E BASKING SHARK RISK ASSESSMENT

Scapa Deep Water Quay
Basking Shark Risk Assessment

May 2025

CONTROL SHEET

Client:	Orkney Island Council Harbour Authority
Project Title:	Scapa Deep Water Quay
Report Title:	Basking Shark Risk Assessment
Document number:	13340
Project number:	674795

Issue Record

Issue	Status	Author	Reviewer	Approver	Issue Date
1	Final	JEP	MM	MM	10/10/2023
2	FinalV2	JEP	IB	EC	16/11/2023
3	Final V3	JEP	MM	MM	21/06/2024
4	Final V4	JEP	GN	MS	19/07/2024
5	Final V5	JEP	GN	IB	30/05/2025

EnviroCentre Limited Office Locations:

Glasgow **Edinburgh** **Inverness** **Banchory**

Registered Office: Craighall Business Park 8 Eagle Street Glasgow G4 9XA
Tel 0141 341 5040 info@envirocentre.co.uk www.envirocentre.co.uk

EXECUTIVE SUMMARY30

EnviroCentre Limited was commissioned by Orkney Islands Council Harbour Authority to undertake a Basking Shark Risk Assessment to inform a basking shark license application in relation to the construction phase of the development of Scapa Deep Water Quay (SDWQ).

Basking sharks are protected under the Wildlife and Countryside Act 1981 (as amended). They are also listed as endangered on the International Union for Conservation of Nature and Natural Resources (IUCN) Red List. Various records of basking shark have been reported in Orkney waters over the years.

Underwater noise is considered to be the main activity which could negatively impact basking sharks, with injury, death and disturbance of individuals being a possibility. Underwater noise modelling was commissioned as part of this assessment based on the construction method considered the most significant for generating underwater noise; dredging.

Dredging has short risk ranges for Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) for basking sharks, being <50m at 1 hour (hr). TTS may be experienced up to 120m for 1hr exposure .There is no acute risk of noise related injury related to the dredging, and animals have time to swim away.

The development will result in increases in vessel movement in and out of the SDWQ area during construction. This vessel increase, would increase the risk of collision with basking sharks, potentially resulting in death or injury to individuals. Basking sharks can often be observed with injuries to their dorsal fins, after colliding with vessels. Studies summarised by NatureScot suggest that basking sharks show very little avoidance measures to approaching vessels. This means the risk of collision is greater rather than disturbance. Therefore, speed limits within the harbour and on vessel approach are considered to be the most appropriate approach.

Cumulative impacts may occur with the extension of the pier at Hatston outlined within the Orkney Harbour Masterplan and within the planning system at the time of writing.

Mitigation in the form of a Basking Shark Protection Plan (BSPP) will be implemented and will reduce the risk of injury as well as limit the potential disturbance. The BSPP includes a Marine Mammal (and basking shark) Observer (MMO) protocol with an exclusion zone of 500m, Passive Acoustic Monitoring (PAM) and soft start construction methods.

Whilst mitigation will reduce the likelihood of impacts from underwater noise, and lessen the severity of the predicted effects, it won’t be possible to completely avoid some level of disturbance to basking shark which may be present in the area. **A derogation licence to permit disturbance basking shark will be required for imperative reasons of overriding public interest.**

Contents

Appendices

Tables

1 INTRODUCTION

1.1 Terms of Reference

EnviroCentre Limited was commissioned by Orkney Islands Council Harbour Authority to undertake a Basking Shark Risk Assessment to inform a basking shark license application in relation to the construction phase of the development of Scapa Deep Water Quay (SDWQ), approximately 8km south of Kirkwall at Bay of Deepdale, Scapa Flow. Please see Appendix A: Proposed Site Location and Layout.

1.2 Scope of Report

The aim of this report is to provide information required by Marine Directorate to determine whether a basking shark derogation licence can be issued. The objectives were as follows:

- Collate existing data in relation to basking shark to establish which species are likely to be present within the development site and the wider zone of influence.
- Identify potential impacts to cetaceans which could occur as a result of the construction phase of the proposed development; and
- Detail mitigation which will be employed to reduce the risk of negative impacts.

1.3 Project Overview

The main purpose of this facility would be to undertake multiple industrial activities that require both deep-water berthing and large laydown area.

It is envisaged that the main activity will be the construction/assembly and maintenance of offshore wind turbines. This is also a potential location for the development of a storage and supply hub for future marine fuels.

There will also be an access road from the A961 to the site.

SDWQ Design Mitigation and Project Description

There have been various changes to the proposed development since the original Scapa Deep Water Quay (SDWQ) EIAR was produced, and these are detailed below. It should be noted that these changes do not affect the assessments within the existing EIAR.

Based on consultee feedback the project team has taken proactive steps during the design and environmental assessment process to reduce the potential negative impacts of the project, a crucial part of responsible project management (mitigation by design), aiming to prevent or minimise environmental impacts before they arise. It must be noted that the overall development footprint and dredge area remain unchanged from the exemplar design.

Design

Environmental Impact Assessment (EIA) is generally considered an iterative process, meaning it is not a one-time only assessment undertaken after a project is designed. Rather, it's a continuous process where findings from the EIA inform and influence the design of the project throughout its development.

In the case of SDWQ, EIA assessments identified potential impacts on certain habitats and wildlife. Based on these findings, the design has been modified.

Exemplar Design

The design has evolved to introduce caissons as opposed to the exemplar design which incorporated a main quay berth face as a solid quay constructed of steel tubular piles with interlocking sheet piles forming a combi wall solution with a further inner tied sheet pile anchor wall. The anticipated tubular steel piles (approx. 2.1m dia.) for the quay wall required drilled rock sockets to provide suitable pile toe fixity below -15m Chart Datum (CD) dredge level. Bauer BG41 Drill rigs or similar working over water from temporary piling platforms from the reclamation bund or a jack up barge with silt booms placed to seaward side. This combi quay wall was to support a concrete cope and deck directly behind followed by general hard core surfaced laydown reclamation area and drainage outside immediate wall active wedge area.

This design solution was initially assessed as appropriate at scheme design stage, however, as stated within Volume 3: Technical Appendix 2.1 of the EIAR, this design "*…may vary once final design and build tender procurement is progressed and contractors individual construction methods are known*".

Caisson Design

The caisson design approach focuses on an alternative quay typology based on concrete caissons which is suitable given the existing ground conditions and the high operational loads.

A caisson is a large, hollow, precast concrete structure used in marine infrastructure. It is floated to position and then carefully sunk onto a prepared foundation, typically consisting of crushed rock or exposed bedrock. Once in place, it serves as a gravity-based retaining structure capable of withstanding lateral earth and hydrostatic pressures, vessel impacts, and environmental forces. Caissons are particularly suitable for deep-water quays due to their robustness, modularity, and adaptability to various seabed conditions.

The prefabrication of caissons off site in Spain allows for a shortened programme and reduces environmental impacts from underwater and airborne noise and vibrations/impact as there is no requirement for marine piling or asociated drilling for the caisson design solution.

The geotechnical assessment based on current ground investigations leads to a materials balance where reuse of component material either dredged or excavated is prioritised.

Dredging works

In addition to the dredging required at the berth pockets the contractors design approach requires additional dredging for the caissons/block wall foundations. The design assumes that the structures will be founded on hard bearing strata, requiring the removal of superficial soils and hard strata from approx. -15m CD down to down to a maximum depth of -20.5m CD. The dredged area edge slopes depend on the material type ranging from 1:3 in superficial soils to 1:1 in engineering rock. Whilst the dredging berth pockets are required to be operative for elevations of -15m CD and -20m CD. The structures have been designed to accommodate an over dredge of 1m.

Dredging

Dredging will be performed as one of the first construction activities in a single campaign. It is proposed to be executed by a combination of different methodologies that can tackle the scope while minimising impacts to the environment and coordinated with the critical path activities.

For reference, the dredge volumes associated with the **exemplar design** were as follows:

Table 1-1: Dredging Area and Sediment Quantities (Exemplar Design)

Dredging Phases	Area (m^2)	Est. Quantities (m^3)
Phases 1 and 2 - Initial to -15m CD	39,000	86,000
Phase 3 -20m CD berthing pocket	26,000	90,000

Of the 176,000m^3 dredge material noted above, 25,000m^3 was intended to be disposed offshore. Sea disposal was originally calculated using a barge expected to carry material up to 1,000m^3 volume, therefore 50 return trips (100 vessel movements in total).

As a result of the modified **caisson design**, additional dredging volume is required compared to the exemplar design to provide the caisson foundations, as detailed below in Table 1-2.

Table 1-2: Dredge Material (Caisson Design)

Material type	Total volume dredged (m^3)	Volume reused on site (m^3)	Volume disposed offshore (m^3)
Sand	249,859	49,972	199,887
Clay	53,022	0	53,022
Rock	61,627	61,627	0
TOTAL	364,508	111,599	252,909

Dredging methods: Sand and clay will be dredged either by hydraulic dredging using a trailer suction hopper dredger (TSHD) or mechanically by means of backhoe or grab dredgers. Rock will be dredged using a cutter suction dredger (CSD) or mechanical equipment such as backhoe dredgers equipped with rock rippers.

Dredging Caisson trench: Additional dredging is required to accommodate the caisson section (rock foundation, scour protection and caisson). Different levels have been considered following assumptions of founding the caisson on suitable hard bearing strata along the full length of the quay line. Width of this trench at the lowest level is 24 m from toe to toe.

Disposal at sea: As stated above, the volume of material (predominantly sand with some clay) to be disposed at sea has increased to a maximum of 252,909m^3 (this figure may reduce once additional geotechnical information is available). Further information about sea disposal is provided in the updated BPEO. It is assumed that 4,000m^3 capacity barge(s) will be used to transport material to the offshore disposal site. Therefore, the revised estimated dredge disposal vessel movements will increase from 50 round trips (100 vessel movements in total)l (over a two-month period or almost 1 vessel movement each day) to approximately 63 rounds trips (126 vessel movements in total) over a 33-week period between end of October 2026 and end of May 2027. This equates to approximately 4 vessel movements each week.

As outlined in section 4.7.2.4 in Volume 1 of the EIAR dated August 2024, the marine deposits within the dredge area comprise an approximate stratigraphic order comprising superficial marine deposits (loose to medium dense gravelly silty sands with shell fragments and occasional cobbles) overlying glacial till. A Dredging Best Practicable Environmental Option Report (BPEO) (Rev 2, May 2025) identifies the dominant sediment type across the majority of the dredge areas is sand. Considering the dredge volume as a whole using averaged particle size analysis data, the dominant sediment type is sand comprising 60% of the total and the remainder made up of 23% silt and 17% comprising gravel sized fractions.

Dredge plume dispersal modelling has been undertaken, utilising a hydrodynamic model, as described in Technical Appendix 4.1, Volume 3 of the EIAR dated August 2024. The model results highlight that due to the relatively coarse nature of the dredge budget, and the weak tidal currents within the vicinity of the proposed dredge pockets, plumes generated as a result of the dredging works will be very localised and short term in duration. Due to the low current speeds, any sands and gravels lost to the water column during dredging will fall out of suspension immediately, within the dredge footprint. Clay and silt lost to the water column during dredging will remain in suspension for longer, being dispersed gradually over the tidal cycle, with the residual dominance of ebb tide currents resulting in net northwards plume dispersal. Total suspended solids concentrations are predicted to be low, highest within the dredge zone and immediate surrounds of the dredger, decreasing towards the plume limits.

Taking into account comments received on the application to date, the SDWQ development proposals have been amended to remove the dredge disposal site from its originally intended location within the Scapa Flow SPA. It has now been agreed that disposal of any dredge arising, to sea, will take place out with the SPA (disposal site FI040 – see Appendix A for a map of the disposal site relative to the proposed SDWQ site). This change is compliant with the EIA process and follows ‘mitigation by design’ principles.

Quay Wall

The quay wall will be formed from reinforced concrete caissons installed on a rock bed foundation, as shown on Figure 1-1 and Figure 1-2.

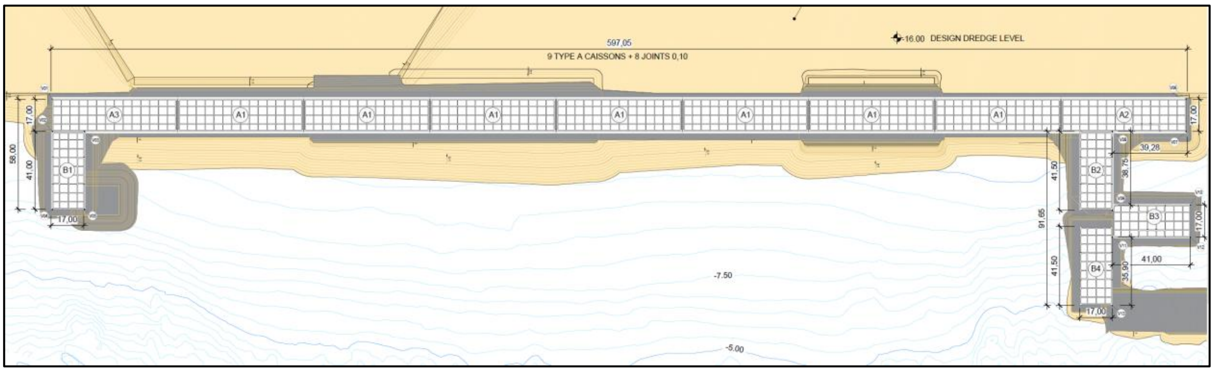


Figure 1-1: General caisson arrangement

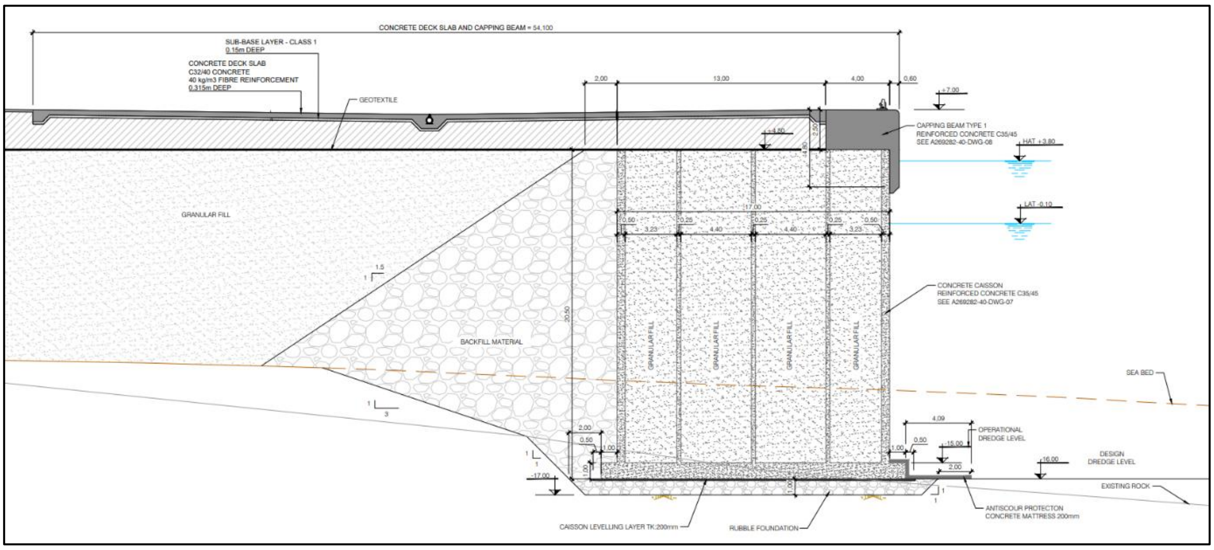


Figure 1-2: Typical caisson cross section

The main quay is composed of nine large reinforced concrete caissons, with a smaller caisson at the south end that ties into the south revetment.

At the north end, the OICHA tug and pilot boat berths are formed by four caissons. At the innermost berths of the tug and pilot boat area, where seabed levels are shallow, concrete block walls are used instead of caissons. Another block wall acts as a retaining structure behind the southern end of the main quay. The block walls are built using large interlocking concrete blocks reinforced with vertical steel bars for added stability.

Caisson transport and unloading

Following fabrication of the caissons in a floating dock in Spain, they will be towed to a sheltered area within the port basin. There, they will be stored in a floating condition, secured with mooring lines/anchors until the arrival of the semisubmersible vessel, which will transport them to the SDWQ site. It is anticipated that 3 or 4 four trips using a semi-submersible vessel will be required to deliver all caissons to the SDWQ site. The estimated transit time for the transfer of the caissons to SDWQ is 8 days (round-trip). Consecutive trips will be undertaken to transport all caissons.

Caissons will be unloaded from the semisubmersible vessel and stored within the project area, as shown on Figure 1-3. They will be prepared with the installation of auxiliary equipment such as winches, mooring ropes and anchors, walking platforms, ballast system, topographic prisms and fenders. Once the weather conditions permit, they will be sunk into their final positions. Alternatively, caissons can be temporarily stored onto the foundation at the quay line and refloated to install within tolerance later. Any temporary storage will be within the project boundary.

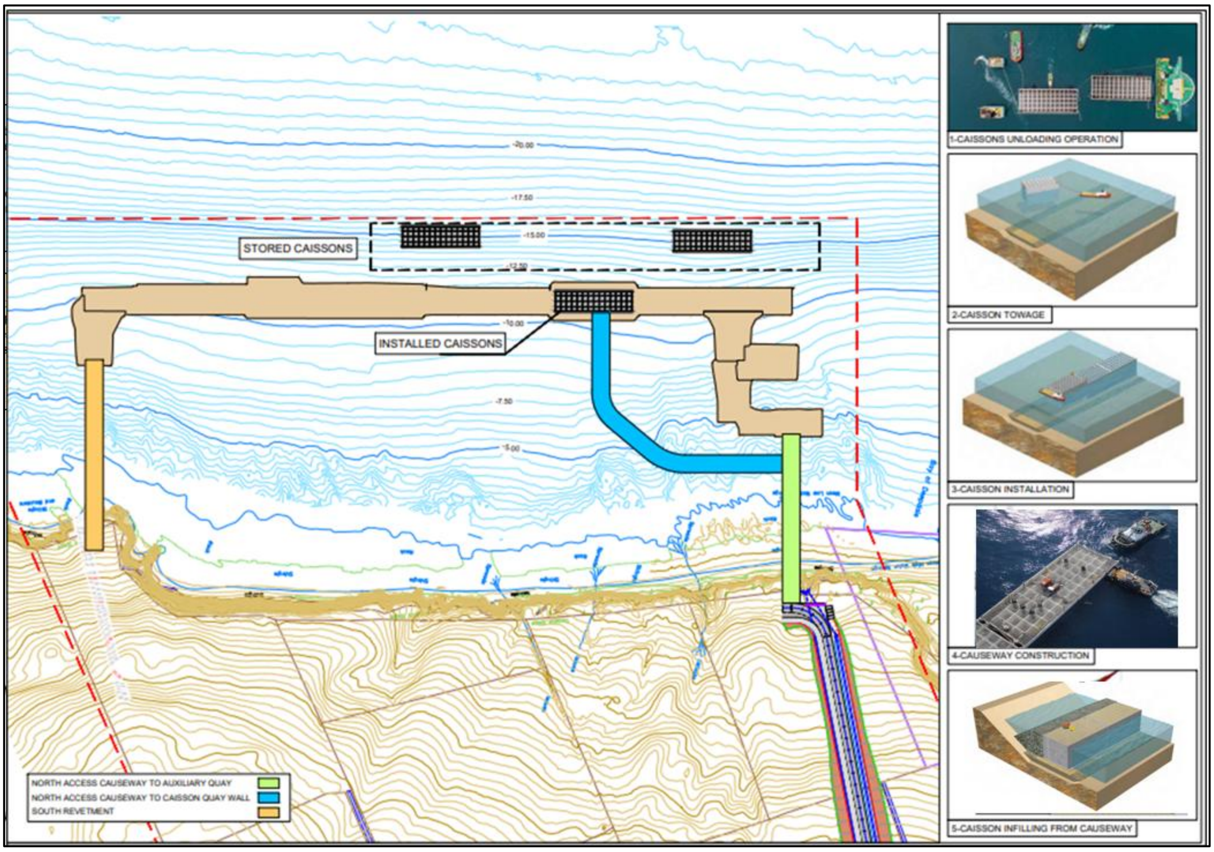


Figure 1-3: Storage area for caissons within project boundary

Caisson installation

The process to install a caisson is typically performed in around 6-8 hours given suitable metocean conditions. Caissons will be towed individually from their temporary storage location to the quay line. Typically, one tugboat will be sufficient, with the same tug used to assist the installation operation.

The caisson will be positioned while sinking, using tugs and winches until a final controlled touchdown on the rock foundation. Each caisson has independent and watertight groups of cells. During the operation, each group of cells is filled simultaneously with sea water either by means of a pump or a valve, with surveyors monitoring the level in each group to ensure that the installation process is performed in a controlled manner.

Each caisson is ballasted with seawater until touchdown on the gravel foundation. If final positioning is within specified tolerances, ballasting continues until the caisson is completely filled with sea water. Where tolerances are not achieved, the caisson is re-floated by de-ballasting water and repeating the operation, until tolerances are met. It is typical for a single operation to achieve successful installation within tolerance.

Revetments

Rock-armoured revetments will be constructed to protect the north and south sides of the site from wave action, as shown on Figure 3x. Armour layers will consist of 2.5 tonne (north) and 4.5 tonne (south) imported rock with appropriately sized underlayers and geotextiles.

Sea Filling

Once caissons are installed, filled and backfilled, and the revetments are also in place closing the perimeter, general infilling will commence. Reclamation material is comprised of dredged material and land-based excavated material (which will be screened on site to remove fines prior to placement). Substantial marine area containment will be achieved before land reclamation fill is progressed, thus minimising material sediment discharge outside the works

This element of the project is largely unchanged when considering the exemplar design and the new development proposals (caisson design).

Excavation Platform

The excavation of soft soils on land will be excavated by mechanical means, and the rock will be excavated by drilling and terrestrial blasting (no marine blasting is proposed). Initially the contractor will install pe-earthworks drainage to control surface water run-off. After installing perimeter cut off V ditches and ahead of main land excavation and land blasting, a 6m high bund will be formed at the seaward boundary of the site by retaining the existing land and excavating behind. This will create a natural noise screen and sediment run off retention barrier. This natural bund will be removed once the remainder of the site is excavated to create the final profile.

1.4 Alternative Consideration

The project was identified as part of the Orkney Harbours Masterplan. At the start of the Masterplan development, optioneering was undertaken through stakeholder discussions / workshops, OICHA internal discussions with staff, market assessments in conjunction with desk-based research. A Strategic Environmental Assessment was used to inform a draft Orkney Harbours Masterplan Phase 1 with details of the process including alternatives considered, reasons for discounting or taking forward options and potential environmental impacts as reported in the Strategic Environmental Assessment – Environmental Report.

1.4.1 Do Nothing

SDWQ is proposed to be a nationally significant deepwater quay for offshore wind. Doing nothing will not allow the long-term future of Orkney, in particular looking at facilities that ensure the decarbonisation of the industry. By doing nothing, what is considered the UK's most significant marine energy infrastructure programme ever undertaken will not be possible and as a result the UK's position for marine-based renewables in Europe and internationally will be weakened.

1.4.2 Relocation

The siting of the proposed development was originally positioned in an area to the north of the Burn of Deepdale. However, following initial site investigations and preliminary ecological surveys it was decided to move the development to its current location. The move was a result of the engineering and environmental considerations as listed below:

- The quantity of overburden and unsuitable material (for development purposes) was determined to be greatly reduced by positioning the development on the land to the south of the burn;
- The current site selected avoided crossing the Burn of Deepdale; and
- Moving the development footprint to the south avoided encroachment into the Gaitnip Local Nature Reserve (LNR) which would have been the case if it was situated to the north of the Burn of Deepdale.

1.5 Report Usage

The information and recommendations contained within this report have been prepared in the specific context stated above and should not be utilised in any other context without prior written permission from EnviroCentre Limited.

If this report is to be submitted for regulatory approval more than 12 months following the report date, it is recommended that it is referred to EnviroCentre Limited for review to ensure that any relevant changes in data, best practice, guidance or legislation in the intervening period are integrated into an updated version of the report.

Whilst the Client has a right to use the information as appropriate, EnviroCentre Limited retains ownership of the copyright and intellectual content of this report. EnviroCentre Limited does not accept liability to any third party for the contents of this report unless written agreement is secured in advance, stating the intended use of the information.

EnviroCentre Limited accepts no liability for use of the report for purposes other than those for which it was originally provided, or where EnviroCentre Limited has confirmed it is appropriate for the new context.

2 METHODS

2.1 Baseline

In order to gather data pertaining to basking shark use of the site, a desk study was conducted. The following sources were checked:

- Orkney Marine Mammal Research Initiative (OMMRI)[1];
- The Shark Trust basking shark sightings[2];
- NatureScot Basking shark satellite tagging project, Commissioned Report[3];
- Sea Watch Foundation (SWF) website for recent sightings[4 & 5];
- The Hebridean Whale and Dolphin Trust (HWDT) Whale Track[6];
- Orcadian Wildlife (OW) website for recent sightings [7]; and
- Scottish Marine Animal Stranding Scheme (SMASS)[8] for stranding records;
- ORCA website for recent records[9]; and
- OMMRI Trustees' Annual Report April 2022-2023[10].

2.2 Underwater Noise Modelling

Underwater noise modelling was commissioned as part of this assessment assess noise levels generated by common construction methods.

Please refer to Irwin Carr Consulting report: 'SDWQ, UW Noise Modelling', Appendix B which details the methods and findings of the underwater noise modelling.

2.3 Disclaimer

It should be noted that the baseline is limited by the reliability of third party information and the geographical availability of biological and/or ecological records and data. The absence of species from biological records cannot be taken to represent actual absence. Species distribution patterns should be interpreted with caution as they may reflect survey/reporting effort rather than actual distribution.

---

[1] Orkney Marine Mammal Research Initiative data request, available at: https://ommri.org/ (Accessed 07/06/2024)
[2] The Shark Trust basking shark sightings available at: https://www.sharktrust.org/basking-shark-project (Accessed 07/06/2024)
[3] Witt, M.J., Doherty, P.D., Godley, B.J. Graham, R.T. Hawkes, L.A. & Henderson, S.M. 2016. Basking shark satellite tagging project: insights into basking shark (Cetorhinus maximus) movement, distribution and behaviour using satellite telemetry. Final Report. Scottish Natural Heritage Commissioned Report No. 908. (Accessed 07/06/2024)
[4] Sea Watch Foundation Cetaceans of Orkney available at: https://seawatchfoundation.org.uk/wp-content/uploads/2012/07/Orkney2.pdf (Accessed 07/06/2024)
[5] Sea Watch Foundation Recent Sightings Orkney available at: https://www.seawatchfoundation.org.uk/recentsightings/ (Accessed 12/12/2023)
[6] HWDT sightings data available at: https://whaletrack.hwdt.org/sightings-map/ (Accessed 07/06/2024)
[7] Orcadian Wildlife information available at: http://orcadianwildlife.co.uk/wPress/cetaceans-in-orkney/ last accessed 12/12/2022
[8] Scottish Marine Animal Stranding Scheme (SMASS) available at: https://strandings.org/map/ last accessed 10/04/2023
[9] ORCA Whale and Dolphin Sightings interactive map, available at: https://orca.org.uk/whale-dolphin-sightings (Accessed 27/05/2024)
[10] OMMRI Trustees' Annual Report 6th April 2022 to 5th April 2023, available at: https://ommri.org/wp-content/uploads/2024/03/22-23-TAR_FINAL.pdf (Accessed 28/05/2024)

3 BASELINE

3.1 Desk Study

Basking sharks are listed as endangered on the International Union for Conservation of Nature and Natural Resources (IUCN) Redlist[11]. They are a PMF and are afforded domestic protection under the Wildlife and Countryside Act. The nearest known basking shark hotspot[12] during the summer months, between May and October is along the coast of the Isle of Skye, approximately 240km south west of Orkney.

No sightings of basking sharks have been recorded within the development area, however records of basking shark have been reported within the waters surrounding Orkney. Table 3-1 lists records of basking shark applicable to the development site:

Table 3-1: Records of Basking Shark

Resource	Date records available	Records/ Information
SWF	N/A	No information available
HWDT	2014-2024	Seven sightings of seven individuals reported to HWDT with the nearest located 41km west of the proposed development site.
OW	N/A	No information available
OMMRI	1936-2020	58 records of basking shark sightings within 10km of SDWQ have been submitted to OMMRI between 1936-2020.
ORCA	N/A	No information available
OMMRI 2022 Sightings Report	N/A	No information available
JNCC	N/A	No information available
SMASS	N/A	No information available

Basking shark are considered likely to be impacted by the SDWQ development, due to number of sightings and record locations.

[11] IUCN Redlist available at: http://www.iucnredlist.org/ (Accessed 07/06/2024)
[12] The Shark Trust basking shark sightings available at: https://www.sharktrust.org/basking-shark-project (Accessed 12/12/2023)

4 BASKING SHARK RISK ASSESSMENT

4.1 Activities Affecting Basking Shark

4.1.1 Underwater Noise Producing Activities

The Marine Scotland 'Guidance for Scottish Inshore Waters: The Protection of Marine European Protected Species from Injury and Disturbance'[13] defines what disturbance means to marine mammals as: 'Changes in behaviour which may not appear detrimental in the short-term, but may have significant long-term consequences. Additionally the effects may be minor in isolation, but may become more significant in accumulation'. This is also considered applicable to basking sharks. Therefore, those disturbances which may be identified that are applicable to basking sharks includes the following behaviour:

- Changes in (direction or speed of) swimming or diving behaviour;
- Certain surface behaviours such as tail splashes or breaching (jumping out of the water); and
- Moving out of a previously occupied area.

The following negative effects are linked to disturbance:

- Displacement from important feeding areas;
- Disruption of feeding;
- Disruption of social behaviours such as communication, pupping, breeding, nursing, resting and feeding;
- Increased risk of injury or mortality;
- Increased vulnerability of an individual or population to predators or physical stress; and
- Changes to regular migration pathways to avoid human interaction.

At the time of underwater noise modelling being undertaken only exemplar tender designs were completed, with works originally involving dredging, piling and drilling, thus the exact details of the construction methodologies were unknown. However, to caveat for this the data used to inform the noise models was interpolated from equipment used on similar projects. Since the underwater noise modelling was undertaken, **piling works have been removed from the design**. Therefore, the construction method below is considered the most significant:

Dredging

Dredging will be undertaken either by hydraulic dredging using a trailer suction hopper dredger (TSHD) or mechanically by means of backhoe or grab dredgers for sand and clay. Cutter suction dredger (CSD) or mechanical equipment such as backhoe dredgers equipped with rock rippers will be used for rock substrate.

The removal of superficial soils and hard strata from approx. -15m CD down to down to a maximum depth of -20.5m CD. Additional dredging is required to accommodate the caisson section (rock foundation, scour protection and caisson). Different levels have been considered following assumptions

[13] https://www.gov.scot/binaries/content/documents/govscot/publications/advice-and-guidance/2020/07/marine-european-protected-species-protection-from-injury-and-disturbance/documents/marine-european-protected-species-guidance-july-2020/marine-european-protected-species-guidance-july-2020/govscot%3Adocument/EPS%2Bguidance%2BJuly%2B2020.pdf

of founding the caisson on suitable hard bearing strata along the full length of the quay line. Width of this trench at the lowest level is 24 m from toe to toe.

4.2 Increased vessel movement

As part of the Navigational Risk Assessment undertaken for this Proposed Development, raw AIS data on vessel movements in Scapa Flow was purchased. The data contains information on vessel movements for a two-week period in August 2023 (14^{th}-28^{th}), representative of a summer period and for a two-week period in February 2024 (12^{th}-26^{th}), representative of the winter period. A range of vessel types (e.g. fishing vessels, dredging vessels, cargo boats, tugboats etc.) were recorded during both the two-week periods in August and February, with a total of 1442 vessel movements per month recorded for August and 1252 vessel movements per month recorded for February.

OICHA have provided information on the current typical monthly vessel movements experienced within the eastern area of Scapa Flow. This is summarised below:

- One Flotta fuel tanker;
- 5 Ship to Ship Operations;
- 3 tugs, each with 11 trips in and out of Scapa Pier;
- Escort duties for 1 tug with 12 trips in and out of Scapa Pier; and
- 22 pilot boat trips: and
- Occasional workboats to the rigs.

This equates to 124 vessel movements each month in the vicinity of the SDWQ site. This is approximately 5% of the total volume of vessel movements within Scapa Flow.

Dredge Disposal During Construction

It is assumed that 4,000m^3 capacity barge(s) will be used to transport material to the offshore disposal site. Therefore, approximately 63 rounds trips (126 vessel movements in total) over a 33-week period between end of October 2026 and end of May 2027. This equates to approximately 4 vessel movements each week.

Caisson Delivery, Scour Protection and Caisson in Filling During Construction

The new caisson design will see the following vessel movements during construction:

Table 4-1: Number of Predicted Vessel Movements During Construction

Vessel	Predicted Number of Vessel Movements.	Timescales
Caisson delivery	8 (4 deliveries) using semi-submersible vessel	June to August 2027
Caisson offloading (3 tugs for 13 caissons)	39	June to August 2027
Caisson installation (1 tug for 13 caissons)	26	June to August 2027
Scour protection	10 trips (20 movements)	Unknown. Taking precautionary approach, these will be undertaken between October and March.
Caisson infilling	15 trips (30 movements)	July 2027 – March 2028. Equates to 1 movement each week.
Dredging	63 trips (126 movements)	October 2026 – May 2027. Equates to 4 movements each week
Total	**249**	

4.3 Cumulative Impacts

The OICHA Harbour Masterplan included a proposal for extension of the pier at Hatston. At the time of writing, this project is being taken forward for planning submission. Many of the impacts to the marine environment are expected to be similar during the construction and operational phases. If the construction phases occur concurrently then additive cumulative effects may occur. If the construction phases are sequential then the period basking shark are exposed to impacts may be prolonged. During the operational phase both projects are expected to result in increased vessel movements and therefore cumulative effects associated with impacts resulting from vessel movements are predicted.

4.4 Impacts of Construction Activities on Basking Sharks

The effects of underwater noise to fish are less well understood as they are in marine mammals, however there is potential for permanent or temporary injury or in extreme circumstances, death in basking shark. Within the modelling report, the terminology for fish has a slightly different meaning with Permanent Threshold Shift (PTS) thresholds meaning thresholds above which mortality and potential mortal injury or recoverable injury. The meaning of Temporary Threshold Shift (TTS) (temporary hearing shift) is the same as marine mammals; effects which an animal can recover from but may experience 'masking' which reduces its ability to communicate with other animals and locate prey, resulting in fatigue. Sound levels below TTS may still have an effect on behaviour such as dispersal away from the area of noise generation.

Basking sharks do not rely heavily on hearing for foraging, instead they rely on their olfactory senses (smell) and their lateral line which senses pressure changes in water and their electrosensory pores detect signals from prey[14]. However, basking shark are sensitive to noise related activities.

Two noise sources were considered for this assessment, but drilling was screened out as it was not considered loud enough to be meaningfully assessed in an environment with many vessels and general human activity. The underwater noise modelling provide a comparison of drilling noise with the other noise producing works and vessel noise which is depicted in

, below.

[14] https://www.marlin.ac.uk/assets/pdf/species/marlin_species_1438_2021-04-07.pdf

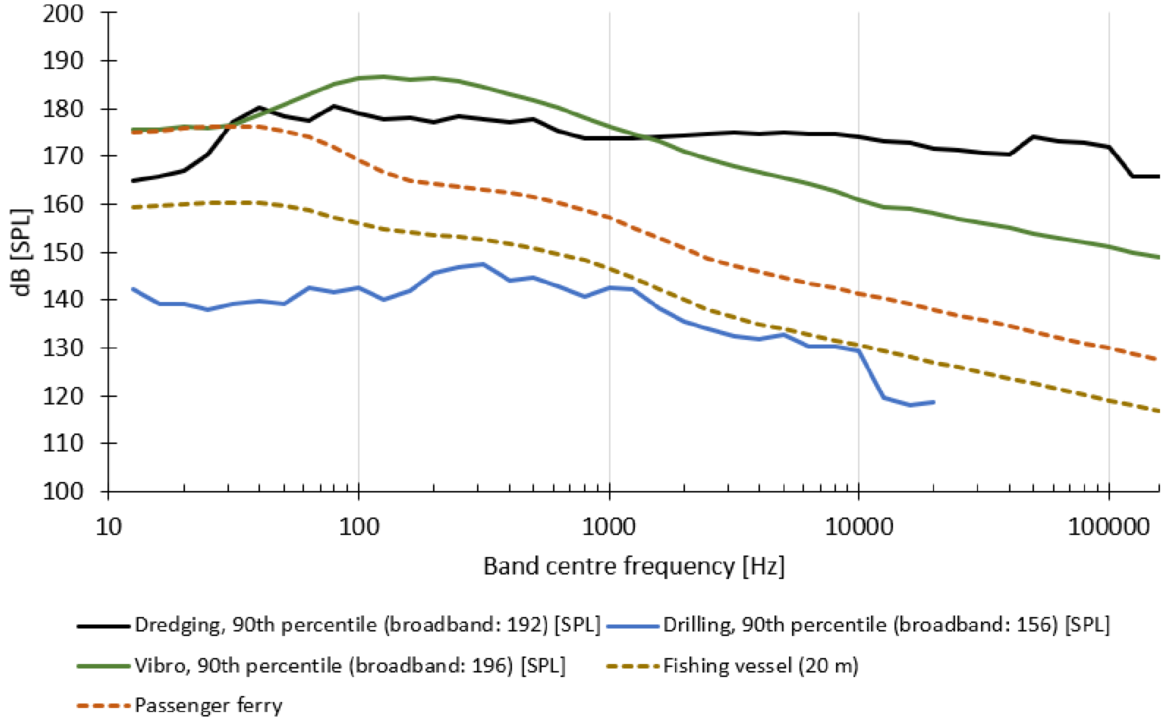


Figure 4-1: Underwater noise modelling figure 7.1 showing the three sound sources considered in the report, alongside a fishing boat and a small ferry for context.

Dredging

The noise from dredging, also presents a short risk range for PTS <50m for basking sharks at 1hr and 8hrs, with TTS a risk out to 120m for 1hr. There is no acute risk of noise related injury related to the dredging, and animals have time to swim away.

Deposition of Dredge Disposal Materials

Following identification and screening of available disposal options by EnviroCentre[15], a combination of on land and at sea disposal were considered the most appropriate options. At sea disposal (within the disposal site) would only consist of material considered unsuitable for construction works i.e. material with high silt content. At sea disposal was considered as it would require minimal transportation requirements and low environmental risk. The selected licensed marine waste disposal site which has been 'open' since 2020, is located 24km from the proposed SDWQ development site. It has been agreed that disposal of any dredge arising, to sea, will take place out with the SPA (disposal site FI040).

As outlined in section 4.7.2.4 in Volume 1 of the EIAR, the marine deposits within the dredge area comprise an approximate stratigraphic order comprising superficial marine deposits (loose to medium dense gravelly silty sands with shell fragments and occasional cobbles) overlying glacial till. A Dredging Best Practicable Environmental Option Report (BPEO) (Technical Appendix 2.2, Volume 3 of this EIAR) has been produced for the proposed development which identifies the dredge budget to consist of approximately 17% gravel, 60% sand, and 23% silt and clay.

Hydrodynamic modelling summarised in Technical Appendix 4.1, Volume 3 of the EIAR show little impact on the surrounding water column and seabed due to the low energy environment in this part of Scapa Flow. In addition, the magnitude or the sediment discharge and dispersion from dredging works

[15] SDWQ BPEO Report Final - Rev1

will be low within the dredge area and its immediate vicinity, and negligible out with this area. Thus, the supporting habitats for basking sharks beyond the development footprint will be maintained.

Overall, the associated risk with degradation of water quality directly associated with the proposed disposal and thus impacts to basking shark is considered to be low i.e. unlikely to cause a change in status of the waterbodies in question at both the dredge and disposal sites.

Comparisons of dredging sound for all activities associated with dredging (dredging itself, transit, placement, pumping and rainbowing – aerial discharge of dredged material in a fountain) for a 2,000ha harbour extension of the Port of Rotterdam using modelling revealed that rainbowing had the second lowest sound levels recorded out of all elements of the dredging activities (sediment consisted of sand)[16]. As such, with dredge noise levels for the SDWQ project having short risk ranges of PTS (<50m) and TTS (120m), based on the modelling example, it could be assumed that disposal would have reduced risk ranges of noise output on basking sharks.

Vessel Movements

In addition, vessel movements of approximately 4 per week over a 31 week period are expected for the dredge disposal for SDWQ. And 126 vessel movements for works associated with caisson delivery, scour protection and caisson installation. This equates to 249 vessel movements in total, which is considered a relatively low number of vessel movements over the length of the period of works. All vessels will follow designated shipping lanes, with the new/novel route of 2.9km (1.6 nautical miles) leading from the main shipping lane into the SDWQ being the only new route section.

Overall, there will be a low increase in the number of vessels in the SDWQ area, associated with the construction phase of the project, with vessels mainly using existing shipping routes and the works are considered to be temporary in nature, however, more vessels increase the risk of collision with basking sharks, potentially resulting in death or injury to individuals.

General Disturbance

Disturbance to basking sharks may occur as a result of the works occurring as basking sharks are sensitive to disturbance. The most likely disturbance to basking sharks as a result of the noise related activities include both physiological (increased stress and cortisol levels, rapid heartbeat and increased breathing rate) and behavioural disturbance (trashing tails, breaching and diving)[17].

It is expected that basking sharks would be likely to exhibit a behavioural change as a result of the noise, predominantly changing direction away from the noise source, with tail splashing occurring. In addition, physiological stress is likely to also occur. This could impact basking sharks energy and fitness levels through disturbing foraging, breeding or causing avoidance of feeding areas for periods of time.

4.5 Effects of Terrestrial Noise from Blasting

Disturbance of basking sharks whilst at the surface of the water could be caused by noise associated from terrestrial blasting, which could have a negative impact on basking sharks.

Although the majority of energy generated within the atmosphere from any surface mineral blasting will be of a sub-audible nature, there will also be a component that is audible, i.e. at frequencies greater than 20 Hz, and as such can be heard as noise and measured in terms of dB(A).

---

[16] https://dredging.org/documents/ceda/html_page/2013-06-woda-technicalguidance-underwatersound_lr.pdf
[17] https://foweyharbour.co.uk/wp-content/uploads/2021/04/basking_shark_code_of_conduct.pdf

Routine blasting operations regularly generate air overpressure levels at the closest point to blast area of around 120 dB and the National Marine Fisheries Service (NMFS) predicts that marine species exposed to $\geq$100 dB (in-air) will be behaviourally harassed[18]. However, the intensity of these noise levels experienced at a distance from the blast site are affected by a range of meteorological conditions (wind speed and direction, temperature, cloud cover and humidity). For example, if a blast is detonated in a motionless atmosphere in which the air temperature is constant, then the air overpressure intensity will decrease purely as a function of distance and will, once outside of the immediate vicinity of the blast, reduce by 6 dB as the distance from source doubles. Although such conditions are very rare, the overall result is that the nominal 6 dB reduction may be greater in some directions from the source and less in others.

A 6m high bund will be formed at the seaward boundary of the site by retaining the existing land and excavating behind, creating a natural noise screen from terrestrial blasting (and other works) and will only be removed once the site is excavated to the final profile. This would reduce the effects of noise on basking sharks at the waters surface.

In addition to bunding, a range of controls and mitigation measures can and should be implemented when undertaking terrestrial blasting, including screens to further dampen sound, which would also reduce the effects of noise on basking sharks at the water's surface.

Due to the reduction in noise doubling from the source of blast site, doubling incrementally, it will be unlikely that basking shark would be negatively impacted to a population level from terrestrial noise associated with blasting.

4.6 Effects of Increased Vessel Movement on Basking Sharks

Increased vessel movement has the potential to increase collisions with basking sharks.

The development and dredge disposal will require a variety of vessels that differ in size, speed and operating procedure. This can result in a wide range of basking shark collision risk levels for different vessels and SDWQ development activities. Although, larger vessels have a greater footprint and therefore may be considered more likely to make encounters with basking sharks, the speed at which smaller vessels travel can be more detrimental to basking sharks.

Basking sharks can often be observed with injuries to their dorsal fins, after colliding with vessels. Studies summarised by NS[19] suggest that basking sharks show very little avoidance measures to approaching vessels, this is likely more apparent during the summer months when they are 'in a trance like state' feeding at the surface. It is unknown how sensitive they are to disturbance from vessel movements.

The increase in the number of vessels travelling through to SDWQ, during construction including dredge disposal, would increase the risk of collision with basking sharks, potentially resulting in death or injury to individuals. However, the likelihood of vessel collisions is dependent upon vessel speed,

[19] NatureScot (2009) Commissioned Report 339: Basking Shark Hotspots on the West Coast of Scotland available at: https://www.nature.scot/doc/naturescot-commissioned-report-339-basking-shark-hotspots-west-coast-scotland (Accessed 07/06/2024)

animal behaviour and vessel manoeuvrability[20]. Vessels travelling at slower speeds in general can allow time for basking sharks and vessel operators to react to avoid collisions.

4.7 Conclusion

Some of the activities associated with the SDWQ development (dredging and vessel movement) have the potential to cause disturbance, injury or in extreme circumstances, death to individual basking shark but the risk is considered to be low. For the most part the activities associated with the proposed development may result in temporary avoidance of a small area of habitat available to individuals. It is considered that with mitigation described in the following Basking Shark Mitigation Plan (BSMP) the risk of death and injury will be negligible. It is not possible to rule out some level of disturbance to individuals which might be present within the area.

Overall, the increase in the number of vessels travelling through to SDWQ, during construction, and dredge disposal, would increase the risk of collision with basking sharks, potentially resulting in death or injury to individuals.

Although there are some uncertainties regarding the overall population status and trends of basking shark in UK waters, it is considered that due to the relatively small area over which individuals are likely to be affected, small number of sightings within the area and the temporary nature of the works, there will not be an overall negative effect on the favourable conservation of the local basking shark population.

[20] SEER U.S. Offshore Wind Synthesis pf Environmental Effects Research: Presence of Vessels: Effects of Vessl Collision on Marine Life (2022): https://tethys.pnnl.gov/sites/default/files/summaries/SEER-Educational-Research-Brief-Effects-of-Vessel-Collision-on-Marine-Life.pdf

5 BASKING SHARK MITIGATION PLAN

The basking shark mitigation will comprise a standard Marine Mammal Observation Protocol (MMOP) as per JNCC guidance will be implemented during dredging operations in sea states less than 4 and during times of optimal visibility

Note: piling and associated drilling no longer required for the caisson design

5.1 Basking Shark Observation Protocol

The Basking Shark Observation Protocol (BSOP) will be implemented so that the construction and dredging works do not cause injury or unnecessary disturbance to basking sharks. This section has been designed with reference to current JNCC guidance 'Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise' (August 2010) [21].

5.1.1 Marine Mammal Observer

A suitably qualified Marine Mammal Observer (MMO), competent in the identification of basking shark at sea, will be present during the dredging. The MMO will undertake observation for basking shark within the mitigation zone before dredging commences and will be dedicated to that one task for the duration of any watch. The MMO will advise the contractors and crews on the implementation of the procedures set out in the agreed protocol, to ensure compliance with those procedures.

The JNCC guidance provides the following definitions of an MMO:

MMO: Individual responsible for conducting visual watches for basking sharks. It may be requested that observers are trained, dedicated and/or experienced.

Trained MMO: Has been on a JNCC recognised course.

Dedicated MMO: Trained observer whose role on board a vessel is to conduct visual watches for basking sharks.

Experienced MMO: Trained observer with three years of field experience observing for basking sharks, and practical experience of implementing the JNCC guidelines.

The MMO will be positioned appropriately to cover the full mitigation zone and will be trained. The identity and credentials of the MMO will be agreed with Marine Directoraite.

5.1.2 MMO Equipment

The MMO will be equipped with binoculars (10X42 or similar) and/or a spotting scope (20-60 zoom or equivalent), a copy of the agreed protocol and the Marine Mammal Recording Form (MMRF), which is a Microsoft Excel spreadsheet containing embedded worksheets named Cover Page, Operations, Effort and Sightings. A Microsoft Word document named Deck forms is also available, and the MMO may prefer to use this when observing before transferring the details to the Excel spreadsheets. Although these forms were developed for seismic surveys, they can be used for dredging operations,

[21] https://data.jncc.gov.uk/data/31662b6a-19ed-4918-9fab-8fbcff752046/JNCC-CNCB-Piling-protocol-August2010-Web.pdf

although many columns will not be applicable. The ability to determine the range of basking sharks is a key skill for MMOs, therefore a hand-held rangefinder will be used to verify the range.

All MMO forms, including a guide to completing the forms; and instructions on how to make a rangefinder are available on the JNCC website: http://jncc.defra.gov.uk/marine/seismic_survey

5.1.3 Communication

The contractor will be responsible for the communication channels between those providing the mitigation service and the crews working on the dredging. A formal chain of communication from the MMO to the contractor, who will start/stop dredging, will be established. In order to confirm the chain of communication and command the MMO will attend any relevant pre-mobilisation meetings.

5.1.4 Mitigation Zone

Following appointment of contractor / Ecological Clerk of Works (ECoW), logistical information will be available/ updated to provide more detailed mitigation zones for the MMO. This may change throughout the construction period due to ground levels changing and depending on the area of works which need to be viewed.

The JNCC guidance defines the mitigation zone as a pre-agreed radius around dredging site (prior to any works. This is the area where a MMO keeps watch for basking sharks (and delays the start of activity should any basking sharks be detected). The extent of this zone represents the area in which a basking shark could be exposed to sound that could cause injury. The MMO should be located on the most appropriate viewing platform to ensure effective coverage of the mitigation zone. The radius of the mitigation zone should be 500m for each activity to cover the PTS and TTS ranges of the activities.

5.1.5 Dredging Protocol

The standard JNCC protocol is outlined below:

1. Dredging will not commence during poor visibility (such as fog) or during periods when the sea state is not conducive to visual searches (above sea state 3 is considered not conducive[22]) as there is a greater risk of failing to detect the presence of basking sharks. Basking shark have slow moving triangular shaped fins, therefore the MMO shall take additional precautions if the sea state exceeds 3. An elevated platform for the MMO to monitor from would be beneficial when the sea state is 3 or above, the dredging works could also be scheduled on a day where the sea is expected to be calm.

2. The MMO(s) should be situated in location that provides the best viewing platform and is likely to be closest to the dredging activities. For example, an elevation area of the coast or a vessels bridge that allows 360 degree cover (depending upon the size of the mitigation zone more than one MMO viewing platform (and therefore more than one vessel) may be required to ensure that the entire mitigation zone can be observed).

3. At least 30 minutes before any type of dredging works, a visual watch known as the ‘pre-works search’, should be carried out in the mitigation zone. The pre-works search should continue until the MMO advises that the mitigation zone is clear of basking sharks, and the works can start.

[22] Detection of marine mammals, particularly porpoises, decreases as sea state increases. According to the JNCC guidance ideally sea states of 2 or less are required for optimal visual detection.

4. The MMO will scan the waters using binoculars or a spotting scope and by making visual observations. Sightings of basking sharks will be appropriately recorded in terms of date, time, position, weather conditions, sea state, species, number, adult/juvenile, behavior, range etc. on the JNCC standard forms. Communication between the MMO and the contractor and the start/end times of the activities will also be recorded on the forms.

5. Dredging works should not be undertaken within 20 minutes of a basking shark being detected within the mitigation zone.

6. If a basking shark is observed within the mitigation zone, it should be monitored and tracked until it moves out of range. The MMO should notify the relevant chain of command of the detection and advise that the operation should be delayed. If the basking shark is not detected again within 20 minutes, it can be assumed that it has left the area and the works may commence.

7. If an MMO is uncertain whether basking sharks are present within the mitigation zone, they should advise that the activity should be delayed as a precaution until they are certain that no animals are present.

8. A soft-start will be employed, with the gradual ramping up of dredging (where possible) power incrementally over a set time period until full operational power is achieved. The soft-start duration will be a period of not less than 20 minutes. This will allow for any basking shark to move away from the noise source.

9. If a basking shark enters the mitigation zone during the soft-start then, whenever possible, the dredging operation will cease, or at least the power will not be further increased until the basking shark exits the mitigation zone and there is no further detection for 20 minutes.

10. If a basking shark enters the mitigation zone during the soft-start then, whenever possible, dredging operation will cease until the basking shark exits the mitigation zone and there is no further detection for 20 minutes.

5.1.6 Reporting

As per the JNCC guidance, reports detailing the dredging activity and basking shark mitigation (the MMO reports) will be sent to Marine Directorate at the conclusion of the activities. Reports will include:

- Completed MMRFs;
- Date and location of the activities;
- A record of all occasions when activities occurred, including details of the duration of the pre-search and soft-start procedures, and any occasions when activities were delayed or stopped due to presence of basking shark;
- Details of watches made for basking shark, including details of any sightings, and details of the activity during the watches;
- Details of any problems encountered during the activities including instances of non-compliance with the agreed protocols; and
- Any recommendations for amendment of the protocols.

5.1.7 Terrestrial Noise Considerations - Blasting

Following appointment of contractor logistical information will be available/ updated to provide more detail regarding terrestrial blasting protocols and blasting methods will be determined by the contractor once commissioned.

The MMO protocol implemented for dredging will also be undertaken for terrestrial blasting.

In addition, the following mitigation methods should be considered to be implemented for terrestrial blasting:

During terrestrial blasting, minimising air overpressure at the source, such that, even under unfavourable weather conditions, all such energy is within acceptable criteria at distance, remains the best practicable approach. It is an approach that all surface mineral sites are obliged to follow under the provisions of The Quarries Regulations 1999.

Detonating cord should be used as sparingly as possible, and any exposed lengths covered with as much material as possible. Just a few feet of exposed cord can lead to significant amounts of audible energy and, hence, high air overpressure levels. Stemming release can be controlled by detonation technique, together with an adequate amount of good stemming material. It should be noted however that detonation cord and stemming release have been virtually eliminated with the use of in hole initiation techniques.

If the use of exposed detonating cord is avoided the characteristic noise of a blast is no longer a sharp crack but rather a dull thump. This is partly due to the detonating sequence and partly due to natural energy dissipation and reduction. Whilst some of the noise perceived by a neighbouring resident would be directly from the blast itself, the lower frequency components of the air overpressure might well induce secondary rattling of windows and ornaments within a property which could augment the overall effect.

Thus, in terms of noise control or reduction in the care and attention to blast design and subsequent implementation, including initiation, necessary for the control of air overpressure is equally applicable to noise.

BS 6472-2:2008 states that “The highest [air overpressure] levels normally measured in the United Kingdom are generally less than 1% of the levels known to cause structural damage.” Therefore, by implementation of the best practice measures, effects due to air overpressure generation by the Proposed Development are anticipated to have a negligible effect on seals in terrestrial environments.

5.2 Vessel Movement Mitigation Protocol

The Harbour Authority implement speed restrictions on vessels within Orkney waters, additionally, leaflets can be created to provide additional advice to port users to avoid disturbance to and/or collision with basking sharks during construction which should include, but is not limited to the following:

- Adherence to Basking Shark Code of Conduct[23].
- A strict speed limit for both onshore and marine traffic will be implemented to reduce risk of collision with basking sharks (4 knots within the water).
- Implementation of a vessel management plan including agreed routes and speed limits.
- Safe vessel operation to minimise risk of collision with basking sharks to be promoted to users. Training courses such as those provided by the WiSe scheme[24] could be offered at regular intervals.

[23] https://foweyharbour.co.uk/wp-content/uploads/2021/04/basking_shark_code_of_conduct.pdf
[24] Information available at: https://www.wisescheme.org/ (accessed 02/06/2023)

Additionally (where possible) leaflets can be created to provide additional advice to quay users to avoid disturbance to and/or collision with basking sharks which should include, but is not limited to the following:

- Keep a safe distance from basking sharks. Never get closer than 100m (200m if another boat is present), but if within 100m, switch the engine to neutral;
- Never drive head on to, or move between, scatter or separate basking sharks. If unsure of their movements, simply stop and put the engine into neutral;
- Spend no longer than 15 minutes near the animals;
- Special care must be taken with mothers and young;
- Maintain a steady direction and a slow 'no wake' speed; and
- Avoid sudden changes in speed.

Wildlife code of conduct methods have been created by NatureScot and are available on their website[25].

5.3 Additional Good Practice Recommendations

If any dead basking shark is anecdotally observed during construction or operation, it should be reported to the Scottish Marine Animal Stranding Scheme (SMASS) (www.strandings.org) and live basking shark strandings will be reported to British Divers Marine Live Rescue (www.bdmlr.org.uk). All dead or stranded basking shark should also be reported to the local NatureScot office.

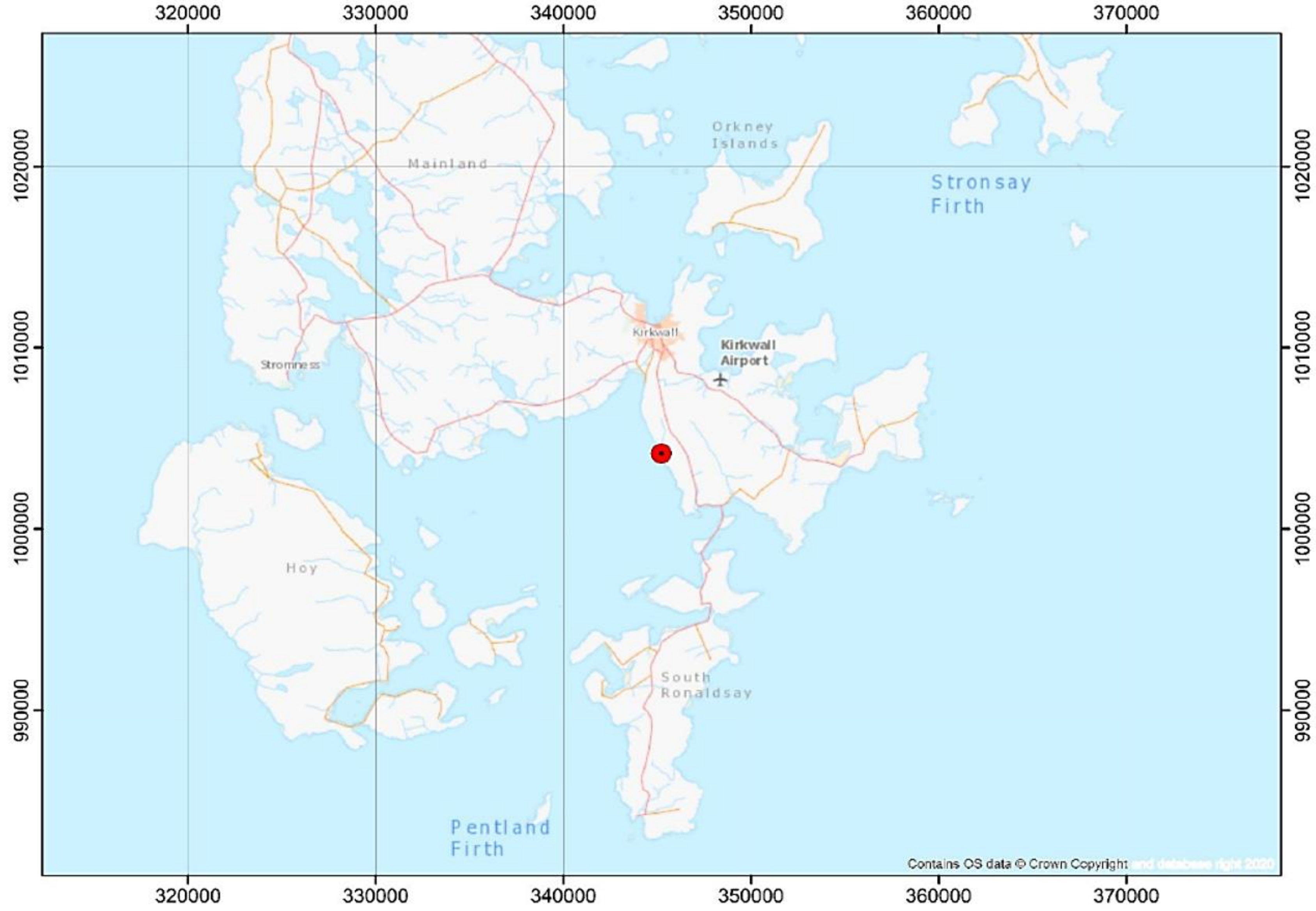
The MMO should keep a record of all basking shark sightings, whether in the mitigation zone or not, to be issued to NatureScot. An understanding of the location of species is essential to appropriately assess the impacts of a proposed development and plan and target effective mitigation, therefore this data could be used to inform future projects. Biodiversity data are extremely important as, aside from use in planning and decision making, they are key to delivering state of environment reporting, education, modelling trends in species and habitat distribution, and research and policy making.

[25] https://www.nature.scot/sites/default/files/2017-06/Publication%202017%20-%20The%20Scottish%20Marine%20Wildlife%20Watching%20Code%20SMWWC%20-%20Part%201%20-%20April%202017%20%28A2263518%29.pdf

APPENDICES

A PROPOSED SITE LOCATION AND DISPOSAL SITE FI040

Site Location

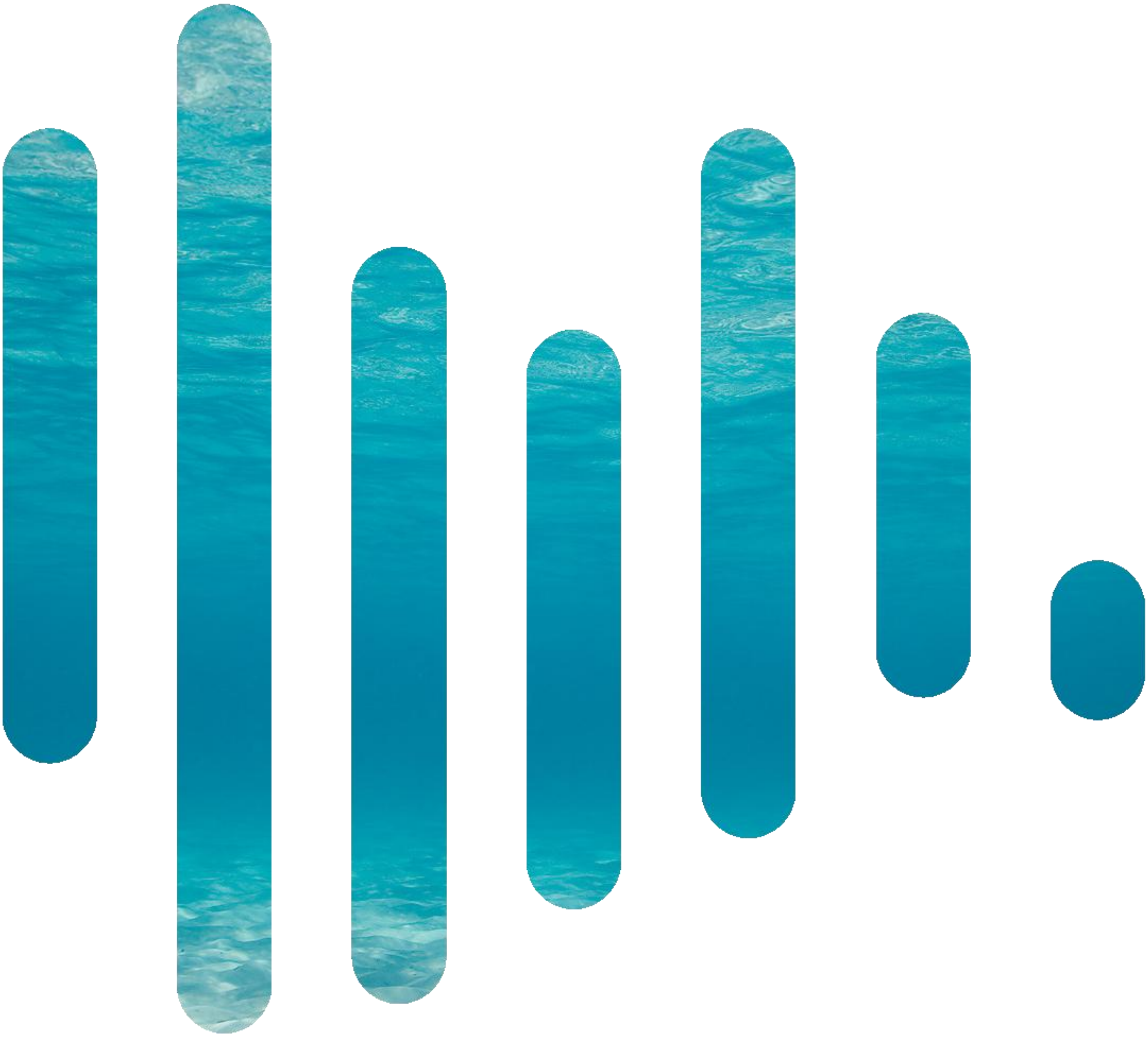


Location of Disposal Site FI040

Source: https://marinescotland.atkinsgeospatial.com/nmpi/default.aspx?layers=712

B UNDERWATER NOISE MODELLING

(Note – Piling and Associated Drilling No Longer Required for the Caisson Design)



Scapa Deep Water Quay, UW Noise Modelling

Kirkwall, Orkney

RP001 Rv4 2022248 (Scapa DWQ, UW Modelling)

19 May 2025

PROJECT: SCAPA DEEP WATER QUAY, UW NOISE MODELLING

PREPARED FOR: ENVIROCENTRE

8 EAGLE STREET,

CRAIGHALL BUSINESS PARK,

GLASGOW, G4 9XA

SCOTLAND

ATTENTION: EMMA CORMACK

REPORT NO.: RP001 2022248 (Scapa DWQ, UW Modelling)

Disclaimer

This report is provided for the stated purposes and for the sole use of the named Client. Irwin Carr Ltd accepts responsibility to the Client alone that the report has been prepared with the skill, care and diligence of a competent engineer, but accepts no responsibility whatsoever to any parties other than the Client. Any such parties rely upon the report at their own risk.

Document Control

Status:	Rev:	Comments	Date:	Author:	Reviewer:
Draft	1.0		19 May 2025	Rasmus Sloth Pedersen	Shane Carr

EXECUTIVE SUMMARY

BRIEF DESCRIPTION OF WORK

In relation to the construction of a deep-water port in Scapa Flow, both dredging, drilling and piling is planned. The noise from these activities can adversely affect local fauna either through direct injury of sensory systems or indirect harm from noise pollution drowning out communication and foraging sounds. Noise modelling has been carried out in respect to the various noise sources and local animals to estimate impact from noise and what mitigation can/needs to be employed to keep impacts below levels of significant harm to the local wildlife.

Source sources (dredging, piling and blasting) are modelled from a combination of empirical models (based on recorded data) and numerical models (calculated source levels from inputs).

CONCLUSION & RESULTS SUMMARY

Dredging

The noise from dredging, while presenting a significant Permanent Threshold Shift (PTS (hearing injury) risk to ranges <210 m for the Very High Frequency (VHF) group (e.g., porpoise), this is only for animals staying close to the activity for extended periods (> 1 hour) and assumes continuous dredging with the dredger level as given by the 90th percentile. For the best estimate (model mean) the PTS risk range is 210m after 8 hours exposure. There is no acute risk of noise related injury related to the dredging, and animals have time to swim away. Further the area ensonified does not “block” access through a channel or strait.

Vibro piling

Prolonged exposure to vibro piling at close range (<50 m) carries some auditory risk for the animals assessed, specifically groups LF, VHF and P- (baleen whales, porpoises and salmon/trout), where the peak pressures in the noise have risk ranges up to 300 m for the VHF group. We therefore suggest surveillance takes place prior to piling to minimise the risk of impact on porpoises. While this is a significant risk for animals close to the activity, we stress that we have used a very conservative approach to estimating the source levels, and the realised emission will likely be significantly lower.

Further, animals will tend to move around, or away from noise, which will limit exposure. In Figure 16, p. 23 and Figure 18, p. 24 we show an example of the effect of using moving receivers (animats, modelled animals) to estimate what might be the effect of movement.

Table of Contents

Abbreviations and Definitions:

PTS	Permanent Threshold Shift
VHF	Very High Frequency
SOFAR	Sound Fixing And Ranging
SSP	Sound Speed Profile
SPL	Sound Pressure Level
Hearing group	Refers to the Southall 2019 hearing groups (Southall, et al., 2019).
"," and "."	Comma "," is used as thousands separator, while dot "." Is used as decimal separator.
TL, PL	Transmission Loss, Propagation Loss. Used interchangeably in this document.
Psu	Practical salinity unit, equivalent to parts per thousand as g/kg, mass of salts per mass of water.
Noise	Sound that causes, or is assumed to cause, annoyance or disadvantage. No automatic significance of impact is associated with this term.
Solver	Mathematical algorithm for calculating sound transmission losses in water.
[]	Square brackets are used throughout to denote units, e.g.: "Pressure [Pa]" means pressure in Pascals.
Degrees	Either angular degrees (0-360) or degrees Celsius
3rd octave, decidecade	Refers to the subdivision of octaves (doublings of frequency) and decades (10x frequency). Using the appropriate base frequency, the two are identical for practical purposes.
Worst case	Used as "reasonable worst case". E.g. use of MHWS instead of historical maximum for max water level. Or 90th percentile as representative of worst-case.
Mean case	The expected case, both median and mean values will inform this.
Signature, Impulse	When in relation to a sound, this refers to the time-pressure signal associated with that sound, normally as a time-series of pressures relative to ambient pressure, in pascals.
Vibro	Vibration pile driving
MSL	Mean Sea Level
β, Log multiplier	Symbol used to denote the factor multiplied by the base ten Log in equations like: "$TL = \beta \times Log_{10}(range)$"
SL, Source level	Apparent monopoint source level as viewed from the acoustic far field

1 INTRODUCTION

In relation to the construction of a deep-water port in Scapa Flow, both dredging, drilling and piling is planned. The noise from these activities can adversely affect local fauna either through direct injury of sensory systems or indirect harm from noise pollution drowning out communication and foraging sounds. Noise modelling has been carried out in respect to the various noise sources and local animals to estimate impact from noise and what mitigation can/needs to be employed to keep impacts below levels of significant harm to the local wildlife.

Source sources (dredging, piling and blasting) are modelled from a combination of empirical models (based on recorded data) and numerical models (calculated source levels from inputs).

1.1 Underwater Acoustics Basics

Underwater acoustics modelling is the application of physical models to characterise the behaviour of sound in environments under the surface of the sea and in the top layers of the seabed. As some familiarity with in-air acoustics is assumed the focus here is on key differences between in-air acoustics and underwater acoustics, making waterborne propagation more efficient than airborne propagation.

This chapter only gives reader a quick overview, please see APPENDIX B – Underwater Acoustics Basics APPENDIX *for more detail.*

1.1.1 SOUND SPEED

Water is much harder to compress than air, and a soundspeed of 1500 m/s is often used as a standard soundspeed in water[1] much as 340 m/s is in air.

The soundspeed changes with depth, "sound speed profile", this is quite important in sound propagation, as refraction (changes in propagation angle) will occur when sound moves between layers of water with varying sound speed. These effects can lead to profoundly inhomogeneous sound fields and SOFAR (Sound Fixing And Ranging) channels.

The same relationships are valid in the sediment, though sediments commonly have soundspeeds higher than water. Soundspeeds from 1700 m/s (fine sand/silt) to 2500 m/s (gravel) are common for non-solid sediments, with solid sediments (rocks) having much higher soundspeeds 2800 m/s (Calcarenite) to 6000 m/s (some granite).

1.1.2 SPREADING LOSS

Most of the propagation loss (loss in dB from source to receiver, "PL") that occurs initially is governed by "spreading loss". It is the simple "thinning out" of acoustic energy as it spreads away from the source, usually in all directions – spherically. This means a reduction in received level of 6 dB per doubling of distance

At longer ranges the medium is no longer unbounded. We reach ranges where the sound has interacted with the surface (near perfect acoustic reflector) or the seabed (lossy acoustic reflector). Here we expect spreading loss to be ~3 dB per doubling of distance.

1.1.3 ABSORPTION

Besides the "thinning out" of the sound energy as described above, the sound is also dissipated into heat by the way the pressure changes interact with water, molecules and particles in its path. This absorption is salinity dependant. Frequencies under 1 kHz experiences almost no absorption, while high frequencies, over 10 kHz, can be attenuated by over 10 dB / km.

Small bubbles, wind or wave induced, will further attenuate especially the high frequencies.

1.1.4 SEDIMENT

Depending on the incident angle of the sound, the frequency and the acoustic properties of the sediment, sound can either mostly penetrate the sediment or mostly be reflected by it.

[1] Varies from 1450 m/s at 0° to 1550 m/s at 30° at salinity of 35 psu.

In shallow areas with soft sediment (acoustically similar to water), it is typical to find that close to the source, at high incidence angles and at low frequencies (<250 Hz) the sound will penetrate into the sediment and dissipate there, leading to very high transmission losses for these frequencies.

1.1.5 SOUND LEVEL UNITS

All references to sound pressure levels (SPL), peak pressure levels (L_p) and sound exposure levels (L_e) refer to a logarithmic ratio between a reported/measured pressure or exposure and a reference pressure or exposure. As an example, a level of 220 L_p (decibel zero-to-peak) is equal to a peak pressure of 100000 Pascals (Pa) over ambient pressure, while 120 L_p is equal to 1 Pa over ambient pressure.

To avoid dealing with these large numbers as pascals (as a linear scale), they are converted to a decibel ratio (Table 1 for definitions). Besides compressing large numbers to a smaller scale this also corresponds better to how animals are thought to perceive sound, namely as relative steps. This means that an increase from 1 to 2 Pa *sounds like* the same increase as from 100 to 200 Pa, even though the first step was only 1 Pa, while the second was 100 Pa. This is better reflected in a logarithmic scale based on ratios, where both steps are equal, here 3 dB.

However, while dBs are practical, they can be hard to compare between studies, due to vague definitions, and so we have adopted the standards set by ISO 18405-2017 (Table 1 below).

For ease of reference please see following overview for unit definition.

Table 1: Definitions.

Unit	Definition	Comments
SPL (dB_{RMS}) ISO 18405- 2017: 3.2.1.1	$SPL = 10 \cdot Log_{10}\left(\frac{\frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} p(t)^2 dt}{1 \cdot 10^{-12} Pa}\right)$	Functionally equivalent to deprecated $20 \cdot Log_{10}\left(\frac{RMS}{1 \cdot 10^{-6} Pa}\right)$
L_p ($dB_{z\text{-}p}$) ISO 18405- 2017: 3.2.2.1	$L_p = 20 \cdot Log_{10}\left(\frac{Pa_{max}}{1 \cdot 10^{-6} Pa}\right)$	This assumes that Pa_{max} is equal or greater than $\sqrt{Pa_{min}^2}$
$L_{p\text{-}p}$ ($dB_{p\text{-}p}$)	$L_{p-p} = 20 \cdot Log_{10}\left(\frac{Pa_{max} - Pa_{min}}{1 \cdot 10^{-6} Pa}\right)$	Often[2] equivalent to $L_P + 6.02\ dB$
L_E (dB_{SEL}) ISO 18405- 2017: 3.2.1.5	$L_E = 10 \cdot Log_{10}\left(\frac{\int_{t_1}^{t_2} p(t)^2 dt}{1 \cdot 10^{-12} Pa}\right)$	For continuous sound this is equivalent to $SPL + 10 \cdot Log_{10}(t_2 - t_1)$ "t" is seconds

Unless otherwise stated SPL has an averaging period of 1 second, and L_E for the duration of the specified event, sometimes indicated as $L_{E\text{-"time"}}$ or $L_{E\text{-single blow}}$.

If the averaging period for SPL is equal to the total even duration then SPL is equal to "Leq" the "equivalent constant level".

When source levels are presented, the same units are used, and it is implicit that all source levels are given as if recorded 1 m from an omnidirectional mono-point source, unless otherwise specified.

[2] If maximum pulse rarefaction is below ambient pressure and compression and rarefaction phases are of equal size.

2 SITE AND LOCAL ENVIRONMENT

The site is located in Orkney, Scotland:

- Scapa DWQ at Lat: 58.920345, Lon: -2.965084. Mean water depths 5-30 m.

The site is sheltered from oceanic swell, with little current and with no major outflows from rivers, meaning that the conditions important for sound propagation are quite stable. The sediment is generally a soft upper layer of mud/silt and gravel overlaid a layer of weathered sedimentary rock, before a stronger layer of sedimentary rock (silt-/mud-/sand-/lime-stone).

Figure 1. General location of Scapa DWQ development (in red circle) on Main Island of the Orkney Islands. Hatston site (just north west of Kirkwall, shown for completeness).

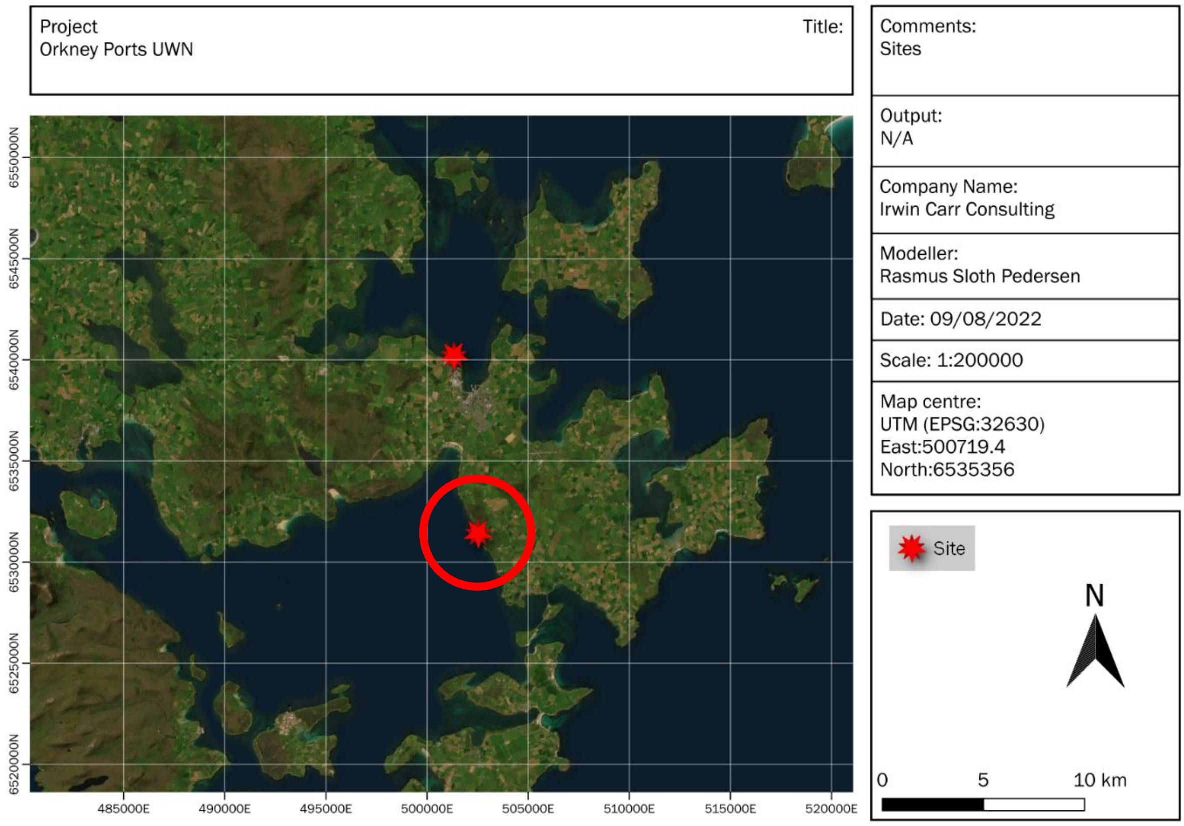
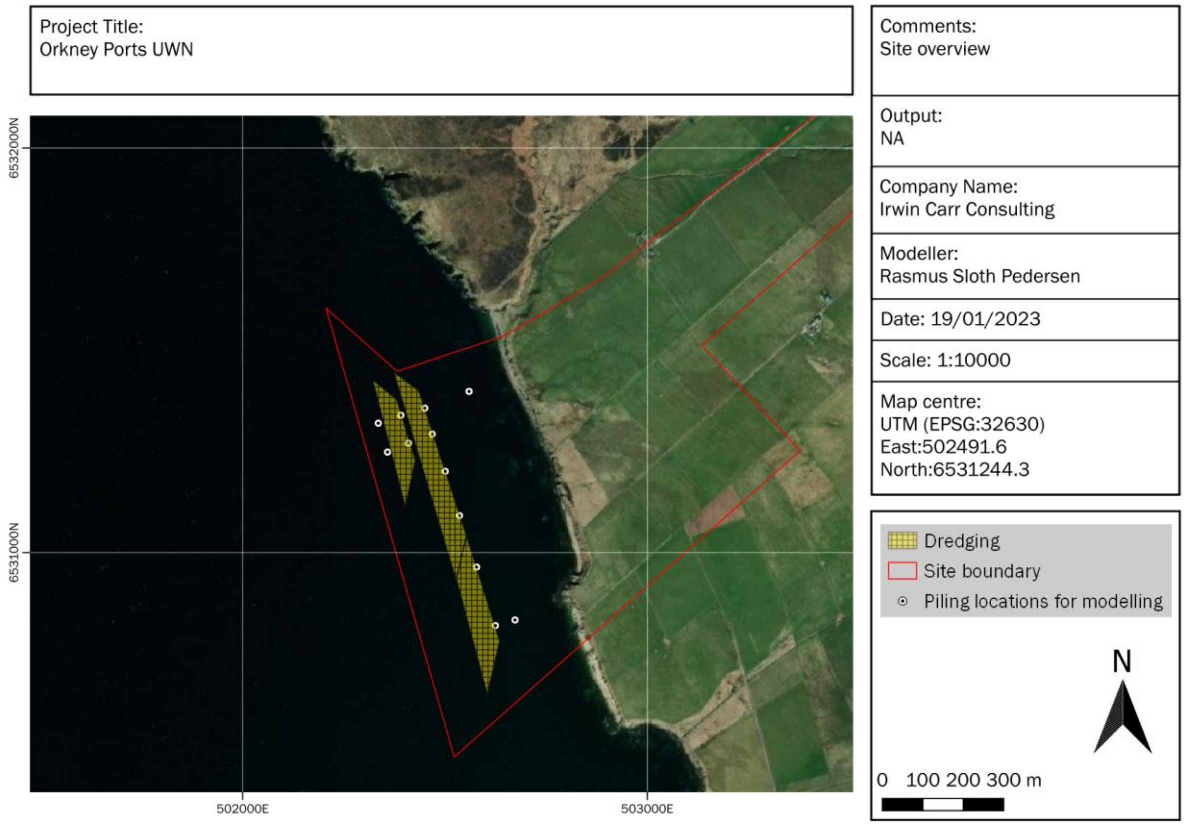


Figure 2. Overview of piling locations for modelling and approximate areas to be dredged.



2.1 Depth, Bathymetry

Depth data for the sites were collected from 3 sources:

- The proponent, detailed data near the site, 4 m resolution.
- EMODNet (European Marine Observation and Data Network, 2019), long range data, ~90 m resolution.
- Nautical charts such as http://fishing-app.gpsnauticalcharts.com, medium range data, variable resolution.

These were corrected to MSL and combined (using a mosaic method) to give the best possible total cover of the area.

For the "worst case" scenario the MHWS (Mean High Water Spring) level is used (deeper water decreases sound transmission loss).

2.2 Water properties

The water properties are important for the sound propagation. Generally the two sites have no major outflows of fresh water so salinity is expected to be near 35 psu (confirmed by (Marine Scotland, 2022)).

2.2.1 TEMPERATURE

The temperature was measured with the inbuilt thermometer of the Soundtrap hydrophone (used for on-site measurements).

Average water temperature at Scapa site during monitoring: 8.9 °C

The water columns are assumed to be well-mixed, given lack of nearby freshwater outflows, windy location, evaporation and generally shallow depths (<30 m).

2.2.2 SOUNDSPEED PROFILE

Given the water properties presented above, we assume the water soundspeed to be constant at all depths, with no significant deviations from the expected values.

The sound speed calculation is based on a widely used model for sound speed in water (Leroy, Robinson, & Goldsmith, 2008), with input of temperature, depth and salinity.

Sound speed in the water is calculated as 1486 m/s

2.3 Sediment properties

Given the project is a construction project there are sediment cores available for sediment characterisation provided by "Causeway Geotech". These give good coverage in the areas close to the Scapa DWQ. For general sediment outside the development area, we have used data from British geological survey (British Geological Survey, 2022).

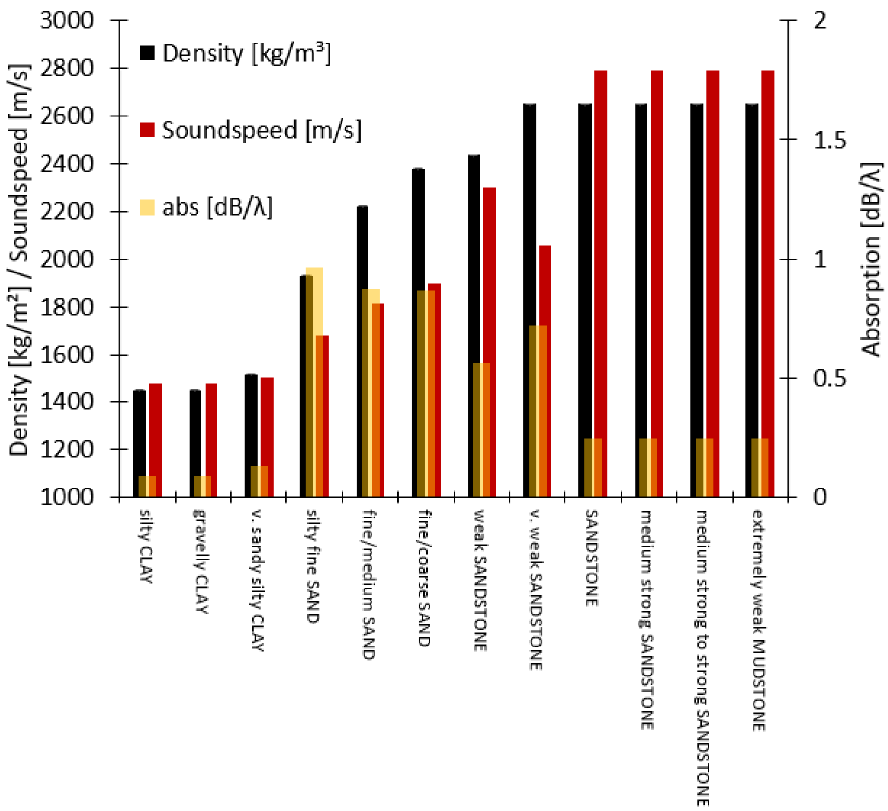
Where samples were taken we mapped the descriptions in the sediment core reports in relation to their Udden-Wentworth or Folk sediment description where these matched the nomenclature well. For other sediment types, e.g. sandstone/mudstone/limestone we have used given values for nominal "sandstone" (Jensen, Kuperman, Porter, & Schmidt, 2011; Boyce, 1981). The cores also contain classifications such as "weak sandstone" this was interpreted as loose, sandy sandstone, and we characterised this with density and soundspeed between that of sandstone and sand. This interpolation was based on an assumption that the scale "very weak-, weak-, medium weak-, sandstone" corresponds to linear interpolation between sand and sandstone (see Table 2 below). We have not changed the properties for categories indicating harder than usual sediments, such as "medium strong", "very strong".

Table 2. Example of interpolation scheme for Sand-sandstone.

Material	Interpolation value	Density [kg/m³]
Sand	0	1931
Very weak sandstone	0.25	2111
Weak sandstone	0.5	2291
Medium weak sandstone	0.75	2470
Sandstone	1	2650

Where we had no direct properties (density, sound speed, absorption) for the sediment we have used a modelling approach to estimate them, following (Ainslie, 2010).

Figure 3. Sediment types. Note that absorption is read on the right vertical axis.



2.4 Background/Ambient Noise

Baseline noise monitoring was carried out on 29-30 November 2022. On both days the weather was very calm (< sea state 1) with no detectable current. The Scapa site was unexpectedly noisy with ~130 dB SPL for all measurements (unaffected by range to our vessel). There were multiple other vessels in the bay, but all far away (> 1km). The most likely source was the small oil platform stationed a few km to the south. This could have some active machinery causing the noise, indicated by the tonal components (seen as horizontal bands in spectrogram in Figure 4).

Note that ambient noise here excludes noise from nearby vessel passes, it is meant as the ambient noise with no identifiable noise sources.

Table 3. Typical background noise levels.

Site	SPL [dB]
Scapa	129.9
Hatston	107.2

Figure 4. Spectrogram of ambient noise at Scapa.

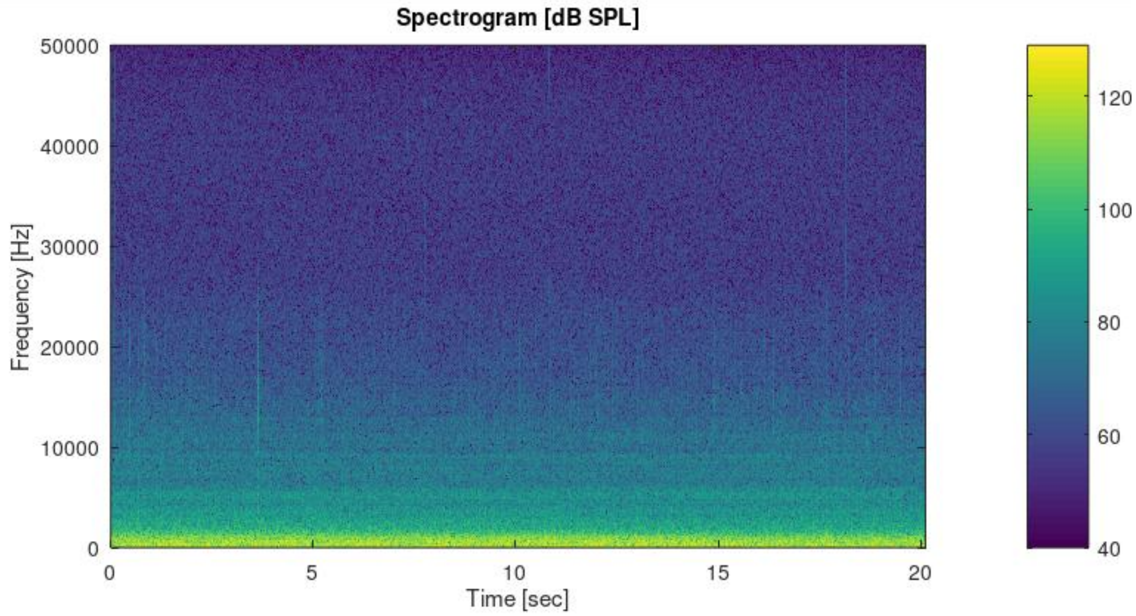


Figure 5. Spectrogram of ambient noise at Hatston.

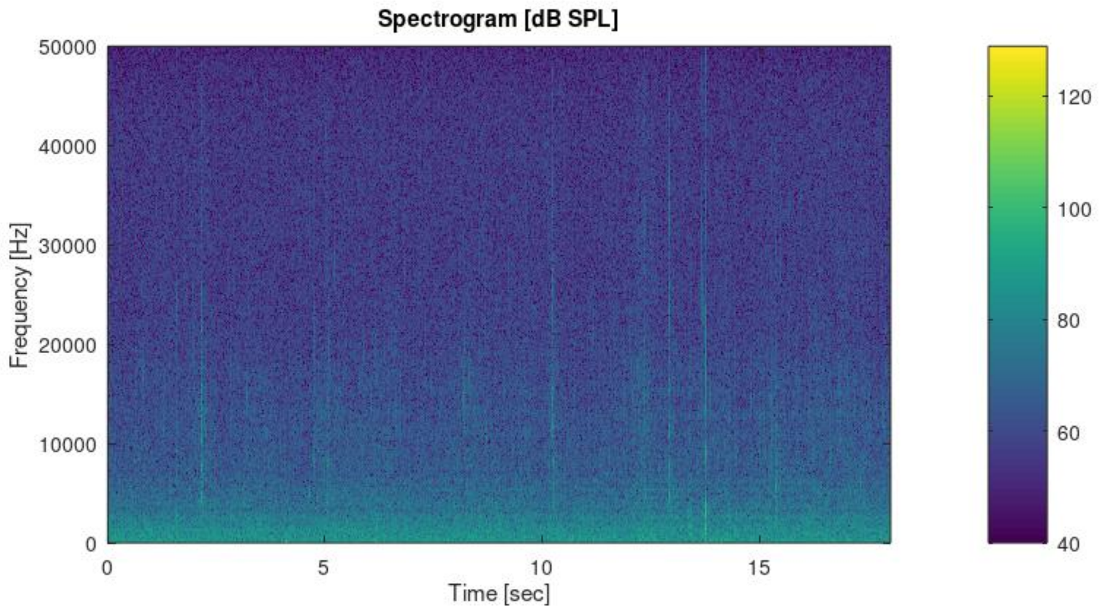
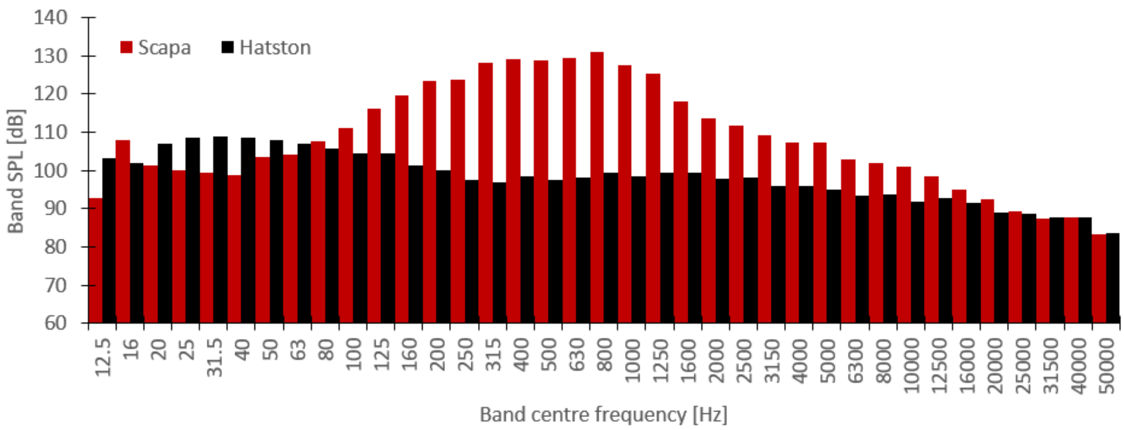


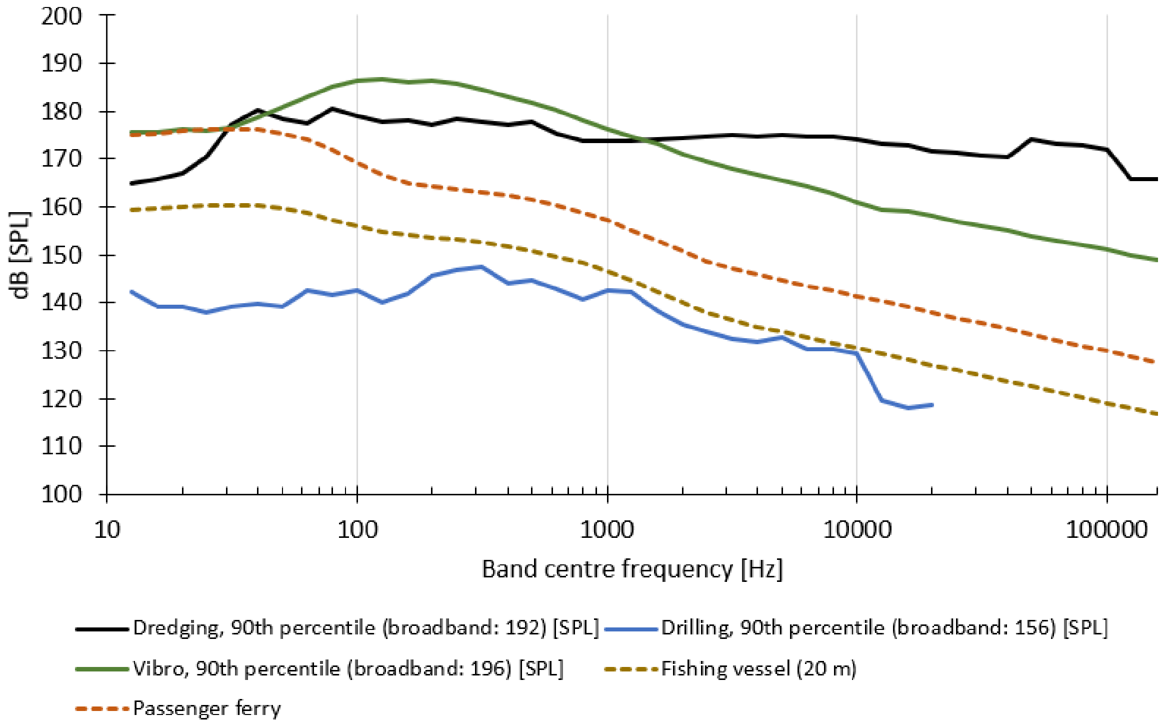
Figure 6. Typical band levels of ambient noise at Scapa and Hatston.



3 SOUND SOURCE MODELLING

We have considered three noise sources for this assessment, but have screened out the drilling as it is not loud enough to meaningfully assess in an environment with many vessels and general human activity (compare with vessel noise in Figure 7, below).

Figure 7. The three sound sources considered in this report. A fishing boat and a small ferry has been added for context.

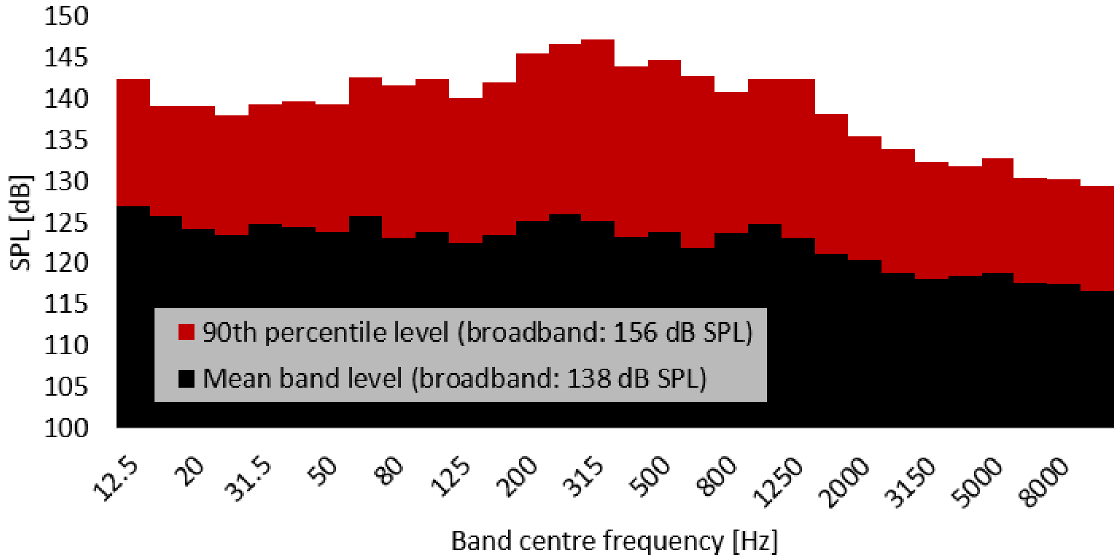


3.1 Drilling

As some hard sediment is expected round piles might be placed in pre-drilled holes, based on the range of noise levels presented in Figure 8, the drilling noise is assumed to be insignificant to the marine life.

The measured levels presented are a summary of 13 different recorded drilling episodes shows noise levels to vary considerably between sites and equipment, and there is no clear connection between drill size, power or sediment type to the emitted noise level. However, given the modest broadband level of even the 90th percentile level (156 dB SPL) this noise source can be ignored.

Figure 8. Example of drilling noise band levels. Data from various drills, diameter 0.1-1.2 m and various rock types.



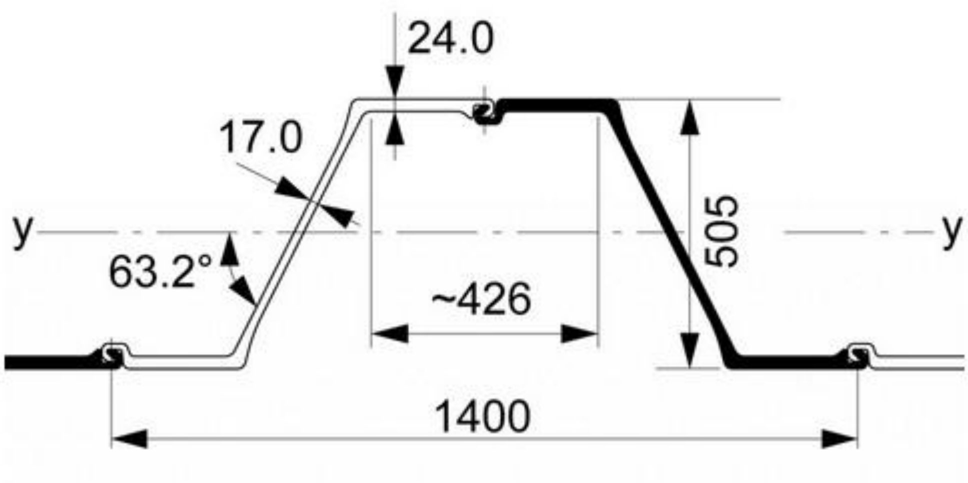
3.2 Vibration Piling Model

Two types of piles are expected to be used:

1. Tubular piles, expected to have a diameter of 2.1 m
2. Sheet piles (Arcelor Mittal AZ52-700[3]).

Both will be vibrated into the sediment or into holes left by the drilling campaign.

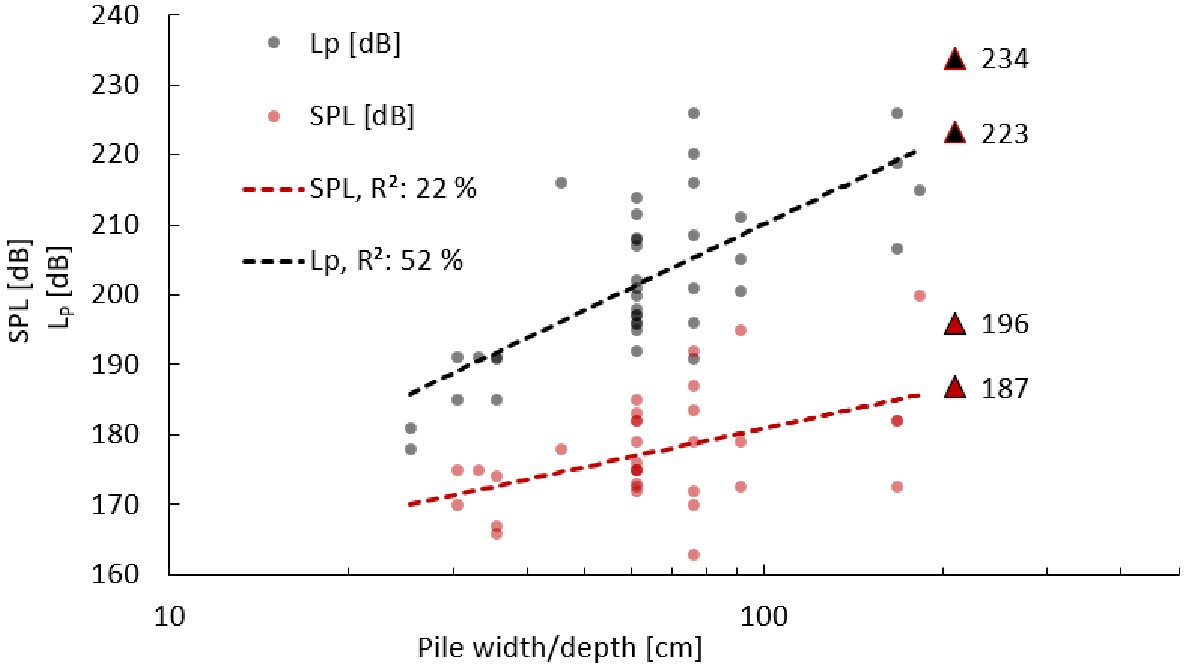
Figure 9. Schematic of the sheet piles.



The diameter of the tubular pile (210 cm) is used a basis for an empirical model based on 50 recorded levels as from CalTrans (CalTrans, 2015).

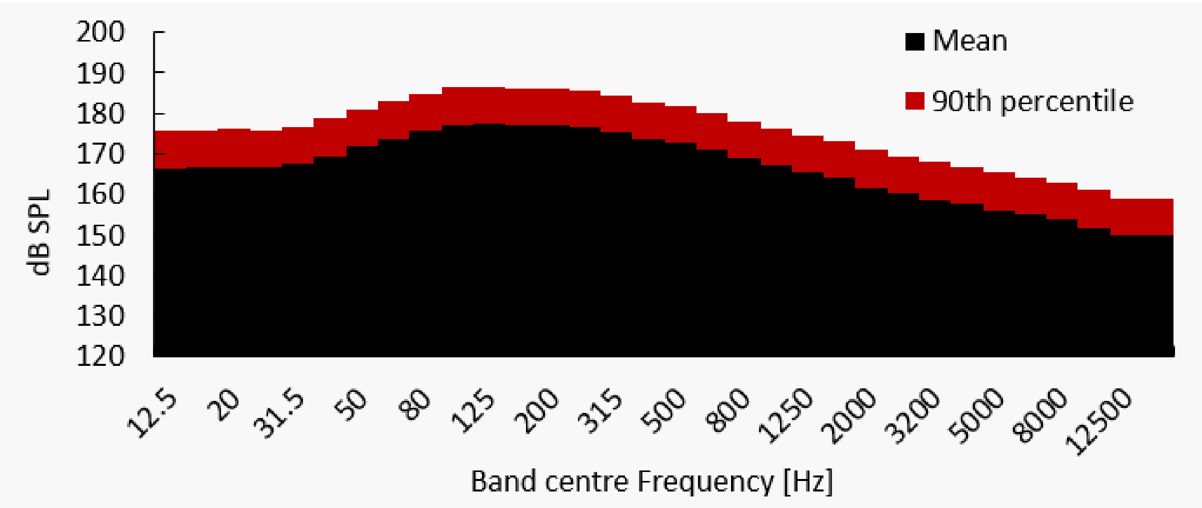
[3] https://sheetpiling.arcelormittal.com/products/az-52-700/

Figure 10. Basis of vibro piling broad band source level as a function of pile size (210 cm diameter).



Given the low confidence we have in this approach (low R^2 values) we use the 90th percentile level as the broadband source level. L_P is estimated to be 234 dB and SPL 196 dB. The frequency content is assumed to be identical to that of the impact piling.

Figure 11. Band levels for vibro-piling.



3.3 Dredging

Dredging is done to chart Datum -15 metres, meaning this will likely be done with a cutter suction dredger (Max reach 15 m) and possible assistance from a backhoe dredger. For the cutter suction dredger a cutter power of 540 kW is assumed, equivalent to the Boskalis “Seine”[4] cutter suction dredger. For cumulative modelling it’s assumed that the dredging is potentially active 24 hours per day. The Backhoe dredging is quieter and has been ignored in favour of using the louder method for the assessment.

[4] https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwibnqWF-sH8AhUQg1wKHfYmBVoQFnoECB8QAQ&url=https%3A%2F%2Fboskalis.com%2Fmedia%2Fqbjnfdlv%2Fseine_cutter_suction_dredger.pdf&usg=AOvVaw1bBD75xRPcFc3H0TUXTFkD

Figure 12. Approximate extent of dredging campaign (yellow hatched area).

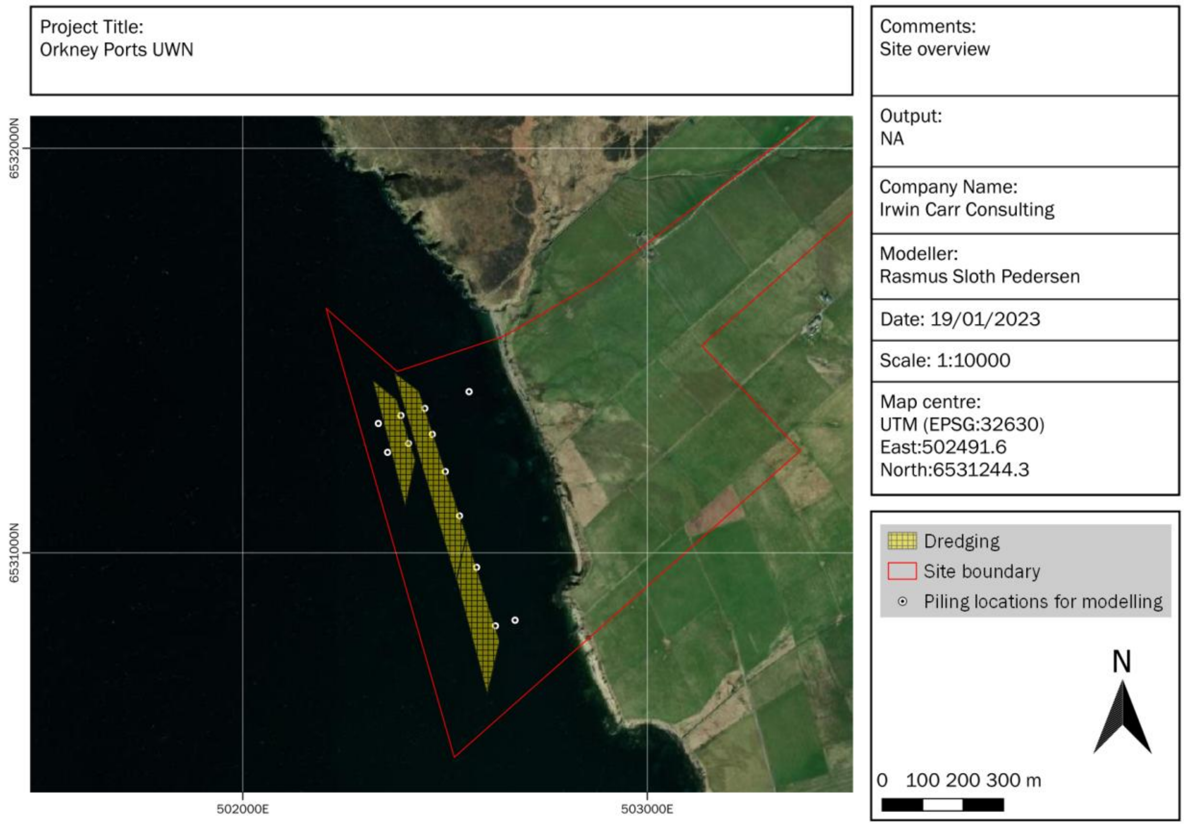
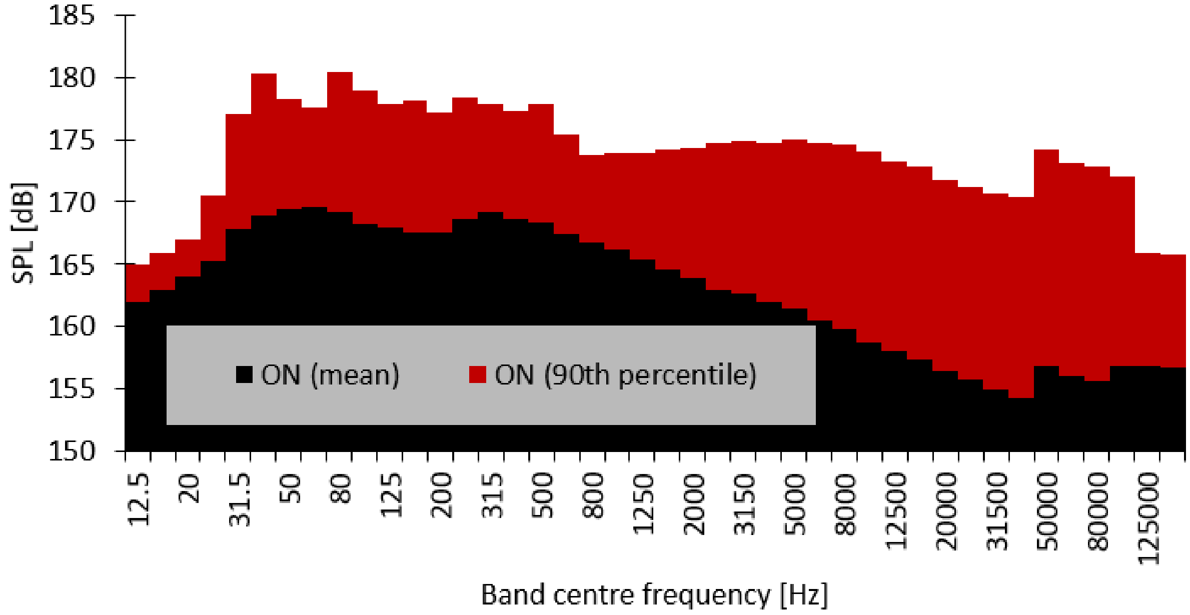


Figure 13. Band levels as modelled for a 540 kW cutter suction dredger with coarse sediment. "ON" refers to active dredging.



4 TRANSMISSION LOSS MODELLING

Transmission loss modelling is done using dBSea underwater noise modelling software.

This software is partially developed by us and can model frequencies from 10 Hz to 168 kHz, normally as 3rd octave bands, but any logarithmic band-spacing can be used. All solvers are range dependent (meaning all conditions can change with range not just depth).

Further details of this modelling software package can be found in APPENDIX A - dBSea.

The sound sources from section 3, Sound Source Modelling, p. 14, was used sources for the model, both as band levels when modelling energy transmission losses (L_E, SPL) and as timeseries/impulse for modelling peak pressure (L_P).

Previous to this assessment measurements of the actual transmission loss for the two sites were measured along two transects for each site. The modelling has been calibrated to match the measurements of these recordings (details in APPENDIX D – MODEL CALIBRATION).

The measurements show a broadband transmission loss consistent with ~12 × Log_{10}(range) at Scapa. However, these are frequency specific, and these losses are not consistent across all frequencies. We have matched the frequency-wise transmission losses to the extend that they are less than 20 × Log_{10}(range) as we find it unlikely that a transmission loss, even for higher frequencies, of > 20 × Log_{10}(range) is sufficiently representative for the site as a whole.

5 ASSESSMENT CRITERIA

5.1 Reporting units

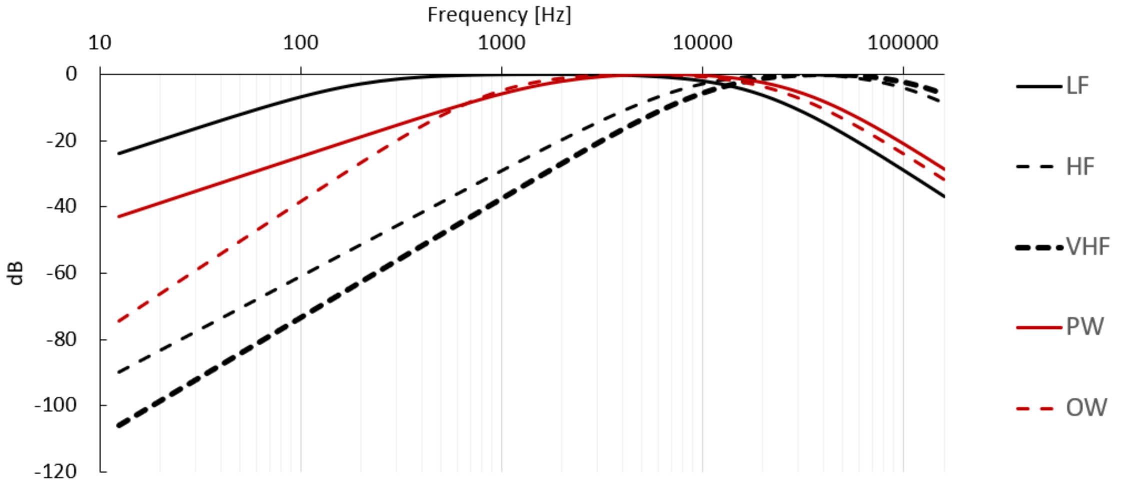
See 1.1.5, p. 8 for definitions.

5.2 Weighting of Noise Levels

When not reporting L_p or $L_{p\text{-}p}$ levels, the noise levels are often weighted according to a generalised hearing sensitivity profile for up to ten different hearing groups. This is done to better reflect the actual impact on the species in question, much like dB(C) level unit for humans.

See Table 4, for full group names and limits.

Figure 14. Weightings for various hearing groups. For L_E levels, the weightings are applied to the noise level to give the weighted noise level (similar to dB(A) or dB(C)-weighted noise for humans).



5.2.1 MARINE MAMMAL WEIGHTINGS

For the marine/aquatic mammals present we will adhere to the thresholds described in “Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing” (National Marine Fisheries Service, 2018), which determines impact from an assessment of area wherein the noise will induce either

"Temporary Threshold Shift" (TTS) or "Permanent Threshold Shift" (PTS)[5] as judged by the weighted SEL level ($L_{E\text{-}24}$) over a typical 24-hour period or by L_P levels, for the different hearing groups.

Please note that the Southall 2019 thresholds and weightings are identical to the NMFS 2018 criteria, only the nomenclature has changed (Southall, et al., 2019; National Marine Fisheries Service, 2018).

Thresholds for behavioural disruption are set by NOAA fisheries[6]. These are 120 dB RMS[7] for continuous noise and 160 dB SPL[8] for impulsive noise.

The hearing groups from the Southall 2019 and the NMFS 2018 guidance were specified by collating available information on marine mammal hearing and generalising their hearing sensitivity into representative groups. This grouping represents a significant research effort and are reviewed by the leading experts (academic, industrial and conservation) on the topic. Because of the large amount of work this represents and the widespread acceptance of the method, the thresholds and the methodology associated, have become de-facto standards for assessing noise impact on marine mammals and represents best available knowledge and practise.

Along with weighting curves, similar in function to the human dB(C) curves, a set of thresholds for hearing impact and injury is associated with the framework and allows for conversion of threshold exceedance into ranges with risk of impact. E.g. we might see that the PW group (true seals) has a risk of PTS at ranges shorter than 50 meters, and a risk of TTS at ranges shorter than 200 meters.

All marine mammal species are covered by the hearing groups and a full list of species in the different groups can be found in the "Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects" (Southall, et al., 2019), but in general the groups cover the following species:

Table 4. Summary of Southall 2019 thresholds and groups with species examples. For full species list see source (National Marine Fisheries Service, 2018; Southall, et al., 2019)

Hearing group	Species examples	Non-impulsive TTS/PTS threshold [$L_{E\text{-}24\ hours}$]	Impulsive TTS/PTS threshold [$L_{E\text{-}24\ hours}$]	Impulsive TTS/PTS threshold [L_p]
PW	Harbour seal, Grey seal	181/201	170/185	212/218
OW	Otters	199/219	188/203	226/232
LF	Minke whale, Humpback whale	179/199	168/183	213/219
HF	Sperm whale, Common dolphin, Bottlenose dolphin, Killer whale, Risso's dolphin, Pilot whales	178/198	170/185	224/230
VHF	Porpoise	153/173	140/155	196/202

It's important to note that the assessment is thus based on the received level of receptors with the above-described auditory sensitivity and not based on the sensitivity of the individual species.

5 TTS/PTS. A temporary/permanent change in hearing sensitivity caused by acoustic stimuli.

6 Available from: https://archive.fisheries.noaa.gov/wcr/protected_species/marine_mammals/threshold_guidance.html

7 Here taken as meaning "SPL"

8 Assumed to be SPL of 90 % of energy in one impulse or SPL of total duration (L_{EQ}).

5.3 Fishes etc.

Impacts of noise on fishes is less well established than for marine mammals, but a review from 2014 (Popper, et al., 2014) provides guidelines on exposure limits for fish and turtles. The report does not directly use the PTS nomenclature (as above for mammals) as many fish have the capacity to repair structural damage to their ear, and even structural damage then cannot be said to be "permanent".

We use "PTS" here to cover the categories "Mortality and potential mortal injury" and "Recoverable injury".

Note that we use the impulsive limits from piling for all impulsive sources as the information for explosions is rather less well documented (and limits are significantly higher).

TTS is directly used in the report, and we use it in the same way here.

As there are no TTS/PTS limits for non-impulsive noise, we apply the limits for cumulative impulsive noise.

Table 5. Overview of Impact piling thresholds from (Popper, et al., 2014) (Table 7.3). We use these for all impulsive noise, even though explosions have separate thresholds (Table 7.2 in report)).

Hearing group	Species examples	Impulsive TTS/PTS threshold [$L_{E\text{-}24\ hours}$]	Impulsive TTS/PTS threshold [L_p]
P* (Fish with no swim bladder)	Sharks, Rays	186/216	TTS not specified/213
P- (Fish with swim-bladder, but not involved in hearing)	Salmon, Trout, Cod, Herring	186/203	TTS not specified/207
P+ (swim-bladder used in hearing)	Carp, Catfish	186/203	TTS not specified/207

5.4 Threshold Interpretation

5.4.1 THRESHOLD TYPES

The three threshold types refer to different ways that sound can affect the hearing of an animal and are ***important to keep in mind*** when evaluating the results of this report:

5.4.1.1 Non-impulsive, $L_{E\text{-}24\ hours}$

The threshold, over which an effect (TTS/PTS) occurs, taking into account ***continuous***[9] sound received by the animal over a typical 24-hour period as sound exposure, L_E.

When presented as a zone on a map, this refers to the area, within which, an animal would suffer the effect, if it stayed there for 24 hours (or the full duration of the activity or as otherwise specified). We thus identify areas given by this limit as areas of TTS-**risk** or PTS-**risk** respectively, i.e., an animal within the area has a risk of suffering from either TTS or PTS within the zone. Alternatively this can be thought of as the total sound-dose limit over 24 hours.

Weightings are applied for non-impulsive L_E (for mammals only[10]).

5.4.1.2 Impulsive, $L_{E\text{-}24\ hours}$

The threshold, over which an effect (TTS/PTS) occurs, taking into account ***impulsive*** sound received by the animal over a typical 24-hour period as sound exposure, L_E.

[9] Please see (National Marine Fisheries Service, 2018) for definitions of "non-impulsive" and "impulsive". For quick reference, if a sound is shorter than 1 second and is clearly intermittent in nature, it is impulsive – otherwise, it's continuous.

[10] When assessing for fish groups levels are not weighted.

When presented as a zone on a map, this refers to the area, within which, an animal would suffer the effect, if it stayed there for 24 hours (or the full duration of the activity or as otherwise specified). We thus identify areas given by this limit as areas of TTS-**risk** or PTS-**risk** respectively, i.e., an animal within the area has a risk of suffering from either TTS or PTS within this zone.
Alternatively this can be thought of as the total sound-dose limit over 24 hours.

5.4.1.2.1 Impulsive $L_{E\ \text{single impulse}}$ / $L_{E\ \#\ \text{impulses}}$

It is sometimes useful to assess the impact of a single/a number of impulse(s). When we do this, we will refer to it as "LE single impulse / LE # impulses".
Like for the Lp, when single-impulse LE is presented as an impact zone, this refers to the area, within which, an animal would suffer the effect acutely/instantly.

Weightings are applied for Impulsive L_E (for mammals only).

5.4.1.3 Impulsive, L_p

The threshold over which an effect (TTS/PTS) occurs, taking into account ***impulsive*** sound received by the animal at any instant as maximal peak pressure.
When presented as a zone on a map, this refers to the area, within which, an animal would suffer the effect acutely/instantly and from just one exposure.
Weightings are ***not*** applied for Impulsive L_P.

5.4.2 MASKING

Levels that are not over threshold can still cause significant impact, if that noise makes foraging, navigation or communication harder due to masking or where biologically relevant sounds are "drowned out" by the anthropogenic noise. Continuous noise is more likely than impulsive noise to cause this form of impact.

5.4.3 DISPERSAL

Many animals can recognise sounds and might be dispersed from an area at noise levels well below TTS limits. Quantifying a level of dispersal from desk-spaced studies is very challenging and not done here.

6 CONCLUSION & RESULTS SUMMARY

Dredging

The noise from dredging, while presenting a significant PTS risk to ranges >500 m for the VHF group, this is only for animals staying close to the activity for extended periods (> 1 hour) and assumes continuous dredging with the dredger level as given by the 90th percentile. For the best estimate (model mean) the PTS risk range is 450 m after 8 hours exposure. There is no acute risk of noise related injury related to the dredging, and animals have time to swim away. Further the area ensonified does not "block" access through a channel or strait.

There is no issue identified for species outside the VHF range.

Vibro piling

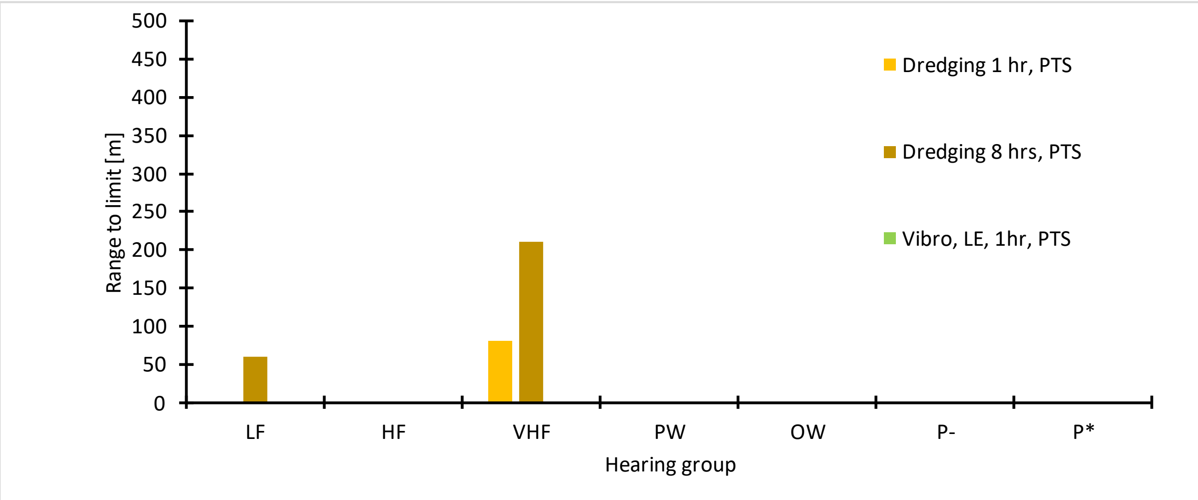
Prolonged exposure to vibro piling at close range (<100 m) carries some auditory risk for the animals assessed, specifically groups LF, VHF and P- (baleen whales, porpoises and salmon/trout), where the peak pressures in the noise have risk ranges up to 300 m for the VHF group. We therefore suggest surveillance takes place prior to piling to minimise the risk of impact on porpoises. While this is a significant risk for animals close to the activity, we stress that we have used a very conservative approach to estimating the source levels, and the realised emission will likely be significantly lower.

Further, animals will tend to move around, or away from noise, which will limit exposure. In Figure 16 and Figure 18 we show an example of the effect of using moving receivers (animats, modelled animals) to estimate what might be the effect of movement.

Table 6. Overview of maximal ranges to limits [m].

Activity	Dredging				Vibro piling			
Dose	1 hr L_E		8 hrs L_E		1 hr L_E		Peak pressure L_P	
Hearing group	TTS	PTS	TTS	PTS	TTS	PTS	TTS	PTS
LF	230	<50	1250	60	760	<50	<50	<50
HF	60	<50	160	<50	<50	<50	<50	<50
VHF	620	80	1350	210	180	<50	550	300
PW	70	<50	250	<50	100	<50	100	<50
OW	<50	<50	<50	<50	<50	<50	<50	<50
P-	120	<50	600	<50	390	<50	<50	125
P*	120	<50	600	<50	390	<50	<50	<50

Figure 15. Overview of PTS risk ranges



7 RESULTS

The noise maps for each activity and hearing group are presented in APPENDIX E – Results.

7.1 Dredging

While exposure to 8 hours of dredging has significant PTS risk ranges (< 210 m) for 2 hearing groups: LF (baleen whales) and VHF (porpoises), but only after prolonged exposure (> 1 hour). The relatively low (compared to limits) source level of the dredging means that there is not acute risk from noise and animals have time to swim away.

Using a model approach to have moving receivers (animats, see Figure 18, p. 24) we can estimate the impact on moving animals. The animats in the model move 0.5-4 m/s depending on the received level and evade levels >120 dB.

Figure 16. Summary of total exposure (L_E) of 225 animats of the VHF group in the soundfield of the dredging. 44 exceeded TTS limit (20 %), none exceeded the PTS limit.

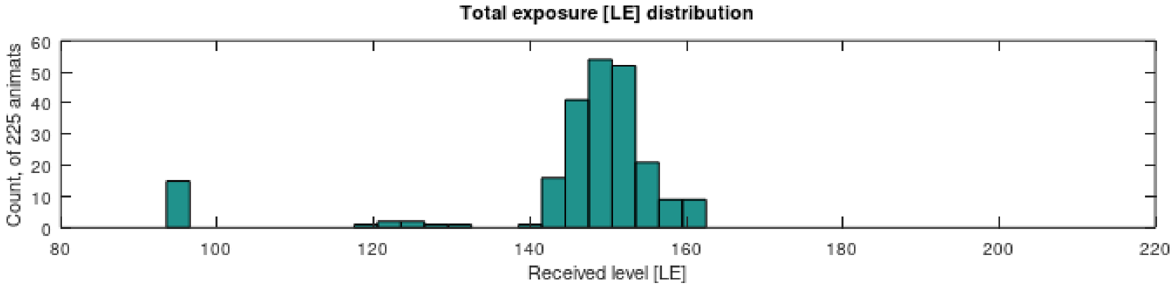


Figure 17. TTS and PTS risk ranges for all groups.

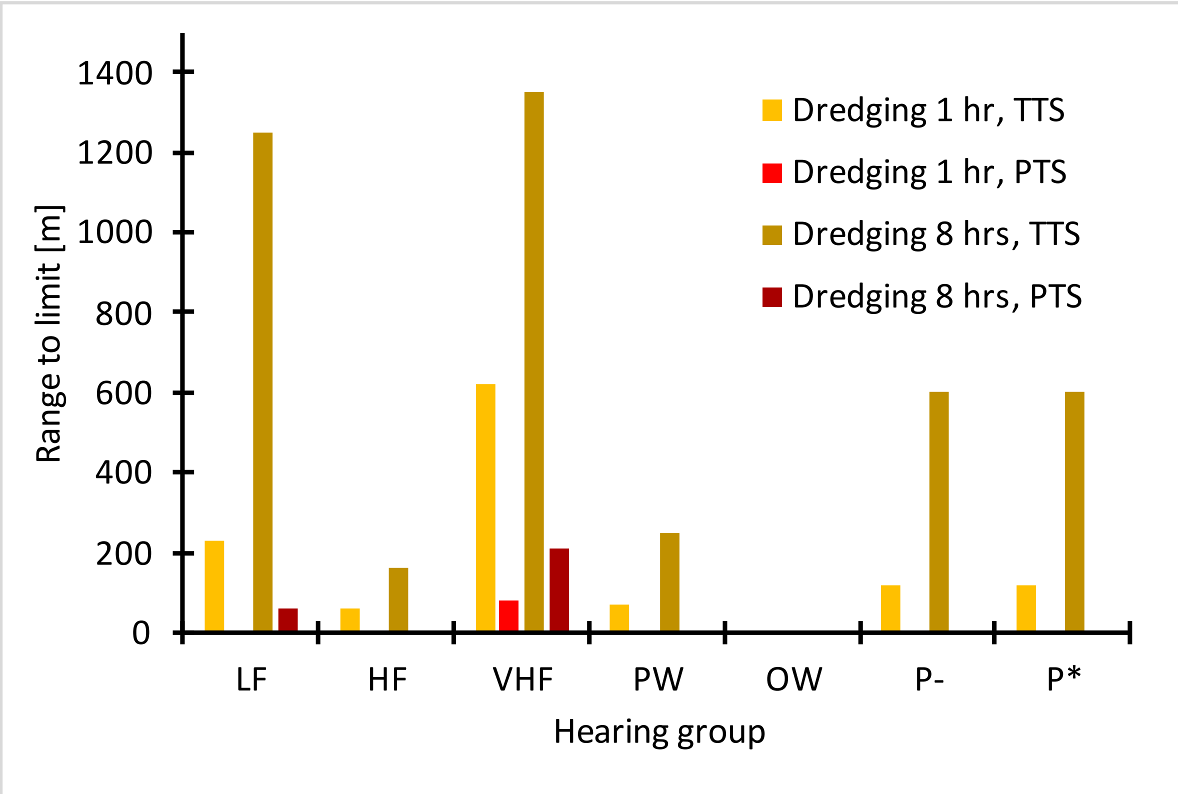
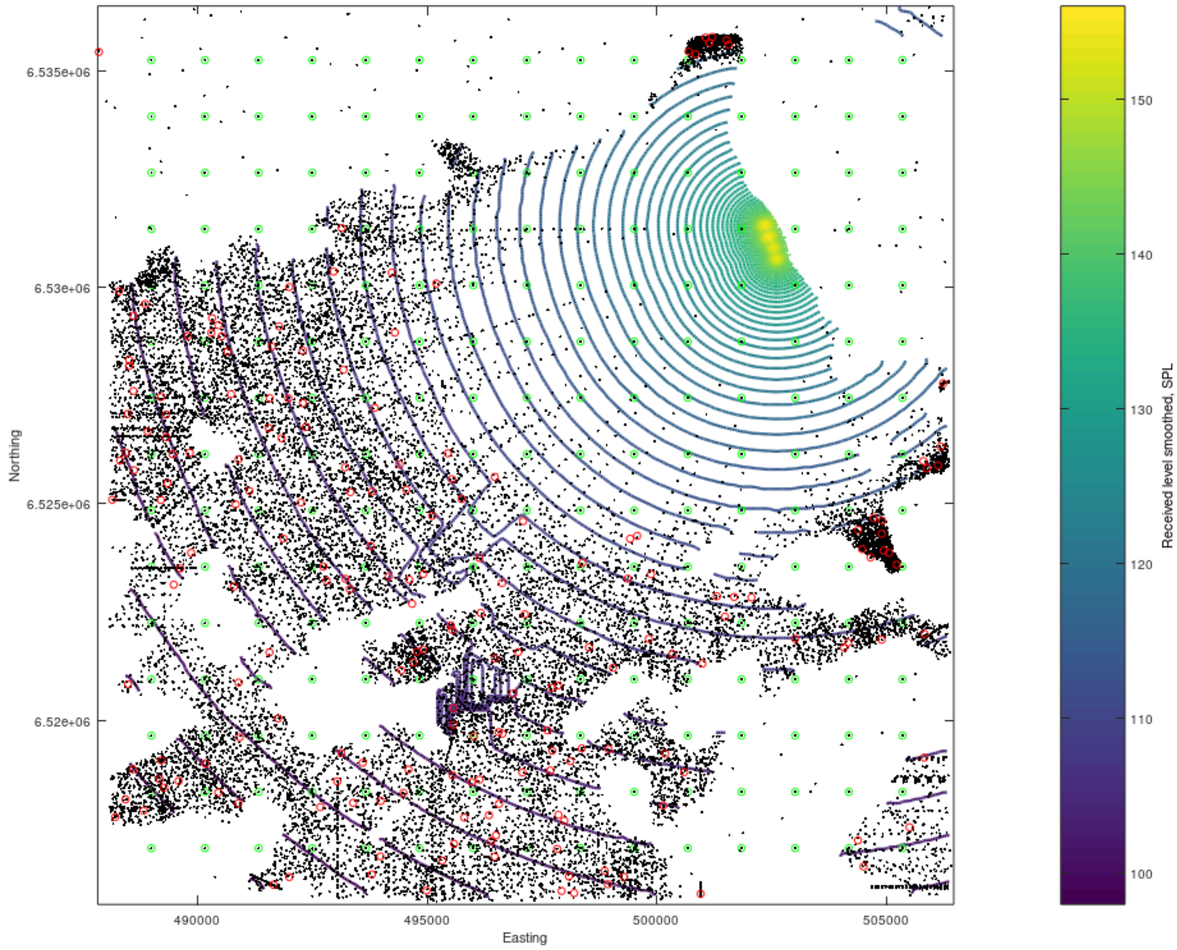


Figure 18. 225 “animats” in the dredger soundfield for 8 hours. Green spots are starting points, and red spots end points. Area covers Scapa Flow.a



7.2 Vibro piling

Longer exposures (> 1 hour) lead to significant PTS risk zones within 50 for all groups, but the proposed duration of vibro piling on this site is less than 1-hour per day.

The peak pressures in the vibro piling have a PTS risk zone max range of 50m. While the risk for the LF and P- groups is only for prolonged exposure, the risk to the VHF group is acute, i.e. the animal has no chance to swim away to avoid the risk.

Figure 19. TTS and PTS risk ranges for all groups.

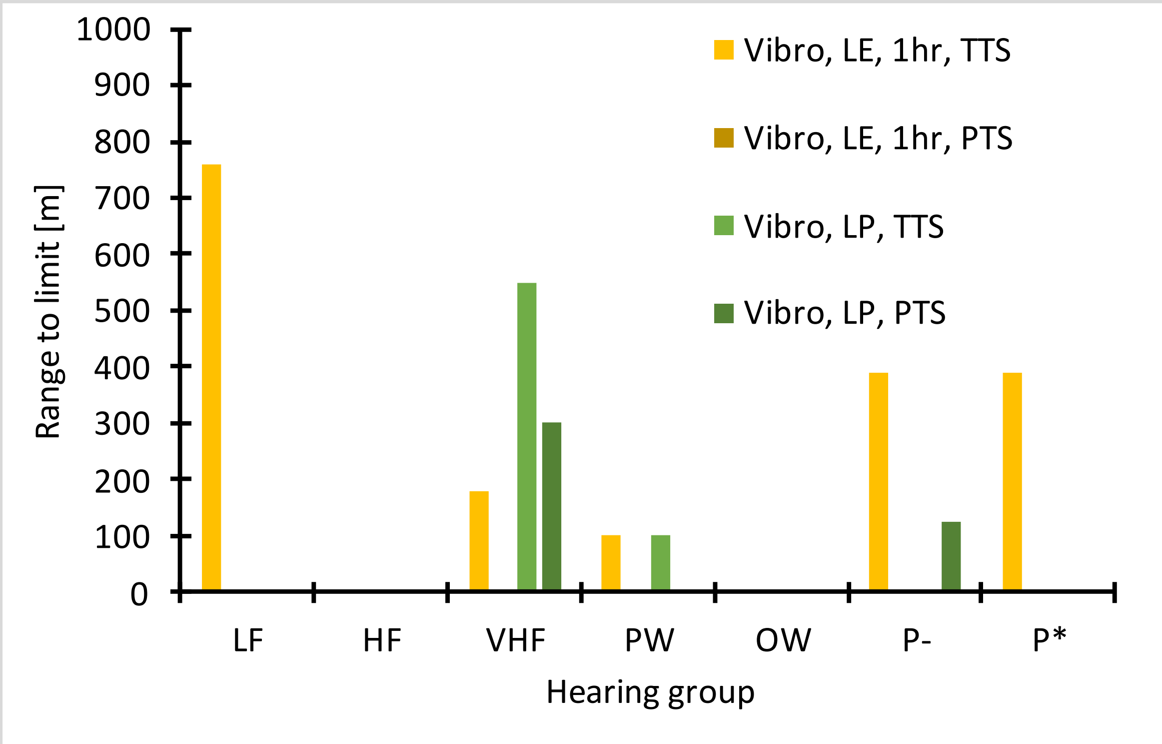
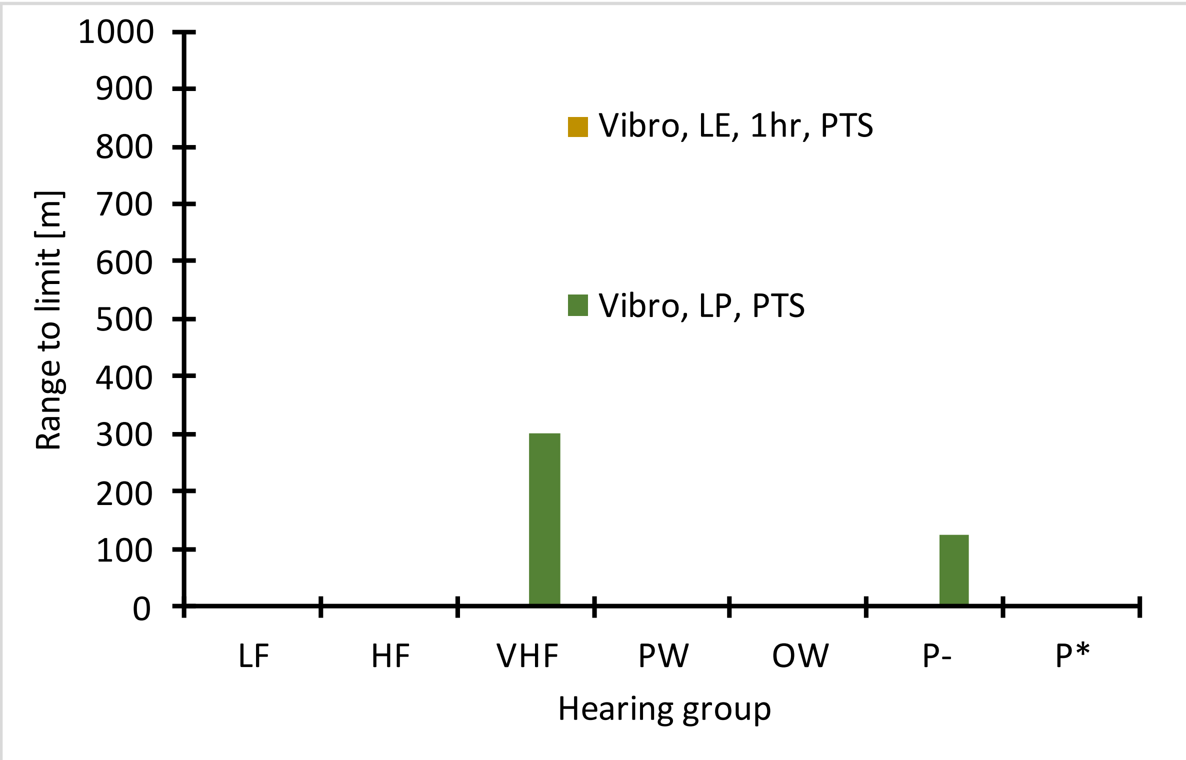


Figure 20. PTS risk ranges for all hearing groups.



8 BIBLIOGRAPHY

Ainslie, M. A. (2010). *Principles of Sonar Performance Modelling.* Heidelberg: Springer. doi:10.1007/978-3-540-87662-5

Audoly, V. M. (2020). Accounting for sea floor properties in the assessment of underwater noise radiated from ships in shallow water. *Proceedings of Meetings on Acoustics* .

Boyce, R. E. (1981). *LABORATORY-DETERMINED SOUND VELOCITY, POROSITY, WET-BULK DENSITY, ACOUSTIC IMPEDANCE, ACOUSTIC ANISOTROPY, AND REFLECTION COEFFICIENTS FOR CRETACEOUS-JURASSIC TURBIDITE SEQUENCES AT DEEP SEA DRILLING PROJECT SITES 370 AND 416 OFF THE COAST OF MOROCCO.* La Jolla: Scripps institution of Oceanography.

British Geological Survey. (2022, June 30). *Geology of Britain Viewer*. Retrieved from British Geological Survey: https://mapapps2.bgs.ac.uk/geoindex/home.html

CalTrans. (2015). *Technical Guidance for the Assessment of Hydroacoustic Effects of Pile Driving on Fish, CALTRANS.* Sacramento: California Department of Transportation.

European Marine Observation and Data Network. (2019, May 01). *Bathymetry portal*. Retrieved from EMODnet: http://portal.emodnet-bathymetry.eu/

Jensen, F. B., Kuperman, W. A., Porter, M. B., & Schmidt, H. (2011). *Computational Ocean Acoustics, Second Edition.* Springer. doi:10.1007/978-1-4419-8678-8

Leroy, C. C., Robinson, S. P., & Goldsmith, M. J. (2008). A new equation for the accurate calculation of sound speed in all oceans. *The Journal of the Acoustical Society of America*, 2774-2782.

Marine Scotland. (2022, 12 12). *Salinity*. Retrieved from Marine Scotland: https://marine.gov.scot/sma/assessment/salinity

National Marine Fisheries Service. (2018). *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0).* Silver Spring: U.S. Department of Commerce.

Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D. A., Bartol, S., Carlson, T. J., . . . Travolga, W. (2014). Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. *Springer Briefs in Oceanography, S3*.

Southall, B. L., Finneran, J. J., Reichmuth, C., E.Nachtigall, P., Ketten, D. R., Bowles, A. E., . . . Tyack, P. L. (2019). Marine Mammal Noise Exposure Criteria:Updated Scientific Recommendations for Residual Hearing Effects. *Aquatic Mammals*, 125-232. doi:10.1578/AM.45.2.2019.125

APPENDIX A - DBSEA

A summary of dBSea's models in standard scenarios can be found in the document (online):
http://www.dbsea.co.uk/media/30782/dBSea-Benchmark-Testing.pdf
(also see Figure 23, p. 29 for one example).

All solvers in dBSea are based on Jensen et al. 2011 (Jensen, Kuperman, Porter, & Schmidt, 2011)

dBSea has four primary models of calculation:

- **Range dependent Parabolic Equation model - dBSeaPE**
  dBSeaPE uses a split-step, wide angle parabolic equation method. It uses either Greene's approximation or several Padé terms (as set by user) to get very wide propagation with low phase error.

  dBSeaPE is best suited to deeper scenarios (>50 m) or where sediment interaction is not dominant relative to sound speed profile. The model is very efficient for low frequencies and only suffers a small efficiency penalty for higher frequencies.

  dBSeaPE will generally be used for deeper/long range scenarios in the frequency interval 10-1000 Hz.
- **Range dependent Normal Modes model - dBSeaModes**
  dBSeaModes is especially suited to shallower and sediment dependent scenarios and will typically be used where water is shallower than 50 m and depth changes are a large proportion of the total depth, or where sediment effects are thought to play a significant role. dBSeaModes incurs a significant efficiency-penalty at high frequencies and will normally be used in the frequency range 10-1000 Hz.
- **Ray tracing**
  dBSea uses a Gaussian raytracing method, dBSeaRay, to calculate transmission losses for higher frequencies (scenario dependent, but normally from 500 Hz). dBSeaRay compares favourably with the opensource BELLHOP model, in that it is accurate to lower frequencies and agrees well with PE and NM models.
- **Full waveform propagation**
  dBSeaRay also supports full waveform propagation in the frequency range 10 Hz to 168 kHz (limited by the waveform sample rate). Used in this way dBSeaRay takes into account all scenario range dependence (as models above) as well as the arrival time, phase information and transmission loss of all significant paths to any number of receivers in the scenario (the results grid).

General notes:

- dBSea is an "Nx2D" solver, meaning it models transmission losses in "N" number of vertical radial slices from the source (Figure 22, p. 28). There is no backwards propagation towards the source, and no sideways reflection/refraction (We're testing dBSea with full 3D solvers currently).

- dBSea models the sediment propagation only for compressional waves, not for shear waves. This generally means that the transmission loss will be slightly underestimated as no energy is transferred into shear waves, and also means that dBSeaRay does not propagate into the sediment, but relies on a complex reflection coefficient (calculated from the sediment layers) to calculate the reflection/refraction properties of the sediment. Given that dBSeaRay is generally only used for higher frequencies, this has very little practical effect, as higher frequencies will only interact weakly with deeper layers of the sediment.

- The individual sources in a scenario are modelled radially (radial coordinates) from the source at several depths. In post-processing levels are transferred to a cartesian "results grid". This results grid stores levels from all sources so that the cumulative level at any point in the scenario can be investigated immediately.

- Levels can be, and are often post-processed to apply a conservative margin and smooth results (Figure 21, p. 28). Radial smoothing (triangular kernel of variable width) is carried out to mitigate modelling artefacts arising from low environment sampling density or chance occurrences. Levels are often made to decrease monotonically from the source to make general trends more visible and decrease the risk of misinterpreting impact ranges.

- When refereeing to a level at a certain range, this usually refers to the greatest level at any depth at that range (unless specifically mentioned otherwise).

Figure 21. Post-processing to eliminate artefacts and ease interpretation. Level are radially smoothed by default, and are made to be monotonically decreasing with increasing range from the source.

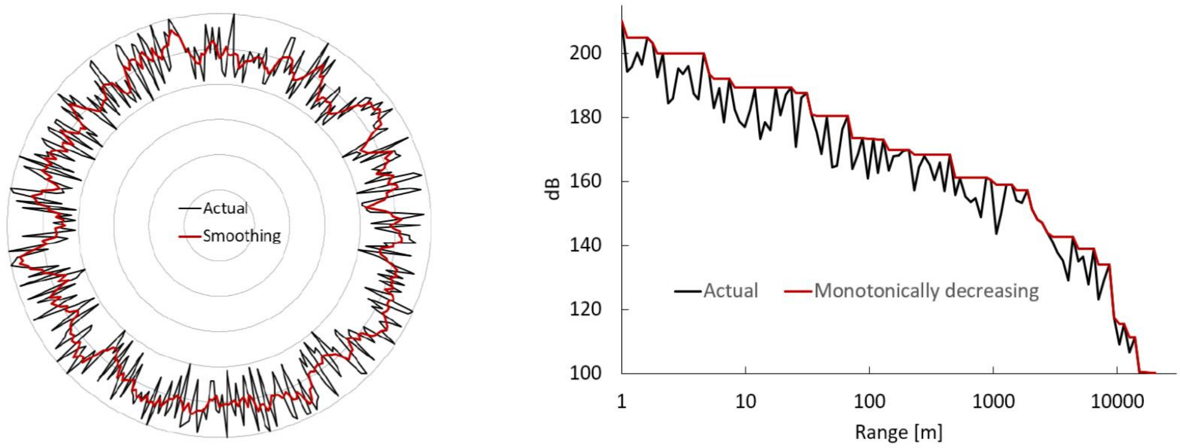


Figure 22. Low resolution schematic of the dBSea modelling space. Source transmission loss is modelled radially from the sources at a number of depths. Results are extracted from a "square" 3D grid that hold cumulative levels from all sources in the scenario.

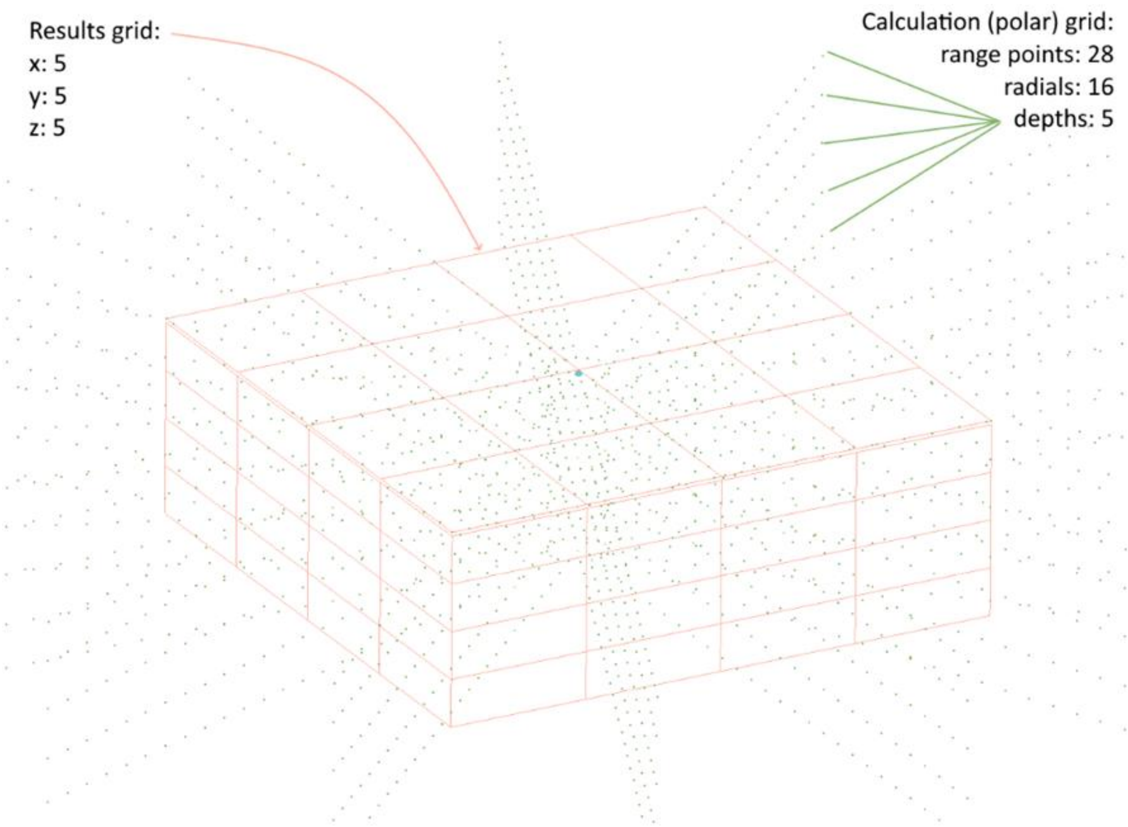
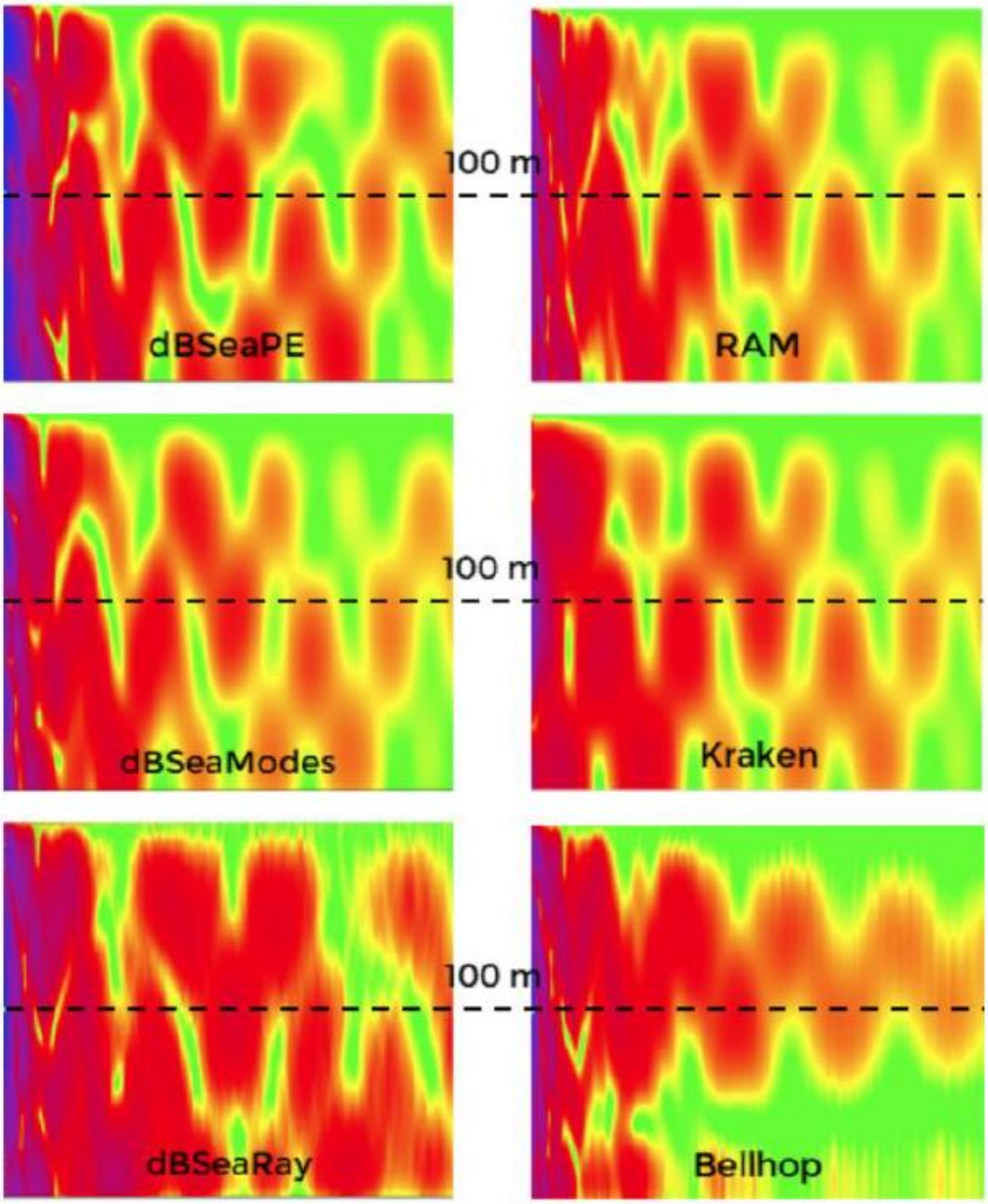


Figure 23. the "Pekeris" standard problem, a low frequency problem. Note that due to sediment effects, neither dBSeaRay nor Bellhop should be relied upon for low frequency problems, and are only include for completeness.



APPENDIX B – UNDERWATER ACOUSTICS BASICS

Sound Speed

Water is much harder to compress than air, and a soundspeed of 1500 m/s is often used as a standard soundspeed in water[11] much as 340 m/s is in air. Soundspeed is given by the following equation:

$$c = \frac{Z}{\rho}$$

$$Soundspeed\ [m/s] = \frac{Acoustic\ impedance\ \left[\frac{kg}{m^2 \cdot s}\right]}{Specific\ density\ [kg/m^3]}$$

Because changes to pressure, salinity and temperature occur with changes in depth, the specific density and acoustic impedance of water changes with depth, and thus the soundspeed changes as well.

The soundspeed profile is quite important in sound propagation, as refraction (changes in propagation angle) will occur when sound moves between layers of water with varying sound speed. This change is quantified in "Snell's Law" and results in sound being "bent" towards the depth of minimal soundspeed. These effects can lead to profoundly inhomogeneous sound fields and SOFAR channels.

The same relationships are valid in the sediment, though sediments commonly have soundspeeds higher than water. Soundspeeds from 1700 m/s (fine sand/silt) to 2500 m/s (gravel) are common for non-solid sediments, with solid sediments (rocks) having much higher soundspeeds 2800 m/s (Calcarenite) to 6000 m/s (some granite).

Spreading loss

Most of the propagation loss (loss in dB from source to receiver, "PL") that occurs initially is governed by "spreading loss". It is the simple "thinning out" of acoustic energy as it spreads away from the source, usually in all directions – spherically.

For a sound source in an unbound medium the initial PL will be dominated by spherical PL:

$$Received\ level = Source\ level_{at\ reference\ range} - 20 \cdot \log_{10}\left(\frac{range}{reference\ range}\right)$$

This means a reduction in received level of 6 dB per doubling of distance and explains the rapid reduction in received levels often seen close to the source, e.g.: with a reference range of 1 m, at 16 meters range, there has been 4 doublings of distance, and thus 24 dB loss (4×6 dB).

At longer ranges the medium is no longer unbounded. We reach ranges where the sound has interacted with the surface (near perfect acoustic reflector) or the seabed (lossy acoustic reflector). Also, at greater ranges a doubling of distance is no longer trivial as the PL from spherical spreading loss from 500 m to 1000 m is also just 6 dB.

Sound Channels and Wave guides

In bounded mediums where the sound energy is confined to cylindrical spreading, the PL (ignoring absorption) is often well-characterised by:

$$Received\ level = Source\ level_{at\ reference\ range} - 10 \cdot \log_{10}\left(\frac{range}{reference\ range}\right)$$

This means a reduction of received level of 3 dB per doubling of distance. Depending on the sediment this kind of "waveguide" can sustain efficient transmission of sound over long ranges, provided the sediment is acoustically hard and there is low absorption (such as is the case for low frequencies or in low salinity).

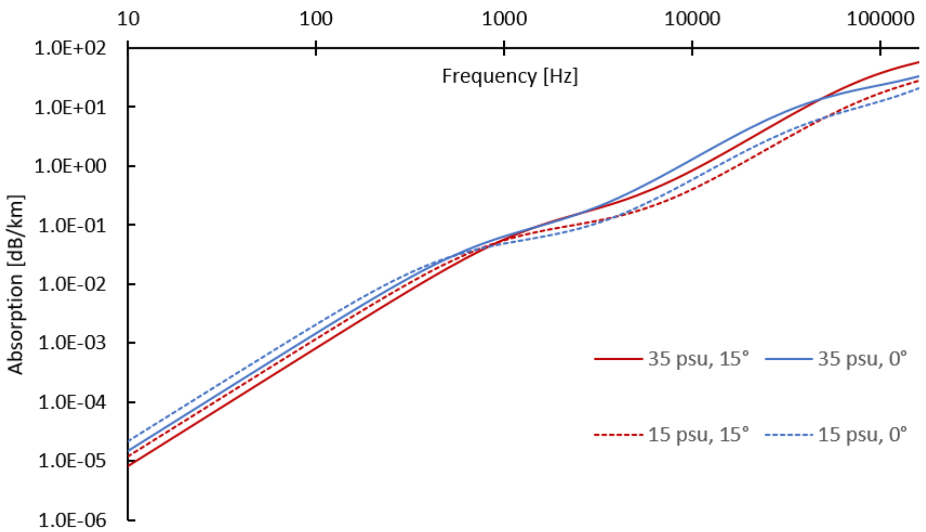
In absence of a bounding from the surface or the seabed, a soundspeed profile with a clear low-speed region, surrounded by higher soundspeeds can act a sound channel, by focusing the sound towards a single depth (with lower soundspeed), limiting the PL from spherical to cylindrical (a SOFAR channel is formed).

[11] Varies from 1450 m/s at 0° to 1550 m/s at 30° at salinity of 35 psu.

Absorption

Besides the "thinning out" of the sound energy as described above, the sound is also dissipated into heat by the way the pressure changes interact with water, molecules and particles in its path. This absorption is mostly governed by the concentration of boric acid and magnesium sulphate and is very dependent on the frequency, with lower frequencies, <1 kHz, experiencing almost no absorption, while high frequencies, > 10 kHz, can be attenuated by over 10 dB / km.

Figure 24. Absorption comparison at salinities of 35 psu & 15 psu and temperatures of 0° and 15°. Both scales are logarithmic. Note how increased salinity increases high-frequency absorption (solid v dashed lines), while a decrease in temperature increases absorption at lower frequencies (red v blue lines).



Small bubbles, wind or wave induced, will further attenuate especially the high frequencies, but as modelling is often done to estimate a worst-reasonable case, or for weather sensitive activities, fair weather with little wind and waves are assumed, thus ignoring this attenuation effect.

Sediment

Depending on the incident angle of the sound, the frequency and the acoustic properties of the sediment, sound can either mostly penetrate the sediment or mostly be reflected by it.

In shallow areas with soft sediment (acoustically similar to water), it is typical to find that close to the source, at high incidence angles and at low frequencies (<250 Hz) the sound will penetrate into the sediment and dissipate there, leading to very high transmission losses for these frequencies. This effect coupled with the high absorption at high frequencies often leads to the soundscape being dominated by frequencies from a few hundred hertz to a few thousand hertz. In deeper water, or with an upward refracting soundspeed profile, low frequencies will tend to dominate the soundscape away from sound sources, as there is no efficient mechanism for attenuating them.

A "cut-off[12]" frequency, below which, there will be high sediment-associated attenuation can be approximated by:

$$f_{cut-off} = \frac{c_{water}}{4 \cdot D \cdot \sqrt{1 - \left(\frac{c_{water}}{c_{sediment}}\right)^2}}$$

With "C_{water}" and "$C_{sediment}$" being the soundspeed in the water and the sediment respectively, and "D" the local depth (Jensen, Kuperman, Porter, & Schmidt, 2011).

[12] The cut-off is not an immediate loss of energy in frequencies under this frequency, but rather something like a high pass, 1st-order, Butterworth filter (Audoly, 2020).

In water with lower salinity and less absorption, the soundscape will tend to have a relatively higher content of high frequencies as these are absorbed much less efficiently when the salinity is lower.

Sound transmission Across Interfaces

Sound waves are reflected and refracted (Snell's law) as they travel through interfaces. Also, depending on acoustic impedance and interface angles only a proportion of the incident acoustic energy is transmitted through that interface (the rest is reflected).

In the following: W: Watt; Pa: Pascal; s: second; m: metre; N: Newton; J: Joule; θ: angle; v: soundspeed; Z: acoustic impedance; p: pressure from ambient;

Snell's law:

$$\frac{\sin\theta_{in}}{\sin\theta_{out}} = \frac{v_{in}}{v_{out}}$$

- rearranged to give transmission angle from incidence angle and soundspeeds:

$$\sin^{-1}\left(\frac{\sin\theta_{in}}{\frac{v_{in}}{v_{out}}}\right) = \theta_{out}$$

Transmission fraction of sound pressure for plane waves (part of the Fresnel equations):

$$\frac{p_{out}}{p_{in}} = \frac{2 \cdot Z_{out} \cdot \cos\theta_{in}}{Z_{out} \cdot \cos\theta_{in} + Z_{in} \cdot \cos\theta_{out}}$$

Reflection fraction of sound pressure for plane waves (part of the Fresnel equations):

$$\frac{p_{out}}{p_{in}} = \frac{Z_{out} \cdot \cos\theta_{in} - Z_{in} \cdot \cos\theta_{out}}{Z_{out} \cdot \cos\theta_{in} + Z_{in} \cdot \cos\theta_{out}}$$

It follows from these relations that for transmission from an acoustically relatively slow medium like water to an acoustically faster medium here exists an incident angle above which there is total reflection, and thus no transmission of acoustic energy through the interface (real interfaces are rugged and lumpy, and perfect reflection is not realistic).

For the water/sediment interface presented here (sediment is sand with a soundspeed of 2000 m/s) this occurs at 0.84 radians (~48.5 degrees) from normal incidence.

The fraction of pressure transmission from water (soundspeed 1500 m/s) to sediment (2000 m/s) is around 146 % at normal incidence and drops as the incidence angle increases away from normal, much faster for water-to-sediment than for sediment-to-water.

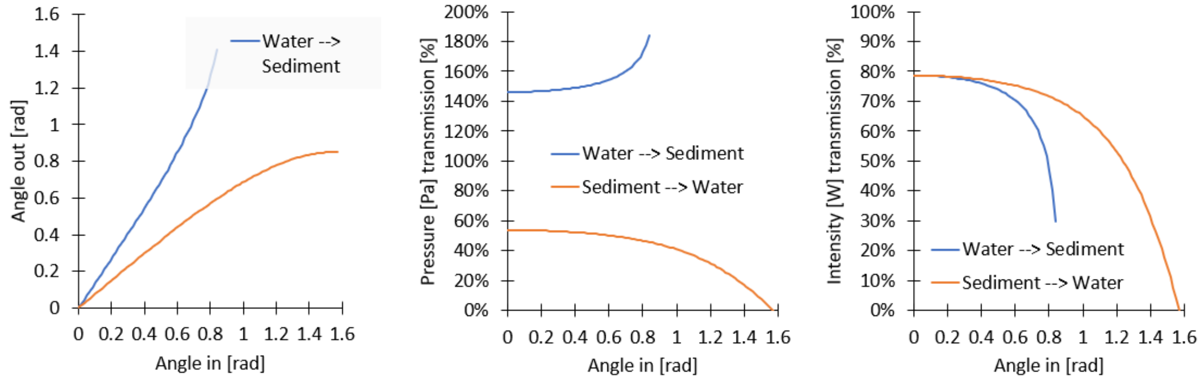
While it may seem counter-intuitive that pressure can increase after transmission over an interface, remember that the energy in the sound is a function of pressure *and* acoustic impedance:

$$I = \frac{p^2}{Z}$$

$$With\ units: [W] = \frac{[Pa]^2}{\left[\frac{Pa \cdot s}{m^3}\right]} = \frac{\frac{N^2}{m^4}}{\frac{\frac{N}{m^2} \cdot s}{m^3}} = \frac{N^2 \cdot m^3}{m^4 \cdot \frac{N}{m^2} \cdot s} = \frac{N}{m \cdot m^{-2} \cdot s} = \frac{J \cdot m}{m^{-1} \cdot s} = \frac{J}{s} = W$$

Thus, if the transmitted intensity fraction is 80 % then the reflected intensity is 20 %; there is energy conservation.

Figure 25. Transmission angles [radians] and fractions as function of incident angle between water and sediment (sand). Note that total reflection from water to sediment occurs around incident angle of 0.84 [rad] (48.5 degrees), meaning there is no transmission of sound at greater incidence angles.



Simplified Propagation Loss Model

Taking all the above into account we can construct a simplified model, that will give a good indication of the expected propagation loss (PL) in scenarios of constant depth:

$$PL = \begin{Bmatrix} r < D \ : & -20 \cdot \log_{10}\left(\frac{r}{r_0}\right) \\ r > D \ : & -20 \cdot \log_{10}\left(\frac{D}{r_0}\right) - 10 \cdot \log_{10}\left(\frac{D}{r_0}\right) \end{Bmatrix} - \alpha(f) \cdot r - l(f) \cdot r$$

Where:

- "r" is horizontal range from source.
- "D" depth at source.
- "r_0" the reference range of the source (often 1 m).
- "f" the frequency,
- "l" the frequency specific leakage loss to the sediment.
- "α" the frequency specific absorption.

Sound Level Units

All references to sound pressure levels, peak pressure levels and sound exposure levels refer to a logarithmic ratio between a reported/measured pressure or exposure and a reference pressure or exposure. As an example, a level of 220 L_p (decibel zero-to-peak) is equal to a peak pressure of 100000 Pascals (Pa) over ambient pressure, while 120 L_p is equal to 1 Pa over ambient pressure.

To avoid dealing with these large numbers as pascals (as a linear scale), they are converted to a decibel ratio (Table 1 for definitions). Besides compressing large numbers to a smaller scale this also corresponds better to how animals are thought to perceive sound, namely as relative steps. This means that an increase from 1 to 2 Pa *sounds like* the same increase as from 100 to 200 Pa, even though the first step was only 1 Pa, while the second was 100 Pa. This is better reflected in a logarithmic scale based on ratios, where both steps are equal, here 3 dB.

However, while dBs are practical, they can be hard to compare between studies, due to vague definitions, and so we have adopted the standards set by ISO 18405-2017 (Table 1 below).

For ease of reference please see following overview for unit definition.

Table 7: Definitions.

Unit	Definition	Comments
SPL (dB$_{RMS}$) ISO 18405- 2017: 3.2.1.1	$SPL = 10 \cdot Log_{10}\left(\frac{\frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} p(t)^2 dt}{1 \cdot 10^{-12} Pa}\right)$	Functionally equivalent to deprecated $20 \cdot Log_{10}\left(\frac{RMS}{1 \cdot 10^{-6} Pa}\right)$
L_p (dB$_{z\text{-}p}$) ISO 18405- 2017: 3.2.2.1	$L_p = 20 \cdot Log_{10}\left(\frac{Pa_{max}}{1 \cdot 10^{-6} Pa}\right)$	This assumes that Pa_{max} is equal or greater than $\sqrt{Pa_{min}{}^2}$
$L_{p\text{-}p}$ (dB$_{p\text{-}p}$)	$L_{p-p} = 20 \cdot Log_{10}\left(\frac{Pa_{max} - Pa_{min}}{1 \cdot 10^{-6} Pa}\right)$	Often[13] equivalent to $L_P + 6.02\ dB$
L_E (dB$_{SEL}$) ISO 18405- 2017: 3.2.1.5	$L_E = 10 \cdot Log_{10}\left(\frac{\int_{t_1}^{t_2} p(t)^2 dt}{1 \cdot 10^{-12} Pa}\right)$	For continuous sound this is equivalent to $SPL + 10 \cdot Log_{10}(t_2 - t_1)$ "t" is seconds

Unless otherwise stated SPL has an averaging period of 1 second, and L_E for the duration of the specified event, sometimes indicated as $L_{E\text{-"time"}}$ or $L_{E\text{-single blow}}$.

If the averaging period for SPL is equal to the total even duration, then SPL is equal to "Leq" the "equivalent constant level".

When source levels are presented, the same units are used, and it is implicit that all source levels are given as if recorded 1 m from an omnidirectional mono-point source, unless otherwise specified.

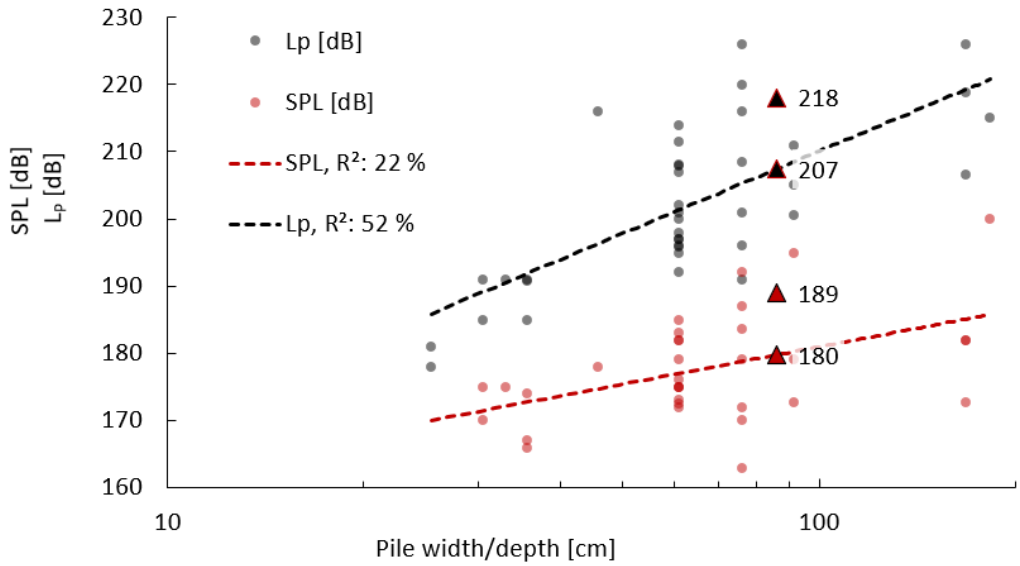
13 If maximum pulse rarefaction is below ambient pressure and compression and rarefaction phases are of equal size.

APPENDIX C – SOURCE MODELS

Vibration piling model

We only have a few recordings (50) from vibration piling and have no dedicated source model for this type of piling. Instead, we rely on published recorded levels as from CalTrans (CalTrans, 2015).

Figure 26. Basis of vibro piling broad band source level as a function of pile size.



Given the low confidence we have in this approach (low R^2 values) we use the 90th percentile level as the broadband source level. L_P is estimated to be 218 dB and SPL 189 dB. The frequency content is assumed to be identical to that of the impact piling.

Table 8. Sources decidecade band levels.

Band centre frequency [Hz]	Dredging, Mean (broadband : 182) [SPL]	Dredging, 90th percentile (broadband: 192) [SPL]	Drilling, Mean (broadband: 138) [SPL]	Drilling, 90th percentile (broadband: 156) [SPL]	Vibro, Mean (broadband: 187) [SPL]	Vibro, 90th percentile (broadband: 196) [SPL]
12.5	162	165	127	142	166	176
16	163	166	126	139	167	176
20	164	167	124	139	167	176
25	165	170	123	138	167	176
31.5	168	177	125	139	168	177
40	169	180	124	140	169	179
50	169	178	124	139	172	181
63	170	178	126	143	174	183
80	169	180	123	142	176	185
100	168	179	124	142	177	186
125	168	178	123	140	178	187
160	168	178	123	142	177	186
200	168	177	125	146	177	186
250	169	178	126	147	177	186
315	169	178	125	147	175	184
400	169	177	123	144	174	183
500	168	178	124	145	173	182
630	167	175	122	143	171	180

800	167	174	124	141	169	178
1000	166	174	125	142	167	176
1250	165	174	123	142	165	175
1600	165	174	121	138	164	173
2000	164	174	120	135	162	171
2500	163	175	119	134	160	169
3150	163	175	118	132	159	168
4000	162	175	118	132	158	167
5000	162	175	119	133	156	165
6300	161	175	118	130	155	164
8000	160	175	117	130	154	163
10000	159	174	117	129	152	161
12500	158	173	110	120	150	159
16000	157	173	109	118	150	159
20000	156	172	109	119	149	158
25000	156	171			148	157
31500	155	171			147	156
40000	154	170			146	155
50000	157	174			145	154
63000	156	173			144	153
80000	156	173			143	152
100000	157	172			142	151
125000	157	166			141	150
160000	157	166			140	149

APPENDIX D – MODEL CALIBRATION

Recorded Transmission losses

Scapa

Broadband transmission losses for exposure levels (L_E) show good consistency between measurements and a transmission loss consistent with -14.7 × Log_{10}(range), suggesting a sediment with some ability to reflect sound back into the water column and form a waveguide.

Transmission loss for peak pressure levels (L_P) were near spherical spreading loss which is consistent with a poorly reflecting bottom resulting in little overlap in arrival times for the source impulse.

There was a clear pattern in the transmission losses versus frequency, with higher frequencies experiencing much higher losses, likely due to interaction with a rough sediment resulting in a lot of scattering.

*Note that for the bands 50 – 1250 Hz the ambient noise at Scapa was above the source level, while we have tried to compensate for this, those values are still subject to considerable uncertainty (*Figure 28*).*

Figure 27. Broadband transmission losses at Scapa. L_P losses follow a near spherical loss pattern while L_E shows a tendency to follow a waveguide with some absorption losses. Thick lines are best fit of logarithmic loss, while thin lines are for loss accounting for the depth at the source. Error bars are expected 95 % of measurements.

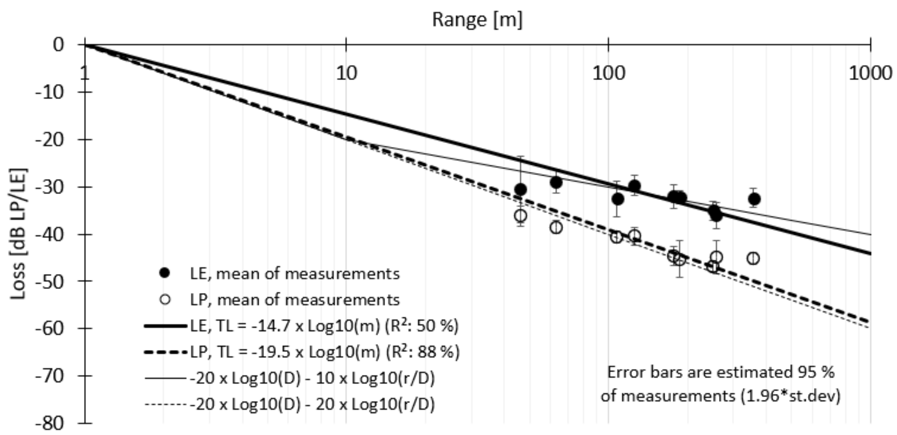
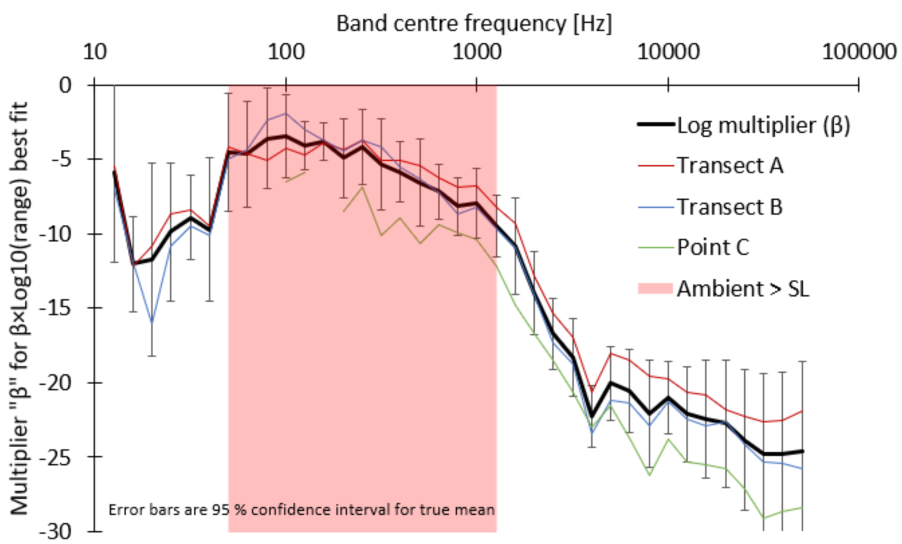


Figure 28. Transmission losses per band shown as the best fit multiplier "β" for a simple logarithmic transmission loss. Error bars are 95 % confidence interval for the true mean. While Transects A & B have some difference, this was not significant at a 10 % level in a t-test. Bands 50 – 1250 Hz have been corrected for contributing ambient noise as ambient noise was near or above recorded levels (red band).



APPENDIX E – RESULTS

Maps are presented with impact for different hearing groups as summarised here

Note that some maps have areas marked as "model artefacts", these are areas where the levels are assumed to not be realistic, but rather an example of a digitisation problem with the bathymetry.

Group	Description	Example species
LF	Low frequency, baleen whales	Mike whale, Fin whale, Blue whale
HF	High frequency, most dolphins	Common dolphin, Risso's dolphin, beaked whales, Bottlenose dolphin, Sperm whale, Killer whale
VHF	Very high frequency, few dolphins and porpoises	Harbour porpoise, Hourglass dolphin
PW	Phocid water, True seals	Harbour seal, Grey seal
OW	Otariid + other water, Fur seals, walruses and aquatic mammals	Walrus, Otter, Polar bear
P-	Fish with swim bladder, not coupled to inner ear	Salmon, Trout, Cod, Herring
P*	Fish with no swim bladder	Sharks and rays

Dredging L_E

Maps are provided for 90th percentile source levels for 1 hours and 8 hours.

Figure 29. Dredging, L_E, 1hr, LF group

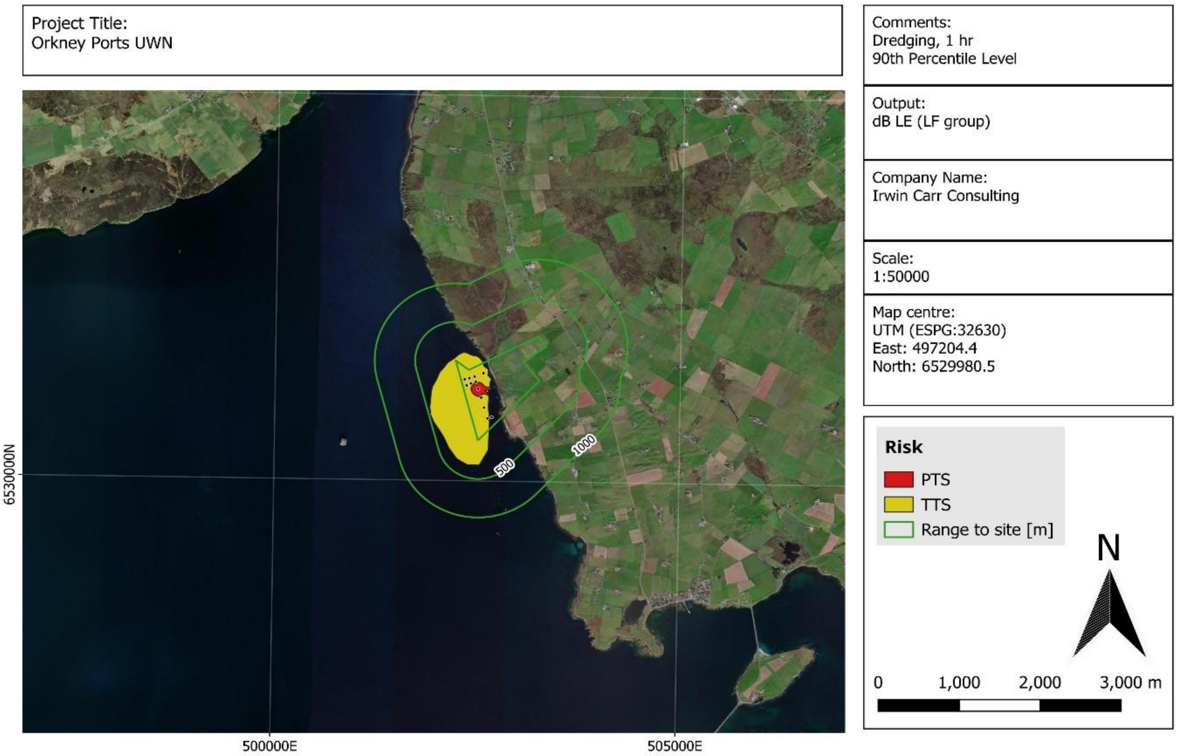


Figure 30. Dredging, L_E, 8hr, LF group

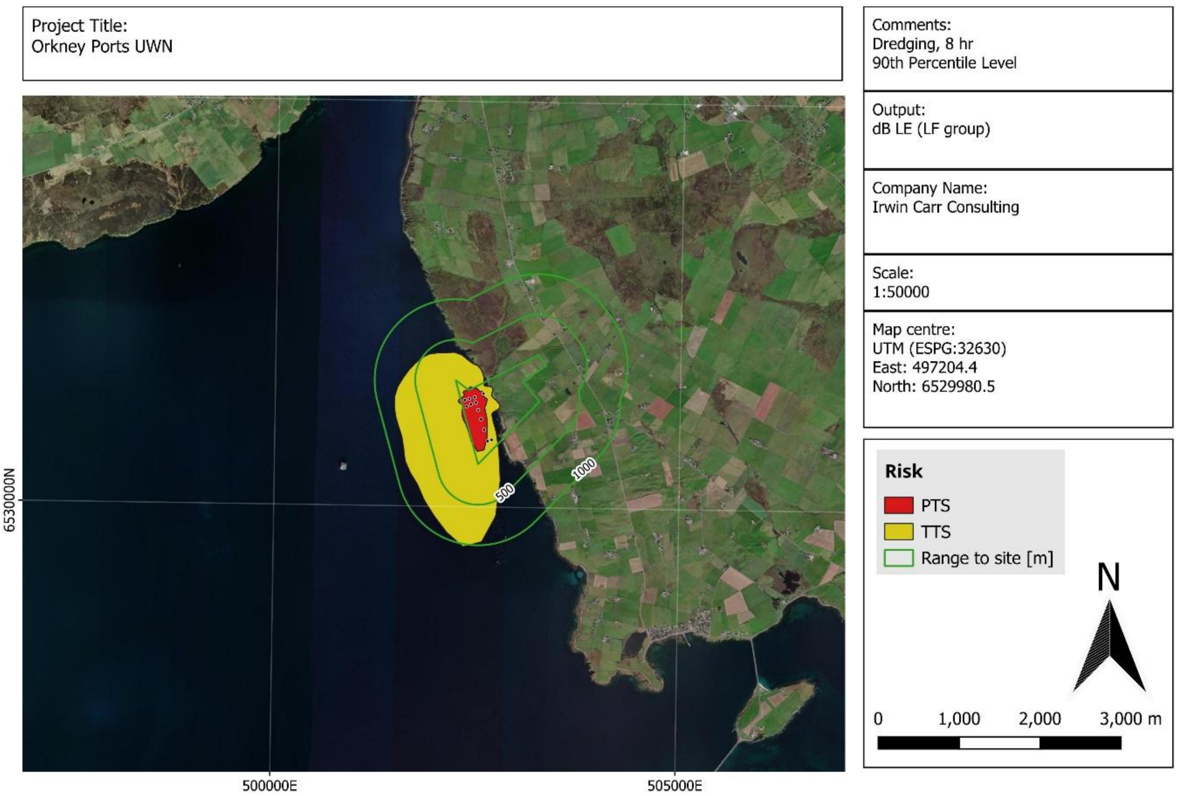


Figure 31. Dredging, L_E, 1hr, HF group

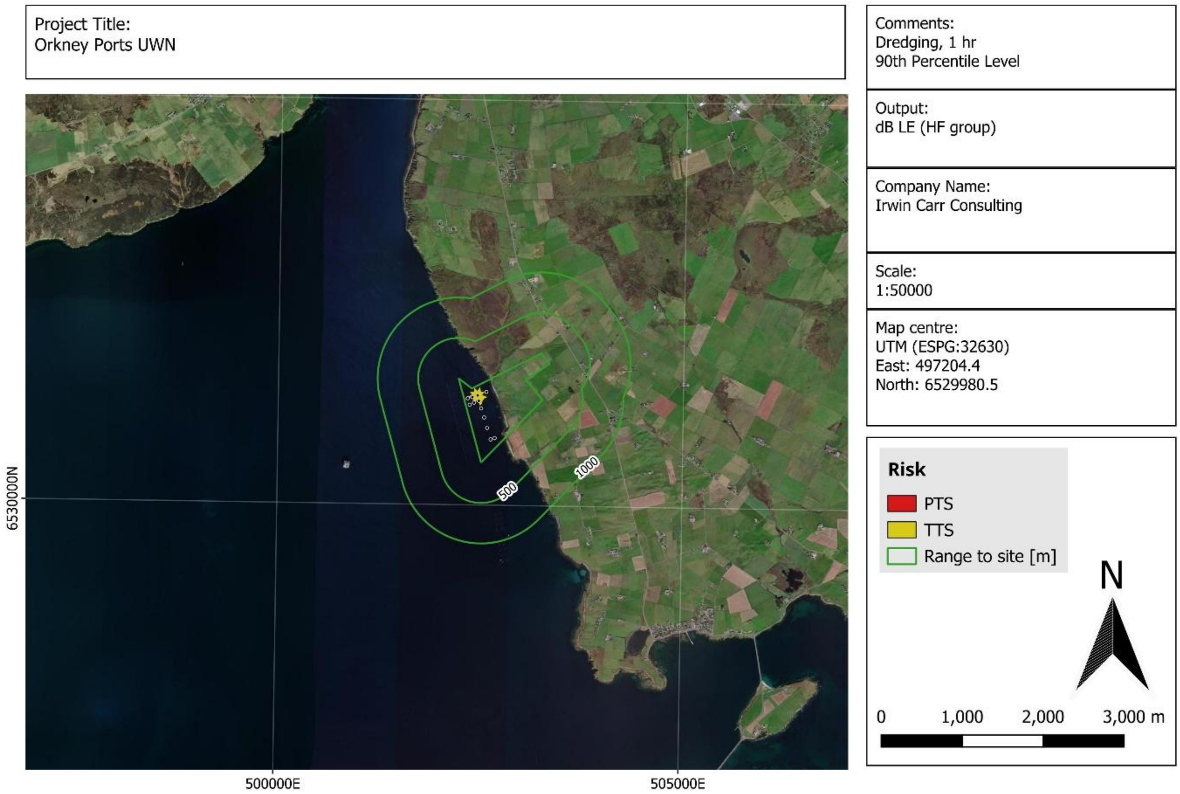


Figure 32. Dredging, L_E, 8hrs, HF group

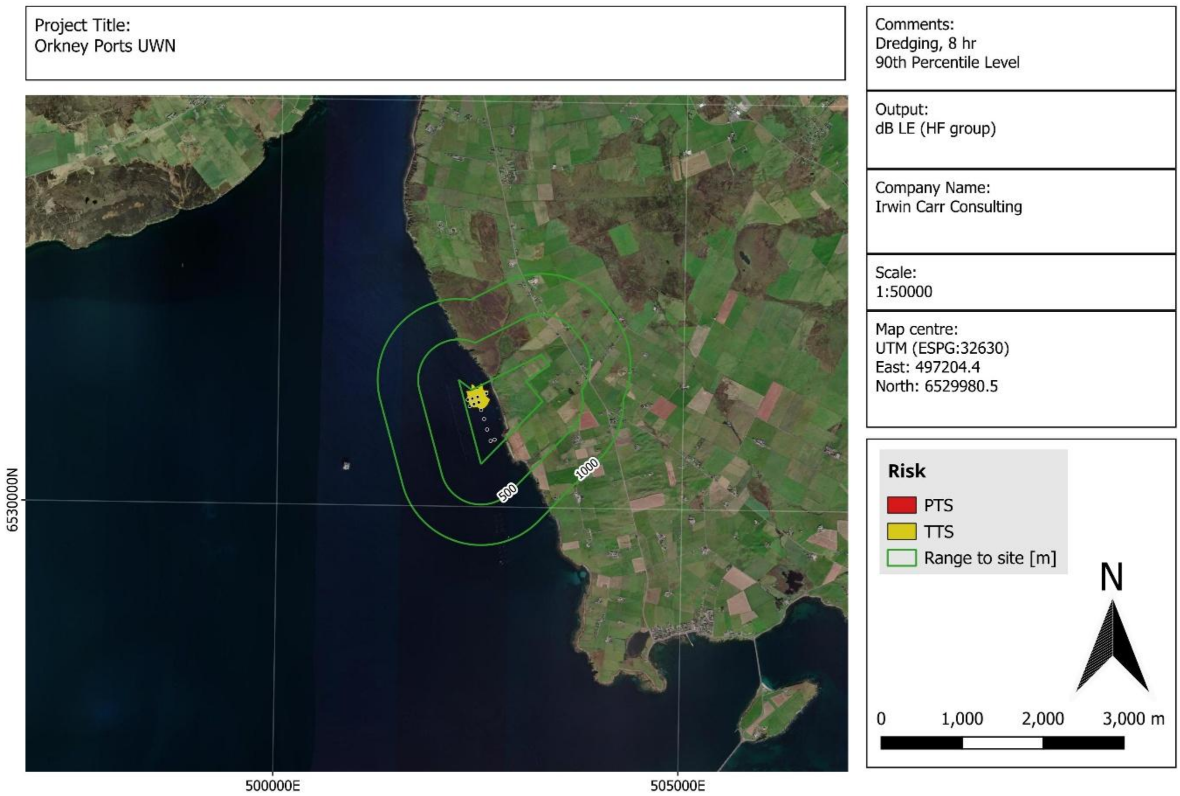


Figure 33. Dredging, L_E, 1hr, VHF group

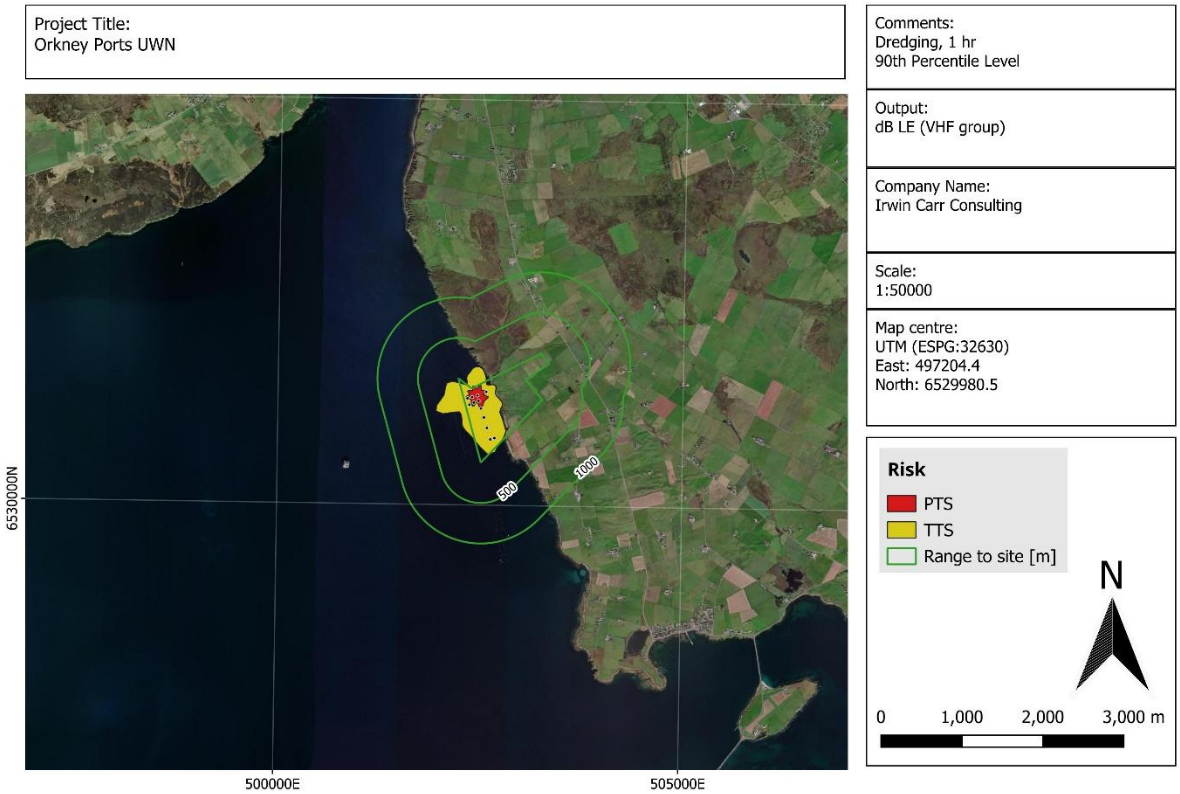


Figure 34. Dredging, L_E, 8hrs, VHF group

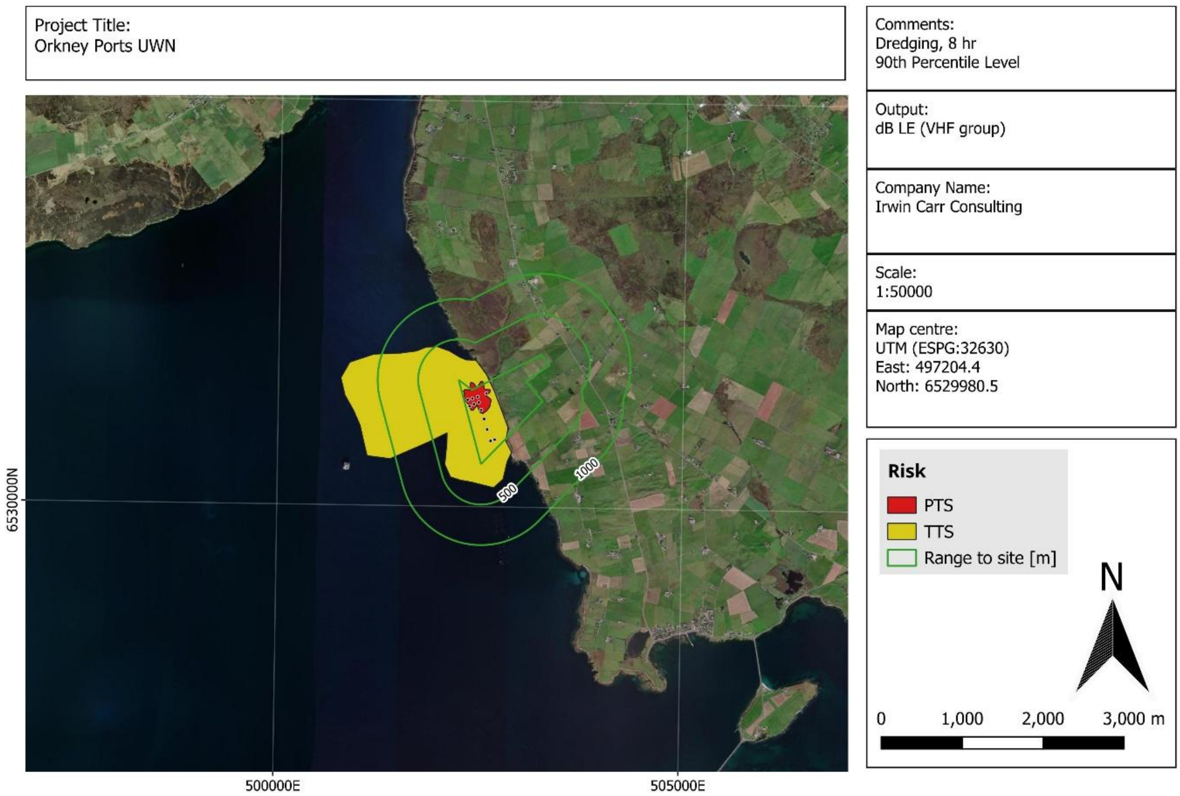


Figure 35. Dredging, L_E, 1hr, PW group

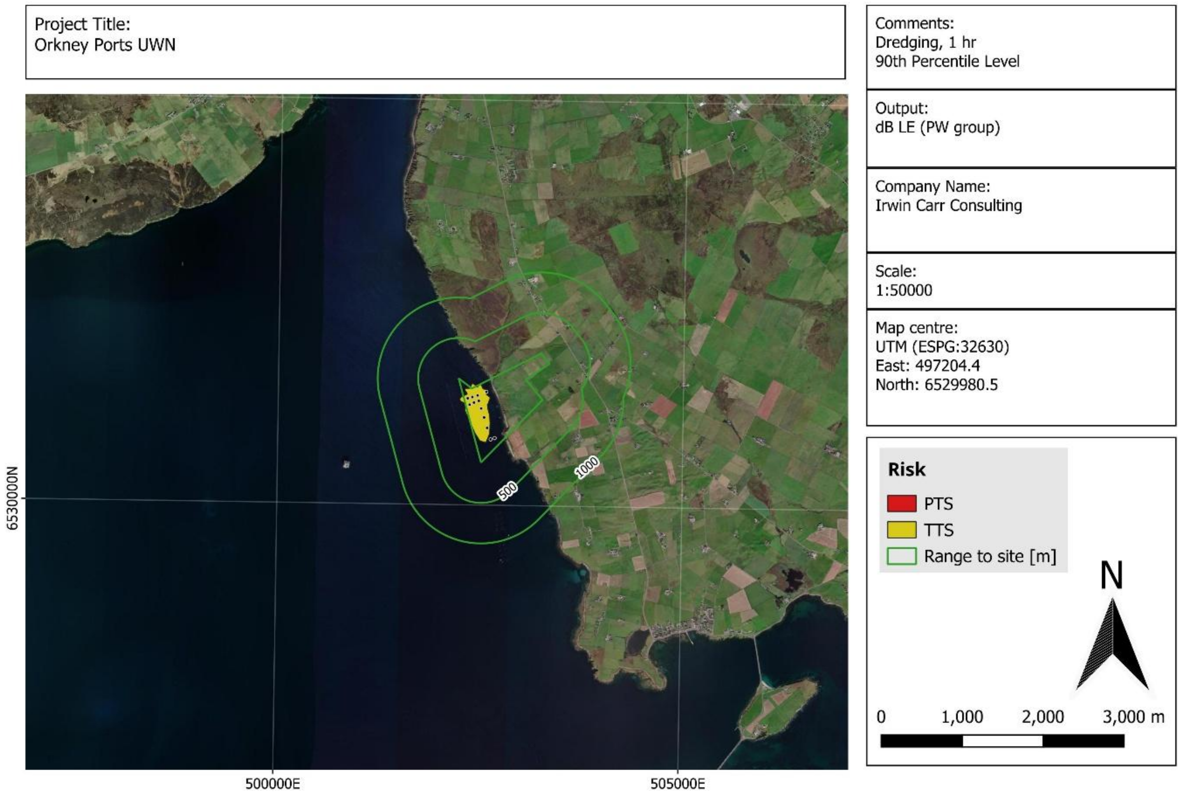


Figure 36. Dredging, L_E, 8hrs, PW group

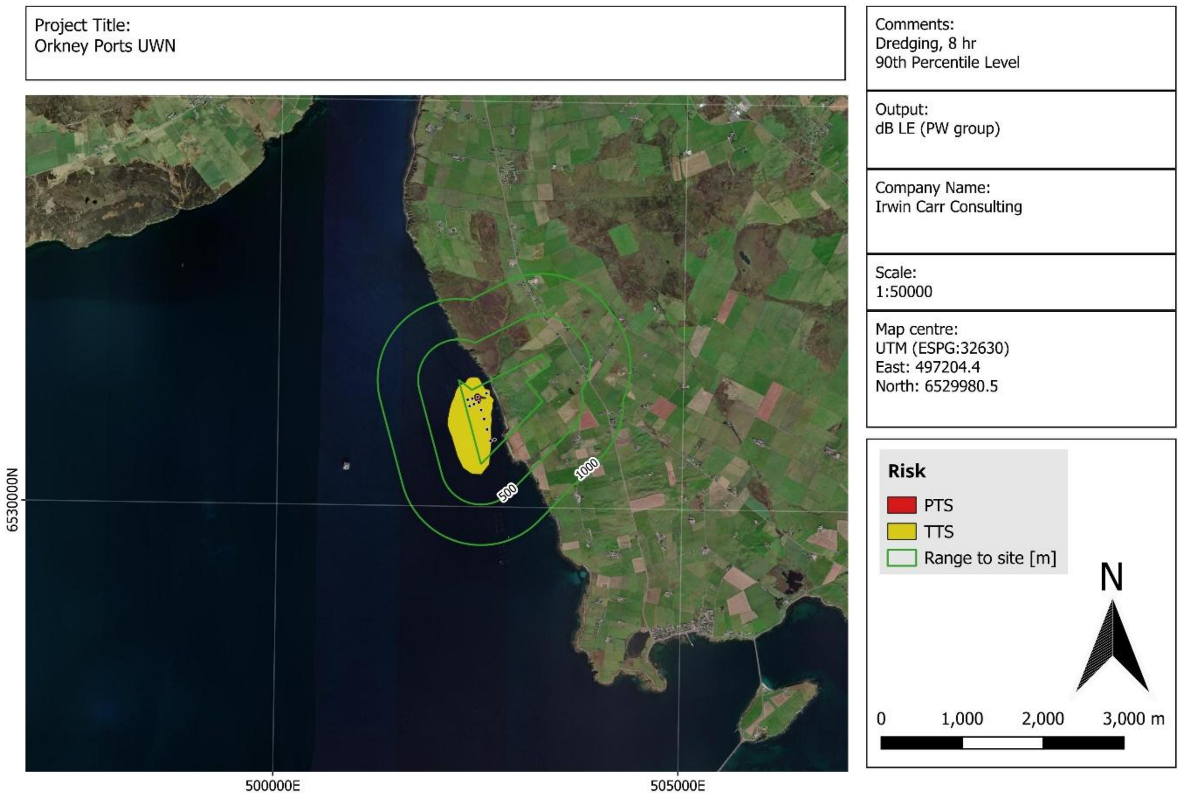


Figure 37. Dredging, L_E, 1hr, OW group

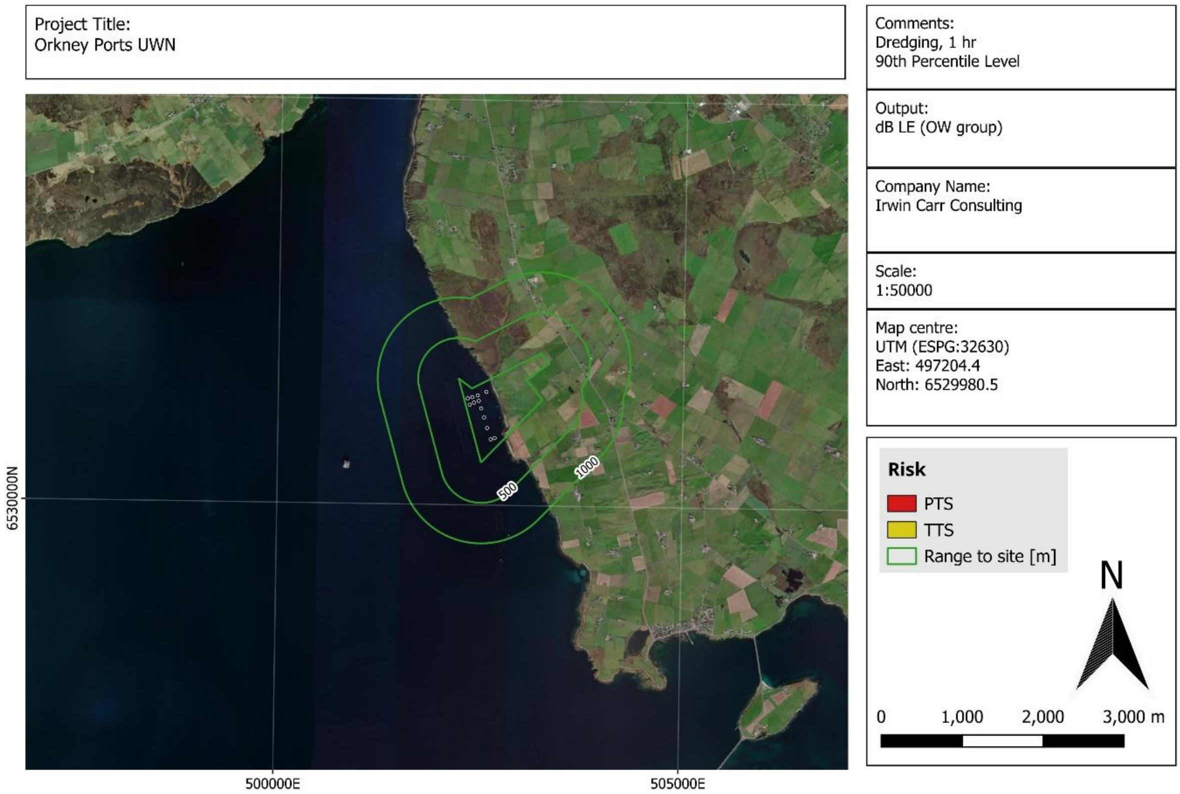


Figure 38. Dredging, L_E, 8hrs, OW group

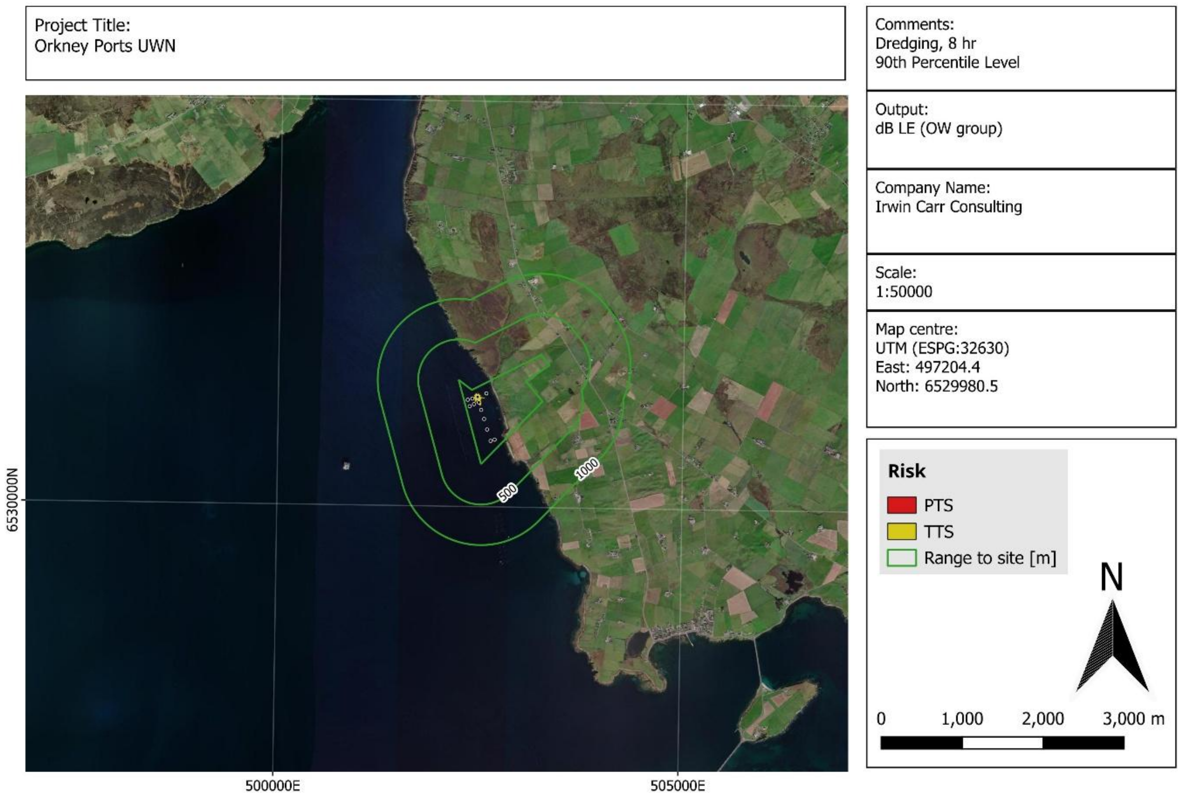


Figure 39. Dredging, L_E, 1hr, P- group

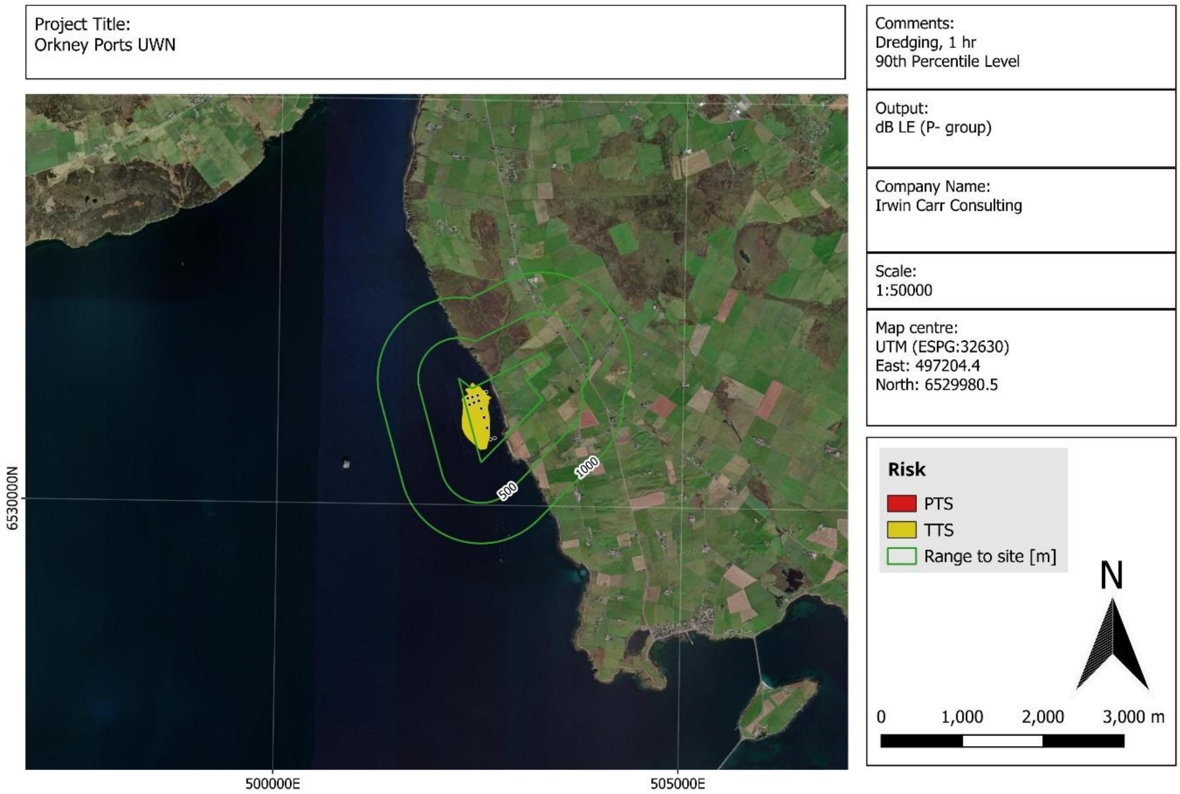


Figure 40. Dredging, L_E, 8hrs, P- group

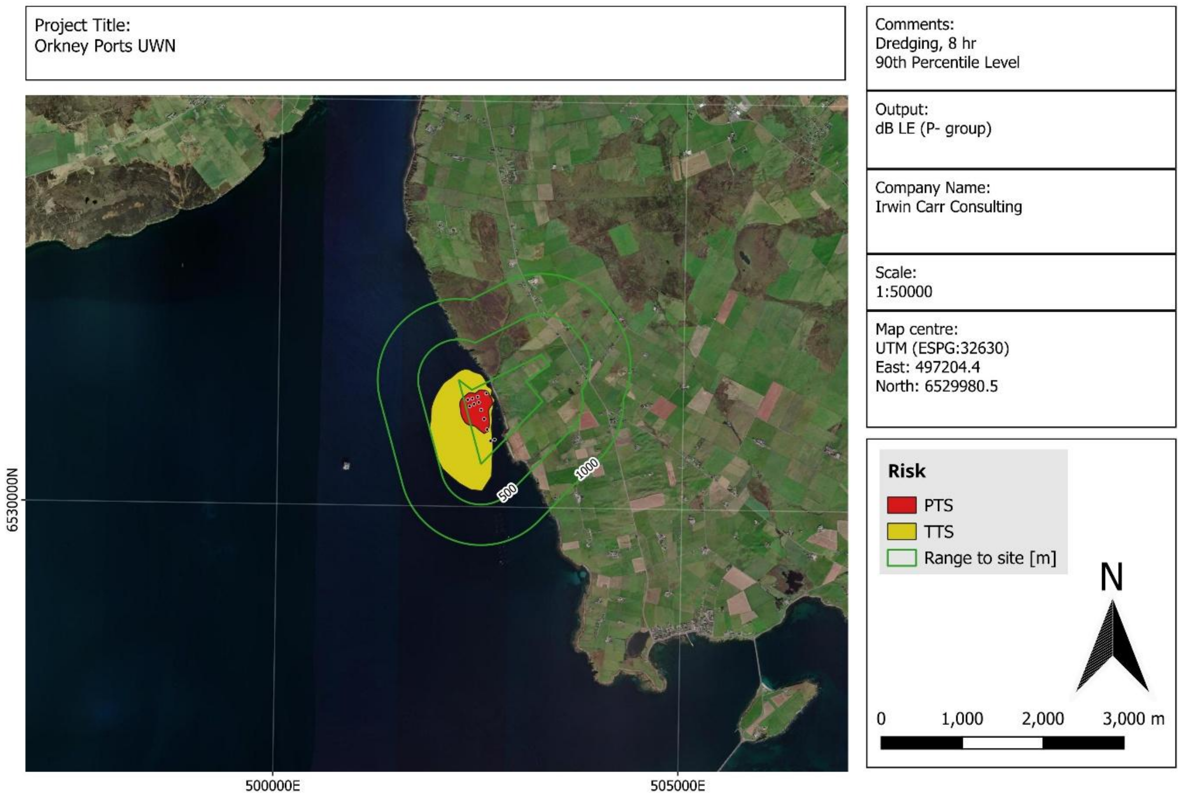


Figure 41. Dredging, L_E, 1hr, P* group

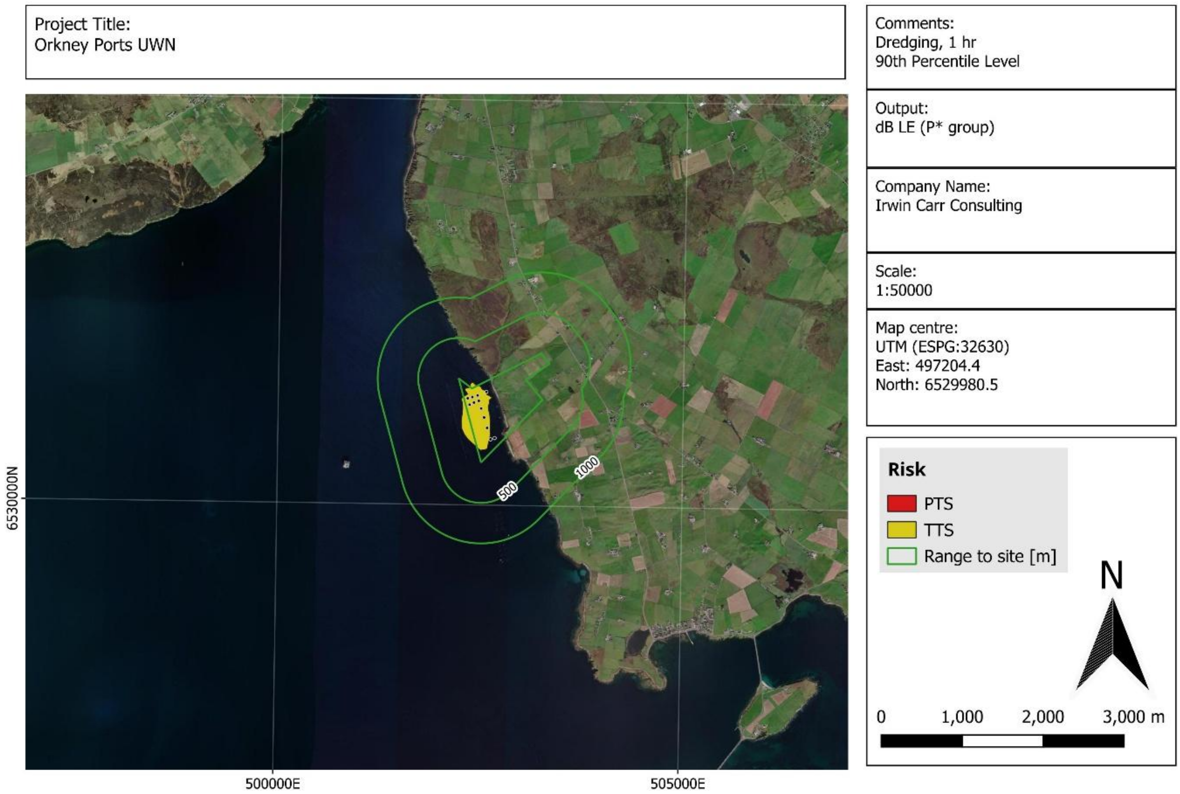
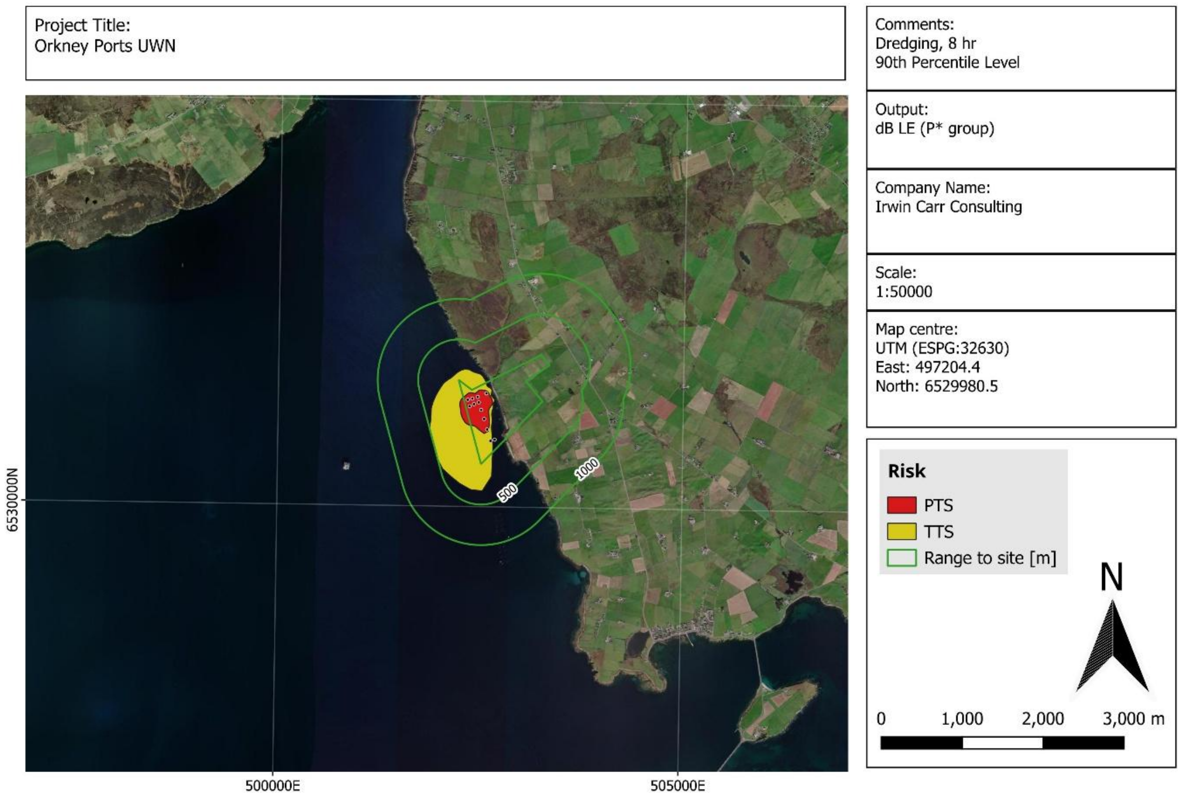


Figure 42. Dredging, L_E, 8hrs, P* group



Vibro Piling LE

Figure 43. Vibro piling, LE, 1 hour, LF group

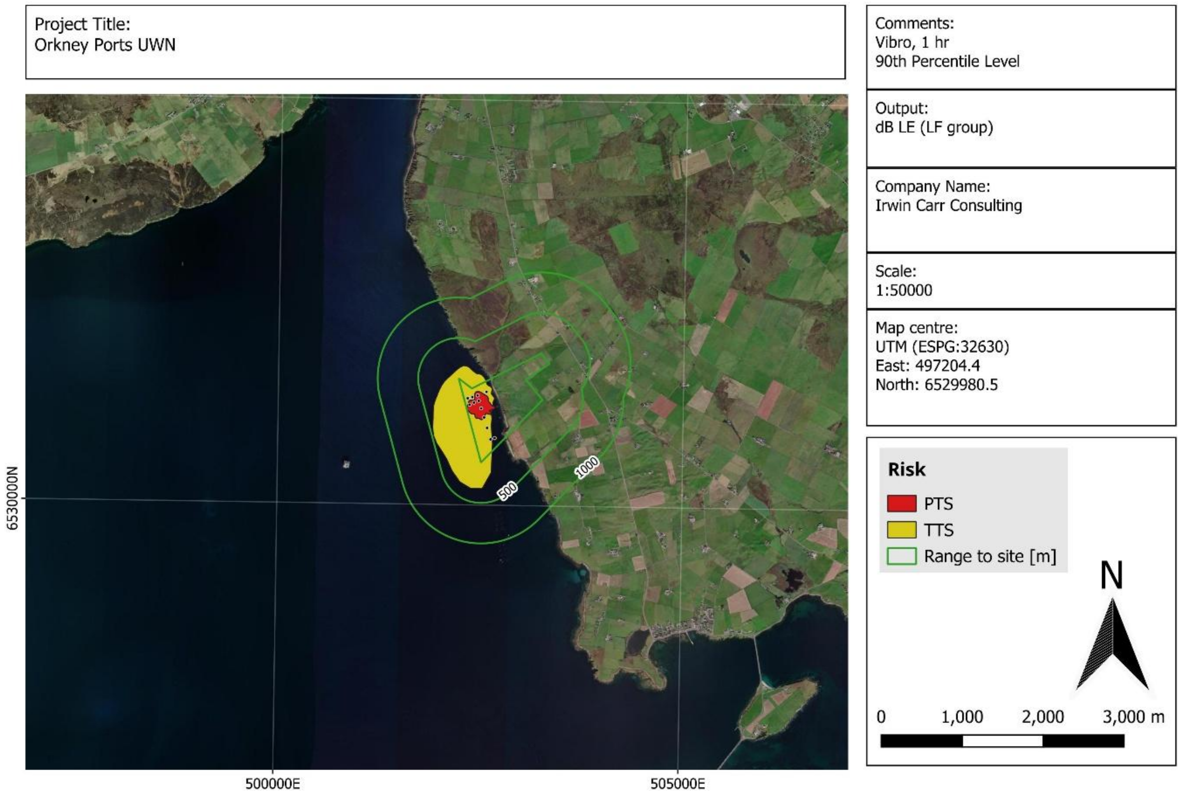


Figure 44. Vibro piling, LE, 1 hour, HF group

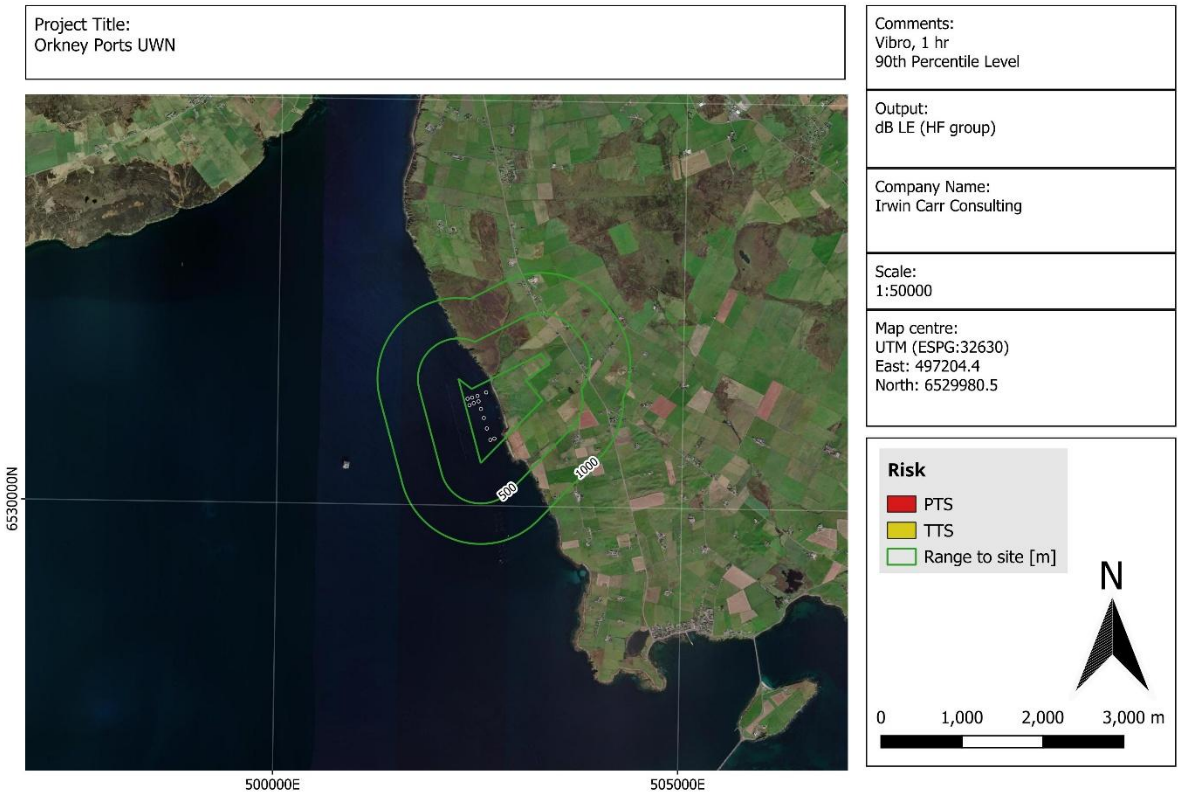


Figure 45. Vibro piling, L_E, 1 hour, VHF group

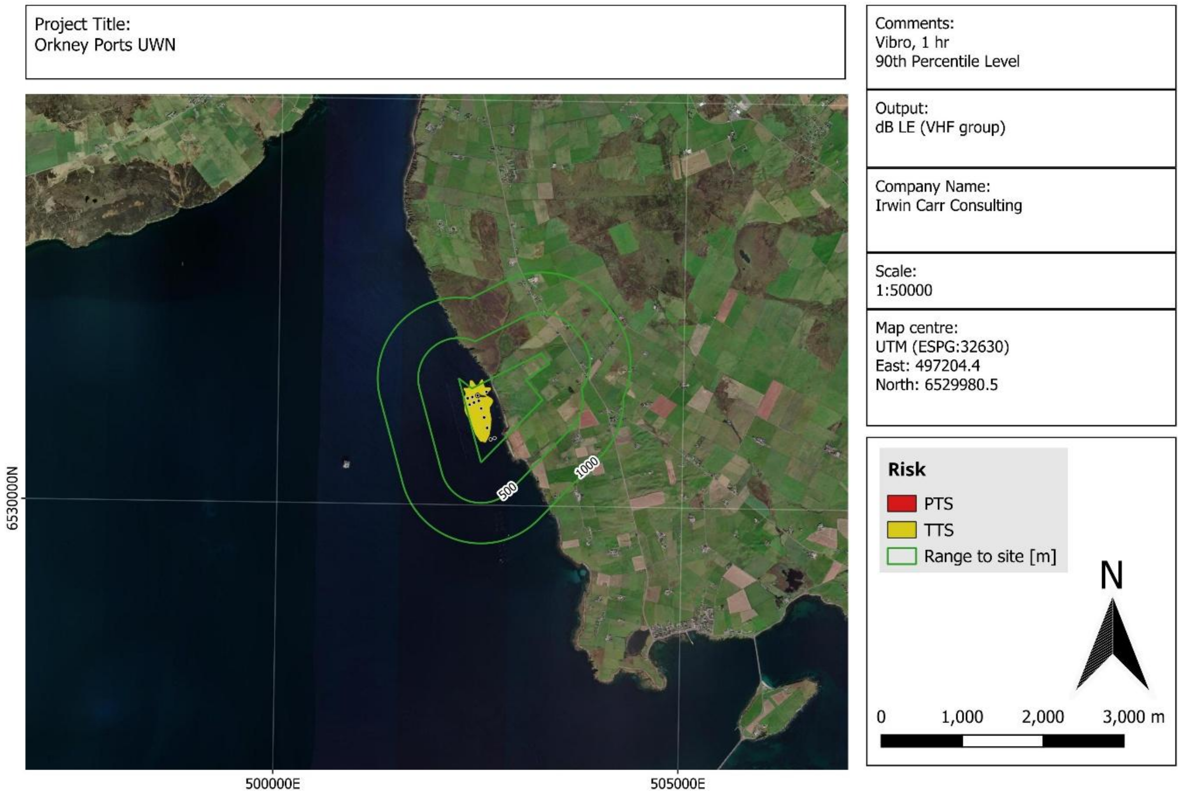


Figure 46. Vibro piling, L_E, 1 hour, PW group

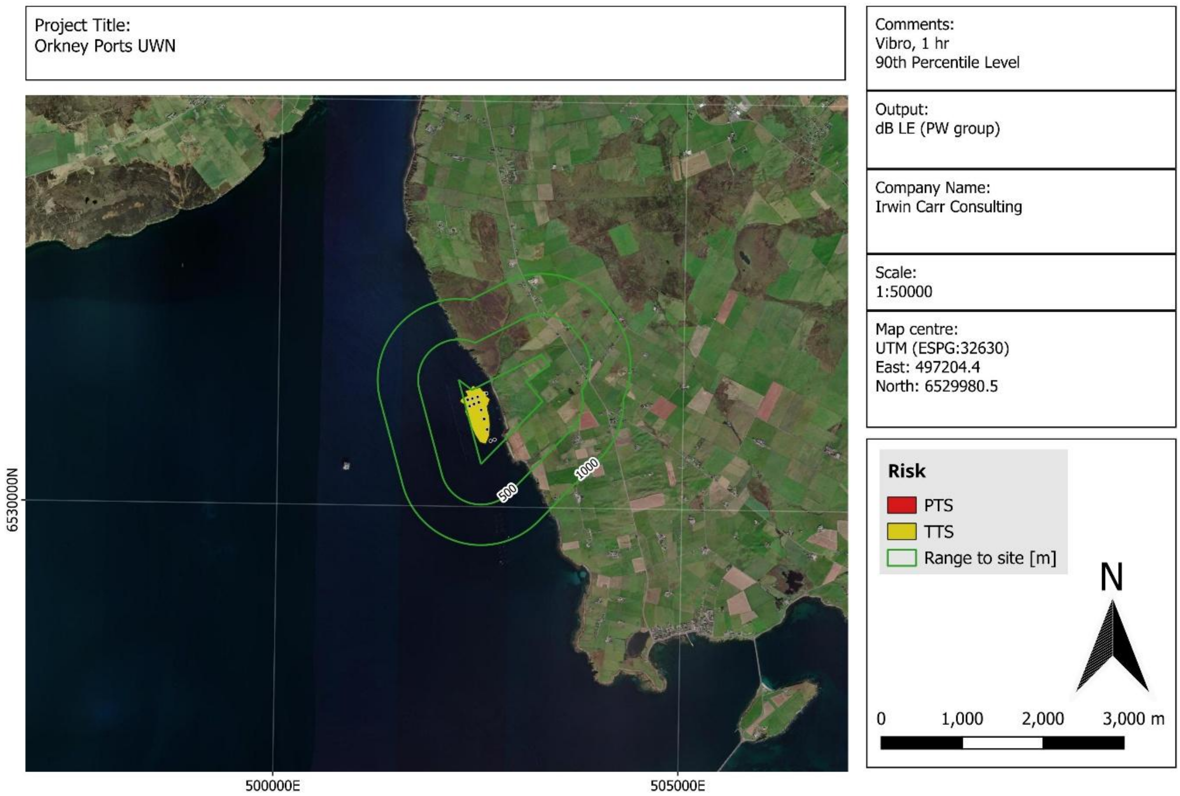


Figure 47. Vibro piling, L_E, 1 hour, OW group

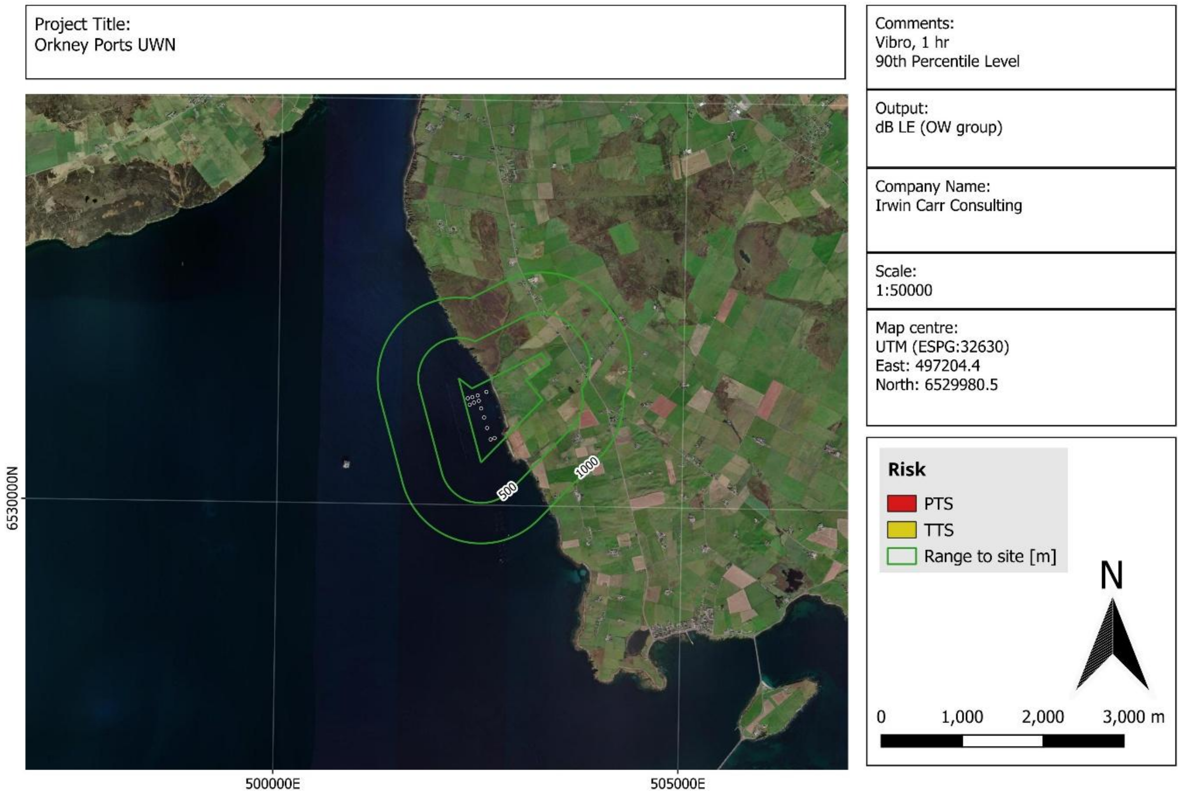


Figure 48. Vibro piling, L_E, 1 hour, P- group

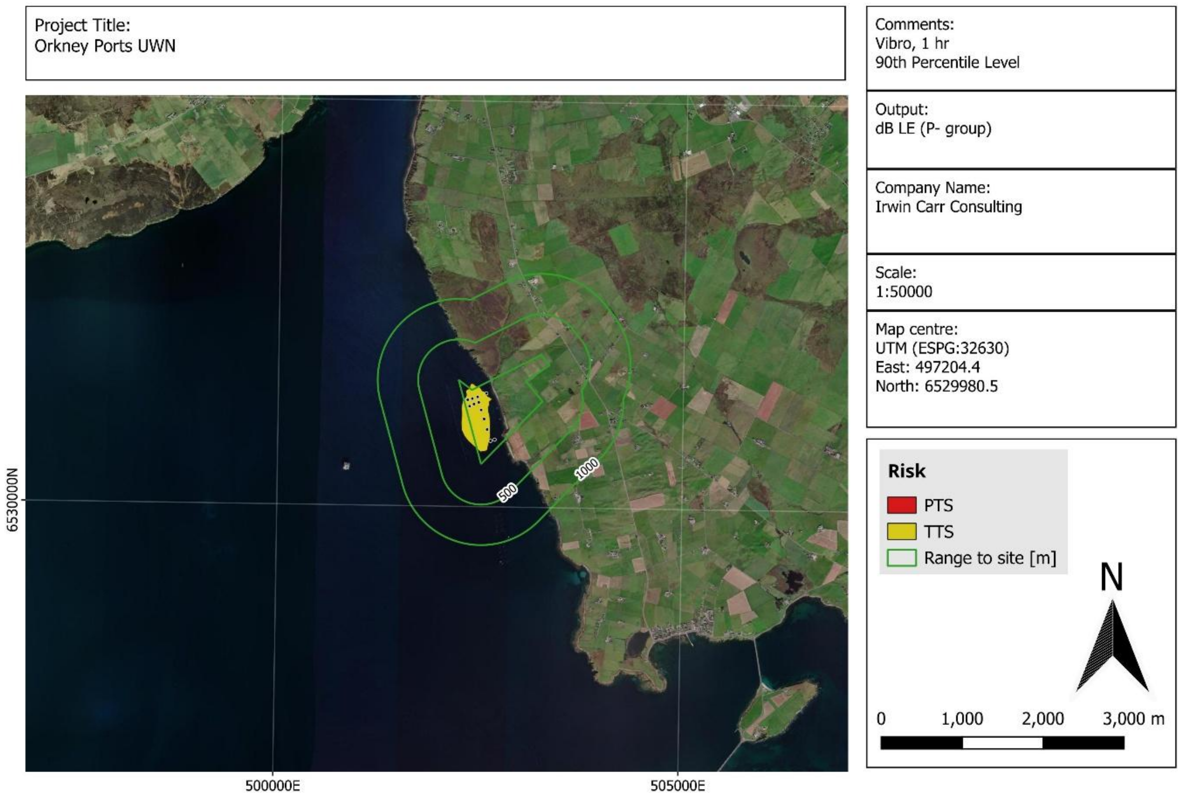
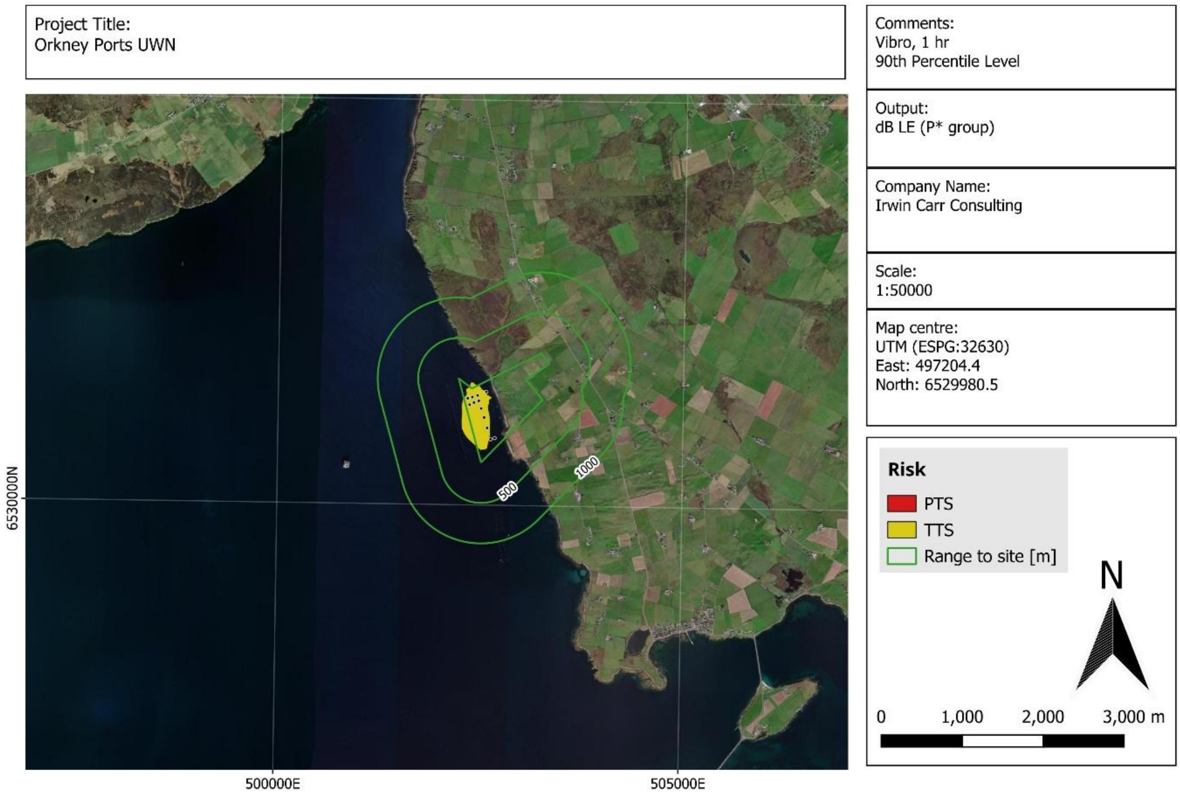


Figure 49. Vibro piling, L_E, 1 hour, P* group



Vibro piling L_P

Figure 50. Vibro piling, L_P, LF group

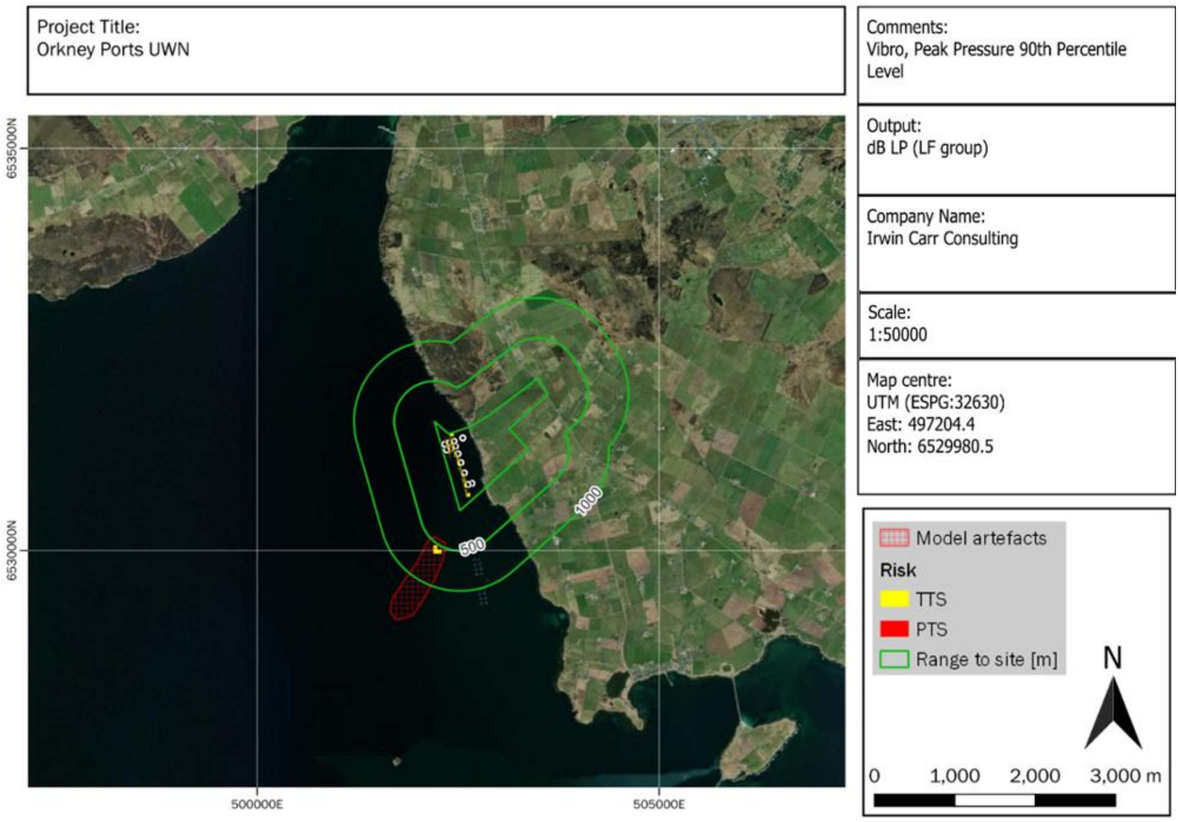


Figure 51. Vibro piling, L_P, HF group

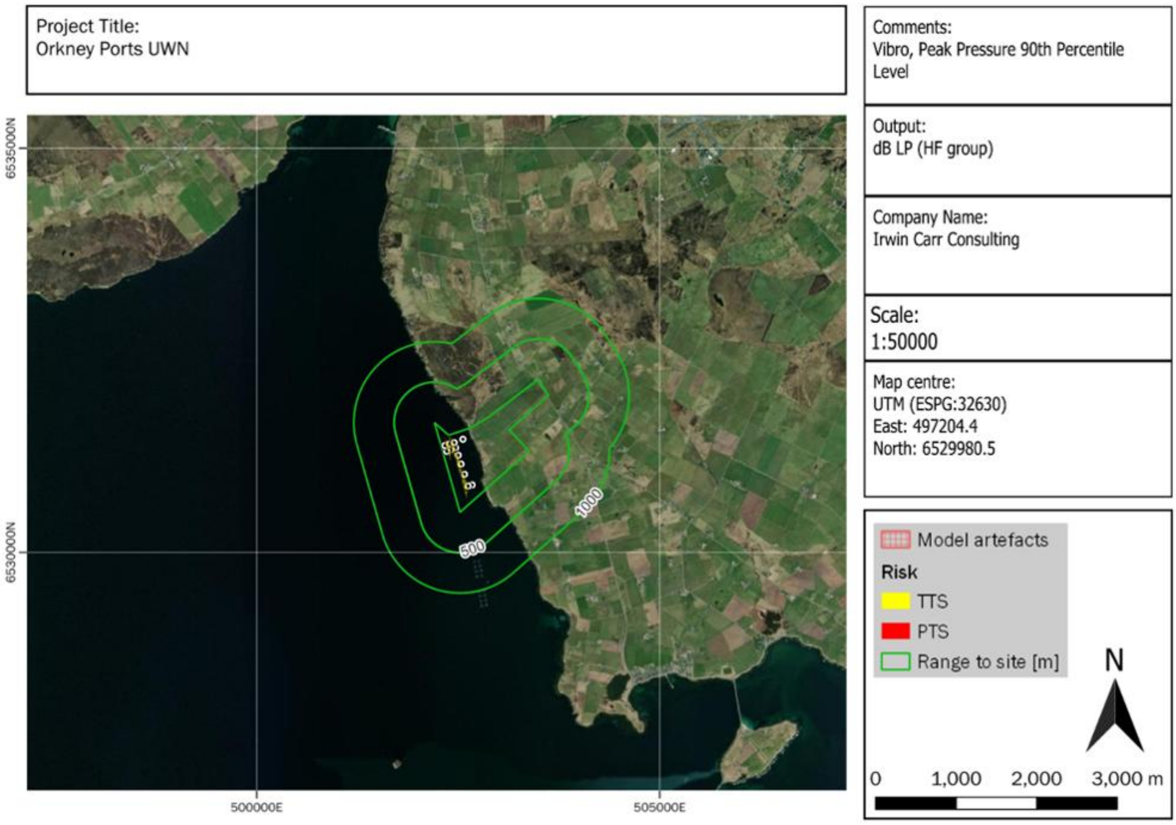


Figure 52. Vibro piling, L_P, VHF group

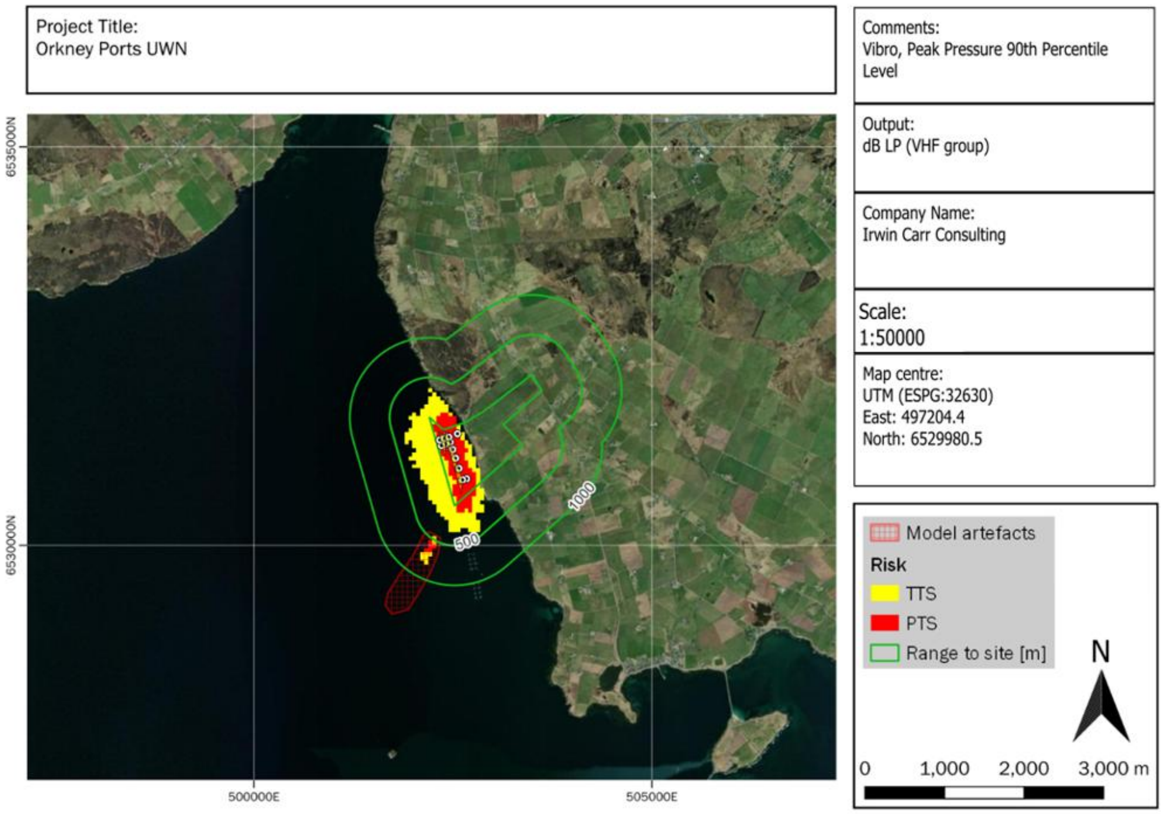


Figure 53. Vibro piling, L_P, PW group

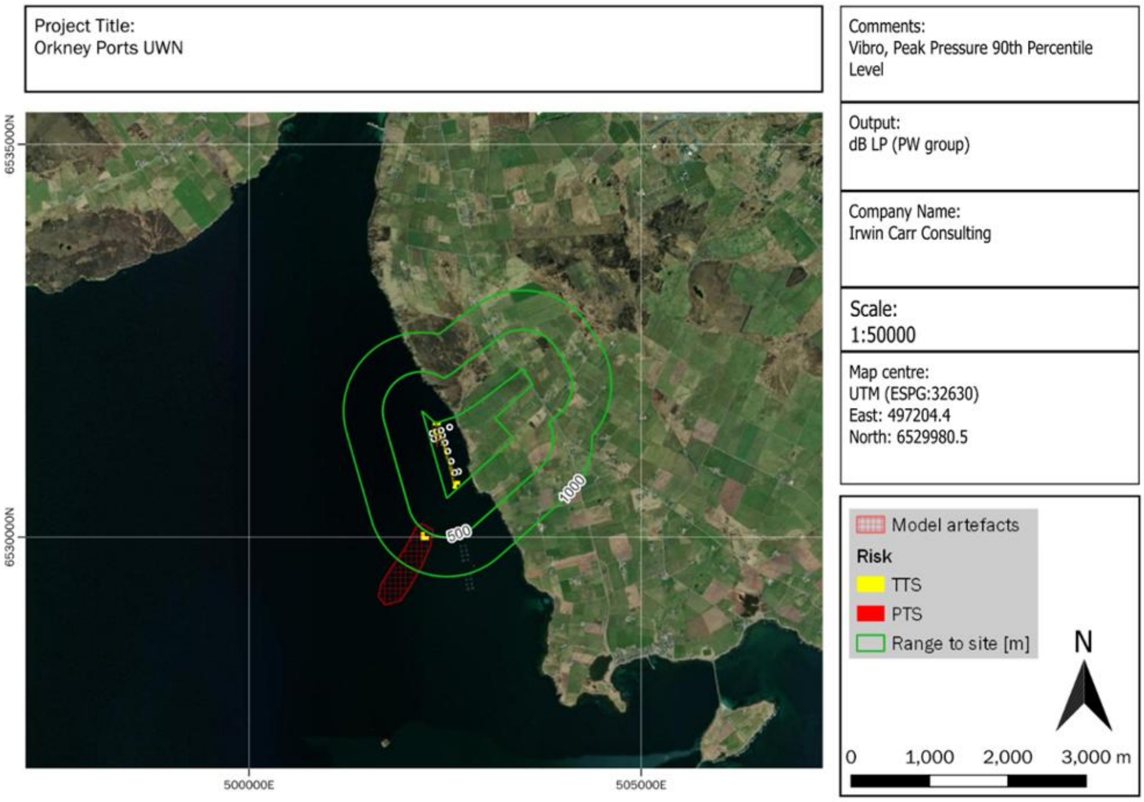


Figure 54. Vibro piling, L_P, OW group

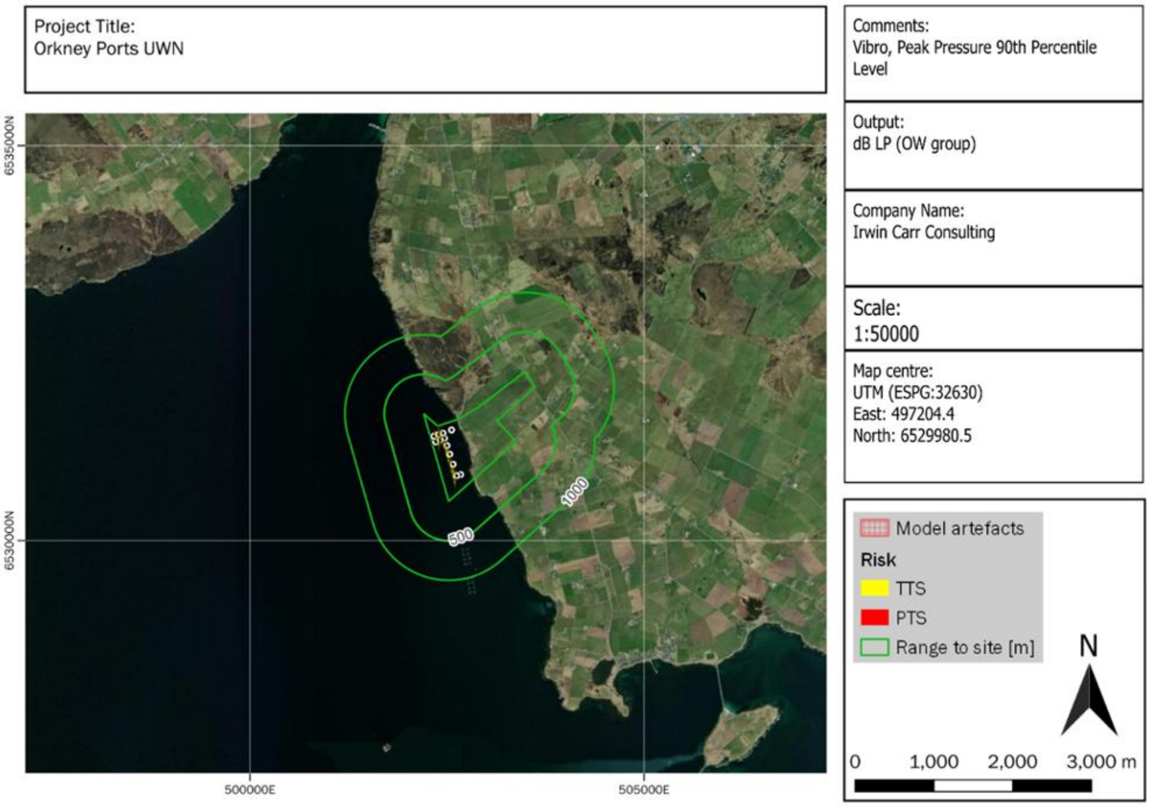


Figure 55. Vibro piling, L_P, P- group

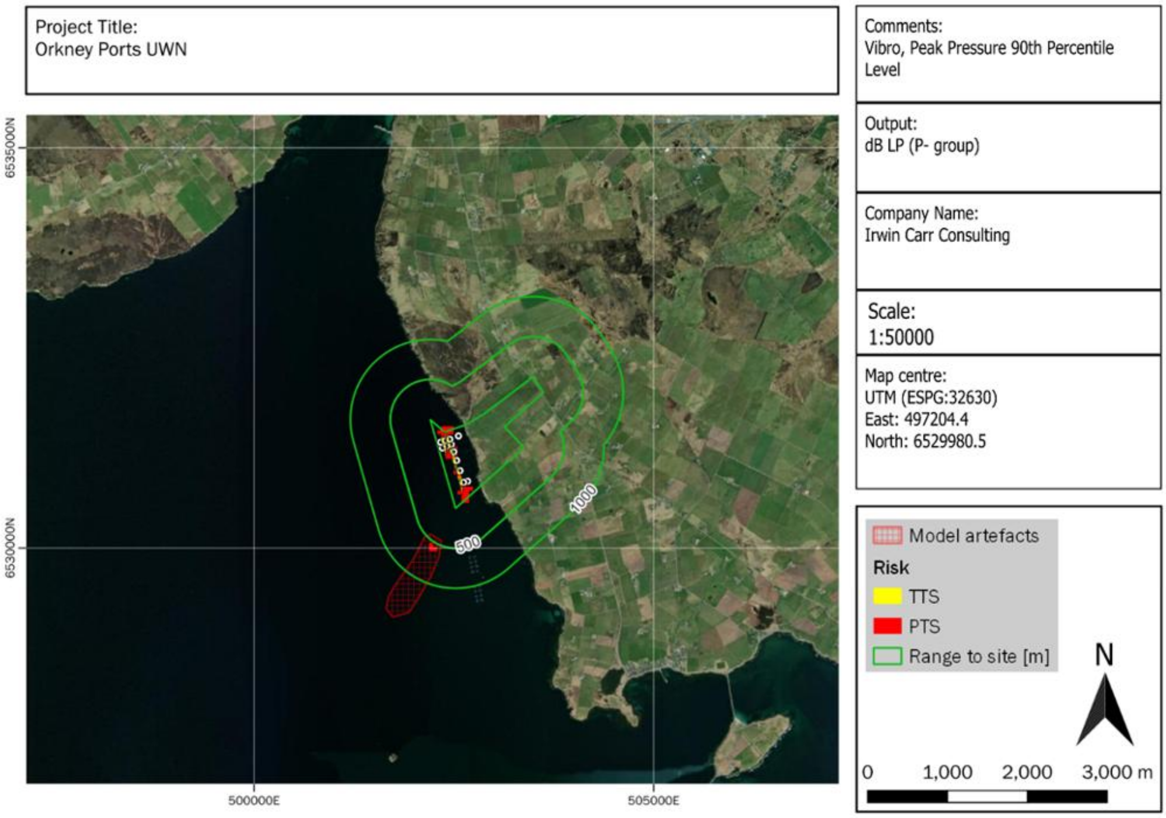


Figure 56. Vibro piling, L_P, P* group