, featuring different conversion factor scenarios. 50

Figure 3-2 Minke whale cumulative PTS impact ranges for locations L07 and N07, featuring different conversion factor scenarios. 52
Figure 3-3 Minke whale cumulative PTS-onset impact ranges for location A01 given 4% and 10% conversion factor scenarios. 53
Figure 3-4 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location N17 overlain the harbour porpoise distribution. CF = 10%, hammer energy = 5000 kJ. 59
Figure 3-5 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location N17 overlain the harbour porpoise distribution. CF = 4%, hammer energy = 5000 kJ.. 60
Figure 3-6 Simulated harbour porpoise population sizes for both the un-impacted and the impacted populations 62
Figure 3-7 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location A01 overlain the bottlenose dolphin distribution. CF = 10%, hammer energy = 5000 kJ. 63
Figure 3-8 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location A01 overlain the bottlenose dolphin distribution. CF = 4%, hammer energy = 5000 kJ. 64
Figure 3-9 Simulated bottlenose dolphin population sizes for both the un-impacted and the impacted populations 66
Figure 3-10 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location L07 overlain the minke whale distribution. CF = 10%, hammer energy = 5000 kJ. 68
Figure 3-11 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location L07 overlain the minke whale distribution. CF = 4%, hammer energy = 5000 kJ. 69
Figure 3-12 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location N17 overlain the grey seal distribution. CF = 10%, hammer energy = 5000 kJ. 71
Figure 3-13 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location N17 overlain the grey seal distribution. CF = 4%, hammer energy = 5000 kJ. 72
Figure 3-14 Simulated grey seal population sizes for both the baseline and the impacted populations by disturbance. 73
Figure 3-15 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location A01 overlain the harbour seal distribution. CF = 10%, hammer energy = 5000 kJ. 74
Figure 3-16 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location A01 overlain the harbour seal distribution. CF = 4%, hammer energy = 5000 kJ..... 75
Figure 3-17 Comparison of August harbour seal counts in Scottish Seal Management Areas (SMAs) from 1991 to 2019. Obtained from SCOS (2021)..... 77
Figure 3-18 Simulated harbour population sizes for both the un-impacted and the impacted populations, assuming the MU is Moray Firth & Northern Coast & Orkney, and assuming Northern Coast & Orkney demographic parameters. 77
Figure 3-19 Simulated harbour population sizes for both the un-impacted and the impacted populations, assuming all impact goes to the Moray Firth (MF) MU, and assuming MF demographic parameters. 78

Figure 3-20 Disturbance contours for grey seals showing that the outermost isopleth (145 dB) ends at the boundary of the model domain. Location N17, CF = 10%, hammer energy = 5000 kJ. 80
Figure 3-21 Disturbance contours for porpoise showing that the outer isopleths (150 - 120 dB) reach the boundaries of the model domain. Location N17, CF = 10%, hammer energy = 5000 kJ. 81
Figure 4-1 Cumulative exposure effect zones for fish species exposed to piling at location A02, for the blow count profile BE80 and the energy conversion factor C.F.=4%. 87
Figure 4-2 Cumulative exposure effect zones for fish species exposed to piling at location L07, for the blow count profile BE80 and the energy conversion factor C.F.=4%. 88
Figure 4-3 Cumulative exposure effect zones for fish species exposed to piling at location N17, for the blow count profile BE80 and the energy conversion factor C.F.=4%. 89
Figure 4-4 Cumulative exposure effect zones for fish species exposed to piling at location A02, for the blow count profile BE50 and the energy conversion factor C.F.=4%. 90
Figure 4-5 Cumulative exposure effect zones for fish species exposed to piling at location L07, for the blow count profile BE50 and the energy conversion factor C.F.=4%. 91
Figure 4-6 Cumulative exposure effect zones for fish species exposed to piling at location N17, for the blow count profile BE50 and the energy conversion factor C.F.=4%. 92
Figure 4-7 Cumulative exposure effect zones for fish species exposed to piling at location A02, for the blow count profile BE80 and the energy conversion factor C.F.=10%. 93
Figure 4-8 Cumulative exposure effect zones for fish species exposed to piling at location L07, for the blow count profile BE80 and the energy conversion factor C.F.=10%. 94
Figure 4-9 Cumulative exposure effect zones for fish species exposed to piling at location N17, for the blow count profile BE80 and the energy conversion factor C.F.=10%. 95
Figure 4-10 Cumulative exposure effect zones for fish species exposed to piling at location A02, for the blow count profile BE50 and the energy conversion factor C.F.=10%. 96
Figure 4-11 Cumulative exposure effect zones for fish species exposed to piling at location L07, for the blow count profile BE50 and the energy conversion factor C.F.=10%. 97
Figure 4-12 Cumulative exposure effect zones for fish species exposed to piling at location N17, for the blow count profile BE50 and the energy conversion factor C.F.=10%. 98

Tables

Table 2-1 Turbine locations and their risk of refusal used for the modelling to inform the Piling Strategy in relation to the original noise modelling locations used in the Moray West EIA 2018. 14
Table 2-2 Summary statistics of the piling profiles used for the marine mammal impact assessment. 19
Table 2-3 Marine mammal PTS-onset thresholds for impulsive noise (Southall et al. 2019). 20
Table 2-4 Fleeing speeds assumed for each marine mammal species/taxon 22
Table 2-5 Population estimates for Grey seal as used in the EIA and for the current Piling Strategy, based on August haul out counts and corresponding scalar. 31
Table 2-6 Population estimates for harbour seal as used in the EIA and for the current Piling Strategy, based on August haul out counts and corresponding scalar. 34
Table 2-7 Species specific MU and density estimates taken forward for impact assessment 36

Table 2-8 Sound exposure thresholds for fish (Popper et al. 2014). 37
Table 2-9 Sensitivity of the Marine Mammal Receptor 38
Table 2-10 Sensitivity of the Fish Receptor 39
Table 2-11 Impact magnitude of marine mammal receptor 40
Table 2-12 Impact magnitude of fish receptor 40
Table 2-13 Impact significance for marine mammal receptor 41
Table 2-14 Impact significance for fish receptor 41
Table 2-15 Parameters used for iPCOD modelling 42
Table 2-16 Changes to piling parameters since the EIA Report 2018 44
Table 3-1 Instantaneous PTS impact ranges for a soft-start hammer energy of 550 kJ, based on a CF of 4% and 10%, for all location and species considered in the noise modelling. 45
Table 3-2 Instantaneous PTS impact ranges for a full hammer energy of 5000 kJ, based on a CF of 4% and 10%, for all location and species considered in the noise modelling. 46
Table 3-3 Probability of animal being present within the instantaneous PTS-onset impact zone at full hammer energy 47
Table 3-4 Maximum cumulative PTS impact based on the piling profiles shown in Table 2-2 and a constant CF of 4% and 10%, respectively, for all location and species considered in the noise modelling. 48
Table 3-5 Number of animals within the cumulative PTS impact are based on the piling profiles shown in Table 2-2 and a constant CF of 4% and 10%, respectively, for all location and species considered in the noise modelling. S: based on summer distribution, NS: based on non-summer distribution 48
Table 3-6 Maximum cumulative PTS impact based on the assumption that 2 monopiles are installed consecutively per day 54
Table 3-7 Estimated impact ranges for minke whale when reducing the conservatism based on assumptions. Given are the estimated PTS thresholds and related impact ranges and number of animals at risk of cumulative PTS 55
Table 3-8 Numbers of harbour porpoise and proportion of relevant management units (MU) predicted to be disturbed from piling, for different piling scenarios. 58
Table 3-9 Results of the iPCOD modelling, giving the mean population size of the harbour porpoise population (UK MU) for years up to 2042 for both impacted and un-impacted populations as well as the mean and median ratio between their annual growth rates. 61
Table 3-10 Numbers of bottlenose dolphins and proportion of relevant management units (MU) predicted to be disturbed from piling, for different piling scenarios. 62
Table 3-11 Results of the iPCOD modelling, giving the mean population size of bottlenose dolphin for years up to 2042 for impacted and un-impacted populations as well as the mean and median ratio between their annual growth rates. 65
Table 3-12 Numbers of minke whales and proportion of relevant management units (MU) predicted to be disturbed from piling, for different piling scenarios. Numbers are based on the summer (S) and non-summer (NS) distribution. 67

Table 3-13 Numbers of grey seals and proportion of relevant management units (MU) predicted to be disturbed from piling, for different piling scenarios. 70
Table 3-14 Numbers of harbour seals and proportion of relevant management units (MU) predicted to be disturbed from piling, for different piling scenarios. 76
Table 3-15 Comparison of the evaluation of sensitivity, magnitude, and impact of Instantaneous PTS on marine mammal species in the 2018 ES and this Piling Strategy. 83
Table 3-16 Comparison of the evaluation of sensitivity, magnitude, and impact of cumulative PTS on marine mammal species in the 2018 ES and this Piling Strategy. 83
Table 3-17 Comparison of the evaluation of sensitivity, magnitude, and impact of disturbance on marine mammal species in the 2018 ES and this Piling Strategy. 84
Table 4-1 Effect ranges for mortality and recoverable injury according to the Popper peak SPL criterion for Atlantic salmon and the sea trout. 85
Table 4-2 Effect areas for mortality, recoverable injury, and TTS according to the Popper SEL_{cum} criterion for the Atlantic salmon and the sea trout. Thresholds for these effects are 210, 203, and 186 dB re 1 μPa^2 s, respectively. 85

Abbreviations and Acronyms

Acronym / Abbreviation	Description
ADD	Acoustic Deterrent Device
BE	Best Estimate
BEIS	Department for Business, Energy & Industrial Strategy
BOWL	Beatrice Offshore Windfarm Ltd
Cefas	Centre for Environment, Fisheries and Aquaculture
CF	Conversion factor
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EPS	European Protected Species
ES	Environmental Statement
GPS/GSM	Global Positioning System/Global System for Mobile communications
iPCoD	interim Population Consequences of Disturbance framework
MORL	Moray Offshore Renewables Ltd.
MPA	Marine Protected Area
MU	Management Unit
NMFS	National Marine Fisheries Service
OSP	Offshore Substation Platforms
OfTI	Offshore Transmission Infrastructure
PTS	Permanent Threshold Shift
RIAA	Report to Inform Appropriate Assessment
SEL	Sound Exposure Level
SEL_{ss}	Single Strike Sound Exposure Level
SEL_{cum}	Cumulative Sound Exposure Level
SLE	Source Level Energy
SPL	Sound Pressure Level
SPL_{peak}	Peak Sound Pressure Level
TTS	Temporary Threshold Shift
UB	Upper Bound
UK	United Kingdom
WTGs	Wind Turbine Generators

Consultation Log

Comment	Moray West Response
NatureScot 9/11/21 Response to: Preliminary underwater noise modelling and impact assessment results	
We recommend that the [East Coast Scotland bottlenose dolphin] MU population size should be based on a 5 year weighted mean of annual estimates. Taken from Arso Civil et al. (2021), the weighted mean population estimate should be 224 (95% CI 214-234).	The recommended population estimate has been used. See section 2.6.2.3.2.
In the cetacean MU paper, abundance estimates are also given for within the UK portion of the MU. We recommend that these estimates are used instead	While these have been presented in the results (e.g. Table 3-8 and Table 3-12), the Applicant considers that the most appropriate population against which to assess impacts is the entire MU. This is explained in section 2.6.2.3.
Our preference would be to use the updated scalars if available in time, but if not, to use the existing scalars together with the Carter et al. (2020) habitat preference maps.	The revised seal scalers were not available to use in time for this assessment.
We agree that the worst-case scenarios are used in the modelling for assessment. However, more detail is needed regarding the methods. As an example –an explanation as to why the 50 blows is the worst case, and how this interacts with hammer energy is needed.	Additional detail is provided in section 2.5.
We have concerns regarding the conclusions of negligible impact for some species for instantaneous and cumulative PTS.	Additional text on the probability of an individual being within the PTS-onset impact range at full hammer energy is provided in section 3.1.
For harbour porpoise, the cumulated PTS range is over 4 km. We assume that this relates to a safe start range ,i.e. if an animal is within 4km at the start of piling, even with swimming away they will accrue enough sound to result in PTS onset.	The assumption is correct. This is explained in section 2.6.2.1.1.2.
We are aware of the research relating to the equal energy rule (re PTScum) and that there may be auditory recovery between strikes. We will need the strike rate also, in order to be able to make a judgment as to how much weight we can give to the EER suggested reason for overestimation.	Strike rate is given in section 2.5: *For modelling, blow rate was set to 28 blows per minute up to 20 m penetration depth, and then changed to 32 blows per minute up to the final penetration depth.* Details relating to the equal energy hypothesis and recovery between strikes is detailed in section 2.6.2.
We agree that impulsive sound will lose 'impulsiveness' as it propagates. However, we do not have information yet as to where this distance may be, and not enough confidence to be able to base an assessment on this assumption alone.	The Applicant acknowledges the limited evidence available at this time. Please see section 3.1.3.3 for further details.
A possible solution to assess when impulsive sound will lose 'impulsiveness' may be to use an interim measure proposed by Southall (2021)	Please see detail in section 3.1.3.3 regarding impulsive sound.

MS-LOT 16/11/21 Response to: Preliminary underwater noise modelling and impact assessment results	
MSS are supportive of NatureScot's recommendation of including an interim measure of impulsiveness/non-impulsive range into the assessment, following Southall et al. (2021) to potentially reduce some of the conservatism in the assessment. If this interim measure is applied, MSS recommend that MS-LOT request a detailed explanation and methodology of how this will be derived and included in the assessment and evidence provided to support the distance selected.	Please see detail in section 3.1.3.3 regarding impulsive sound.
Currently, a flat CF is modelled over the full duration of the piling profile MSS suggest that a more realistic varying CF over the piling profile, for example from Thompson et al. (2020), could also be modelled to investigate if this alters the predicted impact zone for cumulative PTS.	The Applicant agrees that a varying CF over the piling profile would be more realistic, however it was not possible to do so for this assessment, as there is currently no information available on how to vary the CF in a monopile profile.
We are in the process of arranging a meeting with the authors of Carter et al. (2020) and Russell et al. (2017) to discuss the caveats of the respective modelling approaches used, with the aim of coming to a conclusion on which would be the more suitable for use in impact assessments. Until such time, MSS recommend using the Russell et al. (2017) seal usage maps.	The assessment has been based on the Carter et al (2020) habitat preference maps. These maps include more telemetry data, more recent haul-out data and better predictions of seal movement away from haul out sites. They are considered to be the best at-sea density surface currently available for seals.
MSS consider cumulative PTS ranges of 30 –45 km for minke whales as significant.	The Applicant highlights the levels of conservatism inherent in the modelling of PTS-onset. Given these conservatisms the resulting impact ranges are considered to be highly precautionary over-estimates. Examples of how these impact ranges could be more realistically modelled is presented in section 3.1.3.
The density surface for minke whales does not appear to cover the development site, MSS would welcome further details on how this has been addressed in the assessment	Detail on the minke whale density surface is provided in section 2.6.2.3.3.2.

1 Introduction

In order to address and fulfil specific requirements of the relevant conditions attached to the Moray West Section 36 consent (condition 11) and Wind Farm and Offshore Transmission Infrastructure (OfTI) Marine Licences conditions 3.2.2.8 and 3.2.2.7, respectively, and in light of refinement of piling parameters since the 2018 application, noise modelling has been undertaken to provide details of expected noise levels resulting from pile-driving and the potential impact of underwater noise on marine mammal and fish species.

This appendix to the Moray West Piling Strategy presents the results of the noise modelling and assessment to inform the design of the mitigation measures to be employed during piling. Also included is a comparison between the updated and original assessment to ensure accordance with the Application and no change in impact significance.

2 Assessment Methodology

Underwater noise modelling has been undertaken by Cefas (Centre for Environment, Fisheries and Aquaculture) using their propagation model (Farcas et al. 2016) and an energy conversion source model. Details of these, and of the assessment criteria applied for fish and marine mammals, are provided below.

2.1 Piling locations and scenarios

60 Wind Turbine Generators (WTGs) and 2 Offshore Substation Platforms (OPSs) are planned to be installed. The locations where WTGs and OSPs may be installed are displayed in Figure 2-1. A pile driveability assessment has been undertaken by Moray West to understand the risk of pile refusal at turbine locations across the Moray West Site and is detailed in Ramboll (2021). The locations selected for modelling were based on a former layout, and have been chosen to be as close as possible to the original locations modelled to inform the marine mammal impact assessment presented in the Moray West Environmental Impact Assessment (EIA) Report 2018 – Volume 2, Chapter 9[1] . This enables comparison with previous modelling where the original modelling locations were placed on the boundaries of the Moray West site in the confirmed layout. Two locations were selected per original location, of which one has a high refusal risk to represent a worst-case scenario, and one with a lower refusal risk for modelling a representative scenario (further details in Section 2.5). Each of the original locations was allocated to specific species based on the proximity to local high densities, haul-out sites (seals) or protected sites. Table 2-1 lists and Figure 2-1 displays the turbine locations used for the modelling to inform the Piling Strategy in relation to the original noise modelling locations (shown in black). Five of the six modelling locations were excluded from the final layout due to their high and moderate risk of pile refusal.

Further to the two locations per species outlined in Table 2-1and agreed with NatureScot (formaly Scottish Natural Heritage (SNH)) and Marine Scotland, additional scenarios have been modelled for minke whale and grey seals:

[1] https://marine.gov.scot/sites/default/files/00538033.pdf

- For minke whale, an additional scenario was modelled for the cumulative PTS with the worst-case piling profile (A01), determined by a short soft-start (22 minutes) and ramp-up (62 minutes) leading to a fast increase in hammer energy during the ramp-up, in order to acknowledge the close proximity of A01 to the higher minke whale densities near the coast as shown in the updated density maps (Figure 2-5) combined with the worst case piling profile.
- For grey seal, the two locations at the northern corner of the Moray West Site (P18, N17) were included in the grey seal assessment for disturbance to acknowledge the high seal density north of the Moray West Site as seen on the updated grey seal density surface (see Section 2.6.2.3.4.2).

Table 2-1 Turbine locations and their risk of refusal used for the modelling to inform the Piling Strategy in relation to the original noise modelling locations used in the Moray West EIA 2018.

Species	Original location	Location	Refusal risk
Dolphin, Seal	1	A01	moderate
		A02	high
Grey seal		P18	low
		N17	high
Harbour porpoise	2	P18	low
		N17	high
Minke whale	3	A01	moderate
		N07	low
		L07	high

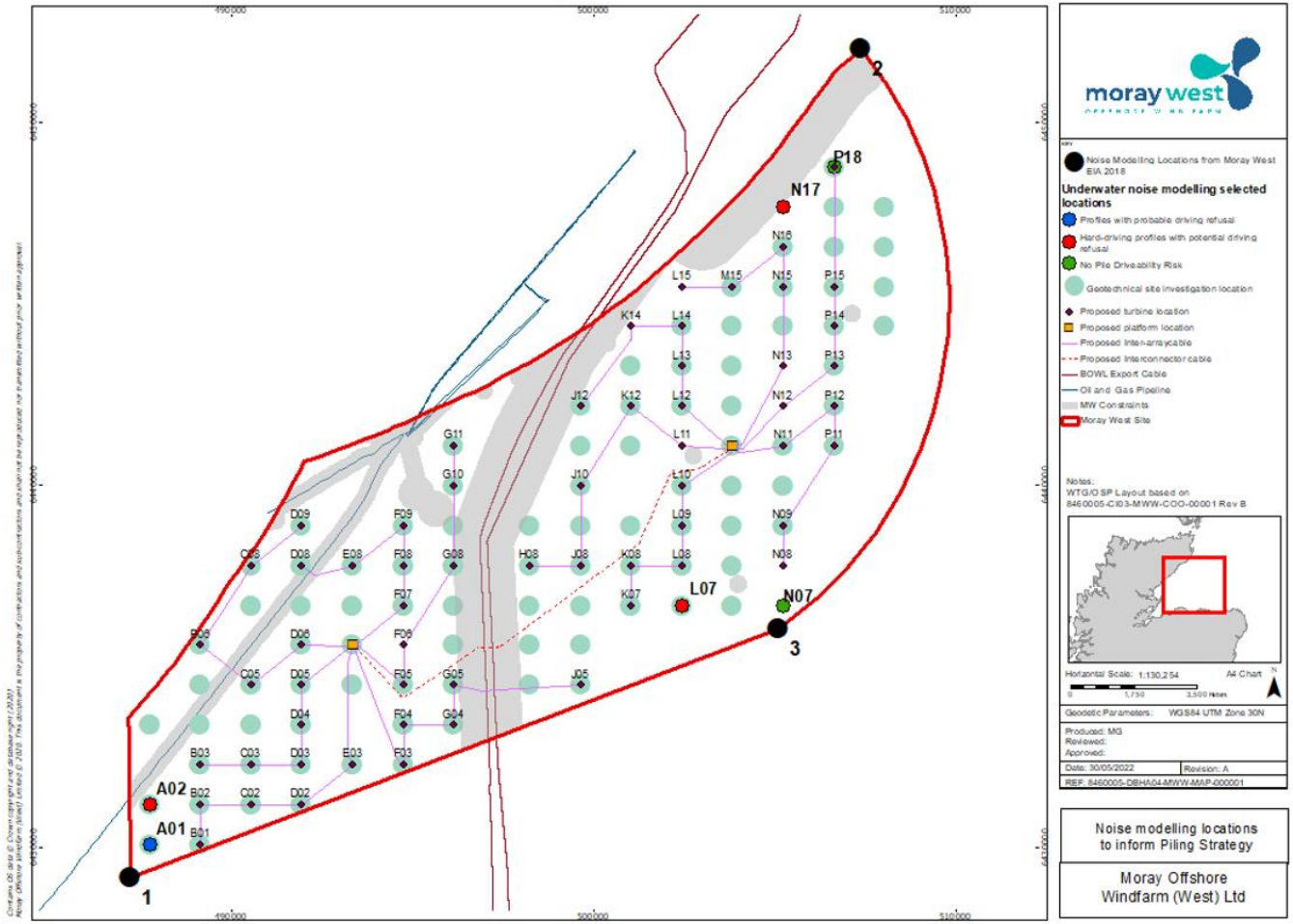


Figure 2-1 Noise modelling locations to inform Piling Strategy – turbine locations with moderate (blue) and high (red) risk of pile refusal are indicated; numbered locations are included in the noise modelling for comparison with the original noise modelling locations used in the Application. The final layout is indicated by small black dots connected with cable lines.

2.2 Source model

In the model, the source level estimate for piling was calculated using an energy conversion model (De Jong and Ainslie 2008), whereby a proportion of the expected hammer energy is converted to acoustic energy:

$$\boldsymbol{SLE} = \mathbf{120} + \mathbf{10}\boldsymbol{log}\mathbf{10}\ (\boldsymbol{\beta Ec0\rho}\ \mathbf{4}\boldsymbol{\pi}) \qquad (1)$$

where E is the hammer energy in joules, SLE is the source level energy for a single strike at hammer energy E, $\boldsymbol{\beta}$ is the acoustic energy conversion efficiency (aka conversion factor, CF), $c0$ is the speed of sound in seawater in ms^{-1}, and ρ is the density of seawater in kgm^{-3}.

This yields an estimate of the source level in units of sound exposure level (SEL; dB re 1 μPa^2s). This energy is then distributed across the frequency spectrum based on previous measurements of impact piling (Ainslie et al. 2012). Hammer energy profiles for the piling scenarios (see Section 2.5) formed the basis of the source level estimates. At the request of Marine Scotland and NatureScot, the acoustic energy conversion efficiencies used to compute the source level energies in Equation (1) were taken as either 4% or 10%, respectively, which represent a significant increase over the 0.5% and 1% values used for the modelling in the Moray West EIA Report 2018 and its appendix. The higher values reflect uncertainty when modelling source levels for large monopiles. The use of the two conversion efficiency values illustrates the sensitivity of modelling predictions to this input parameter.

Equation (1) gives the source level energy for a single strike. The field values of the single strike SEL (SEL_{ss}), as well as the cumulative SEL (the total SEL generated during a specified period), SEL_{cum}, were computed using a propagation model, as detailed in Section 2.3. The peak sound pressure level (SPL_{peak}) was calculated from the SEL_{ss} using the empirical linear equations linking peak sound pressure levels and sound exposure levels for piling sources found by Lippert et al. (2015).

2.3 Propagation model

Cefas's propagation model (Farcas et al. 2016) is based on a parabolic equation solution to the wave equation (RAM; Collins (1993)). This model considers the bathymetry, sediment properties, water column properties, and tidal cycle. The model is a quasi-3D model consisting of 360 2D transects extending away from the source at intervals of one degree. Sound propagation is modelled at each discrete frequency in the source spectrum (10 frequencies per 1/3 octave band). Transects are then resampled and integrated over frequency (using the appropriate auditory weightings where needed). Finally, the resulting levels are averaged over depth to produce noise maps.

2.4 Input data

Aside from estimated source levels of pile driving, the main model inputs for the noise propagation model were bathymetry, water temperature and salinity (used to compute sound speed), and the acoustic properties of the seabed sediments.

Bathymetric data in UTM30N projection at 90 m resolution was provided to Cefas by Moray West. These data show that through the Moray West Site the water depth varies from a minimum of approximately

35 m near the northern boundary with Moray East to a maximum of 54 m near the southern limit of the Site.

Typical seawater temperatures in the Moray West Site are between about 6°C in February and 14°C in August. A balanced choice of 8°C was used for the modelling, which is the water temperature used for modelling in the EIA.

The acoustic properties of the seabed sediments were used to construct a geoacoustic model of the seafloor. These properties were derived from the seabed core data by correlating the core sediment information with published acoustic properties of various sediment types (Hamilton 1980).

2.5 Piling profiles

A drivability assessment and driving induced fatigue analyses at the intended WTG locations has been undertaken to inform the hammer selection and identification of location-specific installation risk and fatigue damage. Pile driving profiles have been determined for the six selected locations for a characteristic best estimate (BE) and upper bound (UB) soil parameters, using an IHC S5500 hammer with a constant blow count and a hammer energy ramp-up. Table 2-2presents summary statistics of the expected piling profiles: minimum and maximum hammer energies used, duration of soft-start (piling with 10% of the maximum hammer energy), duration of the ramp-up (increase in hammer energy up to maximum hammer energy used in the profile) and duration of the whole sequence, as well as number of blows used. Piling profiles for the six locations used for modelling are illustrated graphically in Figure 2-2.

Two different blow counts were used, 80 blows per 25 cm and 50 blows per 25 cm. With 80 blows per 25 cm, a lower maximum hammer energy was generally needed. The ramp-up time was also longer and the duration of the piling and number of pile strikes higher compared to profiles with 50 blows per 25 cm. While profiles with a low hammer energy are preferred by engineers at locations with low drivability risk, higher hammer energies might occasionally be needed at locations where refusal risk is higher. Therefore, for the locations with a low refusal risk, piling profiles with 80 blows per 25 cm were used for the noise modelling. For moderate and high refusal risk locations, piling profiles with 50 blows per 25 cm were considered as the worst-case scenario for marine mammals, as the shorter ramp-up time compared to 80 blows per 25 cm leads to a fast rise in the cumulative sound exposure level, SEL_{cum} (definition see Section 2.6.1) while the sound energy received by a fleeing animal near the end of the piling profile is influencing the SEL_{cum} less. Despite the higher number of blows and longer piling duration of the piling profiles with 80 blows per 25 cm, these are, therefore, not considered as worst-case profile for the marine mammal impact assessment. For modelling, blow rate was set to 28 blows per minute up to 20 m penetration depth, and then changed to 32 blows per minute up to the final penetration depth.

Modelling was also conducted assuming that two monopiles could be installed consecutively within a 24 hour period. This was only conducted for low refusal risk locations since it was expected that only one monopile would be installed per day at moderate and high risk locations.

For fish, locations A02, L07 and N17 were modelled with both blow counts, as the animals were kept stationary for modelling the SEL_{cum}, resulting in six scenarios.

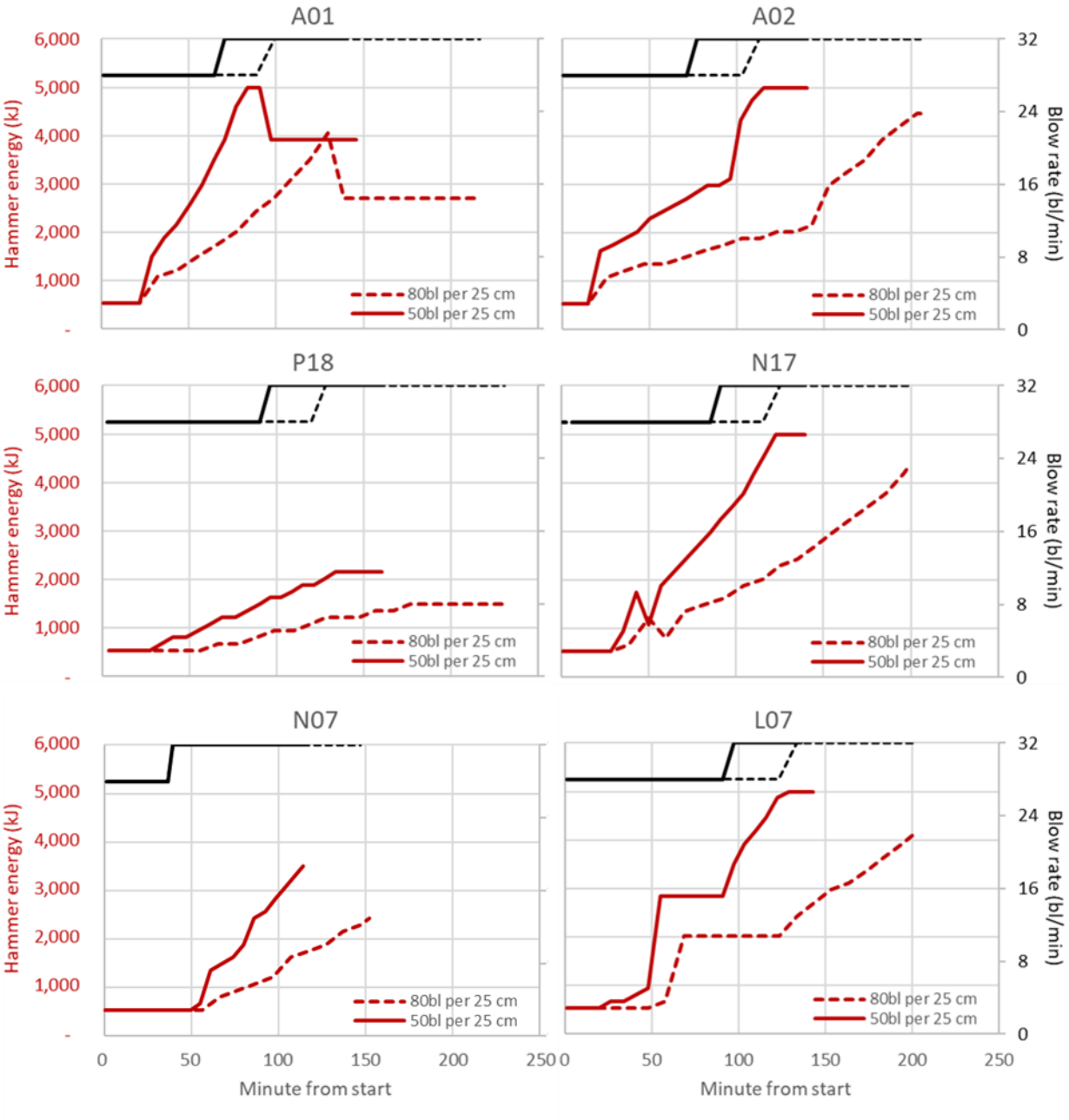


Figure 2-2 Piling profiles from the six locations considered for modelling, showing hammer energy (red) and blow rate (black) over time.

Table 2-2 Summary statistics of the piling profiles used for the marine mammal impact assessment.						
Parameter	**Locations**					
	P18	**N07**	**A01**	**A02**	**N17**	**L07**
Refusal risk	low	low	moderate	high	high	high
Minimum hammer energy (kJ)	541	541	541	541	541	541
Maximum hammer energy (kJ)	1,486	2,432	5,000	5,000	5,000	5,000
Duration soft-start (min)	56	56	22	15[2]	28	20
Duration ramp-up (min)	120	96	62	100	95	109
Piling duration (min)	231	152	146	140	139	143
Total number of blows	1,750	1,220	1,106	1,104	1,074	1,058

2.6 Metrics modelled and Assessment Criteria

2.6.1 Metrics

Three noise metrics were modelled for assessing auditory injury and disturbance ranges:

1. Peak sound pressure level (SPL_{peak}): SPL_{peak} was estimated for the initial and maximum hammer energies to assess instantaneous permanent threshold shift (PTS) risk at start of piling and during piling;
2. Cumulative sound exposure level (SEL_{cum}): SEL_{cum} was considered over a 24 hour period based on the piling profiles presented in Table 2-2, assuming one monopile is installed during the 24 hour period to assess risk of cumulative PTS for marine mammals; and the risk of temporary threshold shift (TTS), and recoverable injury and mortality in fish;
3. Single strike sound exposure level (SEL_{ss}): SEL_{ss} was based on the maximum hammer energy of 5,000 kJ[3] to inform assessment of risk of disturbance in marine mammals, and recoverable injury and mortality in fish.

[2] JNCC Guidance describes the soft-start as the gradual ramp up of piling power until full operational power is achieved. The soft-start duration should be a period of not less than 20 minutes.

In this PS, ramp-up of the hammer energy will follow the soft-start procedure (minimum of 15 min). Overall, the soft-start and ramp up procedures will be longer than the 20 minutes recommended by JNCC Guidance.

[3] The outcomes of the pile driveability assessment have indicated that most of the pile foundations can be driven to the target penetration depth using pile driving hammer energies up to 4,000 kJ. There is the potential for maximum hammer energies of up to 4,400 kJ to be required for those locations with harder ground conditions. The maximum hammer energy required at all pile locations across Moray West Site will not exceed 4,400 kJ.

2.6.2 Marine Mammal Assessment Criteria

2.6.2.1 Permanent Threshold Shift (PTS) Assessment

2.6.2.1.1 Thresholds

For marine mammals, the risk of PTS was assessed using the updated Southall criteria (Southall et al. 2019) (Table 2-3). The Southall thresholds are based on a dual criteria approach to assess instantaneous and cumulative PTS.

Table 2-3 Marine mammal PTS-onset thresholds for impulsive noise (Southall et al. 2019).

Species	Species Group	Instantaneous PTS threshold Unweighted SPL_{peak} (dB re 1 µPa)	Cumulative PTS thresholds Weighted SEL_{cum} (dB re 1 µPa^{2}s)
Harbour porpoise	Very high frequency cetacean	202	185
Minke whale	Low frequency cetacean	219	183
Bottlenose dolphin	High frequency cetacean	230	185
Harbour seal	Phocid carnivores in water	218	185
Grey seal			

2.6.2.1.1.1 Instantaneous PTS

The first metric of the dual criteria is pressure-based, taken as peak sound pressure level (SPL_{peak}). Any single exposure at or above this pressure-based threshold is considered to have the potential to cause PTS regardless of the exposure duration, therefore called "instantaneous PTS". For the assessment of the SPL_{peak}, received sound level predictions are not weighted according to the frequency content of the sound ('unweighted').

An estimate was made of the probability of a single individual being within the instantaneous PTS-onset impact range during the first strike of a single pile based on the average densities of a species in the area. The approach taken was based on the method outlined in Thompson (2015):

- Use density data to estimate the area around a piling location that should contain 1 individual.
- Randomly position that individual within that area and measure the distance to the pile. Repeat 100,000 times.

- Produce a probability density function for distances to the pile for the 100,000 randomly placed individuals.
- Estimate the probability of occurrence in the impact zones of interest at the start of any piling event.

2.6.2.1.1.2 Cumulative PTS

The second metric, the cumulative sound exposure level (SEL_{cum}), is energy-based and is a measure of the accumulated sound energy that an animal is exposed to over an exposure period. An animal is considered to be at risk of experiencing "cumulative PTS" if the SEL_{cum} exceeds energy-based thresholds for either impulsive or continuous noise (Southall et al. 2019). Southall et al. (2019) calculates the PTS-onset thresholds based on the assumption that an animal's hearing threshold will shift by 2.3 dB per dB SEL received from an impulsive sound, but only 1.6 dB per dB SEL when the sound received is non-impulsive. The PTS-onset threshold for non-impulsive sound is therefore 15 dB higher than for impulsive sound, as more energy is needed to cause PTS with non-impulsive sound compared to impulsive sound.

The calculation of SEL_{cum} is made with frequency-weighted sound levels, using species hearing group-specific weighting functions to reflect the hearing sensitivity of each functional hearing group. To assess the risk of cumulative PTS, it is, first, necessary to make assumptions on how animals may respond to noise exposure, since any displacement of the animal relative to the noise source will affect the sound levels received. In addition, assumptions need to be made about whether the sounds received by those animals are impulsive or continuous (see Southall (2021) and below).

For this assessment, it was assumed that animals would flee from the pile foundation at the onset of piling. A fleeing animal model was therefore used to determine the cumulative PTS impact ranges to determine the minimum distance to the pile site at which an animal can start to flee without the risk of experiencing cumulative PTS.

The fleeing model simulates the animal displacement and their noise exposure for a given piling scenario by placing an animal agent in each grid cell of the domain (i.e. every 90 m by 90 m) and allowing them to move on the domain grid according to a set of pre-defined rules. The position of all agents and the cumulated exposure are re-evaluated at short time intervals (e.g. 1 to 5 minutes) and at the end of the piling activity scenario, the total cumulated exposure of all animal agents is mapped back to their starting positions on the grid.

In the case of single location piling, the model assumes that the animal agents are fleeing at constant speeds (Table 2-4), along straight lines away from the pile location, as long as the local water depth exceeds a minimum value (Table 2-4), and for the entire duration of piling. If an animal agent moving along the straight line from the pile location arrives in water shallower than the allowed minimum depth, then a change in direction is calculated and effected in the same way as it was done in the Moray West EIA, except that for the EIA modelling the animal stopped after 25 km.

It should be noted that, as indicated in Table 2-4, these rules do not apply to the seal agents, who are allowed to move in any depths of water and even move to the shore, thus stopping their sound exposure.

Table 2-4 Fleeing speeds assumed for each marine mammal species/taxon

Species	Harbour Porpoise	Bottlenose dolphin	Minke Whale	Harbour and grey seals
Swimming speed (m/s)	1.4	1.52	2.1	1.8
Swimming speed source	Scottish Natural Heritage (2016)	Median swim speed of unpublished tracking data from the Moray Firth (Bailey and Hastie)	Scottish Natural Heritage (2016)	Scottish Natural Heritage (2016)
Minimum depth constraint (m)	5	5	10	0

2.6.2.1.2 Precaution in PTS assessment with emphasis on cumulative PTS

Choosing sound levels at which an animal is at risk of PTS-onset as a threshold to determine PTS impact ranges is a conservative approach for both the instantaneous as well as the cumulative PTS. At a Department for Business, Energy & Industrial Strategy (BEIS) funded expert elicitation workshop held at the University of St Andrews (March 2018), experts in marine mammal hearing discussed the nature, extent and potential consequence of PTS to UK marine mammal species harbour porpoise, bottlenose dolphins, harbour seal and grey seal (Booth and Heinis 2018). This workshop outlined and collated the best and most recent empirical data available on the effects of PTS on marine mammals. The key outcome of the workshop was that the experts agreed that the effects of PTS-onset from piling would cause only a very small precited effect on survival or fertility (i.e. <5 % reduction in survival or fertility).

There is considerable uncertainty associated with the estimation of PTS impact ranges, but this is especially so for cumulative PTS impact ranges. This is partly because the sound levels an animal receives, and which are cumulated over a whole piling sequence, are difficult to predict over such long periods of time. This is due to uncertainties underlying estimates of source levels, noise propagation models and the 3D distribution, speed and responsive movements of animals.

More fundamentally, two key assumptions underly predictions of PTS-onset using the SEL_{cum} threshold values provided by Southall et al. (2019). As detailed in Southall et al. (2019), these assumptions are:

a) the amount of sound energy that an animal is exposed to within 24 hours will have the same effect on its auditory system, regardless of whether it is received all at once (e.g. as a single loud pulse) or in several smaller doses spread over a longer period (such as a series of pile strikes). This is called the equal-energy hypothesis; and,

b) the sound from pile-driving keeps its impulsive character, regardless of the distance between the exposed animal and the sound source.

There is growing scientific consensus that both these assumptions are incorrect, and lead to considerable conservatism in assessments (Southall et al. 2021). For example:

a) there is a recovery of a sound-induced threshold shift if the dose is applied in several smaller doses (e.g. between hammer strikes or in piling breaks). Finneran (2015) highlight several marine mammal studies where an intermittent pattern of exposure reduces the resulting threshold shift (e.g. Kastak et al. 2005, Mooney et al. 2009, Finneran et al. 2010, Kastelein et al. 2013). Intermittent noise thus allows for some recovery of the threshold shift between exposures. Importantly, duty cycles and silent periods in-between sound used in recent experiments by Kastelein et al. (2014) are similar to those used in Moray West piling profiles, indicating that the threshold for PTS could be raised by at least 2-3 dB.

b) pulsed sound from piling loses its impulsive characteristics while propagating away from the sound source (Hastie et al. 2019, Southall et al. 2019, Martin et al. 2020). It is recognised that these changes in noise characteristics with distance will also result in exposures becoming less physiologically damaging (Southall et al. 2019, Martin et al. 2020). Whilst there is not yet consensus on how best to define the transition from impulsive to non-impulsive noise (NMFS 2016), Hastie et al. (2019) showed that the noise signal experienced a high degree of change in its impulsive characteristics within 3- 9 km from the source. Based on these and other recent findings, Southall (2021) notes that "*it should be recognized that the use of impulsive exposure criteria for receivers at greater ranges (tens of kilometers) is almost certainly an overly precautionary interpretation of existing criteria*".

In addition to the above-mentioned conservatisms, the cumulative PTS impact ranges were estimated using a constant conversion factor of 4% and 10%, respectively. Comparisons of the current modelling approach to measured noise levels recorded during monopile installation at the Offshore wind farms Galloper (OSC 2017), Racebank (NIRAS Consulting Ltd 2017) and Triton Knoll (Banda et al. 2020) illustrate that noise levels would correspond to conversion factors largely ranging between 0.5% and 10%+ within a piling profile. Noise levels requiring a conversion factor of >8 % were recorded at two of the three wind farms, and only for intermediate hammer energies during parts of the piling profile. Maximum hammer energies were not reached in any of the installations monitored at those three wind farms. The use of a constant conversion factor of 10% will therefore lead to an overestimate of the cumulative PTS impact ranges.

In practice, assessments have typically dealt with these uncertainties by using conservative values at all stages of the process. As a result, the conservatism in source level estimates, the propagation model assumptions and threshold criteria are all compounded, resulting in highly precautionary predicted PTS impact ranges. Whilst this does provide an indication of extreme worst-case scenarios, these are not in line with current scientific understanding and risk constraining efforts to identify more likely scenarios

that can be used to balance the costs and benefits of potential mitigation measures (see Thompson et al. 2020).

2.6.2.2 Behavioural Disturbance Assessment

In contrary to the assessment of auditory injury, there are no established or recommended thresholds for the assessment of disturbance. This assessment was therefore based on the current best practice methodology. This incorporates the application of a species-specific dose-response approach rather than a fixed behavioural threshold approach as used in earlier assessments.

The application of a dose-response curve allows for evidence-based estimates about animal response varying with dose, which is supported by a growing number of studies. A dose-response curve is used to quantify the probability of a response from an animal to a dose of a certain stimulus or stressor (Dunlop et al. 2017) and is based on the assumption that not all animals in an impact zone will respond. The dose is either given as the received weighted or unweighted sound level at the receiver or determined indirectly by using the distance from the sound source (Sinclair et al. 2021). This is currently considered to be the best practice methodology to assess disturbance in the latest guidance provided in Southall et al. (2021).

To predict the number of animals potentially disturbed, noise contours at 5 dB (SEL_{ss}) intervals were generated by noise modelling (Section 2.2) and were overlain on species density surfaces (see below). This allowed for the quantification of the number of animals that will potentially respond.

The dose-response relationship adopted in this assessment for all cetaceans was developed by Graham et al. (2017b) using data on harbour porpoises collected during Phase 1 of piling at the Beatrice Offshore Wind Farm (Figure 2-3). Since the development of this initial dose-response curve in 2017, additional data from later pile driving events at Beatrice Offshore Windfarm were presented in Graham et al. (2019). These later analyses showed that the probability of porpoises responding to piling noise decreased over the construction period (Graham et al. 2019). Therefore, using the dose-response relationship derived from the initial piling events for all piling events in this impact assessment is precautionary, as evidence shows that porpoise responses are likely to diminish over the construction period. A detailed discussion and explanation on this dose-response relationship is given in the MORL (Moray Offshore Renewables Ltd.) ES (Environmental Statement). Technical Appendix 7.3 D[4]

In the absence of species-specific data on bottlenose dolphins or minke whales, this dose-response curve has been adopted for all cetaceans. This is likely to be highly over precautionary as porpoise are considered to be particularly responsive to anthropogenic disturbance (e.g. Brandt et al. 2013, Thompson et al. 2013, Tougaard et al. 2013, Brandt et al. 2018, Sarnocinska et al. 2019, Thompson et al. 2020, Benhemma-Le Gall et al. 2021). Therefore, the number of individuals of these other species predicted to experience behavioural disturbance is considered to be an over-estimate.

[4] https://www.morayeast.com/application/files/3915/8014/0965/Appendix-7-3-D-Behavioural-Responses-to-Noise.pdf

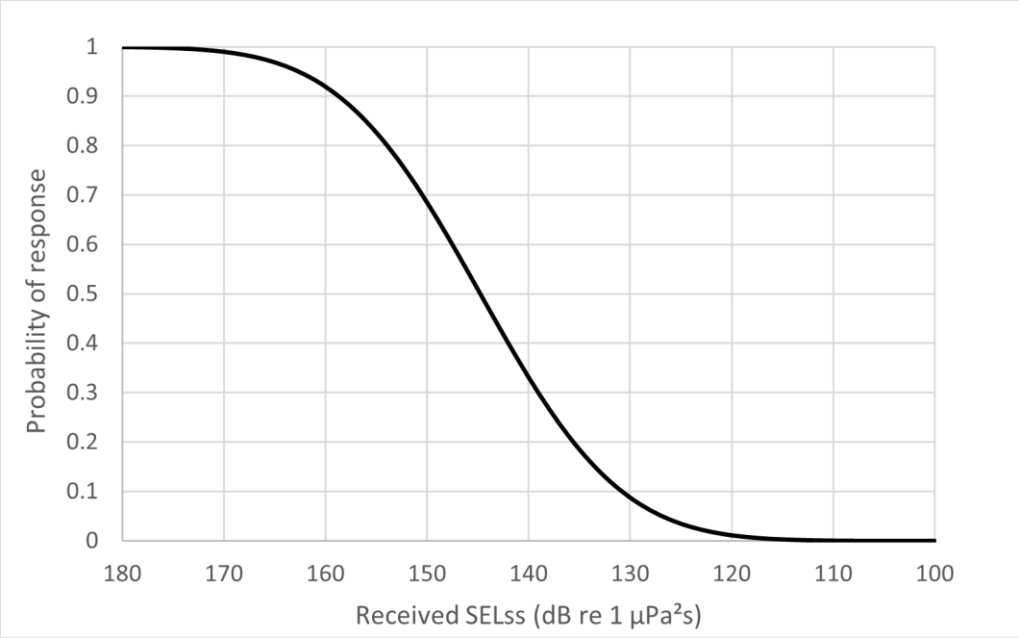


Figure 2-3 Dose-response relationship for harbour porpoise developed by Graham et al. (2017) used for all cetacean in this assessment

For both species of seal, a dose-response relationship was derived from harbour seal telemetry data collected during several months of piling at the Lincs Offshore Wind Farm (Whyte et al. 2020) (Figure 2-4). The Whyte et al. (2020) study updates earlier dose-response information presented in Russell et al. (2016b) and Russell and Hastie (2017). Based upon the analyses in Whyte et al. (2020) it has been assumed that all seals are displaced at sound exposure levels above 180 dB re 1 μPa^2s. This is a conservative assumption since harbour seals were not exposed to such high noise levels in that study. It is also important to note that the percentage decrease in response in the categories 170≤175 and 175≤180 dB re 1 μPa^2s is slightly anomalous (higher response at a lower sound exposure level) due to the small number of spatial cells included in the analysis for these categories (n= 2 and 3 respectively). Given the large confidence intervals on these data, this assessment presents the mean number of seals predicted to be disturbed alongside the 95% confidence intervals, for context.

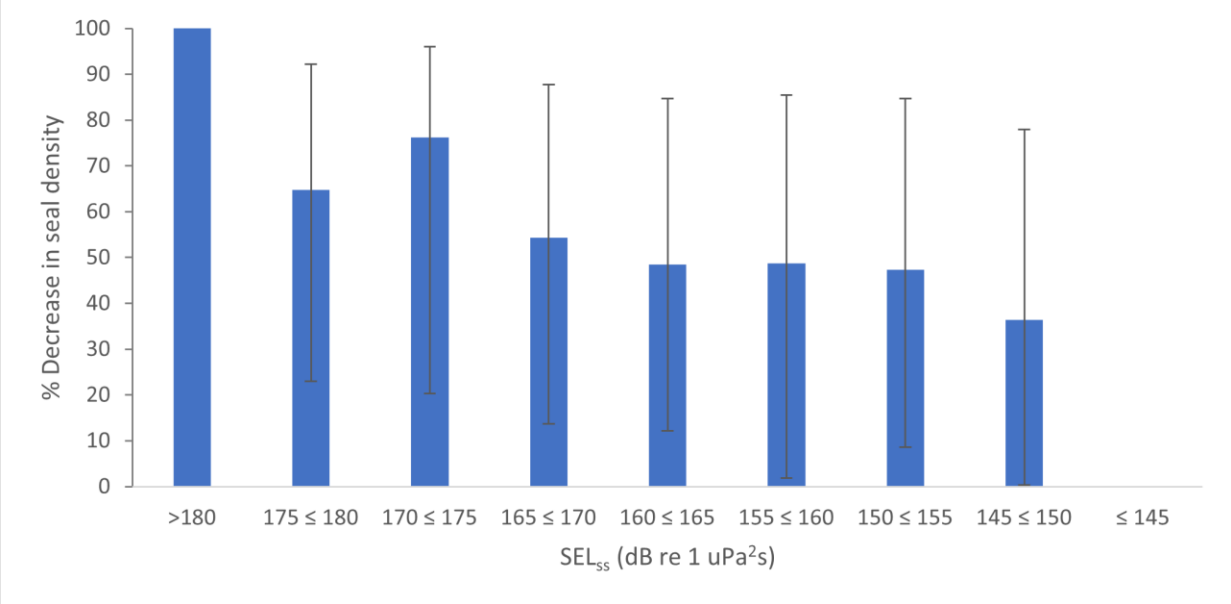


Figure 2-4 Dose-response data for harbour seal derived from the data collected and analysed by Whyte et al. (2020) used for harbour and grey seals in this assessment

2.6.2.3 Density and Management Unit Data

Since the Moray West EIA was submitted in 2018, there have been updates to marine mammal management unit (MU) abundance estimates a well as species specific density surfaces. The changes since the EIA submission are detailed below.

NatureScot requested that both the entire MU and the UK portion of the MU is presented in this underwater noise impact assessment to support the Piling Strategy[5]. Therefore, this has been presented here for both harbour porpoise and minke whales. It is worth noting that while the IAMMWG (2021) report does give the portion of the MU within the UK Exclusive Economic Zone (EEZ), there is no explanation as to the biological basis of this division of the MU. Since, by definition, the entire MU is "a geographical area in which the animals of a particular species are found to which management of human activities is applied" this is considered to be more appropriate to assess impacts against.

2.6.2.3.1 Harbour porpoise

2.6.2.3.1.1 MU

Since the Moray West EIA, the estimated North Sea MU size for harbour porpoise has been updated. The current estimate for the North Sea MU is 346,601 porpoise (95% CI: 289,498- 419,967), of which 159,632 animals are considered as UK portion (IAMMWG 2021). This is slightly higher than the MU estimate used in the Moray West EIA (345,373, 95% CI: 246,526- 495,752).

[5] NatureCcot response to Moray West preliminary underwater noise modelling & impact assessment results. 09 November 2021. Ref: CNS REN OSWF MORAY WEST

2.6.2.3.1.2 Density

The density surface used in Moray West EIA was a 4x4 km grid density surface, created for Moray East (Moray Offshore Renewables Ltd 2012). There is no updated density surface available for harbour porpoise, and thus the same density surface is used in the impact assessment presented in this Piling Strategy.

2.6.2.3.2 Bottlenose dolphin

2.6.2.3.2.1 MU

Since the Moray West EIA, the estimated Coastal East Scotland MU size for bottlenose dolphins has been updated. The current estimate for the Coastal East Scotland MU is 224 dolphins (95% CI: 214- 234) (Arso Civil et al. 2021). This is slightly higher than the MU estimate used in the Moray West EIA (195, 95% CI: 164-224).

2.6.2.3.2.2 Density

The density surface used in Moray West EIA was a 4x4 km grid density surface, created for Moray West, revised from the density surface used for Moray East (Moray Offshore Renewables Ltd 2012). There is no updated density surface available for bottlenose dolphins, and thus the same density surface is used in the impact assessment presented in this Piling Strategy.

2.6.2.3.3 Minke whale

2.6.2.3.3.1 MU

Since the Moray West EIA, the estimated Celtic and Greater North Sea MU size for minke whales has been updated. The current estimate for the Celtic and Greater North Sea MU is 20,118 whales (95% CI: 14,061-28,786), of which 10,288 animals are considered as UK portion (IAMMWG 2021). This is slightly lower than the MU estimate used in the Moray West EIA (23,528, 95% CI: 13,989-39,572).

2.6.2.3.3.2 Density

Two density surfaces were used in Moray West EIA (Addendum to Section 36 Consent and Marine Licence Application): the estimates obtained for the Moray Firth area of commercial interest (Paxton et al. 2016) and the SCANS III density estimates (Hammond et al. 2017).

Given there are known to be areas of relatively high density within the Moray Firth, such as the area surrounding the Southern Trench NCMPA (Nature Conservation Marine Protected Area) (Paxton et al. 2014), it is not considered appropriate to use a uniform density estimate as provided by Hammond et al. (2017). Additionally, seasonal estimates of minke whale abundance should be considered, since minke whales are primarily present in Scottish waters in the summer months (Paxton et al. 2014). It was therefore decided to combine the most recent abundance and density estimate from SCANS III with the density distribution information presented by Paxton et al. (2014). New density surfaces were therefore created for this Piling Strategy, using the seasonal density distribution maps in Paxton et al. (2014) as a relative distribution and then scaling them with the absolute abundance estimate given by SCANS III. This way the most recent abundance estimate (SCANS III) was combined with information on the seasonal

distribution (Paxton et al. 2014), under the assumption that the seasonal distribution is stable over the years.

The new minke whale density maps were created as follows: The Paxton et al. (2014) density surface lies within SCANS III Block S. Within SCANS III Block S with an average density of 0.0095 whales/km^2, and the minke whale abundance estimate is 383 whales (Hammond et al. 2017, Hammond et al. 2021). For the area of SCANS III Block S that is not covered by the Paxton et al. (2014) density surface, a uniform density estimate of 0.0095 whales/km^2 in the summer was used. This resulted in a total of 237 minke whales expected to be present within the area that is not covered by the Paxton et al. (2014) density surface. This left a remaining 146 minke whales to be distributed throughout the Paxton et al. (2014) density surface, therefore the Paxton et al. (2014) summer density surface was scaled such that the total across all cells was 146 minke whales. This resulted in the summer density surface shown in Figure 2-5 which has been used in the Piling Strategy.

For the non-summer density surface, information from Paxton et al. (2016) was consulted. Paxton et al. (2016) provides abundance estimates for minke whales in the Moray Firth in spring (30 animals), summer (210 animals), autumn (20 animals) and winter (30 animals). To create the non-summer density surface, the summer densities within each grid cell were scaled down with a factor reflecting the ratio between the Paxton et al. (2016) summer density and the average over the respective non-summer densities. This assumes that the relative distribution of minke whales with SCANS III Block S remains the same across the year, though the abundance (and therefore density) changes significantly. The resulting non-summer density is given in Figure 2-6.

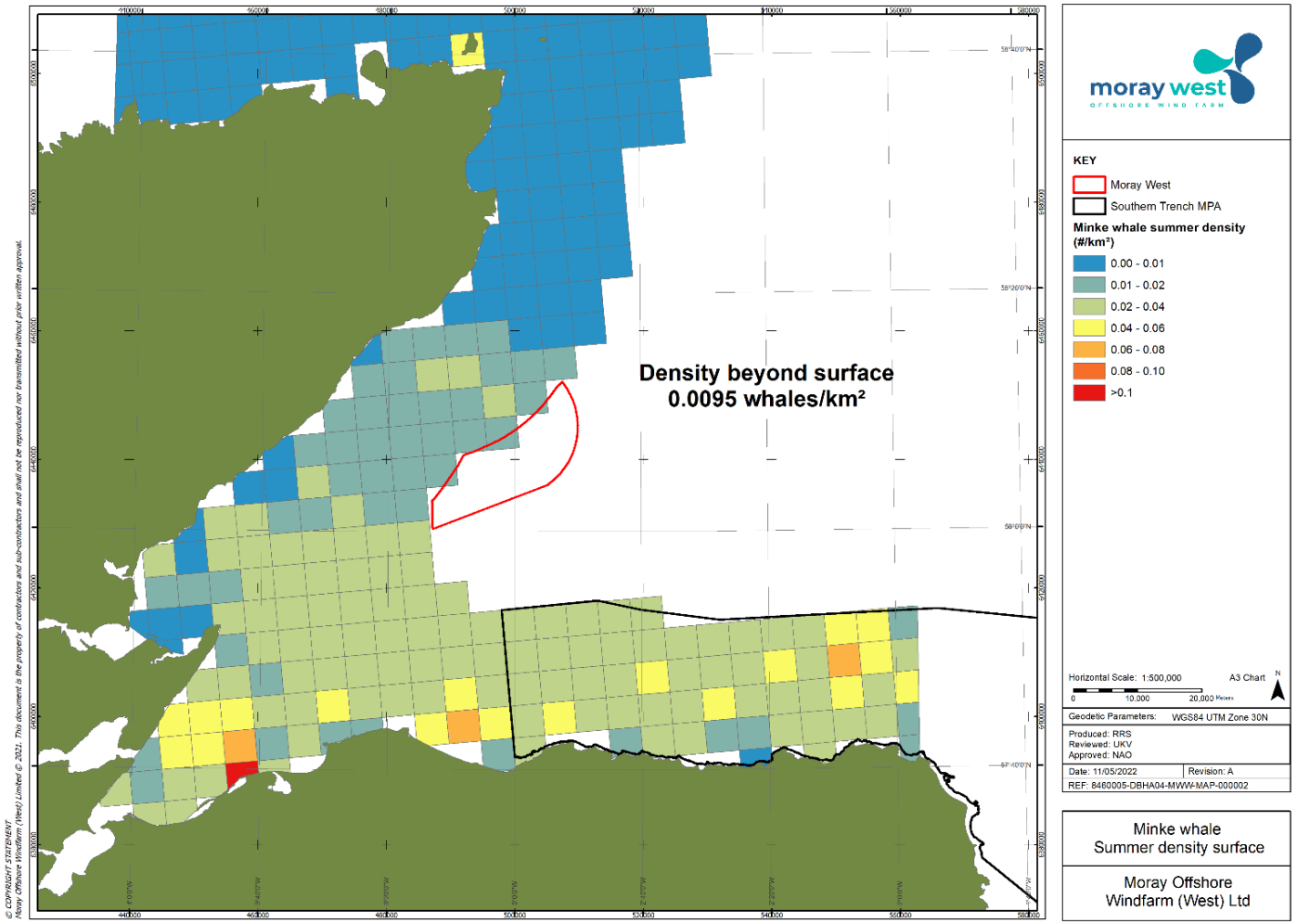


Figure 2-5 Minke whale summer density surface based on SCANS III block S density estimate and the relative minke whale distribution as presented in Paxton et al. (2014)

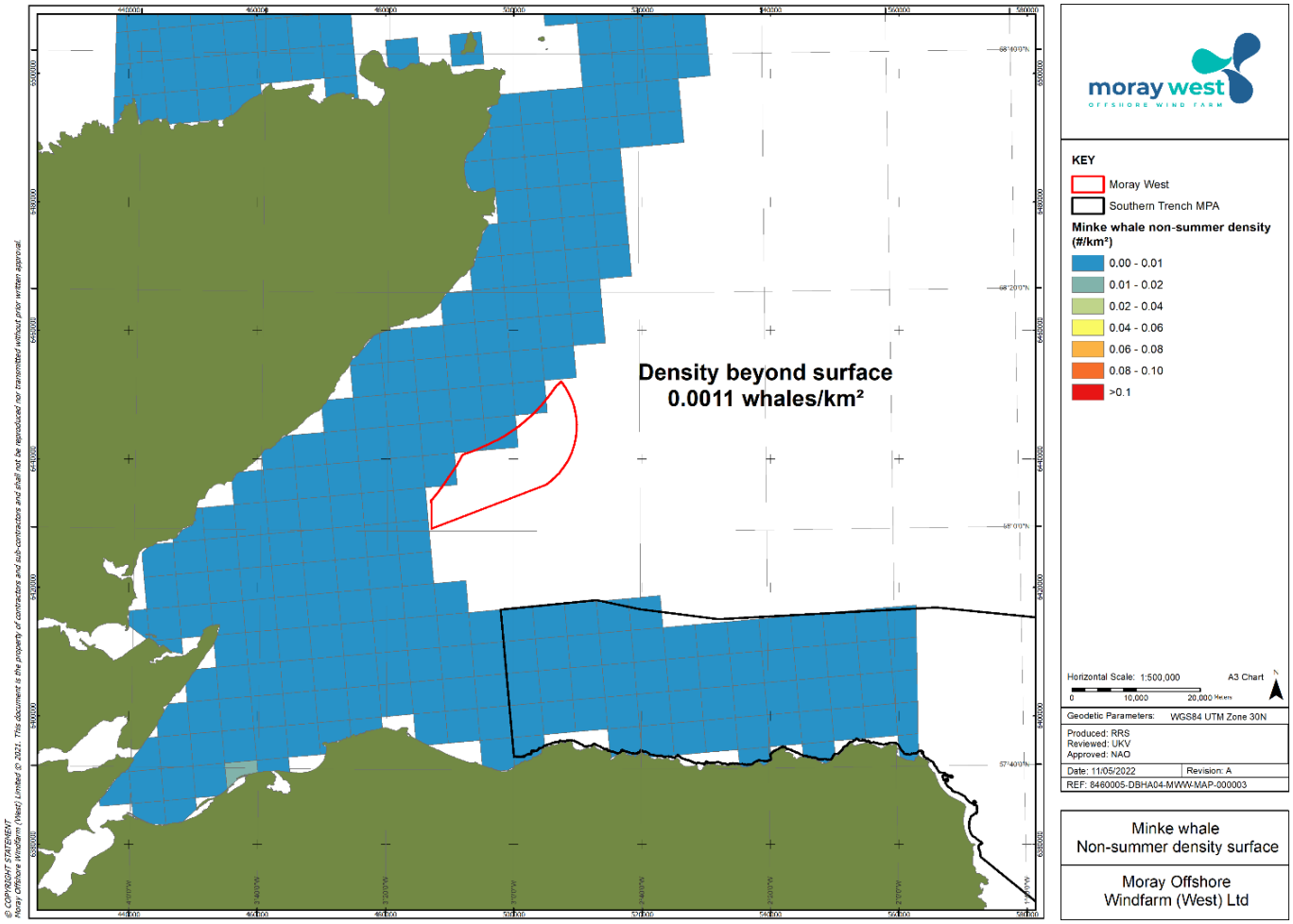


Figure 2-6 Minke whale non-summer density surface based on SCANS III block S density estimate and the relative minke whale distribution as presented in Paxton et al. (2014) and the absolute densities given in Paxton et al. (2016).

2.6.2.3.4 Grey seal

2.6.2.3.4.1 MU

The approach used for the Moray West EIA was to take the August haul-out count for the Moray Firth MU and scale it to account for the proportion of seals at sea at the time of the count. This resulted in a population estimate for the Moray Firth MU of 3,577 grey seals. Since the EIA, the haul-out counts for both species have been updated, as has the scaler used for grey seals. Using the same approach, this resulted in a population estimate for the Moray Firth MU of 6,933 grey seals (Table 2-5).

In 2018, 10 grey seals were tagged in the Moray Firth MU, at tagging locations in the Dornoch Firth, Findhorn and Ardersier. These telemetry data are presented in the seal habitat-preference map report (Carter et al. 2020). The resulting telemetry track data shows that the grey seals moved out of the Moray Firth MU and into both the North Coast and Orkney MU and the East Scotland MU (Figure 2-7). Therefore, there is connectivity between the three MUs. As such it is most appropriate to consider that the relevant population against which to assess impacts is the combined Moray Firth, North Coast and Orkney and East Scotland MUs.

Combining the most recent haul-out count for the Moray Firth MU (1,657) with the most recent haul-out count for the North Coast and Orkney MU (8,599) and the most recent haul-out count for the East Scotland (3,683), results in a total August haul-out count of 13,939 grey seals, which scales to an estimated 58,322 grey seals in the combined MUs (accounting for those at sea at the time of the survey).

Table 2-5 Population estimates for grey seal as used in the EIA and for the current Piling Strategy, based on August haul out counts and corresponding scalar.

	EIA	Current
August haul out count	1,252 (2016 count)	1,657
Scalar	Grey seals haul-out for approximately 0.35 of the survey time (Lonergan et al. 2011).	23.9% of the total population are available to count during the August surveys (Russell et al. 2016a).
Population estimate	3,577	6,933

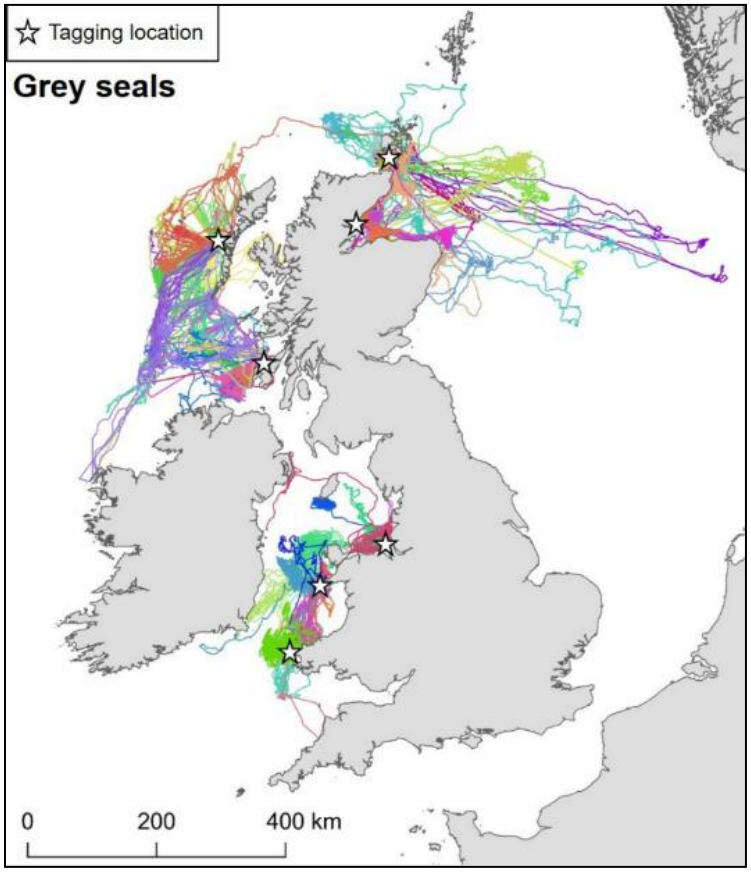


Figure 2-7 Grey seal GPS tracking data from tags deployed during the project of Carter et al. (2020). Tracks are coloured by individual (n=100). White stars denote deployment locations (clockwise from bottom left); Ramsey & Skomer Islands, Bardsey Island, Dee Estuary, Islay & Oronsay (West Scotland), the Monach Isles (Western Isles), Orkney & Pentland Firth (North Scotland & Northern Isles), Dornoch Firth (Moray Firth). Source: Figure 1 of Carter et al. (2020).

2.6.2.3.4.2 Density

The density surface used in Moray West EIA was a 5x5 km grid specific density (Russell et al. 2017). Since then, seal habitat preference maps have been created for the UK (Carter et al. 2020), which are now considered to be the best and more recent estimate of the at-sea distribution of grey seals. Therefore, the impact assessment presented here uses a grey seal density distribution map shown in Figure 2-8 and based on the newer habitat preference map.

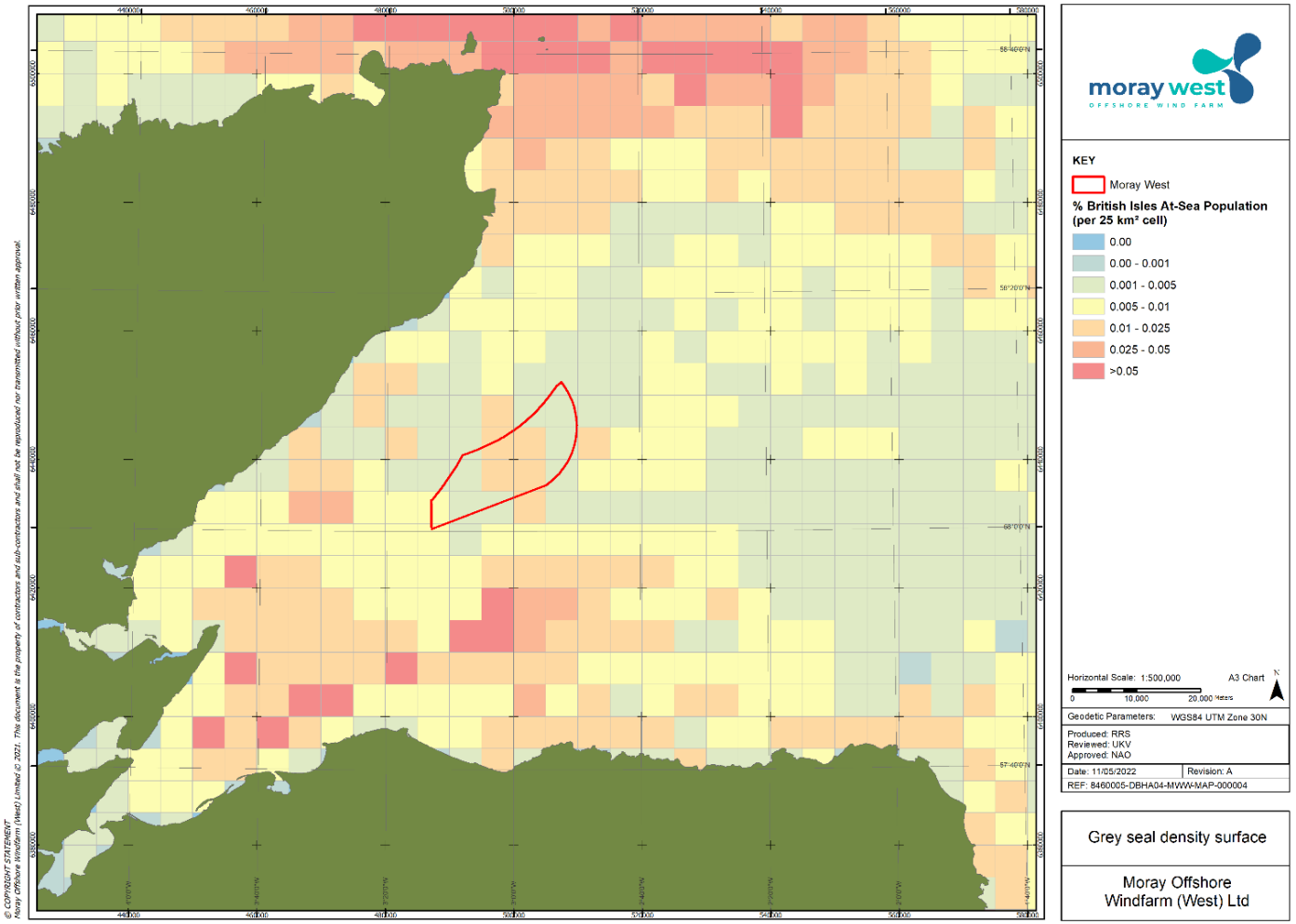


Figure 2-8 Grey seal density surface map based on Carter et al. 2020.

2.6.2.3.5 Harbour seal

2.6.2.3.5.1 MU

The approach used for the Moray West EIA was to take the August haul-out count for the Moray Firth MU and scale it to account for the proportion of seals at sea at the time of the count. This resulted in a population estimate for the Moray Firth MU of 1,306 harbour seals. Since the EIA, the haul-out counts have been updated, this resulted in a population estimate for the Moray Firth MU of 1,496 harbour seals (Table 2-6).

Table 2-6 Population estimates for harbour seal as used in the EIA and for the current Piling Strategy, based on August haul out counts and corresponding scalar.

	EIA	Current
August haul out count	940 (2016 count)	1,077 (2016-2019 count period)
Scalar	The percentage of the total population hauled-out during the August surveys is 72% (Lonergan et al. 2013).	The percentage of the total population hauled-out during the August surveys is 72% (Lonergan et al. 2013).
Population estimate	1,306	1,496

As part of the Strategic Regional Marine Mammal Monitoring Programme for the Moray Firth, a total of 57 harbour seals were tagged at Loch Fleet with GPS/GSM tags in September 2014, February 2015 and February-March 2017 (Graham et al. 2017a). These telemetry data show that harbour seals tagged in the Moray Firth MU do not all remain within the Moray Firth, with seals showing movement out of the Moray Firth and into the North Coast and Orkney MU (Graham et al. 2017a; Figures 8-10). Therefore, there is connectivity between the two MUs and as such it is most appropriate to consider that the relevant population against which to assess impacts is the combined Moray Firth and North Coast and Orkney MUs.

Combining the most recent haul-out count for the Moray Firth MU (1,077) with the most recent haul-out count for the North Coast and Orkney MU (1,405), results in a total August haul-out count of 2,482 harbour seals, which scales to an estimated 3,447 harbour seals in the combined MUs (accounting for those at sea at the time of the survey).

2.6.2.3.5.2 Density

The density surface used in Moray West EIA was a 4x4 km grid density surface, created for Moray West (Bailey 2017). Since then, seal habitat preference maps have been created for the UK (Carter et al. 2020), which are now considered to be the best and more recent estimate of the at-sea distribution of harbour seals. Therefore, the impact assessment presented here uses a harbour seal density distribution map shown in Figure 2-9and based on the newer habitat preference map.

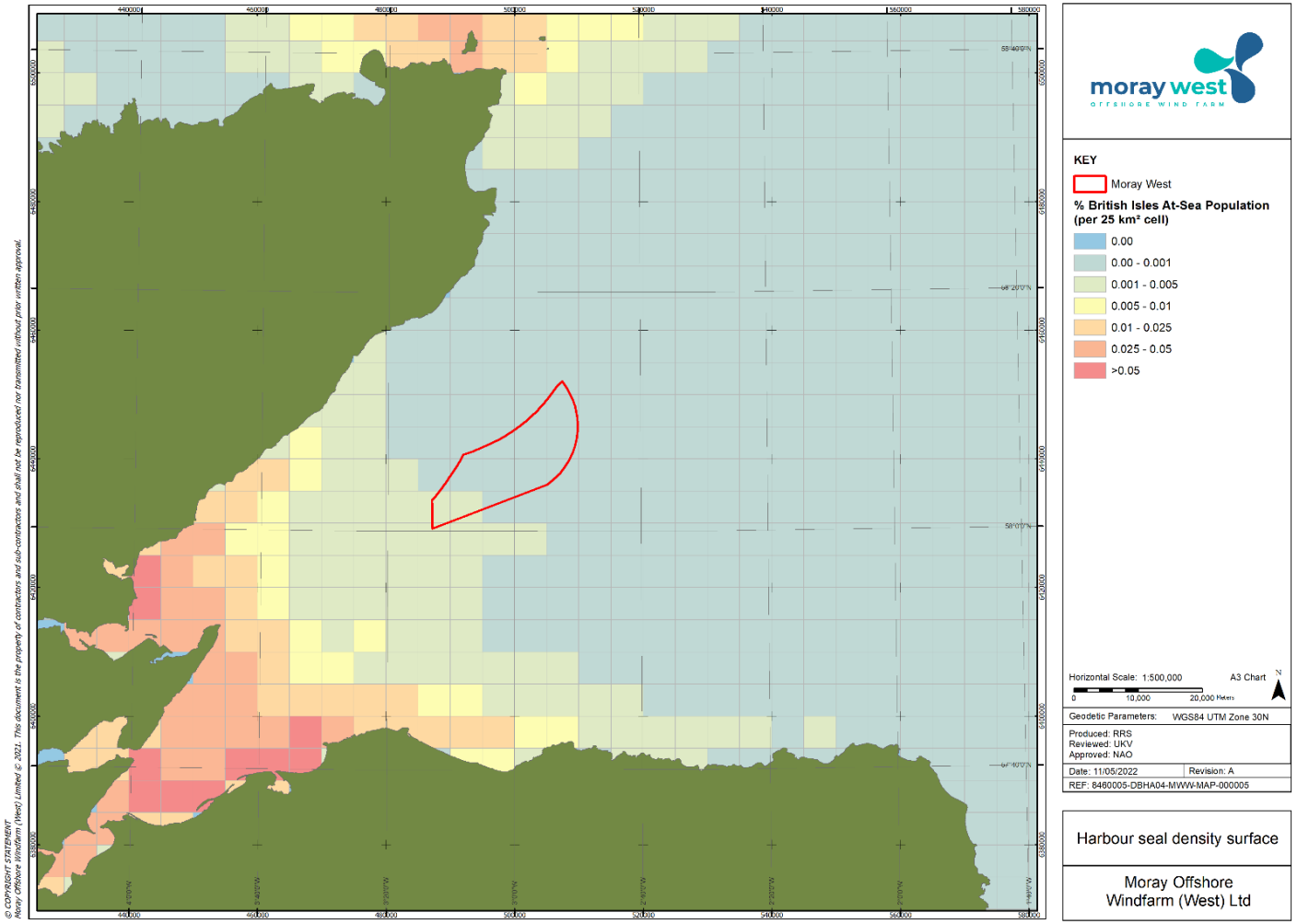


Figure 2-9 Harbour seal density surface map based on Carter et al. (2020).

2.6.2.3.6 Summary

Table 2-7 summarises the MU and density estimates that are used in the impact assessment.

Table 2-7 Species specific MU and density estimates taken forward for impact assessment

Species	MU	MU size	Density
Harbour porpoise	North Sea	346,601 (entire MU) 159,632 (UK portion)	4x4 km grid specific revised densities (Moray Offshore Renewables Ltd 2012)*
Minke whale	Celtic and Greater North Seas	20,118 (entire MU) 10,288 (UK portion)	Newly created summer and non-summer density surfaces based on a combination of data: seasonal abundance estimates (Paxton et al. 2016), density surfaces (Paxton et al. 2014) and the SCANS III density estimates (Hammond et al. 2017)*
Bottlenose dolphin	Coastal East Scotland	224	4x4 km grid specific revised densities, revised from Moray Offshore Renewables Ltd (2012)*
Grey seal	Moray Firth & North Coast and Orkney MUs combined	58,322	5x5 km grid specific densities (Carter et al. 2020)
Harbour seal	Moray Firth & North Coast and Orkney MUs combined	3,447	5x5 km grid specific densities (Carter et al. 2020)
* where impact contours extend beyond the density surface, the relevant SCANS III density estimate is used			

2.6.3 Fish Assessment Criteria

For fish, the most relevant criteria are considered to be those contained in the recent Sound Exposure Guidelines for Fishes and Sea Turtles (Popper et al. 2014). These guidelines group fish into the following categories based on their anatomy and the available information on hearing of other fish species with comparable anatomies:

Group 1 fish: *fish species with no swim bladder or other gas chamber* (e.g. elasmobranchs and flatfish). These species are less susceptible to barotrauma and are only sensitive to particle motion, not sound pressure.

Group 2 fish: *fish species with swim bladders but the swim bladder does not play a role in hearing* (e.g. salmonids). These species are susceptible to barotrauma, although hearing only involves particle motion, not sound pressure.

Group 3 fish: *fish species in which hearing involves a swim bladder or other gas volume* (e.g. Atlantic cod, herring). These species are susceptible to barotrauma and detect sound pressure as well as particle motion.

For impulsive noise from impact piling sources, the guidelines specify dual metric (SEL_{cum} and SPL_{peak}) criteria for recoverable injury and mortality, and an SEL_{cum} criterion for TTS (Table 2-8). None of these thresholds apply frequency weightings. Note that fish species considered in this assessment, namely the Atlantic salmon *(Salmo salar*) and the sea trout (*Salmo trutta*), have a swim bladder but it is not used in hearing, and thus falls into the second hearing group from Table 2-8. The other hearing groups ('no swim bladder' and 'swim bladder involved in hearing') were not assessed.

Table 2-8 Sound exposure thresholds for fish (Popper et al. 2014).

Hearing group	TTS	Recoverable injury		Mortality	
	SEL_{cum} (dB re 1 μPa^2s)	SEL_{cum} (dB re 1 μPa^2s)	SPL_{peak} (dB re 1 μPa)	SEL_{cum} (dB re 1 μPa^2s)	SPL_{peak} (dB re 1 μPa)
Group 1 Fish: no swim Bladder	186	216	213	219	213
Group 2 Fish: swim bladder is not involved in hearing	186	203	207	210	207
Group 3 Fish: swim bladder involved in hearing	186	203	207	207	207

The noise model applied the thresholds for Group 2 under both SEL_{cum} and SPL_{peak} metrics in the assessment. The SPL_{peak} was modelled for both the soft-start hammer energy and the maximum hammer energy of the piling scenarios considered in the assessment. For the $SEL_{cum,}$ the modelling adopted a conservative approach by assuming that fish are stationary and do not flee away from the noise source.

The assessment considered three locations, namely A02, L07, and N17, and both 'best estimate' blow count scenarios at each location, namely BE50 (50 blows/25 cm), and BE80 (80 blows/25 cm). In contrast with the modelling for the marine mammal assessment, where the duration of the piling profile alongside with the distribution of the strike energies within the piling profile are important factors for determining the cumulative exposure of the fleeing animal receptors, for the stationary fish receptors the cumulative exposure is determined only by the total energy of the piling profile (the sum of all the strike energies within the profile). The BE50 piling profiles are using higher strike energies (up to 5000 kJ) and are also have shorter duration than the corresponding BE80 profiles, but they also have slightly less total energy. Thus, the largest cumulative SEL effect zones for fish are expected for the BE80 profiles, as they have higher total energy than the corresponding BE50 profiles, while for marine mammals the profile duration and strike energy distribution factors can lead to a reversed outcome.

2.6.4 Assessment of potential effects

The criteria for determining the significance of effects is a two-stage process that involves defining the sensitivity of the receptors and the magnitude of the impacts. This section describes the criteria applied

in this section to assign values to the sensitivity of receptors and the magnitude of potential impacts. These criteria follow those used in the Moray West EIA Report 2018 – Volume 2, Chapter 8 and 9.

2.6.4.1 Sensitivity criteria

The sensitivities of different marine mammal species have been based on a four-point scale that takes account of the sensitivity of individual receptors in terms of the effect of the impact on the individual's ability to feed, reproduce and ultimately survive. The definitions of sensitivity are provided in Table 2-9 and Table 2-10 and include consideration of the receptor's ability to adapt to, tolerate or recover from the effect.

Table 2-9 Sensitivity of the Marine Mammal Receptor

Receptor sensitivity	Description
High	No ability to adapt behaviour so that survival and reproduction rates are affected. No tolerance – Effect will cause a change in both reproduction and survival rates. Limited ability for the animal to recover from the effect.
Medium	Limited ability to adapt behaviour so that survival and reproduction rates may be affected. Limited tolerance – Effect may cause a change in both reproduction and survival rates. Some ability for the animal to recover from the effect.
Low	Ability to adapt behaviour so that survival and reproduction rates are unlikely to be affected. Some tolerance – Effect unlikely to cause a change in both reproduction and survival rates. Ability for the animal to recover from the effect.
Negligible	Receptor is able to adapt behaviour so that survival and reproduction rates are not affected. Receptor is able to tolerate the effect without any impact on reproduction and survival rates. Receptor is able to return to previous behavioural states/ activities almost immediately.

Table 2-10 Sensitivity of the Fish Receptor	
Receptor sensitivity	**Description / Reason**
High	No or very low capacity to accommodate the proposed form of change; and / or receptor designated and /or of international or national level importance. Likely to be rare with minimal potential for substitution. May also be of high socioeconomic importance.
Moderate	Moderate to low capacity to accommodate the proposed form of change; and / or receptor designated and / or of national or regional level importance. Likely to be relatively rare. May also be of moderate socioeconomic importance.
Low	Moderate to high capacity to accommodate the proposed form of change; and / or receptor not designated but of district level importance.
Negligible	High capacity to accommodate the proposed form of change; and / or receptor not designated and only of local level importance.

2.6.4.2 Impact magnitude

Impact magnitude has been considered in terms of the duration of the effect and the number of animals affected with sufficient severity to alter the future population trajectory and change the conservation status or long-term viability of the population. The definitions of impact magnitude are provided in Table 2-11 and Table 2-12.

Table 2-11 Impact magnitude of marine mammal receptor	
Receptor sensitivity	**Description**
High	The impact would affect the behaviour and distribution of sufficient numbers of individuals, with sufficient severity, to affect the favourable conservation status and/ or the long-term viability of the population at a generational scale.
Medium	Temporary changes in behaviour and/ or distribution of individuals at a scale that would result in potential reductions to lifetime reproductive success to some individuals although not enough to affect the population trajectory over a generational scale. Permanent effects on individuals that may influence individual survival but not affecting enough individuals to alter population trajectory over a generational scale.
Low	Short-term and/or intermittent and temporary behavioural effects in a small proportion of the population. Reproductive rates of individuals may be impacted in the short term (over a limited number of breeding cycles). Survival and reproductive rates very unlikely to be impacted to the extent that the population trajectory would be altered.
Negligible	Very short term, recoverable effect on the behaviour and/or distribution in a very small proportion of the population. No potential for any changes in the individual reproductive success or survival therefore no changes to the population size or trajectory.

Table 2-12 Impact magnitude of fish receptor	
Magnitude	**Description / Reason**
High	Permanent changes, over large parts of the near- and far-field, to key characteristics or feature of the particular environmental aspect's character or distinctiveness.
Moderate	Noticeable, temporary (for part of the project duration) change, or barely discernible change for any length of time, encountered within the near-field and parts of the far-field, to key characteristics or features of the particular environmental aspect's character or distinctiveness
Low	Noticeable, temporary (for part of the project duration) change, or barely discernible change for any length of time, restricted to the near-field and immediately adjacent far-field areas, to key characteristics or features of the particular environmental aspect's character or distinctiveness.
Negligible	Changes which are not discernible from background conditions.
No change	No measurable change.

2.6.4.3 Significance criteria

The significance of the effect upon marine mammals is determined using a matrix of the magnitude of the impact and the sensitivity of the receptor. The particular method employed for this assessment is presented in Table 2-13and Table 2-14.

For the purposes of this assessment, any potential impact with a significance level identified as major or moderate is considered to be significant in EIA terms and mitigation may be required, while impacts of minor or less have been concluded to be not significant in terms of the EIA Regulations.

Table 2-13 Impact significance for marine mammal receptor

		Sensitivity			
		High	**Medium**	**Low**	**Negligible**
Magnitude	**High**	Major	Major	Moderate	Minor
	Medium	Major	Moderate	Minor	Negligible
	Low	Moderate	Minor	Minor	Negligible
	Negligible	Minor	Minor	Negligible	Negligible

Table 2-14 Impact significance for fish receptor

		Magnitude				
		High	**Moderate**	**Low**	**Negligible**	**No change**
Sensitivity	**High**	Major	Moderate	Moderate	Minor	Negligible
	Moderate	Moderate	Moderate	Minor	Negligible	Negligible
	Low	Moderate	Minor	Negligible	Negligible	Negligible
	Negligible	Minor	Negligible	Negligible	Negligible	Negligible

2.6.5 Population modelling

Population modelling has been conducted for bottlenose dolphin, harbour porpoise, harbour and grey seal. The interim Population Consequences of Disturbance (iPCoD) framework (Harwood et al. 2014, King et al. 2015) has been used to predict the potential population consequences of the predicted amount of disturbance resulting from the piling at Moray West. iPCoD uses a stage-structured model of population dynamics with nine age classes and one stage class (adults 10 years and older). The model is used to run a number of simulations of future population trajectory with and without the predicted level of impact to allow an understanding of the potential future population-level consequences of predicted behavioural responses and auditory injury.

There is a lack of empirical data on the way in which changes in behaviour and hearing sensitivity may affect the ability of individual marine mammals to survive and reproduce. Therefore, in the absence of empirical data, the iPCoD framework uses the results of an expert elicitation process described in Donovan

et al. (2016) to predict the effects of disturbance and PTS on survival and reproductive rates. The process generates a set of statistical distributions for these effects and then simulations are conducted using values randomly selected from these distributions that represent the opinions of a "virtual" expert. This process is repeated many 100s of times to capture the uncertainty among experts. While the iPCoD model is subject to many assumptions and uncertainties relating to the link between impacts and vital rates, the model presents the best available scientific expert opinion at this time.

Despite these limitations and uncertainties, this assessment has been carried out according to best practice, using the best available scientific information, and the latest expert elicitation results from Booth and Heinis (2018). The information provided is therefore considered to be sufficient to carry out an adequate assessment for bottlenose dolphin, harbour porpoise, harbour and grey seal. In the latest update of the iPCOD model there was no elicitation for minke whale, which is why no population modelling was conducted for this species.

The piling scenario used for population modelling (see Section 2.6.5) is given in Table 2-15.

Table 2-15 Parameters used for iPCOD modelling

Parameter	Description
Number of WTGs	60
Number of OSP	2
Number of piles	62 monopiles
Concurrent piling	None
Number of piling days	62 (assuming 1 pile is installed in 1 day)
Piling window	3-months window: August – October 2023 inclusive
Piling schedule	Start date: 01/08/2023, End date: 31/10/2023, Piling days: 62 • Aug: 24 piling days (3 piling days followed by 1 non-piling day) • Sep: 21 piling days (3 piling days followed by 1 non-piling day) • Oct: 17 piling days (random distribution)

2.6.6 Comparison with EIA Report 2018

For both marine mammals and fish, a comparison has been made between the results of the original Moray West EIA Report 2018 and the results of the assessment based on the revised project design parameters presented here.

Several changes to the piling parameters have been made since the Moray West EIA 2018. These are outlined in Table 2-16. The key parameters that have changed are: a reduction in the number of turbines (71% of Moray West EIA 2018), a reduction in the piling construction window (60% of Moray West EIA

2018), a reduction in the minimum hammer energy at the soft-start (54% of Moray West EIA 2018) and removal of concurrent piling.

For marine mammals, there have been updates to the MUs and density surfaces since the ES. These are described above in Section 2.6.2.3.

There has been no change to the PTS-onset thresholds used for marine mammals and fish. The Moray West EIA Report 2018 presented the National Marine Fisheries Service (NMFS) (2016) PTS-onset thresholds for marine mammals; this Piling Strategy presents the Southall et al. (2019) PTS-onset thresholds. These thresholds are the same; the only difference between the two is that Southall et al. (2019) renamed the hearing group "High-frequency cetaceans" (harbour porpoise) to "Very-high-frequency cetaceans" (dolphin species) and "Mid-frequency cetaceans" to "High-frequency cetaceans". In each case, the name of the hearing group was amended but the threshold values remained the same.

The behavioural dose-response curve used for cetaceans remains the same between the Moray West EIA Report 2018 and here (Graham et al. 2017b). The behavioural dose-response curve used for seal species has been updated since the 2018 ES, with the original as presented in Russell and Hastie (2017) updated by Whyte et al. (2020) to reflect amendments to the underlying underwater noise propagation modelling.

For the noise modelling, a conversion factor of 4% and 10%, respectively has been used here, as opposed to the 0.5% of the ES and 1% of the ES-Appendix (see Section 2.2). For the fleeing model in the ES and its Appendix it was considered that animals would stop fleeing at 25 km. This stop was omitted for the fleeing model in this Piling Strategy.

Table 2-16 Changes to piling parameters since the EIA Report 2018		
Parameter	**EIA Report 2018**	**Piling Strategy**
Number of turbines	85	60
Turbine foundations	Jacket pin-pile or monopile	Monopile only
Maximum piling period	10 months	3 months[6]
Maximum hammer driving energy[7]	5,000 kJ	5,000 kJ
Soft-start maximum hammer driving energy	1,000 kJ	550 kJ
Concurrent piling	Yes	No
Number of piling days	87 (assuming 1 vessel) 44 (assuming 2 vessels)	62 (assuming 1 vessel)

2.6.7 Comparison with 2018 RIAA

Harbour seal and bottlenose dolphin were the focal species in the Report to Inform Appropriate Assessment (RIAA) conducted in 2018. These are still relevant at the time of writing the Piling Strategy. For the comparison, iPCOD modelling results from the 2018 RIAA were compared with those obtained in the Piling Strategy assessment.

3 Marine Mammal Assessment Results

3.1 Auditory injury

3.1.1 Instantaneous PTS

The PTS impact ranges for marine mammals for the soft-start are presented in Table 3-1. For all species, except harbour porpoise, the instantaneous PTS-onset impact range for soft-start pile strikes is <50 m. For harbour porpoise, the maximum instantaneous PTS-onset impact range at soft-start is 672 m for a 10% CF at the low driveability risk location P18.

For all species except harbour porpoise, these ranges are similar to those resulting from the risk assessment for instantaneous injury from piling presented in Annex 3 of the Moray East Piling Strategy[8].

[6] For the purpose of the iPCOD modelling it has been assumed a piling window of 3 months (August-October 2023) as a reaslitic scenario as described in Table 2-15. The overall pile installation programme as described in the Piling Strategy is considered up to 8 months, as a worst case scenario taking into account the time for pile installation activities other than the pile driving, operational downtime due to weather and other unforseen delays.

[7] The maximum consented hammer driving energy (5,000 kJ) has been used for the purpose of the underwater noise modelling and to inform the impact assessment presented here. Moray West has committed to not exceed a maximum hammer energy of 4,400 kJ at all pile locations across Moray West Site.

[8] https://marine.gov.scot/sites/default/files/moray_east_wind_farm_ps_v.3_redacted.pdf

That document highlighted the low probability of individuals of those species being present in the injury zone at the start of piling, in the absence of any mitigation. Furthermore, studies at Moray East demonstrated that harbour porpoises move away from piling sites following the use of Acoustic Deterrent Devices (ADD) mitigation measures (Graham et al. Submitted). Finally, studies at both Beatrice and Moray East offshore windfarms sites in the Moray Firth (Benhemma-Le Gall et al. 2021) and other North Sea sites (Brandt et al. 2018) have shown that harbour porpoises are displaced from the immediate vicinity of the piling location prior to the commencement of ADD mitigation and pile driving, likely due to increased vessel traffic. During the construction of the Beatrice and Moray East, harbour porpoise occurrence decreased with increasing vessel presence, with the magnitude of decrease depending on the distance to the vessel (Benhemma-Le Gall et al. 2021). For example, the probability harbour porpoise occurrence at a mean vessel distance of 2 km decreased by up to 95% from a probability of occurrence of 0.37 when no vessels were present to 0.2 for the highest vessel intensity of 9.8 min per km^2. At a mean vessel distance of 3 km, the probability decreased by up to 57% to 0.16 for the highest vessel intensity. No apparent response was observed at 4 km. Therefore, it is expected that harbour porpoise detections will significantly decline in close proximity to construction vessels, such that it is expected that there will be a very low probability of a porpoise being present within 672 m of the pile once the piling soft-start commences.

The impact of instantaneous PTS-onset from the soft-start is therefore assessed as being of **negligible** magnitude for all species.

Table 3-1 Instantaneous PTS impact ranges for a soft-start hammer energy of 550 kJ, based on a CF of 4% and 10%, for all location and species considered in the noise modelling.

Species	Location	Refusal Risk	Hammer Energy	4% CF	10% CF
Bottlenose dolphin	A01	moderate	550 kJ	10 m	18 m
	A02	high	550 kJ	10 m	18 m
Seals	A01	moderate	550 kJ	31 m	48 m
	A02	high	550 kJ	31 m	48 m
Harbour porpoise	P18	low	550 kJ	300 m	672 m
	N17	high	550 kJ	288 m	669 m
Minke whale	N07	low	550 kJ	29 m	46 m
	L07	high	550 kJ	29 m	46 m

The instantaneous PTS-onset impact ranges for full hammer energy for marine mammals are presented in Table 3-2. For all species, except harbour porpoise, the instantaneous PTS-onset impact range at full hammer energy modelled with a CF of 10% is <400 m, and <160 m for a CF of 4%. For harbour porpoise,

the maximum instantaneous PTS-onset impact range at full hammer energy with a CF of 10% is 2.6 km, and 1.5 km for a CF of 4%.

The probability of a single individual bottlenose dolphin being within the 54 m radius during the first strike at full hammer energy across 60 piling events is also essentially zero (<0.000001 (0%)). For minke whales, the probability of a single individual minke whale being within the 327 m radius during the first strike at full hammer energy across 60 piling events is also very low (0.0165 (1.65%)). This probability estimate is considered to be an overestimate since it assumes that animals have not moved out of the impact radius during the period of pre-construction vessel activity and the soft-start, which is extremely unlikely.

Table 3-2 Instantaneous PTS impact ranges for a full hammer energy of 5000 kJ, based on a CF of 4% and 10%, for all location and species considered in the noise modelling.

Species	Location	Refusal Risk	Strike Energy	4% CF	10% CF
Bottlenose dolphin	A01	moderate	5,000 kJ	33 m	54 m
	A02	high	5,000 kJ	33 m	54 m
Seals	A01	moderate	5,000 kJ	159 m	393 m
	A02	high	5,000 kJ	159 m	396 m
Harbour porpoise	P18	low	5,000 kJ	1,503 m	2,586 m
	N17	high	5,000 kJ	1,500 m	2,595 m
Minke whale	N07	low	5,000 kJ	132 m	327 m
	L07	low	5,000 kJ	144 m	354 m

For harbour porpoise, grey seals and harbour seals, in the absence of any mitigation or any response prior to the first strike at full hammer energy, the cumulative probability of an individual being within the instantaneous PTS-onset zone across 62 piling events is essentially 1 (>0.999999 (>99.9%)). The probability of an animal being present within the instantaneous PTS-onset impact zone at full hammer energy is summarized inTable 3-3.

When evaluating the risk of instantaneous PTS-onset for full hammer energy, it should be noted that predicted ranges for full hammer energy are conservative given that full hammer energy is often not reached during installation (see Section 2.6.2.1.2 and the Beatrice Offshore Windfarm Ltd (BOWL) & Moray East Piling Reports). Furthermore, there is now evidence that porpoises are displaced by vessel activity (Benhemma-Le Gall et al. 2021), ADD and piling noise (Graham et al. 2019, Graham et al. Submitted). Assuming a fleeing speed of 1.4 m/s upon the first pile strike, animals should be at minimum 2.4 km away from the piling location at the end of the soft-start. When full hammer energy is reached at the end of the ramp-up (>120 minutes after pile driving starts) (see Table2-2), animals are predicted to be at least 10 km away.

The likelihood of an animal actually being in these PTS-onset impact ranges is negligible, given that in reality they will have already been displaced by the presence of construction vessels, the ADD mitigation, the soft-start and the ramp-up before the first strike at full hammer energy is reached.

In summary, the impact of instantaneous PTS at soft-start and for full hammer energy is assessed as being of **negligible** magnitude for all species.

Table 3-3 Probability of animal being present within the instantaneous PTS-onset impact zone at full hammer energy

Species	Instantaneous PTS-onset range (km)	Density (#/km^2)	Area of circle containing 1 individual (km^2)	Radius of circle containing 1 individual (km)	Probability of animal being present
Bottlenose dolphin	0.054	0.00048*	2063.5	25.63	<0.000001
Grey seal	0.396	0.94567*	1.1	0.58	> 0.999999
Harbour seal	0.396	0.64500*	1.6	0.70	> 0.999999
Harbour porpoise	2.595	1.46875*	0.7	0.47	> 0.999999
Minke whale	0.327	0.00950ǂ	105.3	5.79	0.0165018
* Maximum density cell within the Moray West array area, ǂ SCANS III density estimate					

3.1.2 Cumulative PTS

3.1.2.1 1 pile per day

Table 3-4 presents the maximum cumulative PTS-onset impact ranges (i.e. the distance at which an animal is safe to start fleeing at the start of piling without the risk of experiencing PTS) for each species and piling scenario combination (assuming 1 pile per day). As outlined in Section 2.6.2.1.2, these are based upon a series of highly conservative assumptions. Table 3-5 provides information of the number of animals that might be within the highly conservative cumulative PTS impact zones.

Table 3-4 Maximum cumulative PTS impact based on the piling profiles shown in Table 2-2and a constant CF of 4% and 10%, respectively, for all location and species considered in the noise modelling.					
Species	**Location**	**Refusal Risk**	**Blow count**	**4% CF**	**10% CF**
Bottlenose dolphin	A01	moderate	BE50	<45 m	<45 m
	A02	high	BE50	<45 m	<45 m
Seals	A01	moderate	BE50	<45 m	127 m
	A02	high	BE50	<45 m	127 m
Harbour porpoise	P18	low	BE80	965 m	2,792 m
	N17	high	BE50	1,986 m	4,825 m
Minke whale	A01	moderate	BE50	29,922 m	33,606 m
	N07	low	BE80	4,972 m	15,162 m
	L07	high	BE50	12,223 m	45,081 m

Table 3-5 Number of animals within the cumulative PTS impact are based on the piling profiles shown in Table 2-2and a constant CF of 4% and 10%, respectively, for all location and species considered in the noise modelling. S: based on summer distribution, NS: based on non-summer distribution					
Species	**Location**	**Refusal Risk**	**Blow count**	**4% CF**	**10% CF**
Bottlenose dolphin	A01	moderate	BE50	<1	<1
	A02	high	BE50	<1	<1
Seals	A01	moderate	BE50	<1	<1
	A02	high	BE50	<1	<1
Harbour porpoise	P18	low	BE80	3	25
	N17	high	BE50	10	72
Minke whale	A01	moderate	BE50	S: 10, NS: <1	S: 39, NS: 4
	N07	low	BE80	S: <1, NS: <1	S: 4, NS: <1
	L07	high	BE50	S: 3, NS: <1	S: 26, NS: 3

The conservative estimates for cumulative PTS impact ranges for bottlenose dolphins and seals are less than 130 m, including the worst-case scenario of a constant 10% CF, with less than one animal potentially within the impact area. The risk of cumulative PTS-onset to these species groups is therefore of **negligible** magnitude.

The conservative cumulative PTS-onset impact ranges for harbour porpoise reach nearly 1 km for the low refusal risk and a constant 4% CF, and 2.8 km when considering a constant 10% CF. At the high refusal risk location, impact ranges reach up to 2 km for a constant 4% CF and 4.8 km for a constant 10% CF (Figure 3-1). The number of animals potentially within those impact areas are 3 and 25 for low refusal risk location, and 10 and 72, respectively, for a high refusal risk location. However, due to the conservative assumptions used to calculate the SEL_{cum} PTS-onset ranges (see Section 2.6.2.1.2) these predicted impact ranges are considered unrealistically high and the number of animals likely to be at risk of experiencing cumulative PTS will be considerably fewer. Furthermore, the high refusal risk location N17 has been excluded from the final wind farm layout, and no further moderate or high refusal risk location is placed within the high-density harbour porpoise area. Therefore, the low refusal risk location P18 is considered as worst-case scenario.

Bearing in mind that a series of pulses is likely to elicit a smaller threshold shift in mammals compared to a single pulse of the same cumulative SEL, and considering the blow rate planned at Moray West, the PTS-onset threshold for harbour porpoise is expected to be 2-3 dB higher than the Southall et al. (2019) threshold (see Section 2.6.2.1.2 for more detail). This would lead to a considerably lower impact range and number of animals within the impact area.

Even under these worst-case scenarios, it should remain possible to mitigate impacts using ADDs under procedures previously developed by other Moray Firth developers (Thompson et al. 2020). ADDs shown to have a significant deterrent effect on harbour porpoises up to 7.5 km away (Brandt et al. 2013). Assuming a swimming speed of 1.4 m/s, it would therefore take 12 minutes of ADD activation for a porpoise starting at the pile location to exit a 1 km impact zone, or 33 minutes to reach the maximum impact range of 2.8 km (and 58 minutes to reach 4. 85 km, when considering the high refusal risk scenario). However, it is likely that many porpoises would have already been displaced by construction vessels (Benhemma-Le Gall et al. 2021). Assuming a displacement of the animals out of a 2 km radius, a 12 minute of ADD activation would be sufficient to displace them out of the maximum impact range (considering the low refusal risk scenario). Using ADD to reduce conservative worst-case estimates of PTS-onset needs to be balanced against known far-field disturbance from ADD (Thompson et al. 2020). Nevertheless, using an ADD activation period of up to 58 minutes before pile start as mitigation measure, the impact of cumulative PTS is assessed as of **negligible** magnitude for harbour porpoise.

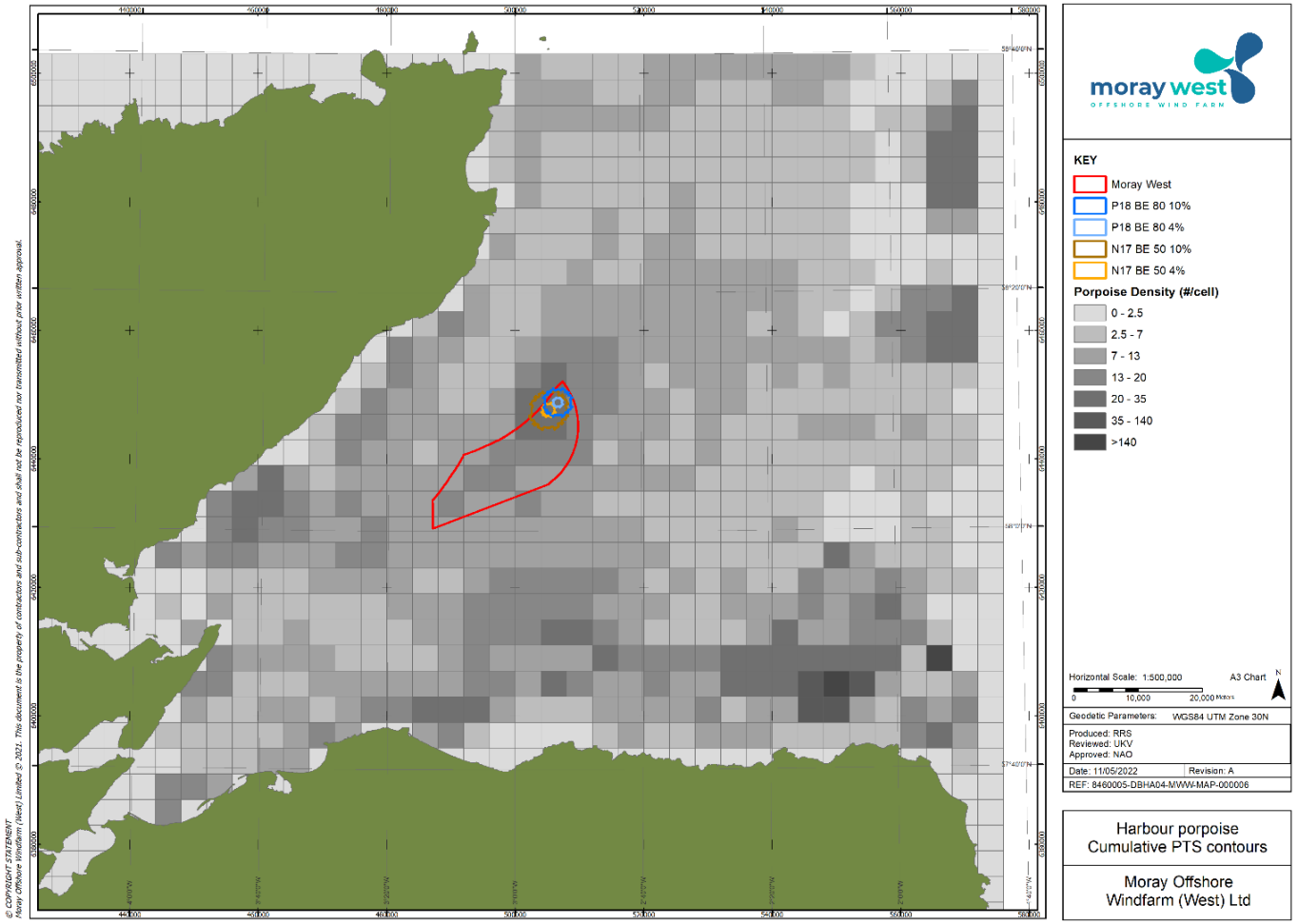


Figure 3-1 Harbour porpoise cumulative PTS-onset impact ranges for locations P18 and N17, featuring different conversion factor scenarios.

The worst-case cumulative PTS-onset impact ranges for minke whales are large for the moderate and high risk refusal locations (maximum 45.081 km location L07 modelled with a constant 10% CF (Figure 3-2 and Figure 3-3). While these modelled locations were excluded from the current layout (Figure 2-1), similarly large impact ranges are expected from the only two high risk refusal locations left in the layout, when considering the conservative approach used for determining cumulative PTS impact ranges.

The conservative assumptions underlying our worst-case estimates (see Section 2.6.2.1.2) mean that impact ranges in Table 3-4 are unrealistically high. At the same time, there is still no consensus on assessment methodologies that would provide more probable estimates of impacts. Nevertheless, to provide context, we also provide a worked example in Section 3.1.3 to highlight the extent to which results for minke whale in Table 3-5 may be affected by the need to use conservative values to address uncertainties highlighted in Section 2.6.2.1.2.

Although these worst-case cumulative PTS-onset impact ranges for minke whales are large, most individuals within such a radius will be exposed to piling noise at ranges of tens of kilometers, where impulsive exposure criteria for receivers are extremely precautionary (Southall 2021). Furthermore, seasonal patterns of occurrence mean that the numbers of individuals that might be within this area is low outside the summer months. Thus, the numbers potentially affected are extremely conservative, and there is potential to further reduce risks by focussing piling activity in non-summer months, particularly at sites where pile refusal is most likely.

In winter, a maximum of 4 minke whales are expected to be within the worst-case cumulative PTS impact zone, whereas in summer months this could be up to 39 minke whales (0.19% MU, 0.38% UK portion). Using criteria that recent studies indicate are more probable, the number of individuals even in summer is reduced to 1-2 animals. The impact as assessed is considered as **negligible** magnitude in EIA terms, as the effect is on such a small proportion of the population that there is expected to be no change to the population size or trajectory.

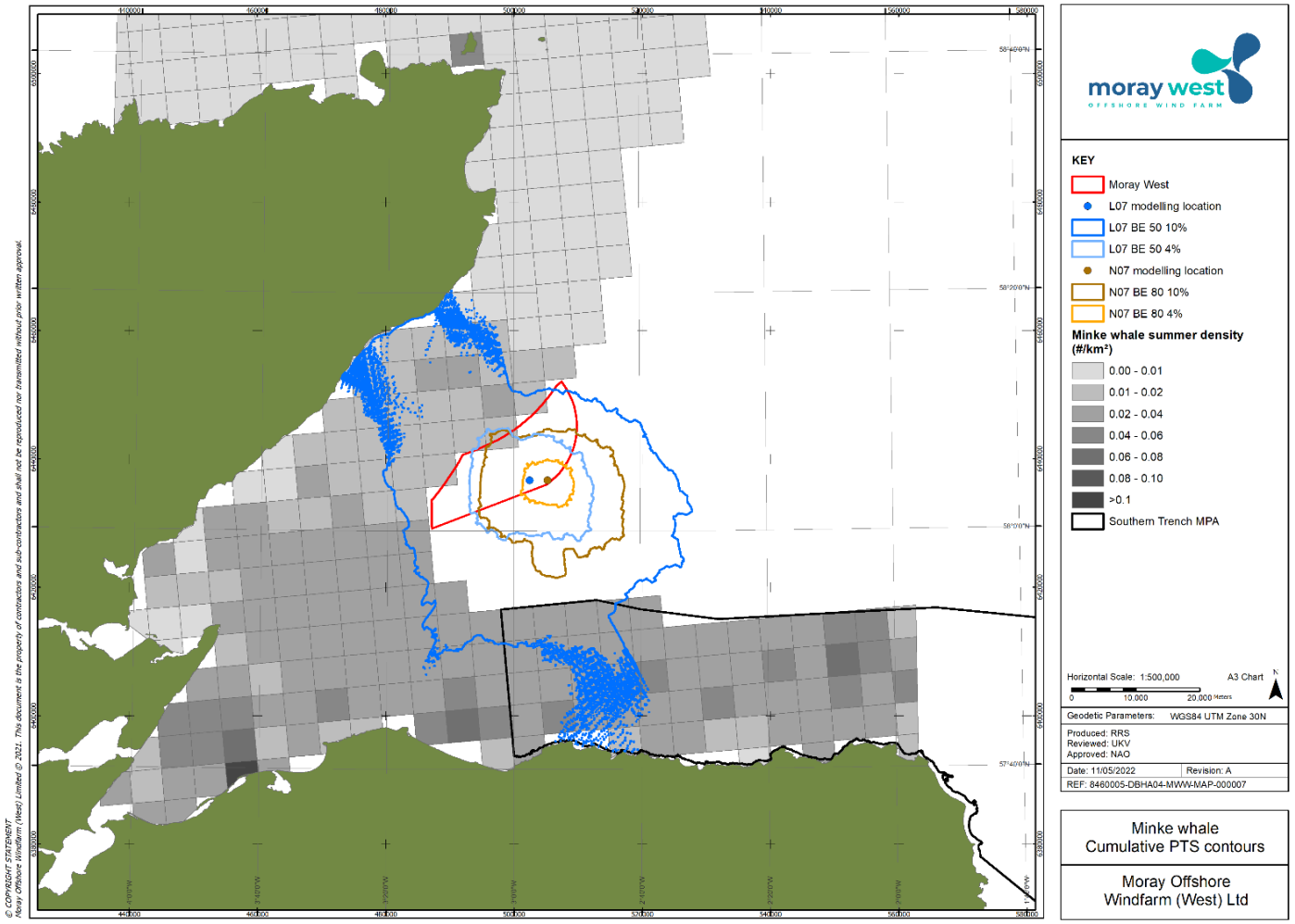


Figure 3-2 Minke whale cumulative PTS impact ranges for locations L07 and N07, featuring different conversion factor scenarios.

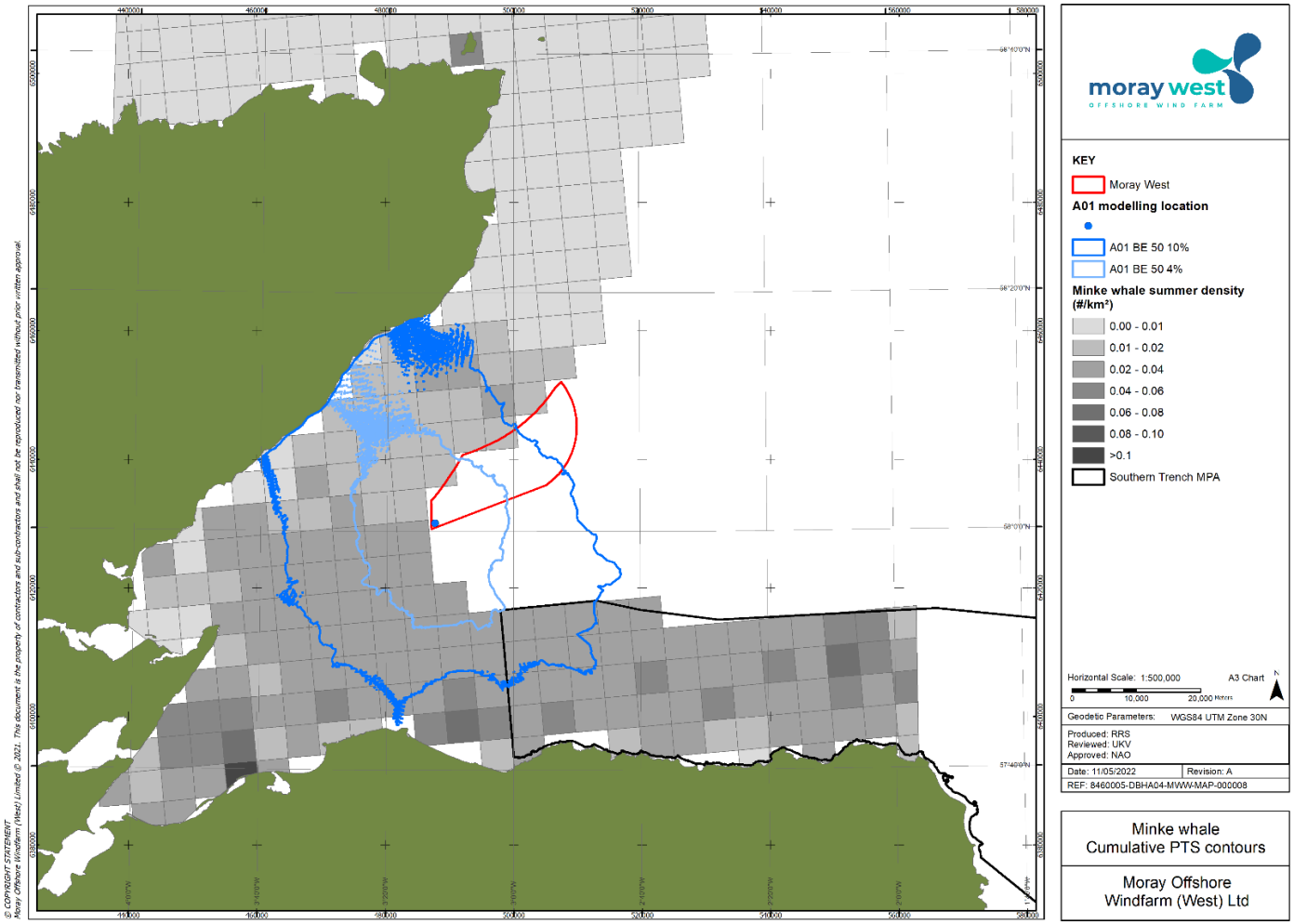


Figure 3-3 Minke whale cumulative PTS-onset impact ranges for location A01 given 4% and 10% conversion factor scenarios.

Despite the high levels of conservatism inherent in the modelling for cumulative PTS, the number of animals predicted to experience PTS per piling day (<1 dolphin, <1 seal, up to 39 minke whales and up to 72 harbour porpoise) is considered to be of negligible magnitude in EIA terms. There is expected to be no change to the population size or trajectory as a result of PTS.

3.1.2.2 2 piles per day

The conservative cumulative PTS-onset impact ranges for two consecutive monopiles for harbour porpoise reach 3.552 km, equating to 28 harbour porpoise (Table 3-6). As stated prevoiusly, it is likely that porpoise would have already been displaced by construction vessels before piling commences (Benhemma-Le Gall et al. 2021). Therefore, assuming a displacement of the animals out of a 2 km radius prior to the start of piling, an ADD activation period would be sufficient to displace them out of the maximum SEL_{cum} impact range. Thus, using an ADD activation period, as detail in the piling mitigation protocol, before the piling commences as a mitigation measure, the impact of cumulative PTS is assessed as **negligible** magnitude for harbour porpoise.

For minke whales, the conservative cumulative PTS-onset impact ranges for two consecutive monopiles for reach 34.743 km, equating to either 6 whales (summer density) or 1 whale (non-summer density) (Table 3-6). Although these worst-case cumulative PTS-onset impact ranges for minke whales are large, most individuals within such a radius will be exposed to piling noise at ranges of tens of kilometers, where impulsive exposure criteria for receivers are extremely precautionary (Southall 2021). Furthermore, seasonal patterns of occurrence mean that the numbers of individuals that might be within this area is low outside the summer months. Thus, the numbers potentially affected are extremely conservative, and there is potential to further reduce risks by focussing piling activity at certain locations in non-summer months, particularly at sites where pile refusal is most likely. The impact as assessed is considered as **negligible** magnitude in EIA terms, as the effect is on such a small proportion of the population that there is expected to be no change to the population size or trajectory.

Table 3-6 Maximum cumulative PTS impact based on the assumption that 2 monopiles are installed consecutively per day. S = summer, NS = Non-summer

Species	Location	# Piles per day	Max cumulative PTS onset range (m)	Number of animals
Harbour porpoise	P18	1	2,792	25
		2	3,552	28
Minke whale	N07	1	15,162	S: 4, NS: <1
		2	34,743	S: 6, NS: <1

3.1.3 Worked example: Cumulative PTS impact ranges for minke whale

To demonstrate the conservatism of the cumulative PTS impact assessment and the magnitude of the conservatism, a worked example is given based on worst-case scenario location A01 with a constant CF of 10%. Here, potential reduction in impact ranges and associated number of animals at risk of PTS will be estimated, where feasible, based on relevant literature and one transect away from the pile site. An overview on the estimates is given in Table 3-7.

Table 3-7 Estimated impact ranges for minke whale when reducing the conservatism based on assumptions. Given are the estimated PTS thresholds and related impact ranges and number of animals at risk of cumulative PTS

Conservatism	Assumption	Threshold (dB re 1 µPa²s)	Impact range	Number of animals
Worst-case scenario	Being realistic, modelled for one transect away from pile site at 312°	183	33.5 km	39 in summer, 4 in non-summer
Assumptions in isolation				
A) PTS-threshold at PTS-onset	PTS-threshold can be at least 1 dB higher without causing significant effects on survival and fertility	184	28 km	31 in summer, 4 in non-summer
B) Equal Energy Hypothesis	PTS-threshold is at least 2-3 dB higher due to TTS recovery in-between pulses	185-186	24.5 km – 21 km	23 / 16 in summer, 3 / 2 in non-summer
C) Impulsiveness of sound	Flexible PTS-threshold	~186	20 km	16 in summer, 2 in non-summer
D) Constant conversion factor	Results of constant 4% CF more realistic than of constant 10% CF	183	12.2 km	3 in summer, < 1 in non-summer
Assumptions applied in successive combination				
A) PTS-threshold at PTS-onset	PTS-threshold can be at least 1 dB higher without causing significant effects on survival and fertility	184	28 km	31 in summer, 4 in non-summer
B) Equal Energy Hypothesis	PTS-threshold is at least 2-3 dB higher due to TTS recovery in-between pulses	186-187	21 km – 13 km	16 / 10 in summer, 2 / 1 in non-summer
C) Impulsiveness of sound	Flexible PTS-threshold	186.2- 187	20 km - 13 km	16 / 10 in summer, 2 / 1 in non-summer
D) Constant conversion factor	Results of constant 4% CF more realistic than of constant 10% CF	186.2- 187	5 – 3 km	2 / 1 in summer and < 1 in non-summer

3.1.3.1 Conservatism A - PTS-threshold is based on PTS-onset level (PTS of 6 dB)

Scientific evidence

PTS-onset (a PTS of 6 dB) is predicted to cause only a very small precited effect on survival or fertility in relation to piling noise (Booth and Heinis 2018). For harbour porpoise, the expert elicitation predicted a similar small effect on survival or fertility for a PTS of 18 dB in adult females (Booth and Heinis 2018). This would increase the PTS-threshold for impulsive sound by nearly 8 dB. No elicitation, however, has been done for minke whale.

Assumption

It is still conservative if the PTS-threshold will be increased by 1 dB, which relates to a PTS of 8.3 dB.

3.1.3.2 Conservatism B - Adoption of the Equal Energy Hypothesis.

Scientific evidence

Experiments of Kastelein et al. (2021) with California sea lions showed that a reduction of the duty cycle from 100% to 90% reduced their TTS to an amount that allows for an increase in PTS-threshold of 2 to 5 dB.

Experiments of Kastelein et al. (2014) with a harbour porpoise exposed to 1-second-long sonar pulses showed at a duty cycle of 25% (3 second silent period) a reduced TTS compared to a 100% duty cycle that allows for an increase in PTS-threshold of 3 to 5 dB. At a duty cycle of 50% (1 second silent period) the resulting TTS reduction would allow for a 2 to 3 dB increase in PTS-threshold. While these experiments were done with non-impulsive sound, a duty cycle of 25% and a silent period of 1.5 second is comparable to what is expected during piling at Moray West (using a blow rate of 28 and 32 blows per minute and assuming a 0.5-second-long pile strike).

Assumption

The PTS-threshold can be increased at least by 2-3 dB to account for the evidence that the equal energy hypothesis is false.

3.1.3.3 Conservatism C - Piling sound received by an animal is impulsive throughout the exposure

Scientific evidence

Impulsive sound loses its impulsive character with increasing distance to the sound source (Hastie et al. 2019, Martin et al. 2020). The distance at which sound becomes fully non-impulsive is discussed. Impulsive sound becomes increasingly less harmful in terms of auditory injury as impulsive characteristics of the signal are reduced (Hamerick et al. 2007, in Martin et al. 2020). The PTS-onset threshold must therefore lie between the PTS-onset for impulsive sound and non-impulsive sound if an animal is exposed to sound with decreasing impulsiveness. In this worked example, such impact range will consequently lie between 33.5 km (impact range for fully impulsive sound) and 0 km (impact range for fully non-impulsive sound).

Assumptions

Impulsive sound becomes fully non-impulsive in the Moray Firth at 25 km (following a conservative estimate proposed in Southall 2021). This estimate is based on the 95 dB SEL contour of the 10 kHz

third-octave-band of a 5000 kJ piling sound modelled with a 10% CF. 95 dB is where the 90th percentile background noise level at 10 kHz can occur in the Moray Firth (Farcas, pers. Comm).

A minke whale swimming away from the pile site will experience TTS with a growth rate of impulsive sound while at distances shorter than 25 km (which is still a conservative assumption given that the impulsive sound becomes increasingly less harmful), and experience a growth rate of non-impulsive sound at distances longer than 25 km.

A TTS of 40 dB leads to PTS-onset, and the sound levels leading to a 40 dB TTS are considered the PTS-onset threshold (following the methodology as applied by Southall et al. (2019).

PTS-onset thresholds increase with increasing distance to the sound source once the animal starts to cross the 25 km contour while being exposed to piling sound.

The threshold obtained for the transect with the maximum impact range is valid for all transects away from the sound source (which is a conservative approach).

3.1.3.4 Conservatism D - Piling profiles are modelled with a constant conversion factor.

Scientific evidence

Noise monitoring during the installation of monopiles at UK offshore wind farms showed a relationship between hammer energy and sound exposure level that can only be explained with a varying conversion factor. Were the same levels to be modelled at Moray West, conversion factors of 0.5 to 10 and above were to be used.

Since the conversion factor is variable, modelling with a constant 10% is considered unrealistic, leading to an over precautionary estimate in most, if not all cases. It is not yet known for monopiles, which factors influence the conversion factor, while for pin piles, the length of the pile in the water column seems to be the major influencing factor (Thompson et al. 2020).

Assumption

For illustration purposes, the assumption in this worked example is that the results of a constant 4% are likely more realistic than those of a constant 10%, resulting in a 4 dB difference between the modelled sound exposure levels (Note that there is a 10 dB difference between conversion factors 1% and 10%, and 13 dB difference between 0.5% and 10%).

3.2 Disturbance

3.2.1 Harbour porpoise

The maximum level of disturbance to harbour porpoise was predicted to occur for the installation of a monopile at location N17 (high refusal risk) assuming a maximum hammer energy of 5,000 kJ and a 10% CF (Figure 3-4). This resulted in a prediction of 4,762 porpoises being disturbed on a single day of piling (this represents 1.37% of the North Sea MU, or 2.98% of the UK portion) (Table 3-8, Figure 3-4).

The number of harbour porpoise predicted to experience disturbance for a low refusal risk piling location (P18) was considerably lower, with disturbance predicted to impact 3,316 porpoises (0.96% of the North Sea MU, or 2.08% UK portion) assuming a maximum hammer energy of 1,486 kJ (Table 3-8, Figure3-5).

Table 3-8 Numbers of harbour porpoise and proportion of relevant management units (MU) predicted to be disturbed from piling, for different piling scenarios.

			4% CF			10% CF		
Location	**Refusal risk**	**Max hammer energy (kJ)**	**# porpoise**	**% entire MU**	**% UK portion**	**# porpoise**	**% entire MU**	**% UK portion**
N17	High	5,000	3,579	1.03%	2.24%	4,762	1.37%	2.98%
P18	Low	1,486	2,309	0.67%	1.45%	3,316	0.96%	2.08%

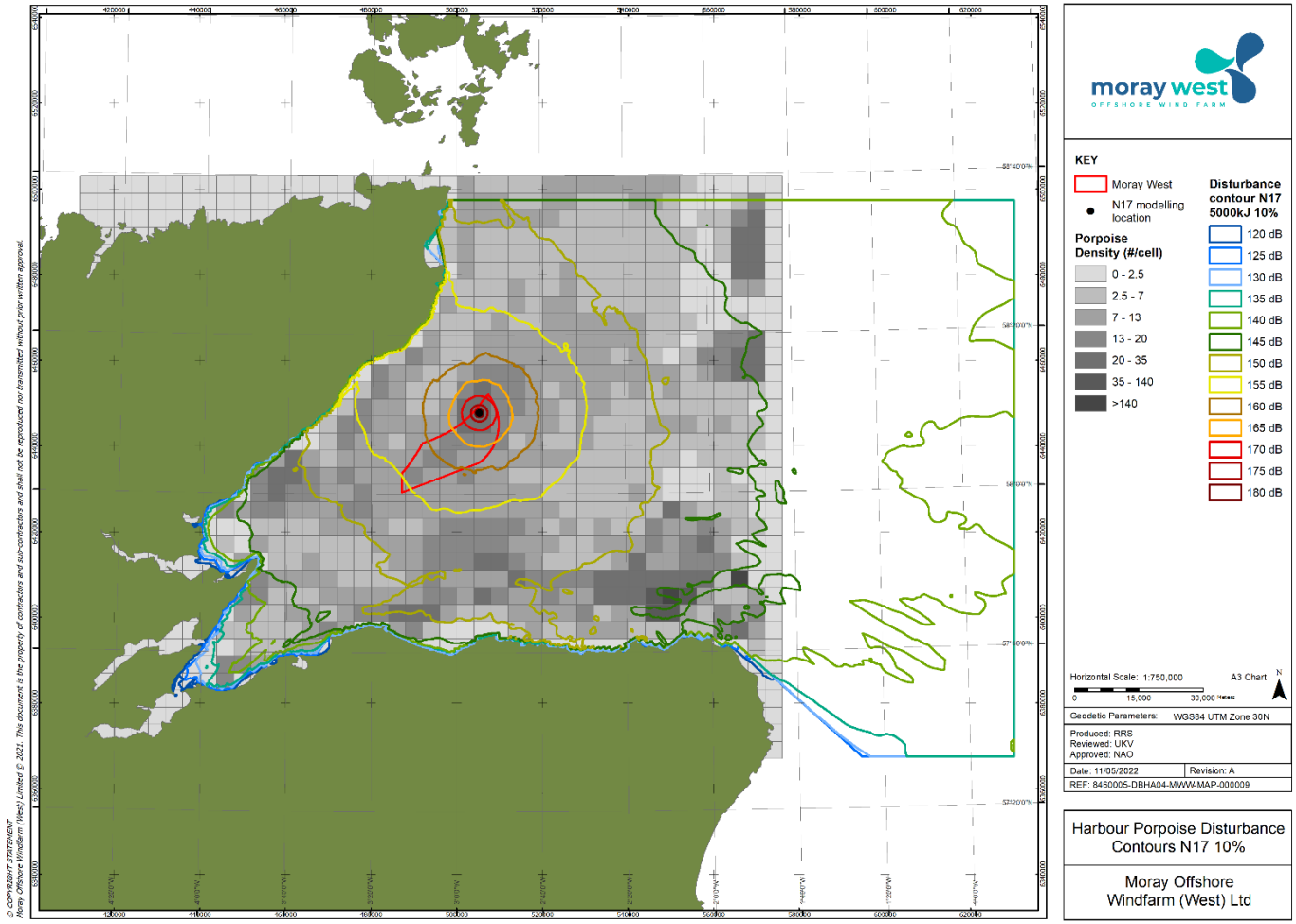


Figure 3-4 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location N17 overlain the harbour porpoise distribution. CF = 10%, hammer energy = 5000 kJ.

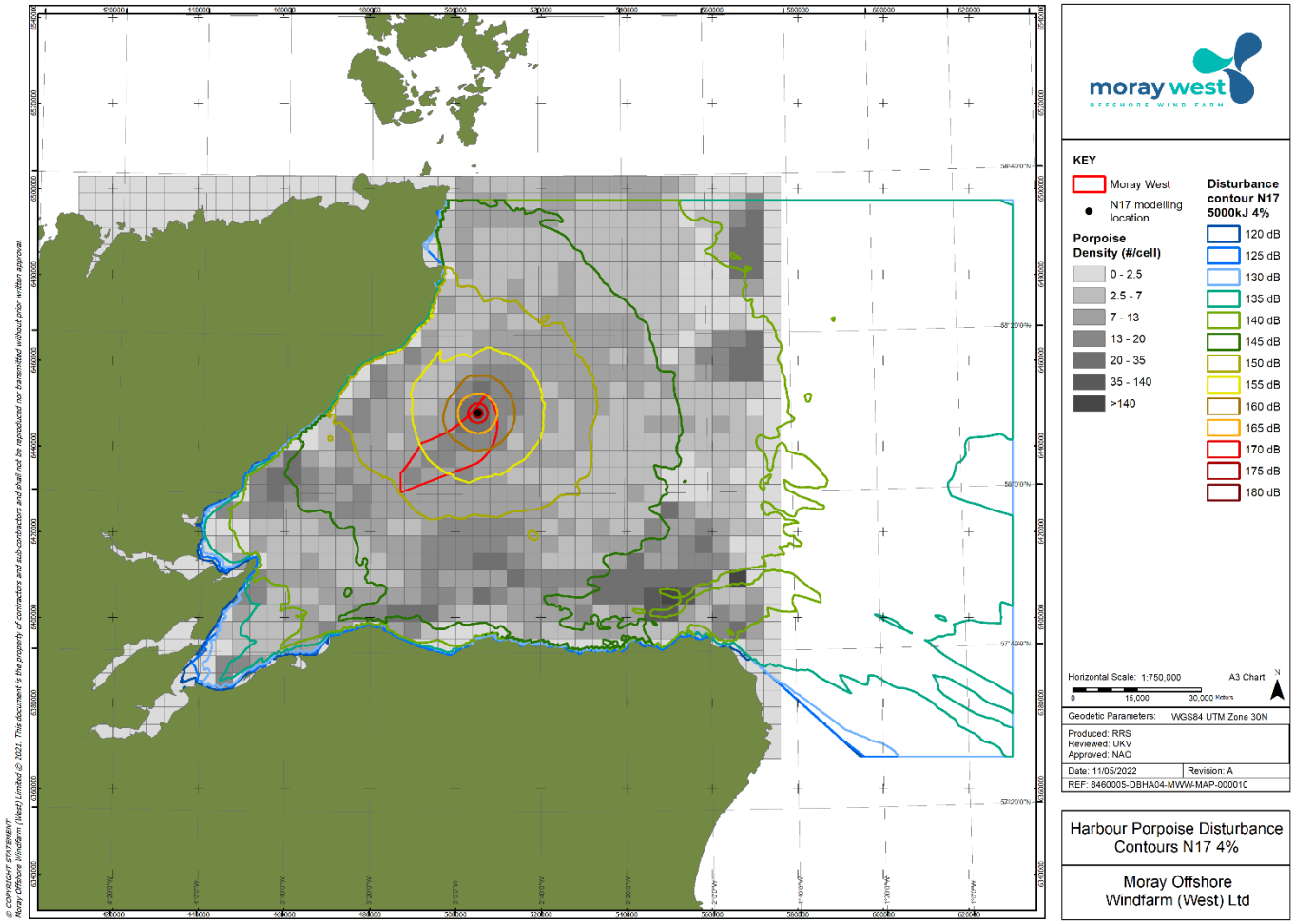


Figure 3-5 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location N17 overlain the harbour porpoise distribution. CF = 4%, hammer energy = 5000 kJ.

Assuming a worst-case of 4,762 porpoise disturbed on every piling day across all 62 piling days, outputs from iPCoD estimate there to be only the slightest discernible impact to the harbour porpoise population (even when considering just the UK portion of the MU) (Figure 3-6 and Table 3-9). The mean population size for the impacted population was predicted to be 99.93% of the un-impacted population size at the end of 2024 (after the pile driving has completed). By the end of 2030 (6 years after piling ends) the mean population size for the impacted population was predicted to be 99.95% of the un-impacted population size. The impacted population is expected to maintain the same increasing trajectory as the un-impacted population after the impact period has ceased.

The magnitude of impact of disturbance from pile driving for harbour porpoise is assessed as **low**, whereby the impact is short-term and temporary behavioural effects are expected in only a small proportion of the population, resulting in potential impacts to individual vital rates but only over the short-term, such that the population trajectory would not be altered.

Table 3-9 Results of the iPCOD modelling, giving the mean population size of the harbour porpoise population (UK MU) for years up to 2042 for both impacted and un-impacted populations as well as the mean and median ratio between their annual growth rates.

Year	un-impacted pop mean	impacted pop mean	Impacted as % un-impacted	Mean ratio of impacted:un-impacted annual growth rate	Median ratio of impacted:un-impacted annual growth rate
Start	159,634	159,634	100%	1	1
End 2024	159,632	159,518	99.93%	1	1
End 2030	158,745	158,671	99.95%	1	1
End 2036	159,851	159,777	99.95%	1	1
End 2042	159,334	159,260	99.95%	1	1



Figure 3-6 Simulated harbour porpoise population sizes for both the un-impacted and the impacted populations

3.2.2 Bottlenose dolphin

The maximum level of disturbance to bottlenose dolphins was predicted to occur for the installation of a monopile at location A01 (moderate refusal risk) assuming a maximum hammer energy of 5,000 kJ and a 10% CF (Table 3-10 and Figure 3-7). This resulted in a prediction of 55 bottlenose dolphins being disturbed on a single day of piling (this represents 24.6% of the East Coast Scotland MU). Figure 3-8 shows the isopleths modelled for a CF of 4% at location A01 for the behavioural impact assessment for completeness.

Table 3-10 Numbers of bottlenose dolphins and proportion of relevant management units (MU) predicted to be disturbed from piling, for different piling scenarios.

			4% CF		10% CF	
Location	**Refusal risk**	**Max hammer energy (kJ)**	**# dolphins**	**% MU**	**# dolphins**	**% MU**
A01	Moderate	5,000	40	17.99%	55	24.60%
A02	High	5,000	40	17.81%	54	24.11%

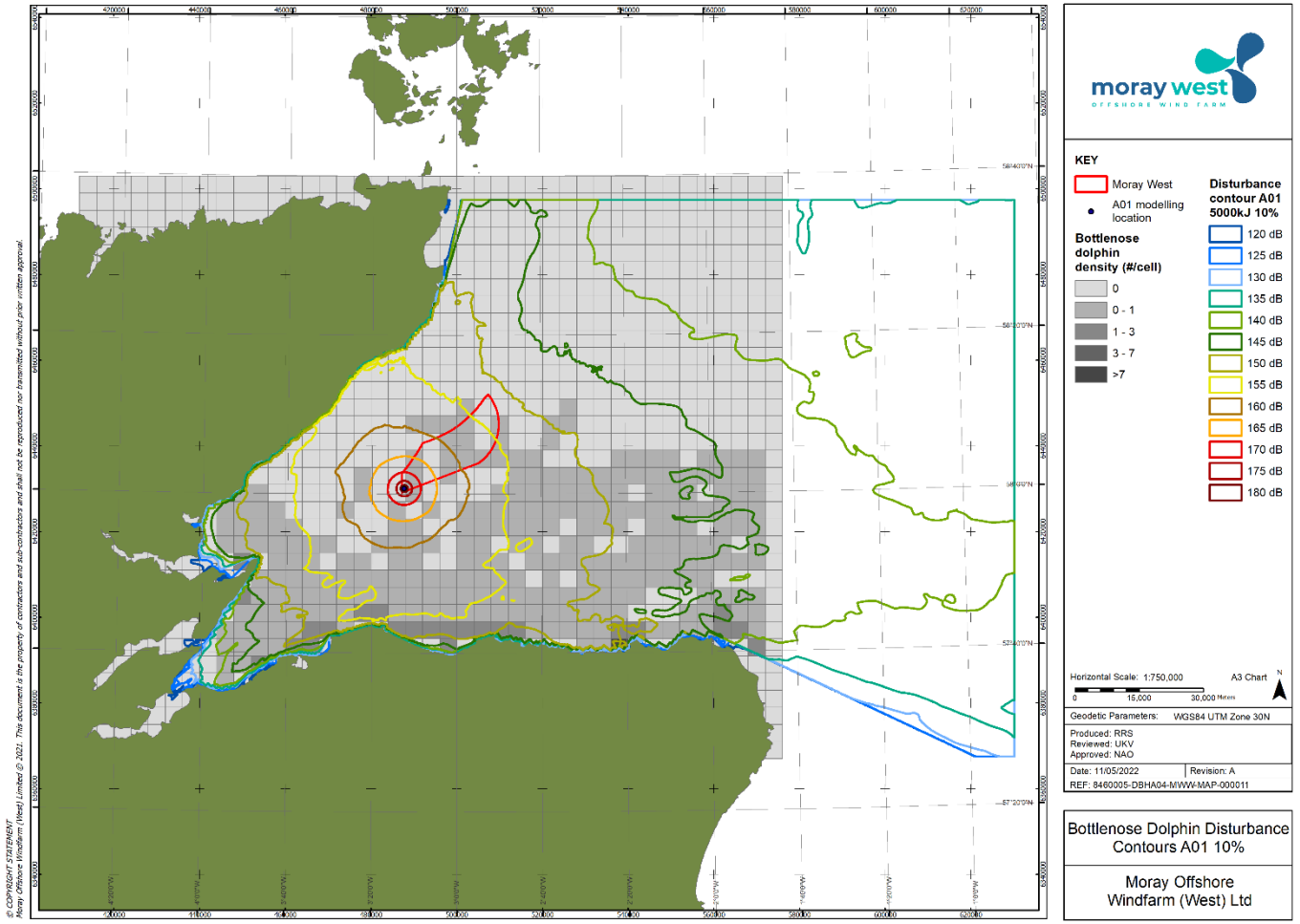


Figure 3-7 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location A01 overlain the bottlenose dolphin distribution. CF = 10%, hammer energy = 5000 kJ.

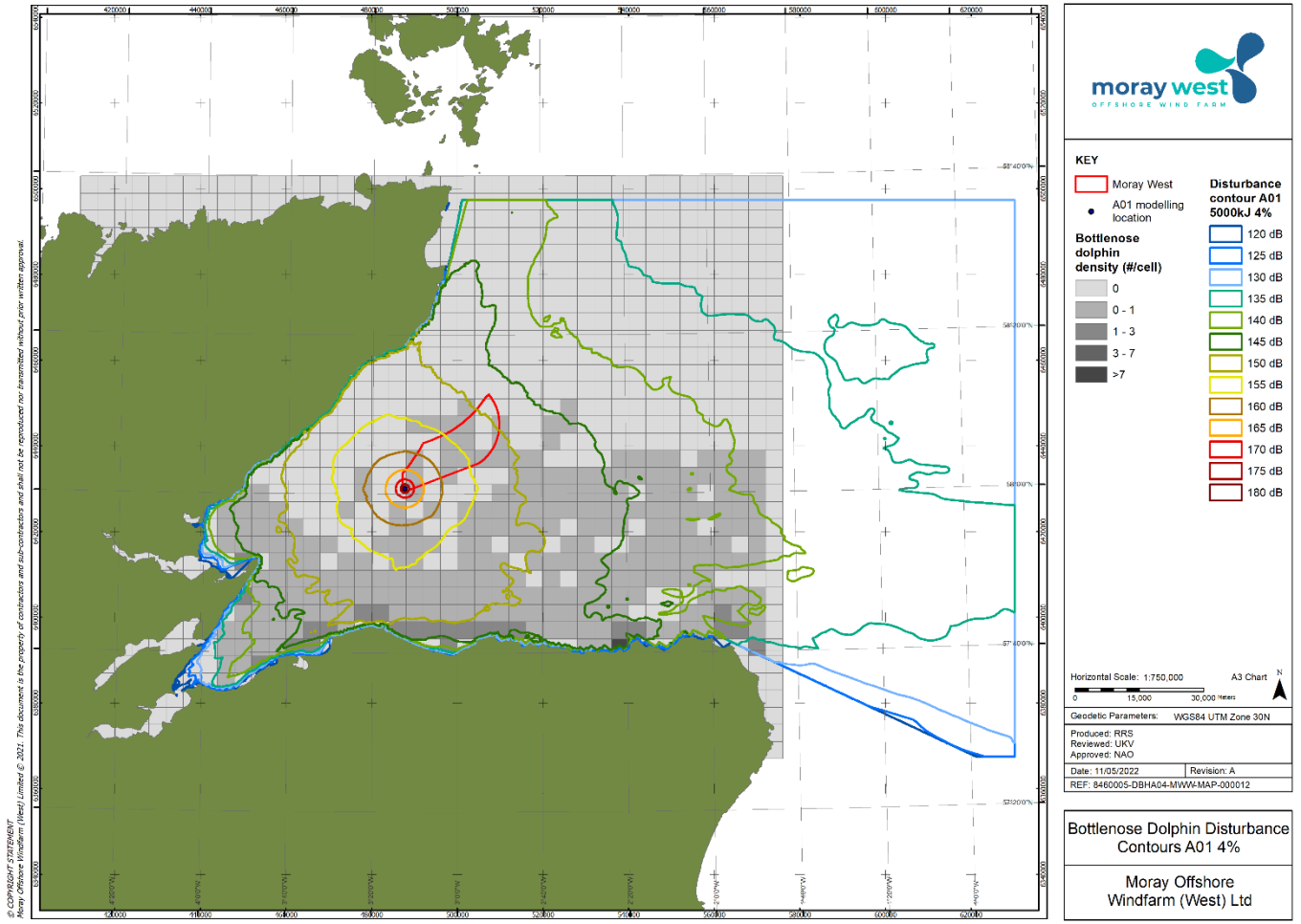


Figure 3-8 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location A01 overlain the bottlenose dolphin distribution. CF = 4%, hammer energy = 5000 kJ.

Assuming an absolute worst case of 55 bottlenose dolphins disturbed on every piling day across all 62 piling days, outputs from iPCoD estimate there to be only a slight discernible impact to the bottlenose dolphin population (Figure 3-9 and Table 3-11). The mean population size for the impacted population was predicted to be 97.5% of the un-impacted population size at the end of 2024 (after the pile driving has completed). By the end of 2030 (6 years after piling ends) the mean population size for the impacted population was predicted to be 98.2% of the un-impacted population size. While there is initially a slight decrease in the population size due to the disturbance impact, the impacted population is expected to maintain the same increasing trajectory after the impact period has ceased.

The magnitude of impact of disturbance from pile driving for bottlenose dolphins is assessed as low, whereby the impact is short-term and temporary behavioural effects are expected in only a small proportion of the population, resulting in potential impacts to individual vital rates but only over the short-term, such that the population trajectory would not be altered.

Table 3-11 Results of the iPCOD modelling, giving the mean population size of bottlenose dolphin for years up to 2042 for impacted and un-impacted populations as well as the mean and median ratio between their annual growth rates.

Year	un-impacted pop mean	impacted pop mean	Impacted as % un-impacted	Mean ratio of impacted:un-impacted annual growth rate	Median ratio of impacted:un-impacted annual growth rate
Start	224	224	100%	1	1
End 2024	240	234	97.5%	0.986	1
End 2030	298	292	98.0%	0.998	1
End 2036	369	362	98.1%	0.999	1
End 2042	457	449	98.2%	0.999	1

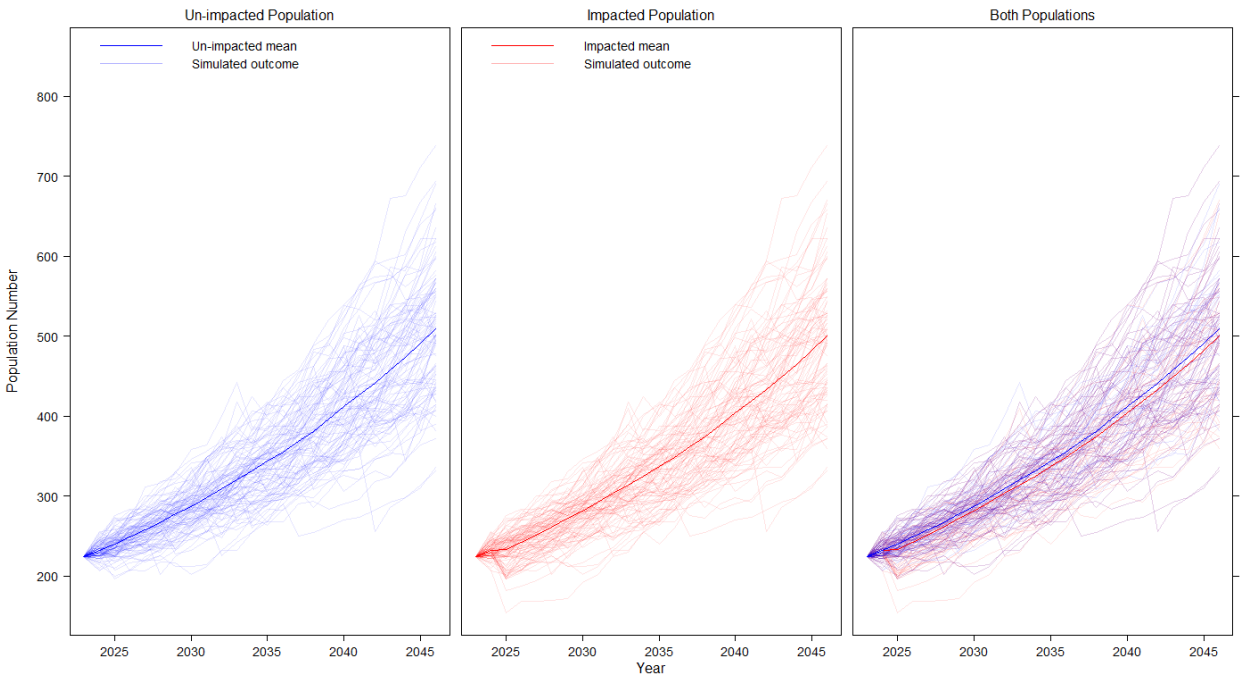


Figure 3-9 Simulated bottlenose dolphin population sizes for both the un-impacted and the impacted populations

3.2.3 Minke whale

The maximum level of disturbance to minke whales was predicted to occur for the installation of a monopile at location L07 (high refusal risk) assuming a maximum hammer energy of 5,000 kJ and a 10% CF (Figure 3-10) (see CF of 4% for comparison in Figure 3-11). This resulted in a prediction of 186 minke whales being disturbed on a single day of piling, if the piling took place in summer (Jul, Aug, Sep) (0.92% MU, or 1.81% UK portion) (Table 3-12).

The number of minke whales predicted to experience disturbance for a low refusal risk piling location (N07) was lower, with disturbance predicted to impact only 141 whales in the summer (0.70% MU, or 1.37% UK portion) (Table 3-12). Given the very low proportion of the entire MU predicted to be impacted, the magnitude of impact of disturbance from pile driving for minke whales is assessed as **negligible** for the entire MU, since there is expected to be no change to the population size or trajectory. Given the fact that piling is expected to occur between October and January inclusive (non-summer months) when the density of minke whales in the area is expected to be extremely low, it is considered highly unlikely that this would occur. When considering the non-summer density estimates, a maximum of 14 minke whales are predicted to be disturbed on a single day of piling (0.07% MU, or 0.14% UK portion). This is also of **negligible** magnitude for the entire MU, since there is expected to be no change to the population size or trajectory.

Table 3-12 Numbers of minke whales and proportion of relevant management units (MU) predicted to be disturbed from piling, for different piling scenarios. Numbers are based on the summer (S) and non-summer (NS) distribution.

			4% CF			10% CF		
Location	**Refusal risk**	**Max hammer energy (kJ)**	**# whales**	**% entire MU**	**% UK portion**	**# whales**	**% entire MU**	**% UK portion**
A01	Moderate	5,000	S: 115 NS: 10	S: 0.57% NS: 0.05%	S: 1.12% NS: 0.10%	S: 161 NS: 13	S: 0.80% NS: 0.07%	S: 1.56% NS: 0.13%
L07	High	5,000	S: 135 NS: 11	S: 0.67% NS: 0.05%	S: 1.31% NS: 0.11%	S: 186 NS: 14	S: 0.92% NS: 0.07%	S: 1.81% NS: 0.14%
N07	Low	2,432	S: 95 NS: 8	S: 0.47% NS: 0.04%	S: 0.93% NS:0.08%	S: 141 NS: 11	S: 0.70% NS: 0.06%	S: 1.37% NS: 0.11%

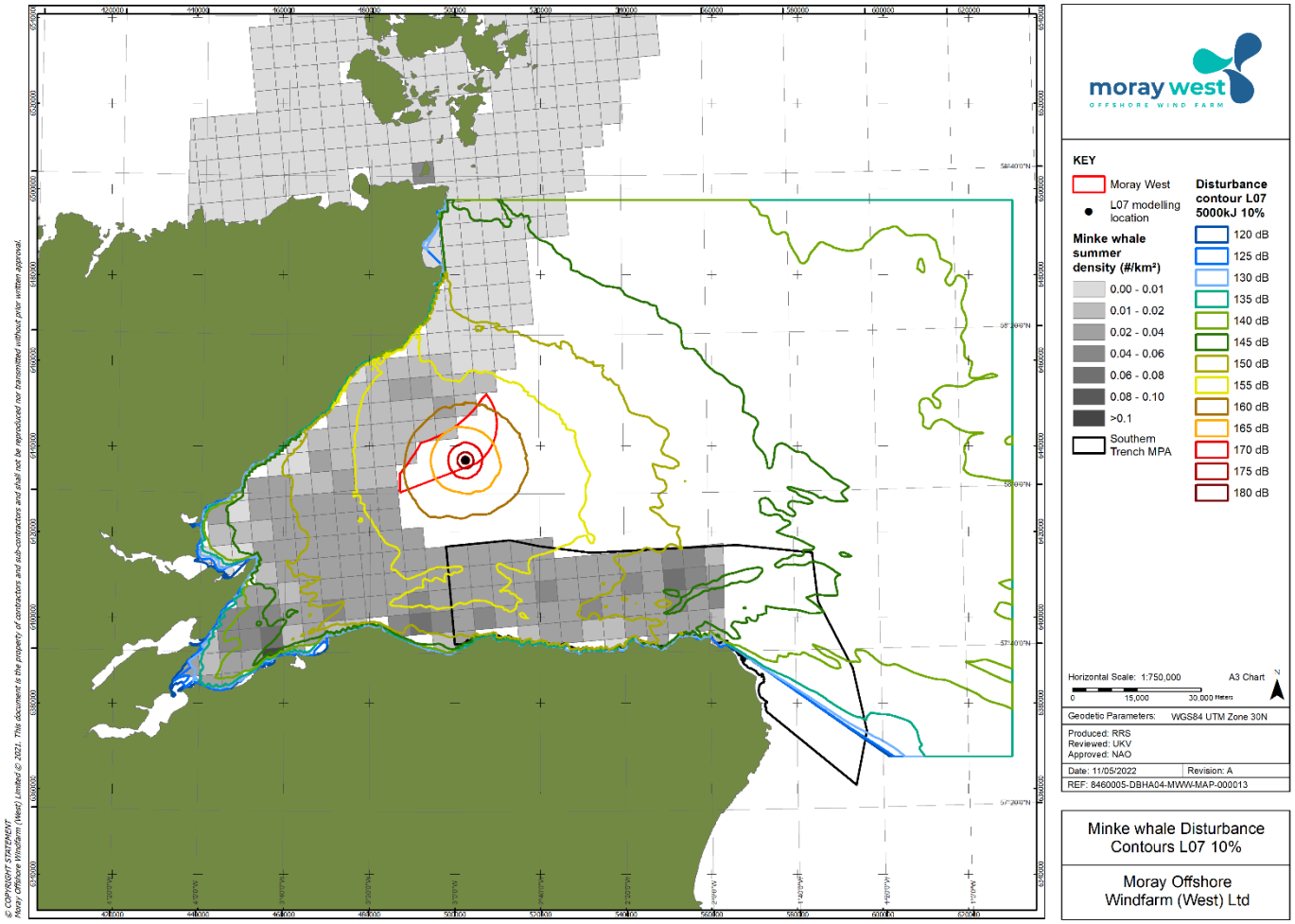


Figure 3-10 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location L07 overlain the minke whale distribution. CF = 10%, hammer energy = 5000 kJ.

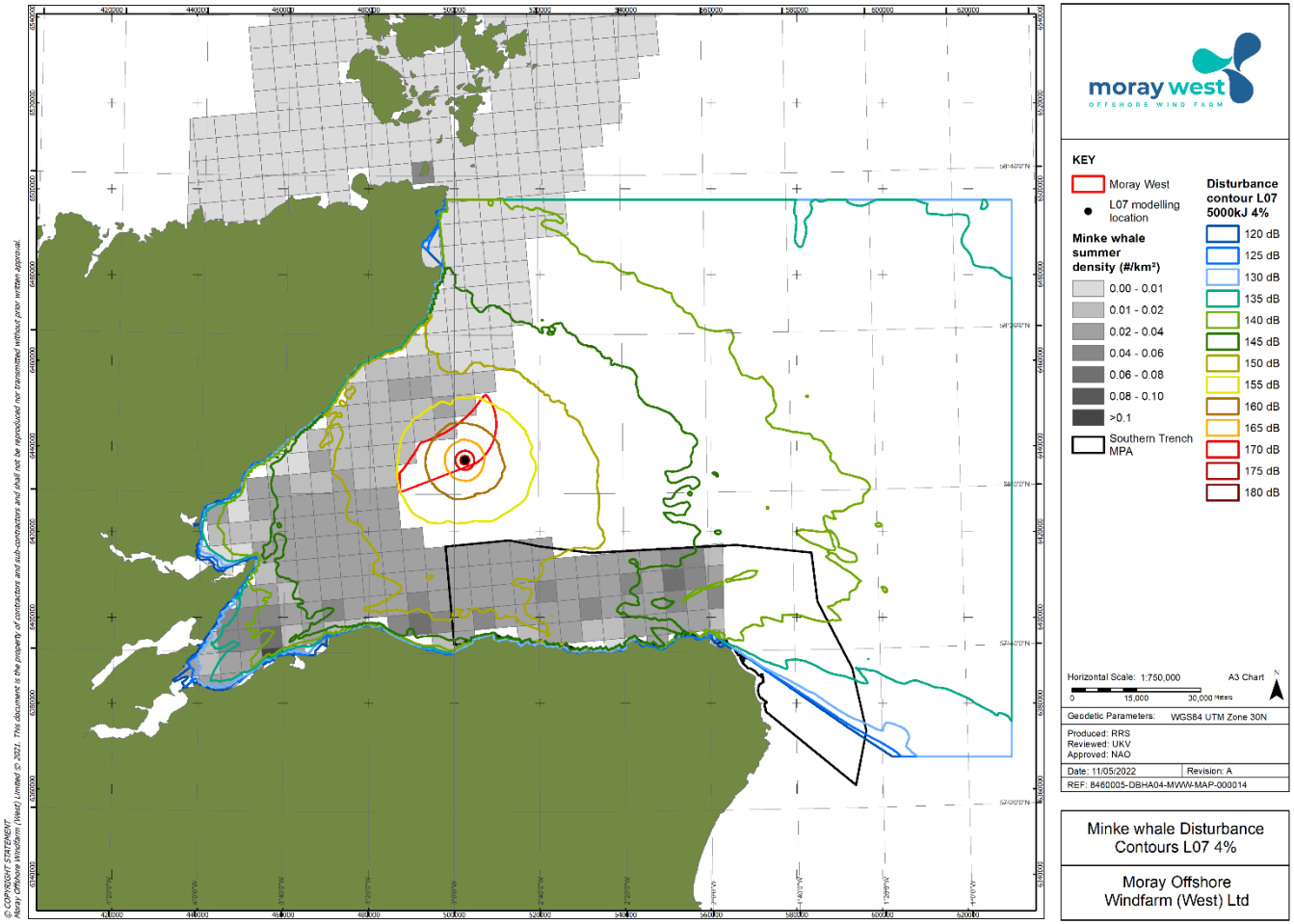


Figure 3-11 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location L07 overlain the minke whale distribution. CF = 4%, hammer energy = 5000 kJ.

3.2.4 Grey seal

The maximum level of disturbance to grey seals was predicted to occur for the installation of a monopile at location N17 (high refusal risk) assuming a maximum hammer energy of 5,000 kJ and a 10% CF (Figure 3-12, see Figure 3-13 for comparison with a 4% CF). This resulted in a prediction of 2,514 grey seals being disturbed on a single day of piling (this represents 4.3 % of the combined Moray Firth & North Coast and Orkney MU) (Table 3-13).

The number of grey seals predicted to experience disturbance at piling location A01 and A02 are similar but slightly lower to those predicted for location N17, and less than half the animals at location P18 (Table 3-13).

Table 3-13 Numbers of grey seals and proportion of relevant management units (MU) predicted to be disturbed from piling, for different piling scenarios.

			4% CF		10% CF	
Location	**Refusal risk**	**Max hammer energy (kJ)**	**# grey seals**	**% MU**	**# grey seals**	**% MU**
A01	Moderate	5,000	1,629 (95% CI: 175 - 3107)	2.79%	2,265 (95% CI: 214 – 4214)	3.88%
A02	High	5,000	1,623 (95% CI: 172 - 3105)	2.78%	2,276 (95% CI: 217 - 4243)	3.90%
N17	High	5,000	1,464 (95% CI: 80 - 2968)	2.51%	2,514 (95% CI: 249 - 4843)	4.31%
P18	Low	1,486	371 (95% CI: 23 - 745)	0.64%	1,141 (95% CI: 64 - 2310)	1.96%

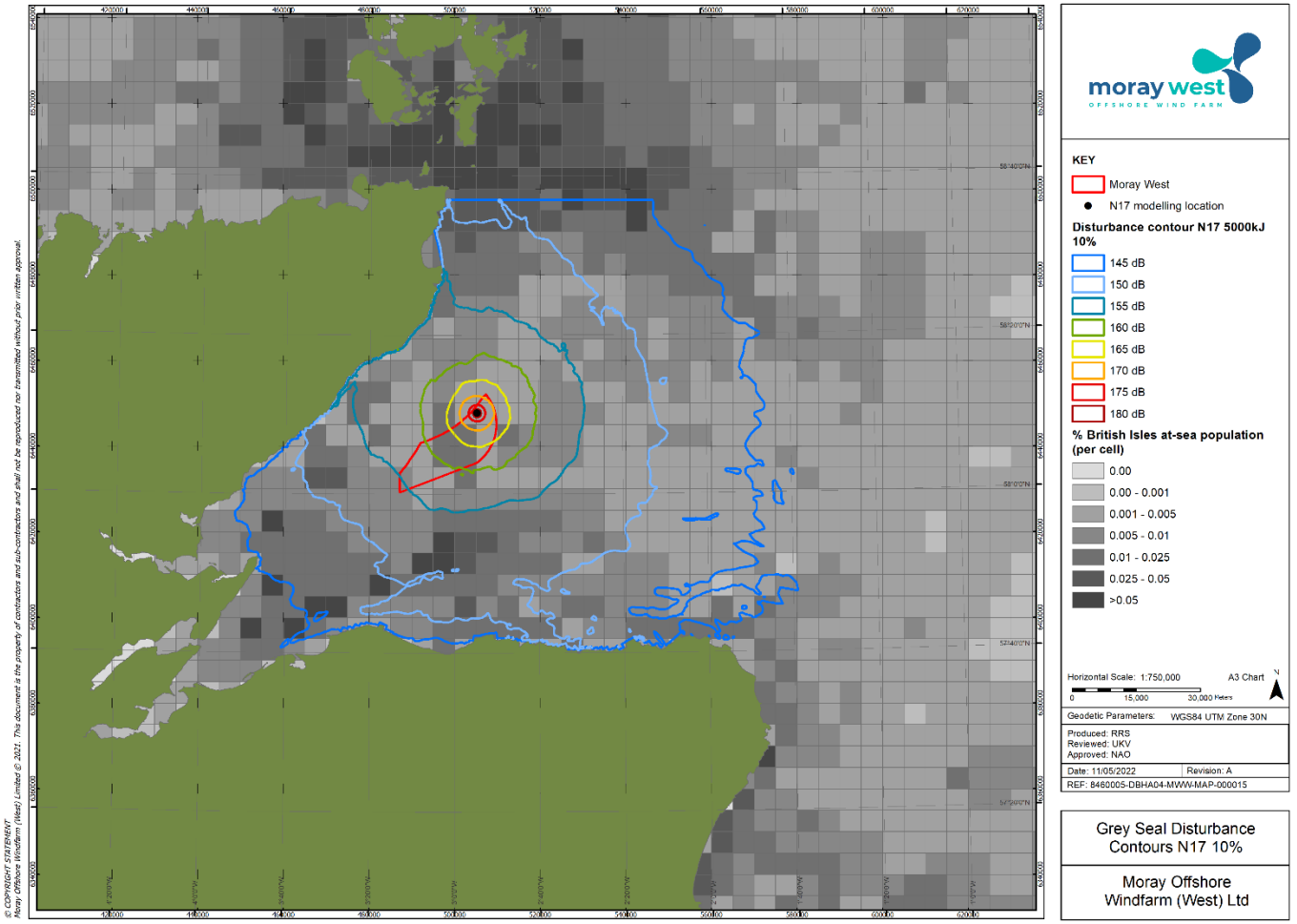


Figure 3-12 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location N17 overlain the grey seal distribution. CF = 10%, hammer energy = 5000 kJ.

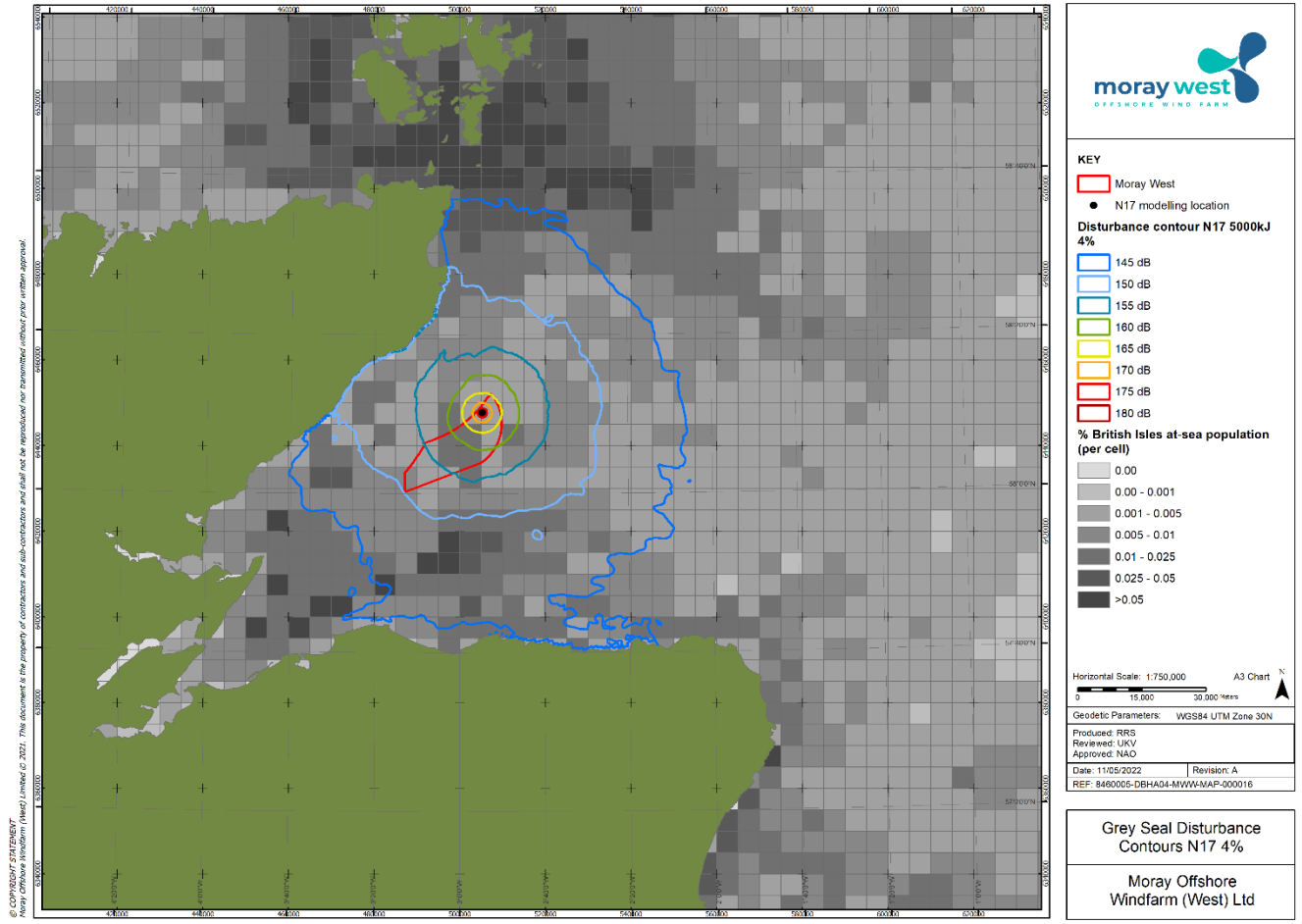


Figure 3-13 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location N17 overlain the grey seal distribution. CF = 4%, hammer energy = 5000 kJ.

Assuming a worst case of 2,514 grey seals disturbed on every piling day across all 62 piling days, outputs from iPCoD estimate there to be no discernible impact to the grey seal population (Figure 3-14). The mean population size for the impacted population was predicted to be the same as the un-impacted population size in every single one of the 25 simulated years.

The magnitude of impact of disturbance from pile driving for grey seals is assessed as **negligible** since there was predicted to be no change to the population size or trajectory.

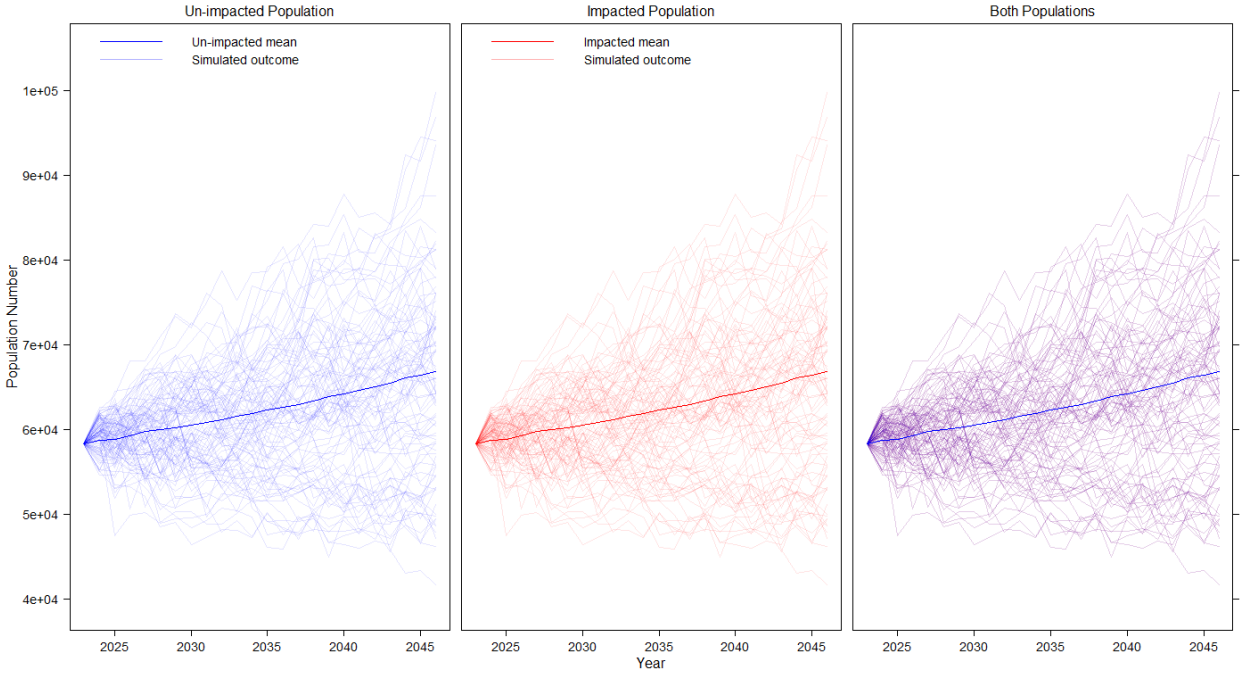


Figure 3-14 Simulated grey seal population sizes for both the baseline and the impacted populations by disturbance.

3.2.5 Harbour seal

The maximum level of disturbance to harbour seals was predicted to occur for the installation of a monopile at location A01 assuming a maximum hammer energy of 5,000 kJ and a 10% CF (Figure 3-15, see Figure 3-16 for comparison with a 4% CF). This resulted in a prediction of 232 harbour seals being disturbed on a single day of piling (this represents 6.72% of the combined Moray Firth & North Coast and Orkney MU) (Table 3-14).

The number of harbour seals predicted to experience disturbance for a moderate refusal risk piling location (A01) was of similar magnitude (Table 3-14).

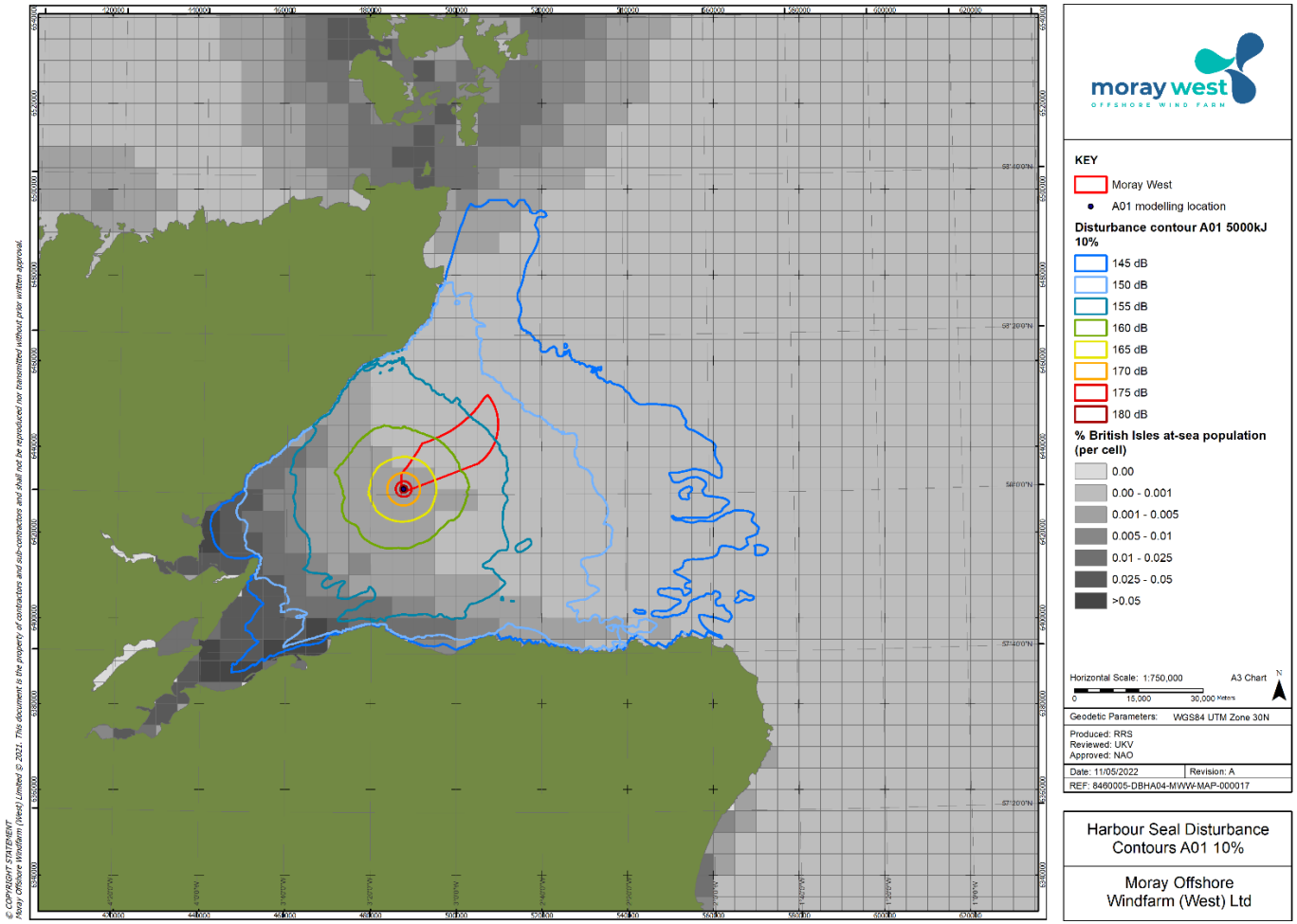


Figure 3-15 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location A01 overlain the harbour seal distribution. CF = 10%, hammer energy = 5000 kJ.

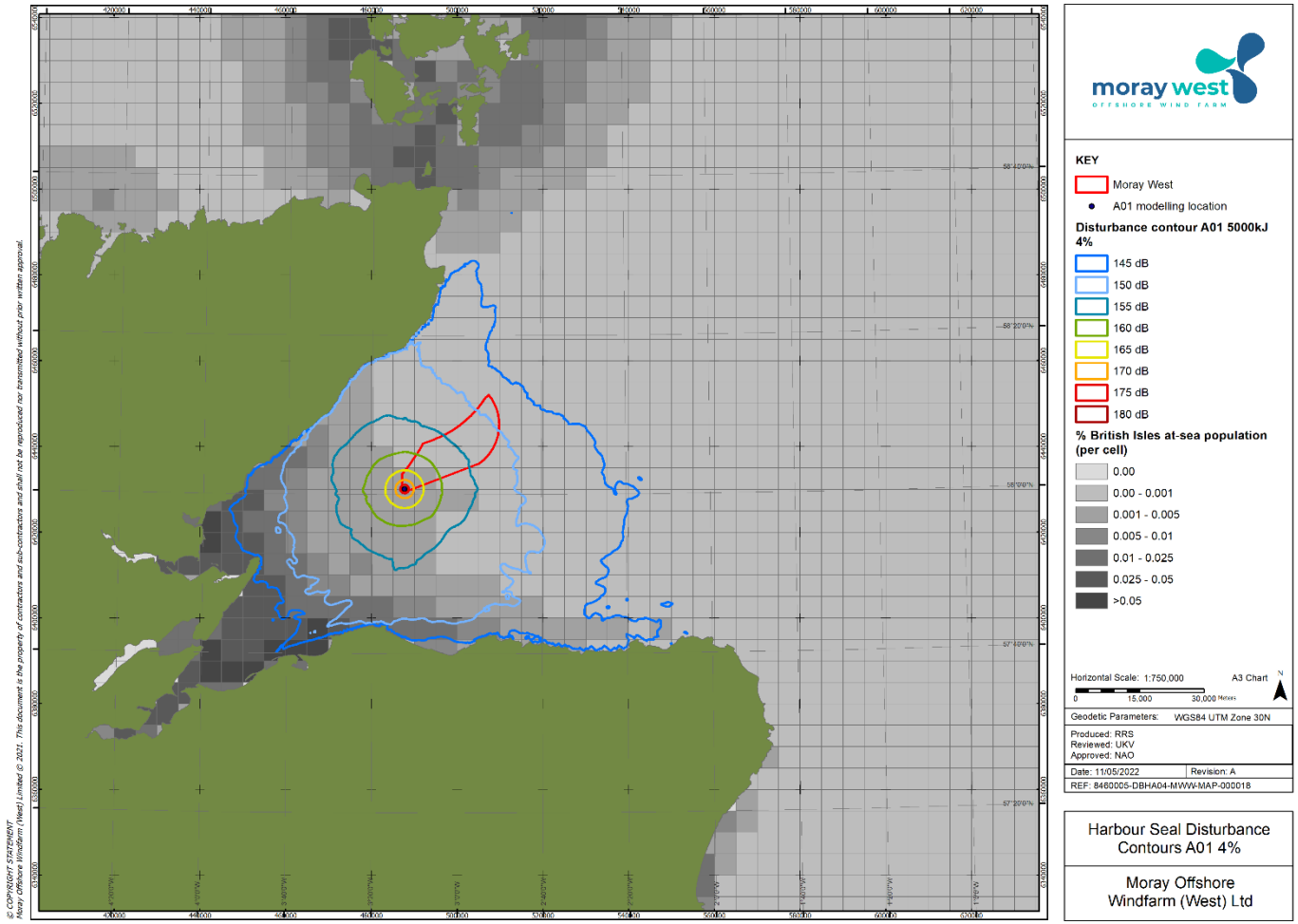


Figure 3-16 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location A01 overlain the harbour seal distribution. CF = 4%, hammer energy = 5000 kJ.

Table 3-14 Numbers of harbour seals and proportion of relevant management units (MU) predicted to be disturbed from piling, for different piling scenarios.						
			4% CF		10% CF	
Location	**Refusal risk**	**Max hammer energy (kJ)**	**# harbour seals**	**% MU**	**# harbour seals**	**% MU**
A01	Moderate	5000	142 (95% CI: 11 - 281)	4.11%	232 (95% CI: 23 – 442)	6.72%
A02	High	5000	139 (95% CI: 11 - 276)	4.02%	229 (95% CI: 22 - 438)	6.65%

The harbour seal population in the North Coast and Orkney MU is in decline, and significant declines in August haul-out counts have been recorded, from 8,787 in the 1996-1997 count period to only 1,405 in the 2016-2019 count period (SCOS 2021). In contrast, the harbour seal population in the Moray Firth MU is relatively stable, with August counts of 1,407 in 1997 to 1,025 in 2019 (SCOS 2021) (Figure 3-17).

Assuming a worst case of 232 harbour seals disturbed on every piling day across all 62 piling days, and if the entire combined Moray Firth and North Coast & Orkney MUs combined are modelled using the demographic parameters for the declining North Coast & Orkney MU, then outputs from iPCoD estimate there to be no discernible impact to the harbour seal population (Figure 3-18). The mean population size for the impacted population was predicted to be the same as the un-impacted population size in every single one of the 25 simulated years and the declining population trajectory remains the same, irrespective of disturbance from the pile driving at Moray West.

Assuming a worst case of 232 harbour seals disturbed on every piling day across all 62 piling days, and if only the Moray Firth MU is modelled, then outputs from iPCoD estimate there to be no discernible impact to the harbour seal population (Figure 3-19). The mean population size for the impacted population was predicted to be the same as the un-impacted population size in every single one of the 25 simulated years.

The magnitude of impact of disturbance from pile driving for harbour seals is assessed as **negligible** since there was predicted to be no change to the population size or trajectory.

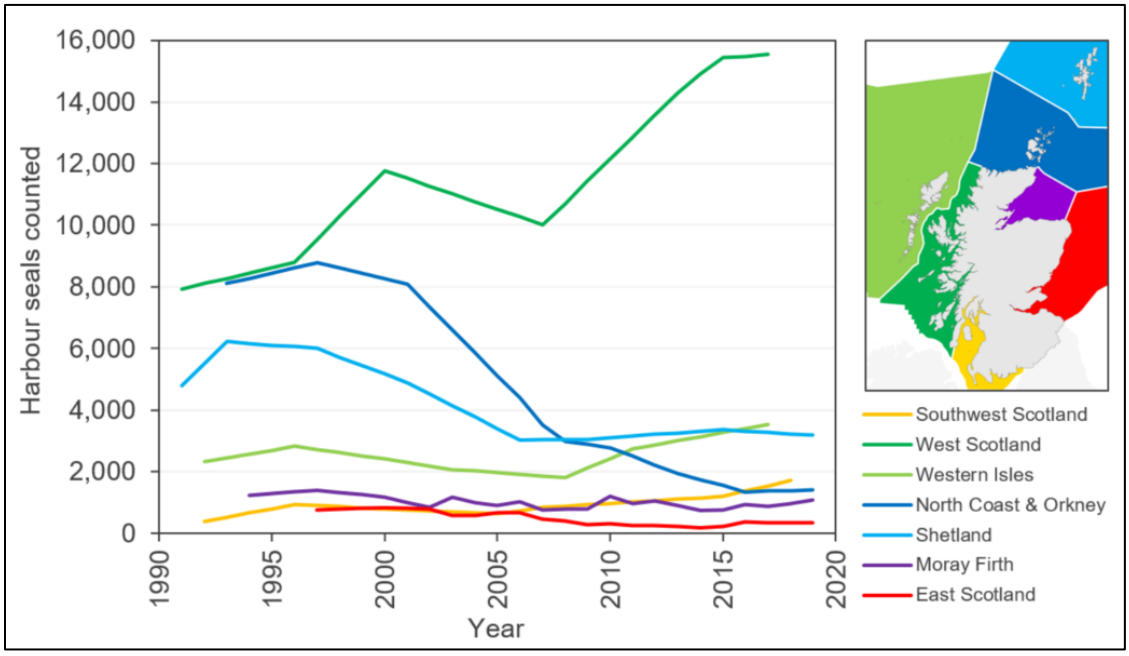


Figure 3-17 Comparison of August harbour seal counts in Scottish Seal Management Areas (SMAs) from 1991 to 2019. Obtained from SCOS (2021).

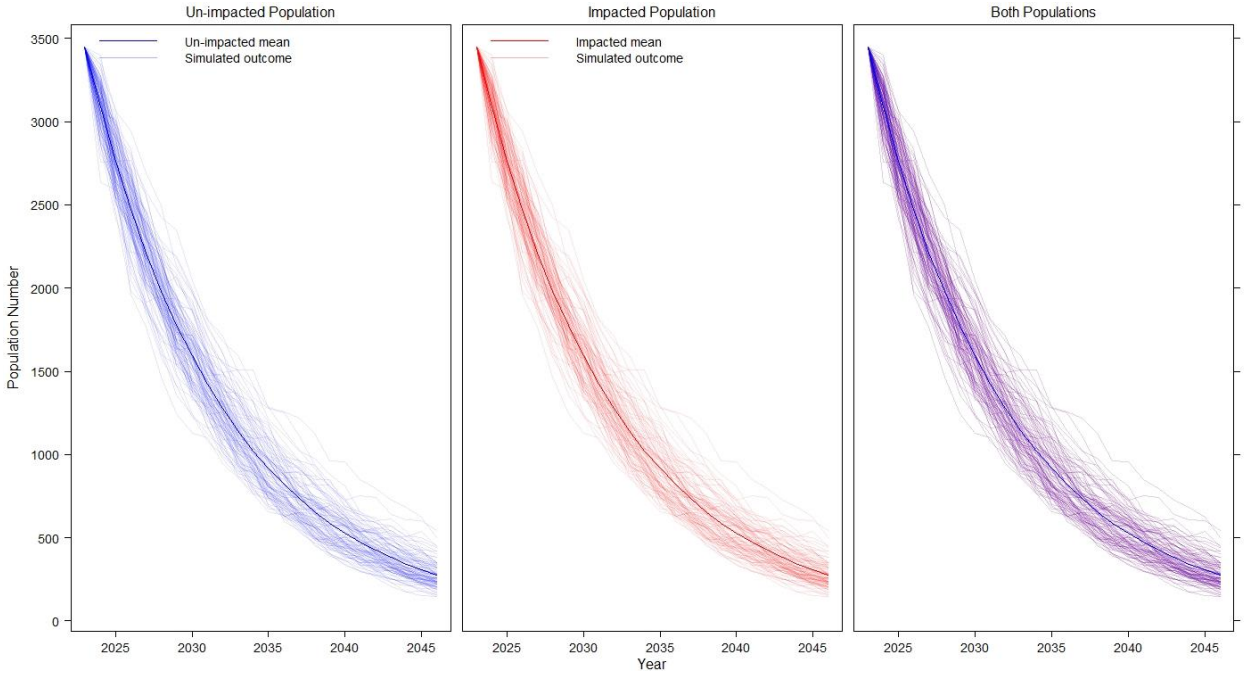


Figure 3-18 Simulated harbour population sizes for both the un-impacted and the impacted populations, assuming the MU is Moray Firth & Northern Coast & Orkney, and assuming Northern Coast & Orkney demographic parameters.

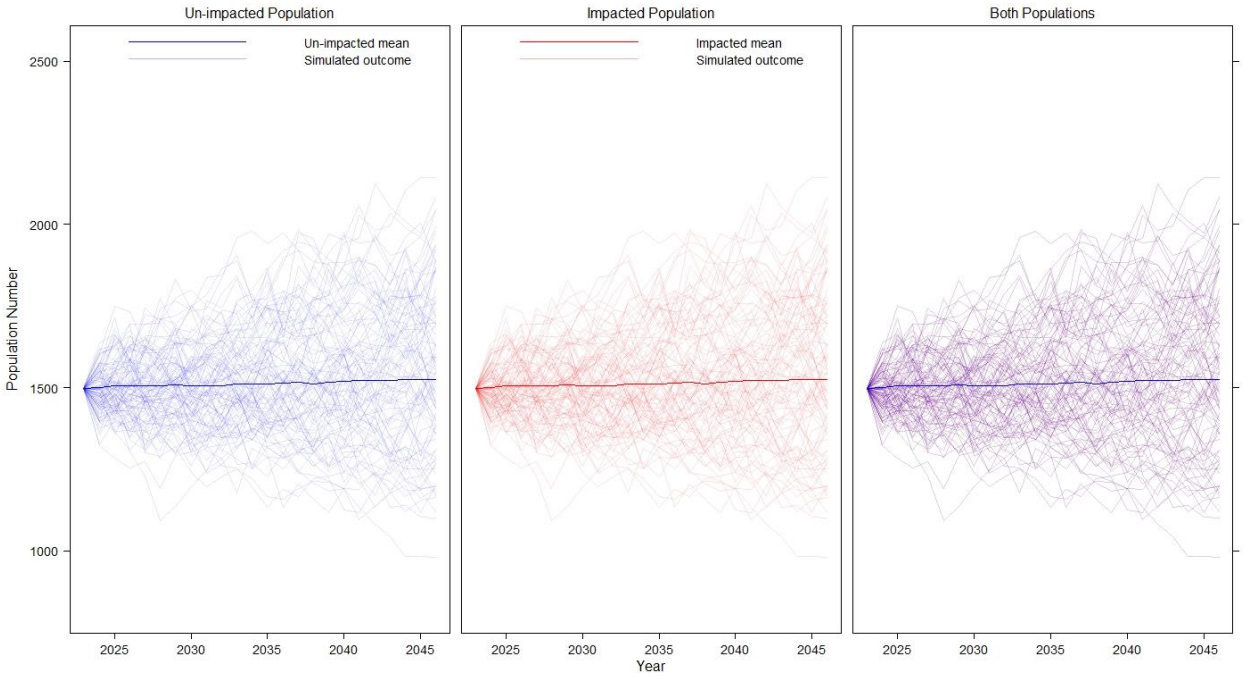


Figure 3-19 Simulated harbour population sizes for both the un-impacted and the impacted populations, assuming all impact goes to the Moray Firth (MF) MU, and assuming MF demographic parameters.

3.2.6 Limitations of disturbance assessment

There is a lack of sufficient empirical data on bottlenose dolphin, minke whale or grey seal responses to pile driving to derive species-specific dose-response curves for these species. The harbour seal dose-response curve has been used for grey seals. This is a reasonable proxy since both species are of the same hearing group. For both bottlenose dolphins and minke whale, the harbour porpoise dose-response curve was used. There are uncertainties regarding the use of this proxy since the species are all classified as being in different hearing groups, and thus in reality their response to the same sound source is unlikely to be the same.

The underwater noise modelling conducted by Cefas was limited to a certain area, and thus some of the lower dB impact contours were cut when they reached the limit of the modelling space. For example, Figure 3-20 clearly shows that the outermost impact contour ends at the edge of the modelling space. It is expected that if the entire 145 dB re 1 µPa²s contour were to be presented, it would overlap with the higher density areas off South Orkney and thus more grey seals would have been considered to be impacted (i.e: the cutting of the impact contour means an unknown portion of the true impact area has been unaccounted for). Figure 3-21 shows an example for isopleths reaching down to an SEL of 120 dB re 1 µPa²s being cut by the limit of the modelling space.

In additional to these issues, it should be recognised that estimates of received noise levels are likely to be extremely conservative given they have been based on the maximum hammer energy. In practice, pile

driving at other UK wind farms and Moray Firth developments has often been completed using much lower than predicted hammer energies (see Section 2.6.2.1.2 and BOWL & Moray East Piling Reports).

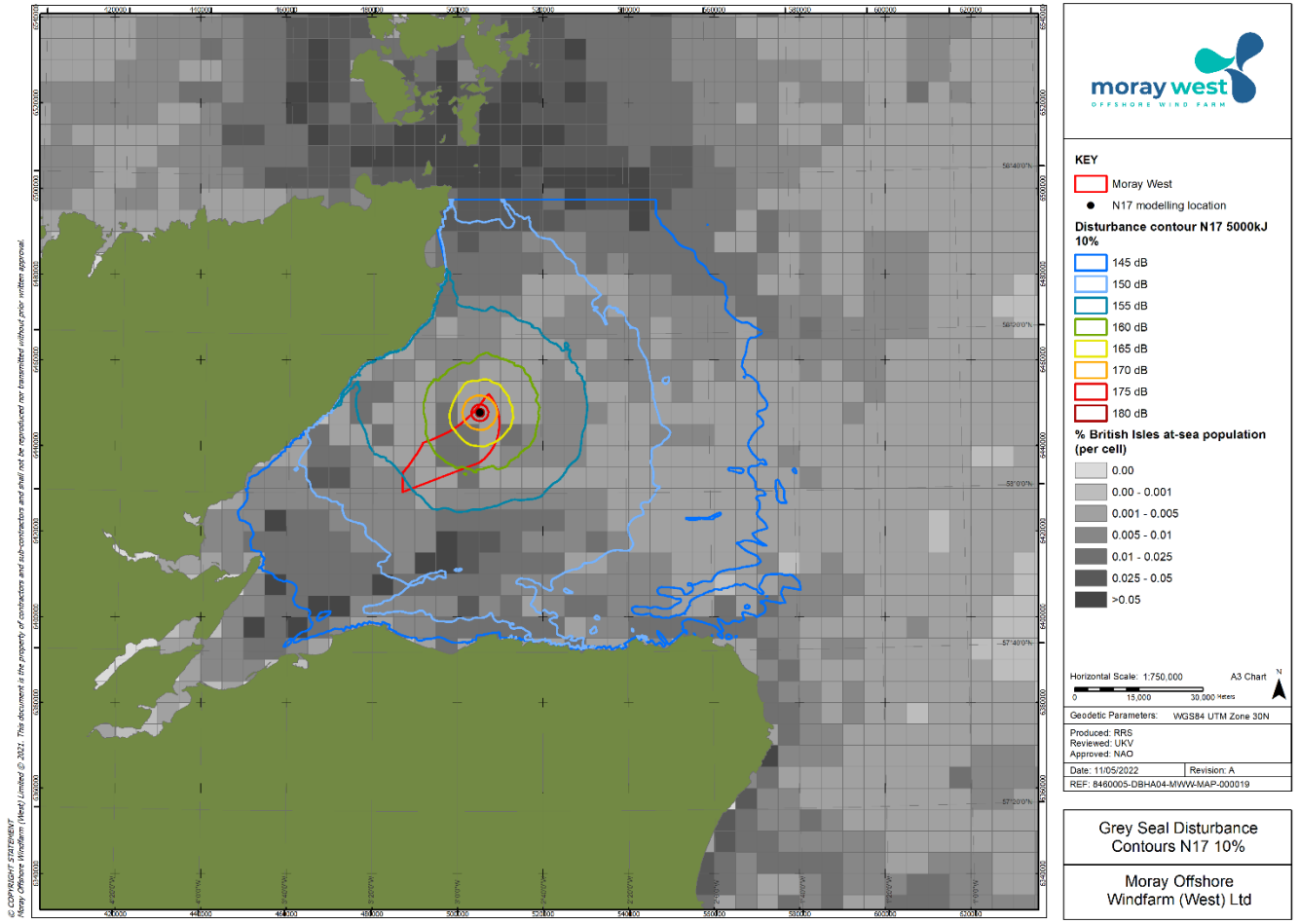


Figure 3-20 Disturbance contours for grey seals showing that the outermost isopleth (145 dB) ends at the boundary of the model domain. Location N17, CF = 10%, hammer energy = 5000 kJ.

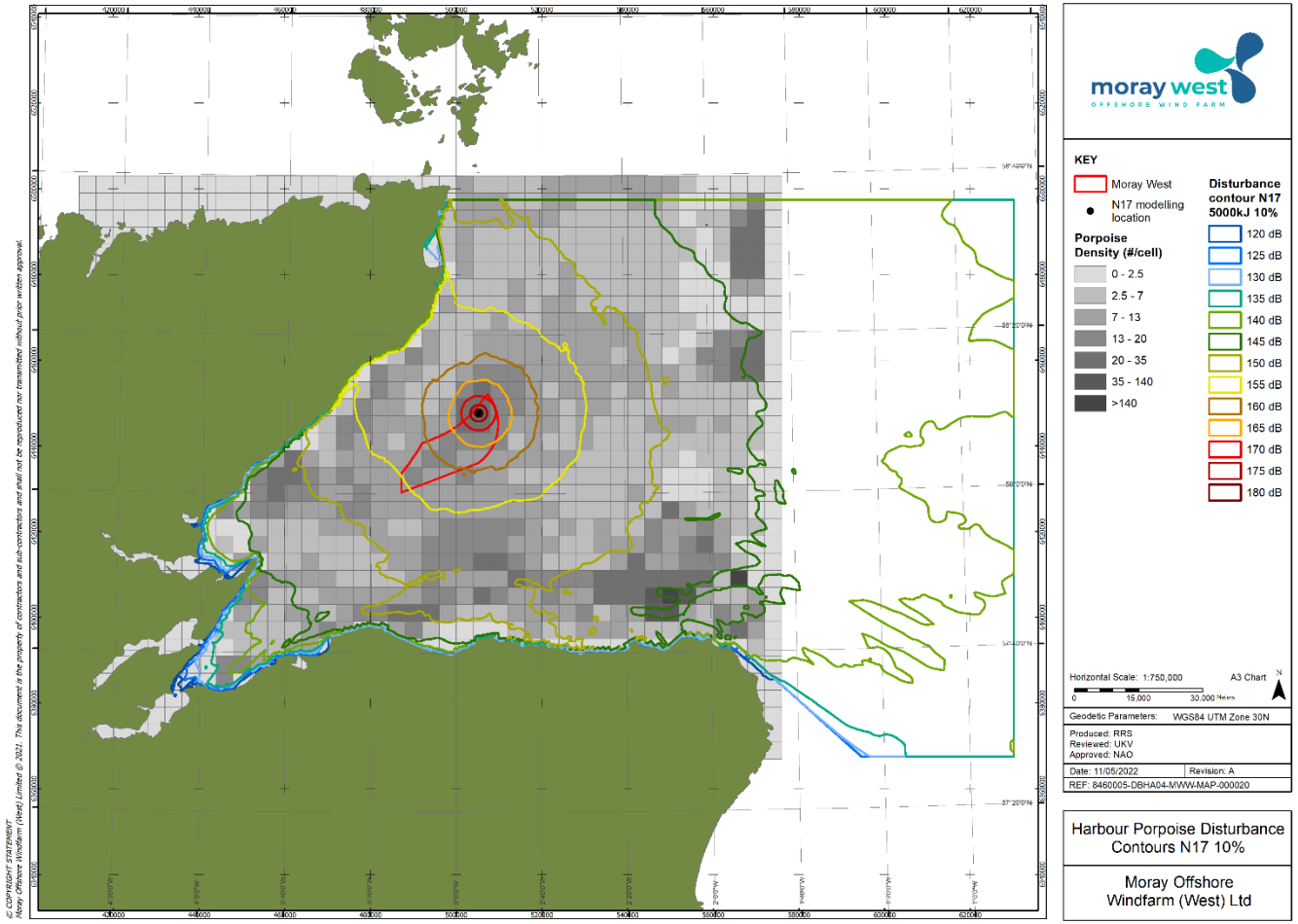


Figure 3-21 Disturbance contours for porpoise showing that the outer isopleths (150 - 120 dB) reach the boundaries of the model domain. Location N17, CF = 10%, hammer energy = 5000 kJ.

3.3 Proposed mitigation measures

Based on the results of the marine mammal assessment detailed above, we propose the following mitigation measures to reduce the risk of injury to negligible.

1. ADD deployment. An ADD-activation period prior commencement of pile driving start to reduce worst case impacts upon harbour porpoise
2. Soft-start procedure with a maximum hammer energy of 550 kJ for a minimum of 15 minutes
3. Ramp-up gradually until a suitable energy level is reached, to maintain a steady rate of pile penetration
4. Installation program designed to focus pile driving in non-summer months (outside July to September) to reduce worst case impacts upon minke whales

Details of the mitigation measures will be given in Appendix D – Piling Mitigation Protocol.

3.4 Comparison to 2018 EIA

The results presented in the Piling Strategy are generally the same as those presented in the Moray West EIA Report 2018. Both the Moray West EIA Report 2018 and this assessment concluded no significant effect of instantaneous or cumulative PTS-onset any marine mammal species when considering impacts against the entire MU (Table 3-15 and Table 3-16).

The proportion of the population impacted increases when considering only the UK portion of the population, however, as stated in Section 2.6.2.3, there is no biological reason to present the UK portion of the MU separately, and this was not done so in the Moray West EIA Report 2018.

Despite changes to the MUs sizes, density surfaces and the seal dose-response relationship, both the Moray West EIA Report 2018 and this Piling Strategy assessment concluded no significant effect of behavioural disturbance to any marine mammal species (Table 3-17).

Table 3-15 Comparison of the evaluation of sensitivity, magnitude, and impact of Instantaneous PTS on marine mammal species in the 2018 ES and this Piling Strategy.

	2018 ES			Piling Strategy		
Species	**Sensitivity**	**Magnitude**	**Impact**	**Sensitivity**	**Magnitude**	**Impact**
Harbour porpoise	High	Negligible	Minor Adverse	High	Negligible	Minor Adverse
Bottlenose dolphin	High	Negligible	Minor Adverse	High	Negligible	Minor Adverse
Minke whale	High	Negligible	Minor Adverse	High	Negligible	Minor Adverse
Grey seal	Medium	Negligible	Negligible	Medium	Negligible	Negligible
Harbour seal	Medium	Negligible	Negligible	Medium	Negligible	Negligible

Table 3-16 Comparison of the evaluation of sensitivity, magnitude, and impact of cumulative PTS on marine mammal species in the 2018 ES and this Piling Strategy. S = summer, NS = non-summer

	2018 ES			Piling Strategy		
Species	**Sensitivity**	**Magnitude**	**Impact**	**Sensitivity**	**Magnitude**	**Impact**
Harbour porpoise	High	Negligible	Minor Adverse	High	Negligible	Minor Adverse
Bottlenose dolphin	High	Negligible	Minor Adverse	High	Negligible	Minor Adverse
Minke whale	High	Negligible	Minor Adverse	High	S: Negligible NS: Negligible	S: Minor adverse NS: Minor Adverse
Grey seal	Medium	Negligible	Negligible	Medium	Negligible	Negligible
Harbour seal	Medium	Negligible	Negligible	Medium	Negligible	Negligible

Table 3-17 Comparison of the evaluation of sensitivity, magnitude, and impact of disturbance on marine mammal species in the 2018 ES and this Piling Strategy. S = summer, NS = non-summer						
	2018 EIA			Piling Strategy		
Species	**Sensitivity**	**Magnitude**	**Impact**	**Sensitivity**	**Magnitude**	**Impact**
Harbour porpoise	Medium	Low	Minor Adverse	Medium	Low	Minor Adverse
Bottlenose dolphin	Medium	Low	Minor Adverse	Medium	Low	Minor Adverse
Minke whale	Medium	Negligible	Minor Adverse	Medium	S: Low NS: Negligible	Minor Adverse
Grey seal	Low	Low	Minor Adverse	Low	Negligible	Minor Adverse
Harbour seal	Medium	Low	Minor Adverse	Medium	Negligible	Minor Adverse

3.5 Comparison to 2018 RIAA

For both focal species of the RIAA, bottlenose dolphin and harbour seal, the iPCoD modelling has indicated that the predicted level of disturbance occurring over a maximum period of two breeding seasons will not result in a significant long-term change in the population growth rate and no long-term change in the population trajectory. These results are in line with those presented in the current assessment in support for the Piling Strategy. Therefore, it is concluded that there will be no adverse effect on the integrity of the bottlenose dolphin feature of the Moray Firth SAC or harbour seal feature of the Dornoch Firth and Morrich More SAC because of pile driving noise.

4 Fish Assessment Results

4.1 SPL_{peak} Assessment of Mortality and Recoverable Injury in Fish

The maximum effect range for mortality or recoverable injury according to the Popper (2014) criteria (which have the same threshold of 207 dB re 1 µPa) was 1570 m, for the BE50 blow count scenarios at 5,000 kJ and 10% energy CF. The corresponding effect range for the 4% energy conversion factor was 880 m (Table 4-1). Instantaneous mortality or recoverable injury arising from the initial, soft-start, hammer strike of 550 kJ was predicted to occur over a maximum range of 255 m for the 10% energy conversion factor, which is reduced to 110 m for the 4% conversion factor.

Table 4-1 Effect ranges for mortality and recoverable injury according to the Popper peak SPL criterion for Atlantic salmon and the sea trout.					
Location(s)	**Blow count**	**Hammer energy (kJ)**	**Threshold (dB re 1 µPa)**	**Maximum effect range (m) at 4% C.F.**	**Maximum effect range (m) at 10% C.F.**
A02, L07, N17	BE50	5000	207	880	1570
A02	BE80	4459	207	815	1460
L07	BE80	4189	207	785	1405
N17	BE80	4324	207	800	1430
A02, L07, N17	BE50	550	207	110	255

4.2 Cumulative SEL Assessment of TTS, Recoverable Injury, and Mortality Effect Zones for Fish

The greatest mortality range predicted for Atlantic salmon and sea trout was 1700 m at location L07 for the blow count profile BE80 and the energy conversion factor of 10%. The corresponding range for the 4% conversion factor was 923 m at location L07, while the maximum range predicted when using the 4% conversion factor was slightly larger, namely 935 m, at location N17. The greatest recoverable injury range was 5,016 m, and the greatest TTS range was 58,702 m, at the same location (L07), blow count profile (BE80) and conversion factor (10%) as for the greatest mortality range. For the 4% conversion factor, these ranges were reduced to 2,783 m for recoverable injury and to 35,979 m for TTS (Table 4-2). The effect areas are shown from Figure 4-1 to Figure 4-12.

Table 4-2 Effect areas for mortality, recoverable injury, and TTS according to the Popper SEL_{cum} criterion for the Atlantic salmon and the sea trout. Thresholds for these effects are 210, 203, and 186 dB re 1 µPa^2 s, respectively.						
Location assessed	**Blow count**	**Conversion factor**	**TTS area (km^2); *range (m)***	**Recoverable injury area (km^2); *range (m)***	**Mortality area (km^2); *range (m)***	**Figure number**
A02	BE80	4%	2053.50; *34,554*	22.03; *2,690*	2.48; *896*	Figure 4-1
L07	BE80	4%	1919.25; *35,979*	23.07; *2,783*	2.54; *923*	Figure 4-2
N17	BE80	4%	1568.11; *33,322*	21.12; *2,690*	2.52; *935*	Figure 4-3
A02	BE50	4%	1890.70; *32,870*	19.47; *2,536*	2.11; *813*	Figure 4-4
L07	BE50	4%	1575.49; *34,841*	18.99; *2,539*	1.98; 826	Figure 4-5

Table 4-2 Effect areas for mortality, recoverable injury, and TTS according to the Popper SEL_{cum} criterion for the Atlantic salmon and the sea trout. Thresholds for these effects are 210, 203, and 186 dB re 1 µPa^2 s, respectively.

Location assessed	Blow count	Conversion factor	TTS area (km^2); *range (m)*	Recoverable injury area (km^2); *range (m)*	Mortality area (km^2); *range (m)*	Figure number
N17	BE50	4%	1432.95; *32,358*	18.40; *2,539*	2.10; *850*	Figure 4-6
A02	BE80	10%	3793.40; *58,135*	69.54; *4,908*	8.80; *1668*	Figure 4-7
L07	BE80	10%	4204.28; *58,702*	73.36; *5,016*	8.74; *1700*	Figure 4-8
N17	BE80	10%	3451.18; *54,787*	64.38; *4,635*	8.23; *1673*	Figure 4-9
A02	BE50	10%	3605.47; *58,068*	62.09; *4,593*	7.11; *1569*	Figure 4-10
L07	BE50	10%	3875.57; *55,707*	62.53; *4,619*	7.40; *1546*	Figure 4-11
N17	BE50	10%	3200.01; *48,060*	57.15; *4,356*	7.38; *1587*	Figure 4-12

4.3 Comparison to 2018 EIA

Based on noise modelling presented in the Moray West EIA Report 2018, any impacts on fish species as a result of piling noise at Moray West Site were considered to be of low magnitude, with the significance of the effect assessed as minor, even for more sensitive species such as salmonids. Although there is some potential for mortality, injury and behavioural effects in the ranges summarised above, piling (noise generation) is predicted to occur over a short duration (up to 248 hours in total) and overlap with sensitive locations and time periods for the fish species considered is limited.

In light of the low potential for any barrier effects to natal rivers as a result of the noise contours, the assessment of potential noise related effects is not expected to exceed that previously assessed within the Moray West EIA Report 2018. It is therefore concluded that the potential for mortality, impairment and behavioural effects would be of negligible significance for Atlantic salmon and sea trout, and therefore not significant in EIA terms.

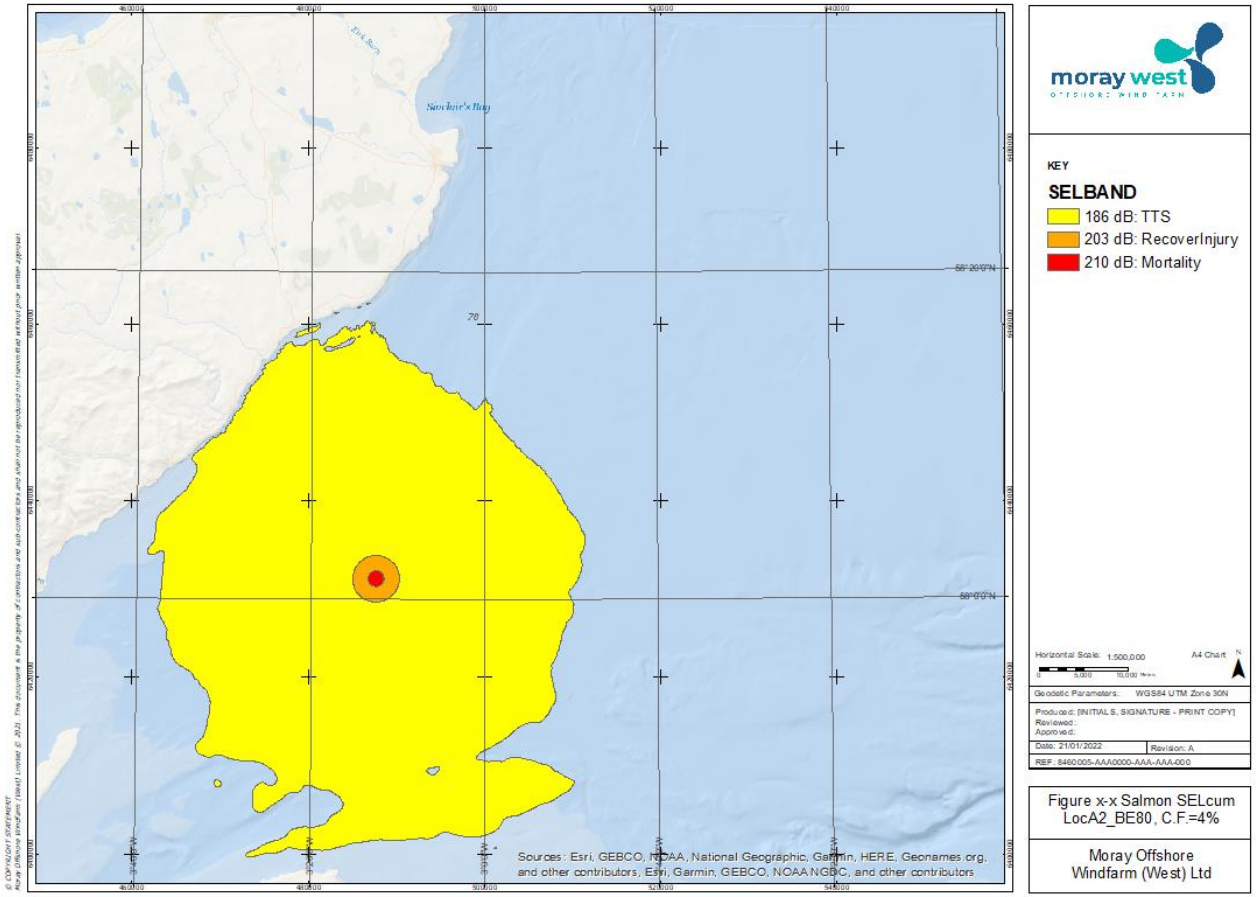


Figure 4-1 Cumulative exposure effect zones for fish species exposed to piling at location A02, for the blow count profile BE80 and the energy conversion factor C.F.=4%.

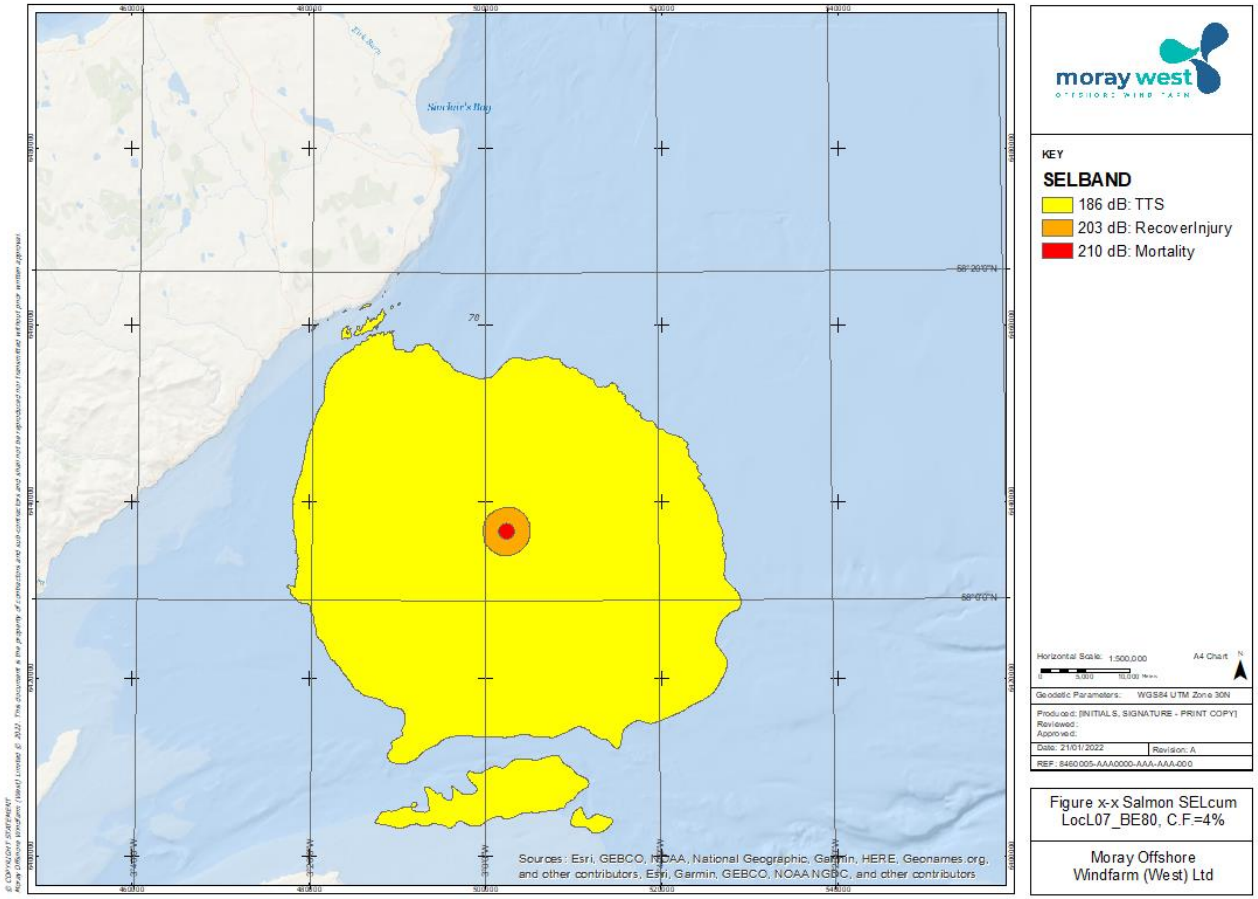


Figure 4-2 Cumulative exposure effect zones for fish species exposed to piling at location L07, for the blow count profile BE80 and the energy conversion factor C.F.=4%.

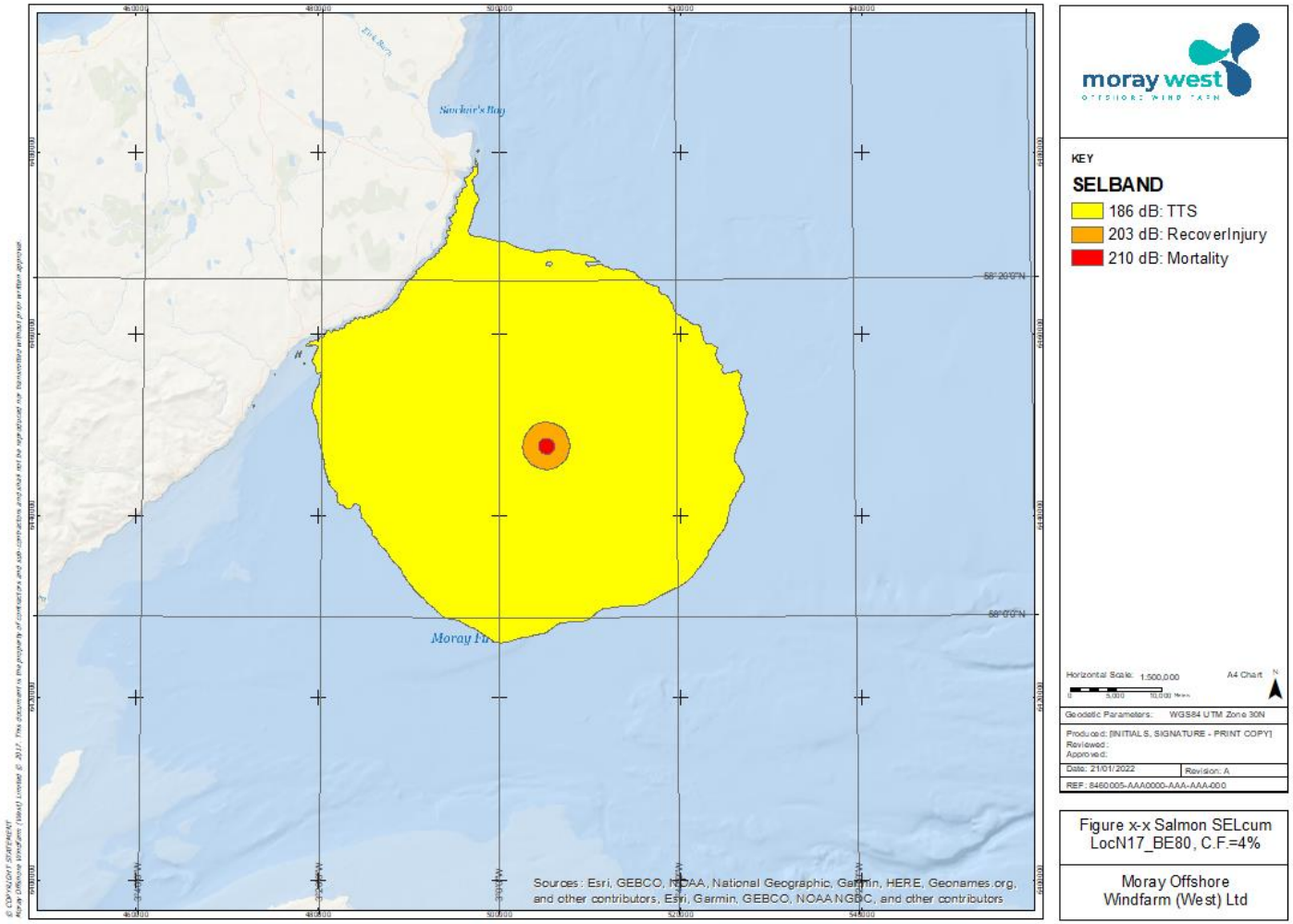


Figure 4-3 Cumulative exposure effect zones for fish species exposed to piling at location N17, for the blow count profile BE80 and the energy conversion factor C.F.=4%.

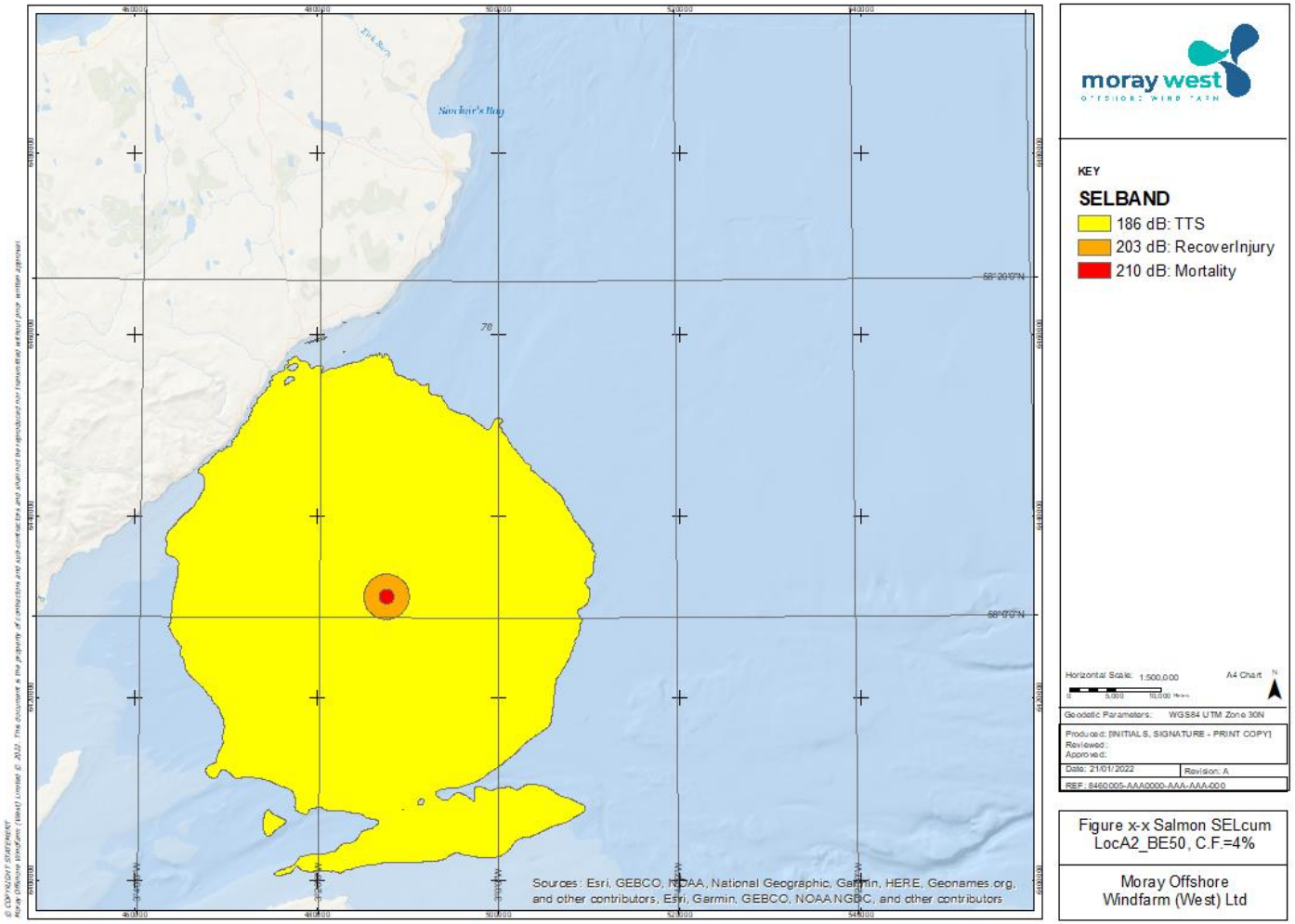


Figure 4-4 Cumulative exposure effect zones for fish species exposed to piling at location A02, for the blow count profile BE50 and the energy conversion factor C.F.=4%.

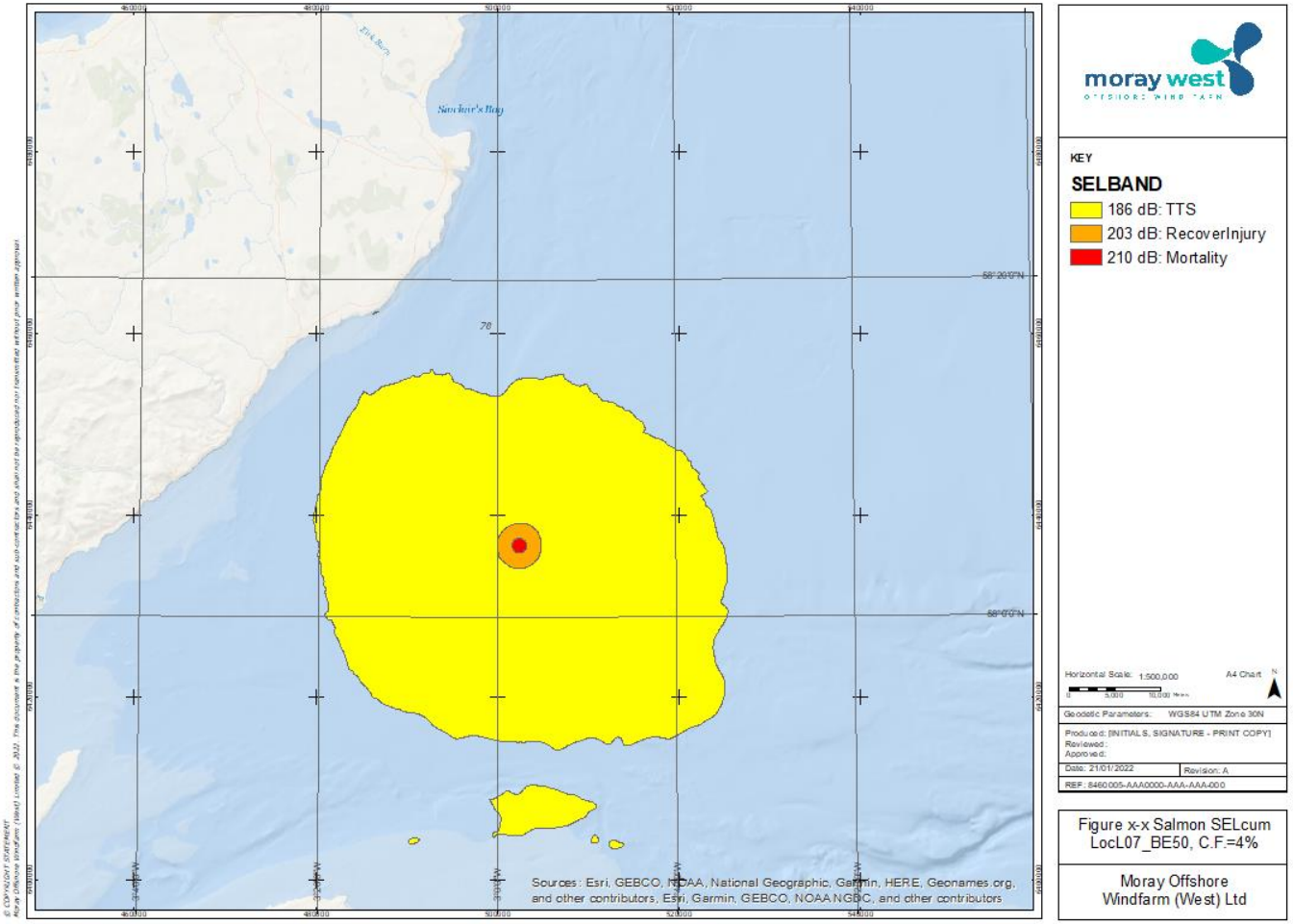


Figure 4-5 Cumulative exposure effect zones for fish species exposed to piling at location L07, for the blow count profile BE50 and the energy conversion factor C.F.=4%.

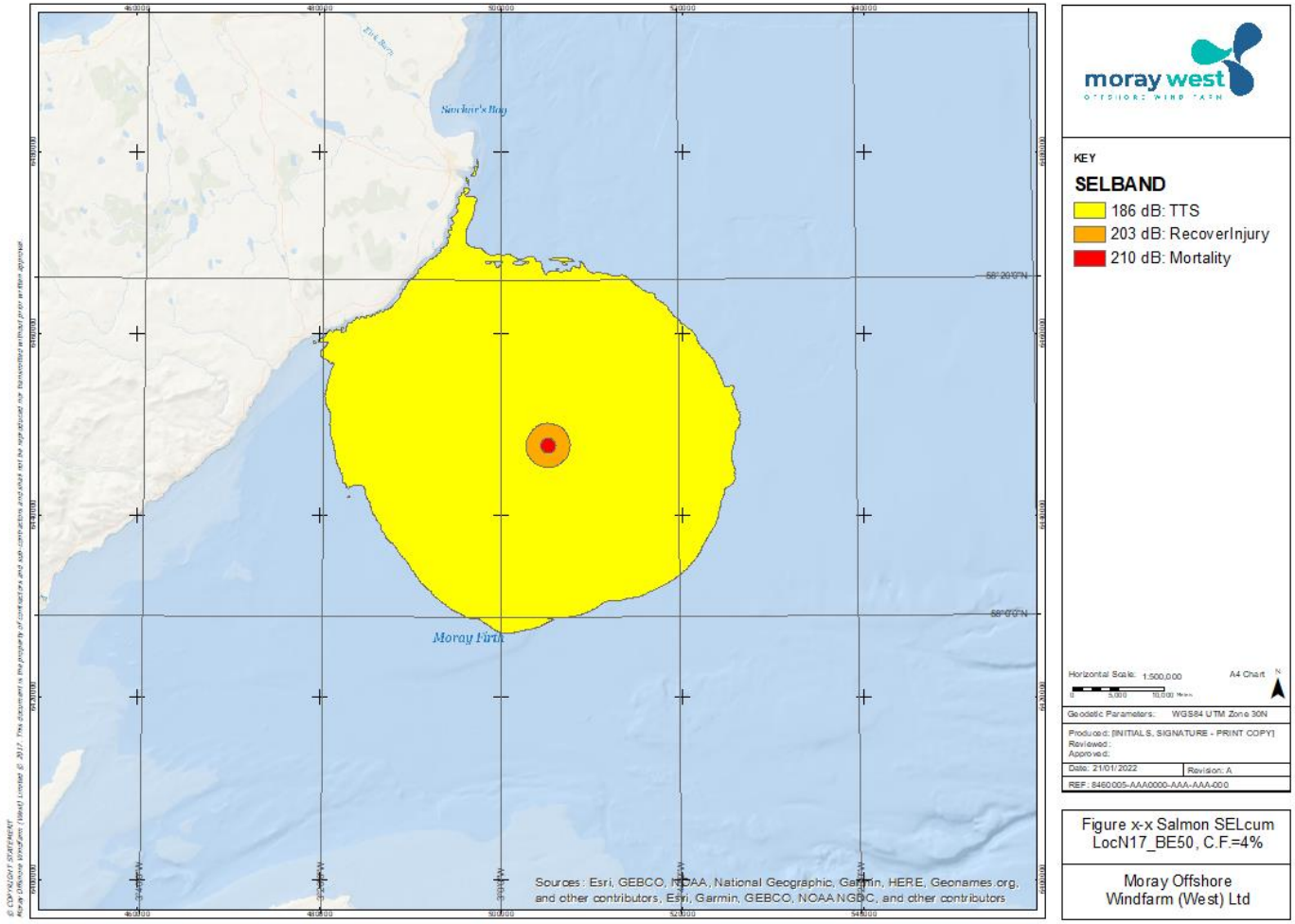


Figure 4-6 Cumulative exposure effect zones for fish species exposed to piling at location N17, for the blow count profile BE50 and the energy conversion factor C.F.=4%.

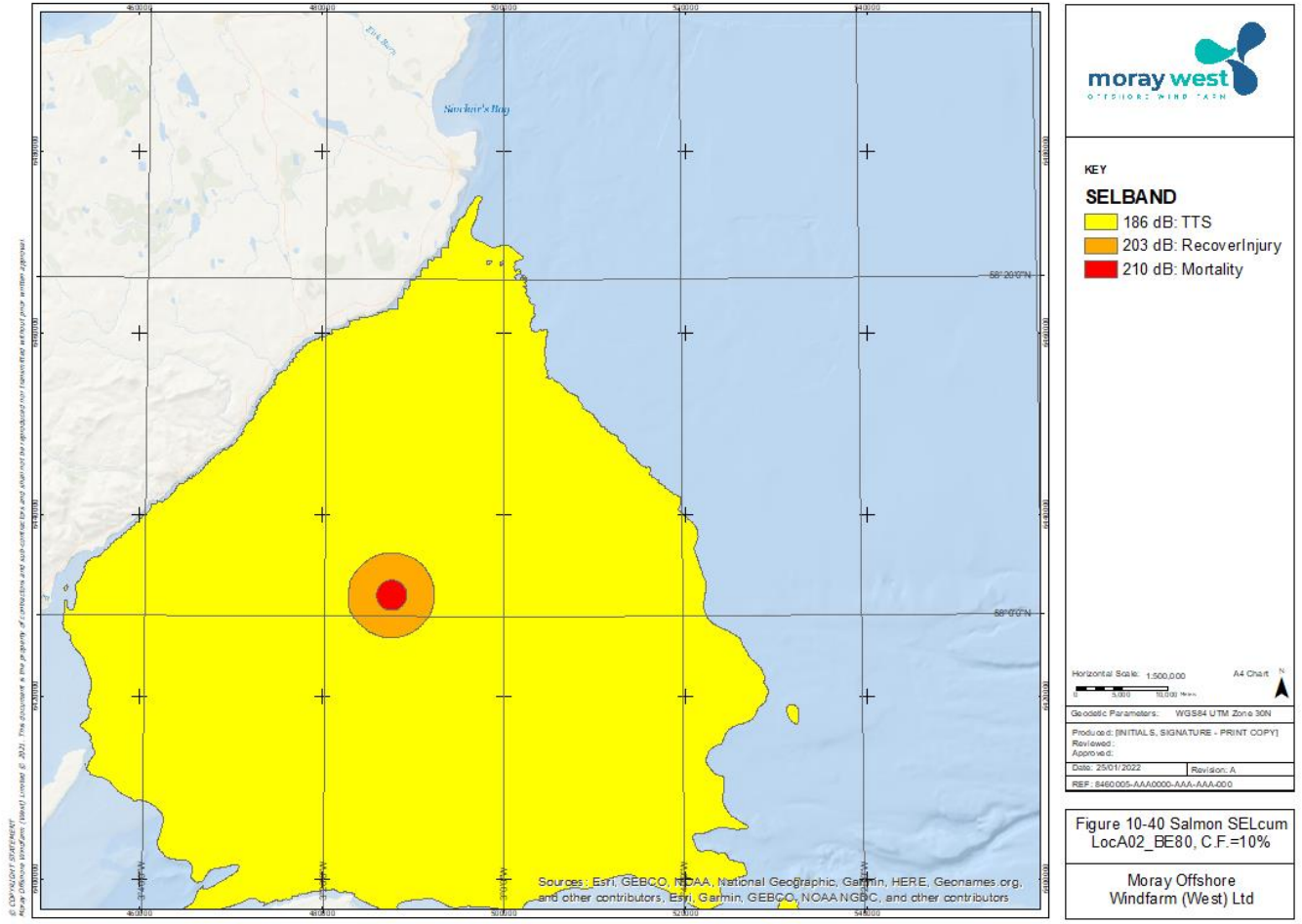


Figure 4-7 Cumulative exposure effect zones for fish species exposed to piling at location A02, for the blow count profile BE80 and the energy conversion factor C.F.=10%.

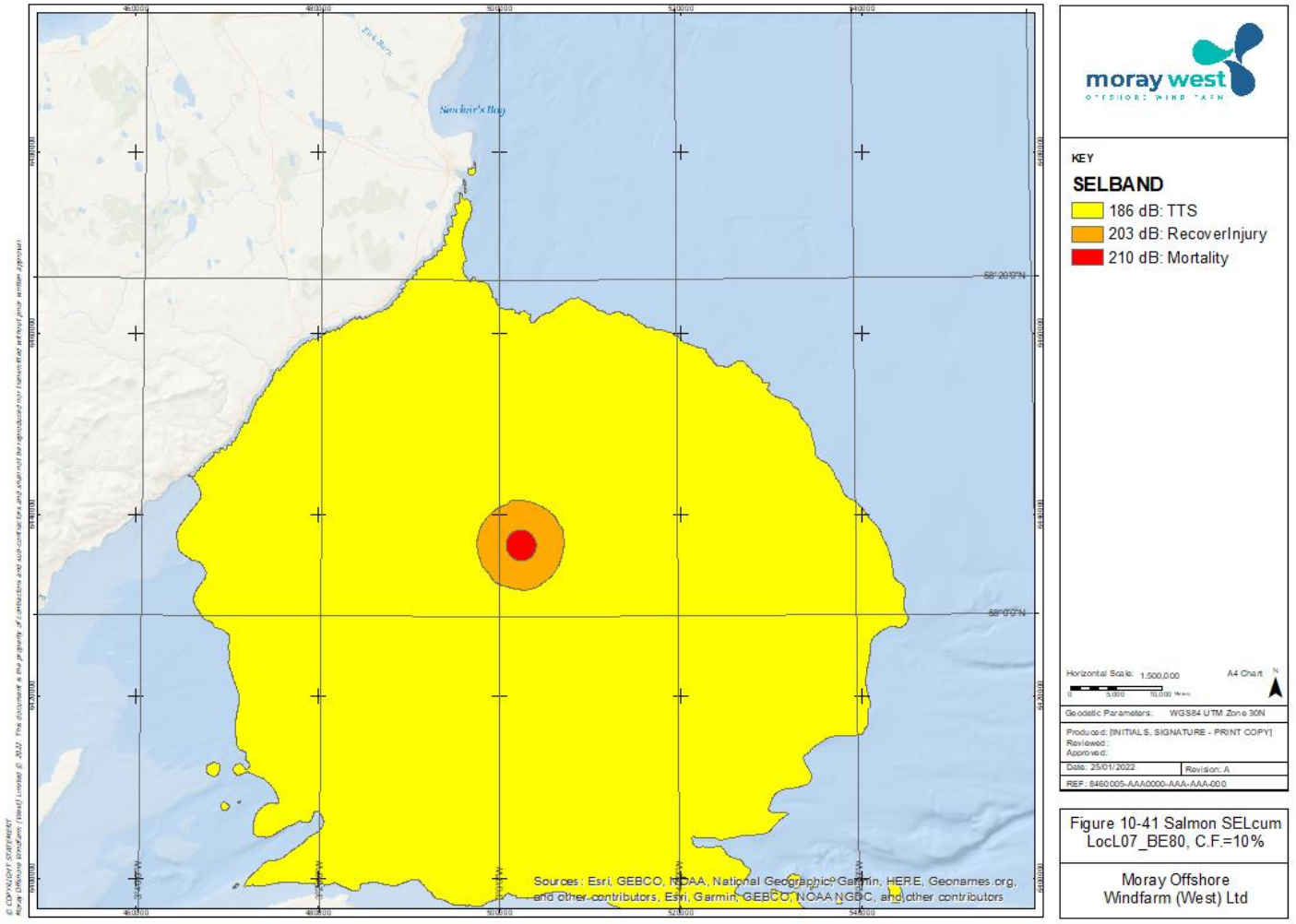


Figure 4-8 Cumulative exposure effect zones for fish species exposed to piling at location L07, for the blow count profile BE80 and the energy conversion factor C.F.=10%.

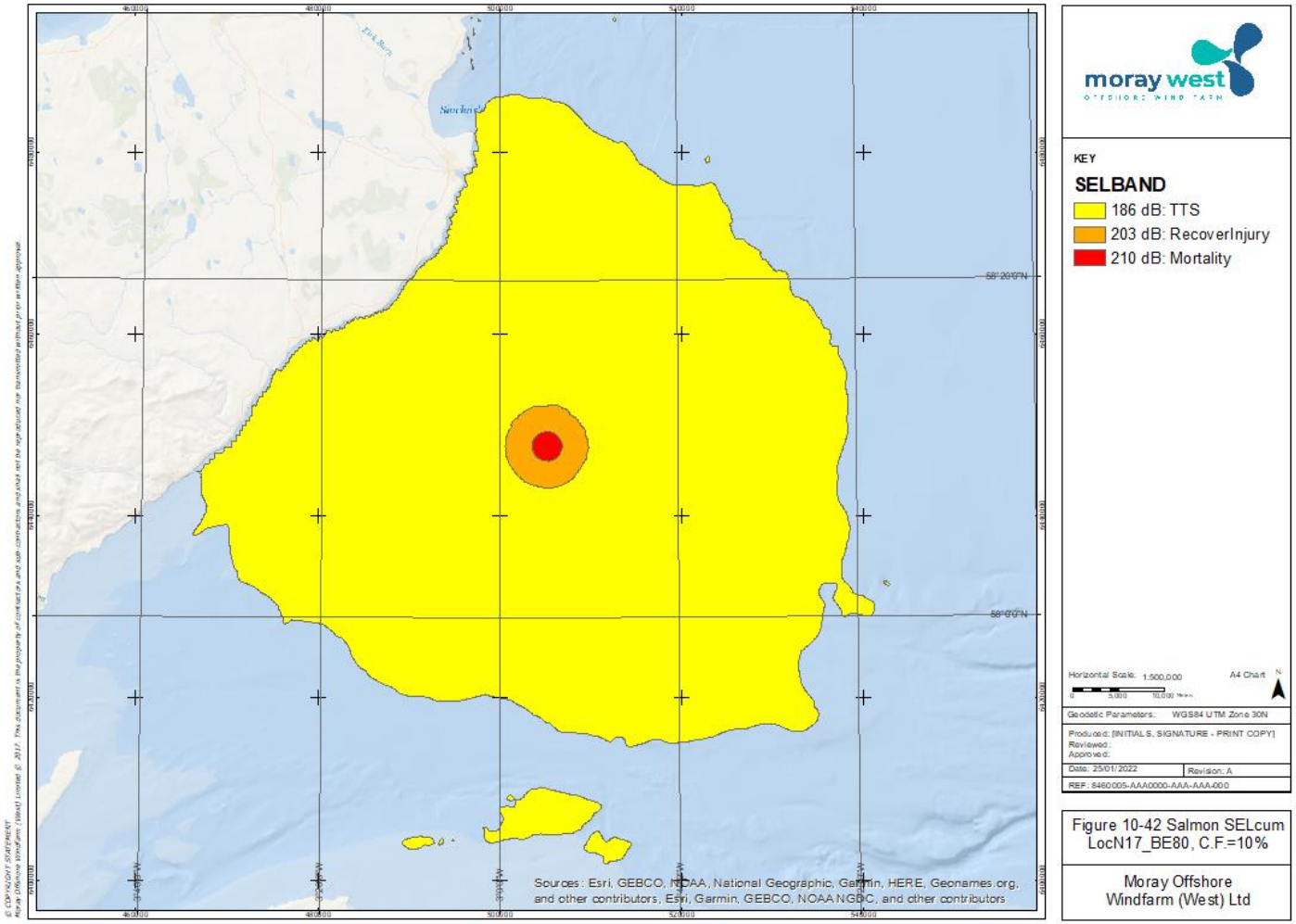


Figure 4-9 Cumulative exposure effect zones for fish species exposed to piling at location N17, for the blow count profile BE80 and the energy conversion factor C.F.=10%.

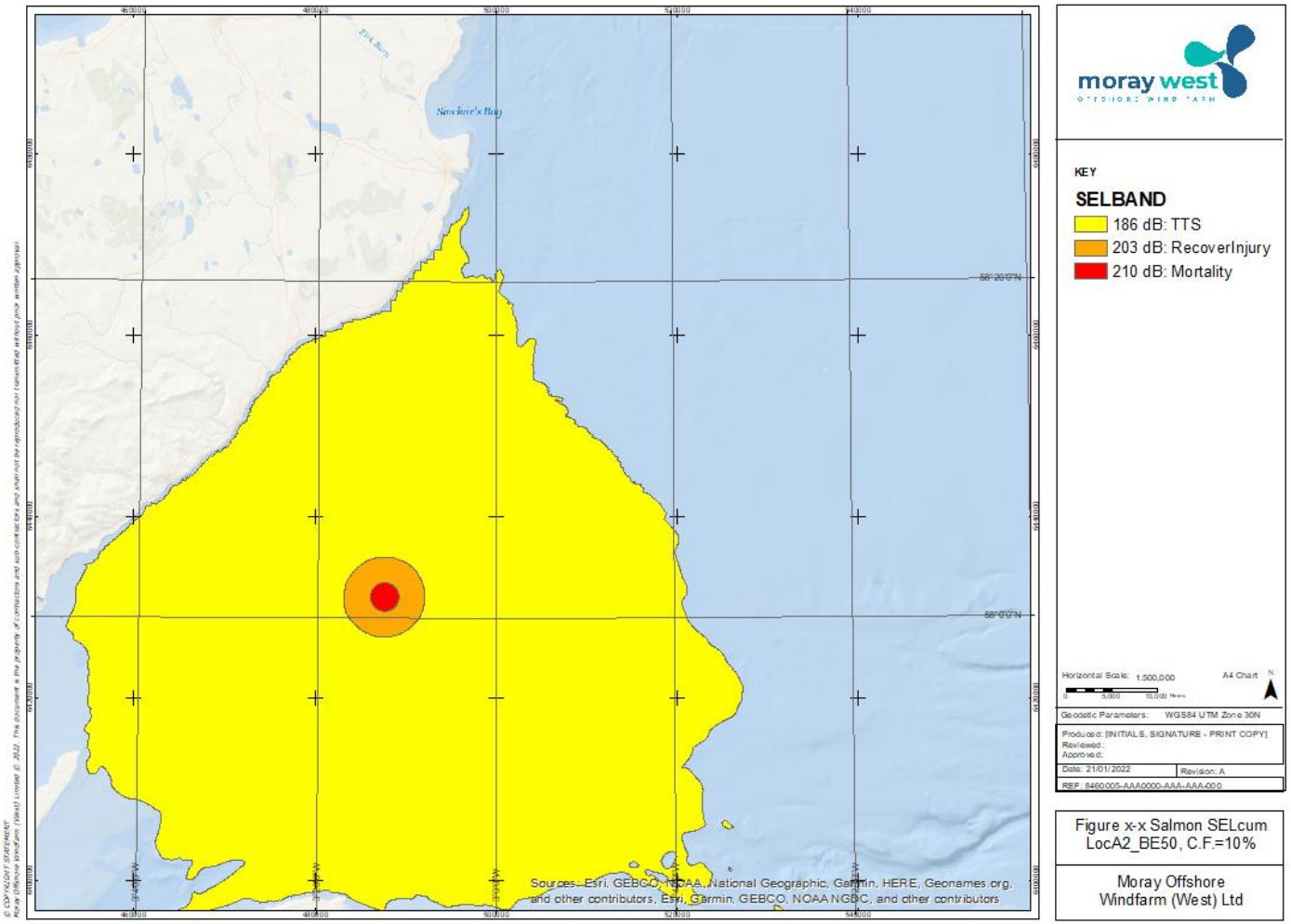


Figure 4-10 Cumulative exposure effect zones for fish species exposed to piling at location A02, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

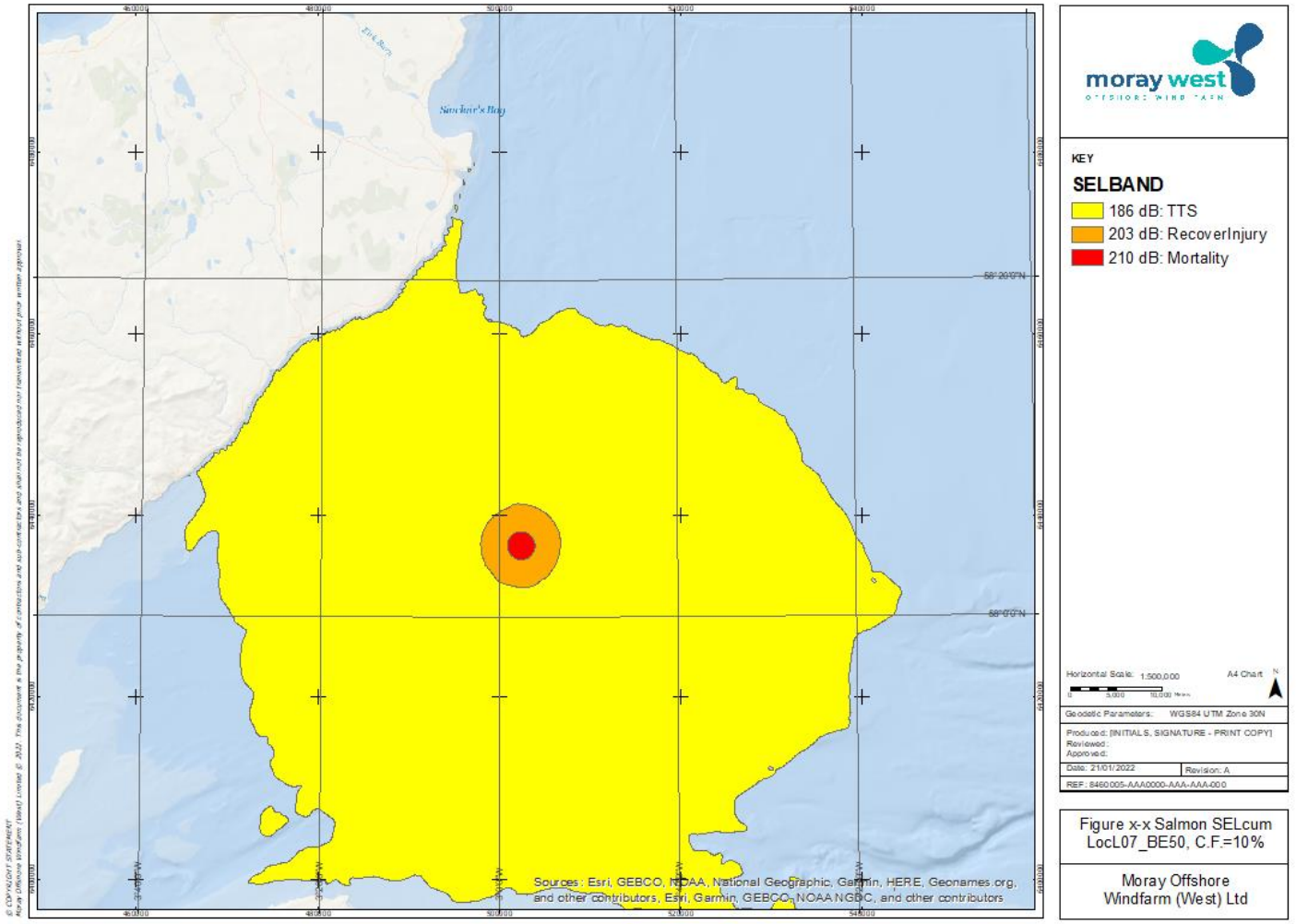


Figure 4-11 Cumulative exposure effect zones for fish species exposed to piling at location L07, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

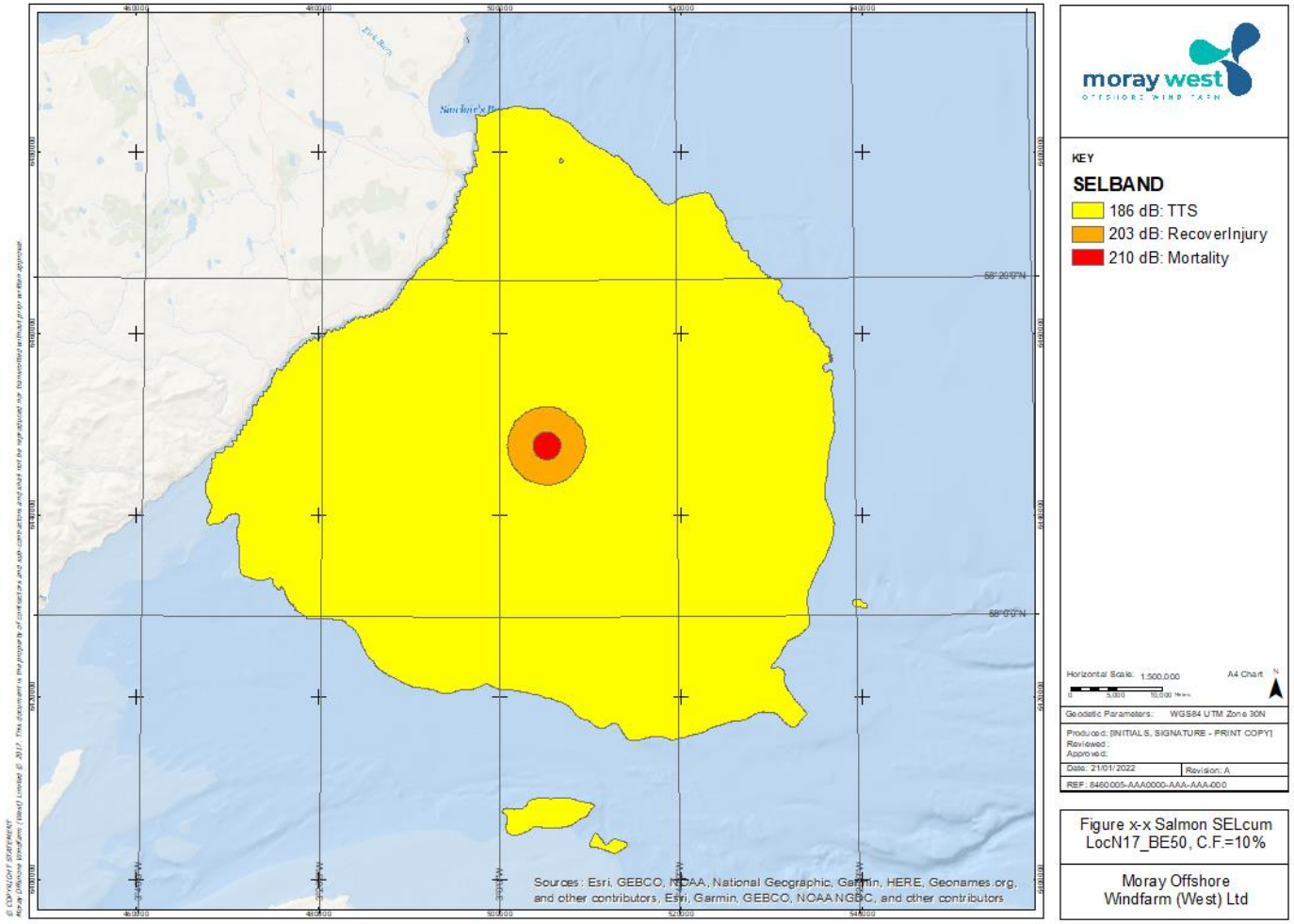


Figure 4-12 Cumulative exposure effect zones for fish species exposed to piling at location N17, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

5 References

Ainslie, M., C. de Jong, S. Robinson, and P. Lepper. 2012. What is the source level of pile-driving noise in water? Pages 445-448 *in* A. H. Popper, AD, editor. Eff. Noise Aquat. Life. Springer, NY.

Arso Civil, M., N. Quick, S. Mews, E. Hague, B. J. Cheney, P. Thompson, and P. Hammond. 2021. Improving understanding of bottlenose dolphin movements along the east coast of Scotland. Final report. provided to European Offshore Wind Deployment Centre (EOWDC).

Bailey, H. 2017. Moray West Marine Mammal Impact Assessment: Habitat-based density modeling of harbour seals.

Banda, N., G. GJimenez, and S. Cook. 2020. Triton Knoll Offshore Wind Farm Project. Analysis of underwater noise and Source Level estimation during the construction of Triton Knoll Offshore Wind Farm. Seiche.

Benhemma-Le Gall, A., I. Graham, N. Merchant, and P. Thompson. 2021. Broad-scale responses of harbor porpoises to pile-driving and vessel activities during offshore windfarm construction. Frontiers in Marine Science **8**:664724.

Booth, C., and F. Heinis. 2018. Updating the Interim PCoD Model: Workshop Report - New transfer functions for the effects of permanent threshold shifts on vital rates in marine mammal species. Report Code SMRUC-UOA-2018-006, submitted to the University of Aberdeen and Department for Business, Energy and Industrial Strategy (BEIS), June 2018 (unpublished).

Brandt, M. J., A.-C. Dragon, A. Diederichs, M. A. Bellmann, V. Wahl, W. Piper, J. Nabe-Nielsen, and G. Nehls. 2018. Disturbance of harbour porpoises during construction of the first seven offshore wind farms in Germany. Marine Ecology Progress Series **596**:213-232.

Brandt, M. J., C. Hoeschle, A. Diederichs, K. Betke, R. Matuschek, S. Witte, and G. Nehls. 2013. Far-reaching effects of a seal scarer on harbour porpoises, *Phocoena phocoena*. Aquatic Conservation-Marine and Freshwater Ecosystems **23**:222-232.

Carter, M., L. Boehme, C. Duck, W. Grecian, G. Hastie, B. McConnell, D. Miller, C. Morris, S. Moss, D. Thompson, P. Thompson, and D. Russell. 2020. Habitat-based predictions of at-sea distribution for grey and harbour seals in the British Isles. Sea Mammal Research Unit, University of St Andrews, Report to BEIS, OESEA-16-76/OESEA-17-78.

Collins, M. D. 1993. A split-step Padé solution for the parabolic equation method. The Journal of the Acoustical Society of America **93**:1736-1742.

De Jong, C. A. f., and M. A. Ainslie. 2008. Underwater radiated noise due to the piling for the Q7 Offshore Wind Park. Journal of the Acoustical Society of America **123**:2987.

Donovan, C., J. Harwood, S. King, C. Booth, B. Caneco, and C. Walker. 2016. Expert elicitation methods in quantifying the consequences of acoustic disturbance from offshore renewable energy developments. Pages 231-237 The Effects of Noise on Aquatic Life II. Springer.

Dunlop, R. A., M. J. Noad, R. D. McCauley, L. Scott-Hayward, E. Kniest, R. Slade, D. Paton, and D. H. Cato. 2017. Determining the behavioural dose–response relationship of marine mammals to air gun noise and source proximity. Journal of Experimental Biology **220**:2878-2886.

Farcas, A., P. M. Thompson, and N. D. Merchant. 2016. Underwater noise modelling for environmental impact assessment. Environmental Impact Assessment Review **57**:114-122.

Finneran, J. J. 2015. Noise-induced hearing loss in marine mammals: A review of temporary threshold shift studies from 1996 to 2015. The Journal of the Acoustical Society of America **138**:1702-1726.

Finneran, J. J., D. A. Carder, C. E. Schlundt, and R. L. Dear. 2010. Growth and recovery of temporary threshold shift at 3 kHz in bottlenose dolphins: Experimental data and mathematical models. The Journal of the Acoustical Society of America **127**:3256-3266.

Graham, I., D. Gillespie, K. Gkikopoulou, G. Hastie, and P. Thompson. Submitted. Directional hydrophone clusters reveal evasive responses of small cetaceans to disturbance at offshore windfarms. Biology Letters.

Graham, I. M., B. Cheney, R. C. Hewitt, L. S. Cordes, G. Hastie, and P. Thompson. 2017a. Strategic Regional Pre-Construction Marine Mammal Monitoring Programme Annual Report 2017. University of Aberdeen.

Graham, I. M., A. Farcas, N. D. Merchant, and P. Thompson. 2017b. Beatrice Offshore Wind Farm: An interim estimate of the probability of porpoise displacement at different unweighted single-pulse sound exposure levels. Prepared by the University of Aberdeen for Beatrice Offshore Windfarm Ltd.

Graham, I. M., N. D. Merchant, A. Farcas, T. R. C. Barton, B. Cheney, S. Bono, and P. M. Thompson. 2019. Harbour porpoise responses to pile-driving diminish over time. Royal Society Open Science **6**:190335.

Hamilton, E. L. 1980. Geoacoustic modeling of the sea floor. The Journal of the Acoustical Society of America **68**:1313-1340.

Hammond, P., C. Lacey, A. Gilles, S. Viquerat, P. Börjesson, H. Herr, K. Macleod, V. Ridoux, M. Santos, M. Scheidat, J. Teilmann, J. Vingada, and N. Øie. 2021. Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys - revised June 2021.

Hammond, P., C. Lacey, A. Gilles, S. Viquerat, P. Börjesson, H. Herr, K. Macleod, V. Ridoux, M. Santos, M. Scheidat, J. Teilmann, J. Vingada, and N. Øien. 2017. Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys.

Harwood, J., S. L. King, R. S. Schick, C. Donovan, and C. G. Booth. 2014. A protocol for implementing the interim population consequences of disturbance (PCoD) approach: Quantifying and assessing the effects of UK offshore renewable energy developments on marine mammal populations. Page 33 Scottish Marine and Freshwater Science.

Hastie, G., N. D. Merchant, T. Götz, D. J. Russell, P. Thompson, and V. M. Janik. 2019. Effects of impulsive noise on marine mammals: investigating range-dependent risk. Ecological Applications **29**:e01906.

IAMMWG. 2021. Updated abundance estimates for cetacean Management Units in UK waters. JNCC Report No. 680, JNCC Peterborough, ISSN 0963-8091.

Kastak, D., M. Holt, C. Kastak, B. Southall, J. Mulsow, and R. Schusterman. 2005. A voluntary mechanism of protection from airborne noise in a harbor seal. Page 148 *in* 16th Biennial Conference on the Biology of Marine Mammals. San Diego CA.

Kastelein, R. A., R. Gransier, and L. Hoek. 2013. Comparative temporary threshold shifts in a harbor porpoise and harbor seal, and severe shift in a seal (L). Journal of the Acoustical Society of America **134**:13-16.

Kastelein, R. A., L. Helder-Hoek, L. N. Defillet, L. A. Huijser, J. M. Terhune, and R. Gransier. 2021. Temporary Hearing Threshold Shift in California Sea Lions (Zalophus californianus) Due to One-Sixth-Octave Noise Bands Centered at 2 and 4 kHz: Effect of Duty Cycle and Testing the Equal-Energy Hypothesis. Aquatic Mammals **47**.

Kastelein, R. A., L. Hoek, R. Gransier, M. Rambags, and N. Claeys. 2014. Effect of level, duration, and inter-pulse interval of 1-2 kHz sonar signal exposures on harbor porpoise hearing. The Journal of the Acoustical Society of America **136**:412-422.

King, S. L., R. S. Schick, C. Donovan, C. G. Booth, M. Burgman, L. Thomas, and J. Harwood. 2015. An interim framework for assessing the population consequences of disturbance. Methods in Ecology and Evolution **6**:1150-1158.

Lippert, T., M. Galindo-Romero, A. N. Gavrilov, and O. von Estorff. 2015. Empirical estimation of peak pressure level from sound exposure level. Part II: Offshore impact pile driving noise. The Journal of the Acoustical Society of America **138**:EL287-EL292.

Lonergan, M., C. Duck, S. Moss, C. Morris, and D. Thompson. 2013. Rescaling of aerial survey data with information from small numbers of telemetry tags to estimate the size of a declining harbour seal population. Aquatic Conservation-Marine and Freshwater Ecosystems **23**:135-144.

Lonergan, M., B. McConnell, C. Duck, and D. Thompson. 2011. An estimate of the size of the British grey seal population based on summer haulout counts and telemetry data. SCOS Briefing Paper 11/06.

Marine Scotland. 2020. The protection of Marine European Protected Species from injury and disturbance. Guidance for Scottish Inshore Waters (July 2020 Version).

Martin, B., K. Lucke, and D. Barclay. 2020. Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals. The Journal of the Acoustical Society of America **147**:2159-2176.

Mooney, T. A., P. E. Nachtigall, M. Breese, S. Vlachos, and W. W. Au. 2009. Predicting temporary threshold shifts in a bottlenose dolphin (Tursiops truncatus): The effects of noise level and duration. The Journal of the Acoustical Society of America **125**:1816-1826.

Moray Offshore Renewables Ltd. 2012. Moray Offshore Renewables Limited Environmental StatementTechnical Appendix 7.3 A - Marine Mammals EnvironmentalImpact Assessment. Produced by Natural Power on behalf of Moray Offshore Renewables Ltd.

NIRAS Consulting Ltd. 2017. Race Bank Noise Monitoring Survey Report. NIRAS Project Number UKN0L3303.

NMFS. 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. Page 189. U.S. Department of Commerce, Silver Spring.

OSC. 2017. Noise monitoring of piling operations at Galloper Offshore Wind Farm. Technical Document No. 4 for GeoSea NV. Ocean Science Consulting Limited, Dunbar, Scotland, 58 pp.

Paxton, C., L. Scott-Hayward, M. Mackenzie, E. Rexstad, and L. Thomas. 2016. Revised Phase III Data Analysis of Joint Cetacean Protocol Data Resources.

Paxton, C., L. Scott-Hayward, and E. Rexstad. 2014. Statistical approaches to aid the identification of Marine Protected Areas for minke whale, Risso's dolphin, white-beaked dolphin and basking shark. Scottish Natural Heritage Commissioned Report No. 594., Scottish Natural Heritage Commissioned Report No. 594.

Popper, A. N., A. D. Hawkins, R. R. Fay, D. A. Mann, S. Bartol, T. J. Carlson, S. Coombs, W. T. Ellison, R. L. Gentry, and M. B. Halvorsen. 2014. ASA S3/SC1. 4 TR-2014 Sound exposure guidelines for fishes and sea turtles: A technical report prepared by ANSI-Accredited standards committee S3/SC1 and registered with ANSI. Springer.

Ramboll. 2021. Moray West foundation feed engineering report: Driveability Assessment.

Russell, D., C. Duck, C. Morris, and D. Thompson. 2016a. SCOS –BP-16/03: Independent estimates of grey seal population size: 2008 and 2014.

Russell, D. J. F., G. D. Hastie, D. Thompson, V. M. Janik, P. S. Hammond, L. A. S. Scott-Hayward, J. Matthiopoulos, E. L. Jones, and B. J. McConnell. 2016b. Avoidance of wind farms by harbour seals is limited to pile driving activities. Pages 1642-1652 Journal of Applied Ecology.

Russell, D., and G. Hastie. 2017. Associating predictions of change in distribution with predicted received levels during piling. Report produced for SMRU Consulting.

Russell, D., E. Jones, and C. Morris. 2017. Updated Seal Usage Maps: The Estimated at-sea Distribution of Grey and Harbour Seals. Scottish Marine and Freshwater Science **Vol 8, No 25**.

Sarnocinska, J., J. Teilmann, J. B. Dalgaard, F. v. Beest, M. Delefosse, and J. Tougaard. 2019. Harbour porpoise (*Phocoena phocoena*) reaction to a 3D seismic airgun survey in the North Sea. Frontiers in Marine Science **6**:824.

SCOS. 2021. Scientific Advice on Matters Related to the Management of Seal Populations: 2020.

Scottish Natural Heritage. 2016. Assessing collision risk between underwater turbines and marine wildlife. Scottish Natural Heritage Guidance Note.

Sinclair, R., S. Kazer, M. Ryder, P. New, and U. Verfuss. 2021. Review and recommendations on assessment of noise disturbance for marine mammals. NRW Evidence Report No. 529.

Southall, B. 2021. Evolutions in Marine Mammal Noise Exposure Criteria. Acoustics Today **17**.

Southall, B., J. J. Finneran, C. Reichmuth, P. E. Nachtigall, D. R. Ketten, A. E. Bowles, W. T. Ellison, D. Nowacek, and P. Tyack. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals **45**:125-232.

Southall, B. L., D. P. Nowacek, A. E. Bowles, V. Senigaglia, L. Bejder, and P. L. Tyack. 2021. Marine Mammal Noise Exposure Criteria: Assessing the severity of marine mammal behavioral responses to human noise. Aquatic Mammals **47**:421-464.

Thompson, P. 2015. 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. 28th July 2015. In: Beatrice Offshore Windfarm Ltd. (2015). Beatrice Offshore Wind Farm Piling Strategy. Prepared by RPS, GoBe Consultants Ltd and Brown and May Marine. Report number LF000005. November 2015.

Thompson, P. M., K. L. Brookes, I. M. Graham, T. R. Barton, K. Needham, G. Bradbury, and N. D. Merchant. 2013. Short-term disturbance by a commercial two-dimensional seismic survey does not lead to long-term displacement of harbour porpoises. Proceedings of the Royal Society B-Biological Sciences **280**:1-8.

Thompson, P. M., I. M. Graham, B. Cheney, T. R. Barton, A. Farcas, and N. D. Merchant. 2020. Balancing risks of injury and disturbance to marine mammals when pile driving at offshore windfarms. Ecological Solutions and Evidence **1**.

Tougaard, J., S. Buckland, S. Robinson, and B. Southall. 2013. An analysis of potential broad-scale impacts on harbour porpoise from proposed pile driving activities in the North Sea. Report of an expert

group convened under the Habitats and Wild Birds Directive - Marine Evidence Group MB0138. 38pp.

Whyte, K., D. Russell, C. Sparling, B. Binnerts, and G. Hastie. 2020. Estimating the effects of pile driving sounds on seals: Pitfalls and possibilities. The Effects of Noise on Aquatic Life **14**:3948-3958.