MORAY OFFSHORE WINDFARM (WEST) LIMITED

Piling Strategy (Revised)

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Document Approval				
Prepared by:	ECoW Review by:	Legal Review by:	Approved by:	Approved by:
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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 Revised 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 to the S36 consent, Wind Farm and OfTI Marine Licences and to address the comments received from the consultation of the original Moray West PS and submitted to MS-LOT for its written approval.

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

The Revised 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 Revised PS.

Scope of the Plan

In line with the requirements of the offshore consent conditions and in line with industry standards and good practice, the Revised 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 pile installation;
- Anticipated maximum pile driving hammer energy required;
- Soft start piling procedures; and
- Mitigation and monitoring to be employed during the pile driving operations.

Structure of the Plan

The Revised PS is structured as follows:

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

Section 2 describes the key piling parameters including 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 Revised 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 S36 and Marine Licences and Moray West's commitment to sustainable construction. The Revised Appendix C presents the updated underwater noise impact assessment and Revised Appendix D sets out the piling mitigation protocol.

Plan Audience

The Revised 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 Revised PS will be monitored by the Moray West Development Team, Moray West's Environmental Clerk of Works (ECoW), and Marine Directorate Licensing Operations Team (MD-LOT).

Plan Locations

The latest version of this Revised 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

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 Revised 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 offshore consents conditions and to address the comments received from the consultation of the original Moray West PS.

The purpose of the Revised PS, is to set out the key pile installation parameters, provide details of the installation methodologies and anticipated duration of pile driving and maximum hammer energies to be used. The Revised PS also presents the additional underwater noise modelling results and provides information on the mitigation strategy that will be implemented during the 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 Revised PS, are presented in full in Appendix B (Table B.1).

1.3 Linkages with other Consent Plans

The Revised 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 Revised 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 Revised PS.

Table 1-1 Revised PS linkage with other Consent Plans

Other Consent Plans	Linkage with Revised 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 Revised PS.
Environmental Management Plan (EMP)	Provides the framework for environmental management during the 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 Wind Turbine Generator (WTG) and Offshore Substation Platform (OSP) layout, seabed information, details on monopile foundations dimensions; as described in this Revised PS.
Vessel Management & Navigational Safety Plan (VMNSP)	Provides details of vessels and management measures for the Development, including those involved in pile installation.

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	Piling Strategy	Provides detail on the design constraints considered in finalising the pile design, installation methodology and programme, sets out key steps during pile installation for the Development. Confirms the key piling parameters including WTG and 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 Revised 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.
Revised 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 60 WTGs and 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.
Revised 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.

1.4.1 Document Control

This Revised 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 Piling Strategy

2.1 Introduction

This section provides details of the Moray West Site ground conditions, 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 62 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 wind turbine generator (WTG) and offshore substation platform (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 Cone Penetration Tests (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 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

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 Pile Foundation Design Parameters

The 60 WTGs and two OSPs will be supported by monopile foundations.

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

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

Component	Number	Key Dimensions
WTG monopile foundation	60	Pile dimensions vary depending on location specific water depth and soil characteristics: • Pile diameter: up to 10 m • Pile Length: up to 95 m
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

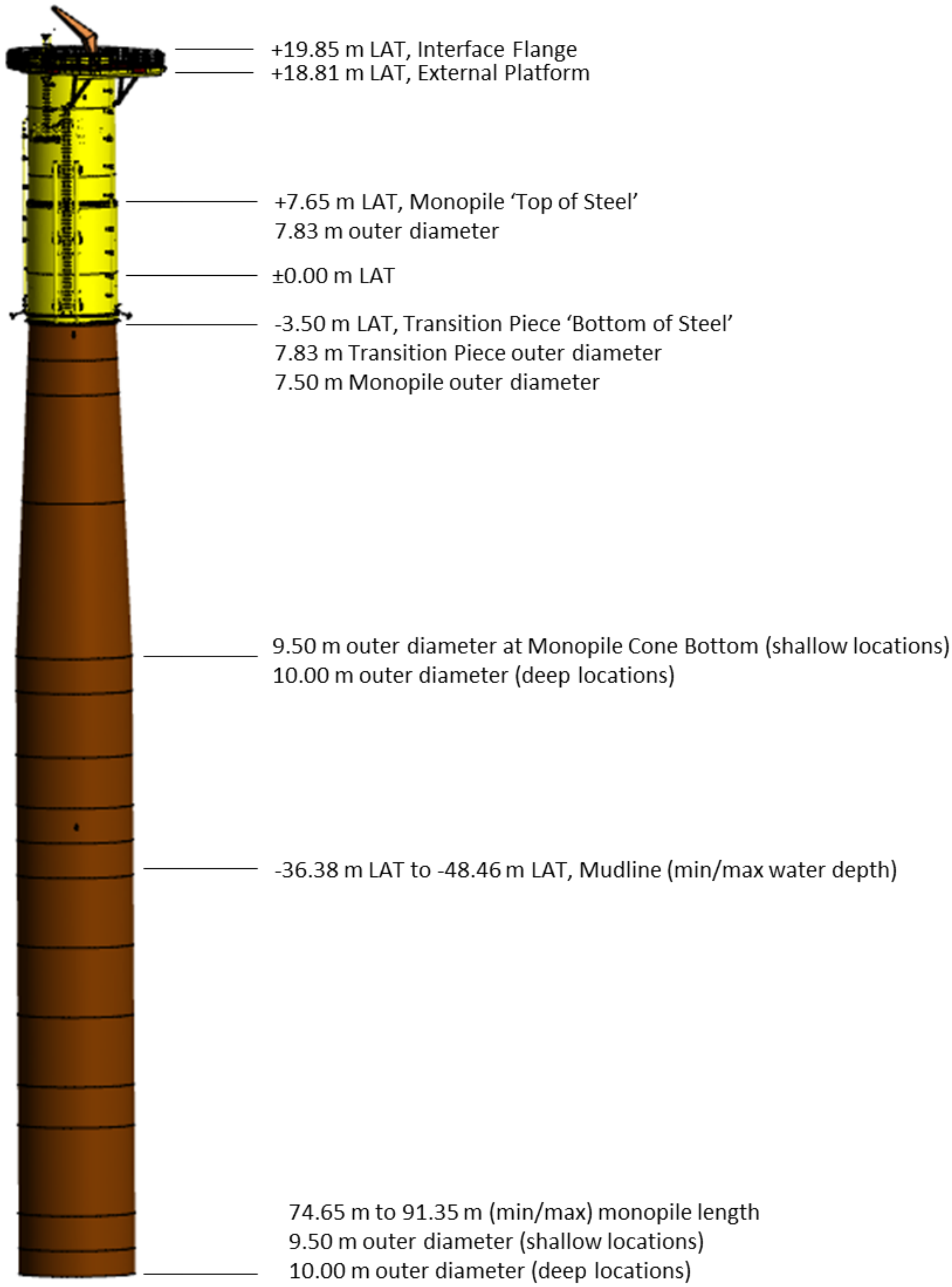

Figure 2-1 Example of Moray West monopile foundation

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

An overview of the pile installation sequence is presented in Figure 2-3 (monopile installation using impact hammer only) and Figure 2-4 (monopile installation using both vibrohammer and impact hammer).

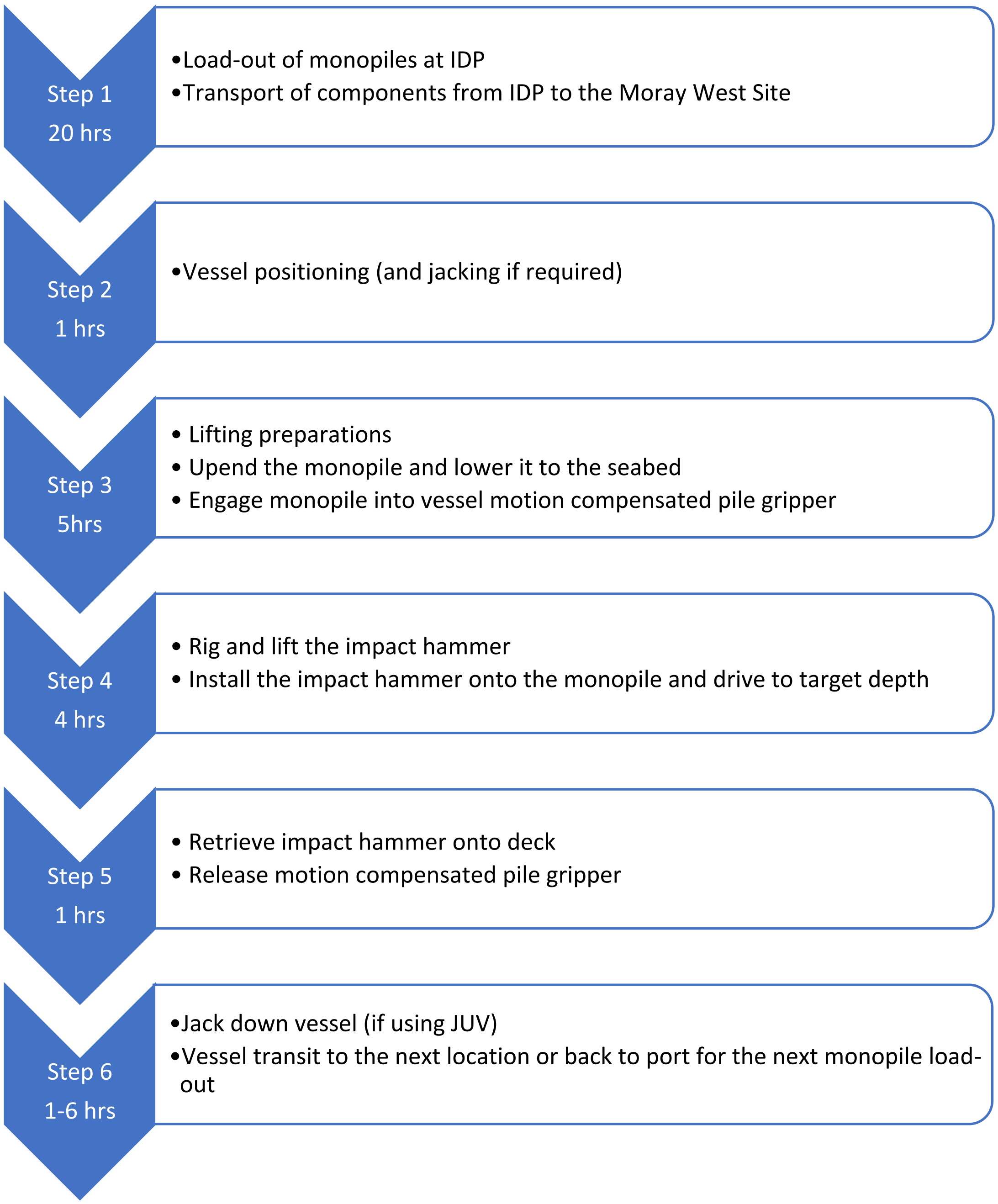

Figure 2-3: Overview of the monopile foundation transport and installation sequence (using impact hammer only)

Step 1 – 20 hrs
- Load-out of monopiles at IDP
- Transport of components from IDP to the Moray West Site

Step 2 – 1 hr
- Vessel positioning (and jacking if required)

Step 3 – 5hrs
- Lifting preparations, connect vibrohammer to monopile
- Upend the monopile and lower it to the seabed
- Engage monopile into vessel motion compensated pile gripper

Step 4 – 1-2 hrs
- Activate vibrohammer and vibro-pile to target depth

Step 5 – 3 hrs
- Deactivate vibrohammer, release and remove from monopile
- Rig and lift impact hammer
- Install the impact hammer onto the monopile and drive to target depth

Step 6 – 1 hr
- Retrieve impact hammer onto deck
- Release motion compensated pile gripper

Step 7 – 1-6 hrs
- Jack down vessel (if using JUV)
- Vessel transit to the next location or back to port for the next monopile load-out

Figure 2-4: Overview of the monopile foundation transport and installation sequence (using vibrohammer and impact hammer)

The 62 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 2-5: 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 the vessel is a JUV the vessel will execute jacking operations.

The monopile will then be upended (as shown in Figure 2-5) 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 into 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 2-6 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 installation engineering (Section 2.4.4.3).

Figure 2-6: 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 Piling Locations

The locations where the 62 monopiles will be installed are shown on Figure 2-7, which represent:

- 60 WTGs,
- 2 OSPs, and
- ‘backup’ locations.

The backup locations will only be utilised if, following further detailed engineering, ground conditions which represent a high risk of pile refusal are to be encountered during the foundation installation operations at one or more of the WTGs or OSP locations and which cannot be overcome by micro-siting.

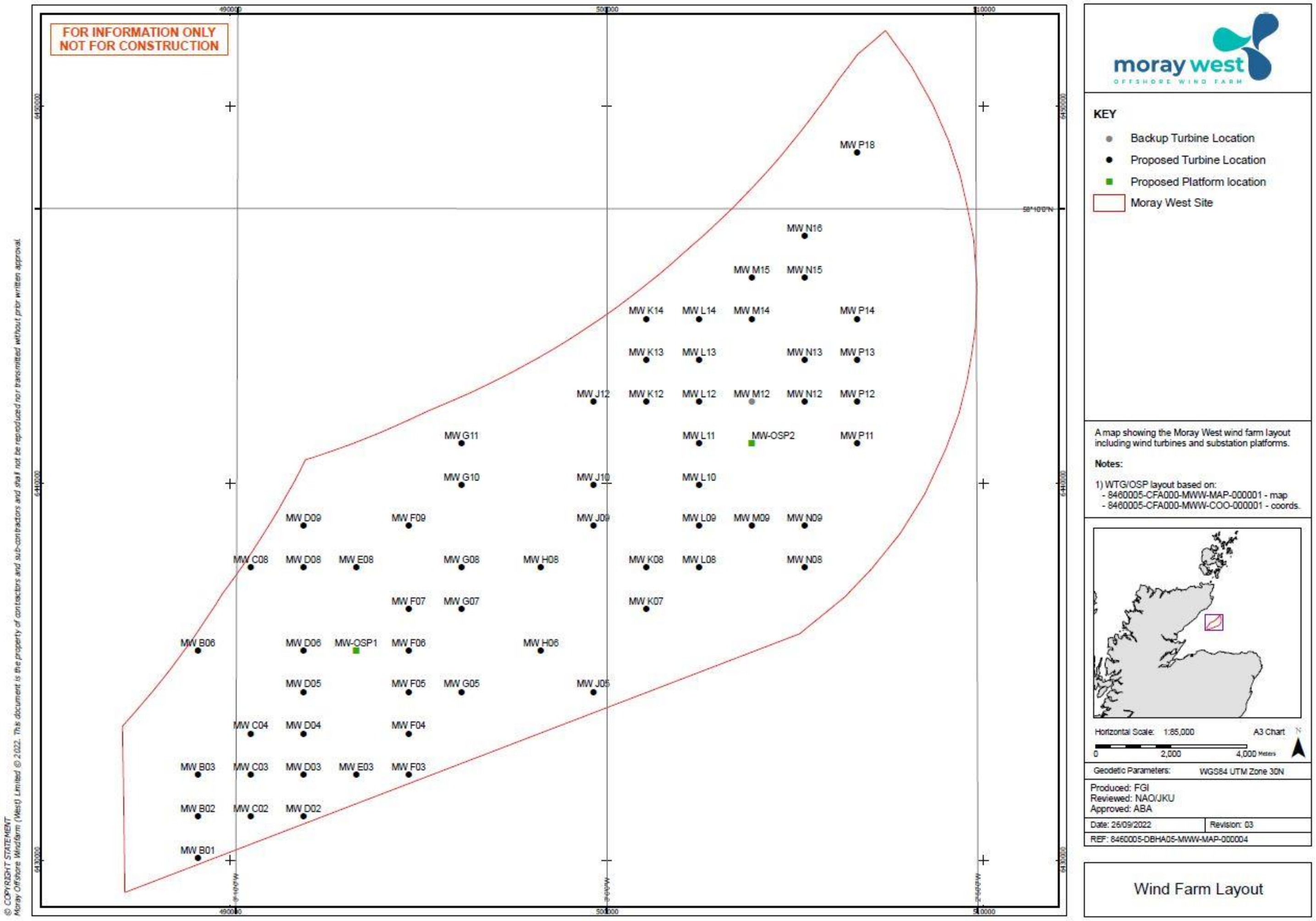

Figure 2-7: Moray West Development Specification and Layout Plan (DSLP) Wind Farm layout and OSP monopile locations (green dots).

2.4.4 Pile Driving

2.4.4.1 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 62 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 62 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 62 monopile foundations to target depth.

Table 2-3 Anticipated hammer energies

Parameter	Modelling Locations (Section 3 and Revised Appendix C)			
	N08	D03	G07	L13
Minimum hammer energy (kJ)	432	432	432	432

Table 2-3 Anticipated hammer energies				
Maximum hammer energy (kJ)	1,295	4,400	4,400	4,400

2.4.4.2 *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 monopile foundation will involve a minimum of a 15-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.

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 Revised 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			
	N08	D03	G07	L13
Risk of pile driving refusal	Negligible	Moderate	Moderate	Moderate
Duration of soft start (min)	15	15	15	24
Duration of ramp-up (min)	160	113	51	120
Total piling duration (min)	190	155	154	184
Total number of blows	5,708	4,294	5,525	4,423

[2] JNCC (2010) 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 Revised PS, the soft-start procedure will consist of a 15-minute period where the hammer energy will not exceed 432 kJ and 28 blows/minute, followed by the gradual ramp-up of hammer energy towards maximum hammer energy. Overall, the combined soft-start and ramp-up procedures will be longer than the 20 minutes recommended by JNCC(2010) guidelines as full hammer energy will not be achieved during the first 20 minutes of piling, if at all.

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

2.4.4.3 Vibro-piling

Further installation engineering may identify the requirement 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 impact 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 Revised PS, however it is currently anticipated that vibro-piling will be used prior to impact piling at 41 of the 62 piling locations (1 OSP and 40 WTGs monopile locations) (Figure 2-8). For the remaining locations the risk of pile punch-through or pile run is sufficiently negligible that a vibro-hammer is not anticipated to be required.

The estimated/approximate durations associated with a combined vibrohammer/impact hammer monopile installation are presented in Figure 2-4 and as follows:

- Vibro-piling = 1-2 hrs (time taken to install the monopile to vibro-piling target depth (m) with a vibrohammer)
- Hammer exchange = 2 hrs (time between end of vibro-piling and start of impact piling, impact piling would commence with a soft-start and ramp up period)
- Impact piling = 1 hr (time taken to complete the remainder of the driving with an impact hammer to overall target depth (m))

The indicative vibro-piling and impact piling depths are shown in Table 2-5.

Table 2-5: Indicative vibro-piling and impact piling depths (m)

Foundation location	Target depth (m bsf)	Vibro-piling depth (m)	Impact piling depth (m)
B01	36.1	20.5	15.6
B02	37.1	21.2	15.9
B03	34.5	21	13.5
B06	35.3	14	21.3
C02	33.2	11.5	21.7
C03	35.5	17	18.5
C04	34.2	22	12.2
C08	35.4	18	17.4
D02	32.2	20	12.2
D03	32.5	17.2	15.3
D04	34.2	12	22.2
D05	35.5	17	18.5
D06	33.7	22	11.7
D08	33.8	10	23.8
D09	36.8	15.5	21.3
E03	30	19	11

Table 2-5: Indicative vibro-piling and impact piling depths (m)

Foundation location	Target depth (m bsf)	Vibro-piling depth (m)	Impact piling depth (m)
E06 (OSP1)	36	19.5	16.5
E08	32.5	11	21.5
F03	32.8	12	20.8
F04	32.9	8.4	24.5
F05	32.7	14	18.7
F06	33.3	16	17.3
F07	32.5	17	15.5
F09	37.1	18	19.1
G05	34.1	15	19.1
G07	31.2	15.5	15.7
G08	32	13	19
G10	33	10	23
G11	34.3	18	16.3
H06	30.4	21	9.4
H08	31.7	12.5	19.2
J05	32.6	0	32.6
J09	31.2	13	18.2
J10	31.6	22	9.6
J12	32.5	15	17.5
K07	34.9	9	25.9
K08	31.7	22	9.7
K12	33.3	20	13.3
K13	33.6	0	33.6
K14	32.3	0	32.3
L08	31.6	22.5	9.1
L09	33.9	30	3.9
L10	34.4	0	34.4
L11	33.5	0	33.5
L12	31.7	0	31.7
L13	32.5	0	32.5
L14	38	0	38
M09	36.5	0	36.5
M11 (OSP2)	37	0	37
M14	33.3	0	33.3
M15	32.9	0	32.9
N08	36.3	0	36.3

Table 2-5: Indicative vibro-piling and impact piling depths (m)			
Foundation location	**Target depth (m bsf)**	**Vibro-piling depth (m)**	**Impact piling depth (m)**
N09	31.5	0	31.5
N12	33	0	33
N13	37	0	37
N15	31.9	4.5	27.4
N16	30.6	0	30.6
P11	36.4	0	36.4
P12	34	0	34
P13	33.5	0	33.5
P14	35	9	26
P18	32.2	0	32.2

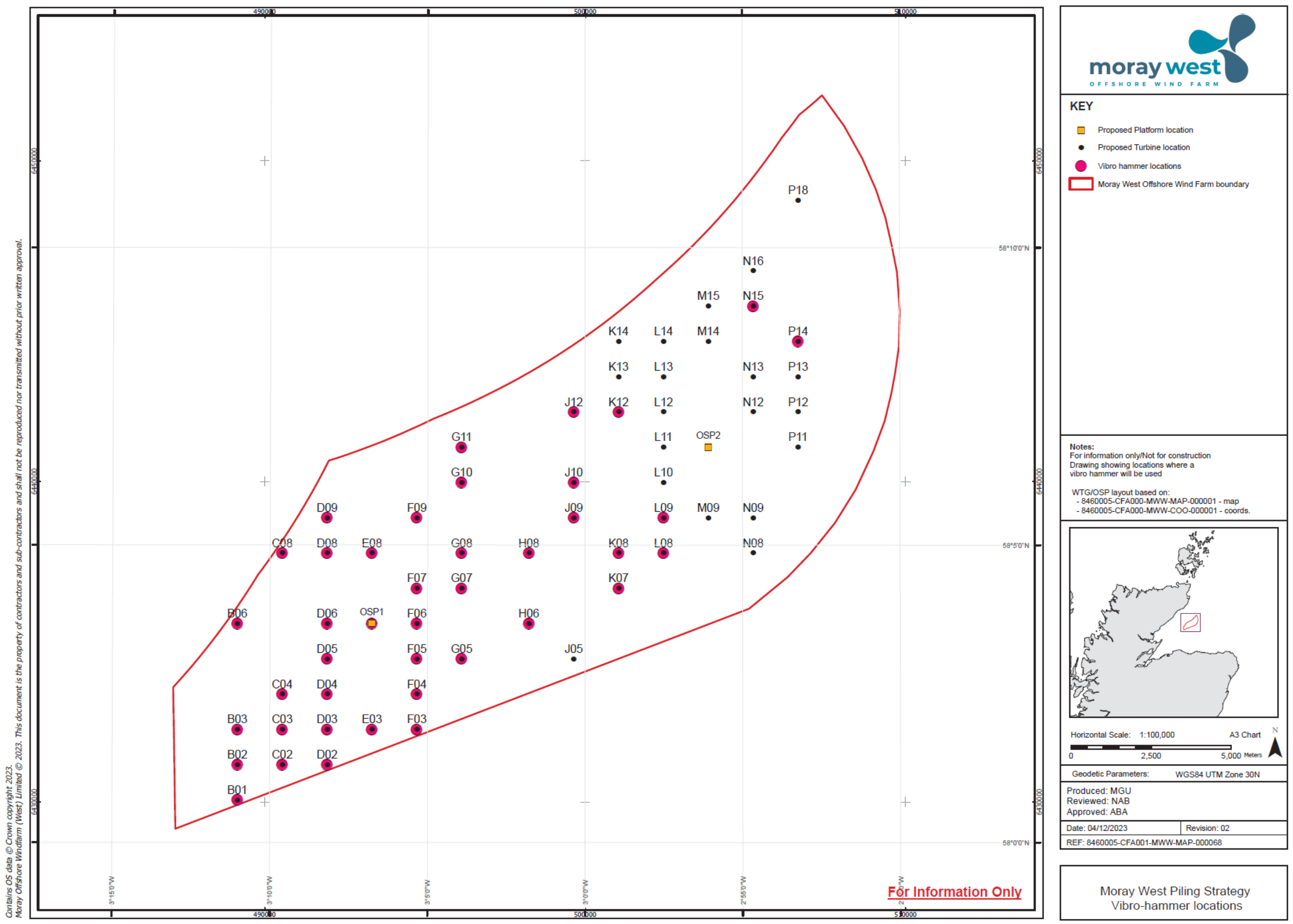

Figure 2-8 Moray West monopile locations where vibro-hammer is anticipated to be used (41 of 62 monopile locations)

2.5 Pile Installation Programme

The installation of the 60 WTGs and two OSP monopile foundations commenced in October 2023 and is planned to be completed by May 2024.

During the 62 monopile installation period there will be an aggerated duration of approximately 248 hours of actual pile driving (noise generation) activity for 62 piles, 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.

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 monopile 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 estimated pile driving durations for the noise modelling locations presented in the Revised Appendix C.

Indicative average operational timescales for the pile installation works are presented in Figure 2-3 and Figure 2-4. 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 2-3 and 2-4), 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.

2.5.3 Concurrent pile installation

Concurrent installation of two monopiles per day will only happen if there is overlap between two installation vessels on Moray West Site. Concurrent piling could occur during a three-month window between February and April 2024.

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. Additional underwater noise modelling has been undertaken to model realistic worst-case impacts of piling noise. Modelling locations have been selected based on proximity to the original modelling locations in the EIA and informed by the pile driveability assessment undertaken by Moray West and Ramboll (2021). Figure 3-1 displays the piling locations used for the additional noise modelling to inform this Revised PS in relation to the original noise modelling locations (shown in black).This driveability assessment identified three levels of pile driving refusal risk based on the soil profiles and the maximum blow count (bl/m) required during pile driving at each location:

- Locations with moderate risk of pile driving refusal (5 locations), which are locations with a hard-driving profile and would require a blow count above 925 bl/m.
- Locations with low risk of pile driving risk (10 locations), which would require blow counts above 602 bl/m but less than 925 bl/m.
- Locations with negligible risk of pile driving refusal (47 locations), which would require blow counts of 602 bl/m or less.

The Revised Appendix C provides details of expected noise levels resulting from pile-driving at the WTGs and OSPs monopile installation locations, and the revised impact of assessment on marine mammal and fish species.

As described in Section 2.4.4, 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 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 Revised 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 62 monopile locations within the Moray West Site.

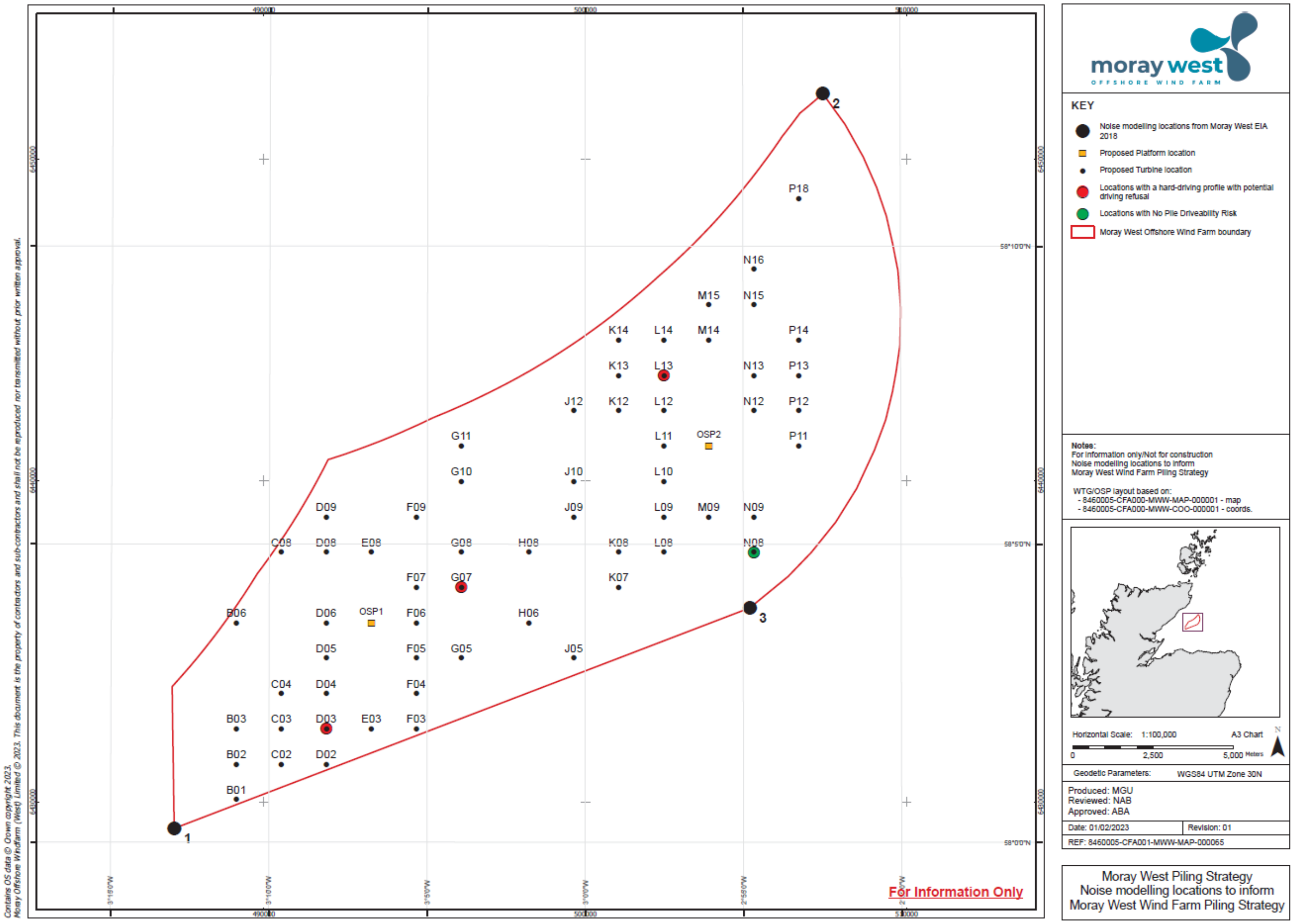

Figure 3-1: Noise modelling locations to inform this Revised PS

4 Marine Mammal Impact Assessment

The Revised Appendix C Underwater Noise Impact Assessment presents the results of the additional underwater noise modelling for the full wind farm (60 Wind Turbine Generators (WTGs) and 2 Offshore Substation Platforms (OPSs) monopile foundations) that uses 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 60 WTGs and two OSPs monopile installation locations.

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 Revised PS. Overall, the results presented in this Revised PS and in the Revised Appendix C are generally the same as those presented in the Moray West EIA Report 2018 and the original Moray West PS.

Population modelling has been conducted for bottlenose dolphin, harbour porpoise, minke whale, harbour and grey seal. The interim Population Consequences of Disturbance (iPCoD) framework has been used to predict the potential population consequences of the predicted amount of disturbance resulting from the piling at Moray West Site. iPCoD modelling results from the Moray West EIA Report 2018 to Inform Appropriate Assessment (RIAA) have been compared with those obtained in the assessment presented in the Revised Appendix C (Section 3.6 of the Revised Appendix C).

A summary of the updated marine mammal impact assessment (see Section 3 of the Revised Appendix C) 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 PTS impact ranges for marine mammals for the soft-start and full hammer energy are presented in comparison with the 2018 EIA results in the Revised Appendix C (Section 3.1).

The maximum instantaneous PTS-onset impact ranges for soft-start and full hammer energy for marine mammals, using a constant 10% CF, are presented in Table 4-1.

For all species, except harbour porpoise, the instantaneous PTS-onset impact range for soft-start pile strikes (432 kJ) is <50 m. For harbour porpoise, the maximum instantaneous PTS-onset impact range at soft-start is 579 m for a 10% CF (Table 4-1). These impact ranges are smaller than those modelled in the original Moray West PS (672 m). 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 monopile installation locations prior to the commencement of pile driving operations.

For all species, except harbour porpoise, the instantaneous PTS-onset impact range at full hammer energy modelled with a CF of 10% is less than 400 m. For harbour porpoise, the maximum instantaneous PTS-onset impact range at full hammer energy with a CF of 10% is 2.4 km (Table 4-1).

Table 4-1 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	Hammer Energy (kJ)		Instantaneous PTS impact ranges (m) 10% CF	
		soft start	full hammer energy	soft start	full hammer energy
Harbour porpoise	L13	432	4,400	579	2,395
Minke whale	G07	432	4,400	<50	313
	N08	432	1,295	<50	84
Bottlenose dolphin	D03	432	4,400	<50	52
Grey and harbour seals	D03	432	4,400	<50	357

As described in Section 3.1.1 of the underwater noise impact assessment (Revised Appendix C), and Table 4-2 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 (Benhemma-Le Gall et al. 2021), 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.

The probability of an animal being present within the instantaneous PTS-onset impact zone at full hammer energy is summarized in Table 4-2.

Table 4-2 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	*0.052*	*0.00048**	2,063.50	25.63	<0.000001
Grey seal	*0.432*	*0.94567**	1.1	0.58	*> 0.999999*

Table 4-2 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**
Harbour seal	*0.357*	*0.64500**	1.6	0.7	*> 0.999999*
Harbour porpoise	*2.395*	*1.46875**	0.7	0.47	*> 0.999999*
Minke whale	*0.313*	*0.00950ɫ*	105.3	5.79	*0.01314*
* Maximum density cell within the Moray West array area, ɫ SCANS III density estimate					

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

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 (see Revised Appendix C, Section 2.7.2.1.2 for details of conservatisms).

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 cumulative PTS impact ranges for bottlenose dolphins and seals are less than 50 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 over 2.5 km when considering a constant 10% CF for location L13 with a moderate risk of pile driving refusal. The number of animals potentially within this impact area is 25 (Table 4-3). However, due to the conservative assumptions used to calculate the SEL_{cum} PTS-onset ranges (see Section 2.7.2.1.2 of the Revised Appendix C) 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. The risk of cumulative PTS-onset on harbour porpoise would be of **negligible** magnitude in EIA terms, considering the implementation of mitigation measures (see the Revised Appendix D - Piling Mitigation Protocol (PMP)), 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 worst-case cumulative PTS-onset impact ranges for minke whale at location G07 are over 28 km and 45 km for 4% and 10% CF, respectively. For the 47 monopile locations (see Section 3) with negligible risk of pile refusal (represented by N08) the impact ranges are much smaller 2.5 km and 11.3 km for 4% and 10% CF, respectively (Table 3-4). The conservative assumptions underlying our worst-case estimates mean that impact ranges for minke whales are unrealistically high. 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 kilometres, where impulsive exposure criteria for receivers are extremely precautionary (Southall 2021) (see Section 2.7.2.1.2 of the Revised Appendix C). The risk of cumulative PTS on minke whales is assessed as being of **negligible** magnitude, given that 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 4-3 Maximum cumulative PTS impact ranges (m) and number of animals based on the assumption that 1 monopile is installed per day (10% CF).

Species	Location	# Piles per day	Max cumulative PTS onset range (m)	Number of animals
Harbour porpoise	N08	1	1,702	5
	L13	1	2,834	25
Minke whale	N08	1	20,398	<1
	G07	1	45,118	3

In summary, the risk of cumulative PTS-onset is therefore of negligible magnitude for all species.

2 piling installation events per day - consecutive

Assessment of cumulative PTS for consecutive 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, the maximum cumulative PTS impact ranges are smaller at 10% CF in the Revised PS (Table 4-4) compared to those in Appendix C of the original Moray West PS (Table 3-6 and 3-7 respectively), and the numbers of animals impacted are 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 1.8 km, equating to 6 harbour porpoise within the impact area (Table 4-4). 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, considering the conservatism bult into the assessment and the mitigation measures that will be implemented prior piling commencing (ADD activation), the impact of cumulative PTS on harbour porpoise is therefore of **negligible magnitude** in EIA terms.

For minke whales, the conservative cumulative PTS-onset impact ranges for two consecutive monopiles reach 20.4 km, equating to less than one minke whale at risk of PTS (Table 4-4). 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 kilometres, where impulsive exposure criteria for receivers are extremely precautionary (Southall 2021). Thus, 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 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 2 piling installation events.

Table 4-4 Maximum cumulative PTS impact range (m) and number of animals within that range based on the assumption that 2 monopiles are installed consecutively per day (10% CF).

Species	Location	# Piles per day	Max cumulative PTS onset range (m)	Number of animals
Harbour porpoise	N08	2	1,793	6
Minke whale	N08	2	20,398	<1

In summary, the risk of cumulative PTS-onset is therefore of negligible magnitude for all species.

3 piling installation events per day

The installation of three monopiles per day results in a small increase in the cumulative PTS-onset impact range for harbour porpoise (1,870 m at 10% CF) but no change in number of animals potentially affected (n=6) compared with installing 2 monopiles consecutively.

For minke whale the cumulative PTS-onset impact range increases to 45.2 km with a potential impact to one animal.

The impact of installing three monopiles per 24 hours 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.

2 piling installation events per day - concurrent

Concurrent installation of two monopiles per day will only happen if there is overlap between two installation vessels on Moray West Site (see Section 2.5.3).

The conservative cumulative PTS-onset impact ranges for harbour porpoise reach 105 km^2, equating to 82 harbour porpoise. However, due to the conservative assumptions used to calculate the SEL_{cum} PTS-onset ranges (see Section 2.7.2.1.2 of the Revised Appendix C) 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.

For minke whale the conservative cumulative PTS-onset impact ranges reach 2,092 km^2 equating to 4 minke whales at risk of PTS. The conservative assumptions underlying the worst-case estimates mean that impact ranges are unrealistically high.

Overall, the Moray West EIA Report 2018, the original Moray West PS and this Revised 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 updated for harbour porpoise, bottlenose dolphin, minke whale and seals. The updated estimate of the disturbance impacts on these species is provided in the Revised Appendix C (Section 3.2).

The magnitude of impact of disturbance from pile driving for harbour porpoise and bottlenose dolphin 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.

For minke whale, given the very low proportion of the entire MU predicted to be impacted, and no discernible impact to the population in iPCoD modelling 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 significant change to the population size or trajectory.

The magnitude of impact of disturbance from pile driving for grey and harbour seals is assessed as **negligible** since there was predicted to be no change to the population size or trajectory.

4.3 Comparison to 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 Revised Appendix C are generally the same as those presented in the Moray West EIA Report 2018 and the Appendix C of the original Moray West PS. Specific comparisons with the 2018 EIA are provided in tables throughout the Revised Appendix C and summarized here for reference:

- Instantaneous PTS for all species (Table 3-1)
- Cumulative PTS for harbour porpoise across all piling scenarios (Table 3-8)
- Cumulative PTS across all piling scenarios for minke whale (Table 3-9)
- Disturbance for harbour porpoise (Table 3-10), bottlenose dolphin (Table 3-12), minke whale (Table 3-14), grey seal (Table 3-16) and harbour seal (Table 3-17)

Both the Moray West EIA Report 2018 and this updated assessment concluded no significant effect of instantaneous or cumulative PTS-onset to any marine mammal species when considering impacts against the entire MU. Furthermore, despite changes to the MU sizes, density surfaces and the seal dose-response relationship, both the Moray West EIA Report 2018 and this Revised PS assessment concluded no significant effect of behavioural disturbance to any marine mammal species.

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.

4.4 Comparison to 2018 RIAA

Harbour seals within the Dornoch Firth and Morrich More Special Aera of Conservation (SAC) are not expected to experience significant disturbance while in the SAC given that the disturbance contours do not overlap with the Dornoch Firth and Morrich More SAC, and there will be no adverse effect on the harbour seal feature of the Dornoch Firth and Morrich More SAC because of piling at Moray West Site. Although harbour seals moving to and from the SAC may be disturbed as a result of piling, iPCoD modelling showed that the predicted level of disturbance will not result in a significant long-term change in population growth rate or trajectory for the Moray Firth MU, and thus no significant impact is expected at the SAC.

Although the numbers of bottlenose dolphins predicted to be disturbed are higher than considered in the 2018 RIAA, any effects are short-term and temporary and therefore there will be no adverse effect on the bottlenose dolphin feature of the SAC. Pile driving at Moray West Site is not expected to contribute to a long-term decline in the use of the SAC site by bottlenose dolphins, nor result in changes to their distribution on a continued or sustained basis, nor result in a behavioural change that would reduce survival or reproduction. iPCoD modelling showed that the predicted level of disturbance will not result in a significant long-term change in population growth rate or trajectory for the Coastal East Scotland MU.

Therefore, it is concluded that there will be no adverse effect on the integrity of both focal species of the RIAA, 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 at Moray West Site.

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 SEL_{cum}), and a single metric (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), given that a piling event is completed fully within a 24h period.

The appraisal of site-specific data fed into the consented Moray West EIA Report 2018 and the non-significant assessment for piling effects on spawning herring, cod, and sandeel. These findings were also reflected in the conditions of the S36 and Marine License consents, which request this Piling Strategy to consider Atlantic salmon and sea trout only.

For this reason, the Fish Impact Assessment (FIA) considers Atlantic salmon and sea trout only. For detailed information on the FIA, please see Section 4 of the Revised Appendix C.

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 (2014) criteria (which have the same threshold of 207 dB re 1 µPa) was 1470 m, for the BE50 blow count scenarios at 4,400 kJ and 10% energy CF. The corresponding effect range for the 4% energy conversion factor was 840 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 3,433 m for three monopiles piled consecutively at location G07 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 G07, was 1,924 m. The greatest recoverable injury range was 9,588 m, and the greatest TTS range was 72,829 m, both at the same location (G07), blow count profile (BE50) and conversion factor (10%). For the 4% conversion factor, these ranges were reduced to 4,151 m for recoverable injury and to 58,310m for TTS.

Effect areas for mortality, recoverable injury, and TTS according to the Popper SEL_{cum} criterion for the Atlantic salmon and the sea trout are presented in the Revised Appendix C

5.2 Comparison to 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, each piling event (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 minor adverse 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 Revised Appendix C – Underwater noise impact assessment (Section 4).

6 Piling Mitigation Protocol

6.1 Marine Mammals Mitigation

The Moray West piling mitigation protocol (PMP) for mitigating the risk of instantaneous and cumulative auditory injury to marine mammals during piling at the 60 WTGs and two OSPs monopile location within Moray West Site is presented in the Revised 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 minimise 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

In order to minimise the risk of injury to minke whales, Moray West has committed to install monopile locations with a risk of pile driving refusal outside the summer months:

1. Locations with a hard-driving profile with moderate risk of pile driving refusal (5 locations): E03, K14, D03, L13, G07
    - None of these locations will be installed concurrently with each other.
    - None of these locations will be installed consecutively with each other.
2. Concurrent piling will only occur when two installation vessels are operating simultaneously for up to 20 days within a 3-month period between February and April 2024.

6.1.2 ADD protocol

An ADD protocol will require the deployment of an ADD prior to piling operations commencing at each of the 62 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.

6.1.4 Vibropiling prior impact piling

It is expected that vibropiling will be used prior to impact piling at 41of the 62 piling locations (1 OSP and 40 WTGs monopile locations). The source level for vibropiling has been measured as 192 dB re 1 μPa (Graham et al. 2017). Since vibropiling produces a continuous (non-impulsive) sound, it is subject to different PTS onset thresholds (173 dB re 1 µPa $SEL_{weighted}$ for very high frequency (VHF) cetaceans) compared to impact piling (155 dB re 1 µPa $SEL_{weighted}$ for VHF cetaceans).

It is, therefore, expected that PTS onset ranges from vibropiling will be minimal.

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 may represent 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 2018 and RIAA and to inform the PS.

Marine mammal pre-construction monitoring commenced in spring 2021 and continued 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 Moray Firth Regional Advisory Group - 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

The 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 MD-LOT.

8 Compliance with the Application

Table 8-1 provides a summary of the parameters considered in this Revised 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 Revised PS

Parameter	Moray West EIA 2018	Moray West Revised PS	Difference
Maximum number of WTG monopile foundations	85	60	25
Maximum number of OSPs monopile foundations	2	2	0
Maximum hammer energy (kJ)	5,000 kJ	4,400 kJ	<600 kJ
Maximum installation time	8 hours per foundation	4 hours per foundation	<4 hours
Pile installation programme	10 months	8 months, as a worst-case scenario	<2 months
Consecutive Piling	No	Yes	Consecutive piling events
Concurrent Piling	Yes	Yes	No difference
Total number of piling days	87 (assuming 1 vessel) 44 (assuming 2 vessels)	62 (assuming one vessel) or <31 (assuming two vessels)	22 (assuming one vessel) <13 (assuming two vessels)
Maximum number of piles per 24 hours (assuming simultaneous piling events)	2	2 concurrent piling events 2 consecutive piling events 3 piling installation events	2 consecutive piling events and 3 piling installation events

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

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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.

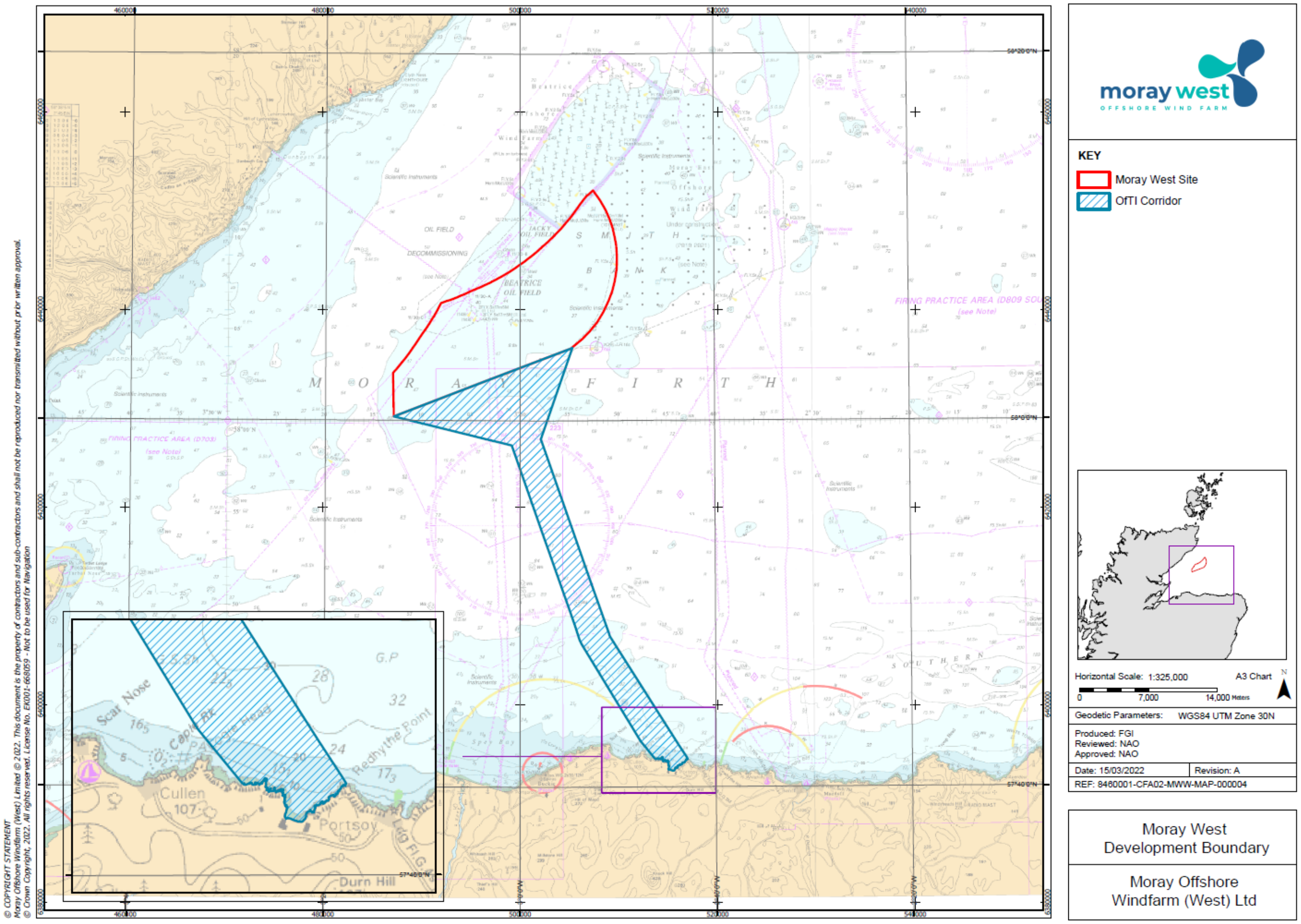

Figure B.1 Geographical location of the Moray West Site and OfTI Corridor.

B.2 Legal Context

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

Table B.1. Consent conditions to be discharged by this Revised PS

Consent Condition Reference	Condition	Addressed
S36 consent Condition 11 Wind Farm Marine Licence Condition 3.2.2.8 OfTI Marine Licence Condition 3.2.2.7	The Company must, no later than six months prior to the Commencement of the Development, submit a Piling Strategy ("PS"), in writing, to the Scottish Ministers for their 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;	Revised 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 Revised 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 Revised 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.	Revised Appendix D
	The PS must, so far as is reasonably practicable, be 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 Waste Management Plan (WMP) and Marine Pollution Contingency Plan (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.

Revised Appendix C – Underwater noise impact assessment

MORAY OFFSHORE WINDFARM (WEST) LIMITED

Piling Strategy (Revised)
Revised Appendix C: Underwater Noise Impact Assessment
Full Wind Farm Piling Strategy

Document Name: 8460005-DBHA04-MWW-REP-000005

Revision: 4

Status: Final

Date: 04-12-2023

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
3	18-04-2023	Final	Third Submission to MS-LOT Moray West Revised Piling Strategy Appendix C (8460005-DBHA04-MWW-REP-000005)	MS-LOT
4	04-12-2023	Final	Fourth Submission to MD-LOT (8460005-DBHA04-MWW-REP-000005)	MD-LOT

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Tables

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
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
PMP	Piling Mitigation Protocol
PS	Piling Strategy
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
SPL	Sound Pressure Level
SPL_{peak}	Peak Sound Pressure Level
TTS	Temporary Threshold Shift
UK	United Kingdom
VHF	Very High Frequency
WTGs	Wind Turbine Generators

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, underwater 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 revision to Appendix C of the Moray West Piling Strategy (PS) presents results of the underwater noise modelling and assessment to inform the design of the mitigation measures to be employed during piling. Also included is a comparison between this revised PS and original Moray West Environmental Impact Assessment (EIA) assessment[1] 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 scenarios and modelled locations

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). In response to consultation on the original Moray West PS, this revision to Appendix C presents results from additional underwater noise modelling for the full wind farm (60 Wind Turbine Generators (WTGs) and 2 Offshore Substation Platforms (OPSs) monopile foundations) that uses more realistic worst-case scenario piling parameters. The locations where WTGs and OSPs monopile foundations may be installed are displayed in Figure 2-1 and the possible piling schedule is illustrated in Figure 2-2.

In the marine mammal impact assessment presented in the Moray West Environmental Impact Assessment (EIA) Report 2018 – Volume 2, Chapter 9[2], three underwater noise modelling locations were selected (black dots numbered 1, 2 and 3 in Figure 2-1). These sites were selected based upon underlying density surfaces, proximity to haul-out sites and proximity to protected areas, with the intention of providing the worst case scenario for each species. Location 1 at the southern tip of the array area was modelled for bottlenose dolphins and seals, Location 2 at the northern tip of the array area for harbour

[1] The Moray West Environmental Impact Assessment (EIA) Report 2018 – Volume 2, Chapter 9 and its Addendum Volume 1, Part 1 Chapter 4 (for impact assessment using a 1% Conversion Factor (CF)). These two assessments are hereafter referred to collectively as the EIA.

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

porpoise, and Location 3 on the south east of the array area for minke whales (see Figure 2-1). In this revised PS, the modelling locations were selected based on proximity to the original modelling locations in the EIA and informed by the pile driveability assessment undertaken by Moray West and Ramboll (2021). This driveability assessment identified three levels of pile driving refusal risk based on the soil profiles and the maximum blow count (bl/m) required during pile driving at each location (see Figure 2.1):

- Locations with moderate risk of pile driving refusal (5 locations), which are locations with a hard-driving profile and would require a blow count above 925 bl/m.
- Locations with low risk of pile driving risk (10 locations), which would require blow counts above 602 bl/m but less than 925 bl/m.
- Locations with negligible risk of pile driving refusal (47 locations), which would require blow counts of 602 bl/m or less.

To model realistic worst case impacts of piling noise Moray West have selected the WTG monopile locations with moderate risk of pile driving refusal closest to each of the original EIA modelling locations (D03 nearest to Location 1, L13 nearest to Location 2 and G07 nearest to Location 3) (Figure 2-1, Table 2-1). The grey seal assessment in this Revised PS provides impacts for both D03 and L13 given the proximity of L13 to higher density grey seal areas to the north of the array area. In addition to this, one location with negligible risk of pile refusal was also modelled (N08) to provide a second location for concurrent and consecutive piling scenarios (Figure 2-1).

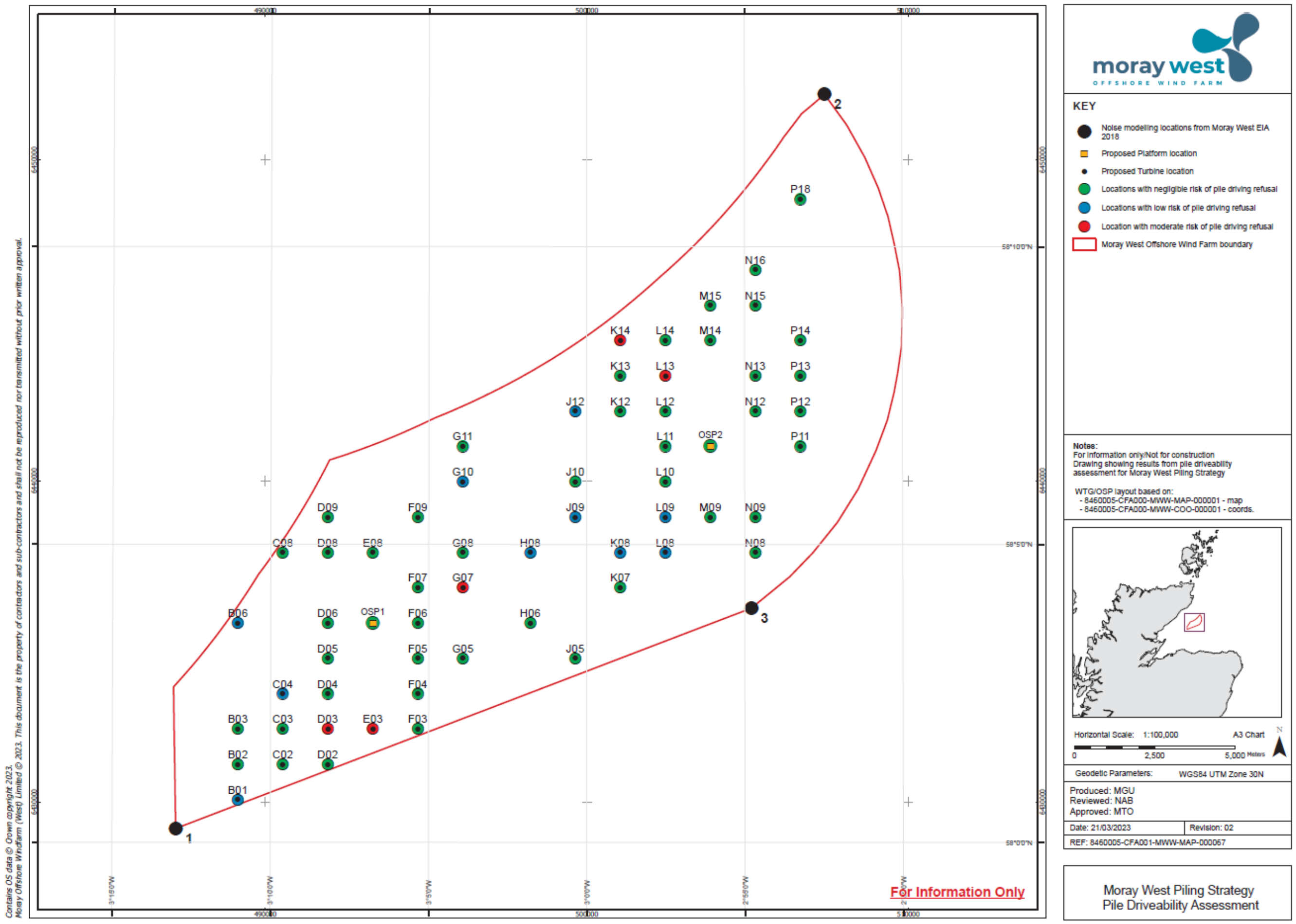

Figure 2-1 Full wind farm layout: 60 WTG locations are shown, those with moderate risk of pile driving refusal are shown in red (n=5, D03, E03, G07, K14, L13), low risk of pile driving refusal in blue (n=10, B01, B06, C04, G10, H08, J09, J12, K08, L08, L09) and negligible risk of pile driving refusal no drivability risk in green (n=45) as well as the 2 OSP locations (yellow squares inside green circles indicating no drivability risk). Black dots numbered 1, 2 and 3 represent modelling locations used in the EIA.

	2023			2024				
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Bokalift 2	Single				Concurrent			-
Orion	-							Single

Figure 2-2 Schematic illustrating possible vessel attendance and indicative piling schedule. Grey bars represent the piling schedule with one vessel on site at a time. Green cells show two vessels operating concurrently for up to three months.

Table 2-1 Monopile locations and their risk of refusal (red – locations with a moderate risk of pile driving refusal , green – locations with a negligible risk of pile driving refusal) used in models for this revised piling strategy in relation to the original noise modelling locations used in the Moray West EIA 2018.

Species	2018 EIA modelling location	Revised PS modelling location
Bottlenose dolphin & Harbour seals	1	D03
Harbour porpoise	2	L13 & N08
Grey seals	1	D03 & L13
Minke whale	3	G07 & N08

For each species, the risk of instantaneous permanent threshold shift (PTS), cumulative PTS and disturbance has been assessed for single monopile installations per day. Based on these results, the risk of cumulative PTS for harbour porpoise and minke whale are further evaluated for the installation of 2 and 3 monopiles consecutively within a 24-hour period and 2 monopiles installed concurrently within a 24-hour period. Potential effects of disturbance (including interim Population Consequences of Disturbance (iPCoD) modelling) are evaluated for all species for the installation of single monopiles and 2 monopiles concurrently within a 24-hour period. Potential impacts to the Southern Trench Marine Protected Area (MPA) for minke whale have also been revised using the piling locations in Table 2-1.

In order to minimize the risk of injury to minke whales, Moray West has committed to install monopile locations with any risk of pile refusal outside of the summer months:

1. Locations with a hard-driving profile with moderate risk of pile driving refusal (5 locations): E03, K14, D03, L13, G07
   - None of these locations will be installed concurrently with each other.
   - None of these locations will be installed consecutively with each other.

2. Concurrent piling will only occur when two installation vessels are operating simultaneously for up to 20 days within a 3-month period between February – April 2024

Impact assessment results are presented accordingly.

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:

$$\boldsymbol{SLE} = \mathbf{120} + \mathbf{10}\boldsymbol{log}\mathbf{10}\,(\boldsymbol{\beta E c 0 \rho}\ \mathbf{4}\boldsymbol{\pi}) \qquad (1)$$

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 $\mu Pa^2 s$). 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 and 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 four locations used for modelling are illustrated graphically in Figure 2-3.

A blow count of 50 blows per 25 cm was used for all locations as the worst-case scenario for marine mammals, as the shorter ramp-up time leads to a fast rise in the cumulative sound exposure level, SEL_{cum} (definition see Section 2.7.1) while the sound energy received by a fleeing animal near the end of the piling profile is influencing the SEL_{cum} less. 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 or three monopiles could be installed consecutively within a 24-hour period, and two monopiles may be installed concurrently.

For fish species, locations N08, G07, L13, and D03 have been modelled with a blow count of 50 blows per 25 cm. For each of the four locations, 4% and 10% conversion factors have been used, giving a total of 8 modelled scenarios.

For the purposes of modelling cumulative effects, fish are conservatively assumed to remain stationary for the 24-hour modelling period, and a total of 36 scenarios are modelled.

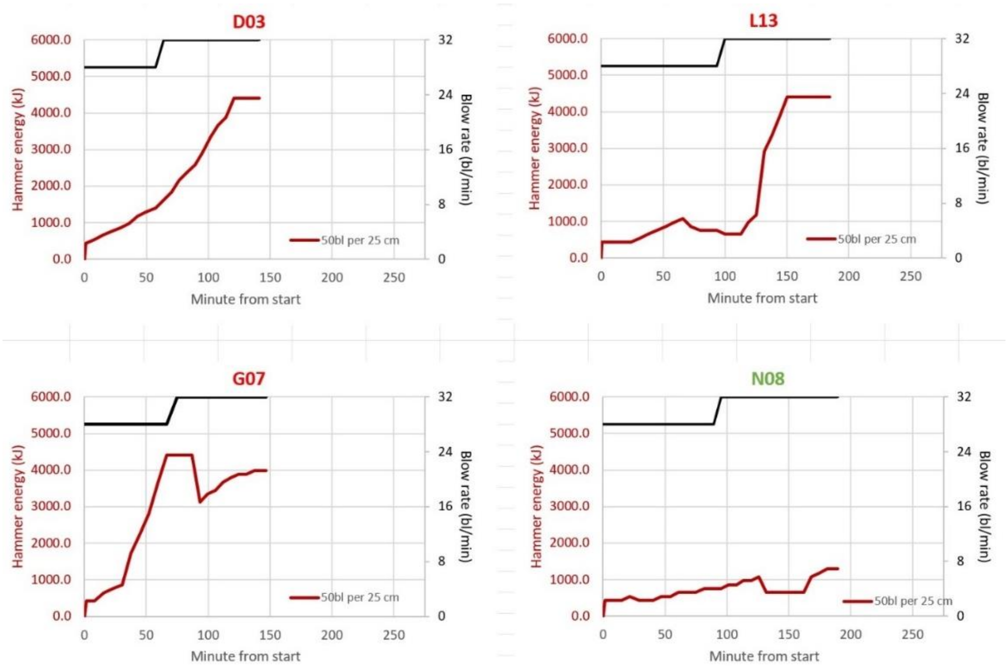

Figure 2-3 Piling profiles from the four monopile locations considered for modelling, showing hammer energy (red) and blow rate (black) over time.

Table 2-2 Summary statistics of the piling profiles used for the marine mammal impact assessment.				
Parameter	**Locations**			
	N08	**D03**	**G07**	**L13**
Minimum hammer energy (kJ)	432	432	432	432
Maximum hammer energy (kJ)	1,295	4,400	4,400	4,400
Duration soft-start (min)	15[3]	15	15	24
Duration ramp-up (min)	160	113	51	120
Piling duration (min)	190	155	154	184
Total number of blows	5,708	4,294	5,525	4,423

[3] JNCC (2010) guidance describes the soft-start as 'the gradual ramping up of piling power, incrementally over a set time period until full operational power is achieved'. The soft-start duration is to be a minimum of 20 minutes. For the Moray West PS, the soft-start procedure will consist of a 15-minute period where the hammer energy will not exceed 432 kJ and 28 blows/minute, followed by the gradual ramp-up of hammer energy towards maximum hammer energy. Overall, the combined soft-start and ramp-up procedures will be longer than the 20 minutes recommended by JNCC (2010) guidelines as full hammer energy will not be achieved during the first 20 minutes of piling, if at all.

2.6 Vibropiling

It is expected that vibropiling will be used prior to impact piling at 41 of the 62 piling locations (1 OSP and 40 WTGs monopile locations). It is anticipated that it could take up to a maximum of 2 hours to change between vibro-hammer and impact-hammer during the monopile installation sequence, and that once the impact hammer is in place, impact piling would commence with a soft-start and ramp-up period.

The source level for vibropiling has been measured as 192 dB re 1 µPa (Graham et al. 2017c). Since vibropiling produces a continuous (non-impulsive) sound, it is subject to different PTS onset thresholds (173 dB re 1 µPa $SEL_{weighted}$ for very high frequency (VHF) cetaceans) compared to impact piling (155 dB re 1 µPa $SEL_{weighted}$ for VHF cetaceans). It is, therefore, expected that PTS onset ranges from vibropiling will be minimal and thus PTS impacts from vibropiling are not assessed in this revised PS.

Evidence of the behavioural responses of marine mammals to vibropiling activities is scarce; however, a study has shown responses of both bottlenose dolphins and harbour porpoise during vibropiling activities (Graham et al. 2017c). Bottlenose dolphins showed minor but significant reductions in presence and encounter durations in the vicinity (< 5km) of construction works during vibropiling, while harbour porpoise showed significantly reduced presence. However, in both cases, effect sizes were very small, and the extent to which a reduction in detections equates to displacement of individuals rather than, for example, masking of detections remains unclear. Disturbance impacts from vibropiling are therefore not assessed in this revised PS as disturbance from impact pile driving is expected to present the worst-case scenario.

2.7 Metrics modelled and Assessment Criteria

2.7.1 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 PTS risk at start of piling and during piling for marine mammals, and recoverable injury and mortality in fish;
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, two, or three monopiles are 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 4,400 kJ[4] to inform assessment of risk of disturbance in marine mammals.

[4] 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.

2.7.2 Marine Mammal Assessment Criteria

2.7.2.1 Permanent Threshold Shift (PTS) Assessment

2.7.2.1.1 Thresholds

For marine mammals, the risk of PTS was assessed using the updated Southall criteria (Southall et al. 2019a) (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. 2019a).

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			

2.7.2.1.1.1 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.

2.7.2.1.1.2 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. 2019a). Southall et al. (2019a) 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 (or continuous). 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 piling location, the model assumes that the animal agents are fleeing at constant speeds (Table 2-4), in a straight line away from the piling location, as long as the local water depth exceeds a minimum value (Table 2-4), and for the entire duration of a piling installation sequence. If an animal agent moving in a straight line away from the piling location arrives in shallower water than the specified minimum depth (Table 2-4), then a change in direction is calculated and effected relative to current direction from the pile location to the present agent position and in order of preference, being +/- 45° (forwards left or right) , +/-90° (sideways left or right), +/-135° (backwards left or right) and, as a last option 180° (backward towards the piling location, but not necessarily to the previous position, unless the previous movement direction was 0°). It should be noted that, as indicated in Table 2-4, these rules do not apply to the seal agents, which were able to move in any depths of water, and even move to the shore, thus preventing further exposure to underwater piling noise.

In the case of concurrent pile driving at two locations, the model still assumes that the animal agents are fleeing at the same constant speeds (Table 2-4), but their fleeing direction is re-evaluated at every step according to their position relative to the two piling locations. Specifically, at a given time, the fleeing direction is calculated by summing up the two vectors originating at the current animal agent position, pointing straight away from the two piling locations, and having their magnitude proportional with the specific dose responses of the animal for the current single strike SEL from the two piling events, respectively. The same minimum water depth rule would apply.

The described methodology used for modelling the fleeing behaviour is the same as the one used for the Moray West EIA 2018, with the only difference between the modelling approach used here and in the original Moray West EIA is that, here, agents were allowed to move beyond 25 km.

In all cases, if multiple successive piles were modelled at a given location, the animal agents are assumed to be moving only during the active piling phases, i.e. they are assumed stationary during the pauses in between successive piles.

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 (m)	5	5	10	0

2.7.2.1.2 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 United Kingdom (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 noise would cause only a very small (<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 accumulated 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. (2019a). As detailed in Southall et al. (2019a), 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-driving 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 hearing 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 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. 2019a, 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. 2019a, 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)[5], Racebank (NIRAS Consulting Ltd 2017)[6] and Triton Knoll (Banda et al. 2020)[7] 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 only two of the three wind farms, and only for intermediate hammer energies during relatively small sections of the piling profile. It should also be noted that 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% throughout the whole piling sequence 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).

2.7.2.2 Behavioural Disturbance Assessment

In contrast 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 and therefore incorporates the application of a dose-response approach.

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.

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[5] Galloper – monopile, 7.5m diammeter, 30m water depth, measured at 750m from the piling site
[6] Racebank - monopile, 7m diammeter, 16-20m water depth, measured at 750m from the piling site
[7] Triton Knoll - monopile, 8.5m diammeter, 18-20m water depth, measured at 500 and 750m from the piling site Compared with Moray West - monopile, 10m diammeter, 33m water depth

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 2-4). Since the development of this initial dose-response curve in 2017, additional data from later pile driving events at Beatrice Offshore Wind Farm were presented in Graham et al. (2019). These later analyses showed that the probability of harbour 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 harbour porpoise responses are likely to diminish over the construction period. A detailed discussion and explanation on this dose-response relationship is given in the Moray Offshore Renewables Ltd. (MORL) Environmental Statement (ES). Technical Appendix 7.3 D[8]

In the absence of species-specific data on bottlenose dolphins or minke whales, the harbour porpoise 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.

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

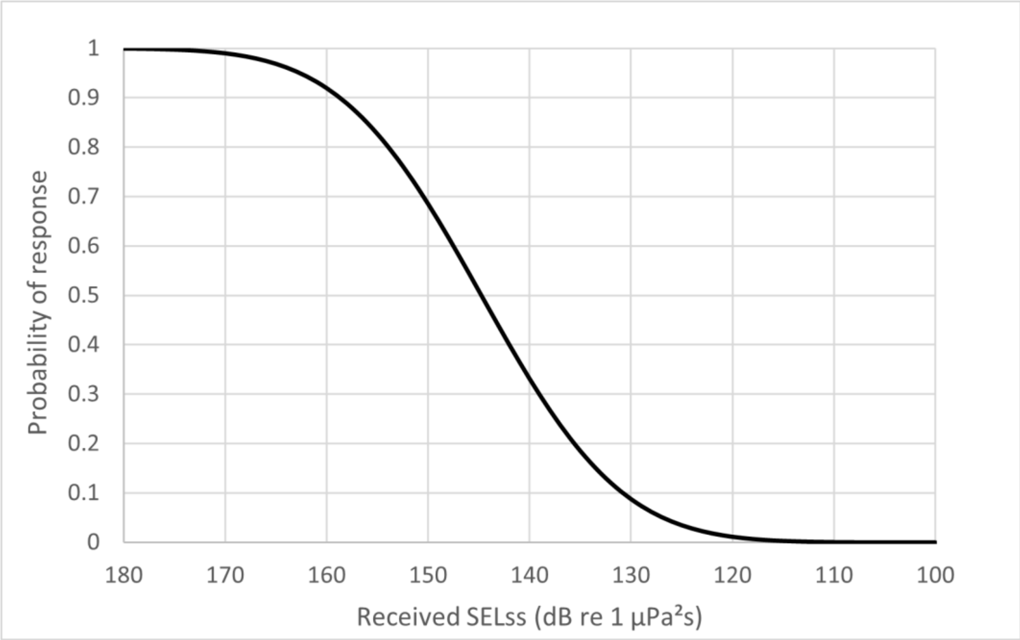

Figure 2-4 Dose-response relationship for harbour porpoise developed by Graham et al. (2017b) used for all cetacean in this assessment.

For both species of seals, 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 2-5). The Whyte et al. (2020) study updates earlier dose-response information presented in Russell et al. (2016) 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 $\mu Pa^2 s$. 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 $\mu Pa^2 s$ 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.

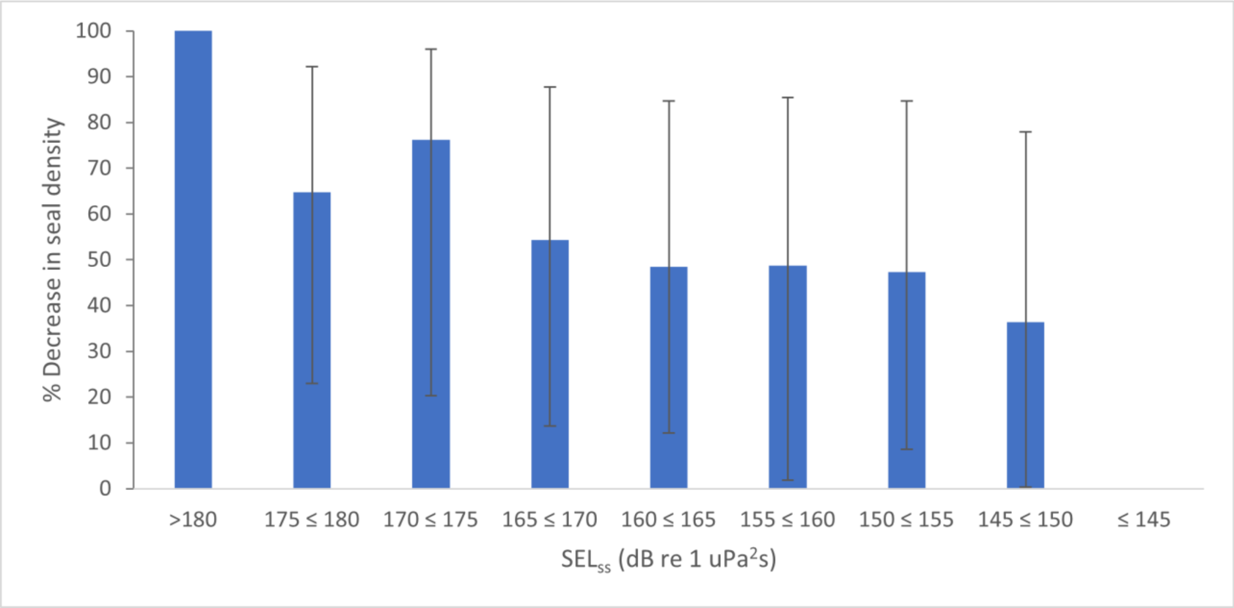

Figure 2-5 Dose-response data for harbour seal derived from the data collected and analysed by Whyte et al. (2020) used for harbour and grey seals in this assessment.

2.7.2.3 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[9]. Therefore, this has been presented here for both harbour porpoise and minke whales. It is worth noting that while the IAMMWG (2022) 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.

2.7.2.3.1 Harbour porpoise

2.7.2.3.1.1 MU

Since the submission of the Moray West EIA Report 2018, 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 the UK portion (IAMMWG 2022). This is

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

slightly higher than the previous MU estimate used in the Moray West EIA (345,373; 95% CI: 246,526- 495,752).

2.7.2.3.1.2 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 revised PS.

2.7.2.3.2 Bottlenose dolphin

2.7.2.3.2.1 MU

Since the submission of the Moray West EIA Report 2018, 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 previously used in the Moray West EIA (195; 95% CI: 164-224).

2.7.2.3.2.2 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 PS.

2.7.2.3.3 Minke whale

2.7.2.3.3.1 MU

Since the submission of the Moray West EIA Report 2018, 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 2022). This is slightly lower than the previous MU estimate used in the Moray West EIA (23,528, 95% CI: 13,989-39,572).

2.7.2.3.3.2 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 MPA (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 (July, August, September) (Paxton et al. 2014). It was, therefore, decided to combine the two data sources, taking the seasonal density distribution maps in Paxton et al. (2014) as a relative distribution (under the assumption that the seasonal distribution is stable over the years) and then scaling them with the most recent absolute abundance estimate given by SCANS III.

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 surfaces are presented in Figure 2-6.

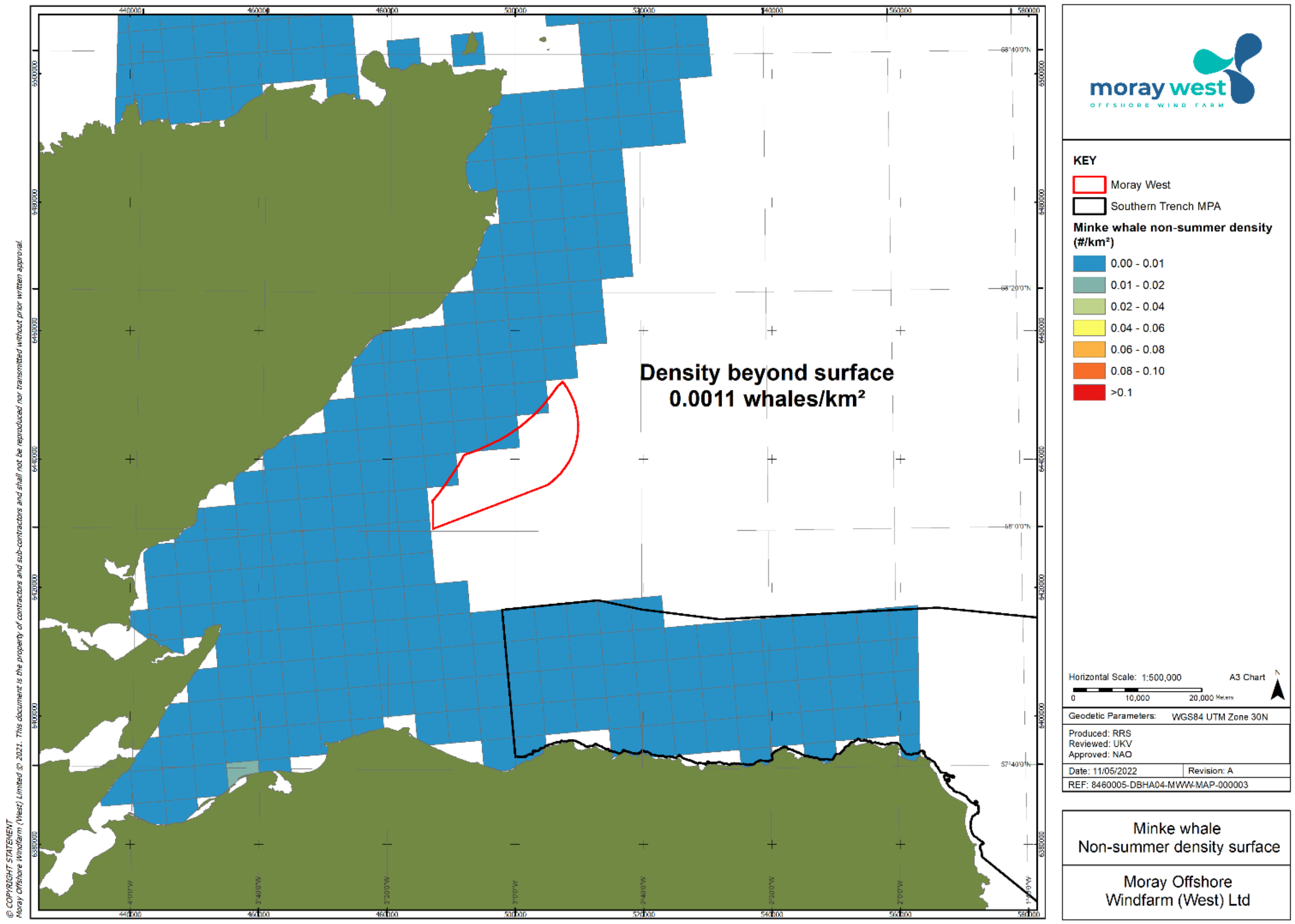

Figure 2-6 Minke whale non-summer density surface based on SCANS III block S density estimate and the relative minke whale distribution as presented in Paxton et al. (2014) and the absolute densities given in Paxton et al. (2016).

2.7.2.3.4 Grey seal

2.7.2.3.4.1 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 (SCOS 2022), as has the scaler used for grey seals.

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 (2,513) 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 (3,782) (SCOS 2022), results in a total August haul-out count of 14,894 grey seals, which scales to an estimated 59,221 grey seals in the combined MUs (accounting for those at sea at the time of the survey) (Table 2-5).

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

	Moray West EIA	Current
August haul out count	1,252 (2016 count)	Moray Firth MU: 2,513 (2019 count) East Scotland MU: 3,782 (2016 count) North Coast and Orkney MU: 8,599 (2019 count)[10] TOTAL = 14,894
Scaler	Grey seals haul-out for approximately 0.35 of the survey time (Lonergan et al. 2011).	Mean estimate of the percentage of the population hauled out of 25.15% (95% CI: 21.45-29.07%)[11]
Population estimate	3,577	59,221

[10] Count data obtained from SCOS (2022): SCOS-BP 21/03 Table 1

[11] SCOS (2022): SCOS-BP 21/02

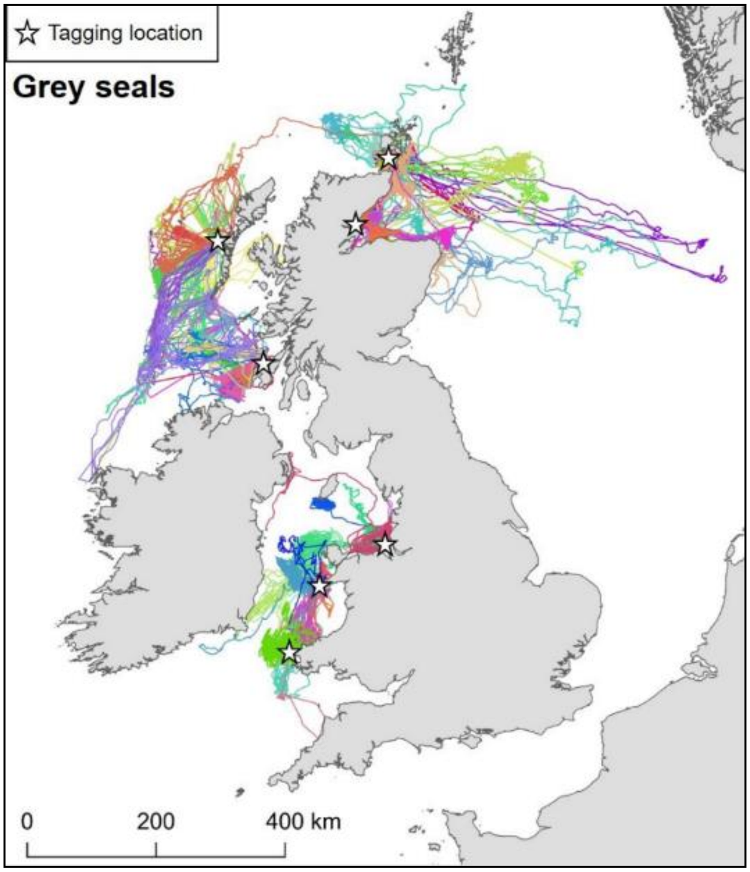

Figure 2-7 Grey seal GPS tracking data from tags deployed during the project of Carter et al. (2020). Tracks are coloured by individual (n=100). White stars denote deployment locations (clockwise from bottom left); Ramsey & Skomer Islands, Bardsey Island, Dee Estuary, Islay & Oronsay (West Scotland),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

2.7.2.3.4.2 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, Carter et al. 2022), 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 the grey seal at-sea distribution map shown in Figure 2-8 and based on the newer habitat preference map.

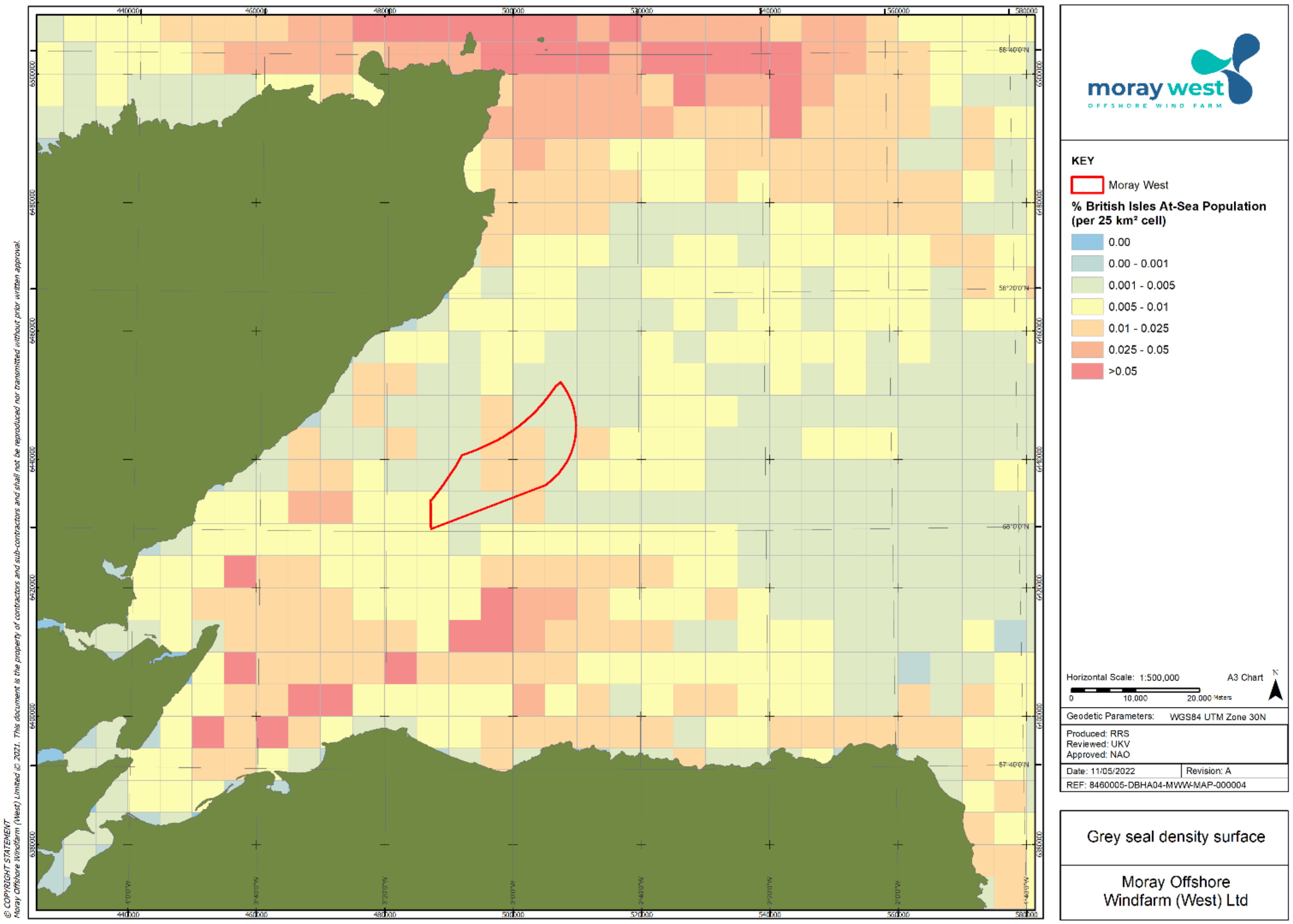

Figure 2-8 Grey seal density surface map based on Carter et al. 2020, Carter et al. 2022.

2.7.2.3.5 Harbour seal

2.7.2.3.5.1 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 (Table 2-6).

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 Global Positioning System/Global System for Mobile communications (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).

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

	Moray West EIA	Current
August haul out count	940 (2016 count)	Moray Firth MU: 1,077 (2019 count period) North Coast & Orkney MU: 1,405 (2019 count) TOTAL: 2,482
Scaler	The percentage of the total population hauled-out during the August surveys is 72% (Lonergan et al. 2013).	
Population estimate	1,306	3,447

2.7.2.3.5.2 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, Carter et al. 2022), 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 the harbour seal at-sea distribution map shown in Figure 2-9 and based on the newer habitat preference map.

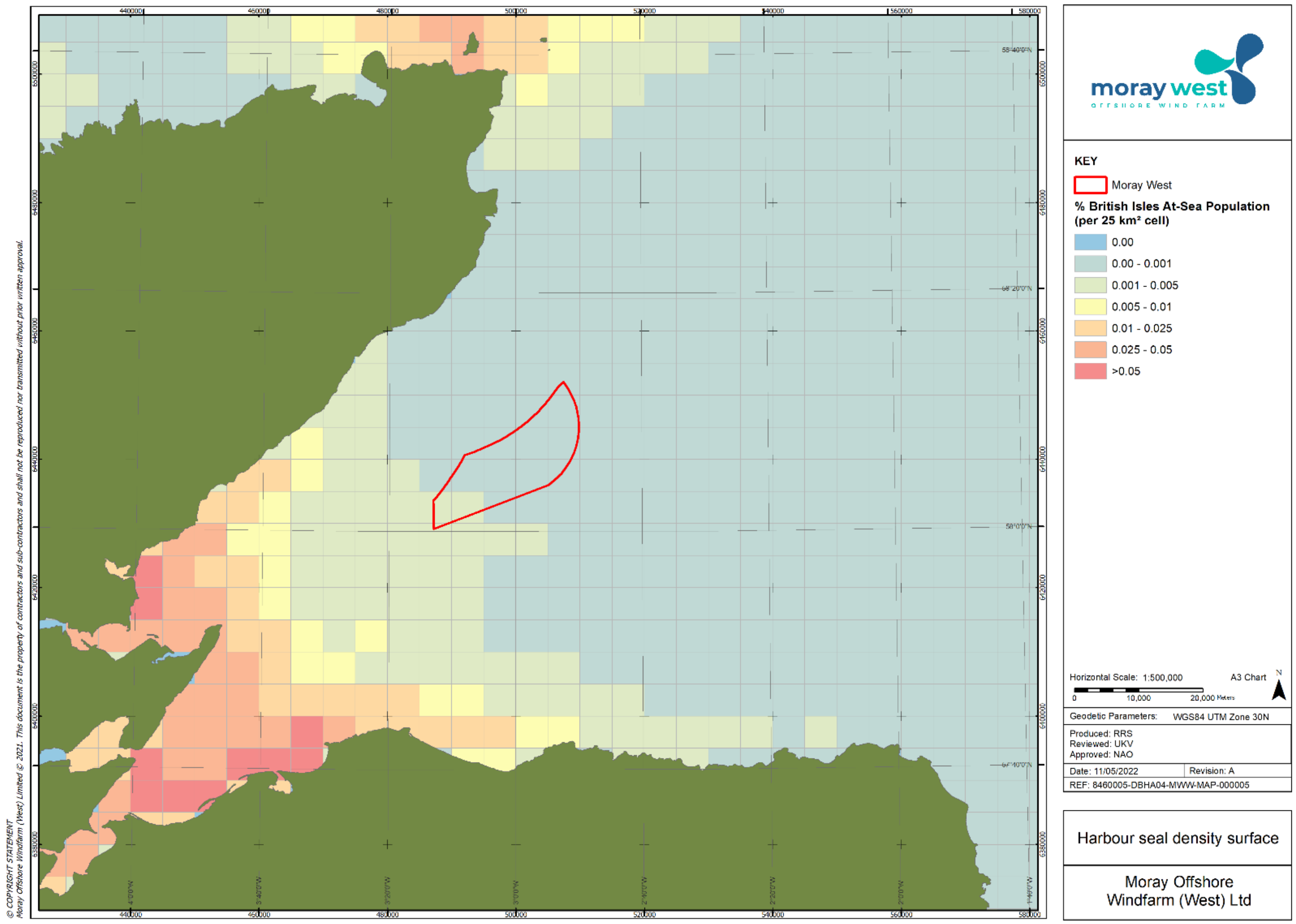

Figure 2-9 Harbour seal density surface map based on Carter et al. (2020), Carter et al. 2022.

2.7.2.3.6 Summary

Table 2-7 summarises the MUs and density surfaces that are used in the current piling strategy impact assessment compared with those used in the Moray West EIA Report 2018.

Table 2-7 Species specific MUs and density surfaces taken forward for impact assessment.

Species	Management units		Density surfaces	
	2018 EIA	Current	2018 EIA	Current
Harbour porpoise	345,373	346,601 (entire MU) 159,632 (UK portion)	Moray Offshore Renewables Ltd (2012)	
Minke whale	23,528	20,118 (entire MU) 10,288 (UK portion)	Paxton et al. (2014) & SCANS III, Paxton et al. (2016)	Paxton et al. (2014) scaled to SCANS III density, SCANS III
Bottlenose dolphin	195	224	Revised from Moray Offshore Renewables Ltd (2012)	
Grey seal	3,534 Moray Firth MU	59,221 Moray Firth, East Scotland & North Coast and Orkney MUs combined	Russell et al. (2017)	Carter et al. (2020), Carter et al. 2022
Harbour seal	1,304 Moray Firth MU	3,447 Moray Firth & North Coast and Orkney MUs combined	Bailey (2017)	Carter et al. (2020), Carter et al. 2022

2.7.3 Fish Assessment Criteria

For fish species, the most relevant criteria are considered to be those contained in the 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). These species are susceptible to barotrauma and detect sound pressure as well as particle motion.

Group 4 fish: *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).

For impulsive noise from impact piling sources, the guidelines specify dual metric (SEL_{cum} and SPL_{peak}) criteria for recoverable injury and mortality, and a single metric (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. The other hearing groups ('no swim bladder' and 'swim bladder involved in hearing') were not assessed.

Table 2-8 Criteria for onset of injury to fish due to impulsive piling (Popper et al., 2014)[12]

Hearing group	TTS	Recoverable injury		Mortality	
	SEL_{cum} (dB re 1 µPa²s)	SEL_{cum} (dB re 1 µPa²s)	SPL_{peak} (dB re 1 µPa)	SEL_{cum} (dB re 1 µPa²s)	SPL_{peak} (dB re 1 µPa)
Group 2 Fish: swim bladder is not involved in hearing	186	203	207	210	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 four locations, namely N08, G07, L13 and D03. A 'best estimate' blow count scenario of BE50 (50 blows/25 cm) for a CF of 4% and 10% has been modelled. The BE50 piling profiles use high strike energies (up to 4400 kJ). 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).

[12] Hearing groups 1,3, and 4 excluded from table as not relevant to this assessment.

2.7.4 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.

2.7.4.1 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 2-10and 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.

2.7.4.2 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.

2.7.4.3 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 2-13 and 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

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

2.7.5 Population modelling

Population modelling has been conducted for bottlenose dolphin, harbour porpoise, minke whale, harbour and grey seal. The iPCoD framework (Harwood et al. 2014b, 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[13]. 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

[13] iPCoD version 5.2

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.

In the latest update of the iPCoD model there was no elicitation for minke whale (PTS or disturbance) or bottlenose dolphins (disturbance) and the results presented here are highly conservative and represent an overestimate of any potential population level effects. Modelling using iPCoD for minke whales is presented here at the request of NatureScot. However, SMRU Consulting advises caution when viewing the results as there are several precautions built both into the iPCoD model and into this specific scenario that mean that the results are considered to be highly precautionary and likely over-estimate the true population level effects. These include, but are not limited to, the following three factors:

- The fact that the model assumes a minke whale will not forage for 24 hours after being disturbed,
- The lack of density dependence in the model (meaning the population will not respond to any reduction in population size), and
- The level of environmental and demographic stochasticity in the model.

The following sections explore the background to each of these factors to illustrate the level of conservatism in this modelling and provide critical context for the evaluation of these results.

2.7.5.1 Duration of disturbance

The iPCoD model for minke whale and bottlenose dolphin disturbance was last updated following the expert elicitation in 2013 (Harwood et al. 2014a). When this expert elicitation was conducted, the experts provided responses on the assumption that a disturbed individual would not forage for 24 hours. However, the most recent expert elicitation in 2018 highlighted that this was an unrealistic assumption for harbour porpoises (generally considered to be more responsive than minke whales and bottlenose dolphin), and was amended to assume that disturbance resulted in 6 hours of non-foraging time (Booth et al. 2019). Unfortunately, minke whales and bottlenose dolphins were not included in the updated expert elicitation for disturbance, and, thus, the iPCoD model still assumes 24 hours of non-foraging time for minke whales and bottlenose dolphin. This is unrealistic considering what we now know about marine mammal behavioural responses to pile driving. A recent study estimated energetic costs associated with disturbance from sonar, where it was assumed that 1 hour of feeding cessation was classified as a mild response, 2 hours of feeding cessation was classified as a strong response and 8 hours of feeding cessation was classified as an extreme response (Czapanskiy et al. 2021). Assuming 24 hours of feeding cessation for minke whales and bottlenose dolphins in the iPCoD model is significantly beyond that which is considered to be an extreme response, and is, therefore, considered to be unrealistic and will overestimate the true disturbance levels expected from the Offshore Development. For this reason, SMRU Consulting does not recommend using the current version of iPCoD for minke whales.

2.7.5.2 Lack of density dependence

Density dependence is described as *'the process whereby demographic rates change in response to changes in population density, resulting in an increase in the population growth rate when density decreases and a decrease in that growth rate when density increases'* (Harwood et al. 2014a). The iPCoD scenario run for bottlenose dolphins assumes no density dependence since there is insufficient data to parameterise this relationship. Essentially, this means that there is no ability for the modelled impacted population to increase in size and return to carrying capacity following disturbance. At a recent expert elicitation on bottlenose dolphins, conducted for the purpose of modelling population impacts of the Deepwater Horizon oil spill (Schwacke et al. 2021), experts agreed that there would likely be a concave density dependence on fertility, which means that, in reality, it would be expected that the impacted population would recover to carrying capacity (which is assumed to be equal to the size of un-impacted population – i.e. it is assumed the un-impacted population is at carrying capacity) rather than continuing at a stable trajectory that is smaller than that of the un-impacted population.

2.7.5.3 Environmental and demographic stochasticity

The iPCoD model attempts to model some of the sources of uncertainty inherent in the calculation of the potential effects of disturbance on marine mammal population. This includes demographic stochasticity and environmental variation. Environmental variation is defined as *'the variation in demographic rates among years as a result of changes in environmental conditions'* (Harwood et al. 2014a). Demographic stochasticity is defined as *'variation among individuals in their realised vital rates as a result of random processes'* (Harwood et al. 2014a).

The iPCoD protocol describes this in further detail: *'Demographic stochasticity is caused by the fact that, even if survival and fertility rates are constant, the number of animals in a population that die and give birth will vary from year to year because of chance events. Demographic stochasticity has its greatest effect on the dynamics of relatively small populations, and we have incorporated it in models for all situations where the estimated population within an MU is less than 3000 individuals. One consequence of demographic stochasticity is that two otherwise identical populations that experience exactly the same sequence of environmental conditions will follow slightly different trajectories over time. As a result, it is possible for a "lucky" population that experiences disturbance effects to increase, whereas an identical undisturbed but "unlucky" population may decrease'* (Harwood et al. 2014a).

This is clearly evidenced in the outputs of iPCoD where the un-impacted (baseline) population size varies greatly between iterations, not as a result of disturbance but simply as a result on environmental and demographic stochasticity. In the example provided in Figure 2-10, after 25 years of simulation, the un-impacted population size varies between 176 (lower 2.5%) and 418 (upper 97.5%). Thus, the change in population size resulting from the impact of disturbance is significantly smaller than that driven by the environmental and demographic stochasticity in the model.

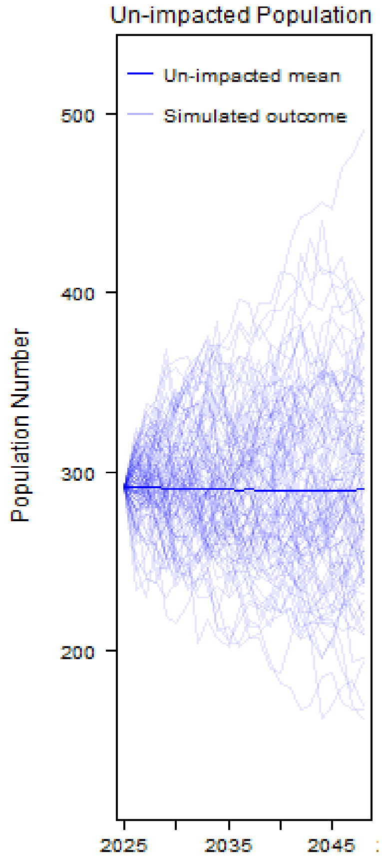

Figure 2-10 Simulated un-impacted (baseline) population size over the 25 years modelled.

2.7.5.4 Summary

All of the precautions built into the iPCoD model mean that the results are considered to be highly precautionary. 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 seal and grey seal. Results are also presented for minke whale but noting the caveat above regarding no update to the expert elicitation for minke whale.

The piling scenario used for population modelling (see Section 2.7.5) is given in Table 2-15.

<table>
<tr><th colspan="2">Table 2-15 Parameters used for iPCoD modelling.</th></tr>
<tr><th>Parameter</th><th>Description</th></tr>
<tr><td>Number of WTGs</td><td>60</td></tr>
<tr><td>Number of OSPs</td><td>2</td></tr>
<tr><td>Number of monopiles</td><td>62 monopiles</td></tr>
<tr><td>Concurrent piling</td><td>Yes – 20 days between February and April 2024</td></tr>
<tr><td>Number of piling days</td><td>20 days concurrent piling
22 days single vessel piling</td></tr>
<tr><td>Piling window</td><td>October 2023 to May 2024 inclusive</td></tr>
<tr><td>Piling schedule</td><td>
<table>
<tr><th>Month</th><th>Piles</th><th>Piling Days</th><th>Notes</th></tr>
<tr><td>Oct</td><td>6</td><td>6</td><td>Single vessel: 05/10, 09/10, 16/10, 17/10, 23/10, 31/10 (actual piling days)</td></tr>
<tr><td>Nov</td><td>6</td><td>6</td><td>Single vessel: 09/11, 10/11, 15/11, 16/11, 17/11, 26/11 (actual piling days)</td></tr>
<tr><td>Dec</td><td>4</td><td>4</td><td>Single vessel: 3/12, 10/12, 19/12, 24/12 (randomly generated)</td></tr>
<tr><td>Jan</td><td>3</td><td>3</td><td>Single vessel: 4/1, 11/1, 24/1 (randomly generated)</td></tr>
<tr><td>Feb</td><td>18</td><td>9</td><td>Concurrent piling: 3/2, 7/2, 10/2, 13/2, 17/2, 19/2, 20/2, 23/2, 26/2 (randomly generated)</td></tr>
<tr><td>Mar</td><td>14</td><td>7</td><td>Concurrent piling: 2/3, 9/3, 11/3, 12/3, 18/3, 21/3, 28/3 (randomly generated)</td></tr>
<tr><td>April</td><td>8</td><td>4</td><td>Concurrent piling: 5/4, 7/4, 19/4, 23/4 (randomly generated)</td></tr>
<tr><td>May</td><td>3</td><td>3</td><td>Single vessel: 8/5, 22/5, 31/5 (randomly generated)</td></tr>
</table>
</td></tr>
</table>

2.7.6 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 whale 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. (2017b) and single strike SEL contours decreasing in 5 dB steps from 180 to 120 dB re 1 µPa²s, following the method as used for the assessment of disturbance (Section 2.7.2.2). 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. (2017b) 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 2.7.2.2).

3) Potential impacts to minke whale prey:

Minke whales in the North Atlantic 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 piling noise on minke whale prey is discussed in the Fish Impact Assessment (Section 4). 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.

2.7.7 Comparison with Moray West EIA Report 2018

For both marine mammals and fish, a comparison has been made between the results of the 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.

For marine mammals, there have been updates to the MUs and density surfaces since the Moray West EIA Report 2018. These are described above in Section 2.7.2.3.

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 Revised Piling Strategy presents the Southall et al. (2019a) PTS-onset thresholds. These thresholds are the same; the only difference between the two is that Southall et al. (2019a) renamed the hearing group 'High-frequency cetaceans' (harbour porpoise) to 'Very-high-frequency cetaceans' and 'Mid-frequency cetaceans' (dolphin species) 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 Moray West EIA Report 2018, 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% and 1% of the Moray West EIA Report 2018-Appendix (see Section 0). For the fleeing model in the Moray West EIA Report 2018 and its Appendix it was considered that animals would stop fleeing at 25 km. This stop was omitted for the fleeing model in this revised PS.

For both auditory injury and disturbance assessments results a table will be provided comparing the 2018 EIA results with those of this assessment in each section below.

Table 2-16 Changes to piling parameters since the Moray West EIA Report 2018.		
Parameter	**Moray West EIA Report 2018**	**Revised Piling Strategy**
Number of WTGs	85	60 (+ 2 OSPs)
WTGs foundations	Jacket pin-pile or monopile	Monopile only
Maximum piling period	10 months	8 months
Maximum hammer driving energy[14]	5,000 kJ	4,400 kJ
Soft-start maximum hammer driving energy	1,000 kJ	432 kJ
Consecutive piling	No	Yes
Concurrent piling	Yes	Yes
Number of piling days	87 (assuming 1 vessel) 44 (assuming 2 vessels)	62 (22 days single vessel piling, 20 days concurrent vessel piling)

2.7.8 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 Revised Piling Strategy. For the comparison, iPCoD modelling results from the 2018 RIAA were compared with those obtained in the Revised PS assessment.

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

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 and full hammer energy are presented in Table 3-1 in comparison with the 2018 EIA results. 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 579 m for a 10% CF at location L13.

Table 3-1 Instantaneous PTS impact ranges (m) for each species for soft start and full hammer energy compared with the 2018 EIA.

Species	Assessment (Location)	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
Harbour porpoise	2018 EIA	…	5,000	….	335	….	….	….	….
	Revised PS (L13)	432	4,400	….	….	241	1,390	579	2,395
Minke whale	2018 EIA	…	5,000	….	<50	….	….	….	….
	Revised PS (G07)	432	4,400	….	….	<50	127	<50	313
	Revised PS (N08)	432	1,295	….	….	<50	44	<50	84
Bottlenose dolphin	2018 EIA	…	5,000	….	<50	….	….	….	….
	Revised PS (D03)	432	4,400	….	….	<50	33	<50	52
Grey and harbour seals	2018 EIA	…	5,000	….	<50	….	….	….	….
	Revised PS (D03)	432	4,400	….	….	<50	145	<50	357

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 PS[15]. 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

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

that harbour porpoises move away from piling sites following the use of Acoustic Deterrent Devices (ADD) mitigation measures (Graham et al. 2023). Finally, 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. 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 0.02 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 harbour porpoise being present within 579 m of the monopile 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.

The instantaneous PTS-onset impact ranges for full hammer energy for marine mammals are presented in Table 3-1. 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 2.4 km, and 1.4 km for a CF of 4%.

An assessment of the probability of an animal being present within the PTS impact radius over the 62 piling events was assessed (Table 3-2). The probability of a single individual bottlenose dolphin being within the 52 m radius during the first strike at full hammer energy across 62 piling events is also essentially zero (<0.000001; 0%). For minke whales, the probability of a single individual minke whale being within the 313 m radius during the first strike at full hammer energy across 62 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.

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 in Table 3-2.

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 2.7.2.1.2 and the Beatrice Offshore Windfarm Ltd (BOWL) &

Moray East Piling Reports). Furthermore, there is now evidence that harbour porpoises are displaced by vessel activity (Benhemma-Le Gall et al. 2021), ADD and piling noise (Graham et al. 2019, Graham et al. 2023). 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 Table 2-2), animals are predicted to be at least 10 km away and, therefore, considerably further than the PTS-onset impact zone.

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 3-2 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	*0.052*	*0.00048**	2,063.50	25.63	<0.000001
Grey seal	*0.432*	*0.94567**	1.1	0.58	*> 0.999999*
Harbour seal	*0.357*	*0.64500**	1.6	0.7	*> 0.999999*
Harbour porpoise	*2.395*	*1.46875**	0.7	0.47	*> 0.999999*
Minke whale	*0.313*	*0.00950ł*	105.3	5.79	*0.01314*
* Maximum density cell within the Moray West array area, ł SCANS III density estimate					

3.1.2 Cumulative PTS

3.1.2.1 1 monopile installed per day

The conservative estimates for cumulative PTS impact ranges for bottlenose dolphins and seals are less than 50 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.

Table 3-3 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) and the number of animals that might be within the highly conservative cumulative PTS impact zones for harbour porpoise (assuming

1 monopile installed per day) compared with the 2018 EIA. As outlined in Section 2.7.2.1.2, these are based upon a series of highly conservative assumptions.

Table 3-3 Maximum cumulative PTS impact range (m) and number of harbour porpoise within that range based on the piling profiles shown in Table 2-2 and a constant CF of 4% and 10%, compared with the 2018 EIA.

Assessment (Location)	1% CF		4% CF		10% CF	
	Impact range (m)	# animals	Impact range (m)	# animals	Impact range (m)	# animals
2018 EIA	289	….	….	….	….	….
Revised PS (L13)	….	….	567	1	2,834	25
Revised PS (N08)	….	….	127	<1	1,702	5

The conservative cumulative PTS-onset impact ranges for harbour porpoise reach over 2.5 km when considering a constant 10% CF for location L13 with a moderate risk of pile driving refusal (Figure 3-1). The number of animals potentially within this impact area is 25. However, due to the conservative assumptions used to calculate the SEL_{cum} PTS-onset ranges (see Section 2.7.2.1.2) 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.

Given that the planned blow rate at Moray West is expected to allow a degree of recovery in hearing shift between pulses (see Section 2.7.2.1.2) the PTS-onset threshold for harbour porpoise is expected to be 2-3 dB higher than the Southall et al. (2019a) threshold. This would lead to a considerably lower impact range and consequently fewer 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 have been shown to have a significant deterrent effect on harbour porpoises up to 7.5 km away (Brandt et al. 2013). Nevertheless, given the use of pre-piling ADD deployment as a mitigation measure (see the Revised Appendix D - Piling Mitigation Protocol (PMP)), the impact of cumulative PTS is assessed as of **negligible** magnitude for harbour porpoise.

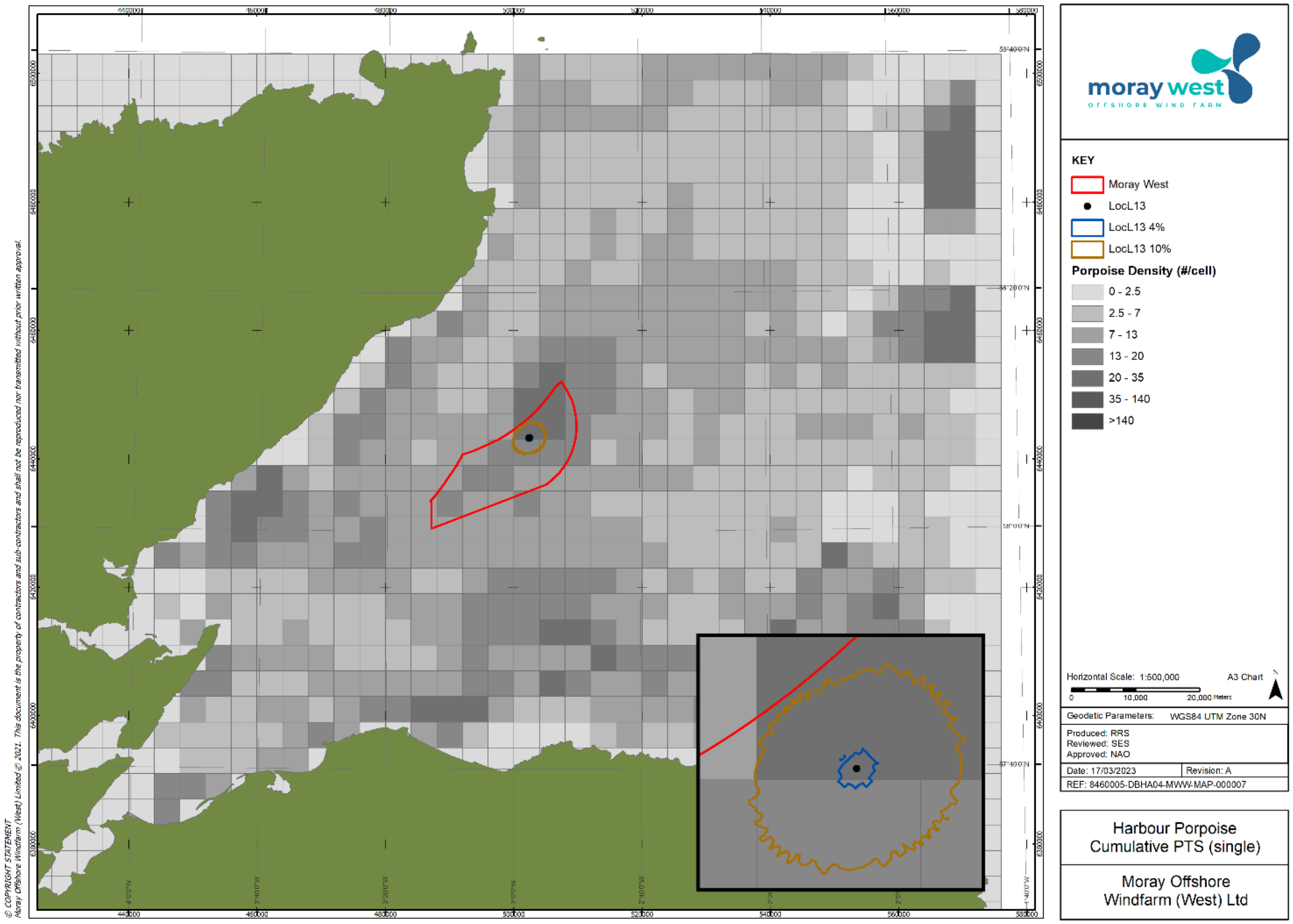

Figure 3-1 Harbour porpoise cumulative PTS-onset impact ranges for location L13, featuring different conversion factor scenarios. Insert zooms in to show 4% CF more clearly.

Table 3-4 presents the maximum cumulative PTS-onset impact ranges and the number of animals that might be within the highly conservative cumulative PTS impact zones for minke whale compared with the 2018 EIA.

Table 3-4 Maximum cumulative PTS impact range (m) and number of minke whale within that range based on the piling profiles shown in Table 2-2 and a constant CF of 4% and 10%, compared with the 2018 EIA.

Assessment (Location)	1% CF		4% CF		10% CF	
	Impact range (m)	# animals	Impact range (m)	# animals	Impact range (m)	# animals
2018 EIA	2,000	<1	….	….	….	….
Revised PS (G07)	….	….	28,302	<1	45,118	3
Revised PS (N08)	….	….	2,450	<1	11,318	1

The worst-case cumulative PTS-onset impact ranges for minke whale at location G07 are over 28 km and 45 km for 4 and 10% CF, respectively (Figure 3-2). For the 47 monopile locations with negligible risk of pile driving refusal (represented here by N08) the impact ranges are much smaller 2.5 km and 11.3 km for 4 and 10% CF, respectively (Figure 3-3). The conservative assumptions underlying our worst-case estimates (see Section 2.7.2.1.2) mean that impact ranges in Table 3-4 are unrealistically high.

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) (and see Section 2.7.2.1.2). A maximum of 3 minke whales are predicted to be within the worst-case cumulative PTS impact zone. However, using criteria that recent studies indicate are more probable (raising the threshold for PTS by 2-3 dB (Section 2.7.2.1.2), the number of individuals even in summer is reduced to <1. 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.

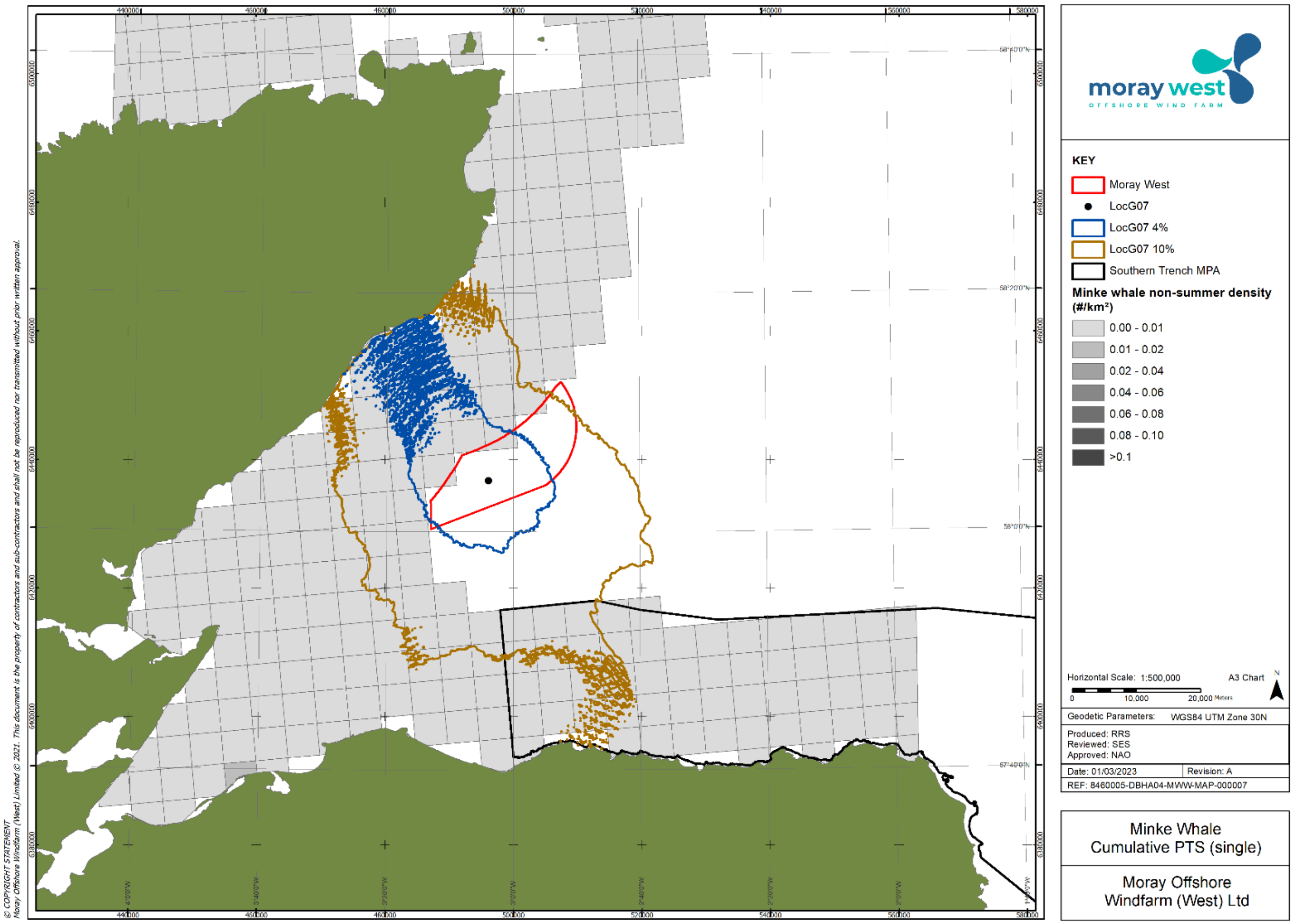

Figure 3-2 Minke whale cumulative PTS impact ranges for location G07, featuring different conversion factor scenarios.

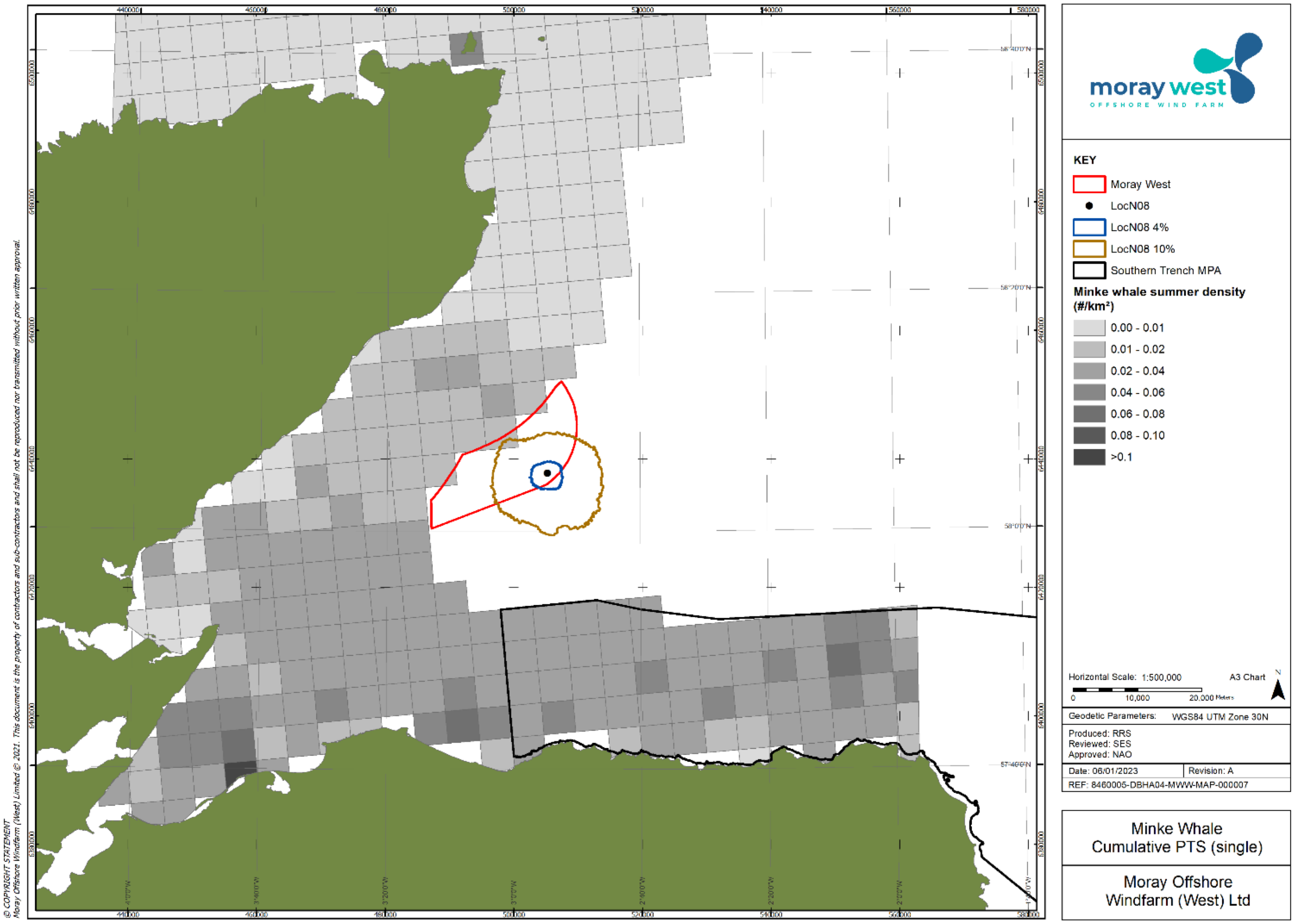

Figure 3-3 Minke whale cumulative PTS-onset impact ranges for location N08 given 4% and 10% conversion factor scenarios.

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 3 minke whales and up to 25 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 in any of these species as a result of PTS.

3.1.2.2 2 monopiles installed per day - consecutive

None of the locations with a moderate risk of pile driving refusal (E03, K14, D03, L13, G07) will be installed consecutively with each other (Section 2.1). The realistic worst case scenario for two monopiles being installed per day is 2 of the 47 locations with negligible risk of pile driving refusal, for which the conservative cumulative PTS-onset impact ranges for harbour porpoise reach 1.8 km, equating to 6 harbour porpoise (Table 3-5). 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, 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 detailed in the Revised PMP, 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 reach 20.4 km, equating to <1 minke whale (Table3-5) at risk of PTS. 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) and see Section 2.7.2.1.2.

Thus, 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 3-5 Maximum cumulative PTS impact based on the assumption that 2 monopiles are installed consecutively per day (10% CF).

Species	Location	# Piles per day	Max cumulative PTS onset range (m)	Number of animals
Harbour porpoise	N08	1	1,702	5
		2	1,793	6
Minke whale	N08	1	11,318	<1
		2	20,398	<1

3.1.2.3 3 monopiles installed per day

If two installation vessels are on site simultaneously it is possible that three monopiles may be installed within a 24 hour period. This results in a small increase in the cumulative PTS-onset impact range for harbour porpoise (1,870 m at 10% CF) but no change in number of animals potentially affected (n=6) compared with installing 2 monopiles consecutively. For minke whale the cumulative PTS-onset impact range increases to 45.2 km with a potential impact to 1 animal. However, it is important to reiterate that most individuals within such a radius will be exposed to piling noise at ranges of tens of kilometres, where impulsive exposure criteria for receivers are extremely precautionary (Southall 2021) and see Section 2.7.2.1.2. Although unlikely to happen if the base case piling schedule is realized, the impact of installing three monopiles per 24 hours 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.

3.1.2.4 2 monopiles installed per day - concurrent

Concurrent installation of two monopiles per day will only happen if there is overlap between two installation vessels on Moray West Site. According to the current piling schedule (Figure 2-2), if this happens, it will only result in concurrent piling during a three month window between February and April 2024 and no monopiles with a moderate risk of pile driving refusal (E03, K14, D03, L13, G07) will be installed concurrently with each other. The realistic worst case scenario is for one of these locations to be installed concurrently with one of the 47 no driveability risk locations for which the conservative cumulative PTS-onset impact ranges for harbour porpoise reach 105 km^2, equating to 82 harbour porpoise (Table 3-6 and Figure 3-4). However, due to the conservative assumptions used to calculate the SEL_{cum} PTS-onset ranges (see Section 2.7.2.1.2) 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.

Given that the planned blow rate at Moray West is expected to allow a degree of recovery in hearing shift between pulses, the PTS-onset threshold for harbour porpoise is expected to be 2-3 dB higher than the Southall et al. (2019a) threshold (see Section 2.7.2.1.2 for more detail). This would lead to a considerably lower impact range and consequently fewer 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 have been shown to have a significant deterrent effect on harbour porpoises up to 7.5 km away (Brandt et al. 2013). Nevertheless, given the use of pre-piling ADD deployment at each pile as a mitigation measure (see the Revised PMP), the impact of cumulative PTS from concurrent piling is assessed as of **negligible** magnitude for harbour porpoise.

Table 3-6 Maximum cumulative PTS impact range and number of harbour porpoise within that range for concurrent piling based on a constant CF of 4% and 10%, compared with the 2018 EIA.						
Assessment (Location)	1% CF		4% CF		10% CF	
	Impact range (m)	# animals	Impact range (km^2)	# animals	Impact range (km^2)	# animals
2018 EIA	324	….	….	….	….	….
Revised PS (N08 and D03)	….	….	8	6	105	82

For minke whale the conservative cumulative PTS-onset impact ranges reach 2,092 km^2 equating to 4 minke whales (Table 3-7 and Figure 3-5) at risk of PTS. The conservative assumptions underlying our worst-case estimates (see Section 2.7.2.1.2) mean that impact ranges in Table 3-7 are unrealistically high.

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 kilometres, where impulsive exposure criteria for receivers are extremely precautionary (Southall 2021) (and see Section 2.7.2.1.2). A maximum of 4 minke whales are predicted to be within the worst-case cumulative PTS impact zone for concurrent piling. However, using criteria that recent studies indicate are more probable (raising the threshold for PTS by 2-3 dB (Section 2.7.2.1.2), the number of individuals even in summer is reduced to <1. 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 3-7 Maximum cumulative PTS impact range and number of minke whale within that range for concurrent piling based on a constant CF of 4% and 10%, compared with the 2018 EIA.

Assessment (Location)	1% CF		4% CF		10% CF	
	Impact range (m)	# animals	Impact range (km^2)	# animals	Impact range (km^2)	# animals
2018 EIA	32,000	< 1	….	….	….	….
Revised PS (N08 and D03)	….	…..	533	1	2,092	4

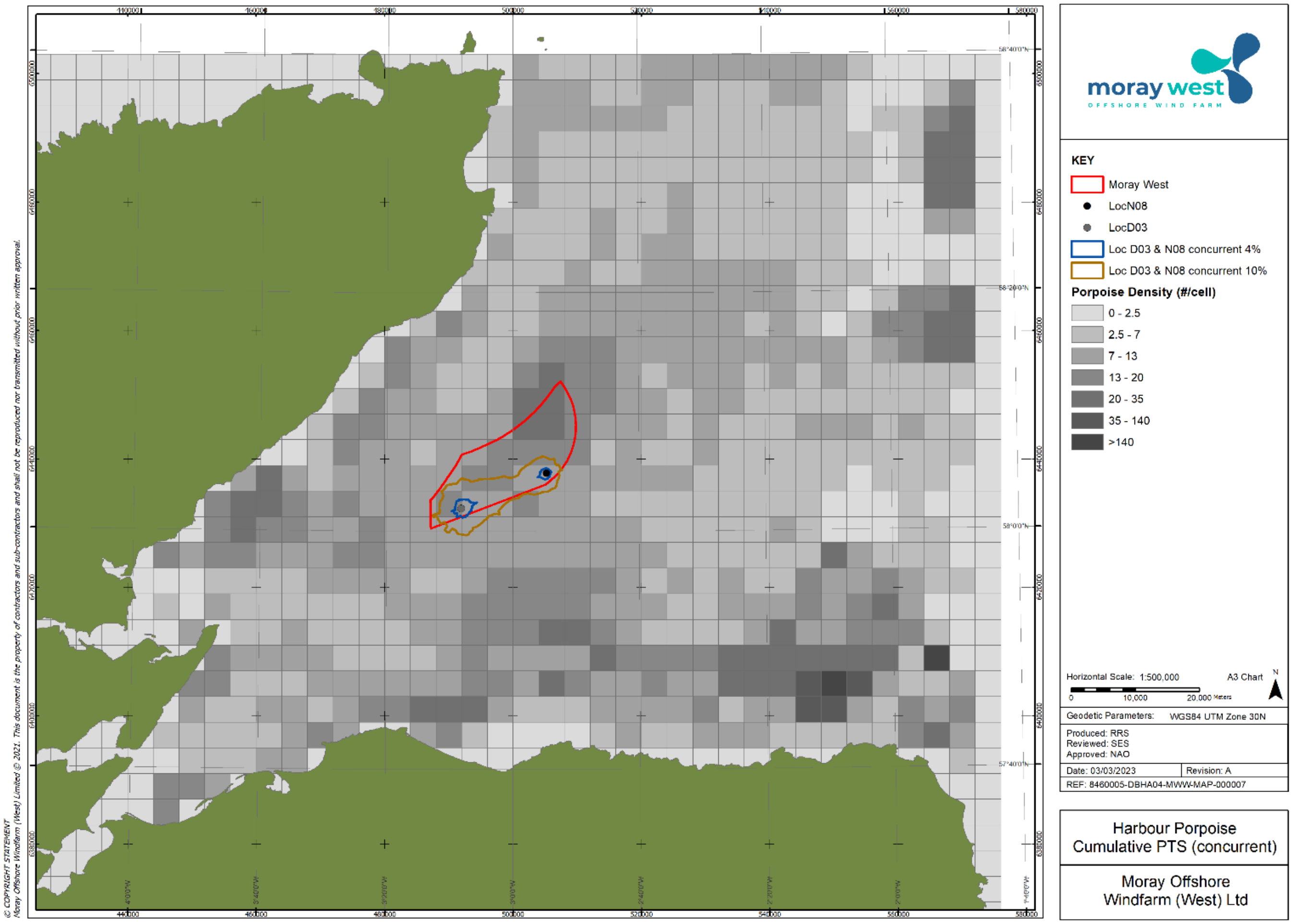

Figure 3-4 Harbour porpoise cumulative PTS-onset impact ranges for concurrent piling at D03 and N08 given 4% and 10% conversion factor scenarios.

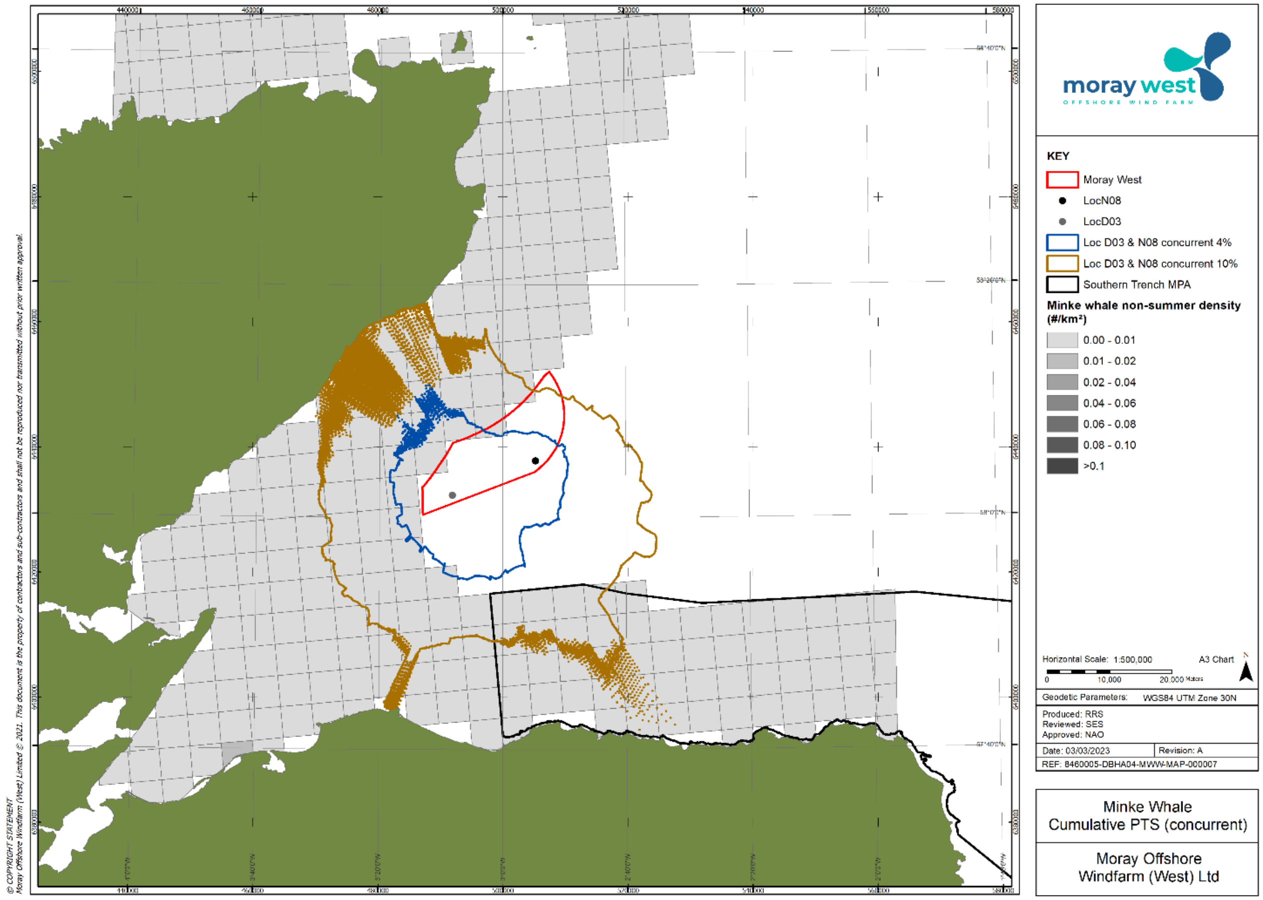

Figure 3-5 Minke whale cumulative PTS-onset impact ranges for concurrent piling at D03 and N08 given 4% and 10% conversion factor scenarios overlain on non-summer densities.

3.1.2.5 Comparison with Moray West EIA for Cumulative PTS

Risk of cumulative PTS for bottlenose dolphins and harbour seals and grey seals at 10% CF for all piling scenarios in this assessment was <1 animal and comparable to the 2018 EIA. Table 3-8 compares cumulative PTS-onset impact ranges and number of animals impacted as presented in the 2018 EIA and for all piling scenarios considered in this Revised Piling Strategy for harbour porpoise. Overall, the impact of cumulative PTS on harbour porpoise is considered as **negligible** magnitude in EIA terms, with the use of ADD measures as described in the Revised PMP there is expected to be no change to the population size or trajectory.

Table 3-8 Comparison of cumulative PTS impact ranges for harbour porpoise for all piling scenarios between the EIA and this revised piling strategy.

Assessment (Location)	1% CF		4% CF		10% CF	
	Impact range (m)	# animals	Impact range (m)	# animals	Impact range (m)	# animals
2018 EIA – single piling event	289	….	….	….	….	….
2018 EIA – concurrent piling events	324	….	….	….	….	….
Revised PS – single piling event (L13)	….	….	567	1	2,834	25
Revised PS – single piling event (N08)	….	….	127	<1	1,702	5
Revised PS - consecutive piling events (N08) 2 monopiles installed per day	….	….	127	<1	1,793	6
Revised PS – concurrent piling events (N08 and D03)	….	….	8 (km^2)	6	105 (km^2)	82

Table 3-9 compares cumulative PTS-onset impact ranges and number of animals impacted as presented in the 2018 EIA and for all piling scenarios considered in this Revised Piling Strategy for minke whale. Overall, the impact of cumulative PTS on minke whales is considered as **negligible** magnitude in EIA terms, since the effect is on such a small proportion of the population there is expected to be no change to the population size or trajectory.

Table 3-9 Comparison of cumulative PTS impact ranges for minke whale for all piling scenarios between the 2018 EIA and this Revised Piling Strategy						
Assessment (Location)	1% CF		4% CF		10% CF	
	Impact range (m)	# animals	Impact range (m)	# animals	Impact range (m)	# animals
2018 EIA – single piling event	2,000	<1	….	….	….	….
2018 EIA - concurrent piling events	32,000	< 1	….	….	….	….
Revised PS – single piling event (G07)	….	….	28,302	<1	45,118	3
Revised PS – single piling event (N08)	….	….	2,450	<1	11,318	<1
Revised PS – consecutive piling events (N08) 2 monopiles installed per day	….	….	3,817	<1	20,398	<1
Revised PS – concurrent piling events (N08 and D03)	….	…..	533 (km^2)	1	2,092 (km^2)	4

3.2 Disturbance

3.2.1 Harbour porpoise

The realistic worst case scenario for disturbance to harbour porpoise from a single monopile installation event was evaluated for the installation of a monopile at location L13 (potential for driving refusal) assuming a maximum hammer energy of 4,400 kJ and a 10% CF (Figure 3-6). This resulted in a prediction of 4,681 porpoises being disturbed on a single day of piling (this represents 1.35% of the North Sea MU, or 2.93% of the UK portion) (Table 3-10, Figure 3-6).

The realistic worst case scenario for disturbance to harbour porpoise from concurrent piling was evaluated for the installation of monopiles at location D03 (potential for driving refusal) and N08 (no driveability risk) assuming a maximum hammer energy of 4,400 kJ for D03 and a 10% CF. This resulted in a prediction of 4,381 porpoises being disturbed on a single day of piling (this represents 1.26% of the North Sea MU, or 2.74% of the UK portion) (Table 3-10, Figure 3-7).

Table 3-10 Comparison of the potential disturbance to harbour porpoise resulting from worst case scenarios in this impact assessment with the 2018 EIA.

Assessment (Location)	Hammer Energy (kJ)	1% CF			4% CF			10% CF		
		# Porpoise	% entire MU	% UK portion	# Porpoise	% entire MU	% UK portion	# Porpoise	% entire MU	% UK portion
2018 EIA – concurrent piling events	5,000	2,207	0.64%	….	….	….	….	….	….	….
Revised PS single piling event (L13)	4,400	….	….	….	3,533	1.02%	2.21%	4,681	1.35%	2.93%
Revised PS concurrent piling events (N08 and D03)	4,400 (D03) 1,295 (N08)	….	….	….	3,284	0.95%	2.06%	4,381	1.26%	2.74%

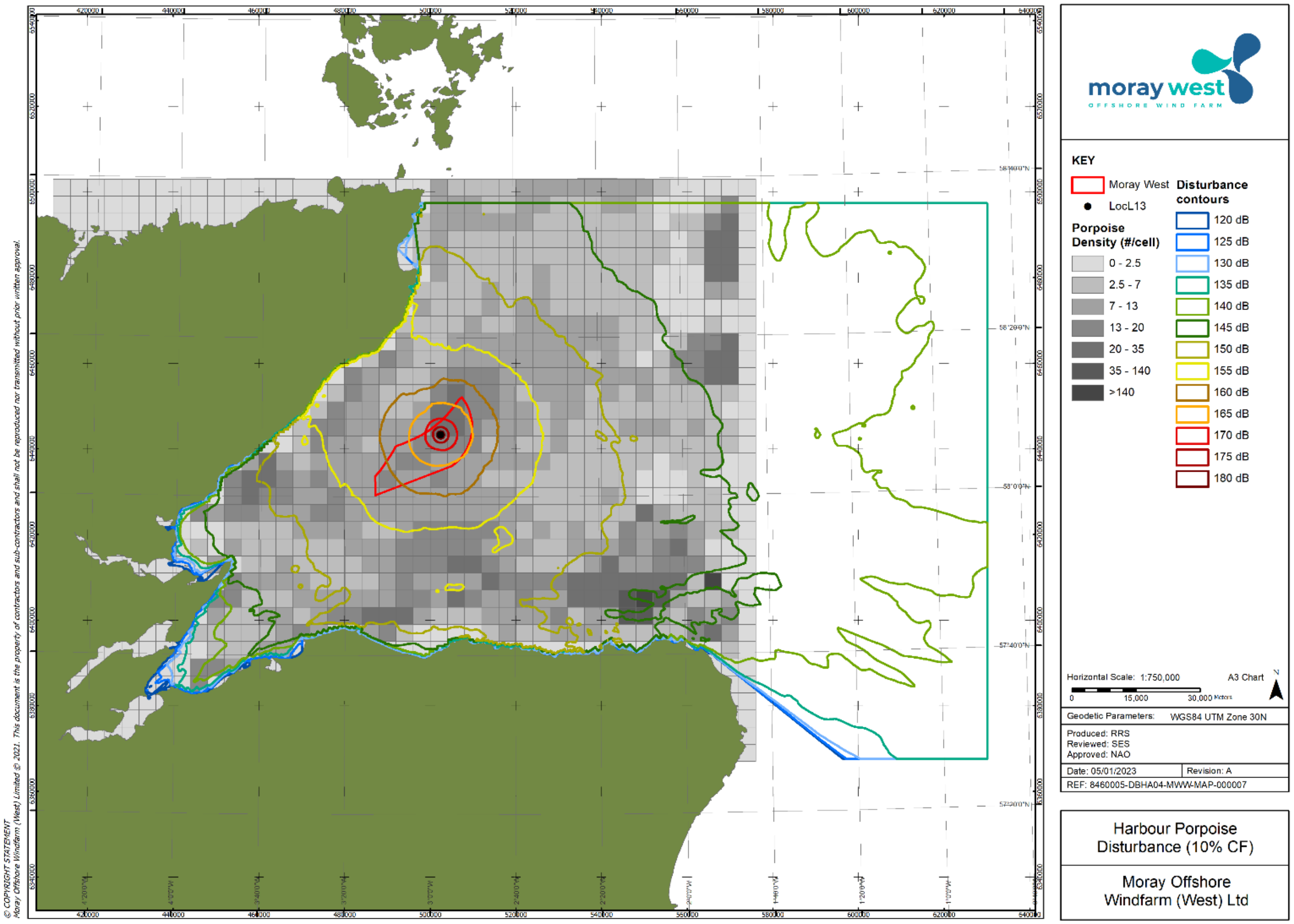

Figure 3-6 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location L13 overlain the harbour porpoise distribution. CF = 10%, hammer energy = 4,400 kJ.

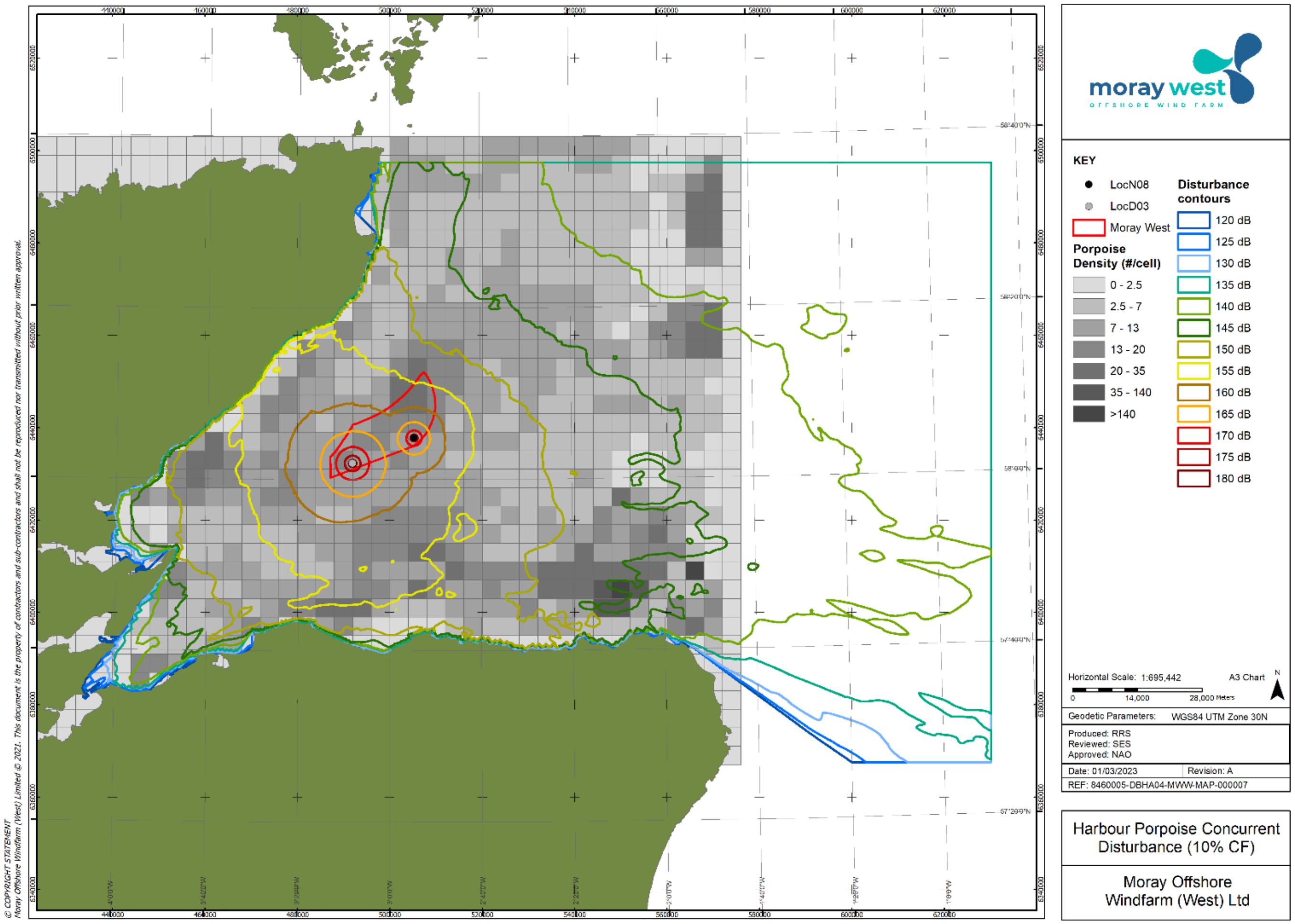

Figure 3-7 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location concurrent piling at D03 and N08 overlain with the harbour porpoise distribution. CF = 10%.

Assuming a worst-case of 4,681 harbour porpoise disturbed on every single vessel piling day (22 days) and 4,381 harbour porpoise disturbed on every concurrent piling day (20 days) (Table 2-15), outputs from iPCoD estimate there to be no discernible impact to the harbour porpoise population, even considering impacts to the UK portion. The mean population size for the impacted population was predicted to be 100% 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 100% of the un-impacted population size (Table 3-11). The impacted population is expected to maintain the same trajectory as the un-impacted population after the impact period has ceased (Figure 3-8).

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 3-11 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 population mean	impacted population mean	Impacted as % un-impacted
Start	159,634	159,634	100
End 2024	159,860	159,719	100
End 2030	159,863	159,772	100
End 2036	160,210	160,120	100
End 2042	159,781	159,691	100

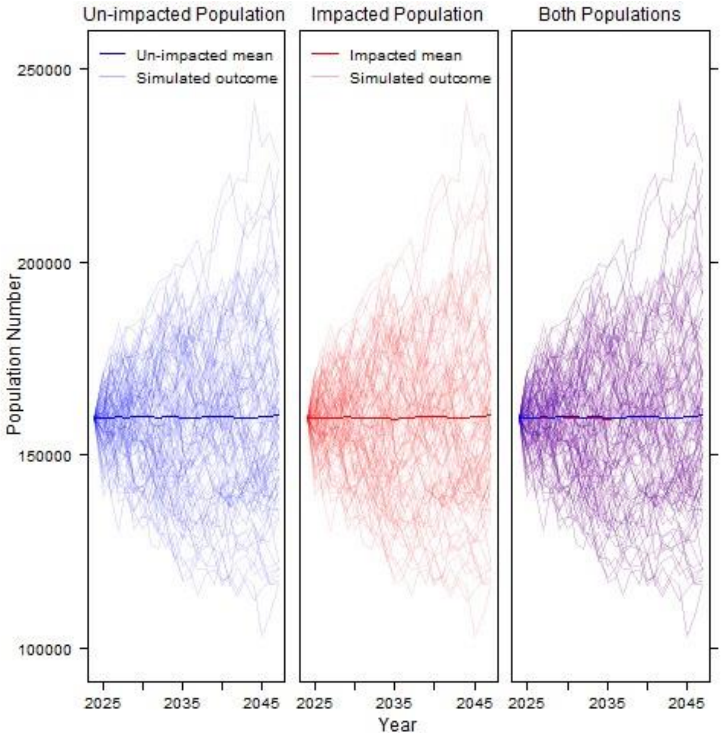

Figure 3-8 Simulated harbour porpoise population sizes for both the un-impacted and the impacted populations.

3.2.2 Bottlenose dolphin

The realistic worst case scenario for disturbance to bottlenose dolphin from a single monopile installation event was evaluated for the installation of a monopile at location D03 (potential for driving refusal) assuming a maximum hammer energy of 4,400 kJ and a 10% CF (Table 3-12 and Figure 3-9). This resulted in a prediction of 53 bottlenose dolphins being disturbed on a single day of piling (this represents 23.75% of the East Coast Scotland MU).

Table 3-12 Comparison of the potential disturbance to bottlenose dolphins resulting from worst case scenarios in this impact assessment with the EIA.

Assessment (Location)	Hammer Energy (kJ)	1% CF		4% CF		10% CF	
		# Dolphins	% MU	# Dolphins	% MU	# Dolphins	% MU
2018 EIA - concurrent piling events	5,000	22	11.28%	….	….	….	….
Revised PS	4,400	….	….	41	18.30%	53	23.75%

Table 3-12 Comparison of the potential disturbance to bottlenose dolphins resulting from worst case scenarios in this impact assessment with the EIA.

Assessment (Location)	Hammer Energy (kJ)	1% CF		4% CF		10% CF	
		# Dolphins	% MU	# Dolphins	% MU	# Dolphins	% MU
single piling event (D03)							
Revised PS concurrent piling events (N08 and D03)	4,400 (D03) 1,295 (N08)	….	….	37	17.69%	54	24.07%

The realistic worst-case scenario for disturbance to bottlenose dolphin from concurrent piling was evaluated for the installation of monopiles at location D03 (potential for driving refusal) and N08 (no driveability risk) assuming a maximum hammer energy of 4,400 kJ for D03 and a 10% CF. This resulted in a prediction of 54 bottlenose dolphins being disturbed on a single day of piling (this represents 24.07% of the East Coast Scotland MU) (Table 3-12 and Figure 3-10).

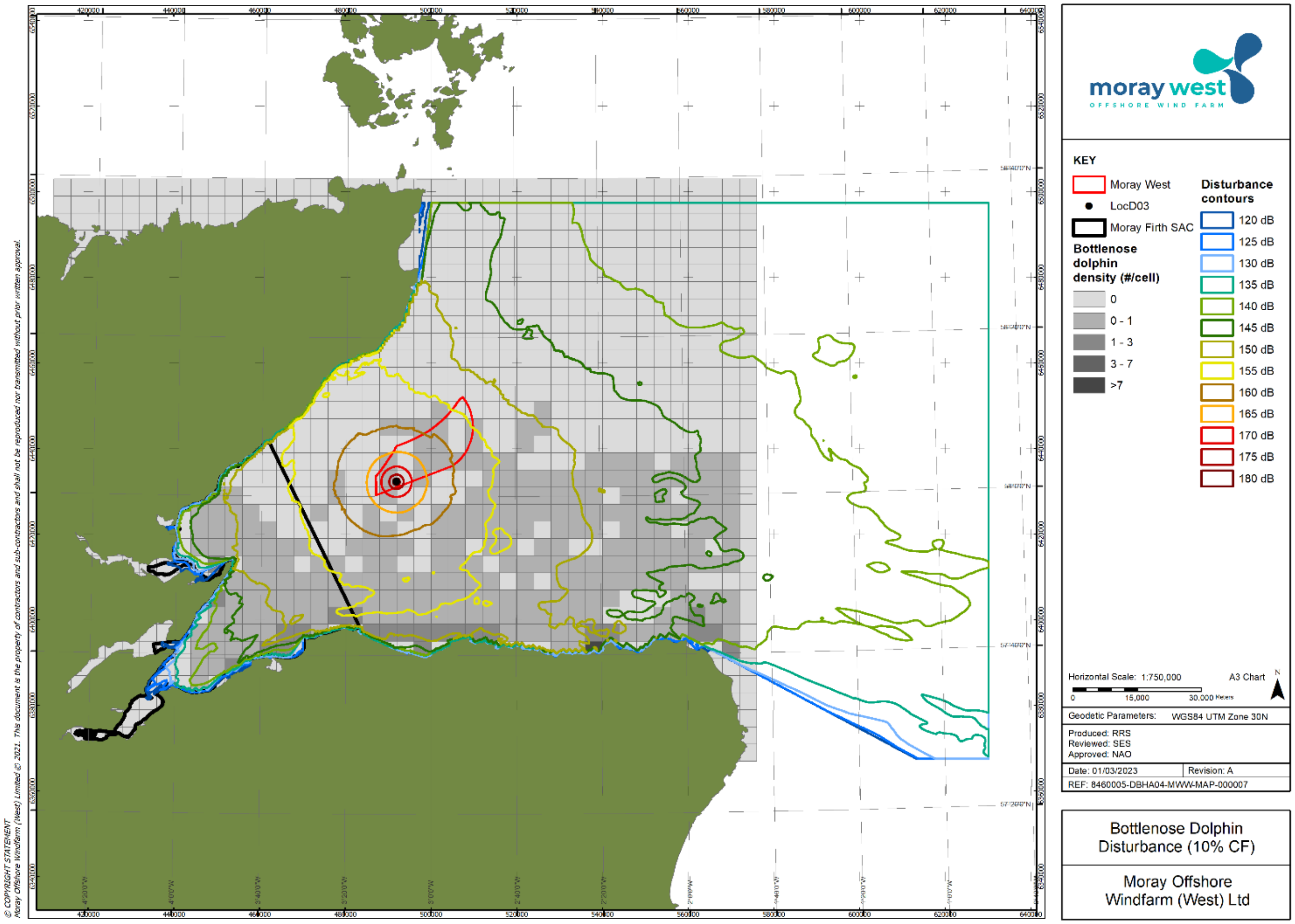

Figure 3-9 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location D03 overlain the bottlenose dolphin distribution. CF = 10%, hammer energy = 4,400 kJ.

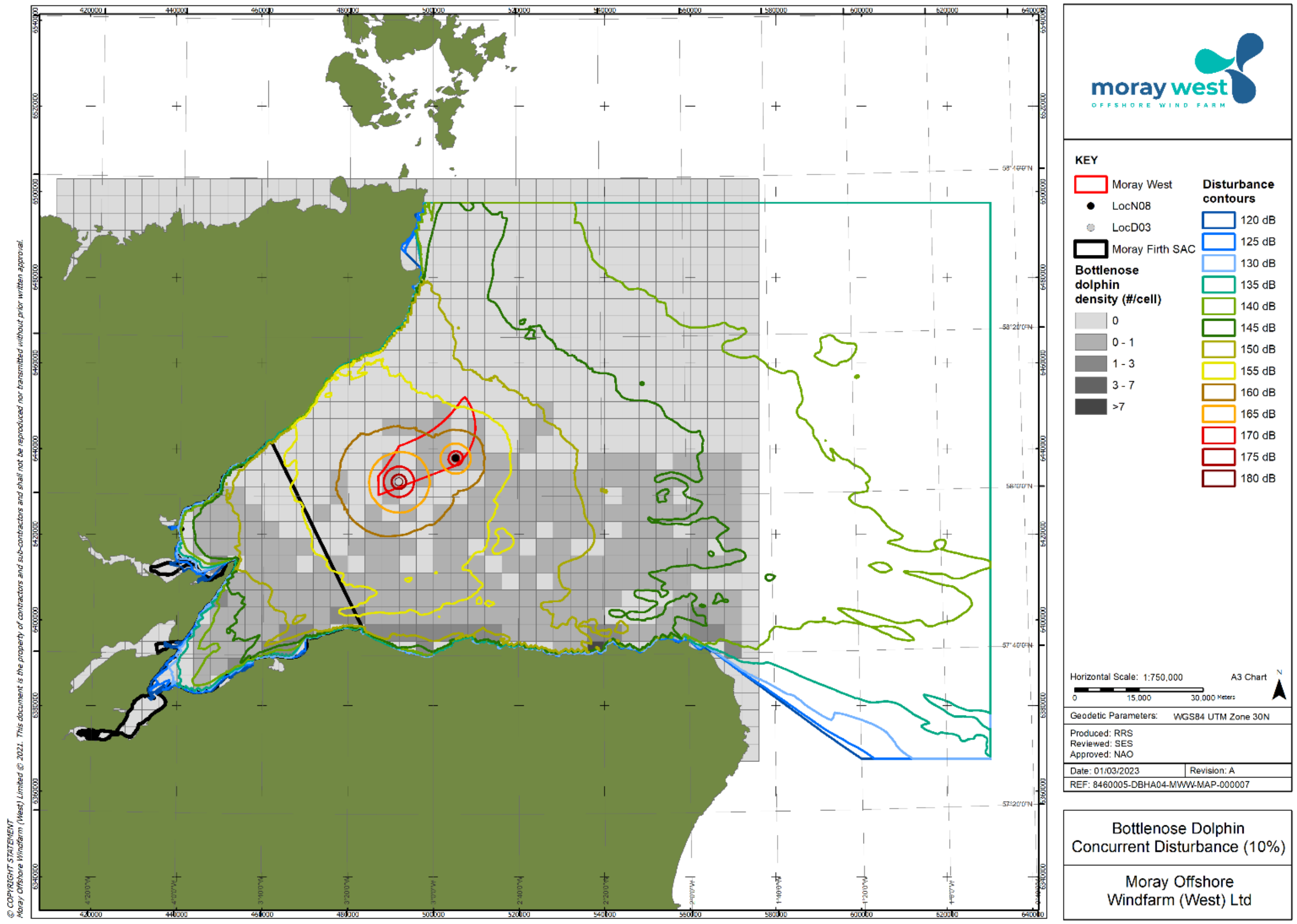

Figure 3-10 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for concurrent piling at D03 and N08 overlain the bottlenose dolphin distribution. CF = 10%.

Assuming a worst-case of 53 bottlenose dolphins disturbed on every single vessel piling day (22 days) and 54 bottlenose dolphins disturbed on every concurrent piling day (20 days) (Table 2-15), outputs from iPCoD estimate there to be only a slight discernible impact to the bottlenose dolphin population (Figure 3-11 and Table 3-13,). The mean population size for the impacted population was predicted to be 97% 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% 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. This is comparable with the slight discernible impact to the population from the iPCoD modelling in the 2018 EIA where 22 animals disturbed daily results in a 98.7% impacted to un-impacted after 24 years.

It is also important to note that the effects of disturbance on bottlenose dolphins were not updated in the latest revisions to the iPCoD model and there are several precautions built into the model which mean that the results are considered to be highly precautionary and likely over-estimate the true population level effects (see Population Modelling Section 2.7.5).

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 3-13 Results of the iPCoD modelling, giving the mean population size of bottlenose dolphin for years up to 2042 for impacted and un-impacted populations.

Year	un-impacted population mean	impacted population mean	Impacted as % un-impacted
Start	224	224	100
End 2024	241	234	97
End 2030	299	294	98
End 2036	371	363	98
End 2042	461	451	98

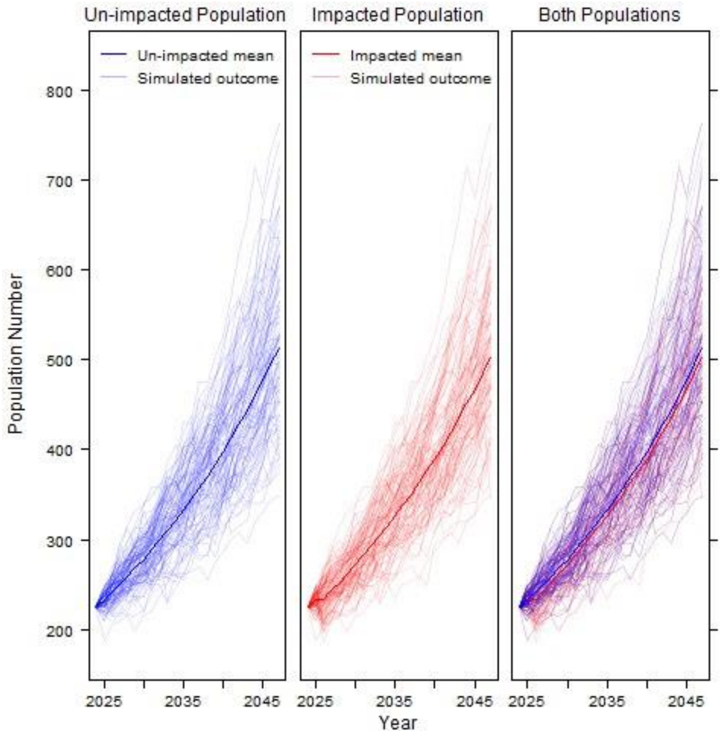

Figure 3-11 Simulated bottlenose dolphin population sizes for both the un-impacted and the impacted populations.

3.2.3 Minke whale

The realistic worst case scenario for disturbance to minke whale from a single monopile installation event was evaluated for the installation of a monopile at location G07 assuming a maximum hammer energy of 4,400 kJ and a 10% CF (Table 3-14 and Figure 3-13). This resulted in a prediction of 13 minke whales being disturbed on a single day of piling (0.06% MU or 0.13% UK portion). The realistic worst case scenario for disturbance to minke whale from concurrent piling was evaluated for the installation of monopiles at locations D03 and N08 assuming hammer energies of 4,400 kJ and 1,295 kJ respectively and a 10% CF (Table 3-15 and Figure 3-15). This also resulted in a prediction of 13 minke whales being disturbed on a single day of piling (0.06% MU or 0.13% UK portion).

Table 3-14 Numbers of minke whales and proportion of relevant management units (MU) predicted to be disturbed resulting from worst case scenarios in this impact assessment.

Assessment (Location)	Hammer Energy (kJ)	1% CF		4% CF			10% CF		
		# Animals	% MU	# Animals	% entire MU	% UK MU	# Animals	% entire MU	% UK MU
Revised PS - single piling event (G07)	4,400	….	….	10	0.05%	0.10%	13	0.06%	0.13%
Revised PS - single piling event (N08)	1,295	….	….	7	0.03%	0.06%	10	0.05%	0.10%
Revised PS - concurrent piling events (D03 and N08)	4,400 (D03) 1,295 (N08)	….	….	10	0.05%	0.10%	13	0.06%	0.13%

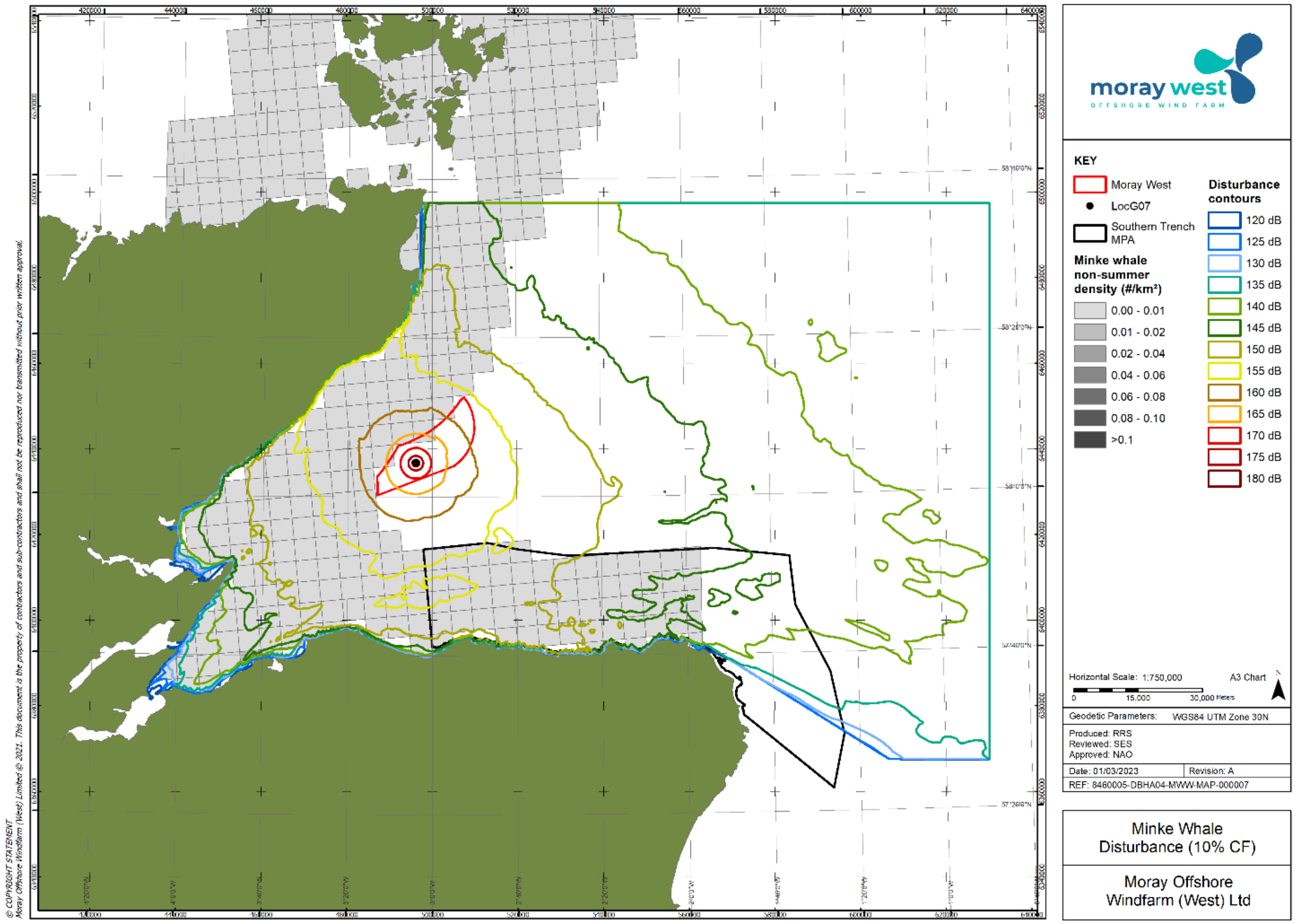

Figure 3-12 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location G07 overlain with minke whale non-summer density. CF = 10%, hammer energy = 4,400 kJ.

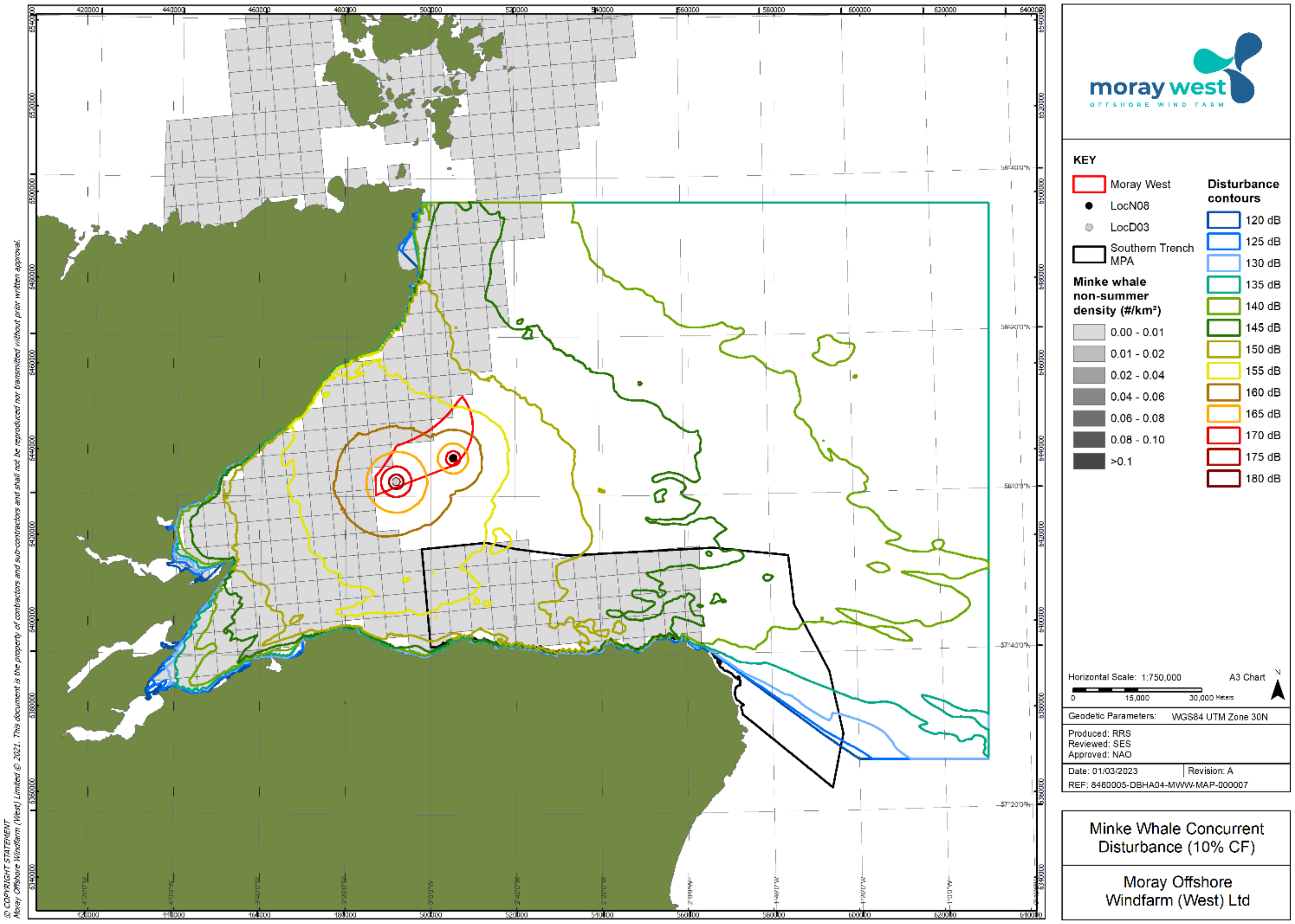

Figure 3-13 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for concurrent piling at locations D03 and N08 overlain with minke whale non-summer density. CF = 10%.

Assuming a total of 13 minke whales were disturbed on every single vessel piling day (22 days) and 13 minke whales were disturbed on every concurrent piling day (20 days) (Table 2-15), outputs from iPCoD estimate there to be no impact to the population (Table 3-15 and 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.

It is important to note that minke whale were not included in a recent update to iPCoD expert elicitation results (Booth and Heinis 2018). For all species that were updated the effects of impact piling were reduced considerably and therefore this assessment of population impacts to minke whale is highly conservative and likely overestimates any potential impact (see Section 2.7.5).

Given the very low proportion of the entire MU predicted to be impacted, and no discernible impact to the population in iPCoD modelling, 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 significant change to the population size or trajectory.

Table 3-15 Results of iPCoD modelling, giving the mean population size of minke whale for years up to 2042 for impacted and un-impacted populations.

Year	un-impacted population mean	impacted population mean	Impacted as % un-impacted
Start	20,120	20,120	100
End 2024	20,131	20,131	100
End 2030	20,055	20,055	100
End 2036	19,974	19,974	100
End 2042	19,953	19,953	100

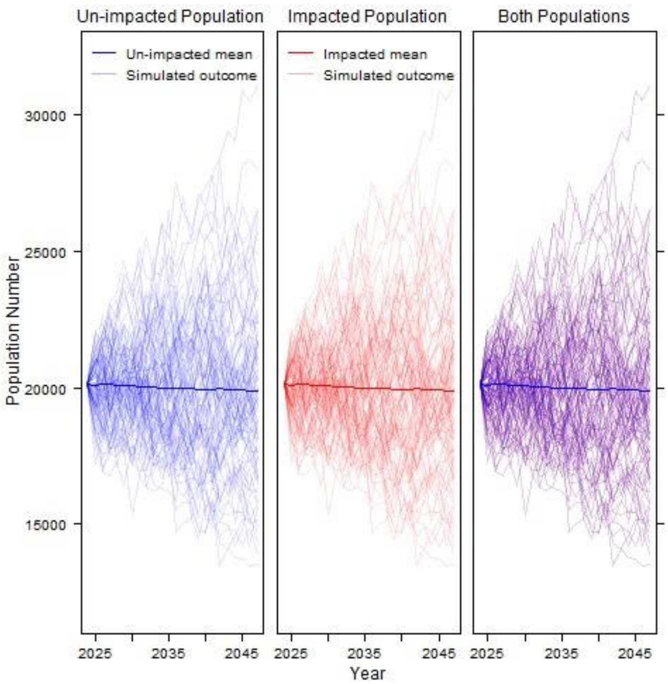

Figure 3-14 Simulated minke whale population sizes for both the un-impacted and the impacted populations.

3.2.4 Grey seal

The realistic worst case scenario for disturbance to grey seals from a single monopile installation event was evaluated for the installation of a monopile at locations D03 and L13 assuming a maximum hammer energy of 4,400kJ and a 10% CF (Table 3-16, Figure 3-15 and Figure 3-16). This resulted in a maximum prediction disturbance of 2,407 grey seals on a single day of piling at location L13 (this represents 4.06% of the combined Moray Firth, East Scotland & North Coast and Orkney MU).

The realistic worst case scenario for disturbance to grey seals from concurrent piling was evaluated for the installation of monopiles at locations D03 and N08 assuming hammer energies of 4,400 kJ and 1,295 kJ respectively and a 10% CF (Table 3-16 and Figure 3-17). This resulted in a predicted disturbance of 2,237 seals on a single day of piling (this represents 3.78% of the combined Moray Firth East Scotland & North Coast and Orkney MU).

Table 3-16 Comparison of the potential disturbance to grey seals resulting from worst case scenarios in this impact assessment compared with the 2018 EIA.

Assessment	Hammer Energy (kJ)	1% CF		4% CF		10% CF	
		# Seals	% MU	# Seals	% MU	# Seals	% MU
2018 EIA - concurrent piling events	5,000	346	9.80%*	….	….	….	….
Revised PS – single piling event (D03)	4,400	….	….	1,567	2.65%	2,232	3.77%
Revised PS – single piling event (L13)	4,400	….	….	1,432	2.42%	2,407	4.06%
Revised PS – concurrent piling events (N08 and D03)	4,400 (D03) 1,295 (N08)	….	….	1,576	2.66%	2,237	3.78%

*The 2018 EIA considered the Moray Firth MU, this assessment considers the Moray Firth, East Scotland & North Coast and Orkney MUs combined (See Table 2-7).

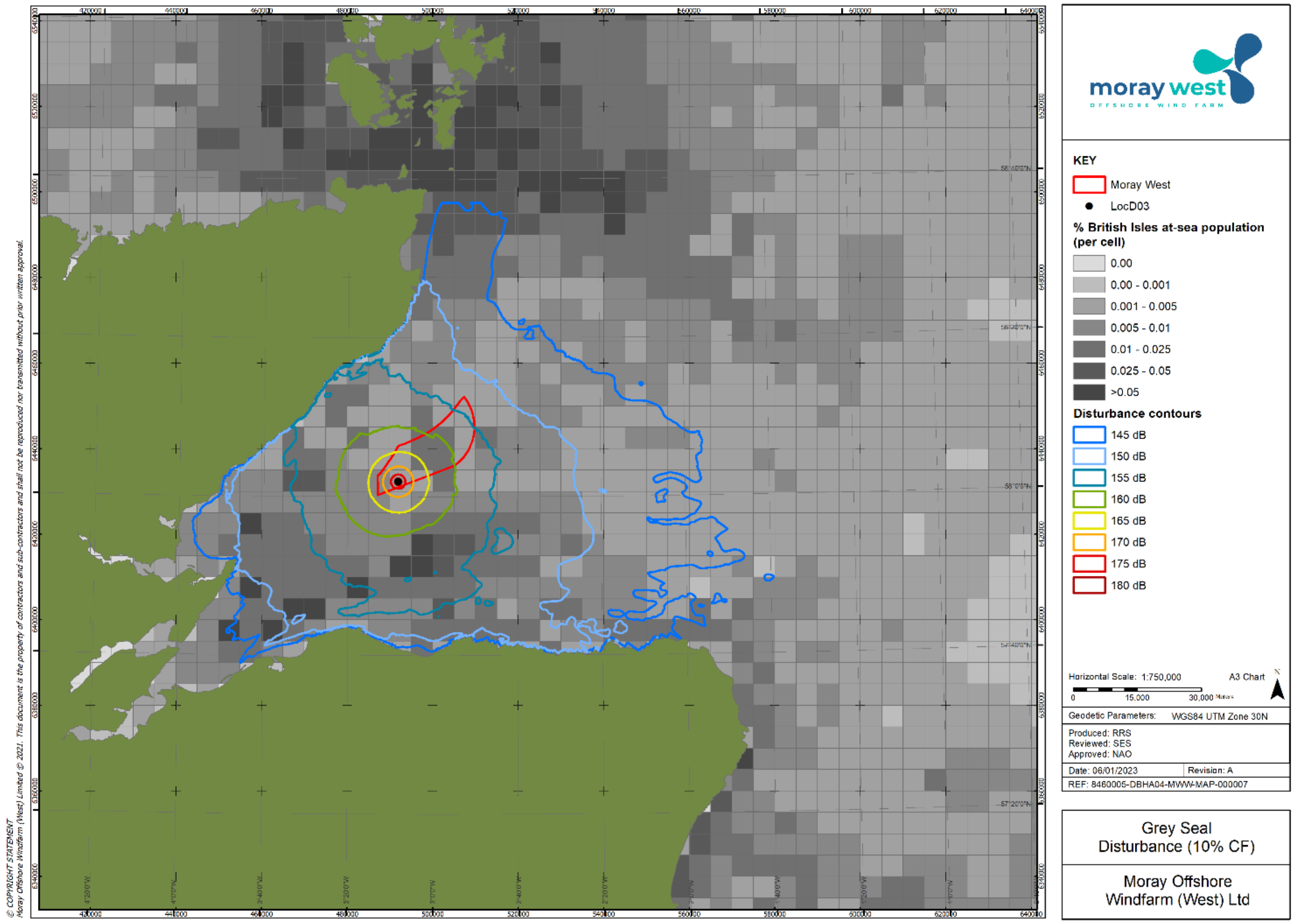

Figure 3-15 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location D03 overlain the grey seal distribution. CF = 10%, hammer energy = 4,400 kJ.

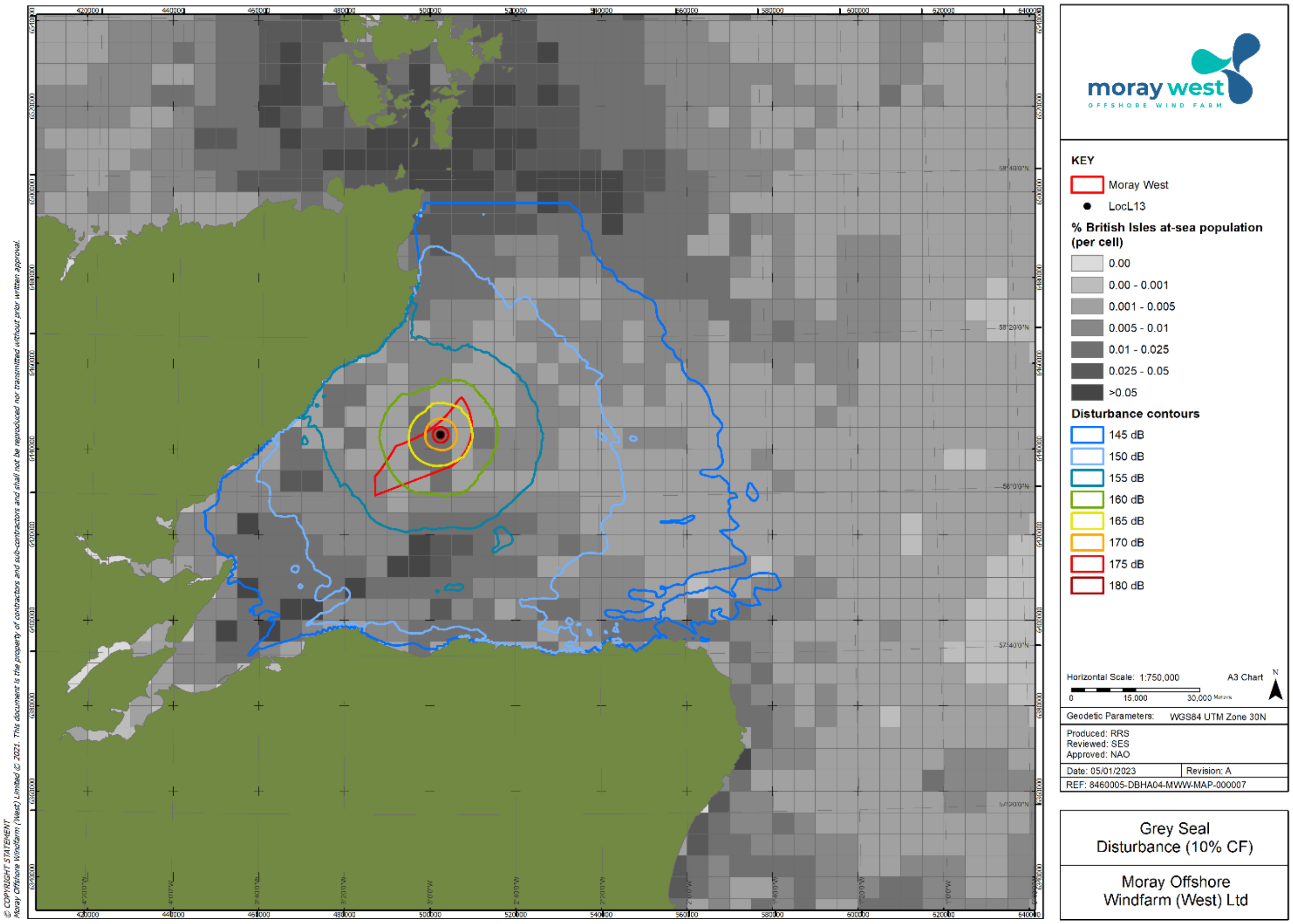

Figure 3-16 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location L13 overlain the grey seal distribution. CF = 10%, hammer energy = 4,400 kJ.

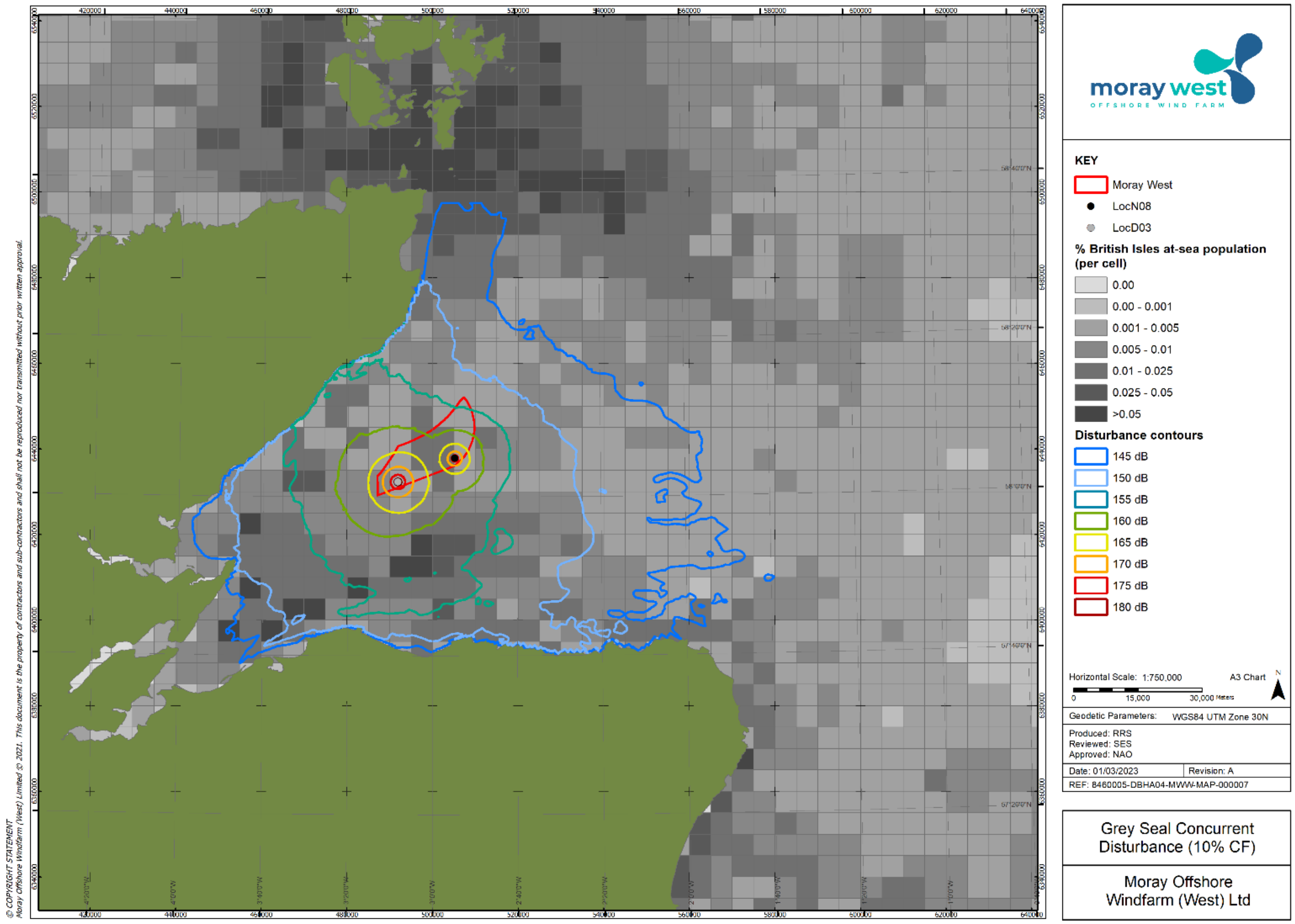

Figure 3-17 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for concurrent piling at locations D03 and N08 overlain with grey seal distribution. CF = 10%.

Assuming a total of 2,407 grey seals were disturbed on every single vessel piling day (22 days) and 2,237 grey seals were disturbed on every concurrent piling day (20 days) (Table 2-15), outputs from iPCoD estimate there to be no discernible impact to the grey seal population (Table 3-17 and 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 for both piling scenarios.

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.

Table 3-17 Results of iPCoD modelling, giving the mean population size of grey seal for years up to 2042 for impacted and un-impacted populations.

Year	un-impacted population mean	impacted population mean	Impacted as % un-impacted
Start	58,322	58,322	100
End 2024	59,122	59,122	100
End 2030	61,342	61,342	100
End 2036	63,662	63,662	100
End 2042	66,002	66,002	100

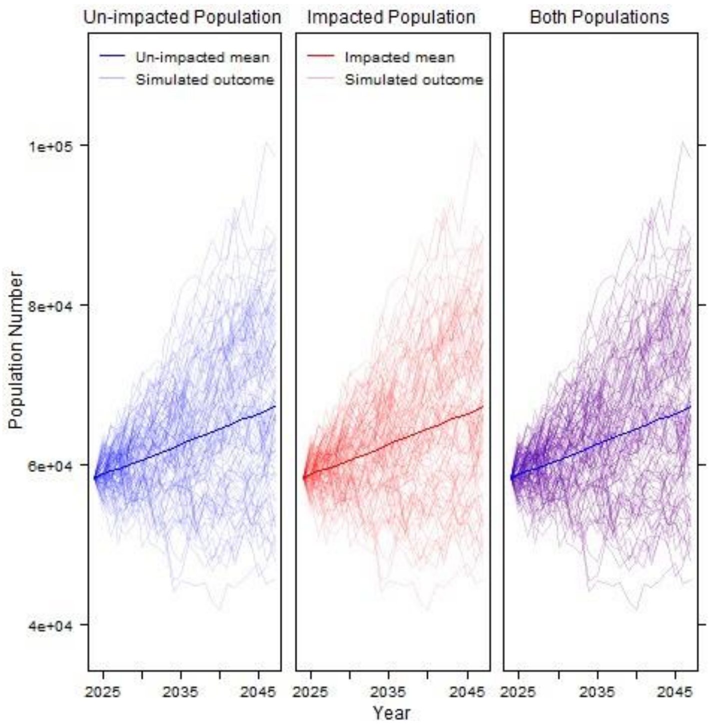

Figure 3-18 Simulated grey seal population sizes for both the un-impacted and the impacted populations.

3.2.5 Harbour seal

The realistic worst case scenario for disturbance to harbour seals from a single monopile installation event was evaluated for the installation of a monopile at location D03 assuming a maximum hammer energy of 4,400 kJ and a 10% CF (Table 3-18 and Figure 3-19). This resulted in a maximum prediction disturbance of 198 harbour seals on a single day of piling (this represents 5.74% of the combined Moray Firth & North Coast and Orkney MU).

The realistic worst case scenario for disturbance to harbour seals from concurrent piling was evaluated for the installation of monopiles at locations D03 and N08 assuming hammer energies of 4,400 kJ and 1,295 kJ respectively and a 10% CF (Table 3-18 and Figure 3-20).

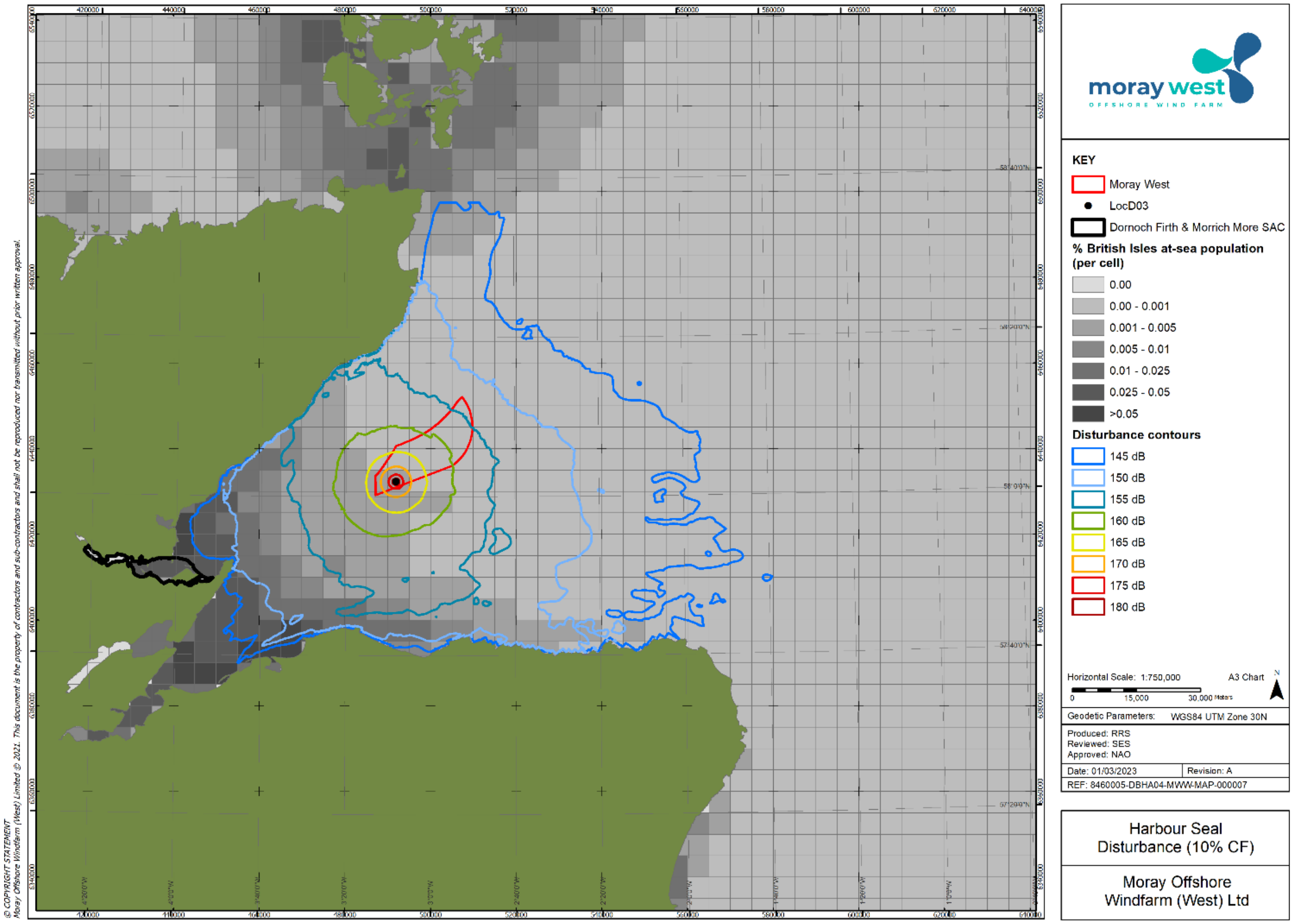

Figure 3-19 Disturbance contours showing SEL_{ss} isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for location D03 overlain the harbour seal distribution. CF = 10%, hammer energy = 4,400 kJ.

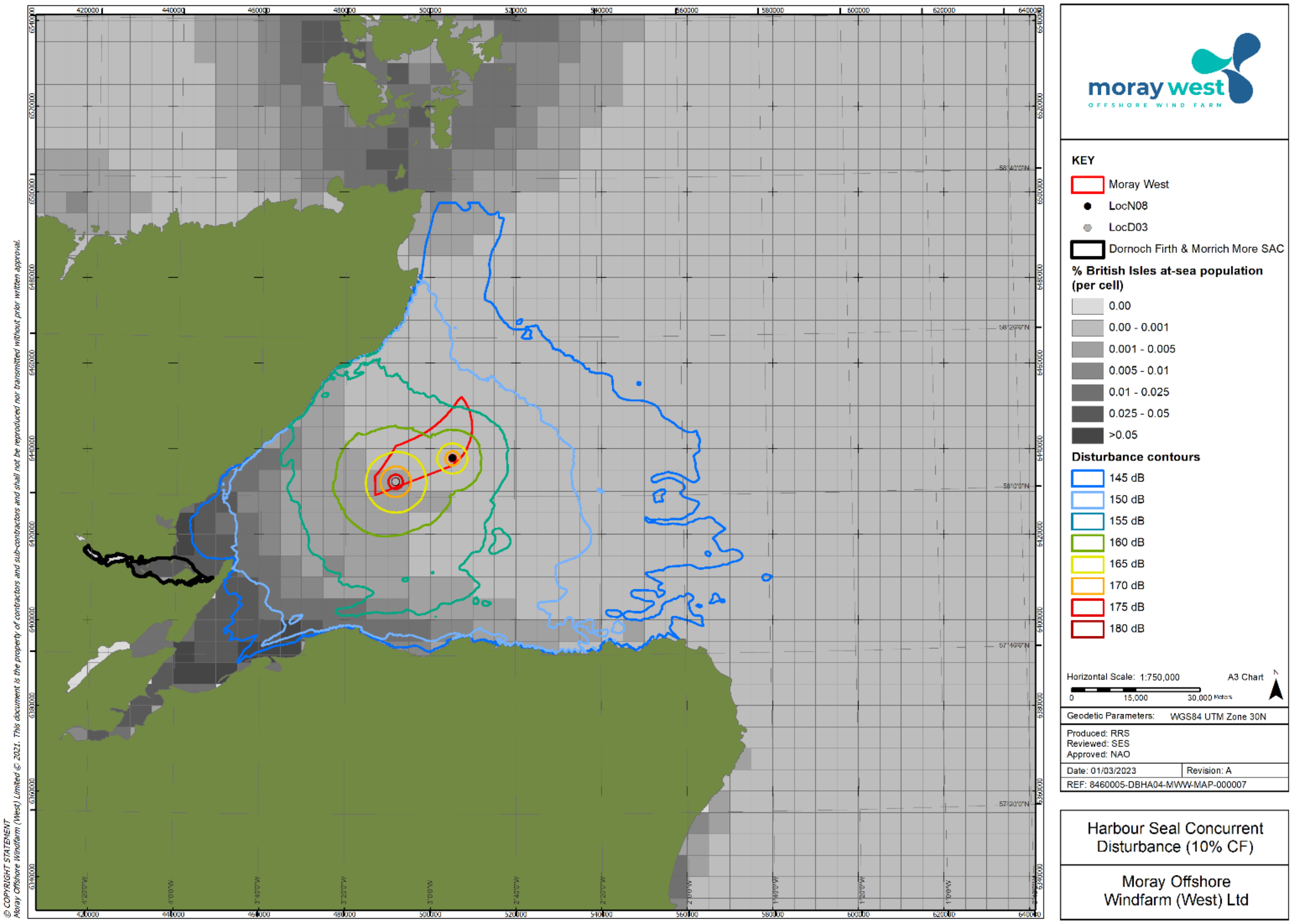

Figure 3-20 Disturbance contours showing SELss isopleths between 120 and 180 dB SEL re 1 µPa²s in 5 dB steps for concurrent piling at locations D03 and N08 overlain on harbour seal distribution. CF = 10%.

Table 3-18 Comparison of the potential disturbance to harbour seals resulting from worst case scenarios in this impact assessment compared with the 2018 EIA.

Assessment (Location)	Hammer Energy (kJ)	1% CF		4% CF		10% CF	
		# Seals	% MU	# Seals	% MU	# Seals	% MU
2018 EIA - concurrent piling events	5,000	36	2.75%	….	….	….	….
Revised PS – single piling event (D03)	4,400	….	….	116	3.36%	198	5.74%
Revised PS – concurrent piling events (N08 and D03)	4,400 (D03) 1,295 (N08)	….	….	116	3.36%	198	5.74%

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 3-21).

Assuming a worst case of 198 harbour seals disturbed on every single vessel piling day (22 days) and 198 harbour seals disturbed on every concurrent piling day (20 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, the outputs from iPCoD estimate there to be no discernible impact to the harbour seal population (Table 3-19 and Figure 3-22). 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 in all scenarios and the declining population trajectory remains the same, irrespective of disturbance from the pile driving at Moray West.

Assuming a worst case of 198 harbour seals disturbed on every single vessel piling day (22 days) and 198 harbour seals disturbed on every concurrent piling day (20 days), and if only the Moray Firth MU is modelled, the outputs from iPCoD estimate there to be no discernible impact to the harbour seal population (Table 3-20 and Figure 3-23). The mean population size for the impacted population was predicted to be the same as the un-impacted population size in every one of the 25 simulated years in all scenarios.

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.

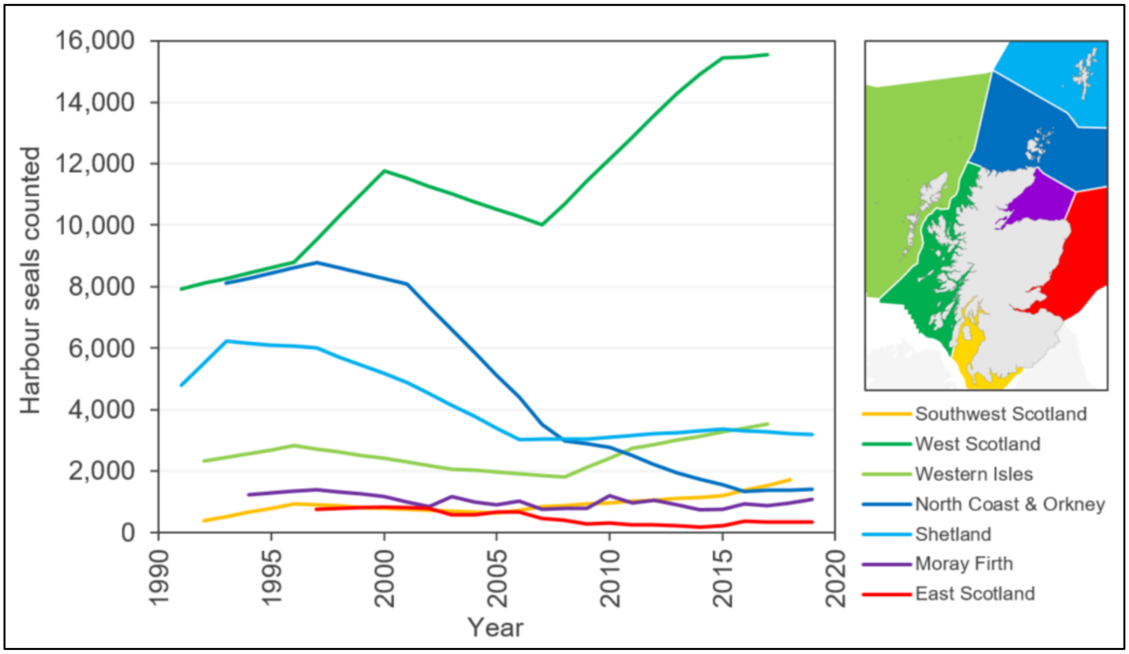

Figure 3-21 Comparison of August harbour seal counts in Scottish Seal Management Areas (SMAs) from 1991 to 2019. Obtained from SCOS (2021).

Table 3-19 Results of iPCoD modelling, giving the mean population size of harbour seal for years up to 2042 for impacted and un-impacted populations (assuming the MU is Moray Firth & Northern Coast & Orkney, and assuming North Coast & Orkney demographic parameters).

Year	un-impacted population mean	impacted population mean	Impacted as % un-impacted
Start	3,448	3,448	100
End 2024	2,770	2,770	100
End 2030	1425	1425	100
End 2036	734	734	100
End 2042	376	376	100

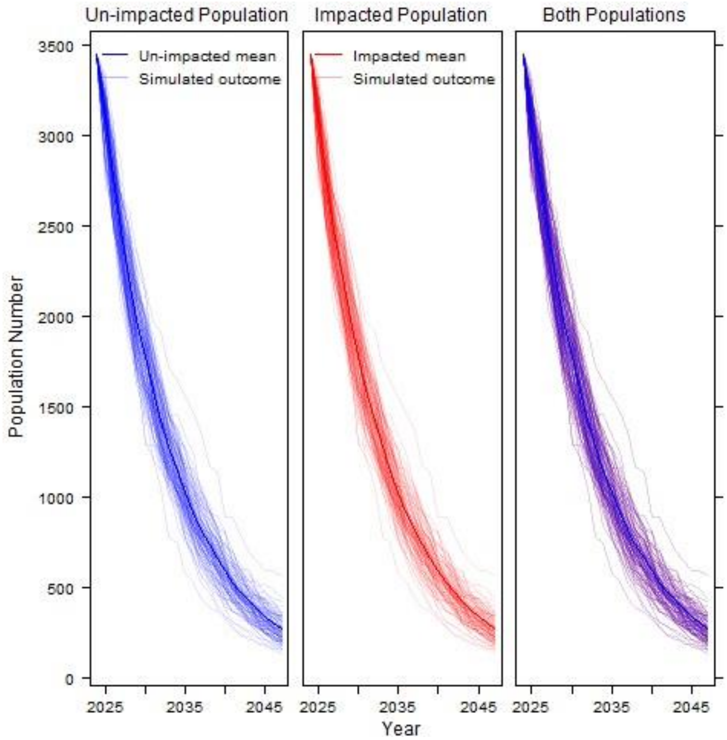

Figure 3-22 Simulated harbour seal population sizes for both the un-impacted and the impacted populations, assuming the MU is Moray Firth & Northern Coast & Orkney, and assuming North Coast & Orkney demographic parameters.

Table 3-20 Results of iPCoD modelling, giving the mean population size of harbour seal for years up to 2042 for impacted and un-impacted populations (assuming all impact goes to the Moray Firth (MF) MU, and assuming MF demographic parameters).

Year	un-impacted population mean	impacted population mean	Impacted as % un-impacted
Start	1,498	1,498	100
End 2024	1,498	1,498	100
End 2030	1,500	1,500	100
End 2036	1,506	1,505	100
End 2042	1,510	1,510	100

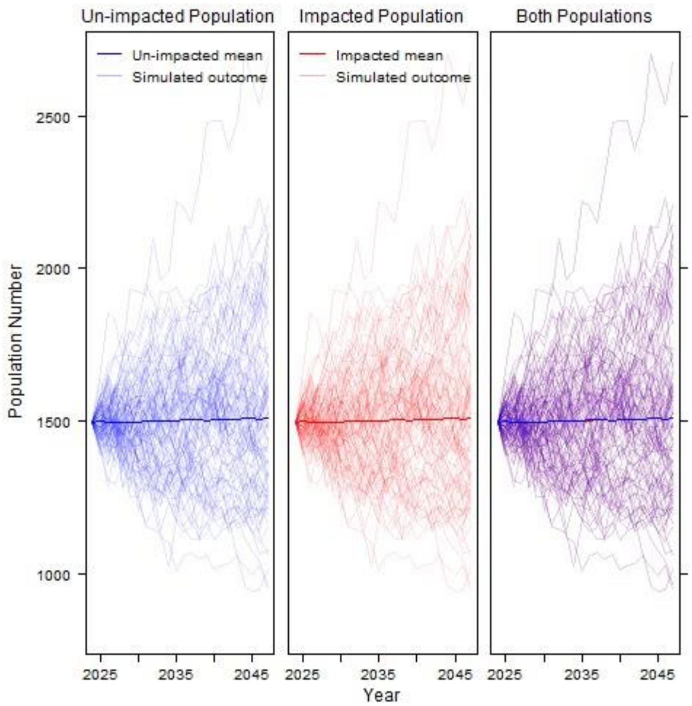

Figure 3-23 Simulated harbour seal population sizes for both the un-impacted and the impacted populations, assuming all impact goes to the Moray Firth (MF) MU, and assuming MF demographic parameters.

3.2.6 Limitations of disturbance assessment

There is a lack of empirical data on bottlenose dolphin, minke whale or sufficient empirical data on 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 3-18 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 µPa^{2}s 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).

The use of the dose-response relationship from Whyte et al. (2020) in conjunction with the modelling results presented here is conservative. The exact drivers behind the dose-response relationship are unknown and are likely to be influenced by a combination of distance from the sound source and the received level. Yet the dose-response curve presented in Whyte et al. (2020) is based upon received level only. Responses of animals are not only elicited by the received level but also by other factors, such as signal shape. The shape of a signal with the same SEL from the same sound source differs depending on distance. Piling noise loses its impulsive character with distance (Southall et al. 2007, Hastie et al. 2019, Southall et al. 2019a), and therefore animals are expected to react less strongly to piling noise with the same received levels when exposed at larger distances. Such an effect has been quantified for blue whales with regard to military sonar, where a received level of 170 dB SEL_{cum} at 1 km resulted in a probability of response at severity score 4-6[16] of >0.5, whereas the same received level of 170 dB SEL_{cum} at 5 km resulted in a probability of response at severity score 4-6 of <0.1 (Southall et al. 2019b) (Figure 3-24). This is important to note, since the original dataset in Whyte et al. (2020) showed that '*predicted seal density significantly decreased within 25 km or above SEL_{ss} 145 dB re 1 µPa²s*'. The 145 dB isopleth resulting from the Cefas modelling extends well beyond 25 km from the sound source (>45 km). Therefore, the received sound at locations beyond the modelling space is unlikely to elicit a response as the signal shape will be different to that received at 25 km in the Whyte et al. (2020) study.

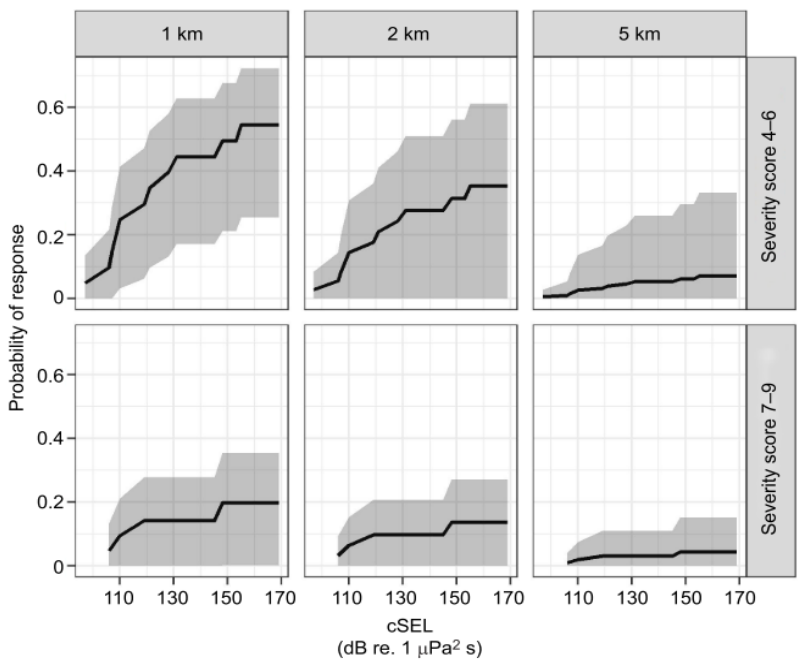

Figure 3-24 Behavioural response probability for blue whales exposed to military sonar as a function of received level and distance from the sound source. Severity score 4-6 denotes 'moderate severity 'and 7-9 denotes 'high severity'. Image taken from Southall et al. (2019b).

In addition 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

[16] Severity score 4-6 denotes "moderate severity"

driving at other UK wind farms and Moray Firth developments has often been completed using much lower than predicted hammer energies (see Section 2.7.2.1.2 and BOWL & Moray East Piling Reports).

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 (Section 2.7.2.3.3), 7 animals are estimated to be within the MPA at any one time in non-summer months.

3.3.2 Auditory injury

There is no overlap between the Southern Trench MPA and predicted auditory injury for single piling event at N08 (Figure 3-3), the location representing the majority of monopiles to be installed on the Moray West Site. There is a small overlap between the Southern Trench MPA and predicted auditory injury for single piling event at G07 (Figure 3-2); however, the predicted impact is <1 minke whale within the MPA boundary being at risk of PTS.

For concurrent piling events at D03 and N08 the risk is also <1 animal despite the highly conservative approach to the impact assessment noted about and in Section 2.7.2.1.2.

It is worth noting the distance from G07 to the nearest edge of the Southern Trench MPA boundary is approximately 20 km. As pulsed sound from piling loses its impulsive characteristics while propagating away from the sound source (Hastie et al. 2019, Southall et al. 2019a, 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. 2019a, Martin et al. 2020). 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*.' Therefore, no minke whales within the MPA are expected to experience injury as a result of pile driving at Moray West.

Therefore, within the Southern Trench MPA the risk of auditory injury can be considered non-significant 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 155 dB at 10% CF for any location modelled, thus results in this section are only presented for ≤155dB. The MPA area within which disturbance is expected with a 10% CF is 42% for location G07 (Table 3-21 and Figure 3-13), 29% for location N08 (Table 3-22 and Figure 3-14) and 42% for locations D03 and N08 installed concurrently (Table 3-23 and Figure 3-15).

Table 3-21 Calculation of the % MPA within which minke whale are potentially disturbed using the Graham et al. (2017) dose-response curve for location G07 and a 10% CF.

dB level	DR	Size of area overlapping with MPA (km²)	Size of area overlapping with MPA (km²)	Effective disturbance area (km²)
155	0.8266	91.4	91.4	76
150	0.6849	663.4	572.1	392
145	0.5090	1,338.9	675.5	344
140	0.3312	1,872.0	533.1	177
135	0.1852	2,010.0	227.9	42
130	0.0878	2,159.2	59.2	5
125	0.0349	2,176.9	17.7	1
120	0.0115	2,179.9	3.0	0
Total			**2179.9**	**1,036**
% of MPA area				**42%**

Table 3-22 Calculation of the % MPA within which minke whale are potentially disturbed using the Graham et al. (2017) dose-response curve for location N08 and a 10%CF.

dB level	DR	Size of area overlapping with MPA (km²)	Size of area overlapping with MPA (km²)	Effective disturbance area (km²)
150	0.6849	237.4	237.4	163
145	0.5090	773.0	535.6	273
140	0.3312	1,323.2	550.2	182
135	0.1852	1,850.9	527.7	98
130	0.0878	2,022.1	171.1	15
125	0.0349	2,104.1	82.0	3
120	0.0115	2,121.9	17.8	0
Total			**2121.8**	**733**
% of MPA area				**29%**

Table 3-23 Calculation of the % MPA within which minke whale are potentially disturbed using the Graham et al. (2017) dose-response curve for concurrent piling at locations D03 and N08 and a 10%CF.

dB level	DR	Size of area overlapping with MPA (km^2)	Size of area overlapping with MPA (km^2)	Effective disturbance area (km^2)
155	0.8266	156.8	156.8	130
150	0.6849	706.3	549.5	376
145	0.5090	1,294.9	588.6	300
140	0.3312	1,851.4	556.6	184
135	0.1852	2,042.5	191.1	35
130	0.0878	2,174.2	131.7	12
125	0.0349	2,235.6	61.4	2
120	0.0115	2,253.6	18.0	0
Total			**2253.6**	**1,039**
% of MPA area				**42%**

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 30% of the MPA is expected to be disturbed when piling no driveability risk locations (N08). This represents the majority of the piling on the Moray West Site in the base case scenario (Section 2.1).

Although just over 40% of the MPA is expected to be disturbed for piling at those locations with a moderate risk of pile driving refusal and for concurrent piling events, are limited in the number of days on which they will occur[17] and are predicted to disturb only 3 animals within the MPA on a given piling day. Although an area of the MPA may be impacted by piling, all disturbance will occur in non-summer months with lower densities of minke whales. Additionally all piling will occur within one annual cycle for a maximum of 62 days. This is expected to result in a non-significant impact (a recoverable change in distribution), especially when considering the generation time of minke whales is 22.1 years (Taylor et al. 2007).

[17] There are only 15 piles with any driveability risk and the potential for concurrent piling depends on two vessels being on-site simultaneously

3.3.4 Prey availability

Piling at the monopile locations within the Moray West Site was assessed to have no impacts to sandeel and herring, prey species of minke whales[18], 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 prey species rely on, due to the piling at the Moray West Site.

3.3.5 Conclusions

We conclude that piling at the Moray West Site does not constitute a significant risk of auditory injury to minke whales within the Southern Trench MPA, and will not reduce absolute densities of minke whales within the MPA. Piling for the installation of the 62 monopiles is not expected to result in significant disturbance as it occurs within one annual cycle and will not contribute to a long-term decline in the use of the MPA by minke whales, 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, pile driving at the Moray West Site will not have a significant impact on the Southern Trench MPA.

3.4 Proposed mitigation measures

In addition to the piling installation programme commitments already made by Moray West to reduce potential impacts to minke whale (Section 2.1), 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 for harbour porpoise:

1) An ADD-activation period prior commencement of pile driving start
2) Soft-start procedure with a maximum hammer energy of 432 kJ
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 in Appendix D – Revised PMP.

3.5 Comparison to 2018 EIA

The results presented in the Revised Piling Strategy are generally the same as those presented in the Moray West EIA Report 2018. Specific comparisons with the 2018 EIA are provided in tables throughout the Revised Piling Strategy and summarized here for reference:

1. Instantaneous PTS for all species (Table 3-1)
2. Cumulative PTS for harbour porpoise across all piling scenarios (Table 3-8)

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[18] Moray Offshore Windfarm (West) Limited, Revised Piling Strategy Appendix C Section 4 Fish Impact Assessment Results.

3. Cumulative PTS across all piling scenarios for minke whale (Table 3-9)

4. Disturbance for:

- harbour porpoise (Table 3-10)
- bottlenose dolphin (Table 3-12)
- minke whale (Table 3-14)
- grey seal (Table 3-16)
- harbour seal (Table 3-17)

Both the Moray West EIA Report 2018 and this assessment concluded no significant effect of instantaneous or cumulative PTS-onset to any marine mammal species when considering impacts against the entire MU (Table 3-24 and Table 3-25).

The proportion of the population impacted increases when considering only the UK portion of the population, however, as stated in Section 2.7.2.3, 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 MU sizes, density surfaces and the seal dose-response relationship, both the Moray West EIA Report 2018 and this Revised PS assessment concluded no significant effect of behavioural disturbance to any marine mammal species (Table 3-26).

Table 3-24 Comparison of the evaluation of sensitivity, magnitude, and impact of Instantaneous PTS on marine mammal species in the 2018EIA and this Revised Piling Strategy.

	2018 EIA			Revised 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 3-25 Comparison of the evaluation of sensitivity, magnitude, and impact of cumulative PTS on marine mammal species in the 2018 EIA and this Revised piling strategy.

	2018 EIA			Revised 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 3-26 Comparison of the evaluation of sensitivity, magnitude, and impact of disturbance on marine mammal species in the 2018 EIA and this Revised piling strategy.

	2018 EIA			Revised 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	Negligible
Harbour seal	Medium	Low	Minor Adverse	Medium	Negligible	Minor Adverse

3.6 Comparison to 2018 RIAA

3.6.1.1 Dornoch Firth and Morrich More SAC

In both realistic worst cases scenarios modelled for harbour seal disturbance (Figure 3-21 and Figure 3-22) the disturbance contours do not overlap with the Dornoch Firth and Morrich More SAC. Thus, harbour seals within the SAC are not expected to experience significant disturbance while in the SAC and there will be no adverse effect on the harbour seal feature of the Dornoch Firth and Morrich More SAC because of piling at Moray West Site. Although harbour seals moving to and from the SAC may be disturbed as a result of piling, iPCoD modelling showed that the predicted level of disturbance will not result in a significant long-term change in population growth rate or trajectory for the Moray Firth MU, and thus no significant impact is expected at the SAC (Figure 3-25).

3.6.1.2 Moray Firth SAC

The conservation objectives of the Moray Firth SAC for bottlenose dolphins are outlined in NatureScot (2021):

1) To ensure that the qualifying features of Moray Firth SAC are in favourable condition and make an appropriate contribution to achieving Favourable Conservation Status.
2) To ensure that the integrity of Moray Firth SAC is maintained or restored in the context of environmental changes:
    - The population of bottlenose dolphin is a viable component of the site.
    - The distribution of bottlenose dolphin throughout the site is maintained by avoiding significant disturbance.
    - The supporting habitats and processes relevant to bottlenose dolphin and the availability of prey for bottlenose dolphin are maintained.

In both realistic worst case scenarios modelled for bottlenose dolphin disturbance (Figure 3-9 and Figure 3-10) there is overlap with the Moray Firth SAC with up to 54 bottlenose dolphins predicted to be disturbed on a given piling day across the entire impact area (Table 3-12). This is an increase from the 14 bottlenose dolphins predicted to be disturbed in the 2018 RIAA. There is the potential for animals within the SAC to be disturbed which may result in very short-term changes to the bottlenose dolphin distribution within the SAC. Despite the number of animals predicted to be disturbed, the disturbance is expected to be non-significant as effects are not expected to be long term or prohibit recovery. Fernandez-Betelu et al. (2021) showed that bottlenose dolphins were not displaced from the southern coast of the Moray Firth by impulsive noise generated by pile driving at Beatrice or Moray East and that they continued using the southern coast during impact pile driving. Given these findings, the piling for Moray West (expected to occur on 62 days spread over 8 months) is not expected to contribute to a long-term decline in the use of the SAC site by bottlenose dolphins, nor result in changes to their distribution on a continued or sustained basis, nor result in a behavioural change that would reduce survival or reproduction. iPCoD modelling showed that the predicted level of disturbance will not result in a significant long-term change in population growth rate or trajectory for the Coastal East Scotland MU (Figure 3-11 and Figure 3-12).

Although the numbers predicted to be disturbed are higher than considered in the 2018 RIAA, any effects are short-term and temporary and therefore there will be no adverse effect on the bottlenose dolphin feature of the SAC.

4 Fish Impact Assessment

4.1 Introduction

4.1.1 Background

The Moray West PS was reviewed by NatureScot on the 11 August 2022 who subsequently provided advice. 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 aligned with the conclusions from the Moray West EIA Report 2018 and the Habitats Regulations Assessment (HRA) which were prepared in 2018.

This section provides an updated FIA for the Moray West Revised PS. The FIA has also been summarised in Section 5 of the Revised PS.

4.1.2 Scope of Fish Impact Assessment

The scope of works undertaken to update the FIA included the following:

- A review of the Moray West Revised PS, in particular the number of piles, size and seasonality to which piling will take place.
- A review of other OWF projects which have had a similar PS and how this could be applied to the updated fish impact assessment for the Revised PS.
- A review of the Moray West Site and freshwater rivers entering the onshore area of the Moray OWF Development Zone.
- 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 Revised PS undertaken by Centre for Environment Fisheries and Aquaculture Science (Cefas).
- Determining the updated noise thresholds / buffer zone predictions based on the above Cefas modelling report and Popper et al (2014) for the Revised PS.
- 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 the Piling Strategy.

4.2 Underwater Noise Modelling

Modelling of underwater piling noise has been carried out 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 2018 ES presented the noise modelling using 0.5% and 1% conversion factors. Although it is now assumed by Cefas in the current modelling, based on an appraisal of the available literature, 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.

Cefas has undertaken noise modelling (January 2023) for the pile driving associated WTG monopile installation at four locations within the windfarm site (locations N08, G07, L13, and D03). The modelling has predicted the effect ranges of piling noise on mortality and potential mortal injury, recoverable injury, and temporary threshold shift (TTS) for relevant fish species. The modelling includes effect estimates for single locations (with up to three consecutive piles at each location), and for concurrent piling at two locations (with up to three consecutive piles at each location). A 'best estimate' blow count scenario of BE50 (50 blows/25 cm) for a CF of 4% and 10% has been modelled. The BE50 piling profiles use high strike energies (up to 4400 kJ).

Underwater noise and risk posed to fish can be characterised by a number of metrics. Peak sound pressure (SPLpeak) (or particle motion) is the maximum absolute value of the instantaneous sound pressure (or motion) during a specified time interval. Sound exposure level (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 SPLpeak thresholds. Instantaneous SPLpeak effects have been modelled at WTG locations D03, N08, G07 and L13. For each of the four locations, 4% and 10% conversion factors have been used, giving a total of 8 modelled scenarios.

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 SELcum metric is used to assess for mortality, recoverable injury and TTS. For the purposes of worst case scenario modelling, fish are conservatively assumed to remain stationary for the 24-hour modelling period. For cumulative SEL_{cum} effects, a total of 36 scenarios are modelled:

- single locations N08, G07 and L13;
- concurrent locations D03-N08, D03-G07 and D03-L13;
- in each case with either 1, 2 or 3 consecutive piles;
- and with 4% and 10% conversion factors.

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 recent 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 species such as cod or herring, the hearing of the salmon is 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 re: 1µPa @1m, 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 re: 1 µPa @1m 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 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).

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). Atlantic salmon 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)[19]

Type of Animal	Parameter	Mortality and Potential Mortal Injury	Recoverable Injury	TTS
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	-

4.4.2 Impact Assessment (Adult Salmonids and Smolts)

4.4.2.1 SPLpeak 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 SPL_{peak}) was 1470 m at location L13, for a maximum hammer energy of 4,400kJ and 10% energy CF. The corresponding effect range for the 4% energy conversion factor was 840 m (Table 4-2).

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

Location(s)	Hammer energy (kJ)	Threshold (SPL_{peak} dB re 1 µPa)	Maximum effect range (m) at 4% C.F.	Maximum effect range (m) at 10% C.F.
N08	1295	207	280	670
G07	4400	207	810	1450

[19] Hearing groups 1,3, and 4 excluded from table as not relevant to this assessment.

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

Location(s)	Hammer energy (kJ)	Threshold (SPL_{peak} dB re 1 µPa)	Maximum effect range (m) at 4% C.F.	Maximum effect range (m) at 10% C.F.
L13	4400	207	840	1470
D03	4400	207	800	1440

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 3433 m for three monopiles piled consecutively (i.e. within a 24-hour period) at location G07 with an energy conversion factor of 10%. The corresponding maximum range for the 4% conversion factor, also at location G07, was 1924 m. The greatest recoverable injury range was 9,588 m, and the greatest TTS range was 72,829m, both at the same location (G07), blow count profile (BE50) and conversion factor (10%). For the 4% conversion factor, these ranges were reduced to 4,151 m for recoverable injury and to 58,310 m for TTS (Table 4-3). The effect areas are shown from Figures 4-1 to 4-18.

Table 4-3 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. Thresholds for these effects are 210, 203, and 186 dB SEL_{cum} re 1 µPa^2 s, respectively. Modelling results for piles driven at single locations (i.e. no concurrent piling)

Location(s)	Conversion factor (%)	Consecutive piles	Mortality area (km^2); *range (m)*	Recoverable injury area (km^2); *range (m)*	TTS area (km^2); *range (m)*	Figure number
N08	4	1	0.01; *45*	4.9; *1283*	548.2; *14,609*	N/A
		2	1.5; *739*	12.6; *2091*	1,115.1; *31,077*	N/A
		3	2.4; *923*	21.8; *2693*	1814.3; *36,309*	N/A
G07	4	1	2.6; *923*	21.9; *2647*	1954.8; *34,216*	N/A
		2	6.7; *1483*	52.5; *4151*	3471.2; *56,032*	N/A

		3	11.4; *1,924*	85.6; *5,464*	4443.3; *58,310*	N/A
L13	4	1	2.0; *827*	17.0; *2,450*	1453.9; *31,646*	N/A
		2	5.2; *1,334*	40.5; *3,812*	2866.1; *52,000*	N/A
		3	8.9; *1,740*	67.1; *4,913*	4038.0; *58,120*	N/A
N08	10	1	1.9; *811*	17.1; *2390*	1447.5; *35,066*	**Figure 4-1**
		2	4.9; *1,282*	40.5; *3,699*	3246.6; *52,090*	**Figure 4-2**
		3	8.6; *1,683*	68.0; *4,929*	4336.; *58,737*	**Figure 4-3**
G07	10	1	8.8; *1,691*	68.3; *4,750*	3959.3; *57,404*	**Figure 4-4**
		2	22.1; *2,666*	157.6; *7,744*	5671.0; *69,890*	**Figure 4-5**
		3	36.5; *3,433*	249.2; *9,588*	6789.5; *72,829*	**Figure 4-6**
L13	10	1	7.1; *1,543*	53.6; *4,396*	3506.0; *54,817*	**Figure 4-7**
		2	17.0; *2,450*	121.9; *6,545*	5576.4; *68,826*	**Figure 4-8**
		3	28.1; *3,122*	191.0; *8,340*	7017.7; *69,079*	**Figure 4-9**

Table 4-4 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. Thresholds for these effects are 210, 203, and 186 dB SEL_{cum} re 1 µPa^2 s, respectively. Modelling results for piles driven at multiple locations concurrently

Location(s)	Conversion factor (%)	Consecutive piles (at each location)	Mortality area (km^2)[20]	Recoverable injury area (km^2)	TTS area (km^2)	Figure number
D03 and N08	4	1	1.8	21.1	2362.3	N/A
		2	6.0	53.3	3915.9	N/A
		3	10.4	92.4	4938.7	N/A
D03 and G07	4	1	4.6	53.6	3177.6	N/A
		2	12.6	117.7	4859.3	N/A
		3	23.8	181.5	5708.8	N/A
D03 and L13	4	1	3.8	34.0	3090.2	N/A
		2	9.8	86.3	4872.3	N/A
		3	17.1	154.2	5917.3	N/A
D03 and N08	10	1	8.2	71.9	4499.4	**Figure 4-10**

[20] Range not included as it is not a meaningful metric for two concurrent piling events at different locations

Table 4-4 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. Thresholds for these effects are 210, 203, and 186 dB SEL_{cum} re 1 μPa^2 s, respectively. Modelling results for piles driven at multiple locations concurrently

Location(s)	Conversion factor (%)	Consecutive piles (at each location)	Mortality area (km^2)[20]	Recoverable injury area (km^2)	TTS area (km^2)	Figure number
		2	20.9	198.0	6105.7	**Figure 4-11**
		3	36.3	330.7	7240.4	**Figure 4-12**
D03 and G07	10	1	17.8	148.8	5314.6	**Figure 4-13**
		2	53.5	318.3	7126.2	**Figure 4-14**
		3	85.9	475.2	8420.9	**Figure 4-15**
D03 and L13	10	1	13.6	117.8	5465.7	**Figure 4-16**
		2	33.8	314.2	7382.0	**Figure 4-17**
		3	58.3	479.1	8697.0	**Figure 4-18**

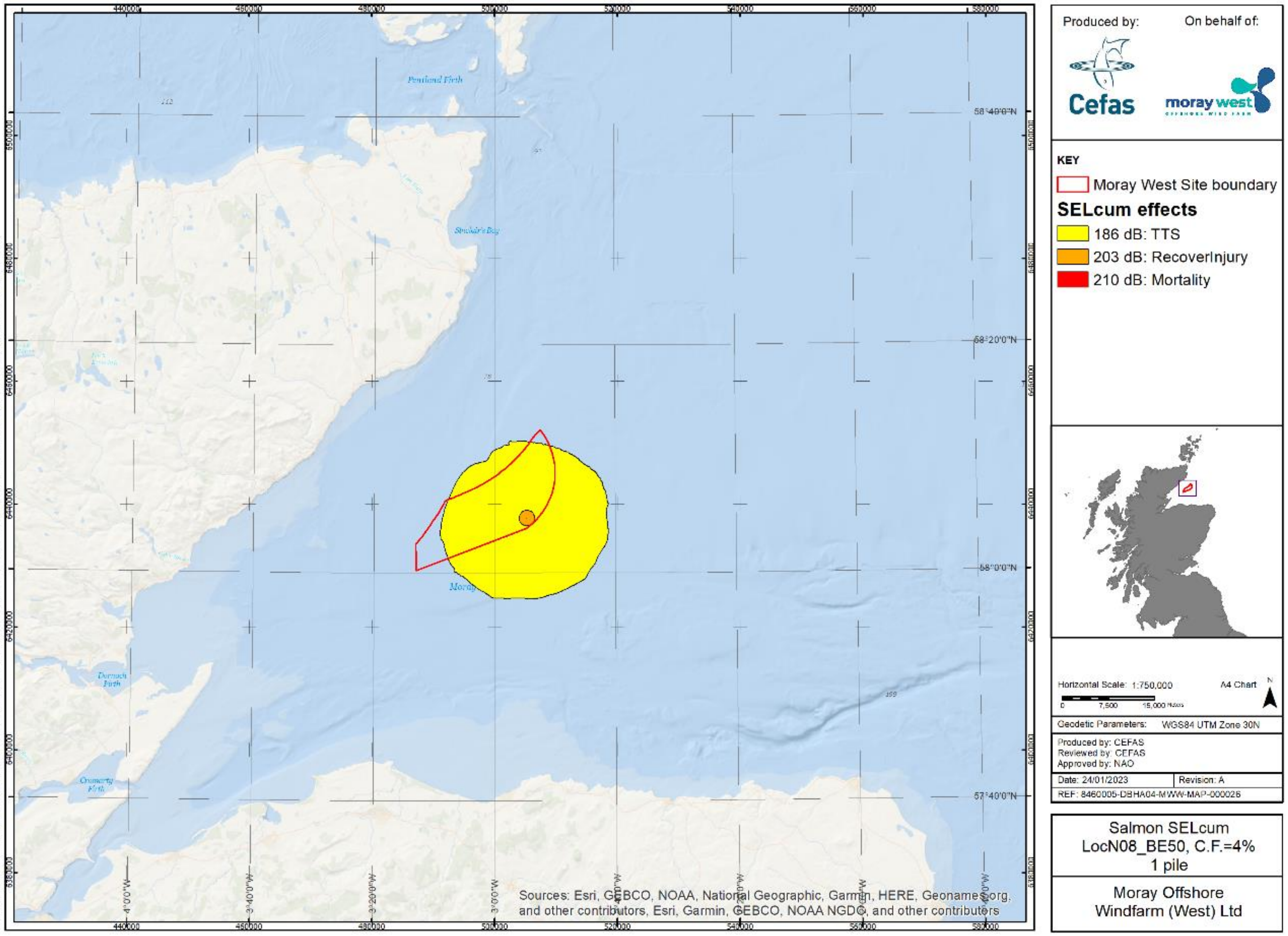

Figure 4-1 Cumulative exposure effect zones for fish species exposed to noise from 1 pile at location N08, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

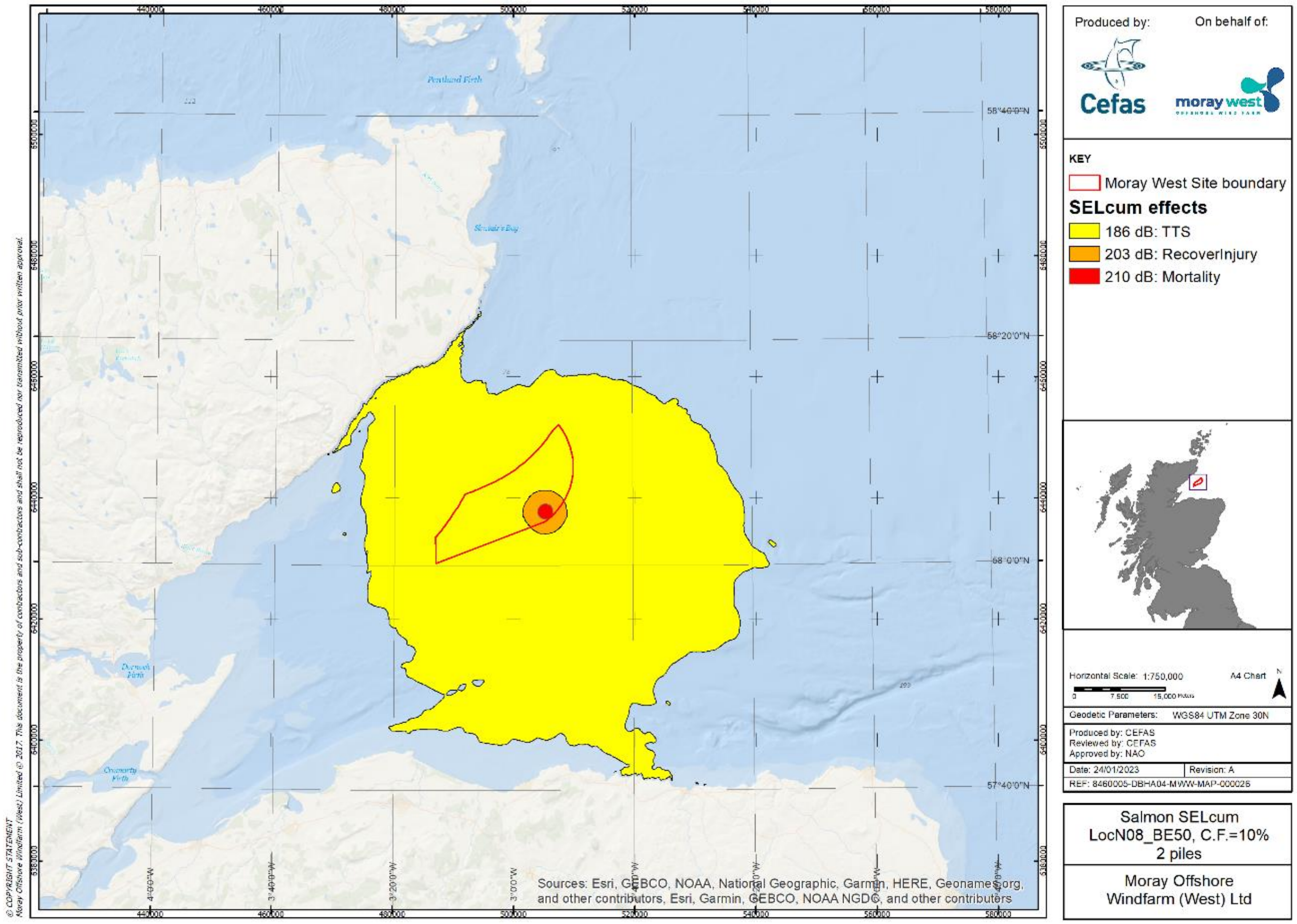

Figure 4-2 Cumulative exposure effect zones for fish species exposed to noise from 2 consecutive piles at location N08, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

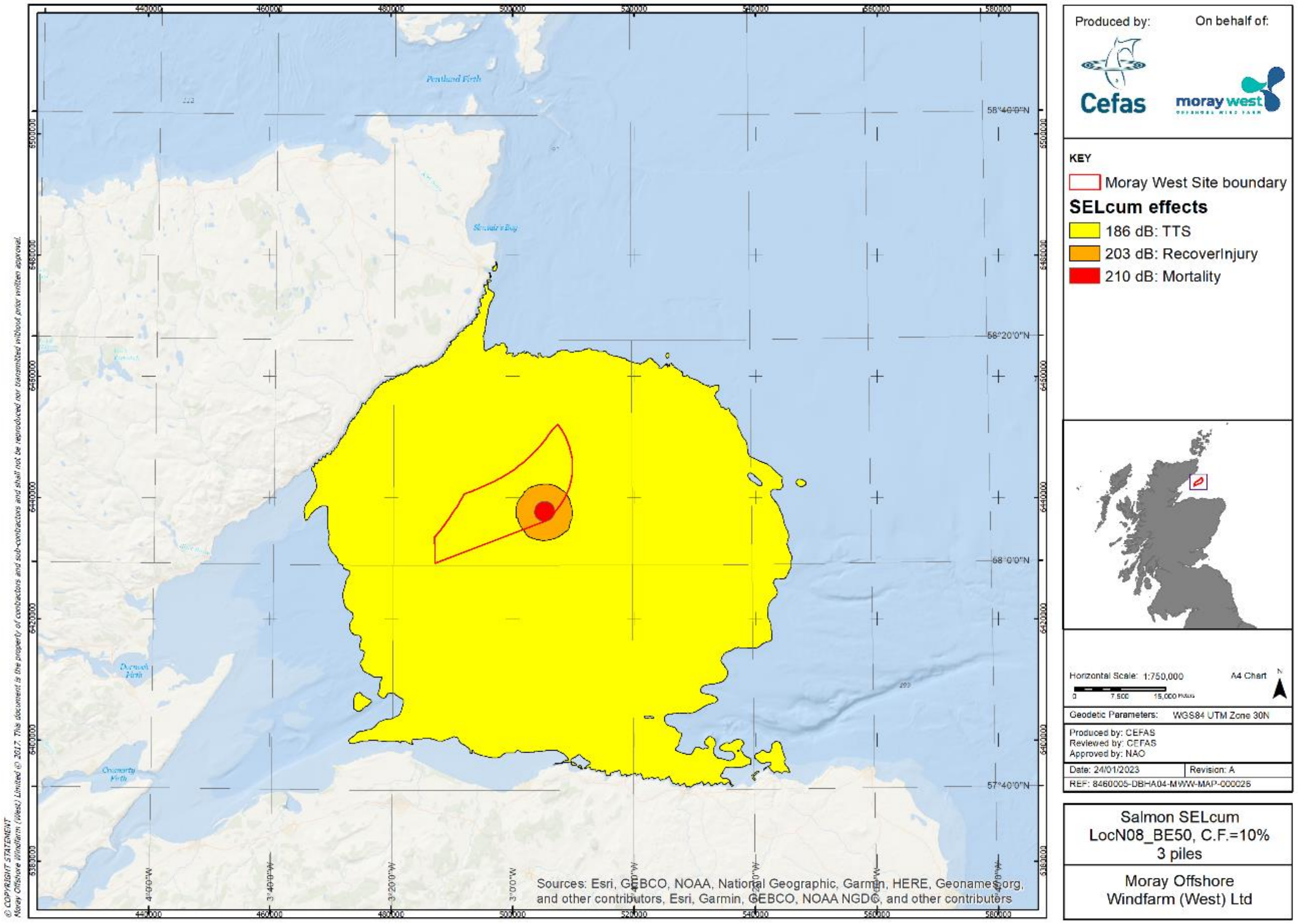

Figure 4-3 Cumulative exposure effect zones for fish species exposed to noise from 3 consecutive piles at location N08, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

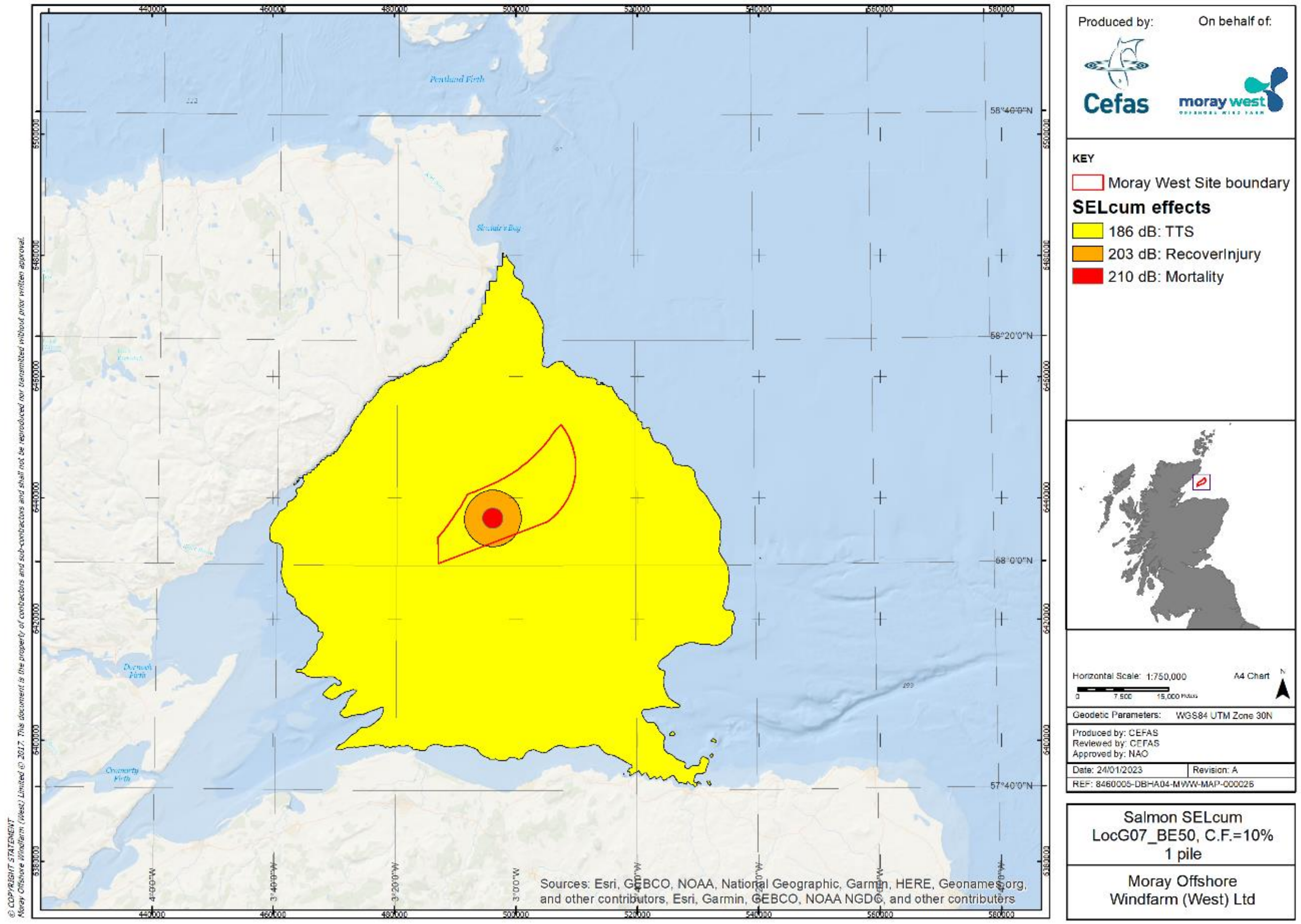

Figure 4-4 Cumulative exposure effect zones for fish species exposed to noise from 1 pile at location G07, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

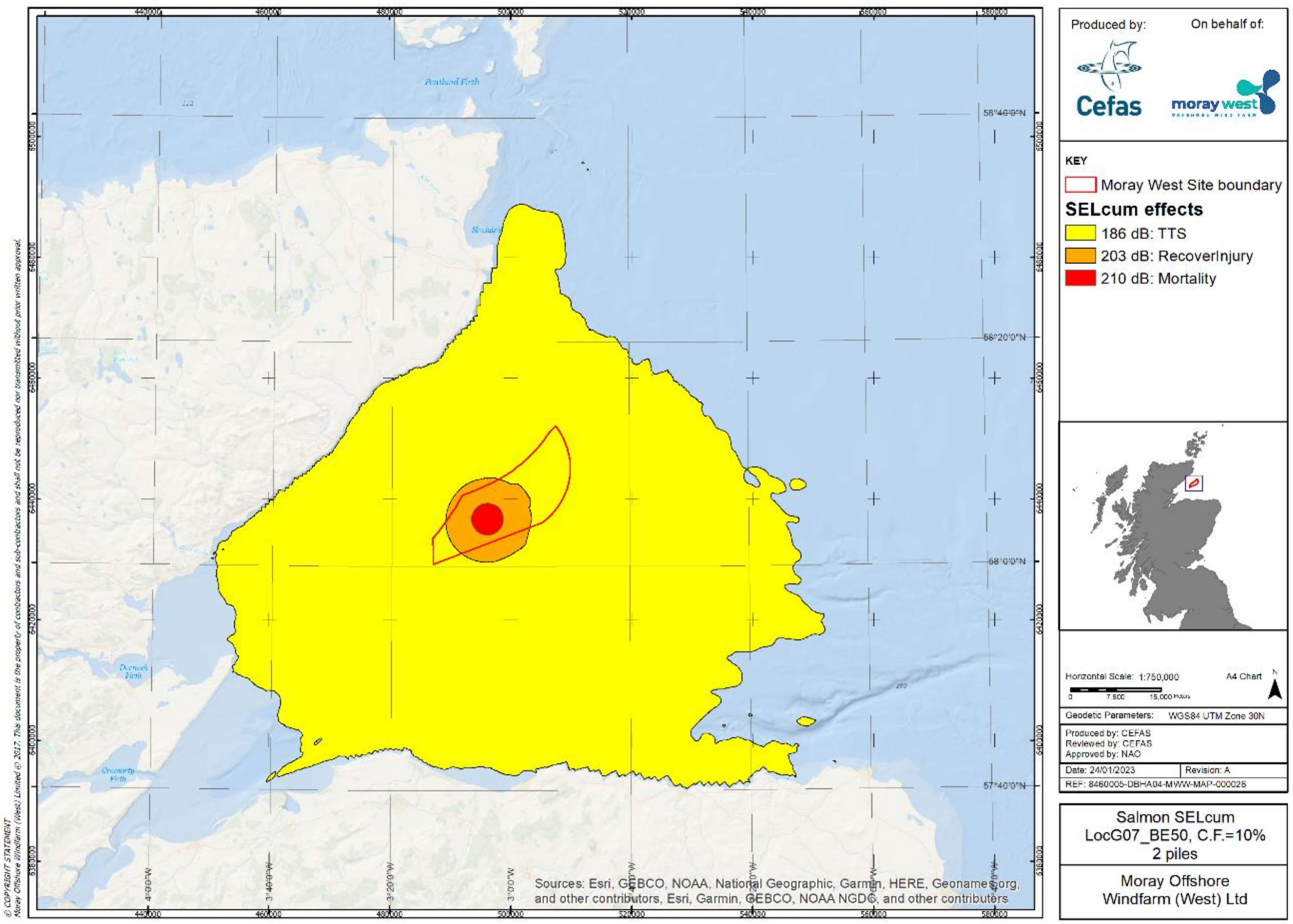

Figure 4-5 Cumulative exposure effect zones for fish species exposed to noise from 2 consecutive piles at location G07, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

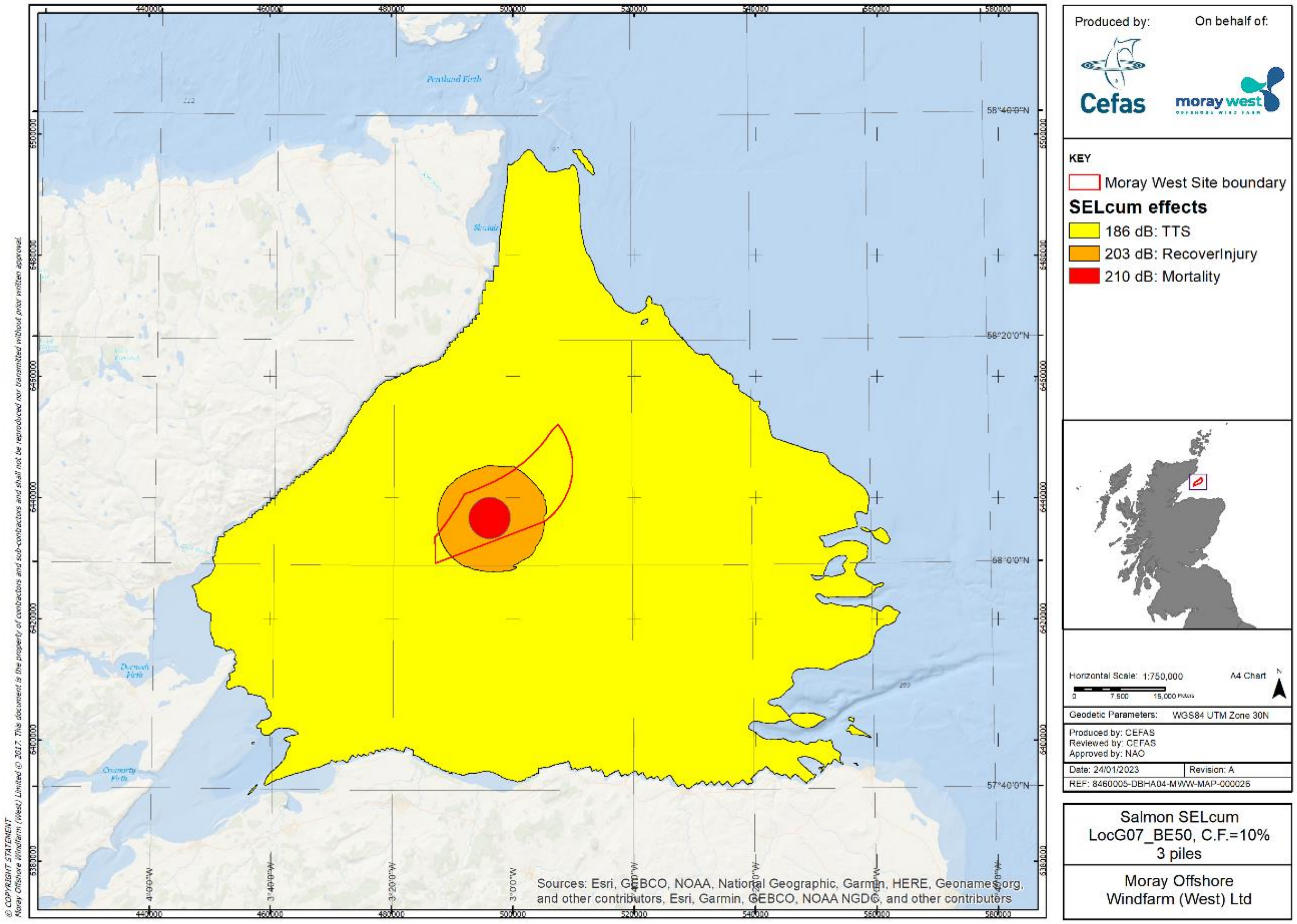

Figure 4-6 Cumulative exposure effect zones for fish species exposed to noise from 3 consecutive piles at location G07, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

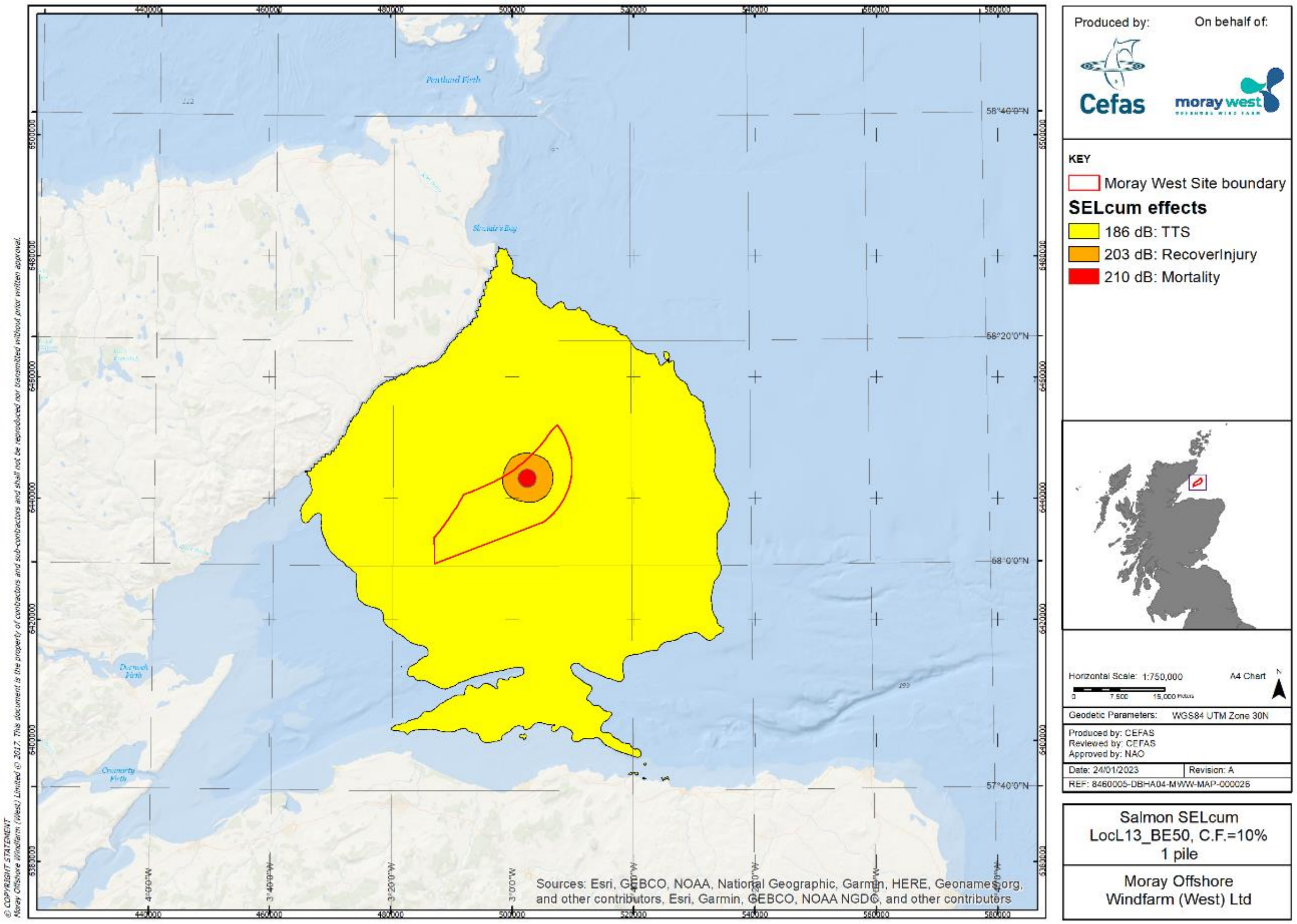

Figure 4-7 Cumulative exposure effect zones for fish species exposed to noise from 1 pile at location L13, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

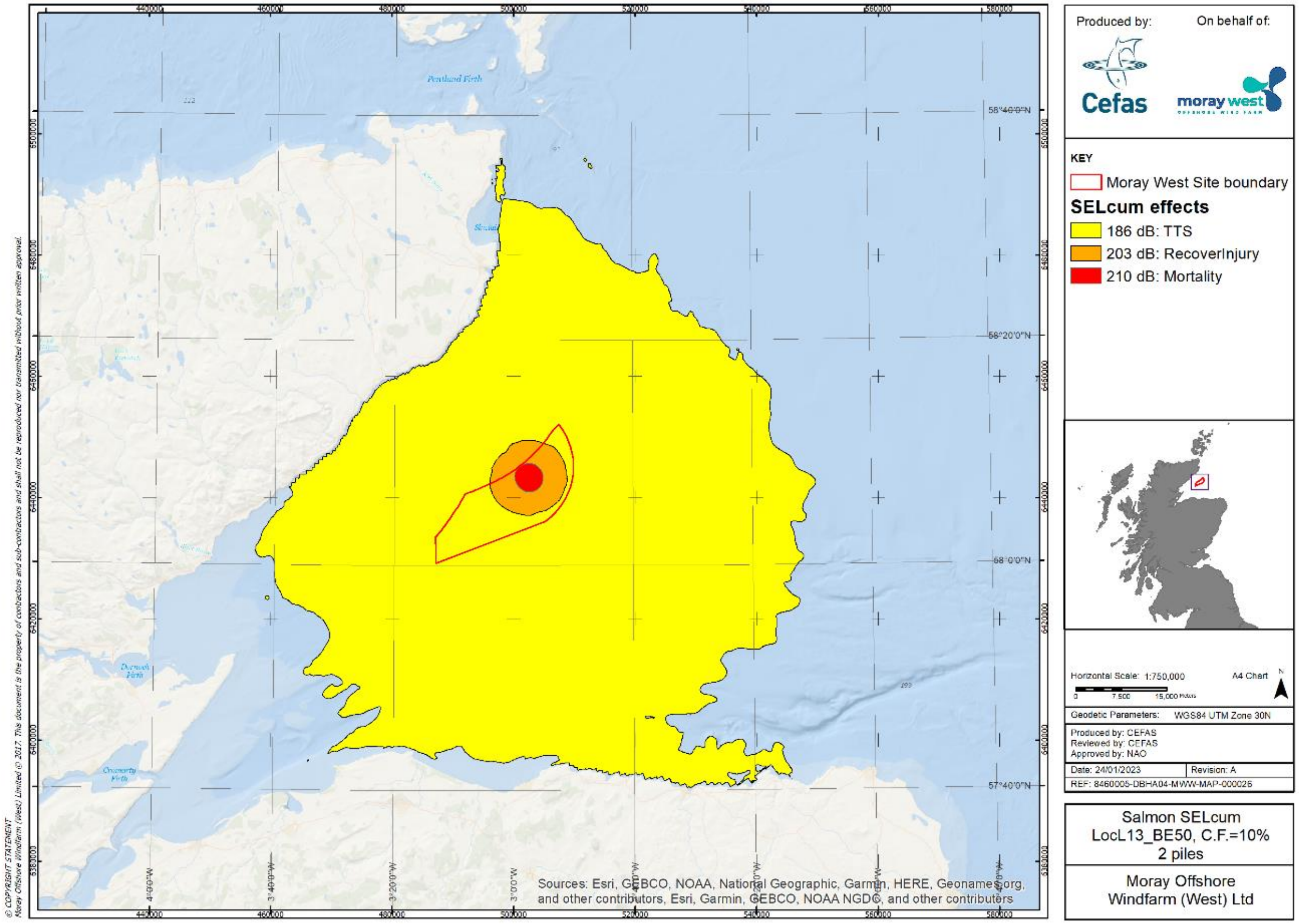

Figure 4-8 Cumulative exposure effect zones for fish species exposed to noise from 2 consecutive piles at location L13, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

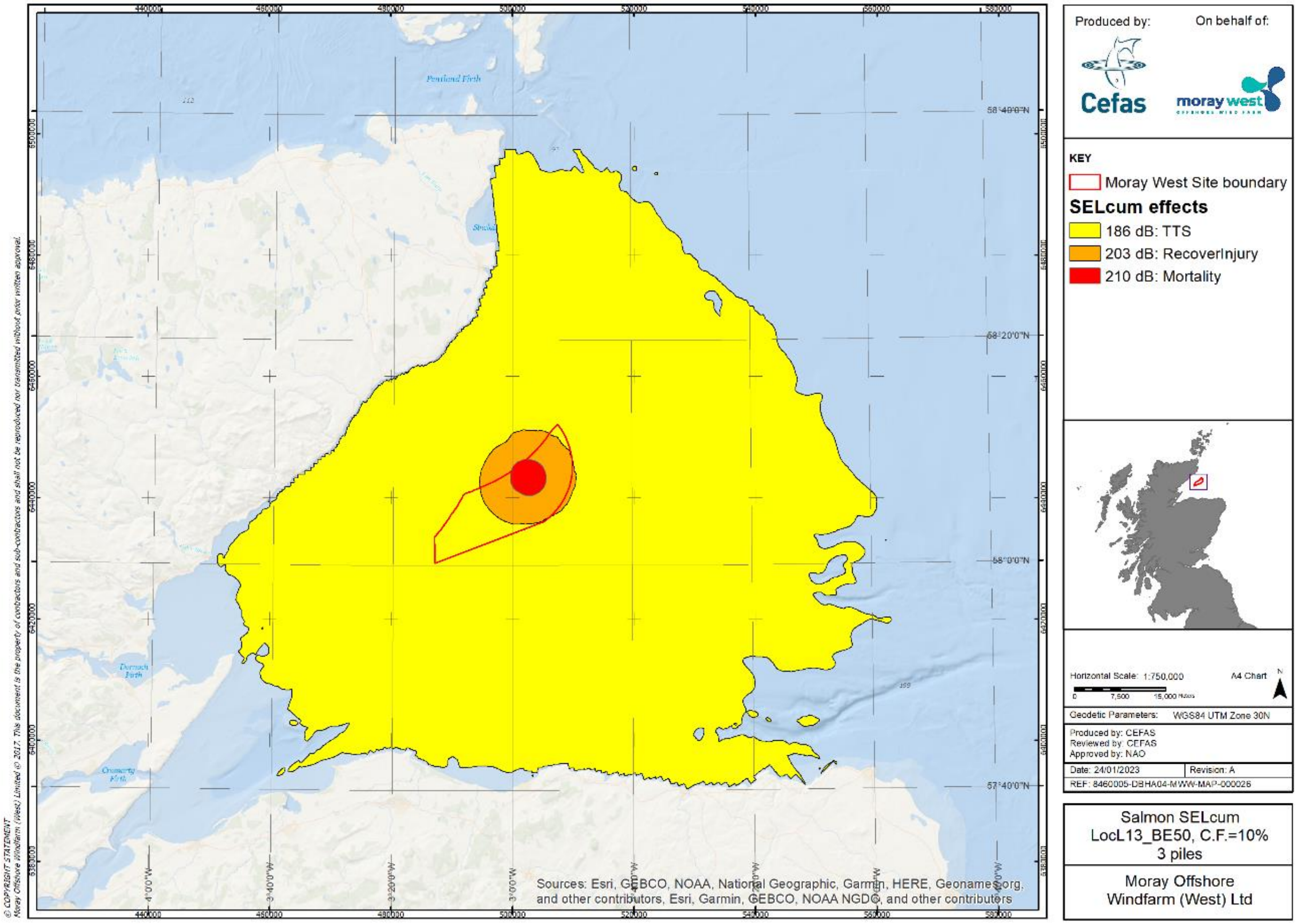

Figure 4-9 Cumulative exposure effect zones for fish species exposed to noise from 3 consecutive piles at location L13, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

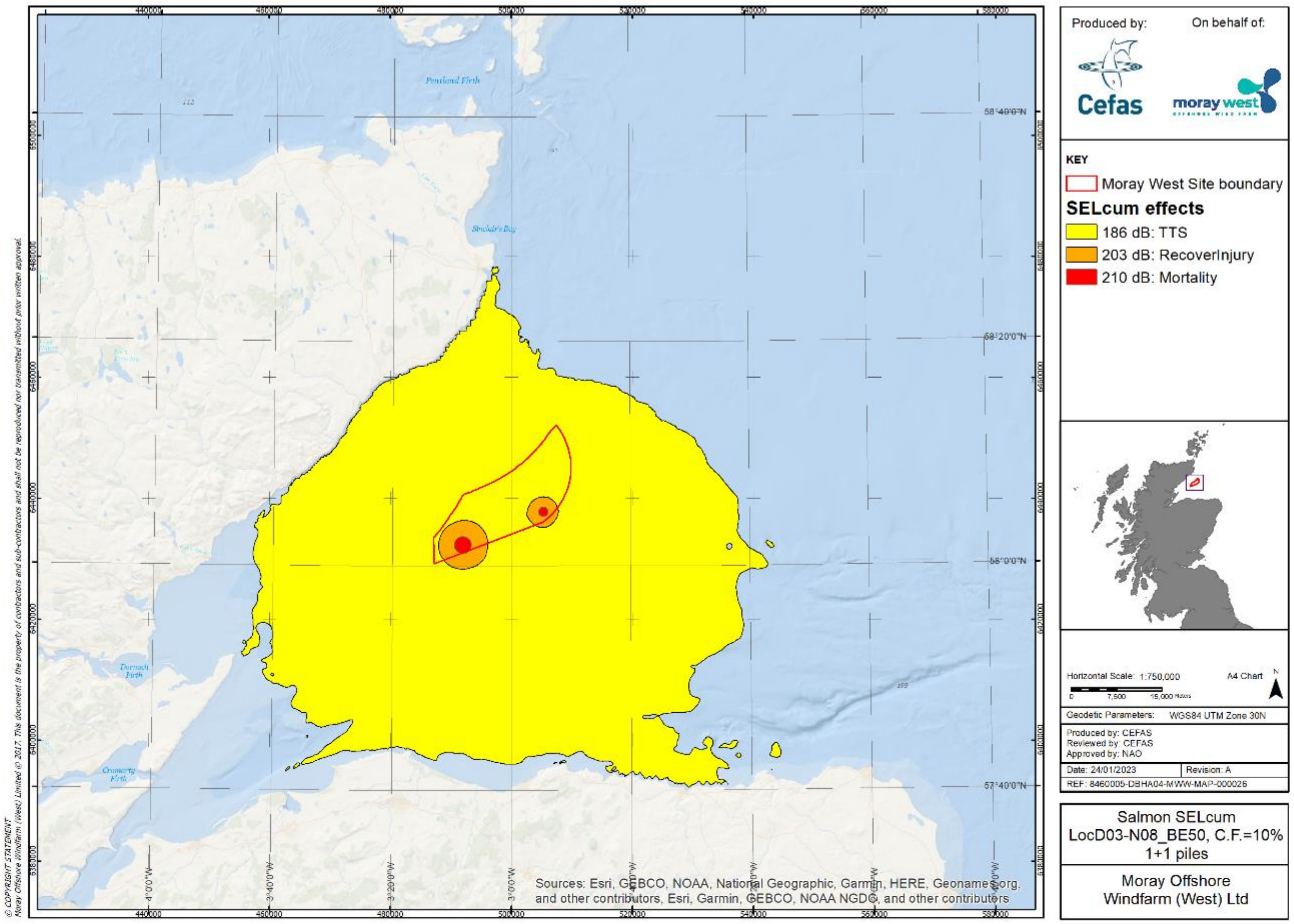

Figure 4-10 Cumulative exposure effect zones for fish species exposed to concurrent piling (within 24hours) at locations D03 and N08, 1 pile at each location, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

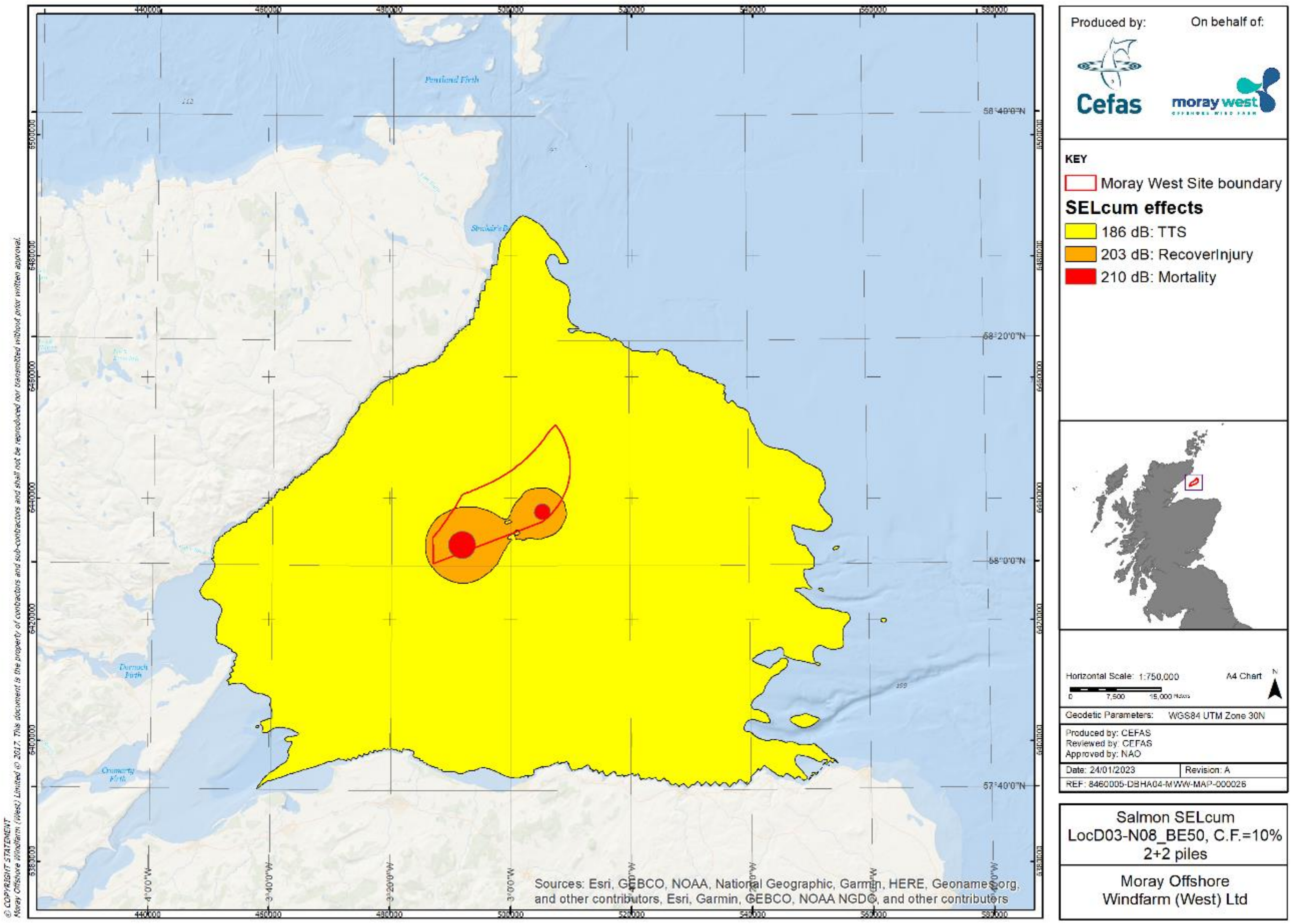

Figure 4-11 Cumulative exposure effect zones for fish species exposed to concurrent piling (within 24hours) at locations D03 and N08, 2 consecutive piles at each location, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

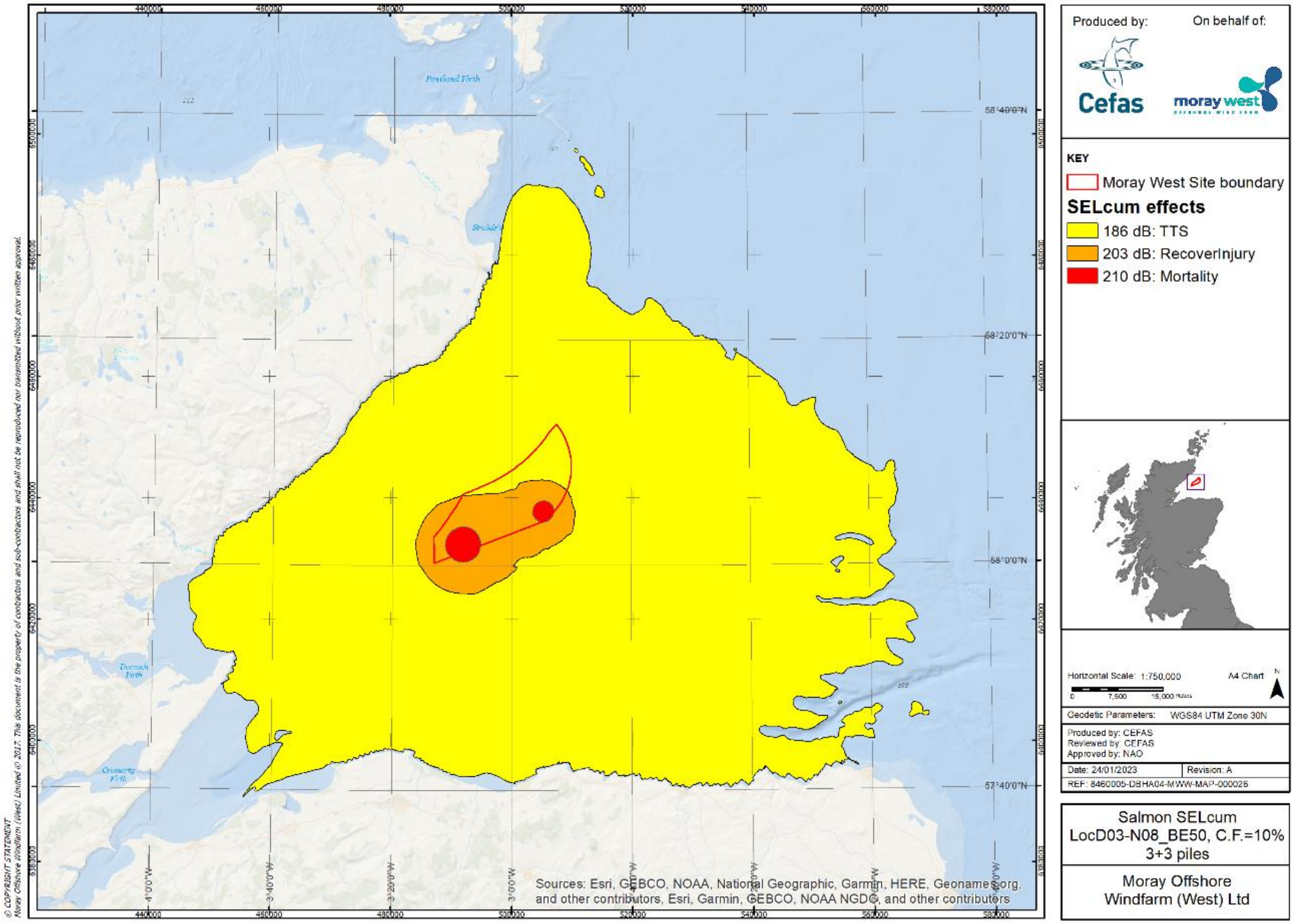

Figure 4-12 Cumulative exposure effect zones for fish species exposed to concurrent piling (within 24hours) at locations D03 and N08, 3 consecutive piles at each location, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

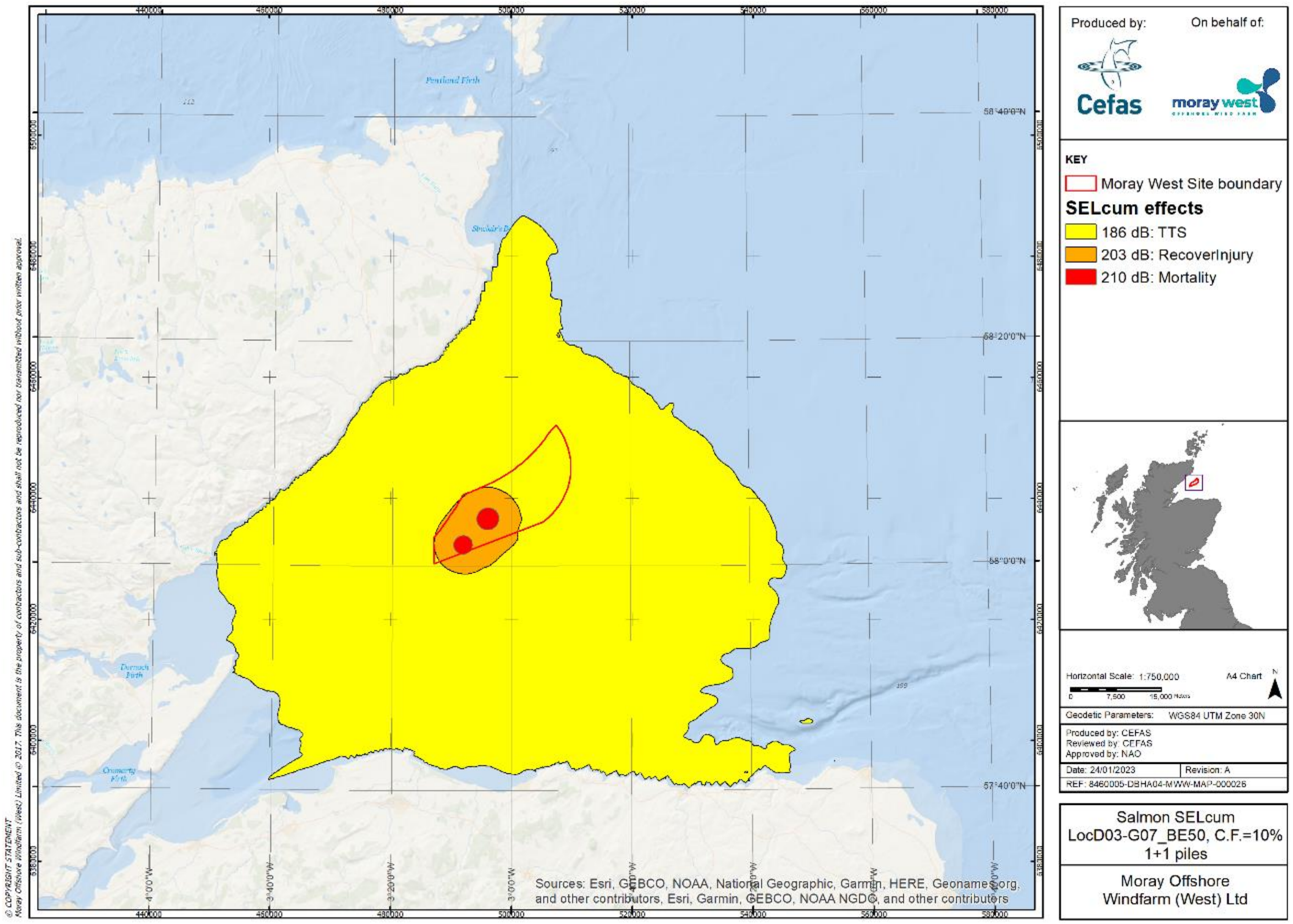

Figure 4-13 Cumulative exposure effect zones for fish species exposed to concurrent piling (within 24hours) at locations D03 and G07, 1 pile at each location, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

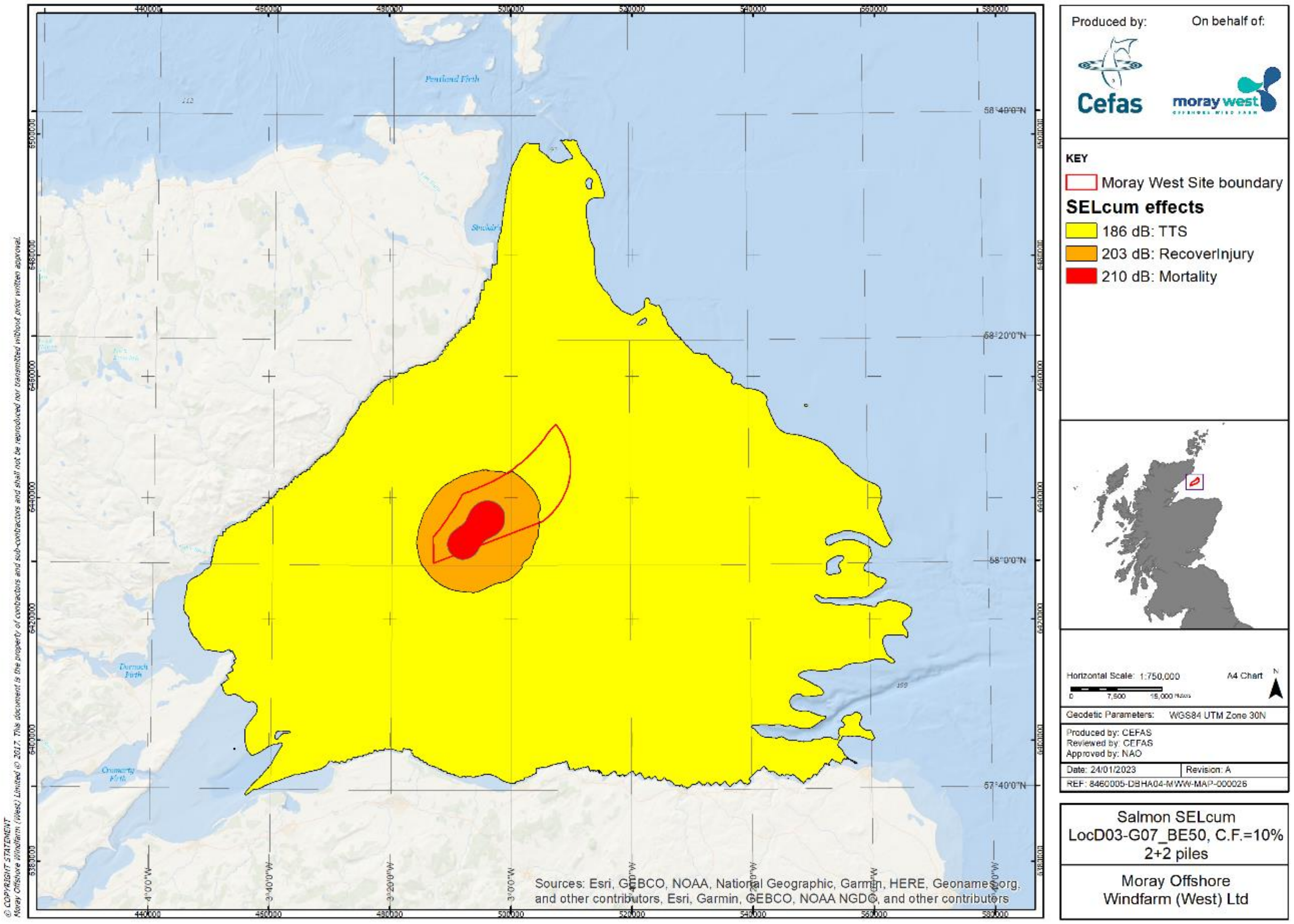

Figure 4-14 Cumulative exposure effect zones for fish species exposed to concurrent piling (within 24hours) at locations D03 and G07, 2 consecutive piles at each location, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

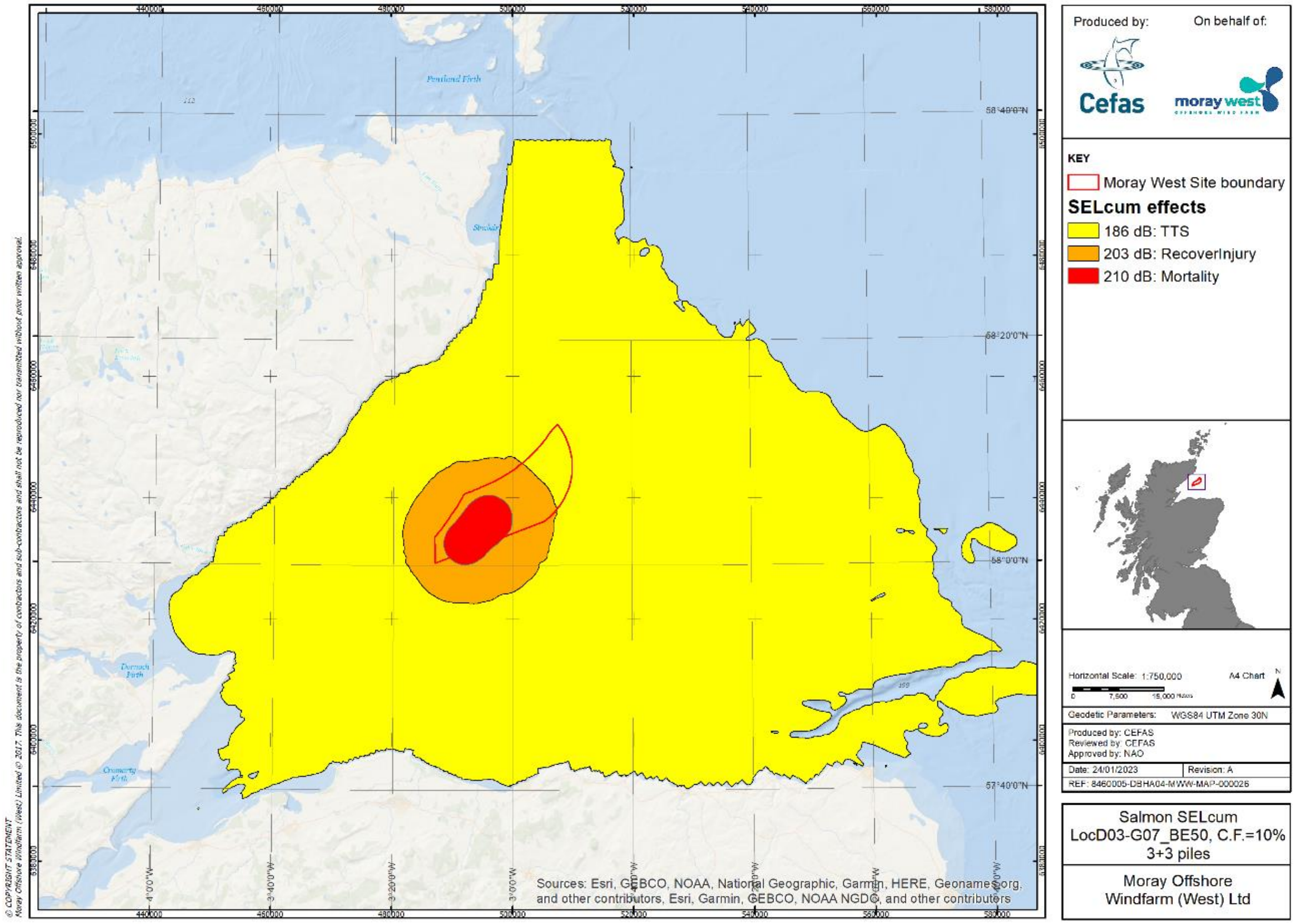

Figure 4-15 Cumulative exposure effect zones for fish species exposed to concurrent piling (within 24hours) at locations D03 and G07, 3 consecutive piles at each location, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

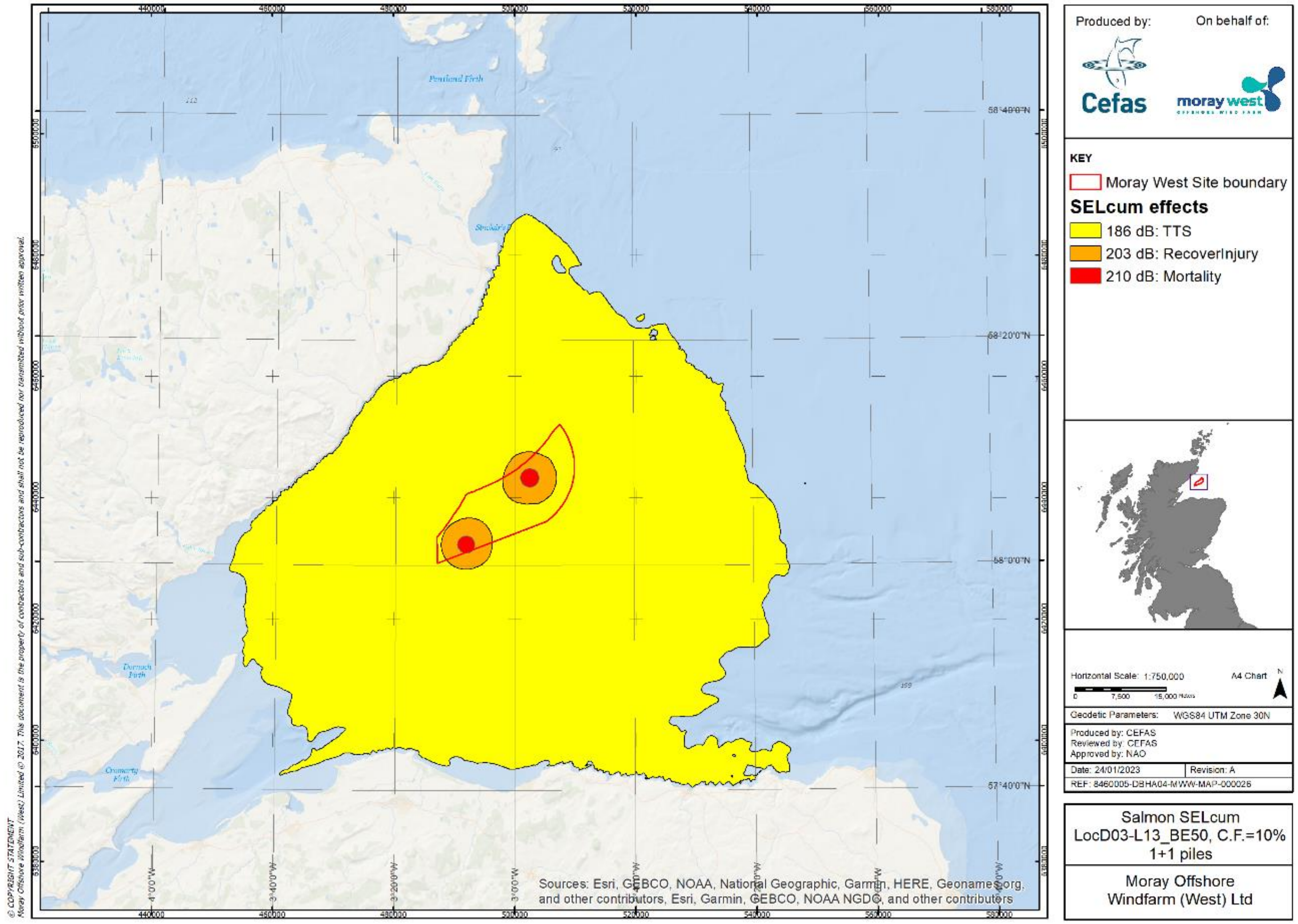

Figure 4-16 Cumulative exposure effect zones for fish species exposed to concurrent piling (within 24hours) at locations D03 and L13, 1 pile at each location, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

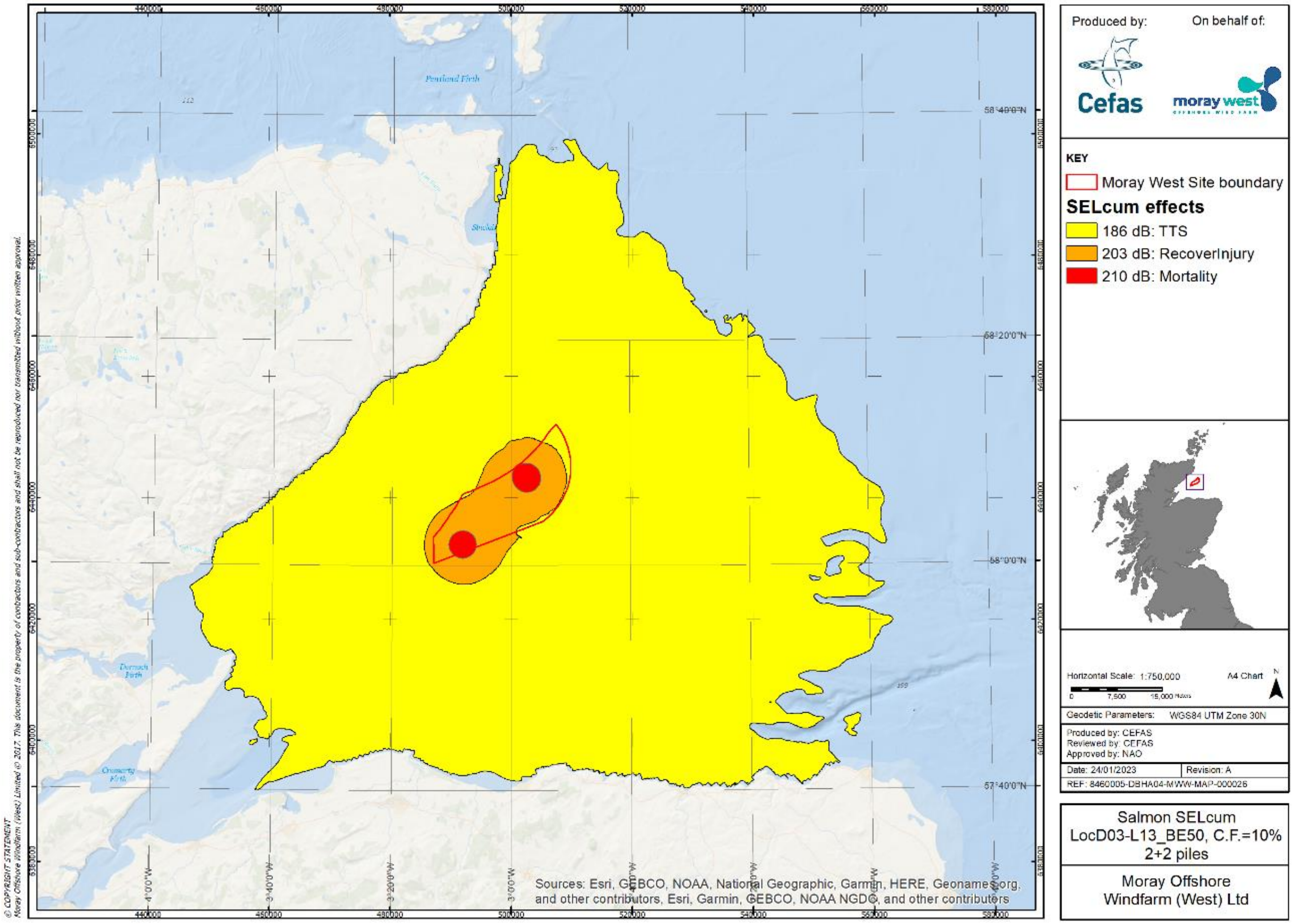

Figure 4-17 Cumulative exposure effect zones for fish species exposed to concurrent piling (within 24hours) at locations D03 and L13, 2 consecutive piles at each location, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

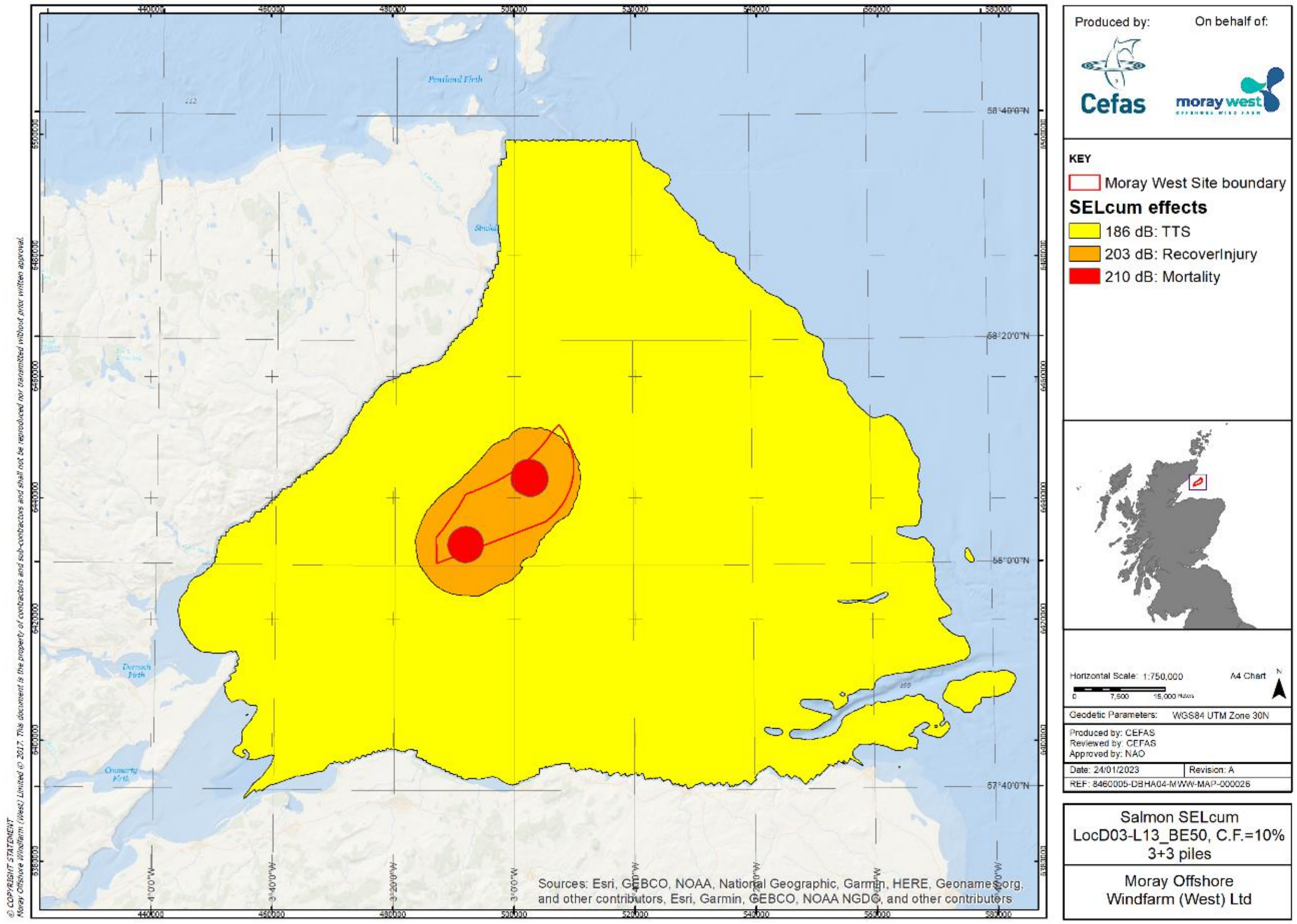

Figure 4-18 Cumulative exposure effect zones for fish species exposed to concurrent piling (within 24hours) at locations D03 and L13, 3 consecutive piles at each location, for the blow count profile BE50 and the energy conversion factor C.F.=10%.

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. 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 OWFs 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 would likely 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). 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 4,400 kJ hammer energy (monopile), recoverable injury ranges may be expected within a maximum of 840 m (at 4% conversion factor) for all fish groups, based on SPL_{peak}, and a maximum of 5,464m 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% conversion factor), there is a potential for mortality, recoverable injury, and TTS within a distance of 3,433m and 9,588m from piling respectively. The risk of these effects may 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 WTGs, 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 (Gill *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 4-5.

Table 4-5 Estimated potential distances and timings for salmonids based on assumed swim speeds based on Drenner *et al.*, (2012)

<table>
<tr><th rowspan="2">Species</th><th rowspan="2">Swim speed (m s⁻¹)</th><th rowspan="2">Distance travelled over a 12 hour period (km)</th><th colspan="3">Worst case range (SEL_{cum} over 12 hour piling period (3 consecutive piles) with 10% conversion factor) (km)</th><th colspan="3">Time taken to travel through range (minutes)</th></tr>
<tr><th>Mortality</th><th>Recoverable Injury</th><th>TTS</th><th>Mortality</th><th>Recoverable Injury</th><th>TTS</th></tr>
<tr><td>Salmonid (adult)</td><td>0.6</td><td>25.9</td><td rowspan="3">3.4</td><td rowspan="3">9.6</td><td rowspan="3">72.8</td><td>94</td><td>267</td><td>2022</td></tr>
<tr><td>Salmonid smolt (maximum speed)</td><td>0.59</td><td>25.5</td><td>96</td><td>271</td><td>2056</td></tr>
<tr><td>Salmonid smolt (minimum speed)</td><td>0.22</td><td>9.5</td><td>258</td><td>727</td><td>5515</td></tr>
</table>

4.4.3 Consideration of other fish species

Despite spawning grounds for cod and herring (as modelled by Coull *et al.*, (1998)) being found within or nearby the site, more recent site-specific cod spawning surveys undertaken at the Moray East Site indicated low abundance of spawning cod in the area. Cod were recorded in low numbers at 35 out of 58 stations with a maximum of nine individuals caught at a single station, with a total of 23 spawning cod caught throughout the survey (MORL, 2012). The relatively low numbers recorded in the survey suggest that there are not extensive cod spawning areas in the Moray Firth Zone (Moray Offshore Windfarm (West) Limited, 2018). Similarly, results from cod spawning surveys undertaken at the Beatrice Offshore Wind Farm (located to the north-east of the Moray West Site) in 2014 also indicated relatively low abundance of spawning cod across the Beatrice Offshore Wind Farm site with only seven stations out of the 40 stations sampled during two trips considered to indicate a "spawning" area (>75 spawning cod/km^2) (BOWL, 2015).

Similarly, ICES International Herring Larvae Survey (IHLS) data for 2008-2017 indicated high herring spawning east of Orkney extending northwards towards Shetland (Moray Offshore Windfarm (West) Limited, 2018), and in the vicinity of the Fraserburgh and Peterhead coastline, with very limited spawning within the Moray Firth and in the vicinity of the Development. Herring spawning activity occurs further to the north around the Orkney and Shetland islands (Coull *et al.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 4-3).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 (Skaret *et al.*, 2005).

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 Offshore Windfarm (West) Limited, 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 4.4.6.

This appraisal of these data fed into the consented Moray West EIA Report 2018 and the non-significant assessment for piling effects on spawning herring, cod, and sandeel. These findings were also reflected in the conditions of the S36 and Marine License consents, which request this Revised PS to consider Atlantic salmon and sea trout only.

For this reason, this Revised PS FIA considers the impacts of pile driving on Atlantic salmon and sea trout only.

4.4.4 Comparative Developments

Very little information on the sound propagation and appropriate conversion factors for the large diameter (up to 10m 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 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 behavioral effects in the ranges summarised above, piling (noise generation) is predicted to occur over a short duration (up to 4 hours in total per monopile) 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 by two changes to the modelling parameters.

Firstly, the SEL_{cum} cumulative noise impact ranges now consider a maximum of three monopiles piled consecutively, whereas the 2018 modelling considered the SEL_{cum} cumulative noise effects of a single monopile. Combined with an assumption of a stationary fish over the 12 hours required to pile three monopiles, this leads to increased SEL_{cum} impact ranges.

Secondly, the conversion factors used in the piling source model have changed from 0.5% and 1% in 2018, to 4% and 10% in the modelling reported here (See Section 2.2 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) 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 NatureScot 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 Section 2.7.2.1.2. 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 windfarm, 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 up to 12 hours of pile driving (as considered in the modelling here). 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^{2}s (Halvorsen *et al.*, 2012). It should be noted that no injuries produced at 217 or 210 dB re 1µPa^{2}s SELcum 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^{2}s 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 ES (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 its 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 minor significance for Atlantic salmon and sea trout, and therefore not significant in EIA terms, with no mitigation required. However, the following mitigation has been proposed for marine mammals, and it will further reduce the already low risk to salmonid species.

1. Soft-start procedure with a maximum hammer energy of 432 kJ for a minimum of 15 minutes (this will allow at-risk fish in extreme proximity to the monopile location to move away).
2. Ramp-up gradually until a suitable energy level is reached, to maintain a steady rate of pile penetration.
3. Optimization of the installation program designed to focus pile driving in non-summer months, if possible (this will avoid the majority of the migratory season from salmon).

Details of the mitigation measures will be given in the Revised PMP.

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Revised Appendix D – Piling mitigation protocol

MORAY OFFSHORE WINDFARM (WEST) LIMITED

Piling Strategy (Revised)
Revised Appendix D: Piling Mitigation Protocol

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Abbreviations and Acronyms

Abbreviation / Acronym	Description
ADD	Acoustic Deterrent Device
BOWL	Beatrice Offshore Windfarm Limited
CEE	Controlled Exposure Experiment
CF	Conversion Factor
ECoW	Environmental Clerk of Works
EMP	Environmental Management Plan
JNCC	Joint Nature Conservation Committee
MMO	Marine Mammal Observer
ORJIP	Offshore Renewables Joint Industry Programme
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
VHF	Very High Frequency
SNCB	Statutory Nature Conservation Bodies
WTG	Wind Turbine Generator

1 Introduction

This document presents the Moray West Revised Piling Mitigation Protocol (PMP) and has been 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 (Moray West).

This Revised PMP will be adhered to during pile driving operations for the installation of 60 wind turbine generators (WTGs) and 2 offshore substation platforms (OSP) monopile foundations across the Moray West Offshore Wind Farm Site (referred to as Moray West Site).

The primary purpose of this Revised 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 Moray West Site.

1.1 Background

Since the implementation of the Joint Nature Conservation Committee (JNCC) guidelines for minimising the risk of injury to marine mammals from piling noise (JNCC 2010), 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. 2023) 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 were successfully implemented during the construction of the offshore wind farms (OWF)(Thompson et al. 2020).

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 piling at 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 Revised Piling Strategy (PS) will aim to successfully:

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

2 Optimisation of pile installation programme

In order to minimise the risk of injury to minke whales, Moray West has committed to install monopile locations with any risk of pile refusal outside the of summer months:

1. Locations with a hard-driving profile with moderate risk of pile driving refusal (5 locations): E03, K14, D03, L13, G07
   - None of these locations will be installed concurrently with each other.
   - None of these locations will be installed consecutively with each other.
2. Concurrent piling will only occur when two installation vessels are operating simultaneously for up to 20 days within a 3-month period between February- April 2024

3 Marine mammal impact ranges for auditory injury

Table 3-1 summarises the maximum instantaneous permanent threshold shift-onset (PTS-onset) impact ranges for the maximum hammer energy at the commencement of soft-start and at full hammer energy at the Moray West Site. The greatest impact ranges are for harbour porpoise, with an instantaneous PTS-onset impact range of 579 m at the commencement of soft-start and 2,395 m at full hammer energy.

Table 3-1 Maximum instantaneous PTS-onset impact ranges (based on a constant 10% conversion factor (CF)) for worst case locations and species considered in noise modelling.

Species	Location	Max PTS-onset range (m) at commence of soft-start (432 kJ)	Max PTS-onset range (m) at full hammer energy (4,400 kJ)
Harbour porpoise	L13	579	2,395
Bottlenose dolphin	D03	16	52
Harbour seal	D03	44	357
Grey seal	D03	44	357
	L13	44	432
Minke whale	N08	40	84[1]
	G07	40	313

Table 3-2 summarises the cumulative PTS-onset impact ranges. However, 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 (as discussed in Section 2.6.2.1.2 of the Revised Appendix C of the Moray West PS). Therefore, we consider the estimates given in Table 3-2 as overly conservative and unrealistic.

[1] Maximum PTS-onset range at full hammer energy is 1,295 kJ at location N08.

Table 3-2 Maximum cumulative PTS -onset impact ranges (based on a constant 10% CF) for all locations and species considered in noise modelling, and number of animals within the impact area based on species density distribution maps.

Species	Location	Max cumulative PTS -onset range (m)	Number of animals
1 monopile installed per day			
Harbour porpoise	N08	1,702	5
	L13	2,834	25
Bottlenose dolphin	D03	< 50	< 1
Harbour seal	D03	50	< 1
Grey seal	D03	50	< 1
	L13	< 50	< 1
Minke whale	N08	11,318	< 1
	G07	45,188	*(locations with moderate risk of pile driving refusal will not be installed in summer)* 3
2 monopiles installed consecutively in one day (one after the other)			
Harbour porpoise	N08	1,792	6
	L13	*(locations with a moderate risk of pile driving refusal will not be installed consecutively with each other)*	
Minke whale	N08	20,398	< 1
	G07	*(locations with a moderate risk of pile driving refusal will not be installed consecutively with each other)*	
3 monopiles installed consecutively in one day (one after the other)			
Harbour porpoise	N08	1,870	6
	L13	*(locations with a moderate risk of pile driving refusal will not be installed consecutively with each other)*	
Minke whale	N08	45,155	1
	G07	*(locations with a moderate risk of pile driving refusal will not be installed consecutively with each other)*	
Species	**Location**	**Max cumulative PTS-onset area (km^2)**	**Number of animals**
2 monopiles installed concurrently in one day (2 vessels, each installing 1 monopile at the same time)			
Harbour porpoise	D03 & N08	105 (km^2)	82
Minke whale	D03 & N08	2,092 (km^2)	4

4 Piling mitigation approach

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

4.1 Vibropiling prior to impact piling

It is expected that vibropiling will be used prior to impact piling at 41of the 62 piling locations (1 OSP and 40 WTGs monopile locations). The source level for vibropiling has been measured as 192 dB re 1 µPa (Graham et al. 2017). Since vibropiling produces a continuous (non-impulsive) sound, it is subject to different PTS onset thresholds (173 dB re 1 µPa $SEL_{weighted}$ for very high frequency (VHF) cetaceans) compared to impact piling (155 dB re 1 µPa $SEL_{weighted}$ for VHF cetaceans). It is, therefore, expected that PTS onset ranges from vibropiling will be minimal.

Evidence of the behavioural responses of marine mammals to vibropiling activities is scarce; however, a study has shown responses of both bottlenose dolphins and harbour porpoise during vibropiling activities (Graham et al. 2017). Bottlenose dolphins showed minor but significant reductions in presence and encounter durations in the vicinity (< 5km) of construction works during vibropiling, while harbour porpoise showed significantly reduced presence. However, in both cases, effect sizes were very small, and of the extent to which a reduction in detections equates to displacement of individuals rather than, for example, masking of detections remains unclear.

It is anticipated that it could take up to a maximum of 2 hours to change between vibro-hammer and impact-hammer during a piling installation sequence, and that once the impact hammer is in place, impact piling would commence with a soft-start period before increasing hammer energy. Therefore, it is expected that vibropiling prior to impact piling would act as an initial deterrence effect in the same way that ADDs do prior to the soft-start of impact piling. As a result, piling operations will transition from vibropiling to impact piling without the requirement for ADD mitigation before the impact piling soft-start.

In the highly unlikely event that it takes more than 6 hours to switch the hammers, pre-piling mitigation will be required prior to the commencement of the impact piling soft-start.

The piling sequence across these 53 piling locations is expected to be:

vibropiling → switch hammer → impact-piling soft-start → ramp-up → full hammer energy.

Pre-piling mitigation will only occur for:

1) piling locations where vibropiling is not used.
2) instances where the break between vibropiling ending and impact piling commencing is >6 hours.

4.2 Use of ADD

This Revised PMP recommends that the most suitable pre-piling mitigation method is the use of Acoustic Deterrent Devices (ADDs), following the rationale and approach used at the adjacent Beatrice Offshore Wind Farm and Moray East Offshore Wind Farm (Thompson et al. 2020) . A similar mitigation protocol to that recommended in this Revised 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 that of following the standard procedure previously recommended by the JNCC (2010).

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 by conducting pre-piling searches of a 500 m mitigation zone for 30 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. 2023). Further details of such studies are presented in Appendix 1. 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 2,395 m at full hammer energy (see Table 3-1).

More recently, JNCC et al. (2016) have stated that 'the SNCBs [Statutory Nature Conservation Bodies] 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.

In addition, there is now evidence that porpoises are displaced by construction vessel activity (Benhemma-Le Gall et al. 2021), ADD and piling noise (Graham et al. 2019, Graham et al. 2023); thus, the likelihood of an animal being with the impact zone at the start of pile driving is extremely low.

4.2.1 ADD protocol

The protocol will require the deployment of an ADD for:

1) piling locations where vibropiling is not used
2) instances where the break between vibropiling ending and impact piling commencing is > 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 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, and 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 maintain a log of all ADD deployments so that reports from each monopile installation can be provided (see section 8).

4.2.1.1 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 4-1).

4.2.1.1.1 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 (7 minutes) (Table 4-1). For all other species, the time required is less than 1 minute. Therefore, the minimum ADD activation period is recommended as 7 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 monopile will involve a soft-start procedure of a minimum of 15 minutes[2] where a maximum hammer energy of 432 kJ will be used. It is anticipated that, following the commencement of the soft-start, animals will continue to move away from the noise source. Therefore, by the end of the 7 minute ADD activation followed by a 15 minute soft-start, it is estimated that harbour porpoise would be at least 1,848 m from the noise source (3.2 times the soft-start instantaneous PTS-onset range) before the hammer energy will be increased further.

[2] JNCC (2010) guidance describes the soft-start as ‘the gradual ramping up of piling power, incrementally over a set time period until full operational power is achieved’. The soft-start duration is to be a minimum of 20 minutes. For the Moray West PS, the soft-start- procedure will consist of a 15-minute period where the hammer energy will not exceed 432 kJ and 28 blows/minute, followed by the gradual ramp-up- of hammer energy towards maximum hammer energy. Overall, the combined soft-start and ramp-up procedures will be longer than the 20 minutes recommended by JNCC (2010) guidelines as full hammer energy will not be achieved during the first 20 minutes of piling, if at all (see section 4.3).

Table 4-1 Estimated time for an animal to exit the maximum instantaneous PTS-onset range (based on a 10% CF) at soft-start for all species considered in noise modelling.			
Species	**Maximum instantaneous PTS-onset range at soft-start (m)**	**Swim speed (m/s)**	**Time required to exit soft-start instantaneous PTS-onset impact range (min)**
Harbour porpoise	579	1.4	7
Bottlenose dolphin	16	1.52	< 1
Harbour seal	44	1.8	< 1
Grey seal	44	1.8	< 1
Minke whale	40	2.1	< 1

At maximum hammer energy (4,400 kJ) (Table 4-2), the time required for bottlenose dolphins, seals and minke whales to exit the instantaneous PTS-onset range is shorter than the initial 7 minute ADD activation. Harbour porpoise have the largest instantaneous PTS-onset impact range at full hammer energy (2,395 m) and slowest swimming speed (1.4 m/s). It will, therefore, take 28.5 minutes for harbour porpoise to exit the instantaneous PTS-onset impact range at full hammer energy. Based on the information provided in the Revised Moray West PS Appendix C: Underwater Noise Impact Assessment, the shortest time frame anticipated between ADD activation and the start of full hammer energy occurs at monopile location G07, with the process taking 73 minutes (7 minute ADD followed by a 15 minute soft-start and a 51 minute ramp-up). This means that when full hammer energy is achieved at location G07, it is expected that harbour porpoise would be at least 6.1 km away and, therefore, well outside the maximum full hammer energy instantaneous PTS-onset range (2,395 m).

In most instances (e.g. location L13, see Table 2-2 in Revised Appendix C of the Moray West PS), it is expected to take much longer before full hammer energy is reached (151 minutes), due to the extended soft-start (24 minutes) and ramp-up (120 minutes) periods. In this scenario, following ADD activation, the soft-start and the ramp-up periods, porpoise will be 12.7 km away from the source and, therefore, even further outside the maximum full hammer energy instantaneous PTS-onset range (2,395 m).

Table 4-2 Estimated time for an animal to exit the maximum instantaneous PTS-onset range (based on a 10% CF) for full hammer energy for all species considered in noise modelling.

Species	**Maximum instantaneous PTS-onset range (m) at full hammer energy (10% CF)**	**Swim speed (m/s)**	**Time required to exit instantaneous PTS-onset impact range at full hammer energy (min)**
Harbour porpoise	2,395	1.4	28.5
Bottlenose dolphin	52	1.52	< 1
Harbour seal	432	1.8	4
Grey seal	432	1.8	4
Minke whale	313	2.1	2.5

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, studies 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).

4.2.1.1.2 Cumulative PTS

A longer ADD activation up to 34 minutes would be needed in order for a harbour porpoise starting at the pile location to exit the cumulative PTS-onset impact ranges (Table 4-3). However, as detailed in the Revised PS Appendix C: Underwater Noise Impact Assessment, the cumulative PTS-impact ranges presented here are highly over-precautionary and unrealistic. Considering that high vessel noise reduces harbour porpoise occurrence to near zero within 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. If the animal starts 2 km from the pile, then ADD activation is only needed for 10 minutes to allow the animal to exit the maximum cumulative PTS impact range from a high refusal risk location (assuming 1 pile/day).

Table 4-3 Estimated time for an animal to exit the maximum cumulative PTS onset range (based on a constant 10% CF) for all species considered in noise modelling, starting at the pile location and at 2 km distance from the pile location, respectively.

Species	Location	Max cumulative PTS-onset range (m) (10% CF)	Swim speed (m/s)	Time required (min) to exit the cumulative PTS-onset impact range starting at	
				Pile location	2 km distance
Harbour porpoise	L13	2,834	1.4	34	10
Bottlenose dolphin	D03	< 45	1.52	< 1	< 1
Harbour seal	L13	< 45	1.8	< 1	< 1
Grey seal	L13 or D03	< 45	1.8	< 1	< 1
*Minke whale**	*N08*	*11,318*	*2.1*	*90*	*74*
	G07	*45,188*		*> 120*	*> 120*

*Minke whale appears greyed out as ADD is not considered an appropriate mitigation measure for cumulative PTS

For minke whale, ADD activation is not considered an appropriate measure for mitigating cumulative PTS and hence they appear in Table 4-3 greyed out. For this species, Moray West has made the commitment to install monopile locations with any risk of pile refusal outside of the summer months (see Section 2).

4.2.1.1.3 ADD duration conclusion

For monopile locations where vibropiling is not used, or when the break between vibropiling and impact piling is more than 6 hours, the ADD should be activated for 10 minutes prior to impact piling commencing. This will ensure all marine mammals (except minke whales; see Section 2) are outside of both the instantaneous and cumulative PTS impact ranges.

4.3 Soft-start and ramp-up

Following the pre-impact piling deployment of the ADDs, a soft-start procedure will commence (Figure 5-1). The installation of each monopile foundation will involve a minimum of a 15 minute soft-start where a maximum hammer energy of 432 kJ will be used at a strike rate of 28 blows/minute. Following this, the hammer energy will ramp-up gradually until a suitable energy level is reached to maintain a steady rate of pile penetration, ensuring that the combined soft-start and ramp-up procedures exceed the minimum 20 minutes according to the JNCC (2010) guidelines (the modelling presented in Revised Appendix C of the Moray West PS: Underwater Noise Impact Assessment assumed the ramp-up duration varies between 51 and 160 minutes depending on location). 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.

4.3.1 Protocol for planned or unplanned breaks in piling

4.3.1.1 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 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 4.2.1.

4.3.1.2 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 NaureScot and MS-LOT on the Moray East Marine Mammal Mitigation Protocol (December 2018). Studies have shown that harbour porpoise detections remain significantly reduced from baseline levels 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 5-1 for summary):

1. 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.
2. For breaks in piling > 10 min but < 6 hours, pile driving will recommence with a full soft-start and ramp-up of hammer energy, wherever this is safe to do so, but without the need for pre-piling ADD deployment.
3. 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.

4.4 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).

5 Piling procedure

A schematic diagram of the steps in the piling procedure with the application of this mitigation protocol is provided in Figure 5-1.

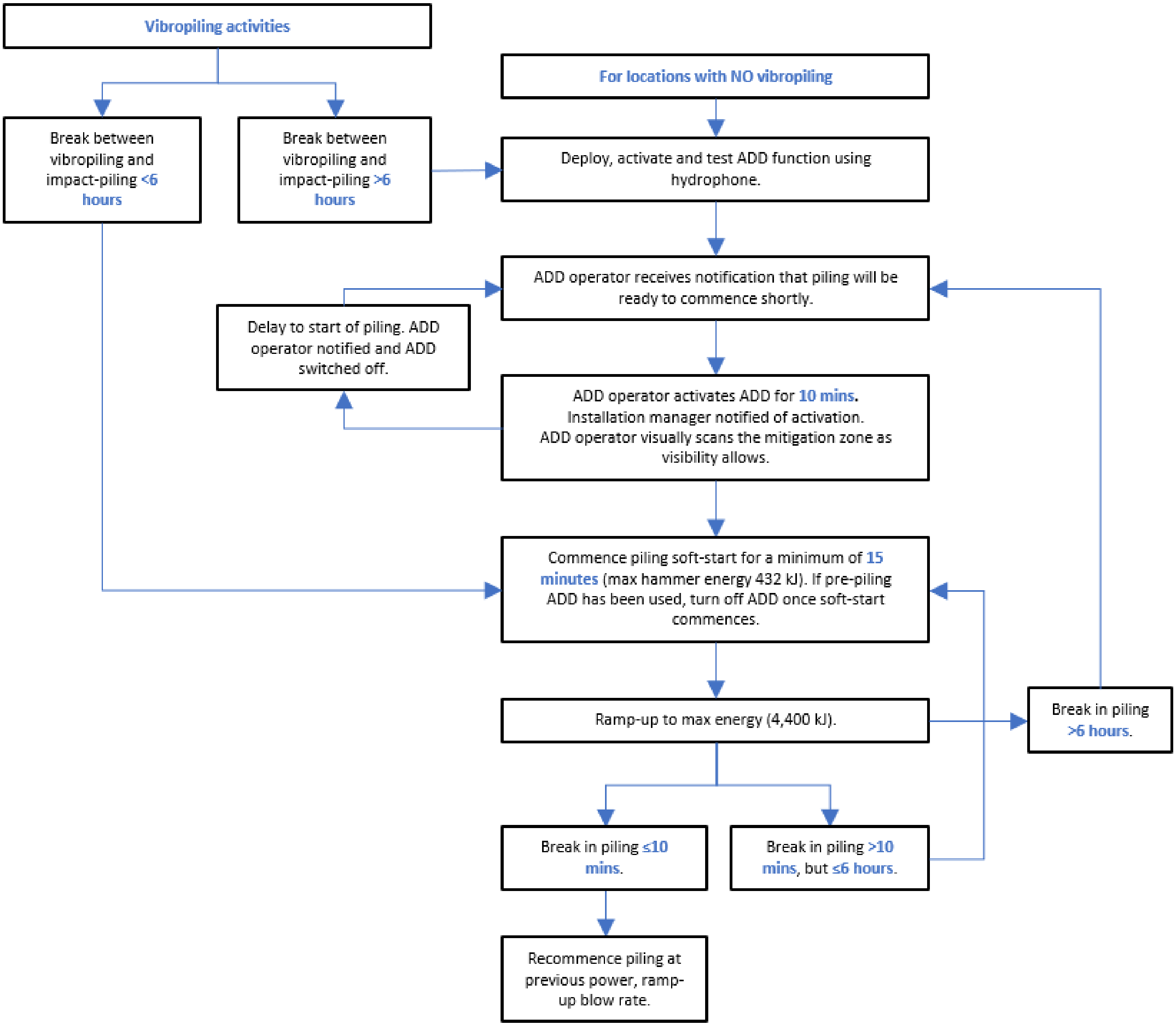

Figure 5-1 Schematic of the piling procedure steps.

6 Roles and responsibilities

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

6.1 Project Manager

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

6.2 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 Revised PMP;
- Ensuring that matters relating to the delivery of this Revised 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 Revised PMP, as well as supporting monitoring and auditing compliance with the PS;
- Establishing contractual obligations for Key Contractors and Subcontractors in relation to the Revised PS and Revised PMP;
- Reporting to the Moray West Foundation Installation Manager on matters related to the Revised PS and Revised PMP; and
- Where necessary, addressing Key Contractor and Subcontractor non-compliance in relation to the Revised PS and Revised PMP.

6.3 Installation Contractor

The Installation Contractor will be required to ensure implementation of and compliance with the Revised Moray West PS and PMP during monopile installation activities and will need to liaise with both the ADD operator and the Moray West Development team and the ECoW.

6.4 Environmental Clerk of Works (ECoW)

The ECoW will provide quality assurance of the Revised Moray West PS (as required under the S36 Consent and Marine Licences) and will provide advice to Moray West on compliance with the Revised PS. The ECoW is responsible for communicating the requirements of the Revised PS and ensuring this Revised PMP is implemented. The ECoW will work with the ADD operator and all other personnel and contractors involved in monopile installation activities to ensure that the requirements of the Revised PS are understood. The ECoW will undertake site inductions with regard to this Revised PMP and ensure that it is implemented. The ECoW will also be responsible for reporting on compliance to the Licensing Authority.

6.5 ADD Operator

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

- Identify an appropriated location for the ADD and PAMS deployment locations (with assistance of the vessel crew) and provide 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.

7 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:

1. Procedure to notify ADD operator to set-up equipment, test and deploy ADDs to allow a minimum of 10 minutes activation prior to soft-start commencing;
2. 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;
3. 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;
4. Procedure for the installation manager to notify ADD operator that soft-start is successfully underway and the ADDs can be deactivated; and
5. 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).

8 Reporting

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

1. A mobilisation report of the ADD and PAMS equipment detailing deployment locations and verification of equipment testing;
2. 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;
3. Record of all sightings of marine mammals in the mitigation zone during the mitigation period, when visibility allows for visual monitoring;
4. Record of ADD deployment, including start and end times of all periods of ADD activation and any problems with ADD deployment;
5. Details of any problems encountered during the piling process including instances of non-compliance with the agreed piling protocol;
6. Record of all incidental sightings of marine mammals around the piling vessel (species, activity and distance/bearing from the vessel recorded); and
7. Any recommendations for amendment of the protocol.

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

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10 Appendices

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 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 10-1).

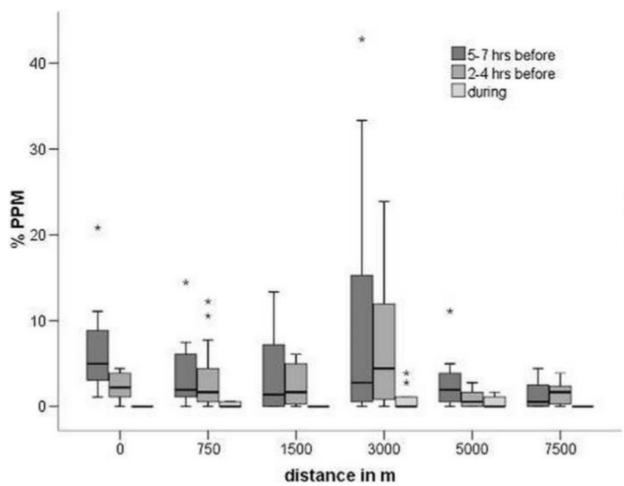

Figure 10-1 Percentage of porpoise positive minutes recorded before and during Lofitech trials at various distances. Figure taken from Brandt et al. (2013b).

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 10-2). 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.

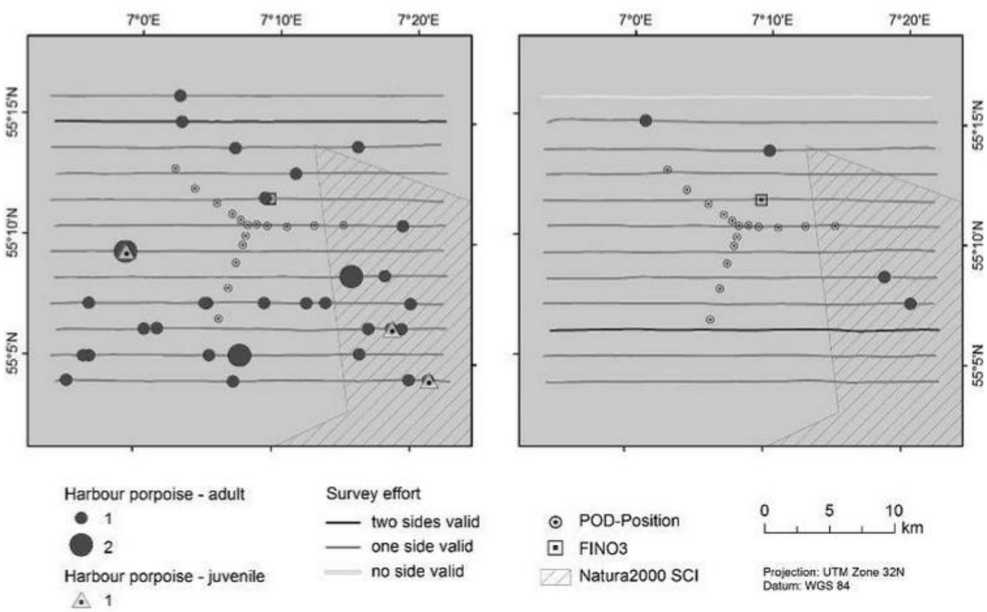

Figure 10-2 Harbour porpoise aerial sightings before (left) and during (right) Lofitech activation. Figure taken from Brandt et al. (2013b).

Brandt et al. (2013a) conducted visual surveys to determine the responses of harbour porpoises to Lofitech ADDs (Figure 10-3 and Figure 10-4). 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.

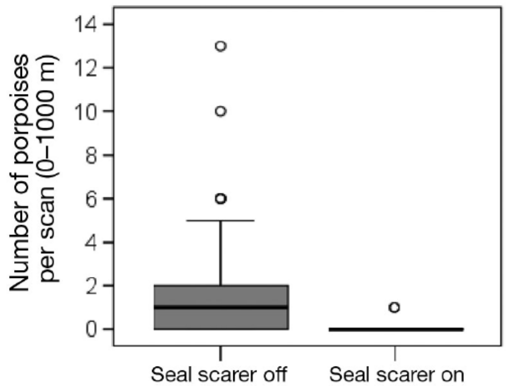

Figure 10-3 Number of harbour porpoises seen during scans when the Lofitech device was active and inactive. Figure taken from Brandt et al. (2013a).

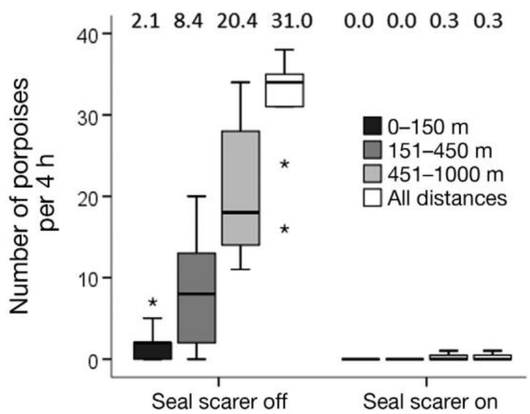

Figure 10-4 Harbour porpoises sightings rates when the Lofitech device was active and inactive over a range of distances. Figure taken from Brandt et al. (2013a).

2. Minke whale

During a study commissioned by the Offshore Renewables Joint Industry Programme (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 10-5). 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 continued to swim further away to between c. 3 km and 4.5 km following exposure.

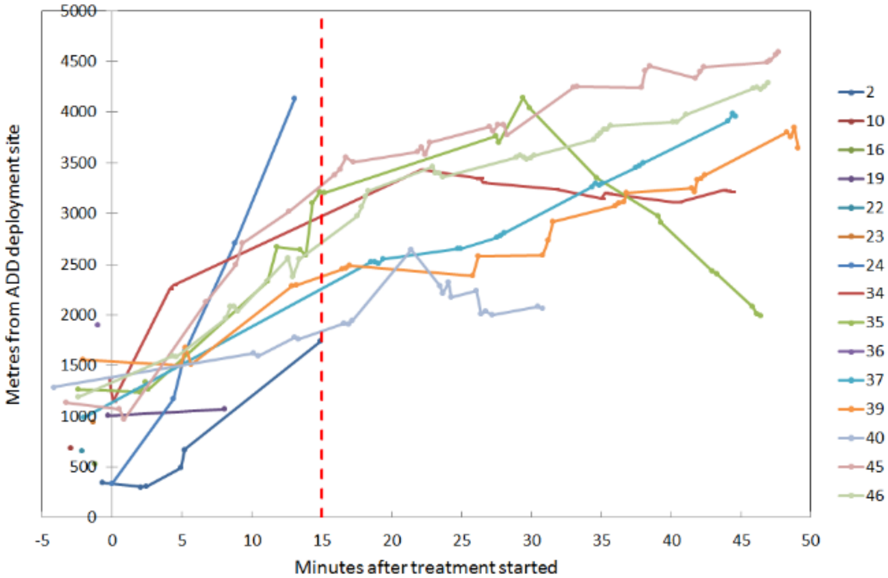

Figure 10-5 Distance of focal whales from the ADD deployment site during treatment and post treatment phases of the experiment. The red dashed line indicates the end of the treatment phase. Figure taken from McGarry et al. (2017).

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 10-6 and Figure 10-7). 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 (Figure 10-6). 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 10-7). Overall, it was concluded that the use the Lofitech device would deter seals up to ~1 km from the source.

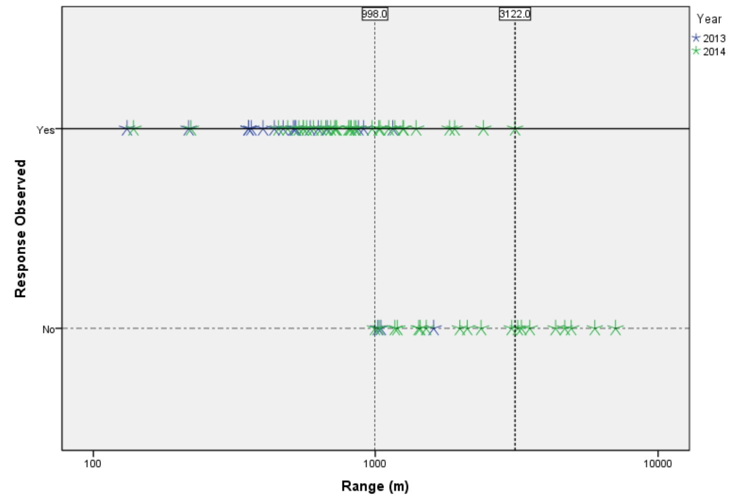

Figure 10-6 Controlled exposure experiments with harbour seals and the Lofitech device which did and did not elicit responses plotted against range. The range of the first closest non-responsive CEE and the most distant responsive CEEs are indicated by the dotted vertical lines. Figure taken from Gordon et al. (2015).

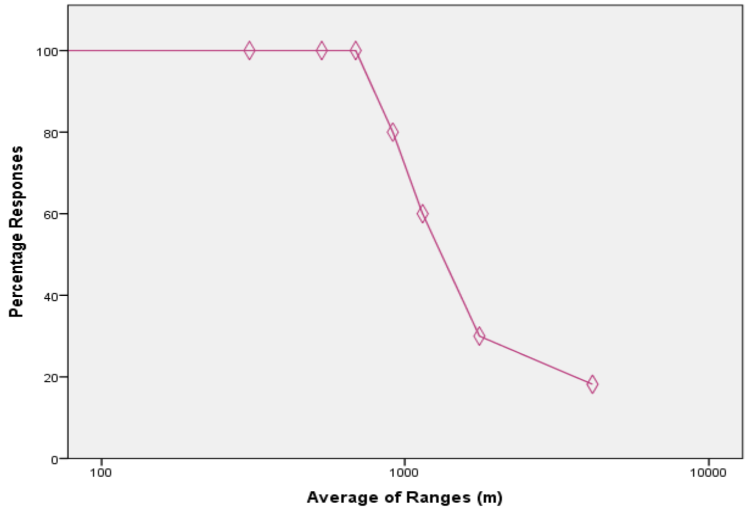

Figure 10-7 Percentage of controlled exposure experiments with harbour seals and the Lofitech device eliciting a response ranked by range. Figure taken from Gordon et al. (2015).

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 <50 m (see Revised 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.