# GIGHA AND TAYINLOAN PORT DEVELOPMENT – GEOPHYSICAL AND GEOTECHNICAL SURVEYS

## European Protected Species & Marine Wildlife Supporting Information Report

Gigha and Tayinloan Port Development
Dec 2024

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# GLOSSARY

| Term | Definition |
|---|---|
| Baseline Environment | The existing conditions as represented by the latest available survey and desktop data which is used as a benchmark to assess the impacts of the proposed surveys. |
| Cetacean | Aquatic mammals constituting the infraorder Cetacea (whales, dolphins, porpoises). |
| Continuous Sound | As defined in the National Physical Laboratory (NPL) 2014 guidelines (NPL, 2014), continuous sounds are sounds where the acoustic energy is spread over a significant time, typically many seconds, minutes or even hours. The amplitude of the sound may vary throughout the duration, but the amplitude does not fall to zero for any significant time. The sound may contain broadband noise and tonal (narrowband) noise at specific frequencies. Examples of continuous sound include ship noise, operational noise from machinery including marine renewable energy devices, and noise from drilling. |
| Decibel (dB) | A relative scale most commonly used for reporting levels of sound. The actual sound measurement is compared to a fixed reference level and the "decibel" value is defined to be $10 \cdot \log_{10}$(“actual”/”reference”), where (“actual”/”reference”) is a power ratio. The standard reference for underwater sound pressure is 1 micro-Pascal (μPa), while 20 micro-Pascals is the standard for airborne sound. The dB symbol is often followed by a second symbol identifying the specific reference value (i.e. re 1 μPa). |
| Impulsive Sound | Typically transient, brief (less than one second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH 1998; ANSI 2005). This category includes sound sources such as seismic surveys, impact piling and underwater explosions. |
| $L_P$ (Peak Level, Peak Pressure Level) | The maximal sound pressure level of an event, formally: “ten times the base-ten logarithm of the maximal squared pressure divided by the reference pressure squared” or “twenty time the base-ten logarithm of the peak sound pressure divided by the reference pressure, where the peak sound pressure is the maximal deviation from ambient pressure”. Defined in ISO 18405:2017, 3.2.2.1 |
| Management Unit | Marine mammal Management Unit (MUs) for marine mammals in UK waters, which provide an indication of the spatial scales at which impacts of plans and projects alone, cumulatively and in combination, need to be assessed for the key cetacean species in UK waters. For cetaceans, these management units are defined by the Inter-Agency Marine Mammal Working Group. For seal species (harbour and grey seal), the Special Committee on Seals (SCOS) provided advice on seal MUs. |
| Neritic | A region of the ocean that spans from the coastline to the edge of the continental shelf, sometimes referred to as the coastal or sublittoral zone., |
| Non-impulsive (Sound Source) | Can be broadband, narrowband, or tonal, brief or prolonged, continuous or intermittent and typically do not have a high peak sound pressure with rapid rise/decay time that impulsive sounds do (ANSI 1995; NIOSH 1998). This category includes sound sources such as continuous vibro-piling, running machinery, some sonar and vessels. |
| Permanent Threshold Shift (PTS) | A total or partial permanent loss of hearing caused by some kind of acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity. |
| Sound Exposure Level (SEL) | The cumulative sound energy in an event, formally: “ten times the base-ten logarithm of the integral of the squared pressures divided by the reference pressure squared”. Equal to the often seen “$L_E$” or “dB SEL” quantity. Defined in: ISO 18405:2017, 3.2.1.5 |
| Sound Pressure Level (SPL) | The average sound energy over a specified period of time, formally: “ten times the base-ten logarithm of the arithmetic mean of the squared pressures divided by the squared reference pressure”. Equal to the deprecated “RMS level”, “$dB_{rms}$” and to Leq if the period is equal to the whole duration of an event. Defined in ISO 18405:2017, 3.2.1.1 |
| Non-impulsive (Sound Source) | Can be broadband, narrowband, or tonal, brief or prolonged, continuous or intermittent and typically do not have a high peak sound pressure with rapid rise/decay time that impulsive sounds do (ANSI 1995; NIOSH 1998). This category includes sound sources such as continuous vibro-piling, running machinery, some sonar and vessels. |
| Temporary Threshold Shift (TTS) | Temporary loss of hearing as a result of exposure to sound over time. Exposure to high levels of sound over relatively short time periods will cause the same amount of TTS as exposure to lower levels of sound over longer time periods. The mechanisms underlying TTS are not well understood, but there may be some temporary damage to the sensory cells. The duration of TTS varies depending on the nature of the stimulus, but there is generally recovery of full hearing over time. |

# ABBREVIATIONS

| Acronym | Description |
|---|---|
| ANSI | American National Standards Institute |
| CMACS | Centre for Marine and Coastal Studies |
| CMAL | Caledonian MacBrayne |
| CGNS | Celtic and Greater North Seas |
| CWSH | Coastal West Scotland and Hebrides |
| DDV | Drop Down Video |
| DECC | The Department of Energy and Climate Change |
| EPS | European Protected Species |
| HF | High Frequency |
| HWDT | Hebridean Whale and Dolphin Trust |
| FCS | Favourable Conservation Status |
| IAMMWG | Inter-Agency Marine Mammal Working Group |
| IMA | Ireland's Marine Atlas |
| IROPI | Imperative Reasons of Overriding Public Interest |
| JNCC | Joint Nature Conservation Committee |
| LF | Low Frequency |
| MBES | Multibeam Echosounder |
| OW | Oceanic Waters |
| MMO | Marine Mammal Observer |
| MD-LOT | Marine Directorate - Licensing Operations Team |
| MU | Management Unit |
| NBN | National Biodiversity Network |
| NIOSH | National Institute for Occupational Safety and Health |
| NOAA | National Oceanic and Atmospheric Administration |
| NRW | Natural Resources Wales |
| OCA | Other Marine Carnivores in Air |
| PAM | Passive Acoustic Monitoring |
| PTS | Permanent Threshold Shift |
| rms | Root mean square |
| SAC | Special Area of Conservation |
| SBP | Sub-bottom Profiler |
| SCOS | Special Committee on Seals |
| SPL | Sound Pressure Level |
| SSS | Side Scan Sonar |
| TTS | Temporary Threshold Shift |
| USBL | Ultra Short Baseline |
| UK | United Kingdom |
| UKMPS | UK Marine Policy Statement |
| VHF | Very High Frequency |
| ZoI | Zone of Influence |

# UNITS

| Unit | Description |
|---|---|
| dB | Decibel |
| Hz | hertz |
| J | Joules |
| kHz | Kilo-hertz |
| kn | Knot |
| km | Kilometre |
| $km^2$ | Kilometre squared |
| $L_E$ | Same as SEL |
| $L_P$ | Peak Level, Peak Pressure Level |
| m | Metres |
| mm | Millimetres |
| $ms^{-1}$ | Metres per second |
| nm | Nautical miles |
| SEL | Sound exposure level |
| SPL | Sound pressure level |
| µPa | micro-Pascal |
| % | Percentage |

# 1 INTRODUCTION

## 1.1 Project overview

The Proposed Development at Gigha ferry port and Tayinloan ferry port (hereafter referred to as ‘Gigha & Tayinloan Port Development’) is being proposed by Argyll & Bute Council in consultation with Caledonian MacBrayne (CMAL) for the construction of a pier/breakwater to provide overnight berthing facilities at Gigha (Ardminish) and a breakwater extension at Tayinloan in order to ensure normal service for a larger ferry at both ports. Gigha & Tayinloan Port Development has been proposed due to the expected growth in demand for ferry routes between small ferry ports identified through the Small Ferries Project Report (Grant Thornton UK LLP, 2010). As a part of several coastal areas in Scotland and Northern Ireland, Gigha & Tayinloan Port Development is included in the planning for the introduction of larger, hybrid/electric ferries.

To progress concept development, detailed geophysical and geotechnical surveys are needed for Gigha & Tayinloan Port Development (the ‘Licensable Operations’). The surveys for the breakwaters and overnight berthing facilities are to take place in the coastal area of Gigha and Tayinloan, Sound of Gigha. RPS has been contracted by Argyll and Bute Council (‘the Client’) to prepare and support delivery of marine European Protected Species (EPS) and Marine Wildlife Risk Assessments for this survey, which will be the first dedicated geophysical and geotechnical surveys for the Gigha & Tayinloan Port Development.

The Gigha & Tayinloan Port Development is situated on the west coast of Scotland. The ferry port at Gigha is located on the Isle of Gigha, off the west coast of the Kintyre Peninsula and is separated from the mainland by the Sound of Gigha, a shallow channel of clear water approximately five kilometres wide. The ferry port on Tayinloan is located on the Scottish mainland and is to the east of Gigha, across the Sound of Gigha (Figure 1.1).

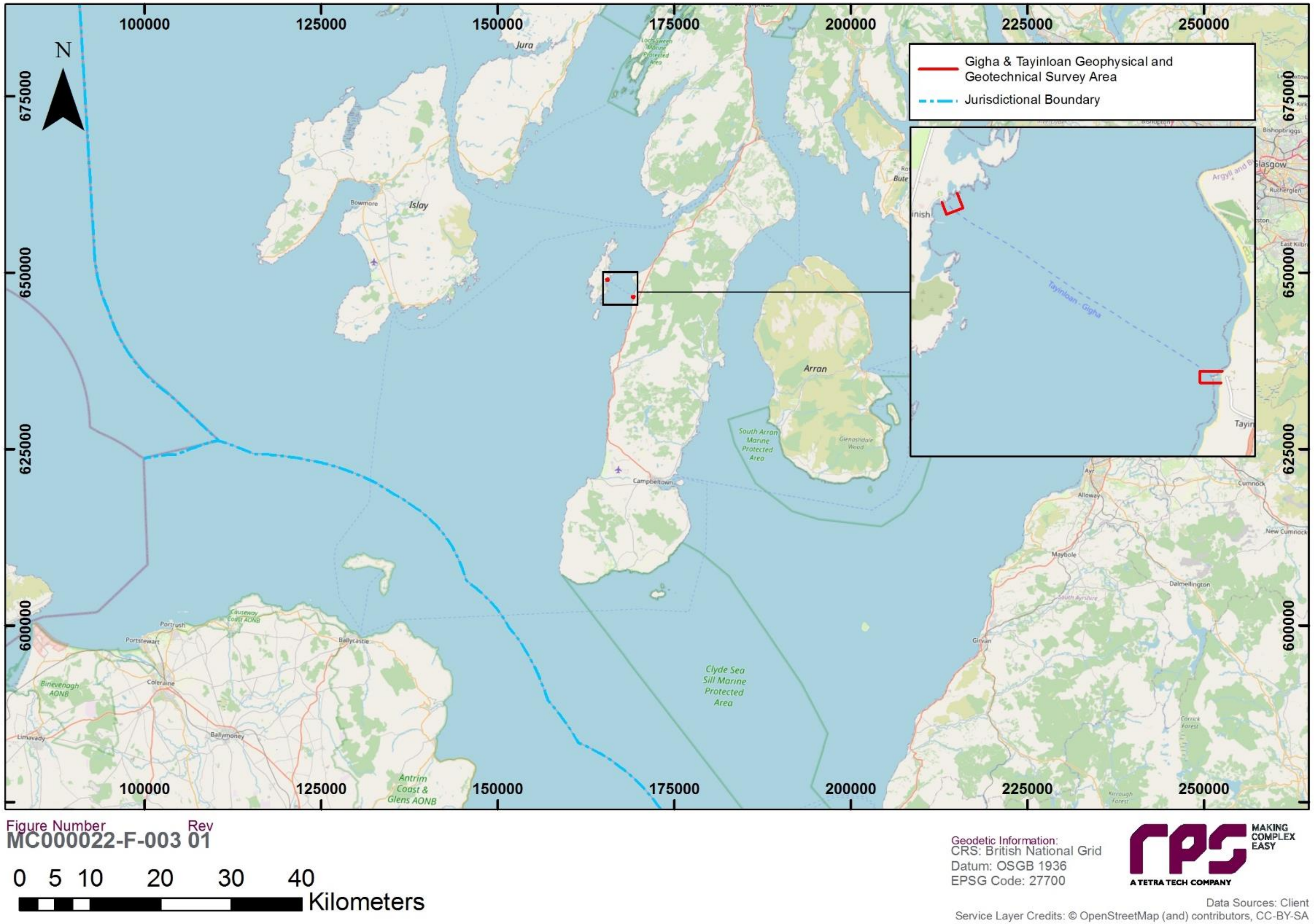


**Figure 1.1: Location of Gigha & Tayinloan Port Development.**

## 1.2 Purpose of the document

As some marine species in the United Kingdom (UK) are protected under law (see section 2) as EPS, marine licence applicants must demonstrate that risks of injury and disturbance have been duly assessed in the vicinity of the surveys.

This EPS and Marine Wildlife Risk Assessment covers the geophysical and geotechnical surveys (the Licensable Operations) within the Gigha & Tayinloan Geophysical and Geotechnical Survey Area (**Figure 1.1**) only. Further details on the survey methods are presented in the survey design section of this report (section 1.3).

This report summarises the legislative context (section 2) with respect to marine EPS identified in the vicinity of the Gigha & Tayinloan Port Development (section 3) and provides an overview of the licensable operations (i.e. noise-producing survey activities) (sections 1.4 and 4.1) that will be undertaken as part of the geophysical and geotechnical surveys. It describes the proposed survey activities, the survey equipment likely to be used and associated noise levels. Underwater noise modelling of the sound sources has been undertaken to assesses the risk of auditory injury or disturbance to marine EPS and proposes mitigation measures (where needed) to reduce those risks to acceptable levels within the relevant legislative context (section 2). Where risks that cannot be mitigated are identified, information will be provided to support EPS and/or marine wildlife licence application(s) (section 5).

## 1.3 Survey design

Detailed geophysical and geotechnical surveys are required to develop the Gigha & Tayinloan Port Development design envelope, and aim to:

- Ground profile for the various elements of the works including its:
    - suitability for piled or ground bearing foundations,
    - suitability for dredging, disposal at sea and/or reuse as fill,
- Profiling the natural deposits at the breakwater extension, overnight berth and within the dredge pocket;
- Bottom profiling to provide updated bathymetry for computational modelling of the baseline environment and proposed development. Informing the impact of the development on hydraulics, sediment transport, waves and harbour disturbance effects; and
- Benthic ecology, cultural heritage and contamination for input to environmental assessments.

Depths at Gigha & Tayinloan Port Development are characterised by shallow waters with survey areas with depths of 0 – 6 m (based on mean high water springs) and up to 50 m within the Sound of Gigha, with the sediment being mainly silty to fine sand and water properties similar to the north Irish sea.

The proposed geophysical and geotechnical surveys are expected to be conducted as outlined in Table 1.1.

**Table 1.1: Proposed timings of Gigha & Tayinloan Port Development geophysical surveys.**

| Survey Component | Indicative Survey Area | Anticipated Duration & Timing |
|---|---|---|
| Gigha (Ardminish) | 0.05 km$^2$ | Works are expected to occur over a 3- 4 week period of 24/7 working (including anticipated weather downtime), within a 6 month period between March and August 2025. |
| Tayinloan | 0.04 km$^2$ | |

## 1.4 Survey equipment

The Gigha & Tayinloan Port Development will be surveyed using a variety of geophysical and geotechnical survey equipment, deployed from sea-going vessels. The number and specification of survey vessels and equipment will depend on the appointed contractor. The speed of surveys is expected to be four to five knots, limited by the survey equipment. Survey transects are yet to be determined and therefore representative locations throughout the survey area were used as basis for underwater noise modelling. In the absence of specific parameters, this report has been prepared using industry standard vessels and survey apparatus (Table 4.1).

## Vessels

The proposed surveys will likely be undertaken by a small survey vessel up to 30 meters in length, travelling at four to five knots. As survey vessel specifications are yet to be confirmed, the noise emitted from a representative vessel (Table 4.1) has been used in the preparation of this report. This smaller vessel will have lower emitted levels and so is covered by the underwater sound assessment (Appendix A). In addition this vessel was used as a proxy for a suitable platform for the geotechnical survey, representing a generic machinery noise (see Table 4.1 for details).

## Geophysical and geotechnical survey equipment

The Gigha & Tayinloan Port Development footprint will be surveyed using a range of geophysical and geotechnical survey techniques. As well as the vessels which emit continuous non-impulsive sound, the noise emitting survey equipment likely to be used in the survey is outlined in Table 1.2. These sound sources are described in detail in section 4.1 below and represent the Licensable Operations in the context of EPS / Wildlife licence applications, as they have the potential to cause direct or indirect effects (including injury or disturbance) on marine mammals, basking shark and marine turtles. Noise levels from representative equipment covering these specification ranges are detailed in Table 4.1.

**Table 1.2: Description of geophysical and geotechnical survey apparatus.**

| Apparatus | Specifications | Description |
|---|---|---|
| **Geophysical survey equipment** | | |
| Side Scan Sonar (SSS) | Dual frequency with low and high nominal frequencies of 200 kHz and 900 kHz<br>Frequency required: >400 kHz<br>Range: <100 m | An impulsive sound source used to generate an accurate image of the seabed; this uses an acoustic beam to obtain a sonic image of a narrow area of seabed to either side of the instrument by measuring the amplitude of back-scattered return signals |
| Multibeam Echosounder (MBES) | A dual head system.<br>Nominal frequencies from 200 kHz to 400 kHz<br>Swath coverage of 120°<br>Ping rate min 40 Hz | An impulsive sound source used to record the two-way travel time of a high frequency pulse emitted by a transducer to obtain detailed maps of the seafloor showing water depths |
| Parametric Sub-bottom Profiler (P-SBP) | Frequency between 2 kHz and 125 kHz | An impulsive sound source used to characterise layers of sediment or rock under the seafloor; they use a transducer which emits a sound pulse vertically downwards towards the seafloor, and a receiver which records the return of the pulse once it has been reflected off the seafloor. |
| Sub-bottom Profiler - chirper/pinger (C-SBP) | Minimum penetration: 30 m<br>Frequency between 1 kHz and 20 kHz<br>The survey speed at which P-SBP surveys are undertaken shall normally be maintained at 4.0 knots (±10%) | An impulsive sound source used to characterise layers of sediment or rock under the seafloor; they use a transducer which emits a sound pulse vertically downwards towards the seafloor, and a receiver which records the return of the pulse once it has been reflected off the seafloor |
| Ultra short baseline (USBL) | Frequency range > 400 kHz | An impulsive sound source used for acoustic positioning |
| **Geotechnical survey equipment** | | |
| Boreholes | Boreholes with some rotary corning with a minimum diameter of 150 mm.<br>Approximately 6 tests at Gigha and 5 tests at Tayinloan | Rotary coring which creates a borehole to create a core sample of the geology or rock of the seafloor |
| Vibrocores | Vibro-corer for collection of 100 mm diameter partially disturbed samples from surface to a maximum depth of 4 m | A vibrating coring technique which is driven by gravity which will collect an undisturbed core sample of the seabed sediments |

| Apparatus | Specifications | Description |
|---|---|---|
| | Approximately 7 tests at Gigha only | |
| Grab samples | Approximately 7 tests at Gigha and 8 at Tayinloan using a 0.1 $m^2$ day grab | A quadrant frame with two jaws which ‘grab’ a sample from the seabed to obtain details of benthic composition and sediment<br>**Note that grab samples are not considered to produce noise levels which pose a risk to any marine receptor considered in this report and are therefore not discussed further.** |

# 2 LEGISLATIVE CONTEXT

Under UK and European law, some marine species are afforded protection from activities that may cause injury or disturbance. These species include (amongst others[1]):

- cetaceans (whales, dolphins and porpoise) and marine turtles, labelled as EPS under Annex IV of the European Commission Habitats Directive (92/43/EEC)(the "Habitats Directive"); transposed individually into UK law under the devolved administrations;
- basking shark, protected under the Wildlife and Countryside Act 1981 (as amended) in Scotland; and
- pinnipeds (seals) under the Marine (Scotland) Act 2010 and seal haul-outs under the Protection of Seals (Designation of Haul-Out Sites) (Scotland) Order 2014.

In Scotland the Habitats Directive is transposed into UK law by the Conservation (Natural Habitats) Regulations 1994 (as amended) (the "Habitats Regulations"), which mandates protection for EPS out to 12 nm. As mentioned above, the Offshore Marine Regulations apply beyond 12 nm. These two pieces of legislation make it an offence to deliberately or recklessly disturb, injure, capture or kill EPS. In brief, marine activities should not be detrimental to the population maintenance of the species concerned, with particular emphasis on breeding or resting areas across their natural range.

EPS licensing makes it possible to permit certain activities (e.g. geophysical surveys) that would otherwise be illegal. Marine Directorate - Licensing Operations Team (MD-LOT) (on behalf of the Scottish Ministers) is the licensing authority for marine casework and is generally advised by NatureScot for applications within 12 nm and the Joint Nature Conservation Committee (JNCC) for those beyond 12 nm. For licences to be granted, the licensing authority need to be satisfied that the following criteria are met:

- Test 1 (Overriding Public Interest Test): If the competent authority is satisfied that, there being no alternative solutions, the Gigha & Tayinloan Area must be carried out for imperative reasons of overriding public interest, which may be of a social or economic nature (Regulation 44(2));
- Test 2 (No Satisfactory Alternatives Test): There are no satisfactory alternative locations for the Development or alternative methods to the Licensable Operations (Regulation 44(3)(a)); and
- Test 3 (Favourable Conservation Status [FCS] Test): The Licensable Operations will not be detrimental to the maintenance of the population of the species concerned at an FCS in their natural range (Regulation 44(3)(b)).

EPS that need to be considered for the Gigha & Tayinloan Port Development's geophysical and geotechnical survey licence are discussed in section 3. If there is a risk of injury or disturbance to EPS that cannot be removed or sufficiently reduced by using alternative methods to those associated with the activity and/or mitigation measures, then the activity may still be able to go ahead under licence provided that the three tests described above are satisfied.

In addition to EPS, basking sharks are protected from disturbance in Scotland under the Wildlife and Countryside Act 1981 (as amended), with a licence from MD-LOT being obligatory for commercial activities such as geophysical surveys. The conditions for granting consent to a project are similar to those required for an EPS licence, starting with the application covering a licensable purpose followed by a justification that there are no satisfactory alternatives and that the licensable actions will not be detrimental to the maintenance of the population of the species concerned at FCS in their natural range.

Article 1(i) of the Habitats Directive defines FCS of a species. The FCS of each EPS considered for this licence has been presented in the species-specific risk assessments in section 5.3.

Whilst not licensable as an EPS or under the Wildlife and Countryside Act 1981 (as amended), seals are afforded protection from injury or killing under the Marine (Scotland) Act 2010 and a number of seal conservation areas have been designated in Scotland to protect harbour seal (as a declining population) in particular. For both grey seal and harbour seal their places of rest and breeding (haul-outs) are also protected under Protection of Seals (Designation of Haul-Out Sites) (Scotland) Order 2014.

[1] Only those protected species susceptible to disturbance and injury from underwater noise are considered for the purposes of this assessment.

## 2.1 Guidance

The JNCC, Natural England and Natural Resources Wales (NRW) (previously Countryside Council for Wales) have produced draft guidance concerning the Habitat Regulations and protection of marine EPS from injury and disturbance in the UK offshore marine area (JNCC *et al.*, 2010). The guidance document provides an example of a preventative approach to ensuring the strict protection of EPS in their natural range as required by Article 12 of the Habitats Directive. Additional guidance also provides an interpretation of the regulations in greater detail for seismic surveys (JNCC, 2017), including mitigation measures designed to reduce the risk of deliberate injury to marine mammals. Relevant measures are incorporated as part of the consenting regimes for geophysical activities within the UK waters. Marine Scotland has also produced guidance concerning Scottish inshore waters and the protection of marine EPS from injury and disturbance (Marine Scotland, 2020). The guidance provides advice for marine users who are planning to carry out an activity in the marine environment which has the potential to kill, injure or disturb an EPS. The guidance clarifies the circumstances in which an EPS licence is required and outlines the process to be followed in applying for a licence, reflecting a precautionary approach given the uncertainties surrounding the issue of disturbance and marine EPS.

The 2010 guidance defines disturbance as significant when "*it is likely to be detrimental to the animals of an EPS or significantly affect their local abundance or distribution*". It also highlights that "*trivial disturbance*" should not be considered as a disturbance offence under Article 12. Trivial disturbance is described as "*sporadic disturbances without any likely negative impact on the animals such as that resulting in short term behavioural reactions which is not likely to result in an offence being committed*" (JNCC *et al.*, 2010).

# 3 SPECIES BASELINE INFORMATION

A summary of the distribution and abundance for each of the key protected species likely to be found within the survey area and surrounding waters is provided below. This information has been used to inform the assessment of risk of injury or disturbance based on the results from the subsea noise modelling (section 4.1). A summary of the key data sources is provided in Table 3.1. For the purpose of this section, the most recent baseline survey data identified has been used to report the protected species densities.

**Table 3.1: Key data sources used to provide baseline of protected marine species within the Gigha & Tayinloan Port Development.**

| Data Source | Date | Description | Reference |
|---|---|---|---|
| SCANS IV distribution maps for cetaceans | Most recent surveys conducted during summer 2022 (published 09/2023) | Estimates of distributions of cetaceans given for spatial blocks around the UK from aerial and sighting surveys. The Gigha & Tayinloan Port Development survey area is located in the general vicinity of survey area CS-F. | Gilles *et al.,* 2023 |
| ObSERVE surveys | Surveys conducted in the summer and winter of 2015 and 2016 (published 2018) | Aerial surveys of cetaceans (and seabirds) in Irish waters: records of occurrence, distribution and abundance in 2015-2017. | Rogan et al., 2018 |
| Atlas of Cetacean Distribution in North-West European Waters | Cetacean distribution | Provides information on the distribution of cetacean species that are known to have occurred in the waters off north-west Europe in the last 25 years. | Reid, Evans and Northridge, 2003 |
| Sea Mammal Research Unit, St. Andrews | 2018 | Aerial thermal-imaging surveys of harbour and grey seals in Northern Ireland | Morris and Duck, 2018a |
| Sea Mammal Research Unit, St. Andrews | 2018 | Aerial Thermal-Imaging Survey of Seals in Ireland | Morris and Duck, 2018b |
| Sea Mammal Research Unit, St. Andrews | 2022 | Habitat-based predictions of at-sea distribution for grey and harbour seals in the British Isles. | Carter *et al.,* 2022 |
| Sea Mammal Research Unit, St. Andrews; Special Committee on Seals (SCOS) | 2022, 2023 | Annual scientific advice on matters related to the management of seal populations, includes population estimates. | SCOS, 2022<br>SCOS, 2023 (interim advice)[2] |
| Inter-Agency Marine Mammal Working Group (IAMMWG) | 2022 | Updated abundance estimates for cetacean Management Units in UK waters. | IAMMWG, 2022 |

## 3.1 Key protected species

The marine protected species relevant to this assessment (i.e. those susceptible to disturbance from underwater noise) that are most commonly documented in the North Channel (into the Sound of Jura), west coast of Scotland, north-western Irish Sea and surrounding areas are presented in the following sections. It should be noted that the monitoring success of marine wildlife sightings (ship or aerial) surveys are highly dependent on abiotic factors (sea state, visibility, re-sightings and seasonality of survey effort etc.), and whilst they are indicative of presence/absence distributions, it can be tenuous to model absolute abundance or densities. Where density estimates have been made for geographic areas (or species management units) of

[2] SCOS (2023) has been reviewed for the latest available estimates, however, it is interim advice and at the time of writing no new seal population estimates were available.

approximate relevance to the, the highest estimates are typically utilised for conservative risk assessments in the interest of adhering to the precautionary principle.

### 3.1.1 European Protected Species (EPS)

#### Cetaceans

#### Harbour porpoise

Harbour porpoise *Phocoena phocoena* are the most commonly observed cetacean species in UK waters, with high densities in the Irish Sea and its northern and southern channels (Wall *et al.,* 2013). Sightings occur year-round throughout the Irish Sea (Baines and Evans, 2009), with a tendency for higher abundance in summer (Rogan *et al.,* 2018). This species prefers habitats where depths range from 5-150 m in highly sloped regions (Booth *et al*., 2013; Buttifant, 2021). Water depth and hydrodynamic variables have been found to have the greatest influence on the distribution of the species within the Irish Sea (Heinänen and Skov, 2015).

The SCANS IV density estimate for the survey area most relevant to the Project (CS-F) is 0.2010 animals per km$^2$ (SCANS IV survey block CS-F), with group sightings comprising 1-5 individuals at any one place/time (ObSERVE IV, north-eastern survey reaches). The IAMMWG population estimate for the UK portion of the West Scotland management unit (MU) (comprising ICES divisions 6a and b) for harbour porpoise is 24,305 animals. Noting however, the species is largely confined to the continental shelf in waters of less than 200 m (IAMMWG, 2022).

#### Bottlenose dolphin

The bottlenose dolphin *Tursiops truncatus* is relatively common in the Irish Sea, especially in south-eastern reaches where a semi-resident populations exists in Cardigan Bay (Baines and Evans, 2009, Centre for Marine and Coastal Studies (CMACS), 2005). Whilst reporting is sparser in the direct vicinity of the Gigha & Tayinloan Port Development, this is located within their natural distribution. Population estimates for the location of the Gigha & Tayinloan Port Development are inconclusive, but the Coastal West Scotland and Hebrides (CWSH) MU, within which the project is located, has a total abundance estimate of 45 animals (IAMMWG, 2022). This has been used in this assessment in section 4.3 and Table 4.7. The SCANS IV density estimate for the survey area most relevant to the Project (CS-F) is 0.0425 bottlenose dolphins per km$^2$ (Gilles *et al.,* 2023).

Most sightings of bottlenose dolphin in UK waters take place between July and September, with a secondary peak in April (Reid *et al.*, 2003). The species often occurs in small groups in coastal areas, moving further offshore during winter months to feed on benthic and pelagic fish species (CMACS, 2005). In coastal waters, bottlenose dolphin have been found to prefer headlands, river estuaries, or sandbanks, where there is typically uneven bottom relief and/or strong tidal currents (Reid *et al*., 2003). There are several recent bottlenose dolphin sightings recorded in the vicinity of the Project by members of the public (Hebridean Whale and Dolphin Trust (HWDT), 2024).

#### Common dolphin

The short-beaked common dolphin (hereafter referred to as common dolphin) *Delphinus delphis* has a large population in UK waters, predominantly occurring offshore and at the southern end of the Irish Sea (Waggitt *et al.*, 2020). They tend to favour coastal, shelf, slope and deep-water habitats with geologic features such as underwater ridges and seamounts where upwelling occurs, increasing nutrient concentrations and supporting higher productivity (National Oceanic and Atmospheric Administration (NOAA), 2022). Whilst not uncommon, they are less frequently observed nearshore (JNCC, 2003; Mackney and Gimenez, 2006).

Sightings in the Irish Sea also occur along the west coast of Scotland, Ireland and to the southwest of England (Reid *et al.*, 2003). Infrequent sightings in the Irish Sea typically occur between June and September (CMACS, 2005). They have been recorded in Irish waters all year round, but strong seasonal shifts in their distribution have been noted, with winter inshore movements onto the Celtic Shelf and into the western English Channel and St. George's Channel resulting in pronounced concentrations (Northridge *et al.*, 2004). A single MU, the Celtic and Greater North Seas (CGNS), has been defined for common dolphin, with an estimated population of 57,417 animals (IAMMWG, 2023).

Prey species tend to be pelagic fish such as mackerel, sardine and sprat. Research undertaken to analyse short-beaked common dolphin foraging habits illustrated that the species is abundant in both neritic and oceanic habitats, suggesting highly variable habitat preferences and associated foraging strategies (CMACS, 2005).

The SCANS IV survey density estimate (area CS-F) is 0.0544 common dolphins per $km^2$ (Gilles *et al.,* 2023). Sightings of common dolphin were rare in the vicinity of the Gigha & Tayinloan Port Development on the ObSERVE surveys, but large pods (anything from individual to super pods in the hundreds) were sighted off the west coasts of Ireland and Scotland (Rogan *et al.,* 2018).

## Risso's dolphin

Risso's dolphin *Grampus griseus* sightings in the UK are for the majority along the west coast of Scotland and the Outer Herbides with consistent annual return migrations (NatureScot, 2023a). This species tends to prefer shelf-edge offshore waters in depths ranging from 400 to 1,000 m (NOAA, 2022; Waggitt *et al.*, 2020). Risso's dolphin is thought to predominantly be a nocturnal forager, targeting deep dwelling benthic organisms (Visser *et al.*, 2021), however, this species is known to perform 'prey switching' between deeper diving for squid and shallow water foraging. Animals will often feed at night to benefit from vertical migration of squid as they can then stay nearer surface to breathe and conserve energy (Benoit-Bird *et al.*, 2019).

A single MU, the CGNS, has been defined for Risso's dolphin, with an estimated population of 8,687 animals (IAMMWG, 2022). The SCANS IV estimated density of Risso's dolphin in the vicinity of the Gigha & Tayinloan Port Development (CS-F) is very low at 0.0027 individuals per $km^2$ (Gilles *et al.,* 2023). The ObSERVE surveys reported seeing them in offshore waters off the west coast of the Ise of Islay (Rogan *et al.,* 2018). Risso's dolphin is considered likely to be present year-round within the vicinity of the Gigha & Tayinloan Port Development, with a higher prevalence during summer months (Waggitt *et al.*, 2020).

## Minke whale

Minke whale *Balaenoptera acutorostrata* is found throughout the Irish Sea, Celtic Deep and Scotland, occurring predominantly during summer months, such as between July and September in the Hebrides (The Department of Energy and Climate Change (DECC), 2016; NatureScot, 2019; Waggitt *et al.*, 2020; NatureScot, 2023b). This seasonal variation within West Scotland has been linked to changes in temporally variable parameters, prey availability and depth and topography (Evans and Waggit, 2023). The lesser sandeel *Ammodytes marinus*, a key food source for minke whale, is known to have both spawning and nursery grounds between Scotland and Northern Ireland and significantly higher sighting rates of minke whale occurred in areas of predicted sandeel abundance in August and September(Reeves *et al*., 2002; Anderwald *et al.,*2012).

Minke whale is most commonly seen alone or in small groups (Reeves *et al.*, 2002), and numerous sightings have been reported by the HWDT and Ireland's Marine Atlas (IMA) in the Northern Channel near the Gigha & Tayinloan Port Development (HWDT, 2024; IMA, 2024). The SCANS IV density estimate is 0.0137 minke whale per $km^2$ for survey area CS-F (Gilles *et al.,* 2023).The greatest number of minke whale sightings from dedicated surveys occur in the St George's Channel westwards from Pembrokeshire across the Celtic Deep to County Wexford, and from County Dublin north-eastwards to around the Isle of Man, where sightings of up to > 5 animals per km have been recorded (Evans and Waggit, 2023). A single MU, the CGNS, has been defined for minke whale, with an estimated population of 10,288 animals for the UK portion of the MU (IAMMWG, 2022).

## Other cetaceans

Other cetacean species that may occur within the northern part of the Irish Sea and west coast of Scotland in the North Channel but are less common and not frequently observed within the region are:

- White-beaked dolphin *Lagenorhynchus albirostris;*
- Atlantic white-sided dolphin *Lagenorhynchus acutus;*
- Striped dolphin *Stenella coeruleoalba* – often mistaken with common dolphin *Delphinus delphis;*
- Killer whale Orcinus orca;
- Long-finned pilot whale *Globicephala melas;*

- Humpback whale *Megaptera novaeangliae; and*
- Fin whale *Balaenoptera physalus.*

Specific risk assessments have not been included for these species given the sparsity of data and the low risk of encountering these within the Gigha & Tayinloan Port Development. It is considered good practice to have a Marine Mammal Observer (MMO) onboard during noise-emitting survey/construction activities so that commencement of activities may be delayed if any marine mammal species is present. All sightings will be logged with species identification recorded and such data will contribute to the evidence-base for the marine mammal baseline.

#### Leatherback turtle

Leatherback turtle *Dermochelys coriacea* have been sighted in Scottish waters between June and October and in the Irish Sea between July and September (Pierpoint, 2000; O'Reilly *et al.,* 2024). A total of 286 leatherback turtles have been recorded around the coasts of Scotland, with more frequent individuals along the western coast with 20 records in the Clyde Sea Area (O'Reilly *et al.,* 2024). More recently, Hanley *et al*. (2013) recorded 16 leatherback turtles in Manx waters between 2001 and 2011. There are also accepted visual observation records of leatherback turtles in the North Channel as well as in the south west Hebrides and near the west coast of the Isle of Arran, recorded through citizen science and compiled in the National Biodiversity Network (NBN) atlas (NBN, 2023). This shows some recordings of the species within 50 km from the Project.

Generally, leatherback turtle occurrence in western Scotland is considered rare (O'Reilly *et al.,* 2024), typically occurring as a result of a current taking them off their usual route. Due to their rare incidence, marine turtles will not be considered further in this risk assessment.

However, should any marine turtles be encountered during the survey works, best practice should be followed including:

- Following the UK Turtle Code, which gives guidance on how to report, approach, handle and rescue individuals (Marine Conservation Society, 2023).

### 3.1.2 Pinnipeds

#### Harbour seal

Harbour seal *Phoca vitulina*, often referred to as the common seal, is widely distributed across the Northern Hemisphere and British Isles. Their densities are found to be substantially higher near to haul-out areas and sites of approximately 30 m water depth (Aarts *et al.*, 2016).

Thompson *et al*. (2019) estimated the population sizes of harbour seals at haul-out locations in the UK during their annual moult and found clear evidence of their presence in near to the Gigha & Tayinloan Port Development, in the Sound of Gigha. There are known haul-out sites with large numbers (>1000 animals) in the southern parts of the Isle of Islay, and the 2011 to 2016 haul out count in the West Scotland SMU (in which Gigha & Tayinloan Port Development lies) was 15,184 animals (Thompson *et al.,* 2019). The presence of harbour seals in the inshore areas of the Gigha & Tayinloan Port Development are also reported (Ocean Ecology, 2022). There is an abundance of suitable haul-out areas and breeding colony sites in the seas of west Scotland (highlighted in Figure 1.2), such as Craighouse Small Isles & Lowlandman's Bay which is the nearest harbour seal haul-out site at approximately 24 km, and similarly Sanda & Sheep Island at approximately 58 km away from Gigha & Tayinloan Port Development which is designated for both harbour and grey seals (Scottish Government's Marine Directorate, 2019). Other sites of importance for seals include the Seal Conservation Area (designated under the Marine Scotland Act) of the Western Isles, which is approximately 153 km from Gigha & Tayinloan Port Development. Given the proximity of these protected areas, including the South-East Islay Skerries SAC which is designated for this species, it is considered likely that this species will be encountered during survey works.

Recent population estimates for harbour seal in the West Scotland seal MU, in which the Gigha & Tayinloan Port Development is located, is 21,666 (calculated from the most recent August counts between 2016 – 2021) (SCOS2022). Carter *et al.* (2022) estimated numbers of at-sea harbour seals in 5x5 km grid cells, based on haul-outs in the British Isles with the latest density estimate of at-sea harbour seals within the vicinity of the Gigha & Tayinloan Port Development being 0.2525 harbour seal per km$^2$.

### Grey seal

Grey seal *Halichoerus grypus* is found in coastal waters around the UK and northern Europe, mainly inhabiting the exposed rocky northern and western coasts of Scotland, Ireland and Wales (Marlin, 2024). The population of the British Isles represents about 38% of the world population (Carter *et al.,* 2019), of which 90% breed in Scotland (Duck, 2002 cited in Marlin, 2024). Like harbour seals they are known to be active and have been recorded around the Isle of Gigha (Ocean Ecology, 2022) with seal haul-out sites and breeding colony sites in the seas of west Scotland (Figure 1.2). These include Nave Island which is nearest haul-out site approximately 57 km for grey seals, and similarly Sanda & Sheep Island at approximately 58 km away from Gigha & Tayinloan Port Development which is designated for both harbour and grey seals (Scottish Government's Marine Directorate, 2019). Other sites of importance for seals include the Seal Conservation Area (designated under the Marine Scotland Act) of the Western Isles, which is approximately 153 km from Gigha & Tayinloan Port Development.

Recent estimated population for grey seal is 16,596 within the West Scotland seal MU (based on counts from August 2018 from SCOS, 2022), which is used for the purposes of this assessment. As discussed for harbour seals Carter *et al.* (2022) estimated numbers of at-sea grey seals in 5x5 km grid cells (25 km$^2$), based on haul-outs in the British Isles with the latest density estimate of at-sea grey seals within the vicinity of the Gigha & Tayinloan Port Development coming to 0.5144 animals per km$^2$.

### 3.1.3 Basking shark

Estimating the abundance of marine species like basking shark *Cetorhinus maximus* can be challenging due to the migratory patterns and home range of this species. Basking shark is found in the Irish Sea and individuals have been observed on the surface in summer and spring months near to the Isle of Man and further north in west Scotland, with the species typically undergoing a north-south migration through the Irish Sea ((Sims *et al.*, 2008); Wilson *et al*., 2020). Large numbers of basking shark are known to aggregate around Tiree, Coll and the Skerryvore reefs (Marine Scotland, 2024), with the areas widely considered hotspots.

Marine Scotland (2024) modelling based on Paxten *et al.* (2014) provides an estimated density of basking shark in the approximate area of the Gigha & Tayinloan Port Development of 0.1-0.2 animals per km$^2$ for sightings data between 2000-2012.

## 3.2 Designated sites

Relevant designated sites identified in the vicinity of the survey area are shown in Table 3.2 and Figure 3.1. The underwater noise modelling results (section 4.2 and Appendix A) indicate that the largest potential Zone of Influence (ZoI) exists to a radius of 4.7 km from the source (i.e. the survey vessel). All designated sites identified in Table 3.2 and Figure 3.1 are located beyond 5 km from the Gigha & Tayinloan Port Development, the closest designated site being the Inner Hebrides and Minches (Special Area of Conservation (SAC)) designated for harbour porpoise.

**Table 3.2: List of designated sites within 100 km of Gigha & Tayinloan Port Development with relevant protected features.**

| Designated Site | Species (Annex II species - primary reason for designation of site) | Distance to Gigha (km) (marine route) | Distance to Tayinloan (km) (marine route) |
|---|---|---|---|
| Inner Hebrides and the Minches SAC | Harbour porpoise (VHF) | 6.3 | 7.8 |
| South-East Islay Skerries SAC | Harbour seal (PCW) | 20.8 | 21.5 |
| Eileanan agus Sgeiran Lios mor SAC | Harbour seal (PCW) | 91.2 | 93.4 |

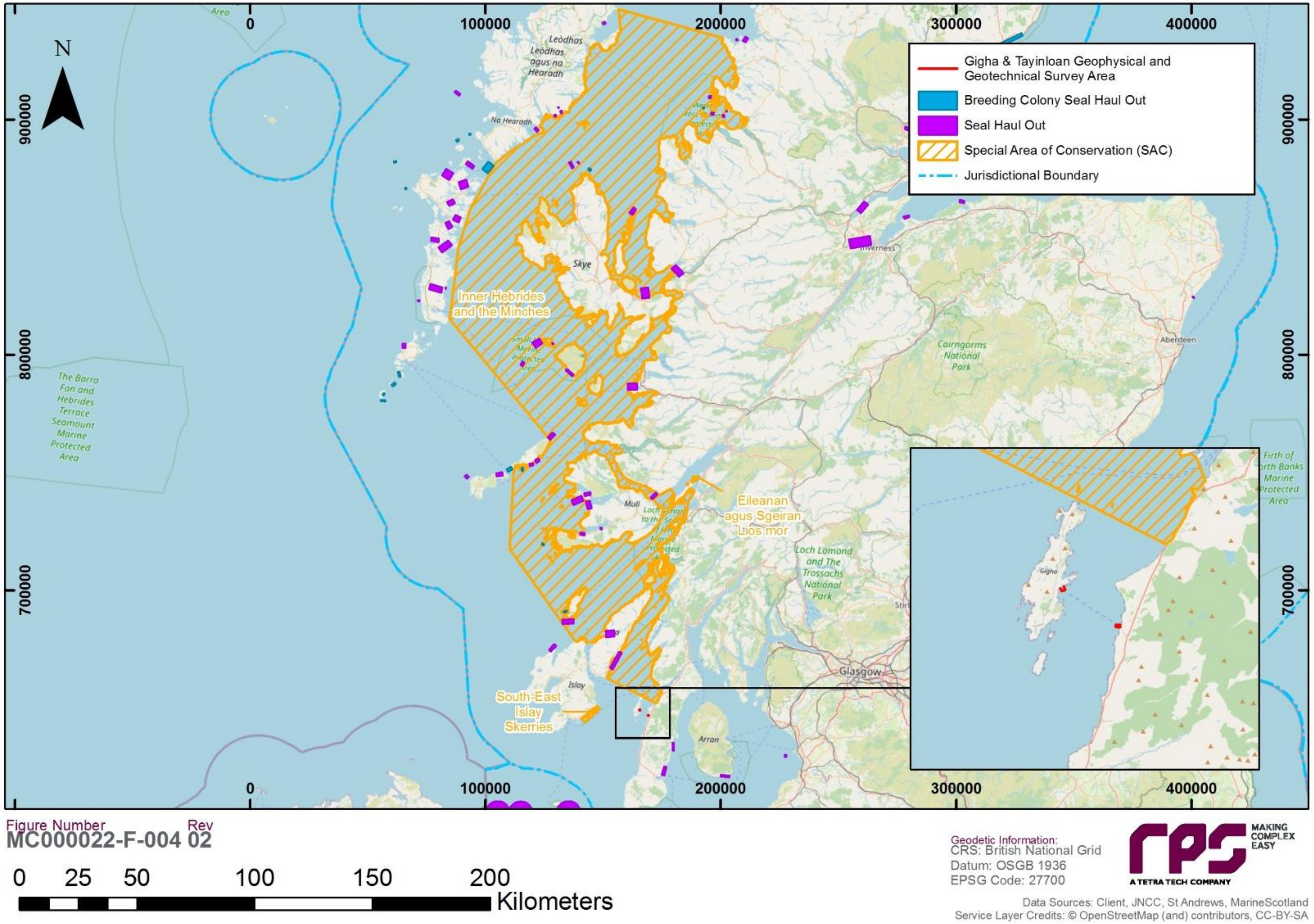


**Figure 3.1: Relevant designated sites within 100 km of the Gigha & Tayinloan Port Development.**

# 4 RISK ASSESSMENT

Anthropogenic underwater noise is readily transmitted into the underwater environment and has the potential to adversely affect marine mammals and basking shark (Richardson, *et al.,* 2013). In particular, cetaceans are capable of generating and detecting sound, and depend on sound for feeding, predator avoidance, communication and navigation (Bailey *et al.,* 2010). Five zones of noise influence have been described by Richardson and Würsig (1997), which vary with the distance from the source (see Appendix A):

- The zone of audibility;
- The zone of masking;
- The zone of responsiveness;
- The zone of temporary hearing loss, this hearing loss is typically classified as a Temporary Threshold Shift (TTS);
- The zone of injury / permanent hearing loss, this hearing loss is typically classified as a Permanent Threshold Shift (PTS).

At close range to a high-level noise source, permanent or temporary hearing damage may occur in marine species, while at very close range gross physical trauma and even death is possible. At long ranges (several kilometres) the introduction of any additional noise could, for the duration of the activity, potentially cause behavioural changes, for example changes in the ability of species to communicate and to determine the presence of predators, food, underwater features, and obstructions.

This assessment considers the zones of auditory injury and disturbance with the relevant thresholds for the onset of effects, compared to the modelled noise level of the geophysical and geotechnical survey. Sound generated by geophysical and geotechnical surveys can be a major contributor to low frequency sound within the hearing ranges of some marine mammals, and therefore has the potential to impact some species (NRW, 2020). Compared to studies on the effects of seismic surveys (which generally employ airguns for oil and gas exploration purposes), there is a comparative evidence-gap on the effects from geophysical surveys. However, similarities are often drawn given the impulsive nature of both types of surveys. The species' at risk from the noise generated by geophysical and geotechnical surveys are outlined in section 3, and the potential impacts to these species are described in section 4.3. These are based on the Southall *et al.,* (2019), Popper *et al.,* (2014) and NOAA (2018) framework for assessing impact from noise on marine mammals and fish.

The primary purpose of the underwater noise risk assessment is to predict the likely range of onset for potential physiological and behavioural effects due to increased anthropogenic noise as a result of the geophysical and geotechnical survey works.

## 4.1 Underwater noise modelling

### Sound sources

The geophysical and geotechnical surveys, and vessels associated with these activities for the Gigha & Tayinloan Port Development (section 1.3) will produce underwater noise that has the potential to disturb or injure sensitive and protected marine fauna such as EPS, basking shark and seals. A subsea noise assessment (Appendix A) was carried out to predict the ranges of effect from the different noise-producing survey equipment specified by the Client (section 1.4). Industry standard representative geophysical survey equipment criteria were used to inform this assessment, with specifications outlined in Table 4.1.

**Table 4.1: Summary of sound sources and activities included in the subsea noise assessment.**

| Equipment | Source level sound pressure level [SPL] (as used in model) | Primary decidecade bands (-20 dB width) | Source model details | Impulsive/non-impulsive |
|---|---|---|---|---|
| **Geophysical survey equipment** | | | | |
| SSS | 173 dB SPL (Spherical equivalent level) | 400,000-900,000 Hz | Generic SSS from 400-900 kHz. | Impulsive |
| MBES | 203 dB SPL (Spherical equivalent level) | 200,000-400,000 Hz | Based on Reason SeaBat T20-P, but +10 dB to allow for other models. | Impulsive |
| SBP-parametric (P-SBP) | 207 dB SPL | 80,000-125,000 Hz (Primary) 2,000-20,000 Hz (Secondary) | Source level adjusted for sediment effects and beam widths. Based on Innomar Standard, worst-case for shallow water. | Impulsive |
| SBP-chirper/pinger (C-SBP) | 184 dB SPL | 1,600-16,000 Hz | Generic shallow water SBP of chirper/pinger type. Source level adjusted for sediment effects and beam widths. | Impulsive |
| USBL | 195 dB SPL | 20,000-31,500 Hz | Assumes non-hull mounted SSS*, 2 Hz ping rate, ping length 10 ms. | Impulsive |
| **Geotechnical survey equipment** | | | | |
| Survey vessel | 160 dB SPL | 10-12,500 Hz | Based on <30 m generic survey vessel. | Non-impulsive |
| Drilling/coring (rotary/vibro/sonic coring) | 187 dB SPL | 50-16,000 Hz | Based on levels from previous work and Reiser *et al.* (2010) | Non-impulsive |
| **Survey vessels** | | | | |
| Survey vessel | 160 dB SPL | 10-12,500 Hz | Based on <30 m generic survey vessel. | Non-impulsive |

The sound sources assessed were separated into two distinct types:

- Impulsive sounds which are typically transient, brief (less than one second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay American National Standards Institute (ANSI) (ANSI, 1986; National Institute for Occupational Safety and Health (NIOSH), 1998; ANSI, 2005). This category includes sound sources such as seismic surveys, impact piling and underwater explosions.
- Non-impulsive (continuous) sounds which can be broadband, narrowband or tonal, momentary or prolonged, continuous or intermittent and typically do not have the high peak sound pressure with rapid rise/decay time that impulsive sounds do (ANSI, 1995; NIOSH, 1998). This category includes sound sources such as continuous vibro-piling, running machinery, some sonar and vessels.

## Modelling assumptions and approach

The noise modelling assessment predicted the ranges for potential auditory injury (PTS and TTS) and behavioural disturbance for marine mammals, basking shark based on the recommended criteria for the different hearing groups (section 4.2). The assessment criteria used in this assessment were developed based on a review of available evidence including national and international guidance and scientific literature. Results are therefore presented for marine mammals (across a range of hearing groups, see Table 4.3) and for the hearing group 'fish'. The hearing group "fish" includes sharks (including basking shark, see Table 4.3) and are for unweighted received levels assessed against the lowest thresholds for fishes as found in guidance (Popper, *et al.,* 2014).

The propagation and sound exposure calculations were conducted over a range of water column depths in order to determine the likely range for injury and disturbance across the varying conditions in the Gigha & Tayinloan Port Development. It should be noted that direction has a strong bearing on the calculated zones for injury and disturbance because a marine mammal could be directly underneath the sound source for greater distances in deep water compared to shallow water.

As a marine mammal or fish swims away from the sound source, the noise it experiences will become progressively more attenuated. Sound exposure calculations (presented in Appendix A) were used in this assessment to estimate the approximate minimum start distance for a marine mammal in order for it to be exposed to sufficient sound energy to result in the onset of potential injury or to estimate if a set exclusion zone is sufficient for an activity (e.g. will an exclusion zone of 500 m be sufficient to prevent exceeding a limit).

Exposure modelling was based on the simplistic assumptions of:

- a marine mammal swimming at a (conservative) constant speed of 1.5 $ms^{-1}$; and
- a 'fish' (including basking shark) swimming at a (conservative) constant speed of 0.5 $ms^{-1}$,

in a perpendicular direction away from a moving vessel. The real-world situation is more complex, and the animal is likely to move in a more complex manner. Reported swim speeds are summarised in Table 4.2 along with the source papers for the assumptions.

**Table 4.2: Swim speed examples from literature**

| Species | Hearing Group | Swim Speed (m/s) | Source Reference |
|---|---|---|---|
| Harbour porpoise | VHF | 1.5 | Otani *et al.,* 2000 |
| Harbour seal | PCW | 1.8 | Thompson, 2015 |
| Grey seal | PCW | 1.8 | Thompson, 2015 |
| Minke whale | LF | 2.3 | Boisseau *et al.,* 2021 |
| Bottlenose dolphin | HF | 1.52 | Bailey and Thompson, 2010 |
| White-beaked dolphin | HF | 1.52 | Bailey and Thompson, 2010 |
| Basking shark | Fish (unweighted) | 1.0 | Sims, 2000 |
| All other fish groups | Fish (unweighted) | 0.5 | Popper *et al.,* 2014 |
| Sea turtles | Fish (unweighted) | 0.56-0.84 & 0.78-2.8 | (F, et al., 1997; SA, 2002) |

The main assumptions for the validity of the results presented were:

- final equipment configuration is not louder than the presented equipment (Table 4.1).
- increasing the locations sampled would lead to a spread in results resembling a normal distribution, allowing statistical methods to be employed for upper bound estimates ($90^{th}$ percentile estimates).
- the survey vessel will travel at a suitable speed while surveying limited by the acquisition rate of the equipment, here assumed to be a maximum of 5 kn = 2.5 $ms^{-1}$.
- Results are presented here as the geographical "risk range" to an auditory threshold (TTS/PTS/behavioural disturbance). A given risk range specifies the expected range, within which, a receiver would exceed the relevant threshold. Risk ranges are given for the $90^{th}$ percentile value.

No results for assessment against the $L_P$ thresholds are included as for all scenarios modelled the ranges to the threshold were below 10 m.

Results are thus *only* given in relation to the auditory injury (PTS/TTS) thresholds (SEL) and behavioural thresholds (SPL).

Several result types (or 'categories') are presented (see section 4.3) to inform this assessment:

- **"1 second exposure risk range":**
  - This is the range of acute risk of impact from the activity (a one second exposure) and is presented to indicate instantaneous risk and for comparison with other studies.
  - This assumes a stationary animal (during the 1-second exposure) with all equipment operating at full power and does not include a soft start. This category assumed no soft start.
- **"Minimal starting range for a fleeing animal with no soft start ":**
  - The minimal range a fleeing animal needs to start fleeing from to avoid being exposed to noise exceeding its TTS/PTS threshold.
  - Animals move in a straight line away from the source at a constant speed (1.5 m/s for marine mammals, 0.5 m/s for 'fish', including basking shark).
- **"Minimal starting range for a fleeing animal with a 10 min soft start with no SBP and no USBL active":**
  - This category is similar to category "1" but with a soft start where equipment has an 8 to 15 dB lower source level for 10 minutes prior to survey start.
  - The minimal range a fleeing animal needs to start fleeing from to avoid being exposed to noise exceeding its TTS/PTS threshold. Animals move in a straight line away from the source at a constant speed (1.5 m/s for marine mammals, 0.5 m/s for 'fish', including basking shark).
- **"Minimal starting range for a fleeing animal with a 20 min soft start with no SBP and no USBL active":**
  - This category is similar to category "1" but with a soft start where equipment has an 8 to 15 dB lower source level for 20 minutes prior to survey start.
  - The minimal range a fleeing animal needs to start fleeing from to avoid being exposed to noise exceeding its TTS/PTS threshold. Animals move in a straight line away from the source at a constant speed (1.5 m/s for marine mammals, 0.5 m/s for 'fish', including basking shark).
- **"Behavioural response range":**
  - The range at which the behavioural limit for marine mammals (160/120 dB SPL impulsive/non-impulsive) or 'fish' (including basking shark) (150 dB SPL) is exceeded.

## 4.2 Impacts of underwater noise

The following section assesses the potential impacts on the relevant EPS, basking sharks and seals from sound produced during the Gigha & Tayinloan Port Development geophysical and geotechnical surveys (see section 4.3). The introduction of additional man-made sound has the potential to result in disturbance or injury, by affecting an animal's ability to feed, avoid predators, communicate, and navigate the marine environment (Nieukirk *et al.,* 2004; Richardson, *et al*., 2013). The impacts include short-term behavioural changes, temporary or permanent auditory damage, and mortality (Southall *et al*., 2019). However, if the frequency resulting from the underwater sound source does not exceed the hearing thresholds of the marine species, they may not experience any effect from this exposure (Carroll *et al.,* 2017). The assessment considers the impact ranges around the vessel and the geophysical survey equipment (rather than the entire survey area). Further details on the approach to underwater noise modelling is detailed in Appendix A.

### Hearing sensitivity

#### Marine mammals

Hearing sensitivity varies between marine mammals and fish, and therefore they have varying sensitivities to noise and susceptibility to noise-induced impacts (NOAA, 2018). Moreover, their reactions to sound have been shown to depend on sound source level, propagation conditions, ambient noise and individual differences (such as age, sex, habitat and previous habituation to noise) (Richardson *et al.,* 1995).

In order to assess the impacts of underwater noise on these species, they are classed into functional hearing groups (Southall *et al*., 2007; Southall *et al.,* 2019). NOAA Fisheries have produced marine mammal acoustic technical guidance, which provides thresholds for the onset of PTS and TTS in marine mammal hearing for all underwater sound sources. These are based on the assumption that, outside of their hearing ranges, it is unlikely that a species will experience an auditory impact.

The hearing weighting function is designed to represent the sensitivity for each group within which acoustic exposures can have auditory effects. The categories include:

- Low Frequency (LF) cetaceans: marine mammal species such as baleen whales (e.g. minke whale);
- High Frequency (HF) cetaceans: marine mammal species such as dolphins, toothed whales, beaked whales and bottlenose whales (e.g. bottlenose dolphin);
- Very High Frequency (VHF) cetaceans: marine mammal species such as true porpoises, river dolphins and pygmy/dwarf sperm whales and some oceanic dolphins, generally with auditory centre frequencies above 100 kHz) (e.g. harbour porpoise);
- Phocid Carnivores in Water (PCW): true seals, earless seals (e.g. harbour seal and grey seal), hearing in air is considered separately in the group Other Marine Carnivores in Air (OCA);
- Other Marine Carnivores in Water (OCA): including otariid pinnipeds (e.g. sea lions and fur seals), sea otters and polar bears; air hearing considered separately in the group OCA; and
- Sirenians: Manatees and dugongs. This group is only represented in the NOAA guidelines.

It should be noted that not all the above categories of marine mammal will be present in the area relevant to the Gigha & Tayinloan Port Development geophysical and geotechnical survey. The classifications of the species likely to be found commonly recorded EPS species in the vicinity of the Gigha & Tayinloan Port Development, according to these criteria is displayed below in Table 4.3.

## Basking shark

Basking shark are a protected marine species which are also considered in this risk assessment. The species are classified by Popper, *et al*., 2014 as group 1 fish (fish with no swim bladder). Basking sharks have only an inner ear and no swim bladder, meaning that they are only sensitive to particle motion (Chapuis *et al*., 2019). Therefore, they are sensitive to low frequency sounds only (between 20 Hz and 1500 Hz), with their hearing sensitivity peaking between 200 and 600 Hz (Carroll, *et al*., 2017) (Table 4.3).

**Table 4.3: Functional marine hearing groups for marine mammals and basking shark potentially present in the survey area. Hearing group classification and estimated auditory band width taken from NOAA Marine Mammal Acoustic Technical Guidance (NOAA, 2018), Southall *et al* (2019) Marine Mammal Noise Exposure Criteria & Popper *et al* (2014).**

| Species | Hearing Group | Estimated auditory bandwidth |
|---|---|---|
| Harbour porpoise | VHF | 275 Hz to 160 kHz |
| Bottlenose dolphin | HF | 150 Hz to 160 kHz |
| Common dolphin | HF | 150 Hz to 160 kHz |
| Risso's dolphin | HF | 150 Hz to 160 kHz |
| Minke whale | LF | 7 Hz to 35 kHz |
| Harbour seal | PCW | 50 Hz to 86 kHz |
| Grey seal | PCW | 50 Hz to 86 kHz |
| Basking shark | Group 1 fish | 20 Hz to 1500 Hz (Peak between 200 and 600 Hz) |

## Assessment Method for Potential Injury

This section summarises the assessment method for potential for injury impacts to species of marine mammal and fish in the survey area. For this study, it is the zones of injury (PTS) that are of primary interest, along with estimates of behavioural impact ranges. The zone of injury in this study is classified as the distance over which a marine mammal can suffer PTS leading to non-reversible auditory injury.

Injury thresholds are based on a dual criteria approach using both un-weighted $L_P$ (maximal instantaneous SPL) and cumulative exposure based on marine mammal hearing weighted sound exposure level (SEL). The hearing weighting function is designed to represent the sensitivity for each group within which acoustic exposures can have auditory effects. To determine the potential spatial range of injury and behavioural change, a review has been undertaken of available evidence, including international guidance and scientific literature.

Both the criteria for impulsive and non-impulsive sound are relevant for this study given the nature of the sound sources used during the survey. The relevant PTS and TTS criteria proposed by Southall *et al.* (2019) are summarised in Table 4.4.

**Table 4.4: PTS and TTS onset acoustic thresholds due to impulsive and non-impulsive sound (Southall *et al*., 2019).**

| Hearing Group | Parameter | Impulsive [dB] | | Non-impulsive [dB] | |
|---|---|---|---|---|---|
| | | PTS | TTS | PTS | TTS |
| Low frequency (LF) cetaceans | $L_P$, (unweighted) | 219 | 213 | - | - |
| | SEL, (LF weighted) | 183 | 168 | 199 | 179 |
| High frequency (HF) cetaceans | $L_P$, (unweighted) | 230 | 224 | - | - |
| | SEL, (HF weighted) | 185 | 170 | 198 | 178 |
| Very high frequency (VHF) cetaceans | $L_P$, (unweighted) | 202 | 196 | - | - |
| | SEL, (VHF weighted) | 155 | 140 | 173 | 153 |
| Phocid carnivores (PCW) pinnipeds | $L_P$, (unweighted) | 218 | 212 | - | - |
| | SEL, (PCW weighted) | 185 | 170 | 201 | 181 |

Basking shark fall into the Popper *et al.,* (2014) classification as a Group 1 fish (fish with no swim bladder). Dual metrics are presented for this hearing group with respect to different physiological injury criteria as set out below (Table 4.5). Further details regarding the injury criteria are presented in section 2.4 of the underwater noise technical report (Appendix A).

**Table 4.5: Criteria for onset acoustic thresholds for Group 1 fish (assigned to basking shark) due to impulsive and non-impulsive sound.**

| Type of animal | | Impulsive [dB] | | | Non-impulsive [dB] | |
|---|---|---|---|---|---|---|
| | Unit | Mortality and potential mortal injury | Recoverable injury (PTS) | TTS | Recoverable injury (PTS) | TTS |
| Fish: no swim bladder (particle motion detection) | SEL | 219[1] | 216[1] | 186[1] | 222 | 210 |
| | $L_P$ | 213[1] | 213[1] | 193[2] | - | - |

[1] (Popper *et al*., 2014)
[2] (Worcester, 2006)
[3] (Washington State Department of Transportation (WSDOT), 2011)

## Assessment method for potential behavioural disturbance

Scientific literature shows that responses to disturbance vary between and within species and depend on the individual characteristics (body size, condition, sex and personality) and extrinsic factors (environmental context, repeated exposure, prior experience and acclimatisation) (Harding, *et al.,* 2019). These factors will affect whether an individual exhibits an aversive response to sound, particularly in an area with high sound levels from to human activities.

Typically, a 'strong disturbance' is one which has the potential to disturb an animal in the wild by causing disruption of behavioural patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering (National Marine Fisheries Service, 2005; JNCC, 2010). The NOAA define strong disturbance in all marine mammals as Level B harassment and for impulsive sound suggests a threshold of 160 dB re 1 µPa (root mean square (rms)) (Table 4.6). This threshold meets the criterion defined by JNCC (2010a) as a 'non-trivial' (i.e. significant) disturbance and is equivalent to the Southall *et al.,* (2007) severity score of five or more on the behavioural response scale. Outside of this threshold, behavioural responses are considered trivial, and unlikely to significantly impact the marine animal, or its population status in the wild. For example, these responses often include minor changes in swimming speed, direction and/or dive profile, modification of vocal behaviour and minor changes to respiratory rate (Southall, *et al.,* 2007). For mild disturbance, a precautionary level of 140 dB re 1 µPa (rms) is used to indicate the onset of low-level marine mammal disturbance effects for all mammal groups for impulsive sound.

For vessel noise (continuous, non-impulsive sound), NOAA (2019) guidance sets the marine mammal level B behavioural disturbance threshold for continuous noise at 120 dB re 1 µPa (rms), which sits approximately mid-way between the range of values identified in Southall *et al*. (2007). Based upon NOAA criteria, disturbance thresholds in this assessment for marine mammals were 120 dB SPL and 160 dB $L_{E\ \text{single impulse}}$ or 1-second $L_E$ for non-impulsive and impulsive sound, respectively (Table 4.6).

Criteria for the onset of behavioural effects for fish were 150 dB SPL for fish with no swim bladder (applied to basking shark) for both impulsive and non-impulsive sound sources. These behavioural changes could include the elicitation of a startle response, disruption of feeding, or avoidance of an area. The underwater noise modelling (see Appendix A) notes that levels exceeding this threshold are not expected to cause direct permanent injury but may indirectly affect the individuals (such as by impairing predator detection) (Hastings, 2002; Worcester, 2006). Note that the non-impulsive threshold can often be lower than ambient noise for coastal waters with some human activity, meaning that response ranges determined using this limit will tend to be higher than actual ranges. In addition, as the levels are unweighted, the ranges will be dominated by low-frequency noise, which is outside the hearing range of most hearing groups.

**Table 4.6: Disturbance criteria for marine mammals used in this study based on NOAA Level B behavioural disruption (NOAA, 2018).**

| Effect | Non-Impulsive Threshold | Impulsive Threshold |
|---|---|---|
| Disturbance (all marine mammals) | 120 dB SPL | 160 dB $L_{E\ \text{single impulse}}$ or 1-second $L_E$ |
| Disturbance (to all fishes, as a proxy for basking shark) | 150 [SPL]* | 160 dB $L_P$ |

*This is based on the impulsive criteria.

## 4.3 Assessment of potential impacts

### Injury

Underwater noise modelling was conducted for the assessment of potential injury for various scenarios for geophysical surveys. For all geophysical survey modelling, the vessel, SSS and MBES are modelled as active (to represent a realistic scenario); only the type of SBP and whether the USBL is active changes between the scenarios modelled. The scenarios include the following:

1. Parametric SBP with active USBL[3] (including SSS, MBES and vessel)
2. Parametric SBP, no USBL (including SSS, MBES and vessel)
3. Chirper/pinger SBP with active USBL[3] (including SSS, MBES and vessel)
4. Chirper/pinger SBP, no USB (including SSS, MBES and vessel)

For PTS, scenario 1 ('Parametric SBP with active USBL (including SSS, MBES and vessel)') is identified as the scenario which presents the greatest risk (i.e. greatest ranges from the source for injury) for all species for geophysical surveys (see Appendix A) and therefore the three remaining scenarios (scenarios 2, 3 and 4) are not discussed further in this context.

For TTS (marine mammals) / recoverable injury ('fish' hearing group), for some hearing groups (LF cetaceans, VHF cetaceans and pinnipeds (PCW)), scenario 3 ('Chirper/pinger SBP with active USBL (including SSS, MBES and vessel)') has been identified as the scenario which presents the greatest risk (i.e. greatest ranges

[3] If the SSS and SBP are hull mounted there is no need for a positioning device (USBL) and this noise source should be removed from consideration

from the source for auditory injury) (see Appendix A). For HF cetaceans and the 'fish' hearing group, scenario 1 ('Parametric SBP with active USBL (including SSS, MBES and vessel) has been identified as the scenario which presents the greatest risk (see Appendix A). As such, scenarios 2 and 4 are not discussed further in this context.

Risk ranges for exceeding PTS (marine mammals) / recoverable injury ('fish' hearing group) and TTS thresholds for all hearing groups during geophysical surveys have been presented in Table 4.7, Table 4.8 and Table 4.9, respectively.

A single underwater noise modelling scenario for geotechnical surveys has been presented which includes the vessel and coring activities. The options proposed for sediment sampling include rotary coring, sonic coring and vibro-coring. Of the three options proposed for sediment sampling, the vibro-coring is the loudest, and has been identified as the scenario which presents the greatest risk (i.e. greatest ranges from the source for injury) for all species for geotechnical surveys (see Appendix A). Risk ranges for exceeding PTS (marine mammals) / recoverable injury ('fish' hearing group) and TTS thresholds for all hearing groups during geotechnical surveys have been presented in Table 4.11 and Table 4.12.

## Geophysical surveys

Instantaneous injury (PTS (marine mammals) / recoverable injury ('fish' hearing group) based on the $L_P$ metric could occur out to a maximum range of 10 m across all hearing groups (Table 4.7). A standard 500 m mitigation zone is recommended for geophysical surveys (JNCC, 2017) and therefore this is determined to be sufficient to reduce the risk of instantaneous injury to negligible for marine mammals, and these ranges would likely result in little to no risk of injury for basking shark. Further details on mitigation are presented in section 4.4.

The underwater noise modelling also presented the risk of injury from cumulative exposure, applying the SEL metric. For marine mammals (PTS) the largest modelled range, not including mitigation, was up to 670 m, for the VHF hearing group (harbour porpoise) (Table 4.7). For all other marine mammal hearing groups maximum PTS ranges, not including mitigation, were 20 m (LF cetaceans), 140 m (HF cetaceans) and 30 m (pinnipeds (PCW)). A soft start can be employed to reduce the range over which the risk of PTS occurs in marine mammals. Table 4.7 demonstrates how a 20 minute soft start would reduce injury ranges (SEL metric) to a maximum of 240 m for harbour porpoise and to less than 10 m for all other marine mammal species (i.e. in line with JNCC guidelines (see section 4.4 for further details). Therefore, by adhering to a soft start of 20 minutes, there is little acute risk for any hearing group to exceed its auditory limits. In addition, marine mammals are very sensitive to noise, including the presence of vessels, and display avoidance movements in response to impulsive noise sources, such as seismic surveys (Thompson, *et al*., 2013). Consequently, it is considered unlikely that an animal would remain in the vicinity of the survey vessel during noise-producing activities. Therefore, these ranges would likely result in little to no risk of injury for marine mammals.

For the 'fish' hearing group (recoverable injury), the largest modelled range, not including mitigation, was 30 m (Table 4.7). Table 4.7 demonstrates how a 20 minute soft start would reduce injury ranges (SEL metric) to less than 10 m for the 'fish' hearing group. Therefore these ranges would likely result in little to no risk of injury for basking shark.

For marine mammals (TTS) the largest modelled range, not including mitigation, was up to 3,700 m, for the VHF hearing group (harbour porpoise) (Table 4.9). For all other marine mammal hearing groups maximum TTS ranges, not including mitigation, were 300 m (LF cetaceans) (Table 4.9), 400 m (HF cetaceans) (Table 4.8) and 330 m (pinnipeds (PCW)) (Table 4.9). A soft start can be employed to reduce the range over which the risk of TTS occurs in marine mammals. Table 4.8 and Table 4.9 demonstrate how a 20 minute soft start would reduce injury ranges (SEL metric) to a maximum of 70 m for HF species and to less than 10 m for all other marine mammal species (i.e. in line with JNCC guidelines (see section 4.4 for further details). For VHF cetacean species (harbour porpoise) the implementation of a soft start does not reduce the risk of TTS to below 500 m, and therefore there is a residual risk of TTS to VHF species. Reiterating however that TTS is a temporary, and reversible impact, and animals are expected to return to their previous baseline state. Table 4.10 demonstrates that the maximum number of harbour porpoise with the potential to experience TTS is nine, which represents 0.0356% of the MU population. For all other hearing groups, for PTS and TTS, less than one animal has the potential to be affected (Table 4.10). Therefore these ranges would likely result in little to no risk of injury for marine mammals.

For the 'fish' hearing group (TTS) the largest modelled range, not including mitigation, was up to 240 m. Table 4.8 demonstrates how a 20 minute soft start would reduce injury ranges (SEL metric) to less than 90 m for the 'fish' hearing group. Therefore these ranges would likely result in little to no risk of injury for basking shark.

**Table 4.7: Risk ranges for exceeding PTS (marine mammals) / recoverable injury ('fish' hearing group) thresholds during geophysical surveys (Parametric SBP and active USBL, SSS, MBES and vessel).**

| Condition | LF [m] | HF [m] | VHF [m] | PCW [m] | 'Fish' [m] |
|---|---|---|---|---|---|
| One second (SEL) | <10 | 10 | 420 | <10 | <10 |
| Fleeing receiver, no soft start (SEL) | 20 | 140 | 670 | 30 | 30 |
| Fleeing receiver, 10 min soft start (SEL) | <10 | <10 | 270 | <10 | <10 |
| Fleeing receiver, 20 min soft start (SEL) | <10 | <10 | 240 | <10 | <10 |
| Peak level ($L_p$) | No results for assessment against the $L_P$ thresholds are included as for all scenarios modelled the ranges to the threshold were below 10 m | | | | |

**Table 4.8: Risk ranges for exceeding the TTS (all hearing groups) threshold during geophysical surveys (Parametric SBP and USBL active, SSS, MBES and vessel).**

| Condition | LF [m] | HF [m] | VHF [m] | PCW [m] | 'Fish' [m] |
|---|---|---|---|---|---|
| One second (SEL) | 10 | 100 | 1500 | 20 | 20 |
| Fleeing receiver, no soft start (SEL) | 260 | 400 | 3500 | 320 | 240 |
| Fleeing receiver, 10 min soft start (SEL) | <10 | 80 | 3500 | <10 | 110 |
| Fleeing receiver, 20 min soft start (SEL) | <10 | 70 | 3500 | <10 | 90 |
| Peak level ($L_p$) | No results for assessment against the $L_P$ thresholds are included as for all scenarios modelled the ranges to the threshold were below 10 m | | | | |

**Table 4.9: Risk ranges for exceeding the TTS (all hearing groups) threshold for all hearing groups during geophysical surveys (Chirper/pinger SBP and USBL active, SSS, MBES and vessel).**

| Condition | LF [m] | HF [m] | VHF [m] | PCW [m] | 'Fish' [m] |
|---|---|---|---|---|---|
| One second (SEL) | 20 | 40 | 1500 | 20 | 10 |
| Fleeing receiver, no soft start (SEL) | 300 | 390 | 3700 | 330 | 150 |
| Fleeing receiver, 10 min soft start (SEL) | <10 | 80 | 3700 | <10 | 90 |
| Fleeing receiver, 20 min soft start (SEL) | <10 | 70 | 3700 | <10 | 90 |
| Peak level ($L_p$) | No results for assessment against the $L_P$ thresholds are included as for all scenarios modelled the ranges to the threshold were below 10 m | | | | |

To demonstrate the efficacy of a 20-minute soft start the numbers of animals potentially affected by PTS and TTS and the corresponding percentage of the relevant MU populations are also presented in Table 4.10. The impact area ($km^2$) has been combined with the density of individuals in the area (individuals per $km^2$) to determine how many animals may be affected by underwater noise from these surveys. As described above, implementation of a 500 m mitigation zone will fully mitigate the risk of PTS for all hearing groups, and will fully mitigate the risk of TTS for all hearing groups other than VHF cetaceans, and therefore it is concluded that no animals will be permanently injured.

**Table 4.10: Maximum number of animals (marine mammals) potentially affected by PTS (marine mammals) / recoverable injury (the 'fish' hearing group) and TTS (all hearing groups) during the proposed geophysical surveys**

NB: For TTS, maximum risk ranges have been drawn from Table 4.8 (scenario 1) and Table 4.9 (scenario 3). For most hearing groups, scenario 3 results in the greatest risk for TTS. Where a "*" is provided in the table below, scenario 1 results in the greatest risk range. For PTS scenario 1 results in the greatest risk for all hearing groups.

[1] Density estimate from Gilles *et al.* (2023
[2] Density estimate from Carter *et al.* (2022)
[3] MU estimate from IAMMWG (2023)
[4] MU estimate from SCOS (2022)

| Species | Density estimate (animals/km$^2$) | Relevant MU | MU population | Threshold | Maximum risk range (km) | | Area of sea affected (km$^2$) | | Number of animals potentially affected | | Proportion of MU population (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | No soft start | With 20 minute soft start | No soft start | With 20 minute soft start | No soft start | With 20 minute soft start | No soft start | With 20 minute soft start |
| Harbour porpoise (VHF) | 0.201[1] | West Scotland | 24,305[3] | PTS (SEL) | 0.67 | 0.24 | 1.41 | 0.1810 | <1 | <1 | 0.0012 | 0.0001 |
| | | | | TTS (SEL) | 3.7 | 3.7 | 43.01 | 43.01 | 9 | 9 | 0.0356 | 0.0356 |
| Bottlenose dolphin (HF) | 0.0425[1] | CWSH | 45[3] | PTS (SEL) | 0.14 | 0.01 | 0.0616 | 0.0003 | <1 | <1 | 0.0058 | 0.00003 |
| | | | | TTS (SEL) | 0.4* | 0.07 | 0.5027 | 0.0154 | <1 | <1 | 0.0475 | 0.0015 |
| Common dolphin (HF) | 0.0544[1] | CGNS | 57,417[3] | PTS (SEL) | 0.14 | 0.01 | 0.0616 | 0.0003 | <1 | <1 | $5.83 \times 10^{-6}$ | $2.98 \times 10^{-8}$ |
| | | | | TTS (SEL) | 0.4* | 0.07 | 0.5027 | 0.0154 | <1 | <1 | 0.000047 | $1.5 \times 10^{-6}$ |
| Risso's dolphin (HF) | 0.0027[1] | CGNS | 8,687[3] | PTS (SEL) | 0.14 | 0.01 | 0.0616 | 0.0003 | <1 | <1 | $1.9 \times 10^{-6}$ | $9.8 \times 10^{-9}$ |
| | | | | TTS (SEL) | 0.4* | 0.07 | 0.5027 | 0.0154 | <1 | <1 | 0.00001 | $4.8 \times 10^{-7}$ |
| Minke whale (LF) | 0.0137[1] | CGNS | 10,288[3] | PTS (SEL) | 0.02 | 0.01 | 0.0013 | 0.0003 | <1 | <1 | $1.7 \times 10^{-7}$ | $4.2 \times 10^{-8}$ |
| | | | | TTS (SEL) | 0.26 | 0.01 | 0.2124 | 0.0003 | <1 | <1 | 0.00028 | $4.2 \times 10^{-8}$ |
| Grey seal (PCW) | 0.5144[2] | West Scotland | 16,596[4] | PTS (SEL) | 0.03 | 0.01 | 0.0028 | 0.0003 | <1 | <1 | $8.76 \times 10^{-6}$ | $9.7 \times 10^{-7}$ |
| | | | | TTS (SEL) | 0.33 | 0.01 | 0.3421 | 0.0003 | <1 | <1 | 0.0011 | $9.7 \times 10^{-7}$ |
| Harbour seal (PCW) | 0.2525[2] | West Scotland | 21,666[4] | PTS (SEL) | 0.03 | 0.01 | 0.0028 | 0.0003 | <1 | <1 | $3.3 \times 10^{-6}$ | $3.7 \times 10^{-7}$ |
| | | | | TTS (SEL) | 0.33 | 0.01 | 0.3421 | 0.0003 | <1 | <1 | 0.00039 | $3.7 \times 10^{-7}$ |

## Geotechnical surveys

A single scenario for geotechnical surveys was modelled, assuming that the vessel, rotary coring, sonic coring and vibro-coring are all active concurrently.

For PTS (marine mammals) / recoverable injury (the ‘fish’ hearing group) for all hearing groups, all modelled risk ranges were less than 10 m (Table 4.11), and therefore there is considered to be little to no risk of injury for all EPS and basking shark. Further details on mitigation are presented in section 4.4.

For marine mammals (TTS) the maximum modelled range was for VHF cetacean species at 1,200 m (Table 4.12). For all other marine mammal hearing groups maximum TTS ranges were 50 m (LF cetaceans), <10 m (HF cetaceans) and 20 m (pinnipeds (PCW)). For VHF cetacean species (harbour porpoise) risk ranges are greater than 500 m, and therefore there is a residual risk of TTS to VHF species. However TTS is a temporary, and reversible impact, and animals are expected to return to their previous baseline state. Table 4.13 demonstrates that the maximum number of harbour porpoise with the potential to experience TTS is less than one, which represents 0.0037% of the MU population. For all other hearing groups, for PTS and TTS, less than one animal has the potential to be affected (Table 4.13). Therefore these ranges would likely result in little to no risk of injury for marine mammals.

For the ‘fish’ hearing group (TTS) the largest modelled range, not including mitigation, was less than 10 m. Therefore these ranges would likely result in little to no risk of injury for basking shark.

**Table 4.11: Risk ranges for exceeding the PTS (marine mammals) / recoverable injury (the ‘fish’ hearing group) threshold during geotechnical surveys**

| Condition | LF [m] | HF [m] | VHF [m] | PCW [m] | ‘Fish’ [m] |
|---|---|---|---|---|---|
| One second | No results for assessment against the $L_P$ thresholds are included as for all scenarios modelled the ranges to the threshold were below 10 m | | | | |
| Fleeing receiver, no soft start | | | | | |
| Peak level ($L_p$) | | | | | |

**Table 4.12: Risk ranges for exceeding the TTS (all hearing groups) threshold for during geotechnical surveys**

| Condition | LF [m] | HF [m] | VHF [m] | PCW [m] | ‘Fish’ [m] |
|---|---|---|---|---|---|
| One second | <10 | <10 | 20 | <10 | <10 |
| Fleeing receiver, no soft start | 50 | <10 | 1,200 | 20 | <10 |
| Peak level ($L_p$) | No results for assessment against the $L_P$ thresholds are included as for all scenarios modelled the ranges to the threshold were below 10 m | | | | |

The numbers of marine mammals potentially affected by PTS and TTS and the corresponding percentage of the relevant MU populations are also presented in Table 4.13. The impact area ($km^2$) has been combined with the density of individuals in the area (individuals per $km^2$) to determine how many animals may be affected by underwater noise from these surveys. As described above, there is considered to be little to no risk that animals will be permanently injured.

**Table 4.13: Maximum number of animals (marine mammals) potentially affected by PTS (marine mammals) / recoverable injury ('fish' hearing group) and TTS during the proposed geotechnical surveys.**

[1] Density estimate from Gilles *et al.* (2023
[2] Density estimate from Carter *et al.* (2022)
[3] MU estimate from IAMMWG (2023)
[4] MU estimate from SCOS (2022)

| Species | Density estimate (animals/km²) | Relevant MU | MU population | Threshold | Maximum risk range (km) | Area of sea affected (km²) | Number of animals potentially affected | Proportion of MU population (%) |
|---|---|---|---|---|---|---|---|---|
| | | | | | No soft start | No soft start | No soft start | No soft start |
| Harbour porpoise (VHF) | 0.201[1] | West Scotland | 24,305[3] | PTS (SEL) | 0.01 | 0.0003 | <1 | $2.6 \times 10^{-7}$ |
| | | | | TTS (SEL) | 1.2 | 4.524 | <1 | 0.0037 |
| Bottlenose dolphin (HF) | 0.0425[1] | CWSH | 45[3] | PTS (SEL) | 0.01 | 0.0003 | <1 | 0.000030 |
| | | | | TTS (SEL) | 0.01 | 0.0003 | <1 | 0.000030 |
| Common dolphin (HF) | 0.0544[1] | CGNS | 57,417[3] | PTS (SEL) | 0.01 | 0.0003 | <1 | $2.98 \times 10^{-8}$ |
| | | | | TTS (SEL) | 0.01 | 0.0003 | <1 | $2.98 \times 10^{-8}$ |
| Risso's dolphin (HF) | 0.0027[1] | CGNS | 8,687[3] | PTS (SEL) | 0.01 | 0.0003 | <1 | $9.8 \times 10^{-9}$ |
| | | | | TTS (SEL) | 0.01 | 0.0003 | <1 | $9.8 \times 10^{-9}$ |
| Minke whale (LF) | 0.0137[1] | CGNS | 10,288[3] | PTS (SEL) | 0.01 | 0.0003 | <1 | $4.18 \times 10^{-8}$ |
| | | | | TTS (SEL) | 0.05 | 0.0079 | <1 | $1.05 \times 10^{-6}$ |
| Grey seal (PCW) | 0.5144[2] | West Scotland | 16,596[4] | PTS (SEL) | 0.01 | 0.0003 | <1 | $9.64 \times 10^{-7}$ |
| | | | | TTS (SEL) | 0.02 | 0.0013 | <1 | $3.89 \times 10^{-6}$ |
| Harbour seal (PCW) | 0.2525[2] | West Scotland | 21,666[4] | PTS (SEL) | 0.01 | 0.0003 | <1 | $3.66 \times 10^{-7}$ |
| | | | | TTS (SEL) | 0.02 | 0.0013 | <1 | $1.46 \times 10^{-6}$ |

## Behavioural disturbance

### Geophysical and geotechnical surveys

For geophysical surveys, as per the assessment of injury, modelling was conducted for four scenarios. The scenario which results in the greatest ranges for behavioural disturbance in Scenario 1 (Parametric SBP with active USBL (including SSS, MBES and vessel) (see Table 4.14 for risk ranges). For geotechnical surveys, as per the assessment of injury, a single scenario for geotechnical surveys was modelled, assuming that the vessel, rotary, sonic and vibro-coring are all active (see Table 4.14 for risk ranges).

For marine mammals, maximum predicted behavioural risk ranges from impulsive noise are 4,300 m for geophysical surveys and 4,700 m for geotechnical surveys. For the 'fish' hearing group, maximum predicted behavioural risk ranges are 670 m for geophysical surveys and 290 m for geotechnical surveys.

There are limited studies directly investigating the temporary disturbance impacts from impulsive noise sources from geophysical surveys. However, there are an abundance of studies on the effects of multi-array seismic surveys on marine mammals which can be useful in supporting predictions of behavioural responses of marine mammals to geophysical survey sources in general, given the overlap of parameters that typically characterise sound sources (i.e. transmission frequency, source level, pulse duration); these findings are summarised below.

Temporary disturbance may have implications on survival and fitness and population-level consequences, particularly for species such as harbour porpoise, which have been shown to forage almost constantly (24 hours a day) to meet their high energy and metabolic requirements, and therefore may be more vulnerable to anthropogenic disturbance (Wisniewska *et al*., 2016). However, several studies suggest that to some extent, marine mammals would be able to adapt their behaviour to reduce impacts on survival and reproduction rates and tolerate elevated levels of underwater sound during site investigation surveys. Marine mammals are also deemed to have a high tolerance to behavioural disturbance, and studies suggest that disturbance is unlikely to be ecologically significant for marine mammals.

For example, harbour porpoise behavioural responses were investigated in response to a commercial two-dimensional seismic airgun survey in the North Sea, conducted over 10 days using an airgun array (impulsive sound source). The results demonstrated that prolonged survey noise did not lead to broad scale displacement of harbour porpoise (Thompson *et al.,* 2013). Furthermore, Nabe-Nielsen *et al.* (2014) found that in response to noise from wind turbines and ships, the impacts on harbour porpoise were minor, and sound was found to have no effect on the survival or resilience of the population. Furthermore, a study by Sarnocińska *et al.* (2020) indicated that although there was temporary displacement and change in harbour porpoise echolocation behaviour in response to a 3D seismic survey, prolonged use of seismic survey sound did not lead to broader-scale displacement into higher-risk habitats. Similar conclusions were also drawn from a ten-month study of overt responses to seismic exploration in humpback whale, sperm whale (*Physeter macrocephalus*) and Atlantic spotted dolphin (*Stenella frontalis*), which demonstrated no evidence of prolonged or large-scale displacement of these mammal species from the region during the survey (Weir, 2008). A study by Kates Varghese *et al*. (2020) on behavioural responses specifically to MBES surveys found that the only marine mammal metric that changed was vocalisation rate and concluded that these changes in behaviour were unlikely to be biologically significant. In addition, the marine mammal species assessed are mobile species, and likely to move away from loud sound sources.

Under the JNCC *et al.,* (2010) guidance these geophysical and geotechnical survey works are considered to be a 'trivial' disturbance (unlikely to result in population-level effects). Whilst the implementation of standard mitigation procedures (i.e. a 500 m mitigation zone) is implemented to reduce the risk of injury to marine mammals, this will also contribute to reducing the risk of disturbance. Under the Marine Scotland (2020) guidance there is, however, a remaining risk of disturbance to EPS in inshore Scottish waters. As the modelled behavioural response range for marine mammals cannot be fully mitigated, an assessment against the three EPS licencing tests is required (section 5).

Risk ranges for geophysical and geotechnical surveys are presented in Table 4.14. The numbers of marine mammals with the potential to be disturbed by geophysical surveys is presented in Table 4.15, and the numbers of marine mammals with the potential to be disturbed by geotechnical surveys is presented in Table 4.16.

**Table 4.14: Maximum risk ranges for exceeding behavioural thresholds for all hearing groups for geophysical surveys (Parametric SBP and active USBL, SSS, MBES and vessel) and geotechnical surveys (vessel, rotary coring, sonic coring and vibro-coring).**

| Survey type | LF, HF, VHF and PCW [m] | Fish [m] |
|---|---|---|
| Geophysical survey (Parametric SBP with active USBL (including SSS, MBES and vessel) | 4,300 | 670 |
| Geotechnical survey (vessel, rotary coring, sonic coring and vibro-coring) | 4,700 | 290 |

**Table 4.15 Maximum number of animals (marine mammals) potentially affected by disturbance during geophysical surveys (Parametric SBP and active USBL, SSS, MBES and vessel).**

[1] Density estimate from Gilles *et al.* (2023
[2] Density estimate from Carter *et al.* (2022)
[3] MU estimate from IAMMWG (2023)
[4] MU estimate from SCOS (2022)

| Species | Density estimate (animals/km$^2$) | Relevant MU | MU population | Maximum disturbance range (km) | Area of sea affected (km$^2$) | Number of animals potentially affected | Proportion of MU population (%) |
|---|---|---|---|---|---|---|---|
| Harbour porpoise (HVF) | 0.201[1] | West Scotland | 24,305[3] | 4.3 | 58.088 | 12 | 0.048 |
| Bottlenose dolphin (HF) | 0.0425[1] | CWSH | 45[3] | 4.3 | 58.088 | 3 | 5.48 |
| Common dolphin (HF) | 0.0544[1] | CGNS | 57,417[3] | 4.3 | 58.088 | 4 | 0.005 |
| Risso's dolphin (HF) | 0.0027[1] | CGNS | 8,687[3] | 4.3 | 58.088 | <1 | 0.002 |
| Minke whale (LF) | 0.0137[1] | CGNS | 10,288[3] | 4.3 | 58.088 | <1 | 0.008 |
| Grey seal (PCW) | 0.5144[2] | West Scotland | 16,596[4] | 4.3 | 58.088 | 30 | 0.180 |
| Harbour seal (PCW) | 0.2525[2] | West Scotland | 15,600[4] | 4.3 | 58.088 | 15 | 0.068 |

**Table 4.16: Maximum number of animals (marine mammals) potentially affected by disturbance during geotechnical surveys (vessel, rotary coring, sonic coring and vibro-coring)**

[1] Density estimate from Gilles *et al.* (2023
[2] Density estimate from Carter *et al.* (2022)
[3] MU estimate from IAMMWG (2023)
[4] MU estimate from SCOS (2022)

| Species | Density estimate (animals/km$^2$) | Relevant MU | MU population | Maximum disturbance range (km) | Area of sea affected (km$^2$) | Number of animals potentially affected | Proportion of MU population (%) |
|---|---|---|---|---|---|---|---|
| Harbour porpoise (VHF) | 0.201[1] | West Scotland | 24,305[3] | 4.7 | 69.40 | 14 | 0.057 |
| Bottlenose dolphin (HF) | 0.0425[1] | CWSH | 45[3] | 4.7 | 69.40 | 3 | 6.55 |
| Common dolphin (HF) | 0.0544[1] | CGNS | 57,417[3] | 4.7 | 69.40 | 4 | 0.007 |
| Risso's dolphin (HF) | 0.0027[1] | CGNS | 8,687[3] | 4.7 | 69.40 | <1 | 0.002 |
| Minke whale (LF) | 0.0137[1] | CGNS | 10,288[3] | 4.7 | 69.40 | <1 | 0.009 |
| Grey seal (PCW) | 0.5144[2] | West Scotland | 16,596[4] | 4.7 | 69.40 | 36 | 0.215 |
| Harbour seal (PCW) | 0.2525[2] | West Scotland | 15,600[4] | 4.7 | 69.40 | 18 | 0.081 |

## Species-specific risk assessment

### Harbour porpoise

The most sensitive species likely to be present in the survey area is the harbour porpoise, which has an estimated auditory band width of 275 Hz to 160 kHz. Thresholds for which injury and behavioural disturbance may be induced are described in Table 4.4 and Table 4.6.

The noise assessment (Appendix A) showed that a harbour porpoise exposed to underwater noise from the geophysical survey equipment has the potential to experience permanent auditory injury (PTS) based on a risk of cumulative exposure (SEL) out to 670 m. The application of a 20 minute soft start would effectively reduce this range to within the 500 m mitigation zone to 240 m (Table 4.7). Recoverable auditory injury (TTS) and fleeing response has the potential to occur out to a maximum distance of 3,700 m (Table 4.9). Behavioural disturbance has the potential to occur out to a maximum distance of 4.3 km (Table 4.14).

The noise assessment (Appendix A) showed that a harbour porpoise exposed to underwater noise from the geotechnical survey equipment may experience auditory injury (PTS) based on a risk of cumulative exposure (SEL) out to 10 m (Table 4.11). Recoverable auditory injury (TTS) and fleeing response has the potential to occur out to a maximum distance of 1,200 m (Table 4.12). Behavioural disturbance has the potential to occur out to a maximum distance of 4.7 km (Table 4.14).

The noise modelling demonstrated that without the implementation of mitigation, less than one harbour porpoise is predicted to have the potential to experience PTS at any one time within the Gigha & Tayinloan Port Development (see Table 4.10 and Table 4.13) for geophysical and geotechnical surveys. Due to the small area over which injury could occur and the low number of animals which may be affected, the risk of injury to harbour porpoise is considered to be negligible. It is likely that animals will be displaced from the area of injury risk prior to commencement of the geophysical and geotechnical surveys due to audio and visual cues from boat movements.

Based on species-specific density estimates, up to nine harbour porpoise (0.0356 of the West Scotland MU) have the potential to experience TTS at any one time within the impact area during the surveys (with or without a 20 minute soft start) as a result of geophysical surveys (Table 4.10). Less than one harbour porpoise has the potential to experience TTS as a result of geotechnical surveys, at any one time (Table 4.13). The number of harbour porpoise with the potential to experience behavioural disturbance is predicted to be up to 12 (0.48% of the West Scotland MU) as a result of geophysical surveys and up to 14 as a result of geotechnical survey (0.057% of the West Scotland MU) (Table 4.15 and Table 4.16).

The proposed mitigation to further reduce the potential for injurious impacts is presented in section 4.4.

Sites designated for harbour porpoise include The Inner Hebrides and the Minches SAC, which lies 6.3 km and 7.8 km from the proposed development areas at Gigha and Tayinloan, respectively (Table 3.2). Harbour porpoise is a wide ranging species and therefore there is potential for animals from this SAC to occur within the Gigha & Tayinloan Port Development.

### Bottlenose dolphin

Thresholds at which injury and behavioural disturbance may be induced in HF cetacean species, such as bottlenose dolphin are described in Table 4.4 and Table 4.6.

The noise assessment (Appendix A) showed that a bottlenose dolphin exposed to underwater noise from the geophysical survey equipment has the potential to experience permanent auditory injury out to 140 m and the application of a 20 minute soft start would effectively reduce this range to less than 10 m (Table 4.7). Recoverable auditory injury (TTS) and fleeing response has the potential to occur out to a maximum distance of 400 m and the application of a 20 minute soft start would effectively reduce this range to 70 m (Table 4.8). Behavioural disturbance has the potential to occur out to a maximum distance of 4.3 km (Table 4.14).

The noise assessment (Appendix A) showed that a bottlenose dolphin exposed to underwater noise from the geotechnical survey equipment has the potential to experience permanent auditory injury out to 10 m (Table 4.11). Recoverable auditory injury (TTS) and fleeing response also has the potential to occur out to a maximum distance of 10 m (Table 4.12). Behavioural disturbance has the potential to occur out to a maximum distance of 4.7 km (see Table 4.14).

Based on species-specific density estimates, less than one bottlenose dolphin has the potential to experience PTS or TTS at any one time within the impact area during the geophysical and geotechnical surveys, with or without a soft start (Table 4.10 and Table 4.13). Due to the small area over which injury could occur and the low number of animals which may be affected, the risk of injury to bottlenose dolphin is considered to be negligible. It is likely that animals will be displaced from the area of injury risk prior to commencement of the geophysical and geotechnical surveys due to audio and visual cues from boat movements. The number of bottlenose dolphin with the potential to experience behavioural disturbance is predicted to be up to three (up to 6.55% of the CGNS MU population) for both geophysical and geotechnical surveys (Table 4.15 and Table 4.16).

The proposed mitigation to further reduce the potential for injurious impacts is presented in section 4.4.

There are no sites designated for bottlenose dolphin within the vicinity of the Gigha & Tayinloan Port Development.

## Common dolphin

Thresholds at which injury and behavioural disturbance may be induced in HF cetacean species, such as the common dolphin are described in Table 4.4 and Table 4.6.

The noise assessment (Appendix A) showed that a common dolphin exposed to subsea noise from the survey equipment would be likely to experience permanent auditory injury out to 140 m and the application of a 20 minute soft start would effectively reduce this range to less than 10 m (Table 4.7). Recoverable auditory injury (TTS) and fleeing response has the potential to occur out to a maximum distance of 400 m and the application of a 20 minute soft start would effectively reduce this range to 70 m (Table 4.8). Behavioural disturbance has the potential to occur out to a maximum distance of 4.3 km (see Table 4.14).

The noise assessment (Appendix A) showed that a common dolphin exposed to underwater noise from the geotechnical survey equipment has the potential to experience permanent auditory injury at 10 m (Table 4.11). Recoverable auditory injury (TTS) and fleeing response also has the potential to occur out to a maximum distance of 10 m (Table 4.12). Behavioural disturbance has the potential to occur out to a maximum distance of 4.7 km (Table 4.14).

Based on species-specific density estimates, less than one common dolphin is predicted to have the potential to experience PTS or TTS at any one time within the impact area during the surveys (with or without a soft start) due to geophysical and geotechnical surveys (Table 4.10 and Table 4.13). Due to the small area over which injury could occur and the low number of animals which may be affected, the risk of injury to common dolphin is considered to be negligible. It is likely that animals will be displaced from the area of injury risk prior to commencement of the geophysical and geotechnical surveys due to audio and visual cues during movement of the boats. The number of common dolphin with the potential to experience behavioural disturbance is predicted to be up to four (up to 0.007% of the CGNS MU population) for both geophysical and geotechnical surveys (Table 4.15 and Table 4.16).

The proposed mitigation to further reduce the potential for injurious impacts is presented in section 4.4.

## Risso's dolphin

Thresholds for at which injury and behavioural disturbance may be induced in HF cetacean species, such as the Risso's dolphin are described in Table 4.4 and Table 4.6.

The noise assessment (Appendix A) showed that a Risso's dolphin exposed to subsea noise from geophysical surveys has the potential to experience permanent auditory injury out to 140 m and the application of a 20 minute soft start would effectively reduce this range to less than 10 m (Table 4.7). Recoverable auditory injury (TTS) and fleeing response has the potential to occur out to a maximum distance of 400 m and the application of a 20 minute soft start would effectively reduce this range to 70 m (Table 4.8). Behavioural disturbance has the potential to occur out to a maximum distance of 4.3 km (see Table 4.14).

The noise assessment (Appendix A) showed that a Risso's dolphin exposed to underwater noise from the geotechnical survey equipment has the potential to experience permanent auditory injury out to 10 m (Table 4.11). Recoverable auditory injury (TTS) and fleeing response also has the potential to occur out to a maximum distance of 10 m (Table 4.12) and behavioural disturbance has the potential to occur out to a maximum distance of 4.7 km (Table 4.14).

Based on species-specific density estimates, less than one Risso's dolphin is predicted to have the potential to experience PTS or TTS at any one time within the impact area during the surveys (with or without a soft start) due to geophysical and geotechnical surveys (Table 4.10 and Table 4.13). Due to the small area over which injury could occur and the low number of animals which may be affected, the risk of injury to Risso's dolphin is considered to be negligible. It is likely that animals will be displaced from the area of injury risk prior to commencement of the geophysical and geotechnical surveys due to audio and visual cues during movement of the boats. The number of Risso's dolphin with the potential to experience behavioural disturbance is predicted to be less than one (up to 0.002% of the CGNS MU population) for both geophysical and geotechnical surveys (Table 4.15 and Table 4.16).

The proposed mitigation to further reduce the potential for injurious impacts is presented in section 4.4.

There are no sites designated for Risso's dolphin within the vicinity of the Gigha & Tayinloan Port Development.

## Minke whale

Thresholds at which injury and behavioural disturbance may be induced in LF cetacean species, such as minke whale are described in Table 4.4 and Table 4.6.

The noise assessment (Appendix A) showed that a minke whale exposed to underwater noise from geophysical surveys has the potential to experience permanent auditory injury out to 20 m and the application of a 20 minute soft start would effectively reduce this range to less than 10 m (Table 4.7). Recoverable auditory injury (TTS) and fleeing response has the potential to occur out to a maximum distance of 300 m and the application of a 20 minute soft start would effectively reduce this range to less than 10 m (Table 4.9). Behavioural disturbance has the potential to occur out to a maximum distance of 4.3 km (Table 4.14).

The noise assessment (Appendix A) showed that a minke whale exposed to underwater noise from the geotechnical survey equipment has the potential to experience auditory injury based on a risk of cumulative exposure (SEL) out to 10 m Table 4.11). Recoverable auditory injury (TTS) and fleeing response also has the potential to occur out to a maximum distance of 50 m (Table 4.12). Behavioural disturbance has the potential to occur out to a maximum distance of 4.7 km (Table 4.14).

Based on species-specific density estimates, less than one minke whale is predicted to have the potential to experience PTS or TTS at any one time within the impact area during the surveys (with or without a soft start) due to geophysical and geotechnical surveys (Table 4.10 and Table 4.13). Due to the small area over which injury could occur and the low number of animals which may be affected, the risk of injury to minke whale is considered to be negligible. It is likely that animals will be displaced from the area of injury risk prior to commencement of the geophysical and geotechnical surveys due to audio and visual cues during movement of the boats. The number of minke whale with the potential to experience behavioural disturbance is predicted to be less than one (up to 0.009% of the CGNS MU population) for both geophysical and geotechnical surveys (Table 4.15 and Table 4.16).

The proposed mitigation to further reduce the potential for injurious impacts is presented in section 4.4.

There are no sites designated for minke whale within the vicinity of the Gigha & Tayinloan Port Development.

## Grey seal

Thresholds at which injury and behavioural disturbance may be induced in pinnipeds are described in Table 4.4 and Table 4.6.

The noise assessment (Appendix A) showed that a grey seal exposed to underwater noise from geophysical surveys has the potential to experience permanent auditory injury out to 30 m and the application of a 20 minute soft start would effectively reduce this range to less than 10 m (Table 4.7). Recoverable auditory injury (TTS) and fleeing response has the potential to occur out to a maximum distance of 330 m and the application of a 20 minute soft start would effectively reduce this range to less than 10 m (Table 4.9). Behavioural disturbance has the potential to occur out to a maximum distance of 4.3 km (Table 4.14).

The noise assessment (Appendix A) showed that a grey seal exposed to underwater noise from the geotechnical survey equipment has the potential to experience auditory injury (PTS) based on a risk of cumulative exposure (SEL) out to 10 m (Table 4.11). Recoverable auditory injury (TTS) and fleeing response has the potential to occur out to a maximum distance of 20 m (Table 4.12). Behavioural disturbance has the potential to occur out to a maximum distance of 4.7 km (Table 4.14).

Based on species-specific density estimates, less than one grey seal is predicted to have the potential to experience PTS or TTS at any one time within the impact area during the surveys (with or without a soft start) due to geophysical and geotechnical surveys (Table 4.10 and Table 4.13). Due to the small area over which injury could occur, low number of animals which may be affected and the mitigation in place (presented in section 4.4) will result in no risk of injury to grey seal and so is considered to be negligible. It is likely that animals will be displaced from the area of injury risk prior to commencement of the geophysical and geotechnical surveys due to audio and visual cues during movement of the boats. The number of grey seal predicted to experience behavioural disturbance as a result of geophysical surveys is 30 (0.180% of the West Scotland MU) (Table 4.15), and as a result of geotechnical surveys is 36 (0.215% of the West Scotland MU),Table 4.16).

There are no SACs designated for grey seal or designated seal haul-outs within the vicinity of the Gigha & Tayinloan Port Development. Given that the impacts of the geophysical and geotechnical surveys are not expected to overlap with either designated haul-out sites or sites designated for grey seal, and it has been concluded that the potential for permanent auditory injury is negligible, it is proposed that a seal licence under the Marine (Scotland) Act 2010 will not be required. As grey seal is on an EPS, this species will therefore not be considered further.

## Harbour seal

Thresholds at which injury and behavioural disturbance may be induced in pinnipeds are described in Table 4.4 and Table 4.6.

The noise assessment (Appendix A) showed that a harbour seal exposed to underwater noise from geophysical surveys has the potential to experience permanent auditory injury out to 30 m and the application of a 20 minute soft start would effectively reduce this range to less than 10 m (Table 4.7). Recoverable auditory injury (TTS) and fleeing response has the potential to occur out to a maximum distance of 330 m and the application of a 20 minute soft start would effectively reduce this range to less than 10 m (Table 4.9). Behavioural disturbance has the potential to occur out to a maximum distance of 4.3 km (Table 4.14).

The noise assessment (Appendix A) showed that a harbour seal exposed to underwater noise from the geotechnical survey equipment has the potential to experience auditory injury (PTS) based on a risk of cumulative exposure (SEL) out to 10 m (Table 4.11). Recoverable auditory injury (TTS) and fleeing response has the potential to occur out to a maximum distance of 20 m (Table 4.12). Behavioural disturbance has the potential to occur out to a maximum distance of 4.7 km (Table 4.14).

Based on species-specific density estimates than one harbour seal is predicted to have the potential to experience PTS or TTS at any one time within the impact area during the surveys (with or without a soft start) due to geophysical and geotechnical surveys (Table 4.10 and Table 4.13). Due to the small area over which injury could occur, low number of animals which may be affected and the mitigation in place (presented in section 4.4) will result in no risk of injury to harbour seal and so is considered to be negligible. It is likely that animals will be displaced from the area of injury risk prior to commencement of the geophysical and geotechnical surveys due to audio and visual cues during movement of the boats. The number of harbour seal predicted to experience behavioural disturbance as a result of geophysical surveys is 15 (0.068% of the West Scotland MU) (Table 4.15), and as a result of geotechnical surveys is 18 (0.081% of the West Scotland MU); Table 4.16).

Sites designated for harbour seal include the South-East Islay Skerries SAC (which lies 20.8 km and 21.5 km from the proposed development areas at Gigha and Tayinloan, respectively) and the Eileanan agus Sgeiran Lios mor SAC (which lies 91.2 km and 93.4 km from the proposed development areas at Gigha and Tayinloan, respectively) (Table 3.2). There is potential for harbour seal associated with the South-East Islay Skerries SAC will occur within the Gigha & Tayinloan Port Development, however given limited foraging ranges of harbour seal, it is less likely that individuals associated with the Eileanan agus Sgeiran Lios mor SAC will occur within the Gigha & Tayinloan Port Development.

Given that the impacts of the geophysical and geotechnical surveys are not expected to overlap with either designated haul-out sites or sites designated for harbour seal, and it has been concluded that the potential for permanent auditory injury is negligible, it is proposed that a seal licence under the Marine (Scotland) Act 2010 will not be required. As grey seal is on an EPS, this species will therefore not be considered further.

### Basking shark

The exact hearing range of basking sharks is unknown, however, five other elasmobranchs have been found to have a hearing range between 20 Hz to 1 kHz with greatest sensitivities at lower frequencies (Mickle *et al.* 2020). Thresholds at which injury and behavioural disturbance may be induced in basking shark have been aligned with Group 1 fish (fish with swim bladder) and are set out in Table 4.5 and Table 4.6.

Based on hearing ranges of other elasmobranchs, it is therefore unlikely this species will be affected by the noise produced during these surveys, especially considering there is no evidence of sound causing mortality or stress in this species. In addition, this species is highly mobile and so significant adverse impacts to this species are considered unlikely. Despite the unlikelihood of being affected by noise, JNCC guidelines and best practice still advise to reduce the pressures associated with acoustic surveys, to ensure to the highest degree of confidence that basking sharks are not disrupted (JNCC 2017).

The noise assessment (Appendix A) showed that a basking shark exposed to underwater noise from the geophysical survey equipment has the potential to experience recoverable injury out to 30 m and the application of a 20 minute soft start would effectively reduce this range to less than 10 m (Table 4.7). TTS has the potential to occur out to a maximum distance of 240 m and the application of a 20 minute soft start would effectively reduce this range to up to 90 m (Table 4.8). Behavioural disturbance range due to geophysical surveys has the potential to occur out to a maximum distance of 670 m (Table 4.14). Species specific densities show that less than one animal has the potential to be within this disturbance range at any one time.

The noise assessment (Appendix A) showed that basking shark exposed to underwater noise from the geotechnical survey equipment has the potential to experience recoverable injury and TTS out to 10 m (Table 4.11 and Table 4.12). Behavioural disturbance due to geotechnical surveys has the potential to occur out to a maximum distance of 290 m (see Table 4.14). Species specific densities show that less than one animal has the potential to be within this disturbance range at any one time.

Whilst mitigation proposed is primarily designed to mitigate for potential impacts to marine mammals, the implementation of a soft start, along with the presence of an MMO and 500 m mitigation zone will also reduce impacts to basking shark (presented in section 4.4).

### Cumulative impacts

Cumulative impacts are those which can occur from survey operations occurring over a similar area at the same time, or operations occurring sequentially, if a receptor is still in recovery (i.e. still recovering from TTS or disturbance), and from numerous simultaneous activities where impacts overlap.

The geophysical and geotechnical activities are due to take place in the Gigha Sound for a maximum of four weeks. The risk assessment concluded that there is no residual risk (following application of mitigation measures) of injury to EPS from this survey alone, and therefore there is considered to be no potential for cumulative impacts.

Whilst the risk assessment predicted a maximum range of 4.7 km for behavioural responses for marine mammals and a maximum ranges of 670 m for behavioural responses for the ‘fish’ hearing group, at any one time, no projects or plans have been identified to overlap geographically or temporally with the Gigha & Tayinloan Port Development. Behavioural disturbance impacts are considered short-term and reversible, and therefore cumulative impacts are not considered further in this assessment.

## Summary of risk of injury and behavioural disturbance

Since the risk of injury can be mitigated effectively through the adoption of a 500 m mitigation zone and a 20 minute soft start (where possible/necessary), see section 4.4), there is considered to be no residual risk of injury to EPS, seals or basking shark.

For disturbance, it is possible that EPS, seals and basking shark may experience some limited behavioural effects. These effects are unlikely to result in any significant disturbance or displacement for these species. In addition, it is expected that, since relevant species are highly mobile, they will be able to adapt their behaviour to reduce effects to some extent, for example through avoidance. However, it is concluded that an EPS Licence for inshore Scottish waters is required in respect of potential disturbance for the proposed geophysical and geotechnical surveys at the Gigha & Tayinloan Port Development.

## 4.4 Mitigation

Mitigation activities will be conducted for geophysical and geotechnical surveys, following JNCC Guidelines (JNCC, 2017). Mitigation measures proposed for the planned geophysical and geotechnical surveys are set out in more detail below.

Unmitigated injury ranges (no soft start) are predicted to occur out to 140 m (PTS) for all hearing groups and 400 m (TTS), other than VHF species (harbour porpoise), where PTS could occur out to 670 m and TTS could occur out to 3,700 m with no soft start. As mentioned previously the application of a 20 minute soft start would effectively reduce the PTS range to 240 m. This falls within the recommended 500 m mitigation zone (JNCC, 2017) and therefore, with standard measures applied (i.e. MMOs, Passive Acoustic Monitoring (PAM) and a 500 m mitigation zone), there would be no residual risk of PTS.

Predicted PTS ranges for the geotechnical surveys do not exceed 10 m (for all hearing groups). It has therefore been concluded that due to the small area over which injury could occur and the low number of animals which may be affected, the risk of injury is considered to be negligible and therefore mitigation in the form of a soft start is not proposed for geotechnical surveys. Standard mitigation measures (MMOs, PAM and a 500 m mitigation zone) will contribute to reducing the risk of TTS as a result of geotechnical surveys.

Further details of measures are described in the following sections.

### Pre-start search

A 30-minute search to establish the presence of marine mammals will be implemented before commencement of geophysical and geotechnical surveys. Dedicated and experienced MMOs/ PAM operatives[4] (potentially dual role for PAM) will operate from the vessel bridge during daylight hours as per current JNCC guidelines (JNCC, 2017). Monitoring will be carried out within the 500 m exclusion zone for marine mammals around all survey equipment to mitigate for predicted PTS ranges for harbour porpoise, from geophysical surveys and to reduce the risk of TTS for all survey equipment.

PAM provides an opportunity to detect and indicate the location of marine mammal vocalisations at sea relative to a hydrophone when visual searching is not possible (i.e. during periods of low visibility or darkness). Marine mammal species are identified by the specific characteristics of the detected click and whistle sounds, the interpretation of which requires a specialised operator. PAM can be used to detect vocalising cetaceans, but it is not applicable for detection of pinnipeds or non-vocalising animals such as basking shark. When conditions are optimal, visual MMO searches are considered to be the most effective monitoring method for marine mammals. PAM should be used as a substitute for visual observations when the full extent of the mitigation zone cannot be seen (JNCC, 2023). JNCC Guidance for The Use of Passive Acoustic Monitoring in UK Waters for Minimising the Risk of Injury to Marine Mammals from Offshore Activities (JNCC, 2023) provides further guidance on specific circumstances when PAM should be utilised.

The MMO/PAM operative(s) will monitor the 500 m mitigation zone and advise if any marine mammals are present within the zone. If marine mammals are detected, the soft-start should be delayed until their passage outside of the mitigation zone and the soft-start should re-commence once 20 minutes have elapsed since the last sighting in the mitigation zone.

It is standard practice for MMOs to transcribe their deck forms and provide a report to the relevant regulatory body (Marine Scotland) and JNCC to encourage assessment of compliance with licence conditions and to ensure the activities minimised the potential for harm. MMO feedback and data improves industry practices and seeks to enhance protection of marine wildlife. The flexibility of the PAM system and ease of deployment/recovery methods will also be considered in relation to existing in-sea equipment to ensure that the PAM system can be used without additional risk to vessel personnel and equipment either during geophysical data acquisition or equipment maintenance schedules during typical line changes or periods of

[4] Note, it is a prerequisite that all MMOs working in the UK Continental Shelf (UKCS) have attended a JNCC-approved course. Whilst some MMO courses may include a basic introduction to acoustic detection techniques, dedicated PAM courses are available, and specialist trained PAM operatives are needed to set up and deploy the equipment and to interpret detected sounds. Newly qualified PAM operators are generally not advised to work in isolation (i.e. they are not the sole PAM operative on board a vessel) for their first five PAM jobs. JNCC guidance states that they should work alongside experienced personnel (with a minimum of 20 weeks of experience) who can act as mentors while they gain experience of deploying PAM and implementing the latest guidelines.

poor weather. If PAM is unavailable and conditions do not permit for successful visual observation, it is generally advised to delay until conditions improve (JNCC, 2023).

It should be noted that PAM in-sea equipment deployment is dependent on operational constraints. PAM will only be deployed when practical during periods of low visibility when MMO visual observation is restricted. JNCC's 2023 guidance on the use of PAM notes that "*while there are benefits to deploying PAM 24-hours a day, real-time monitoring of detections is only needed during the pre-activity search and soft-start (unless specified otherwise in a consent or licence)"*. The Applicant will advise MMOs in the event of any significant periods where PAM is not available. PAM efforts will focus on providing a marine mammal monitoring capability of the area within 500 m of the source array, during the 30-minute monitoring period prior to soft-start at night or during periods of poor visibility.

## Soft start

For geophysical surveys, where equipment allows, a 20-minute soft start period will be employed prior to the start of the survey, during which there will be a gradual build-up (or soft-start) of source power over the 20-minute period with power reduced to 10% of modelled power, as per the soft-start procedures and current JNCC guidelines (JNCC 2017). This soft-start procedure is utilised while commencing underwater activities to gradually increase the sound intensity over a specific period of time and area. Effectively, this procedure aims to deter marine mammals from the surrounding area prior to full volume being reached so that the noise exposure to marine mammals and the associated risk of injury is reduced and/or mitigated. This procedure aims to deter marine animals from the surrounding area prior to full volume being reached so that the noise exposure and associated risk of injury is reduced and/or mitigated. Monitoring for marine mammals within 500 m will still commence 30 minutes prior to the commencement of the soft-start thus there will be circa one hour lead time until the start of data acquisition. Where a soft start is not possible, the presence of the sampling platform (vessel or barge) will itself emit similar noise to the sampling activity and will serve as a type of soft start. In this case, monitoring for marine mammals within 500 m will still commence 30 minutes prior to the start of data acquisition.

## Breaks in operation of survey equipment

For breaks of <10 minutes there is no requirement for soft-start and the survey can recommence at the same source level provided no marine mammals have been detected in the mitigation zone during this break. For breaks of >10 minutes the full mitigation procedure (as described above) will be adopted including pre-survey monitoring and soft-start.

## Summary of mitigation requirements

As described previous the following mitigation measures are proposed for the survey equipment:

- Geotechnical – prestart 30-minute search over 500 m mitigation zone; and
- Geophysical – prestart 30-minute search over 500 m mitigation zone and 20-minute soft start.

# 5 THREE EPS LICENCING TESTS

## 5.1 Test 1: Overriding Public Interest

### Guidance

NatureScot guidance states that under Regulation 44 of the Habitats Regulations certain activities which would normally constitute an offence against European Protected Species (EPS) can be carried out legally under a licence (NatureScot, 2020). There are several different purposes for which a license can be granted including; '*preserving public health or public safety or other Imperative Reasons of Overriding Public Interest (IROPI) including those of a social or economic nature and beneficial consequences of primary importance for the environment*'. Only public interests will be relevant for the Public Interest Test and generally, only when it is a long-term interest. Examples of objectives that the Scottish Government consider to be relevant to meet the Public Interest Test are provided in the Guidance and include:

- Where there is clear and demonstrable direct environmental benefit on a national or international scale;
- Where failure to proceed would have unacceptable social and/or economic consequences; and
- Where the project is of national importance, or, possibly, regional importance.

NatureScot Guidance states that, when determining an EPS Licence application, the licensing authority will take into account whether an activity or development is required to meet, or contribute to meeting, a specific need such as maintaining the health, safety, education or environment of Scotland's people (including sustainable development and renewable or green energy), complying with national planning policies and supporting economic or social development (including nationally important infrastructure development projects and employment) (NatureScot, 2020).

### Policy and legislation

The following paragraphs set out some key policy support for economic development projects in general, and the Gigha & Tayinloan Port Development in particular:

- The UK Marine Policy Statement 2011 (UKMPS) is currently the only marine policy document in effect for the area in which the Gigha & Tayinloan Port Development is situated. It includes a high-level objective of ensuring a strong, healthy and just society, ensuring there is equitable access for those who want to use and enjoy the coast, seas and their wide range of resources and assets. It also recognises that properly planned developments in the marine area can provide environmental and social benefits as well as drive economic development, provide opportunities for investment and generate export and tax revenues. The Gigha & Tayinloan Port Development should allow the operation of berthing and docking a new hybrid/electric ferry, this will undoubtedly contribute to ensuring equitable access, as well as driving economic development, and providing opportunities for investment. These benefits, however, must be weighed against the environmental impacts including the extent to which development will impact on the ecosystem and other activities taking place within the marine environment.
- Scotland's National Marine Plan provides that key priorities under the heading of Shipping, Ports, Harbours and Ferries include: "Sustainable growth and development of ports and harbours as a competitive sector, maximising their potential to facilitate cargo movement, passenger movement and support other sectors; and Safeguarded essential maritime transport links to island and remote mainland communities" (Marine Scotland, 2015). A key priority under the heading of Recreation and Tourism is "Continued and improved access to marine and coastal resources for tourism activities and recreational use*"*. As described above, Gigha & Tayinloan Port Development will meet the priorities of the National Marine Plan by providing the growth and development of the pier, allowing passenger movement of the local community and tourists between the mainland (Tayinloan) and the Island Gigha.

## Purpose of the geophysical and geotechnical surveys

The Scottish Government contributes towards Gigha & Tayinloan Port Development for the ferry services as they are responsible for the delivery of lifeline ferry services in Scotland (Grant Thornton UK LLP, 2010). Transport Scotland objectives include ensuring the maintenance of affordable sea links to and between Scotland's Island communities and to improve the level, quality, and cost-effectiveness of services to rural communities and remote islands. In the Scottish Ferries Review Consultation (Transport Scotland, 2010) Transport Scotland expresses that it aims to meet the European Union requirements including to:

- "*ensure the provision of a suitable standard of transport connection in terms of quality, frequency and capacity, to island (or in some cases remote peninsula) communities which would otherwise suffer social and economic disadvantage;*
- *ensure ferry fares and freight charges are not excessive;*
- *ensure that ferry services are delivered efficiently; and*
- *ensure that the necessary level of service is provided for the minimal amount of public subsidy*".

The aim of Gigha & Tayinloan Port Development – geophysical and geotechnical surveys, is to provide information on the:

- Ground profile for the various elements of the works including its:
  - suitability for piled or ground bearing foundations,
  - suitability for dredging, disposal at sea and/or reuse as fill,
- Profiling the natural deposits at the breakwater extension, overnight berth and within the dredge pocket,
- Bottom profiling to provide updated bathymetry for computational modelling of the baseline environment and proposed development. Informing the impact of the development on hydraulics, sediment transport, waves and harbour disturbance effects.
- Benthic ecology, cultural heritage and contamination for input to environmental assessments.

Therefore, surveys are required for Gigha & Tayinloan Port Development for various purposes, including engineering design and environmental assessments. Several surveys will be executed:

- Bathymetric and SBP Surveys: seabed bathymetry surveys and sub-bottom profiling is required within the development and dredge area to inform engineering design. It is expected that this will be mostly undertaken by MBES and appropriate geophysical survey techniques to capture the level of rockhead, and the nature, thickness and location of the sub surface strata to rockhead.
- Bathymetric Surveys: The seabed bathymetry is required over the larger area to inform the model development for tides, waves, harbour disturbance and sediment transport.
- SSS: SSS surveys are required for cultural heritage environmental assessments (noting that magnetometers are passive equipment, and do not emit noise that would be considered potentially harmful to marine animals).
- Drop Down Video Surveys (DDV) and Report: DDV is required at the seven benthic grab sample locations, to identify the different habitats (noting that there are no noise outputs from this activity that would be considered potentially harmful to marine animals).

If Gigha & Tayinloan Port Development geophysical and geotechnical surveys (the Licensable Operations) do not proceed, Gigha & Tayinloan Port Development would not be able to progress, making it more difficult to ensure that a suitable standard of transport connection in terms of quality, frequency and capacity are operating between Gigha and Tayinloan. This could cause the island community to suffer social and economic disadvantages.

## Conclusions

The Licensable Operations are a solution to a fundamental and essential step required for Gigha & Tayinloan Port Development pier and breakwater. Applying the relevant guidance, it is clear that the development which contribute to economic and social development are specifically recognised by SNH as the types of development which can fulfil the requirements of the Overriding Public Interest Test.

## 5.2 Test 2: No Satisfactory Alternatives

Regulation 44(2) of the Habitat Regulations 1994 requires the regulatory authority to be satisfied that there is no satisfactory alternative before an EPS Licence can be issued for the Licensable Operations. This section provides an assessment of the alternatives that were considered as part of the design of Gigha & Tayinloan Port Development. After consideration of all alternatives, it was concluded that there was no suitable alternative to the survey design proposed (set out in section 1.3).

The following sub-sections summarise the different options that have been considered as alternatives to the proposed Licensable Operations.

### Do nothing

Data collected from the ground investigations and surveys is needed for Gigha & Tayinloan Port Development detailed design to commence. Without the information from the ground investigations, an overly conservative structure would be designed, which would likely occupy a greater footprint and therefore cause greater long term environmental impacts. With the results of the ground investigation, an efficient design can be progressed, informed by the potential environmental impacts - at the earliest possible stage. This allows mitigations to be built into the design from the outset.

Surveys will inform decisions that need to made for Gigha & Tayinloan Port Development including engineering design and environmental assessments (see above) .

### Reprocessing existing data

Existing bathymetric survey data is available in the locality of the slipways at Gigha and Tayinloan. Information is required over a much larger area to inform the hydraulic modelling. This should also be up to date in the area where sub-bottom profiling is proposed, to ensure the survey results are as accurate as possible.

Existing ground investigation data is available at Tayinloan and has been considered in the preliminary design to date, and in the scoping of the proposed investigations. The existing data is not suitable as the sole basis for the design of this project for the following reasons:

- Geoenvironmental testing only remains valid for three years to inform licensing. Further samples and testing will be required to inform the reuse or disposal of any dredged material.
- The previous investigations were designed to inform a smaller scheme, they therefore do not provide adequate information to comply with:
  - Eurocode 7 Geotechnical Design; and
  - BS 6349-1-3 Maritime works - General. Code of practice for geotechnical design.

No existing ground investigation data is available at Gigha. Additional data is therefore required, as described above. Given the poor recovery in the weathered rock from the existing boreholes in Tayinloan, the need for sonic drilling has been established, to gain good quality rock samples for testing and subsequently design of a suitable structure.

### Alternative vessel

All vessels that have been identified for the survey conform to industry and regulatory standards. The proposed vessels will allow both accurate data quality collection and a relatively low impact on the marine environment, given the remote inshore nature of the survey area, and dispersive potential of the associated emissions. The vessels are robust in adverse weather, allowing the survey to be completed in less time than would be possible with a smaller vessel, thereby minimising the potential disturbance on the marine environment by adhering to the shortest possible campaign to achieve the required data acquisition.

### Alternative equipment and parameters

The use of SSS, Magnetometer and DDVo, are the industry standard methodologies for characterising the seabed. High-resolution detail of the seabed including the recording of seabed features or objects is required for cultural heritage and benthic assessments, to ensure the proposed modifications to the ferry terminals have minimal impact of their environs.

The use of MBES and SBP are the industry standard methodologies for obtaining accurate elevations, sub-bottom sediment levels and rock levels in underwater settings. No other equipment (including, for example, pressure transducers) provides the level of accuracy required for the Gigha & Tayinloan Port Development.

All equipment will be operated at the lowest practicable sound levels to minimise disturbance risk and will be operated over the shortest practicable period to obtain the necessary measurements and achieve the survey objectives. The use of SSS, Magnetometer, MBES and SBP are used to generate unique perspectives of the seafloor that cannot be assessed through other technologies such as multi-beam sonar. When used in conjunction with MBES and physical sampling data (from geotechnical surveys) SBP provide a detailed view of the marine geological environment. To further reduce the acoustic properties of the equipment would affect their functionality and capacity to perform the work required.

The use of boreholes and vibrocores (rotary coring, sonic coring and vibro-coring) and grab samples, are the industry standard methodologies for taking physical samples of the seabed and underlying sediment. Samples are required for lab sampling to facilitate chemical and physical analysis, required to identify any potential contamination in the sediments, and their engineering properties. The least intrusive investigations have been utilised, which still provide the required information. For example, in shallow dredge areas, only grab samples are required; where deeper dredge is contemplated deeper samples from vibrocores are needed; and where potentially piled structures are to be located boreholes with rock coring are proposed. The physical sampling has been minimised by utilising the sub-bottom profiling. Sufficient intrusive investigations are proposed to calibrate the SBP, which will then provide an overview of the sub-bottom environment.

### Alternative location, timing and duration

#### General location

Overall, it is not possible to consider an alternative location for the survey. As Gigha & Tayinloan Port Development geophysical and geotechnical surveys relate specifically to the refurbishment of Gigha & Tayinloan Port Development there are no alternative sites to be considered for the project. Gigha Ferry Slipway – Outline Business Case by Mace in 2012 for Argyll and Bute Council details at a more strategic level the location of the project.

#### Timing constraints and considerations

The ground investigations and surveys are planned to commence between March and conclude latest August 2025. The survey duration is estimated to be up to 4 weeks on site, but subject to operational constraints, as well as favourable weather and sea conditions, the contractor/ the applicant will seek to minimise the duration of the survey.

#### Necessity of covering two survey areas

Consideration of the environmental sensitivity of the Gigha and Tayinloan Port Development area was undertaken as part of survey feasibility to minimise interaction with particularly sensitive areas, where applicable. However, the data collected from the geophysical and geotechnical surveys is needed for Gigha & Tayinloan Port Development works to commence. The surveys will inform decisions for Gigha & Tayinloan Port Development including engineering design and environmental assessments.

## 5.3 Test 3: Favourable Conservation Status (FCS)

Regulation 44(3)(b) of the Habitat Regulations 1994 requires the regulatory authority to be satisfied that the licensed activities must not be detrimental to the maintenance of the population of species concerned at FCS in their natural range. The EU Habitats Directive includes the definitions for FCS below:

- the "conservation status" of a species means, *"the sum of the influences acting on the species concerned that may affect the long-term distribution and abundance of its populations* […]";
- the "favourable conservation status" of a species means: *"population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats, and the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future, and there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis*."

The species baseline information of this report (section 3) has identified five species of cetacean (besides those excluded from assessment due to sparsity of evidence) that have the potential to occur in the vicinity of Gigha & Tayinloan Port Development and for which effects from the Licensable Operations must be assessed against FCS. The species to which this licence application applies are:

- Harbour porpoise,
- Bottlenose dolphin,
- Common dolphin,
- Risso's dolphin, and
- Minke whale.

As a licence is also sought under the Wildlife and Countryside Act 1981 (as amended) with respect to potential disturbance to basking shark the assessment has also considered any changes to FCS for this species.

The noise modelling assessment (section 4) determined that a 4.3 km behavioural response range remained for geophysical survey and a 4.7 km behavioural response range remained for geotechnical survey for marine mammals from non-continuous noise that could not be mitigated for. The noise modelling assessment (section 4) determined that a 0.67 km behavioural response range remained for geophysical survey and a 0.23 km behavioural response range remained for geotechnical survey for basking sharks from non-continuous noise that could not be mitigated for.

The aim of this section is to assess the likely impact of this disturbance on the FCS of the above cetaceans and basking shark.

## Harbour porpoise

For geophysical surveys the noise modelling assessment (section 4Appendix A) demonstrated that, for harbour porpoise, without mitigation,  less than one individual has the potential to experience PTS ( 0.0012% of the West Scotland MU). Up to nine individuals may have the potential to experience TTS (recoverable injury) (0.0356% of the West Scotland MU). The likelihood of an animal experiencing PTS or TTS will be reduced with the implementation of mitigation measures as detailed in section 4.4 (JNCC, 2017).

For geotechnical surveys the noise modelling assessment (section 4) demonstrated that, for harbour porpoise, without mitigation, less than one individual has the potential to experience PTS and TTS (up to a maximum of 0.0037% of the West Scotland MU). The likelihood of an animal experiencing PTS or TTS will be reduced with the implementation of mitigation measures as detailed in section 4.4.

Behavioural effects may extend to 4.3 km for geophysical surveys and 4.7 km for geotechnical surveys, resulting in the potential for up to 12 animals (0.048%) and 14 animals (0.057% of the West Scotland MU), respectively, to experience behavioural effects at any one time.

Given that mitigation measures will be implemented to reduce the likelihood of auditory injury, the remaining behavioural effects are predicted to affect very small numbers of animals in the context of the wider population. As such, the regional harbour porpoise population is likely to continue "*maintaining itself on a long-term basis as a viable element of its natural habitats*", as defined by the first FCS test.

The proposed geophysical and geotechnical survey will be short-term, taking place over a maximum of four weeks and will be carried out over a small area (0.0835 $km^2$), with only a small proportion of that total area affected at any one time in the context of the West Scotland MU. The use of geophysical and geotechnical survey equipment is not expected to create a barrier to movement for any EPS and is therefore not expected to reduce the range of the local harbour porpoise population (reported as "Favourable" in the most recent FCS status assessment), with the "*natural range of the species neither being reduced nor likely to be reduced for the foreseeable future*", as defined by the second FCS status test.

Harbour porpoise are highly mobile, utilising habitats over a wide area. Any habitat likely to be affected therefore will constitute a very small proportion of the habitats available to the harbour porpoise population. The survey area is not likely to represent a key habitat in the context of the wider region. As such, it is predicted that the third FCS test, namely that "*there is, and will probably continue to be, a sufficiently large habitat to maintain harbour porpoise populations on a long-term basis*", will be satisfied.

## Bottlenose dolphin

For geophysical surveys the noise modelling assessment (Appendix A section 4) demonstrated that, for bottlenose dolphin, without mitigation, less than one individual has the potential to experience PTS and TTS (up to a maximum of 0.0475% of the CWSH MU). The likelihood of an animal experiencing PTS or TTS will be reduced with the implementation of mitigation measures as detailed in section 4.4 (JNCC, 2017).

For geotechnical surveys the noise modelling assessment (section 4) demonstrated that for bottlenose dolphin, without mitigation, less than one individual has the potential to experience PTS and TTS (up to a maximum of 0.00003% of the CWSH MU). The likelihood of an animal experiencing PTS or TTS will be reduced with the implementation of mitigation measures as detailed in section 4.4.

Behavioural effects may extend to 4.3 km for geophysical surveys and 4.7 km for geotechnical surveys, resulting in the potential for up to three animals (up to 6.55% of the CWSH MU) to experience behavioural effects at any one time.

The geophysical and geotechnical surveys will be short-term, taking place over a maximum of four weeks and will be carried out over a small area (0.0835 km$^2$). Although some animals may be disturbed during the survey, animals are expected to return to the area immediately after the surveys have ceased. On this basis, the proposed geophysical and geotechnical surveys are not anticipated to prevent the bottlenose dolphin population from continuing to "*maintain itself on a long-term basis as a viable element of its natural habitats*", as defined by the first FCS test.

The use of geophysical and geotechnical survey equipment is not expected to create a barrier to movement for any EPS and is therefore not expected to reduce the range of the local bottlenose population (reported as "Favourable" in the most recent FCS status assessment), with the "*natural range of the species neither being reduced nor likely to be reduced for the foreseeable future*", as defined by the second FCS status test.

Bottlenose dolphin have been known to exhibit flexibility in their habitat use and therefore any habitat likely to be affected will constitute a very small proportion of the habitat available to the bottlenose dolphin population. The survey area is not likely to represent a key habitat in the context of the wider region. As such, it is predicted that the third FCS test, namely that "*there is, and will probably continue to be, a sufficiently large habitat to maintain bottlenose dolphin populations on a long-term basis*", will be satisfied.

## Common dolphin

For geophysical surveys the noise modelling assessment (Appendix Asection 4) demonstrated that, for common dolphin, without mitigation, less than one individual has the potential to experience PTS and TTS (up to a maximum of 0.000048% of the CGNS MU). The likelihood of an animal experiencing PTS or TTS will be reduced with the implementation of mitigation measures as detailed in section 4.4 (JNCC, 2017).

For geotechnical surveys the noise modelling assessment (Appendix Asection 4) demonstrated that, for common dolphin, without mitigation, less than one individual has the potential to experience PTS and TTS (up to a maximum of $2.98 \times 10^{-8}$ of the CGNS MU). The likelihood of an animal experiencing PTS or TTS will be reduced with the implementation of mitigation measures as detailed in section 4.4.

Behavioural effects may extend to 4.3 km for geophysical surveys and 4.7 km for geotechnical surveys, resulting in the potential for up to four animals (up to 0.007% of the CGNS MU) to experience behavioural effects at any one time.

Given that mitigation measures will be implemented to avoid auditory injury, the behavioural effects will be spatially limited and are therefore predicted to affect a very small numbers of animals in the context of the wider population. As such, the CGNS common dolphin population is likely to continue "*maintaining itself on a long-term basis as a viable element of its natural habitats*", as defined by the first FCS test.

The proposed geophysical and geotechnical survey will be short-term, taking place over a maximum of four weeks and will be carried out over a small area (0.0835 $km^2$), with only a small proportion of that total area affected at any one time in the context of the CGNS MU (IAMMWG, 2022). The use of geophysical and geotechnical survey equipment is not expected to create a barrier to movement for any EPS and is therefore not expected to reduce the range of the local common dolphin population (reported as "Favourable" in the most recent FCS status assessment), with the "n*atural range of the species neither being reduced nor likely to be reduced for the foreseeable future*", as defined by the second FCS status test.

The common dolphin is a highly mobile and wide-ranging species encountered along the west coast of Scotland, Ireland and to the southwest of England (Reid *et al.*, 2003). Any habitat likely to be affected therefore will constitute a very small proportion of the habitat available to the common dolphin population. The survey area is not likely to represent a key habitat in the context of the wider region. As such, it is predicted that the third FCS test, namely that "*there is, and will probably continue to be, a sufficiently large habitat to maintain common dolphin populations on a long-term basis*", will be satisfied.

## Risso's dolphin

For geophysical surveys the noise modelling assessment (Appendix Asection 4) demonstrated that, for Risso's dolphin without mitigation, less than one individual has the potential to experience PTS and TTS (up to a maximum of 0.00001% of the CGNS MU). The likelihood of an animal experiencing PTS or TTS will be reduced with the implementation of mitigation measures as detailed in section 4.4 (JNCC, 2017).

For geotechnical surveys the noise modelling assessment (Appendix Asection 4) demonstrated that, for Risso's dolphin without mitigation, less than one individual has the potential to experience PTS and TTS (up to a maximum of 9.8 x $10^{-9}$% of the CGNS MU). The likelihood of an animal experiencing PTS or TTS will be reduced with the implementation of mitigation measures as detailed in section 4.4.

Behavioural effects may extend to 4.3 km for geophysical surveys and 4.7 km for geotechnical surveys, resulting in the potential for less than one animal (up to 0.002% of the CGNS MU) to experience behavioural effects at any one time.

Given that mitigation measures will be implemented to avoid auditory injury, the behavioural effects will be spatially limited and are therefore predicted to affect very small numbers of animals in the context of the wider population. As such, the Celtic and Greater North Sea Risso's dolphin population is likely to continue "*maintaining itself on a long-term basis as a viable element of its natural habitats*", as defined by the first FCS test.

The proposed geophysical and geotechnical survey will be short-term, taking place over a maximum of four weeks and will be carried out over a small area (0.0835 $km^2$), with only a small proportion of that total area affected at any one time) in the context of the CGNS MU (IAMMWG, 2022). The use of geophysical and geotechnical survey equipment is not expected to create a barrier to movement for any EPS and is therefore not expected to reduce the range of the local Risso's dolphin population (reported as "Favourable" in the most recent FCS status assessment), with the "*natural range of the species neither being reduced nor likely to be reduced for the foreseeable future*", as defined by the second FCS status test.

The Risso's dolphin is known to be highly mobile and can travel long distances as illustrated by their presence in all temperate and tropical waters around the world. Any habitat likely to be affected therefore will constitute a very small proportion of the habitat available to the Risso's dolphin population. The survey area is not likely to represent a key habitat in the context of the wider region. As such, it is predicted that the third FCS test, namely that "*there is, and will probably continue to be, a sufficiently large habitat to maintain Risso's dolphin populations on a long-term basis*", will be satisfied.

## Minke whale

For geophysical surveys the noise modelling assessment (Appendix A 4) demonstrated that, for minke whale, without mitigation, less than one individual has the potential to experience PTS and TTS (up to a maximum of 0.00028% of the CGNS MU).The likelihood of an animal experiencing PTS or TTS will be reduced with the implementation of mitigation measures as detailed in section 4.4 (JNCC, 2017).

For geotechnical surveys the noise modelling assessment (section 4 Appendix A) demonstrated that, for minke whale, without mitigation, less than one individual has the potential to experience PTS and TTS (up to a maximum of 1.05 x 10-6% of the CGNS MU). The likelihood of an animal experiencing PTS or TTS will be reduced with the implementation of mitigation measures as detailed in section 4.4.

Behavioural effects may extend to 4.3 km for geophysical surveys and 4.7 km for geotechnical surveys, resulting in the potential for less than one animal (up to 0.009% of the CWSH MU) to experience behavioural effects at any one time.

Given that mitigation measures will be implemented to avoid auditory injury, the behavioural effects will be spatially limited and are therefore predicted to affect very small numbers of animals in the context of the wider population. As such, the CGNS minke whale population is likely to continue "*maintaining itself on a long-term basis as a viable element of its natural habitats*", as defined by the first FCS test.

The proposed geophysical and geotechnical survey will be short-term, taking place over a maximum of four weeks and will be carried out over a small area (0.0835 $km^2$), with only a small proportion of that total area affected at any one time) in the context of the CGNS MU (IAMMWG, 2022). The use of geophysical and geotechnical survey equipment is not expected to create a barrier to movement for any EPS and is therefore not expected to reduce the range of the local minke whale population (reported as "Favourable" in the most recent FCS status assessment), with the "*natural range of the species neither being reduced nor likely to be reduced for the foreseeable future*", as defined by the second FCS status test.

The minke whale is known to have a large spatial distribution, undergoing seasonal movements between foraging and breeding grounds. Any habitat likely to be affected therefore will constitute a very small proportion of the habitat available to the minke whale population. The survey area is not likely to represent a key habitat in the context of the wider region. As such, it is predicted that the third FCS test, namely that "*there is, and will probably continue to be, a sufficiently large habitat to maintain minke whale populations on a long-term basis*", will be satisfied.

## Basking shark

Basking shark is classified by Popper, *et al*., 2014 as a group 1 fish (fish with no swim bladder). Basking shark have only an inner ear and no swim bladder, meaning that they are only sensitive to particle motion (Chapuis *et al*., 2019). Therefore, they are considered sensitive to low frequency sounds only (between 20 Hz and 1500 Hz), with hearing sensitivity peaking between 200 Hz and 600 Hz (Carroll, *et al*., 2017), however, little information exists on sound detection in basking shark.

For geophysical surveys the noise modelling assessment (Appendix A 4) demonstrated that, for the 'fish' hearing group, without mitigation, recoverable injury ranges could extend out to 30 m and TTS could extend out to 240 m. For geotechnical surveys the noise modelling assessment (Appendix A 4) demonstrated that, for the 'fish' hearing group, without mitigation, recoverable injury ranges and TTS could extend out to 10 m.

The noise modelling assessment (section 4) predicted a maximum 0.67 km behavioural response range for geophysical surveys and a maximum 0.29 km behavioural response range for geotechnical surveys for basking shark. Marine Scotland (2024) modelling based on Paxten *et al.* (2014) provides an estimated density of basking shark in the vicinity of the Gigha & Tayinloan Port Development of 0.1 - 0.2 animals per $km^2$ for sightings data between 2000-2012.

Mitigation measures will be implemented for marine mammals, some of which has the potential to minimise injury impacts for basking shark. Given relevant mitigation measures (20 minute soft start) and the low density of basking shark in the area, surveys are predicted to affect very small numbers of animals in the context of the wider population.

The proposed geophysical and geotechnical survey will be short-term, taking place over a maximum of four weeks and will be carried out over a small area (0.0835 $km^2$), with only a small proportion of that total area affected at any one time) in the context of the basking shark population on the West Coast of Scotland. The use of geophysical and geotechnical survey equipment is not expected to create a barrier to movement for basking shark and is therefore not expected to reduce the range of the local basking shark population (reported as "Endangered" in the most recent IUCN Red List assessment).

Basking shark are found in the Irish Sea and individuals have been observed on the surface in summer and spring months near to the Isle of Man and further north, with the species typically undergoing a north-south migration through the Irish Sea ((Sims *et al.*, 2008); Wilson *et al*., 2020). Large numbers of basking shark are known to aggregate around Tiree, Coll and the Skerryvore reefs (Marine Scotland, 2024), with the areas widely considered hotspots. Any habitat likely to be affected therefore will constitute a very small proportion of the habitat available to the basking shark population. The survey area is not likely to represent a key habitat in the context of the wider region.

# 6 CONCLUSION

Table 6.1 Provides an overview of the conclusions and associated justifications for which licences are required in Scottish waters.

**Table 6.1: Licence application conclusions**

| Relevant Licence applications | Relevant legislation | Is a licence being applied for? | Justification |
|---|---|---|---|
| EPS licence (inshore waters) | The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended) | Yes | For activities taking place in Scottish inshore waters, guidance from Scottish Government (2020) states, where an activity is likely to cause disturbance or injury to an EPS, an EPS licence is required to undertake the activity legally. Gigha & Tayinloan Port Development is located entirely in inshore waters. **Therefore, it is concluded that a licence is required.** |
| EPS licence (offshore waters) | The Conservation of Offshore Marine Habitats and Species Regulations 2017 | No | For activities taking place in Scottish waters beyond 12nm (the offshore marine area), The Marine Directorate refers to the JNCC (2010) guidance disturbance effects from these surveys on EPS are considered to qualify as ‘trivial disturbance’ (as defined by JNCC *et al.* (2010) “sporadic disturbances without any likely negative impact on the animals” as trivial disturbance) and are therefore unlikely to significantly impact the marine animal, or its population status in the wild. Considering this guidance, it is predicted that an EPS licence for Scottish waters beyond 12nm is not required.<br>**It is proposed that a licence will not be required.** |
| Basking shark licence | Wildlife and Countryside Act 1981 | Yes | Guidance from the Scottish Government (2023) states that if an activity taking place in the Scottish Territorial Sea (0-12 nm) is likely to cause to disturbance or injury to basking sharks, a licence is required to undertake activity legally. Gigha & Tayinloan Port Development is located inside of Scottish territorial waters and potential disturbance could occur.<br>**It is concluded that a licence is required.** |
| Seal licence | Under the Marine (Scotland) Act 2010 | No | With the implementation of mitigation measures outlined in section 4.4, the proposed geophysical and geotechnical surveys will not “intentionally or recklessly kill, injure or take any seal”.<br>**Therefore, it is proposed that a licence is not required.** |

The Applicant understands that in order for an EPS licence to be granted for the specific purposes set out in the Conservation (Natural Habitats) Regulations 1994 (as amended), the regulator would need to be satisfied that the Application passes each of the three tests namely: (1) Overriding public interest; (2) No satisfactory alternatives; and (3) Favourable conservation status. This document, in support of an Application for an EPS licence, has sought to demonstrate compliance with these three tests.

The proposed surveys will contribute to long-term strategic economic development and regeneration, in addition to reducing green house gas emissions through new hybrid/electric transport technology whilst providing valuable services to local populations, therefore the Licensable Operations fulfil the requirements of Test 1: Overriding Public Interest. The Licensable Operations are a solution to a fundamental and essential step required for the sustainable construction of the proposed project, and the option of 'do nothing' is not considered to be a realistic option. As such it can be demonstrated that the Licensable Operations fulfil the requirements of Test 2: No Satisfactory Alternatives.

The Applicant has sought to demonstrate that, should the Gigha & Tayinloan Port Development geophysical and geotechnical surveys (the Licensable Operations) consents be granted, the activities would not be detrimental to the maintenance of the FCS of EPS likely to occur within the zone of potential impact of the Licensable Operations. Those EPS include harbour porpoise, bottlenose dolphin, common dolphin, Risso's dolphin and minke whale.

Based on the output of noise modelling, in conjunction with available data on relevant populations, habitat use and natural range, it was demonstrated that for all five species, the number of animals affected in the context of the wider MU populations will be small and therefore unlikely to significantly affect the population as a whole. The populations of EPS in the vicinity of the survey area will continue to maintain themselves on a long-term basis as a viable component of their natural habitats.

In addition, it was demonstrated that for all EPS, the Licensable Operations are not predicted to create a barrier to movement for EPS and are therefore not likely to reduce the range of populations, with the natural range of each species neither being reduced nor likely to be reduced for the foreseeable future. Finally, it was demonstrated that any habitat likely to be affected by the Licensable Operations will constitute a very small proportion of the available habitat to these EPS and therefore it is predicted that there is, and will probably continue to be, a sufficiently large habitat to maintain EPS populations on a long-term basis. As such the Applicant has demonstrated that the Licensable Operations fulfil the requirements of Test 3: Favourable Conservation Status.

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# Appendix A: Gigha and Tayinloan Port Development Subsea Noise Technical Report

# GIGHA AND TAYINLOAN PORT DEVELOPMENT

## SUBSEA NOISE TECHNICAL REPORT

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# Glossary

| Term | Meaning |
|---|---|
| Decibel (dB) | A relative scale most commonly used for reporting levels of sound. The actual sound measurement is compared to a fixed reference level and the "decibel" value is defined to be $10 \cdot \log_{10}$(“actual”/”reference”), where (“actual”/”reference”) is a power ratio. The standard reference for underwater sound pressure is 1 micro-Pascal (μPa), while 20 micro-Pascals is the standard for airborne sound. The dB symbol is often followed by a second symbol identifying the specific reference value (i.e. re 1 μPa). |
| Grazing angle | A glancing angle of incidence (the angle between a ray incident on a surface and the line perpendicular to the surface). |
| Permanent Threshold Shift (PTS) | A total or partial permanent loss of hearing caused by some kind of acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity. |
| Temporary Threshold Shift (TTS) | Temporary loss of hearing as a result of exposure to sound over time. Exposure to high levels of sound over relatively short time periods will cause the same amount of TTS as exposure to lower levels of sound over longer time periods. The mechanisms underlying TTS are not well understood, but there may be some temporary damage to the sensory cells. The duration of TTS varies depending on the nature of the stimulus, but there is generally recovery of full hearing over time. |
| Sound Exposure Level (SEL) | The cumulative sound energy in an event, formally: “ten times the base-ten logarithm of the integral of the squared pressures divided by the reference pressure squared”.<br>Equal to the often seen “$L_E$” or “dB SEL” quantity.<br>Defined in: ISO 18405:2017, 3.2.1.5 |
| Sound Pressure level (SPL) | The average sound energy over a specified period of time, formally: “ten times the base-ten logarithm of the arithmetic mean of the squared pressures divided by the squared reference pressure”.<br>Equal to the deprecated “RMS level”, “$dB_{rms}$” and to Leq if the period is equal to the whole duration of an event.<br>Defined in ISO 18405:2017, 3.2.1.1 |
| Peak Level, Peak Pressure Level ($L_P$) | The maximal sound pressure level of an event, formally: “ten times the base-ten logarithm of the maximal squared pressure divided by the reference pressure squared” or “twenty time the base-ten logarithm of the peak sound pressure divided by the reference pressure, where the peak sound pressure is the maximal deviation from ambient pressure”.<br>Defined in ISO 18405:2017, 3.2.2.1 |
| Source Level (SL) | Here taken to mean the level (SEL/SPL/$L_P$) at 1 meter range. If not otherwise stated it’s assumed the source is omnidirectional (equal level in all directions). For sources larger than 1 m in radius the Source Level is back-calculated to 1 m. |
| decidecade | Used to refer to a step in frequency, similar to “one-third-octave”, defined as a ratio of $10^{0.1} \approx 1.259$ (one third octave is 21/3 ≈ 1.260).<br>Used interchangeably with “3rd octave”. |
| noise | Sound that is irrelevant, unwanted or harmful to the organism(s) in question. Noise is often detrimental, but not necessarily so. |
| kurtosis | A statistical measure of “peakedness” of a distribution (of e.g. pressure values in a sound pulse) Defined in ISO 5479:1997 |

# Acronyms

| Term | Meaning |
|---|---|
| ADD | Acoustic Deterrent Device |
| LF | Low Frequency (Cetaceans) |
| HF | High Frequency (Cetaceans) |
| VHF | Very High Frequency (Cetaceans) |
| MF | Mid Frequency (Cetaceans) – **DEPRECATED** only for reference to NOAA/NMFS 2018 groups |
| OW/OCW | Otariid pinnipeds/Other Carnivores in water (refers to the same weighting and animal groups) |
| PW/PCW | Phocid pinnipeds |
| NMFS | National Marine Fisheries Service |
| RMS | Root Mean Square |
| SEL | Sound Exposure Level, [dB] |
| SPL | Sound Pressure Level, [dB] |
| $L_P$ | Peak Pressure Level, [dB] |
| SL | Source Level [dB] |
| TTS | Temporary Threshold Shift |
| PTS | Permanent Threshold Shift |
| SSS | Side scan sonar – Towed sonar device typically positioned 10-15 m above the sediment, main purpose is to characterise the sediment surface texture. |
| MBES | Multi beam echosounder – Uses multiple narrow beams to measure the depth across a swath below the vessel. |
| SBP | Sub Bottom Profiler – Any device/system that uses acoustics to record echoes from within the sediment, examples include seismic arrays, sparkers, boomers, chirpers, pingers and associated recorder array. |
| USBL | Ultra Short Baseline Array – Small array of at least 4 hydrophones and a pinger to measure positions of equipment under water. |
| UHRS | Ultra High-Resolution Seismic survey – Usually a sparker driven sub bottom characterisation system. |
| c. | Circa, i.e., approximately |

# Units

| Unit | Description |
|---|---|
| dB | Decibel (Sound) |
| Hz | Hertz (Frequency) |
| kHz | Kilohertz (Frequency) |
| kJ | Kilojoule (Energy) |
| km | Kilometre (Distance) |
| $km^2$ | Kilometre squared (Area) |
| m | Metre |
| ms | Millisecond ($10^{-3}$ seconds) (Time) |
| $ms^{-1}$ or m/s | Metres per second (Velocity or speed) |
| kn | Knots (speed), 1 kn = 0.514 m/s, 1 m/s = 1.944 kn |
| µPa | Micro Pascal |
| Pa | Pascal (Pressure: newton/$m^2$) |
| psu | Practical Salinity Units (parts per thousand of equivalent salt in seawater, weight-based) |

| Unit | Description |
|---|---|
| $kg/m^3$ | Specific density (of water, sediment or air) |
| Z | Acoustic impedance [$kg/(m^2 \cdot s)$ or $(Pa \cdot s)/m^3$] |

Units will generally be enclosed in square brackets e.g.: “[m/s]”

# 1 INTRODUCTION

This Subsea Noise Technical Report presents the results of a desktop study considering the potential short-term effects of underwater noise on the marine environment from the proposed geophysical and geotechnical surveys in the Sound of Gigha, Scotland (hereafter referred to as “the Survey”). This survey is in preparation of the proposed construction of a pier/breakwater at Gigha ferry terminal and a breakwater extension at Tayinloan terminal. The Surveys area are located within c. 200 m of the existing breakwaters and covers c. 0.05 km² at Tayinloan and c. 0.03 km² at Gigha. The sediment is mostly fine sand, and water properties in the area relatively stable given the lack of major river outflows and a modest tidal range.

Sound is readily transmitted in the underwater environment and there is potential for the sound emissions from anthropogenic sources to adversely affect marine life such as marine mammals or fish. At close ranges from a noise source with high noise levels, permanent or temporary hearing damage may occur to marine species, while at a very close range gross physical trauma is possible. At long ranges (several kms) the introduction of any additional noise could, for the duration of the activity, potentially cause behavioural changes, for example to the ability of species to communicate and to determine the presence of predators, food, underwater features, and obstructions.

This report provides an overview of the potential effects due to underwater noise from the Survey on the surrounding marine environment based on the Southall et al. 2019 and Popper et al. 2014 frameworks for assessing impact from noise on marine mammals and fishes.

Consequently, the primary purpose of the underwater noise assessment is to predict the likely range of onset for potential physiological and behavioural effects due to increased anthropogenic noise as a result of the Survey.

# 2 ASSESSMENT CRITERIA

## 2.1 General

To determine the potential spatial range of injury and disturbance, assessment criteria have been developed based on a review of available evidence including national and international guidance and scientific literature. The following sections summarise the relevant assessment criteria and describe the evidence base used to derive them.

Underwater noise has the potential to affect marine life in different ways depending on its noise level and characteristics. Assessment criteria generally separate sound into two distinct types, as follows:

- **Impulsive sounds** which are typically transient, momentary (less than one second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI, 2005; ANSI, 1986; NIOSH, 1998). This category includes sound sources such as seismic surveys, impact piling and underwater explosions. Additionally included here are sounds under 1 second in duration with a weighted kurtosis over 40 (see note below*).
- **Non-impulsive** (and continuous) sounds which can be broadband, narrowband or tonal, momentary, brief or prolonged, continuous or intermittent and typically do not have a high peak sound pressure with rapid rise/decay time that impulsive sounds do (ANSI, 1995; NIOSH, 1998).This category includes sound sources such as continuous vibro-piling, running machinery, some sonar equipment and vessels. Additionally included here are sounds over 1 second in duration with a weighted kurtosis under 40 (see note below*).

* Note that the European Guidance: "Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications" (MSFD Technical Subgroup on Underwater Noise, 2014) includes sonar as impulsive sources (see Section 2.2). However, the guidance suggests that *"all loud sounds of duration less than 10 seconds should be included"* as impulsive.
This contradicts research on impact from impulsive sounds suggesting that a limit for "impulsiveness" can be set at a kurtosis[1] of 40 (Martin, et al., 2020). See examples in Appendix A, Impulsiveness.
This latter criterion has been used for classification of impulsive versus non-impulsive for sonars and similar sources. The justification for departing from the MSFD criterion is that the Southall et al. 2019 and the Popper et al. 2014 framework limits are based on the narrower definition of impulsive as given in "Impulsive sounds" above.

There is scope for some sounds to be classified as both impulsive and non-impulsive, depending on the criteria applied. Examples are pulses from sonar-like sources that can contain very rapid rise times (<0.5 ms), sweep a large frequency range and have high kurtosis. However, given that the scientific work carried out to identify impulsive thresholds were done with "pure" impulses (from a near instantaneous event), sonar-like sounds are sometimes not included in this, impulsive, category. This argument ignores that sounds used for establishing the non-impulsive thresholds (often narrowband slowly[2] rising pulses), are markedly less impulsive (lower kurtosis, narrower bandwidth) than what is sometimes seen in pulses from sonar-like sources and are thus also not representative for all sonar-like pulses.

Given impulsive sound's tendency to become less impulsive with increased range, a minimal range can be established where the noise is no longer impulsive (here kurtosis <40 is used) (Appendix A, Impulsiveness). This range is here established using raytracing, but as the effect varies with exact depth and range of source and receiver, the transition range to non-impulsive used for exposure modelling is doubled from the modelled range where kurtosis goes below 40.

The acoustic assessment criteria for marine mammals and fish in this report has followed the latest international guidance (based on the best available scientific information), that are widely accepted for assessments in the UK, Europe and worldwide (Southall, et al., 2019; Popper, et al., 2014).

[1] Statistical measure of the asymmetry of a probability distribution.

[2] Slowly in this context is >10 ms – slow relative to the integration time of the auditory system of marine mammals.

## 2.2 Effects on Marine Animals

Underwater noise has the potential to affect marine life in different ways depending on its noise level and characteristics. Richardson *et al.* (1995) defined four zones of noise influence which vary with distance from the source and level, to which an additional zone has been added "zone of temporary hearing loss". These are:

- **The zone of audibility**: This is defined as the area within which the animal can detect the sound. Audibility itself does not implicitly mean that the sound will affect the animal.
- **The zone of masking**: This is defined as the area within which sound can interfere with the detection of other sounds such as communication or echolocation clicks. This zone is very hard to estimate due to a paucity of data relating to how animals detect sound in relation to masking levels (for example, humans can hear tones well below the numeric value of the overall sound level). Continuous sounds will generally have a greater masking potential than intermittent sound due to the latter providing some relative quiet between sounds. Masking only occurs of there is near-overlap in sound and signal, such that a loud sound at e.g., 1000 Hz will not be able to mask a signal at 10,000 Hz[3].
- **The zone of responsiveness**: This is defined as the area within which the animal responds either behaviourally or physiologically. The zone of responsiveness is usually smaller than the zone of audibility because, as stated previously, audibility does not necessarily evoke a reaction. For most species there is very little data on response, but for species like harbour porpoise there exists several studies showing a relationship between received level and probability of response (Graham IM, 2019; Sarnoci´nska J, 2020; BOOTH, 2017; Benhemma-Le Gall A, 2021).
- **The zone of temporary hearing loss**: The area where the sound level is sufficient to cause the auditory system to lose sensitivity temporarily, causing loss of "acoustic habitat": the volume of water that can be sensed acoustically by the animal. This hearing loss is typically classified as Temporary Threshold Shift (TTS).
- **The zone of injury / permanent hearing loss**: This is the area where the sound level is sufficient to cause permanent hearing loss in an animal. This hearing loss is typically classified as Permanent Threshold Shift (PTS). At even closer ranges, and for very high intensity sound sources (e.g., underwater explosions), physical trauma or acute mortal injuries are possible.

For this study, it is the zones of injury (PTS) that are of primary interest, along with estimates of behavioural impact ranges. To determine the potential spatial range of injury and behavioural change, a review has been undertaken of available evidence, including international guidance and scientific literature. The following sections summarise the relevant thresholds for onset of effects and describe the evidence base used to derive them.

## 2.3 Thresholds for Marine mammals

The zone of injury in this study is classified as the distance over which a fleeing marine mammal can suffer PTS leading to non-reversible auditory injury. Injury thresholds are based on a dual criteria approach using both un-weighted $L_P$ (maximal instantaneous SPL) and marine mammal hearing weighted SEL. The hearing weighting function is designed to represent the sensitivity for each group within which acoustic exposures can have auditory effects. The categories include:

- **Low Frequency (LF) cetaceans**: Marine mammal species such as baleen whales (e.g. minke whale *Balaenoptera acutorostrata*).
- **High Frequency (HF) cetaceans**: Marine mammal species such as dolphins, toothed whales, beaked whales and bottlenose whales (e.g., bottlenose dolphin *Tursiops truncatus* and white-beaked dolphin *Lagenorhynchus albirostris*).

[3] The exact limit of how near a noise can get to the signal in frequency before causing masking will depend on the receivers auditory frequency resolution ability, but for most practical applications noise and signal frequencies will need to be within 1/3rd octave to start to have a masking effect.

- **Very High Frequency (VHF) cetaceans**: Marine mammal species such as true porpoises, river dolphins and pygmy/dwarf sperm whales and some oceanic dolphins, generally with auditory centre frequencies above 100 kHz) (e.g., harbour porpoise *Phocoena phocoena*).

- **Phocid Carnivores in Water (PCW)**: True seals, earless seals (e.g., harbour seal *Phoca vitulina* and grey seal *Halichoreus grypus*); hearing in air is considered separately in the group PCA.

- **Other Marine Carnivores in Water (OCW)**: Including otariid pinnipeds (e.g., sea lions and fur seals), sea otters and polar bears; in-air hearing is considered separately in the group Other Marine Carnivores in Air (OCA).

- **Sirenians (SI)**: Manatees and dugongs. This group is only represented in the NOAA guidelines.

These weightings are used in this study and are shown in Figure 2-1. It should be noted that not all of the above hearing groups of marine mammal will be present in the Survey area, but all hearing groups are presented in this report for completeness.

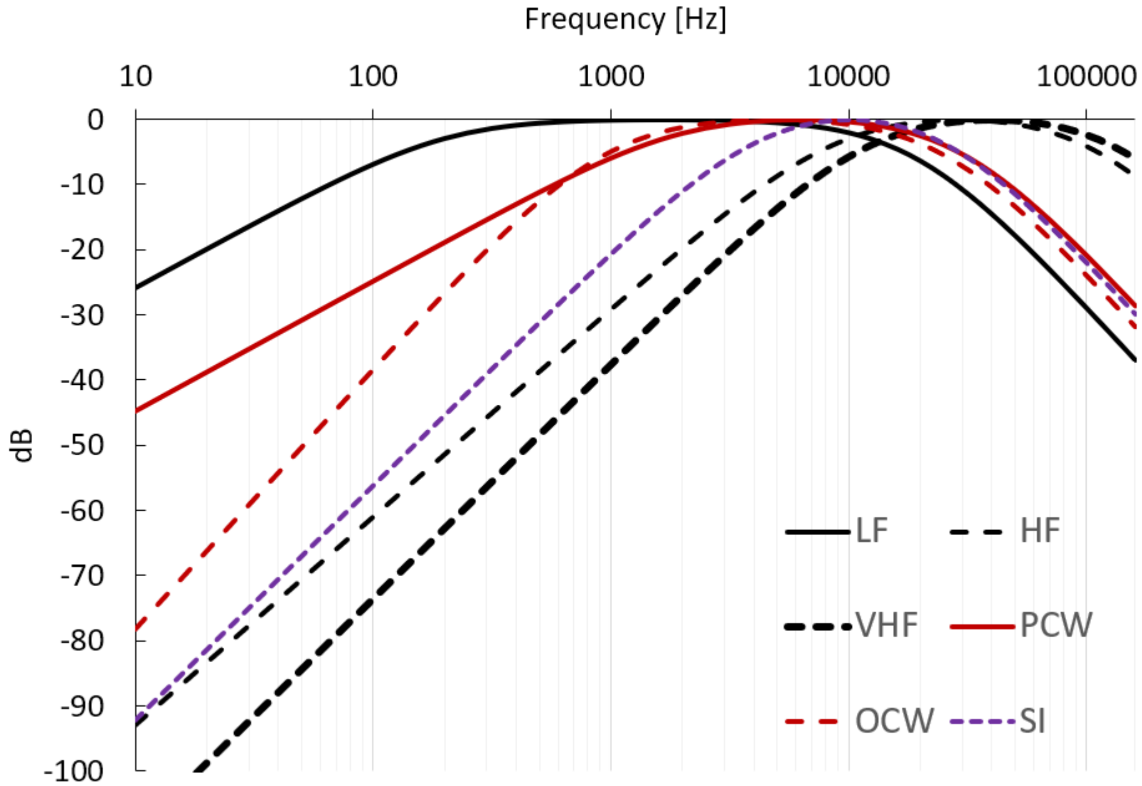


**Figure 2-1: Auditory weighting functions for seals, whales and sirenians (NMFS, 2018; Southall et al. 2019)**

Both the criteria for impulsive and non-impulsive sound are relevant for this study given the nature of the sound sources used during the Survey. The relevant PTS and TTS criteria proposed by Southall *et al.* (2019) are summarised in Table 2-1.

**Table 2-1: PTS and TTS onset acoustic thresholds (Southall *et al., 2019*; Tables 6 and 7)**

| Hearing Group | Parameter | Impulsive [dB] | | Non-impulsive [dB] | |
|---|---|---|---|---|---|
| | | PTS | TTS | PTS | TTS |
| Low frequency (LF) cetaceans | $L_P$, (unweighted) | 219 | 213 | - | - |
| | SEL, (LF weighted) | 183 | 168 | 199 | 179 |
| High frequency (HF) cetaceans | $L_P$, (unweighted) | 230 | 224 | - | - |
| | SEL, (MF weighted) | 185 | 170 | 198 | 178 |

| Hearing Group | Parameter | Impulsive [dB] | | Non-impulsive [dB] | |
|---|---|---|---|---|---|
| | | PTS | TTS | PTS | TTS |
| Very high frequency (VHF) cetaceans | $L_P$, (unweighted) | 202 | 196 | - | - |
| | SEL, (HF weighted) | 155 | 140 | 173 | 153 |
| Phocid carnivores in water (PCW) | $L_P$, (unweighted) | 218 | 212 | - | - |
| | SEL, (PW weighted) | 185 | 170 | 201 | 181 |
| Other marine carnivores in water (OCW) | $L_P$, (unweighted) | 232 | 226 | - | - |
| | SEL, (OW weighted) | 203 | 188 | 219 | 199 |
| Sirenians (SI) (NOAA only) | $L_P$, (unweighted) | 226 | 220 | - | - |
| | SEL, (OW weighted) | 190 | 175 | 206 | 186 |

These updated marine mammal injury criteria were published in March 2019 (Southall, et al., 2019). The paper utilised the same hearing weighting curves and thresholds as presented in the preceding regulations document NMFS (2018) with the main difference being the naming of the hearing groups and introduction of additional thresholds for animals not covered by NMFS (2018). A comparison between the two naming conventions is shown in Table 2-2.

The naming convention used in this report is based upon those set out in Southall *et al*. (2019). Consequently, this assessment utilises criteria which are applicable to both NMFS (2018) and Southall *et al*. (2019).

**Table 2-2: Comparison of Hearing Group Names between NMFS (2018) and Southall *et al.* (2019)**

| NMFS (2018) hearing group name | Southall *et al*. (2019) hearing group name |
|---|---|
| Low-frequency cetaceans (LF) | LF |
| Mid-frequency cetaceans (MF) | HF |
| High-frequency cetaceans (HF) | VHF |
| Phocid pinnipeds in water (PW) | PCW |
| Otariid pinnipeds in water (OW) | OCW |
| Sirenians (SI) | Not included |

## 2.4 Disturbance to Marine Mammals

Disturbance thresholds for marine mammals are summarised in Table 2-3. Note that the non-impulsive threshold can often be lower than ambient noise for coastal waters with some human activity, meaning that ranges determined using this limit will tend to be higher than actual ranges. However, the levels are unweighted and ranges to threshold will be dominated by low-frequency sound, which for most hearing groups is outside their hearing range. For hearing groups with low thresholds this can mean that their range to TTS/PTS is *larger* than the range to the behavioural threshold, e.g., the PTS threshold for impulsive sound for the VHS group is 155 dB SEL, while the behavioural threshold is 160 dB SPL. For a typical scenario, for 1 second's exposure (SEL equals SPL for 1-second durations) that means the range to the behavioural threshold will be approximately twice the range to the PTS threshold (a difference of 5 dB). This is just one of the reasons why this behavioural threshold should be interpreted with caution.

**Table 2-3: Disturbance Criteria for Marine Mammals Used in this Study based on Level B harassment of NMFS (National Marine Fisheries Service, 2005)**

| Effect | Non-Impulsive Threshold | Impulsive Threshold |
|---|---|---|
| Disturbance (all marine mammals) | 120 dB SPL | 160 dB $SEL_{single\ impulse}$ or 1-second SEL |

## 2.5 Injury and Disturbance to Fishes

The injury criteria used in this noise assessment are given in Table 2-4 and Table 2-5 for impulsive noises and continuous noise respectively. $L_P$ and SEL criteria presented in the tables are unweighted. Physiological effects relating to injury criteria are described below (Popper, et al., 2014):

- **Mortality and potential mortal injury**: either immediate mortality or tissue and/or physiological damage that is sufficiently severe (e.g., a barotrauma) that death occurs sometime later due to decreased fitness. Mortality has a direct effect upon animal populations, especially if it affects individuals close to maturity.

- **Recoverable injury ("PTS" in tables and figures)**: Tissue damage and other physical damage or physiological effects, that are recoverable, but which may place animals at lower levels of fitness, may render them more open to predation, impaired feeding and growth, or lack of breeding success, until recovery takes place.

  The PTS term is used here to describe this, more serious impact, even though it is not strictly permanent for fish. This is to better reflect the fact that this level of impact is perceived as serious and detrimental to the fish.

- **Temporary Threshold Shift (TTS)**: Short term changes (minutes to few hours) in hearing sensitivity may, or may not, reduce fitness and survival. Impairment of hearing may affect the ability of animals to capture prey and avoid predators, and also cause deterioration in communication between individuals, affecting growth, survival, and reproductive success. After termination of a sound that causes TTS, normal hearing ability returns over a period that is variable, depending on many factors, including the intensity and duration of sound exposure.

Popper et al. 2014 does not set out specific TTS limits for $L_P$ and for disturbance limits for impulsive noise for fishes. Therefore publications: "Washington State Department of Transport Biological Assessment Preparation for Transport Projects Advanced Training Manual" (WSDOT, 2011) and "Canadian Department of Fisheries and Ocean Effects of Seismic energy on Fish: A Literature review" (Worcester, 2006) on effects of seismic noise on fish are used to determine limits for these:

- The criteria presented in the Washington State Department of Transport Biological Assessment Preparation for Transport Projects Advanced Training Manual (WSDOT, 2011). The manual suggests an un-weighted sound pressure level of 150 dB SPL (assumed to be duration of 95 % of energy) as the criterion for onset of behavioural effects, based on work by (Hastings, 2002). Sound pressure levels in excess of 150 dB SPL are expected to cause temporary behavioural changes, such as elicitation of a startle response, disruption of feeding, or avoidance of an area. The document notes that levels exceeding this threshold are not expected to cause direct permanent injury but may indirectly affect the individual fish (such as by impairing predator detection). It is important to note that this threshold is for onset of potential effects, and not necessarily an 'adverse effect' threshold. The threshold is implemented here as either single impulse SEL or 1 second SEL, whichever is greater.

- The report from the Canadian Department of Fisheries and Ocean "Effects of Seismic energy on Fish: A Literature review on fish" (Worcester, 2006) found large differences in response between experiments. Onset of behavioural response varied from 107-246 dB $L_P$, the $10^{th}$ percentile level for behavioural response was 158 dB $L_P$.

Given the large variations in the data from the two sources above, we have rounded the value to 160 dB $L_P$ as the behavioural threshold for fishes for impulsive sound, and 150 dB SPL for non-impulsive sound.

*Note that while there are multiple groups of fish presented, we have used the thresholds of the more sensitive group for all fish thus covering all fishes (203/186 PTS/TTS for impulsive sound & 222/204 PTS/TTS for non-impulsive sound). These lower thresholds also cover "Eggs and Larvae.*

**Table 2-4: Criteria for onset of injury to fish and sea turtles due to impulsive noise. For this assessment the lowest threshold for any group is used for all groups (shown in bold).**

| Type of animal | Unit | Mortality and potential mortal injury [dB] | Recoverable injury (PTS) [dB] | TTS [dB] | Behavioural [dB] |
|---|---|---|---|---|---|
| Fish: no swim bladder (particle motion detection)<br>Example: Sharks. | SEL | 219[1] | 216[1] | 186[1] | 150[3] |
| | $L_P$ | 213[1] | 213[1] | 193[2] | 160[2] |
| Fish: where swim bladder is not involved in hearing (particle motion detection).<br>Example: Salmonoids. | SEL | 210[1] | 203[1] | 186[1] | 150[3] |
| | $L_P$ | 207[1] | 207[1] | 193[2] | 160[2] |
| Fish: where swim bladder is involved in hearing (primarily pressure detection).<br>Example: Gadoids (cod-like). | SEL | 207[1] | **203[1]** | **186** | **150[3]** |
| | $L_P$ | 207[1] | **207[1]** | **193[2]** | **160[2]** |
| Sea turtles | SEL | 210[1] | (*Near*) High*<br>(*Mid*) Low<br>(*Far*) Low | - | - |
| | $L_P$ | 207[1] | | - | - |
| Eggs and larvae | SEL | 210[1] | (*Near*) Moderate<br>(*Mid*) Low<br>(*Far*) Low | - | - |
| | $L_P$ | 207[1] | | - | - |

[1] (Popper et al. 2014) [2] (Worcester, 2006) [3] (WSDOT, 2011)

* Indicate (range) and risk of effect, e.g., "(Near) High", meaning high risk of that effect when near the source.

Where Popper et al. 2014 present limits as ">" 207 or ">>" 186, we have ignored the "greater than" and used the threshold level as given.

Relevant thresholds for non-impulsive noise for fishes relating to PTS, TTS, and behaviour are given in Table 2-5. Note that for the behaviour threshold we have used the impulsive threshold as basis for the continuous noise threshold, in absence of better evidence.

**Table 2-5: Criteria for fish (incl. sharks) due to non-impulsive noise from Popper et al. 2014.**

| Type of animal | Unit | Mortality and potential mortal injury | Recoverable injury (PTS) [dB] | TTS [dB] | Behavioural [dB] |
|---|---|---|---|---|---|
| All fishes | SEL | - | 222† | 204† | 150 [SPL]* |

*This is based on the impulsive criteria.

†Based 48 hours of 170 dB SPL and 12 hours of 158 dB SPL

# 3 METHOD, ENVIRONMENT AND SITE

The following sections are based on information from the project description, from earlier projects in the area and written communication with the client or client's representative (includes updates to site boundary and sound source specifications).

## 3.1 Survey Site

The Survey sites and nearby surroundings are characterised by shallow water (c. 5 m with survey areas and up to 50 m in the Sound of Gigha), generally silty to fine sandy sediment and water properties similar to the north Irish sea and (Figure 3-1, Figure 3-2 & Figure 3-3).

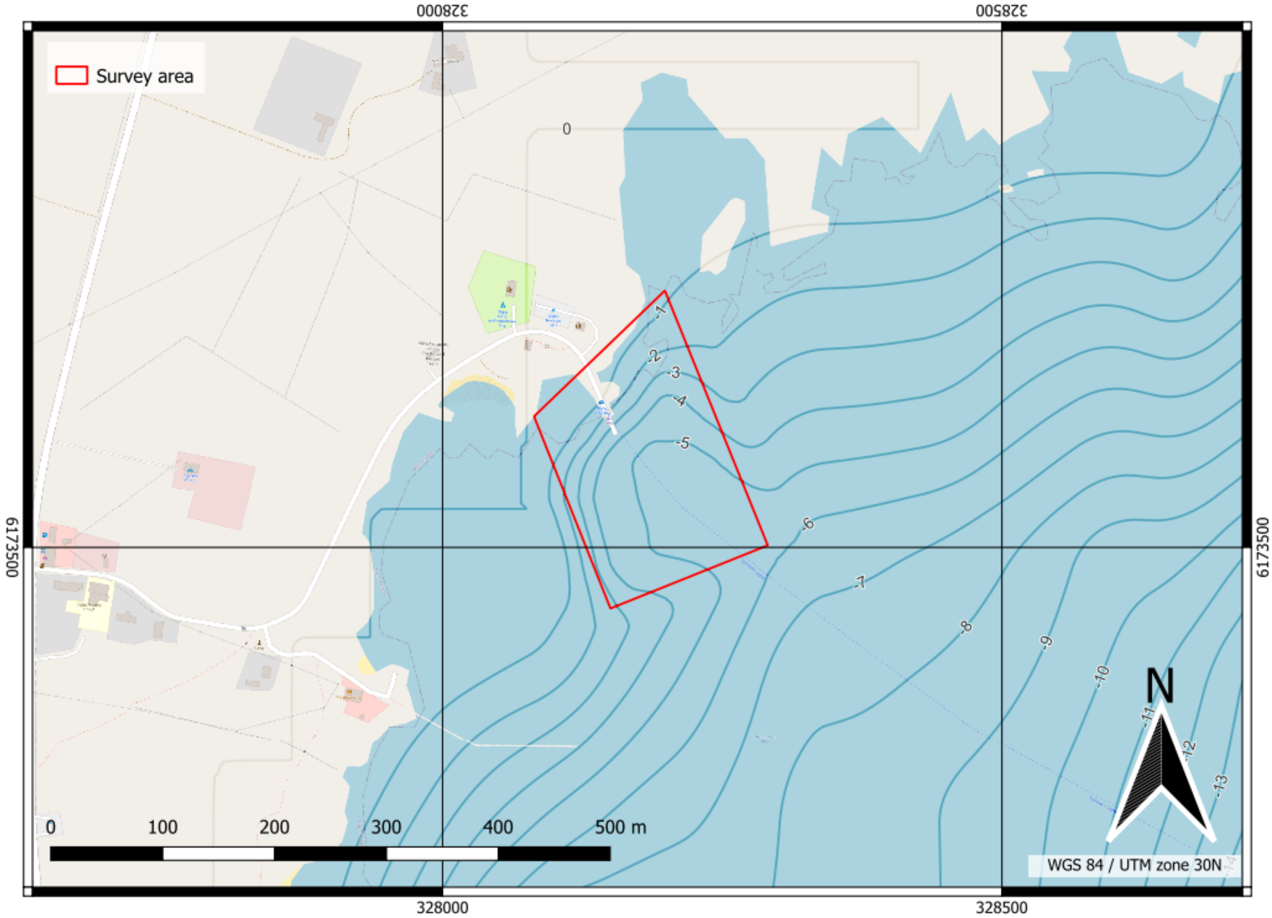


**Figure 3-1: Survey location at Gigha. Background map: OpenStreetMap. Contours and bathymetry: EMODNet.**

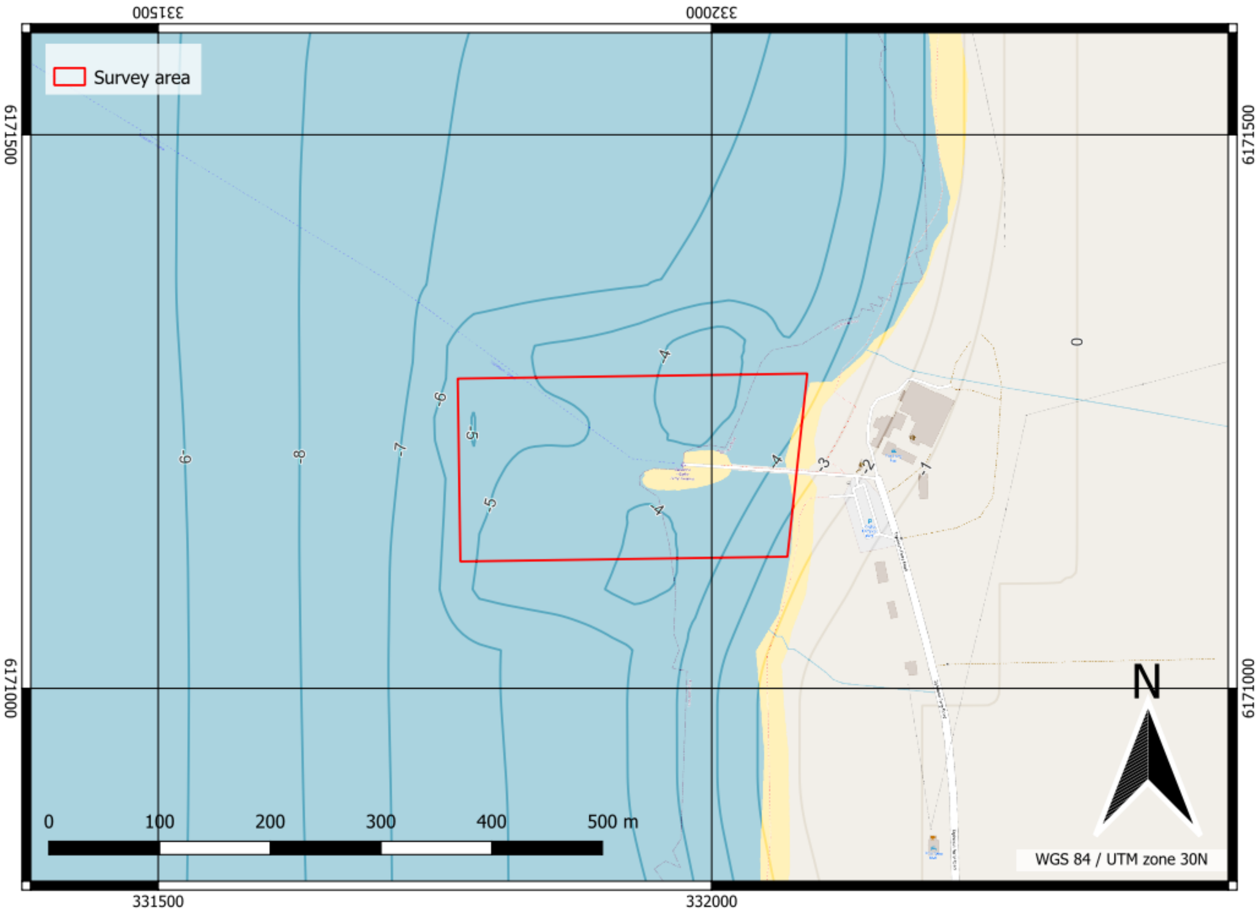


**Figure 3-2. Survey location at Tayinloan. Background map: OpenStreetMap. Contours and bathymetry: EMODNet.**

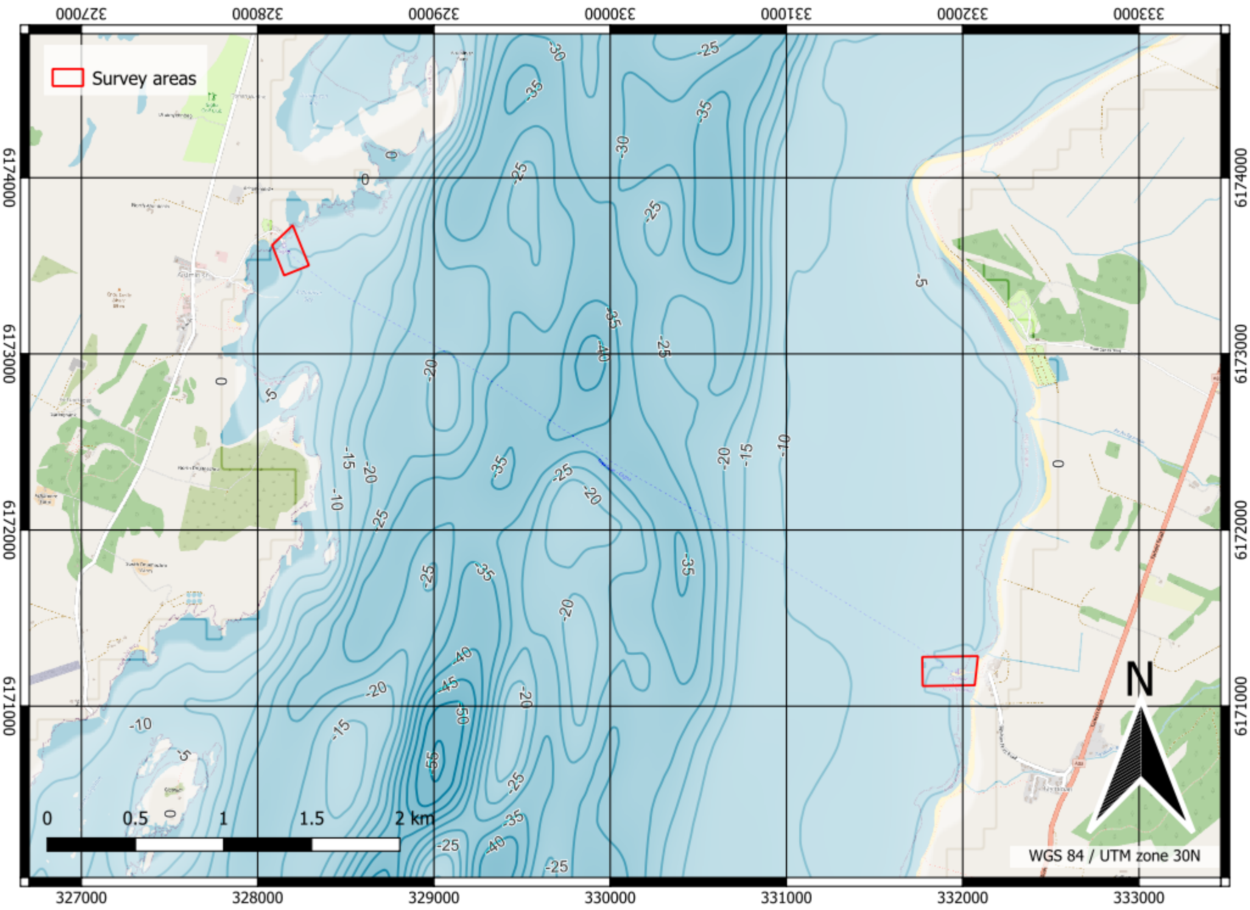


**Figure 3-3. Survey locations in sound of Gigha. Background map: OpenStreetMap. Contours and bathymetry: EMODNet.**

The area to be surveyed is c. 0.08 km² of depths from 0 to 6 meters (at mean high water springs "MHWS").

The survey speed is expected to be 4-5 kn (2.1-2.6 m/s), limited by the survey equipment. The survey transects plan is yet to be determined so representative locations throughout the survey area have been used as basis for the modelling rather than a specific survey plan.

## 3.2 Water Properties

Water properties were determined from historical data for the area. Where a range of values are expected, the value resulting in the lowest transmission loss was chosen for a more conservative assessment (more noise at range). This assumption also covers seasonal variation.

- Temperature: 15°C – maximal temperature (during August), given by seatemperature.org for Ayr and Larne, similar sites in the region.
- Salinity: 34 psu – Marine Scotland Information (Annual Mean Near-bed Salinity | Marine Scotland Information)
- Soundspeed profile: Assumed uniform given high mixing as a result of tidal flows and generally shallow water and absence of river outflows.

## 3.3 Sediment Properties

Sediment properties are based on sediments given in Table 3-1.

A previous geotechnical campaign at Tayinloan provided good information on sediment composition at this site. No information was available from the Gigha site, so a similar, but acoustically harder sediment, was assumed for this site, partially informed by images from the site (leading to lower propagation loss, a conservative measure). A sediment model (Ainslie, 2010) was used to derive the acoustic properties of the sediment from the grain size. (Table 3-1).

**Table 3-1: Sediment Properties for the two survey areas.**

| Site | Sediment type (ISO 14688-1:2017) | Density [kg/m³] | Soundspeed [m/s] | Grain size [mm] (nominal) |
|---|---|---|---|---|
| Gigha | fine Sand | 1902 | 1697 | 0.11 |
| Tayinloan | medium Silt | 1551 | 1544 | 0.011 |

*The capitalised word indicates the main sediment type, e.g.,"*silty gravelly fine to coarse **S**and*".

# 4 SOURCE NOISE LEVELS

Underwater noise sources are usually quantified in dB scale with values generally referenced to 1 µPa pressure amplitude as if measured at a hypothetical distance of 1 m from the source (called the Source Level). In practice, it is not usually possible to measure at 1 m from a source, but the metric allows comparison and reporting of different source levels on a like-for-like basis. In reality, for a large sound source, this imagined point at 1 m from the acoustic centre does not exist. Furthermore, the energy is distributed across the source and does not all emanate from an imagined acoustic centre point. Therefore, the stated sound pressure level at 1 m does not occur for large sources. In the acoustic near-field (i.e. close to the source), the sound pressure level will be significantly lower than the value predicted by the back-calculated source level (SL).

## 4.1 Source Models

The noise sources and activities investigated during this assessment are summarised in Table 4-1.

Note that:

1. The ping rate, and therefore the SPL and SEL of the sound source varies with the local depth.

2. Due to differences in sediment, the angle at which the sediment will tend to reflect sound back into the water column efficiently changes. As we use this information to derive practical source levels for highly directional sources, this will change with sediment type (further information below and in Appendix A & Figure 8-7).

3. To account for the shallow depth and therefore assumed short duration of pulses from MBES, SSS and pinger/chirper we have assessed the weighted kurtosis in order to determine impulsiveness (Section 2.1).

Sonars and echosounder generally use tone pulses of either constant frequency or as a frequency sweep, these pulses are typically windowed to limit "spectral leakage[4]". We assume use of a Von Hann window (sometimes "Hanning") which gives effective attenuation of frequencies outside the intended frequencies. This means that while a sonar with centre a frequency of 200 kHz is well above the hearing range of any mammal, there will be energy at 100 kHz c. 50 dB lower than the source level at 200 kHz. This is accounted for in the assessment. Note that this might contrast with some guidelines, such as the "JNCC guidelines mitigation during geophysical surveys" (JNCC, 2017), which state that "*Multi-beam surveys in shallower waters (<200m) are not subject to these requirements* [mitigation for protection of European Protected Species]" however, given the fact there is substantial energy outside the nominal frequency range of any echo sounder (see example in Figure 4-1) we included this energy spread here.

[4] Acoustic phenomenon where a sharp change in pressure produces sound in a wide frequency range (similar to an ideal impulse) outside the intended frequencies.

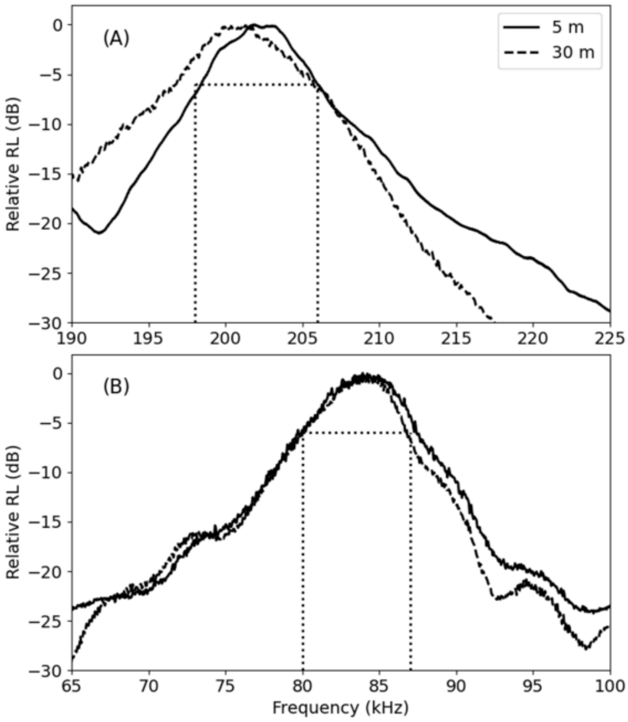


**Figure 4.** The relative received levels (RLs, in decibels (dB)) of the signals of the acoustic frequency bandwidth of the dual-frequency echosounder used in this study, as observed at two different depths. The dotted lines indicate the −6 dB acoustic bandwidths of 198–206 (**A**) and 80–87 kHz (**B**). The peak frequencies of the two channels were found to be 201.5 (**A**) and 84 kHz (**B**).

**Figure 4-1. Example of recorded levels from an echosounder showing significant energy outside the nominal frequencies, necessitating assessment at those frequencies too (Burnham, et al., 2022).**

Highly directional sources with narrow beams (sonars and echosounders) will tend to ensonify only a narrow cone of water at any given time. For multibeam echosounders or side scan sonars the beam(s) sweeps though the water, side to side, to get wider sediment coverage. For this type of sonar, we have converted the source to an omnidirectional source with the same acoustic energy as the original but represented as an omnidirectional source. This simplifies the calculation process, but yields identical results, and means that we account for the probabilistic nature of an animal being “ensonified” by the source.

For beams only directed vertically down, such as sub-bottom profilers we account for the directivity in the beam as well as the ability of the sediment to reflect the sound emitted, so that we can account for the fact that primarily a narrow cone directly below the source is ensonified with high sound levels, and also that a significant attenuation occurs in the sediment where sound enters at steep angles. In practice we use the angle with the highest level after accounting for directivity combined with sediment loss to a range of 100 m.

**Table 4-1: Summary of Sound Sources and Activities Included in the Subsea Noise Assessment**

| Equipment | Source level [SPL] (as used in model) | Primary decidecade bands (-20 dB width) | Source model details | Impulsive/non-impulsive |
|---|---|---|---|---|
| Survey vessel | 160 dB SPL | 10-12,500 Hz | Based on <30 m generic survey vessel. | Non-impulsive |
| MBES | 203 dB SPL (Spherical equivalent level) | 200,000-400,000 Hz | Based on Reason SeaBat T20-P, but +10 dB to allow for other models. | Impulsive |
| SSS | 173 dB SPL (Spherical equivalent level) | 400,000-900,000 Hz | Generic SSS from 400-900 kHz. | Impulsive |
| USBL | 195 dB SPL | 20,000-31,500 Hz | Assumes non-hull mounted SSS*, 2 Hz | Impulsive |

| Equipment | Source level [SPL] (as used in model) | Primary decidecade bands (-20 dB width) | Source model details | Impulsive/non-impulsive |
|---|---|---|---|---|
| | | | ping rate, ping length 10 ms. | |
| SBP-parametric (P-SBP) | 207 dB SPL | 80,000-125,000 Hz (Primary)<br>2,000-20,000 Hz (Secondary) | Source level adjusted for sediment effects and beam widths.<br>Based on Innomar Standard, worst-case for shallow water. | Impulsive |
| SBP-chirper/pinger (C-SBP) | 184 dB SPL | 1,600-16,000 Hz | Generic shallow water SBP of chirper/pinger type.<br>Source level adjusted for sediment effects and beam widths. | Impulsive |
| Drilling/coring (rotary/vibro/sonic coring) | 187 dB SPL | 50-16,000 Hz | Based on levels from previous work & (Reiser, et al., 2010) | Non-impulsive |

*If the SSS and SBP are hull mounted there is no need for a positioning device (USBL) and this noise source should be removed from consideration.

In additional to the activities outlined above, there may also be grab sampling. However, this activity has not been modelled given the low noise levels associated with the activity.

### 4.1.1 Equipment

This section presents details on each sound source individually. Combined sources are presented in Section 4.1.2.

#### 4.1.1.1 Survey Vessels

A small survey vessel of up to 30 meter's length, travelling at 4-5 kn (equipment limited), is assumed to be representative for a suitable vessel for carrying out the geophysical survey. Broadband level of the vessel is 160 dB SPL with decidecade band levels given in Figure 4-2 (maximal band level is 149.5 dB SPL at the 12.5 Hz band). Smaller vessels will have lower emitted levels and are therefore covered by this assessment.

This vessel is also used as proxy for a suitable platform for the geotechnical survey, representing generic machinery noise.

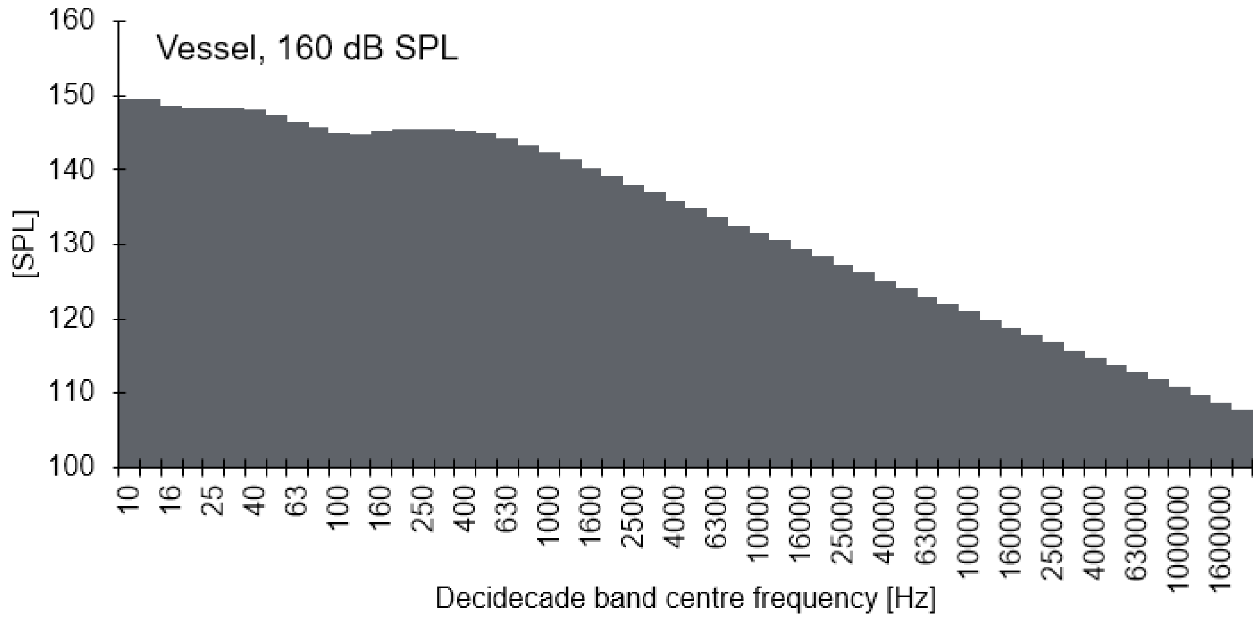


**Figure 4-2. Vessel source band levels. Broadband level: 160 dB SPL. Based on generic survey craft at 4 kn.**

## 4.1.1.2 Multibeam Echosounder (MBES)

The “Reason SeaBat T20-P” or similar shallow water model is a likely MBES for this survey. Nominal frequencies from 200 kHz to 400 kHz are assumed. In-beam levels for this source is 218 dB SPL, while the equivalent spherical level is 203 dB SPL (maximally 197 dB SPL in each band). Band levels are presented in Figure 4-3.

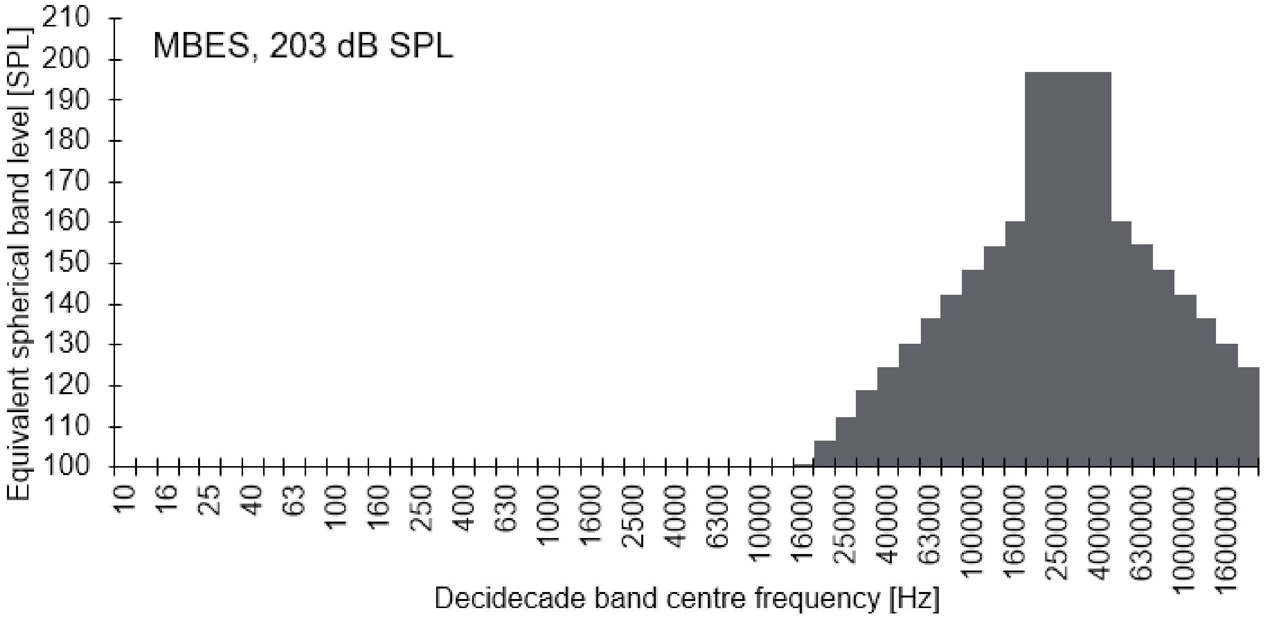


**Figure 4-3. MBES source band levels as equivalent spherical/omnidirectional levels.**

Given the shallow water (<6 m depth) it’s likely that shorter pulses will be used as they offer sufficient energy for a clear returning echo. This will increase kurtosis (“impulsiveness”) and modelling reveals weighted kurtosis near the limit value (39 for the VHF hearing group) for realistic ping rates for the depth. Therefore, the MBES is modelled as an impulsive noise source.

### 4.1.1.3 Side Scan Sonar (SSS)

No specific model of side scan sonar (SSS) has been determined for The Survey, except for specification of nominal frequencies >400 kHz. To address this uncertainty a generic SSS model has been generated from seven commonly used SSS systems (from EdgeTech, C_MAX and Klein Systems). We have used the 90th percentile level as the representative level. In-beam levels for this source is 182 dB SPL, while the equivalent spherical broadband level is 173 dB SPL (Figure 4-4). This difference is due to the very narrow beams of SSS systems (0.5-2 degrees) which means that while the sound level is high in the beam, the mean sound level in a surrounding sphere is much smaller.

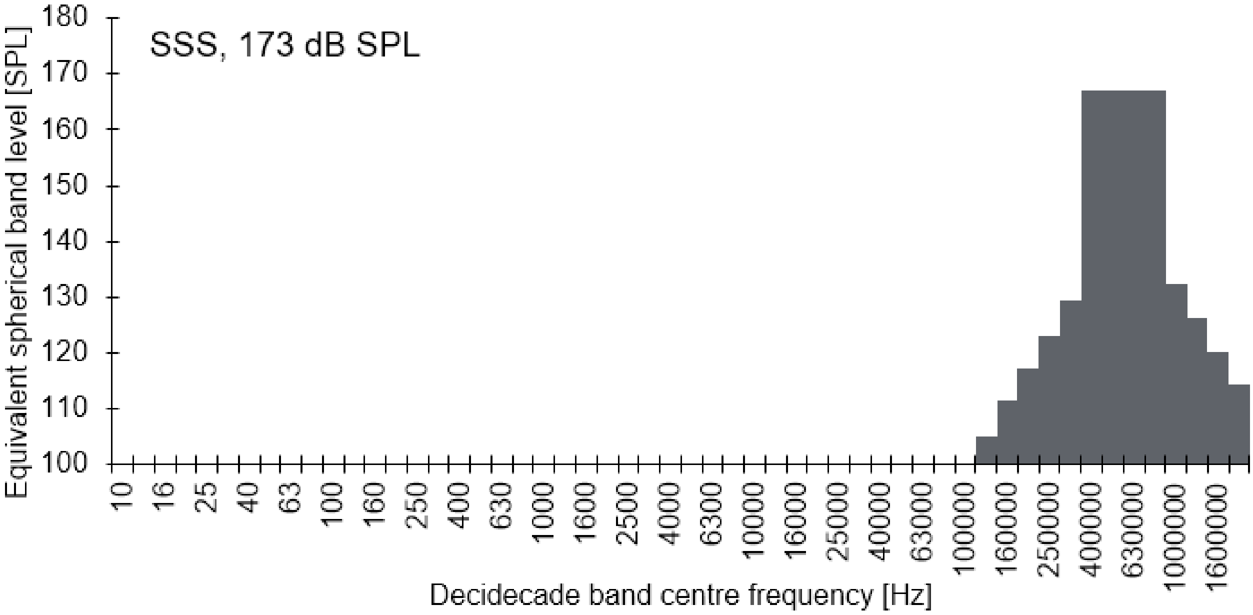


**Figure 4-4. SSS source band levels as equivalent spherical/omnidirectional levels.**

Given the shallow water (<6 m depth) it's likely that shorter pulses will be used as they offer sufficient energy for a clear returning echo. This will increase kurtosis ("impulsiveness") and modelling reveals weighted kurtosis over the limit value (353 for the VHF hearing group) for realistic ping rates for the depth. Therefore, the SSS is modelled as an impulsive noise source.

### 4.1.1.4 Ultra Short Base-Line positioning system (USBL)

If the SSS or SBP is deployed as a towfish (towed behind the vessel) it's accurate positions will need to be known. A USBL positioning system is a common solution. Here a generic USBL is used, with a 10 ms pulse length and 2 Hz ping rate, consistent with popular models (Edgetech BATS, IxBlue GAPS, Sonardyne Ranger). A max SPL [$L_P$] of 215 dB is assumed giving an SPL of 195 dB (maximal single band level 190 dB SPL, Figure 4-5).

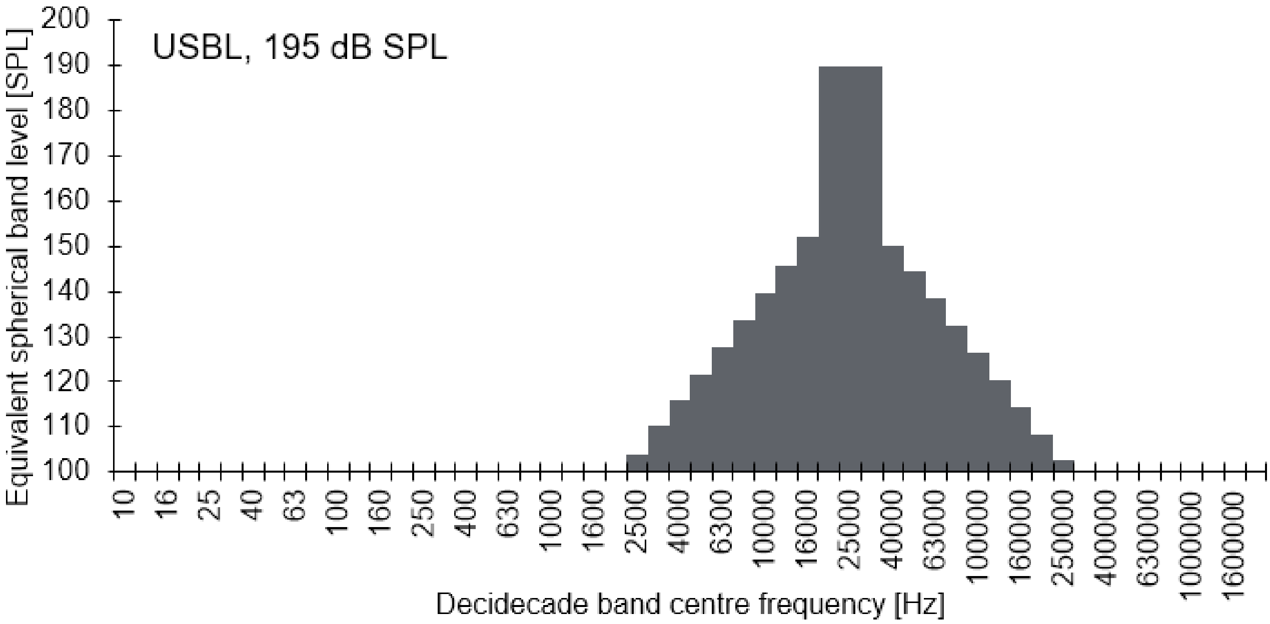


**Figure 4-5. USBL source band levels.**

The relatively short pulses and slow repetition of pulse gives a weighted kurtosis over the limit value (87 for the VHF hearing group). Therefore, the USBL is modelled as an impulsive noise source.

#### 4.1.1.5 Sub-bottom Profiler (SBP)

##### 4.1.1.5.1 Parametric SBP (P-SBP)

The Survey might use a parametric SBP such as the “Innomar Medium” sub-bottom profiler. These SBPs use two higher frequencies (“primary frequencies”) to generate an interference pattern at lower frequencies (“secondary frequencies”). This means that the secondary beam can be made extraordinarily narrow, leading to a much smaller sound impact (Appendix A, Figure 8-8). We account for these differences in beam pattern by including the sediment reflection loss at high incidence angles (see Appendix A, Figure 8-7) to reduce the effective source level accordingly.

The source level for the P-SBP is split into two regions according to the nominal frequencies, accounting for some spectral leakage (Figure 4-6) and assuming the full range of frequencies is used during The Survey (a conservative assumption). The total, broad band level for the parametric SBP is 207 dB SPL, with the secondary frequencies being 154 dB SPL.

Given the shallow water (<6 m depth) it’s likely that shorter pulses will be used as they offer sufficient energy for a clear returning echo. This will increase kurtosis (“impulsiveness”) and modelling reveals weighted kurtosis near the limit value (67 for the VHF hearing group) for realistic ping rates for the depth. Therefore, the P-SBP is modelled as an impulsive noise source.

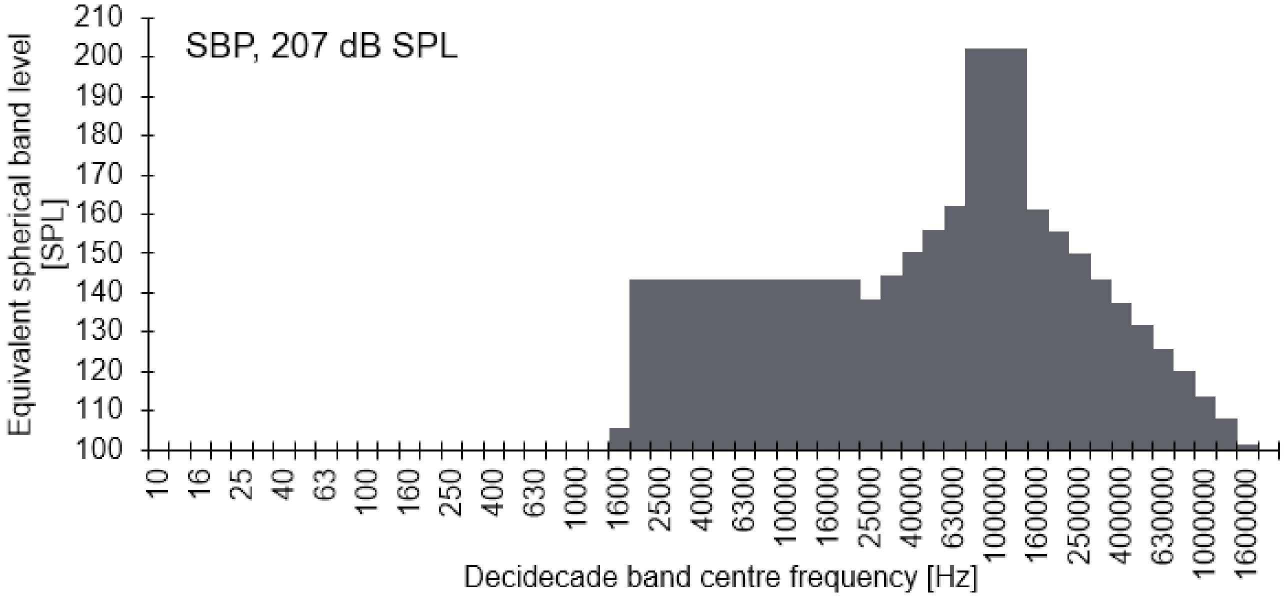


**Figure 4-6. Parametric SBP source band levels as equivalent spherical/omnidirectional levels. Primary frequencies 85 kHz – 115 kHz, secondary frequencies 2 kHz – 22 kHz.**

#### 4.1.1.5.2 Chirper/Pinger SBP (C-SBP)

A chirper or pinger type SBP might be used for this survey, as no specific model has been specified we have use a generic model based on common SBPs of this type. These have wide beams and therefore comparatively higher acoustics impact relative to their in-beam source levels. A single SBP source have been generated to represent both these sources as they are acoustically similar. Total broad band level for this SBP is 184 dB SPL with band levels given in Figure 4-7.

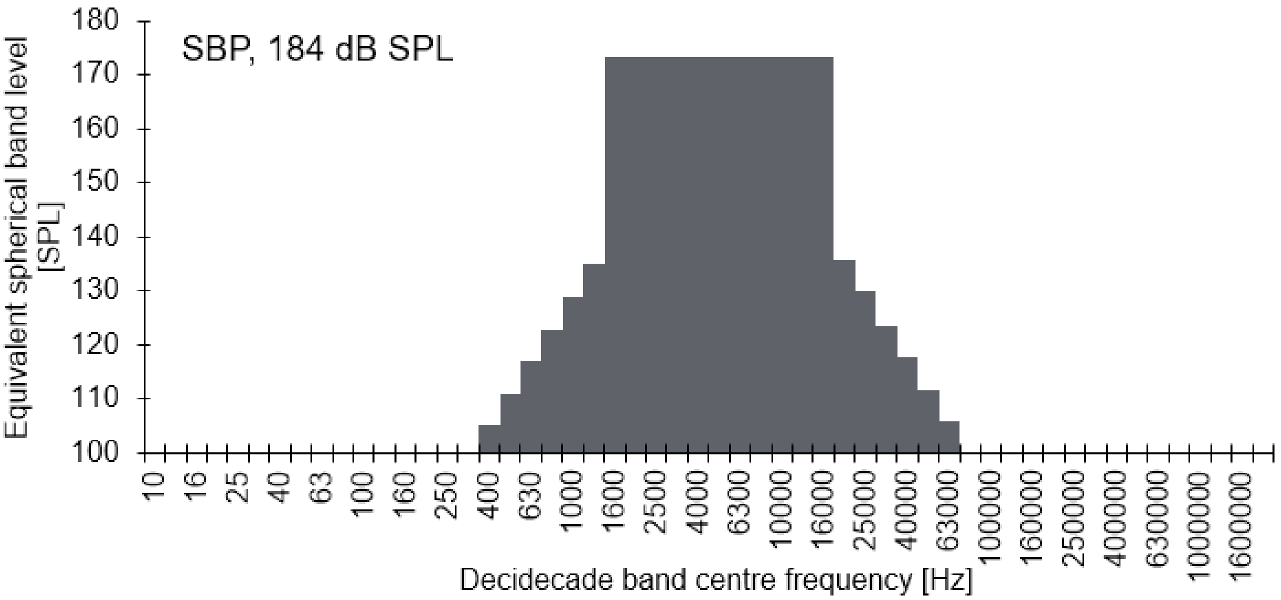


**Figure 4-7. Chirper/Pinger type SBP band levels.**

Given the shallow water (<6 m depth) it's likely that shorter pulses will be used as they offer sufficient energy for a clear returning echo. This will increase kurtosis ("impulsiveness") and modelling reveals weighted kurtosis near the limit value (79 for the VHF hearing group) for realistic ping rates for the depth. Therefore, the C-SBP is modelled as an impulsive noise source.

#### 4.1.1.6 Drilling/Coring

For extraction of physical samples, rotary coring, sonic coring or vibro-coring will be carried out. Band levels are shown in Figure 4-8. No band levels for sonic coring were available. However, the sampling methodology and broadband level means that it can be assumed to be less noisy than vibro-coring. The “Drilling/Coring” activity is a non-impulsive sound source with a broadband level of 187 dB SPL.

Of the three options proposed for sediment sampling, the vibro-coring is the loudest, and has been used as a worst-case assumption for this assessment.

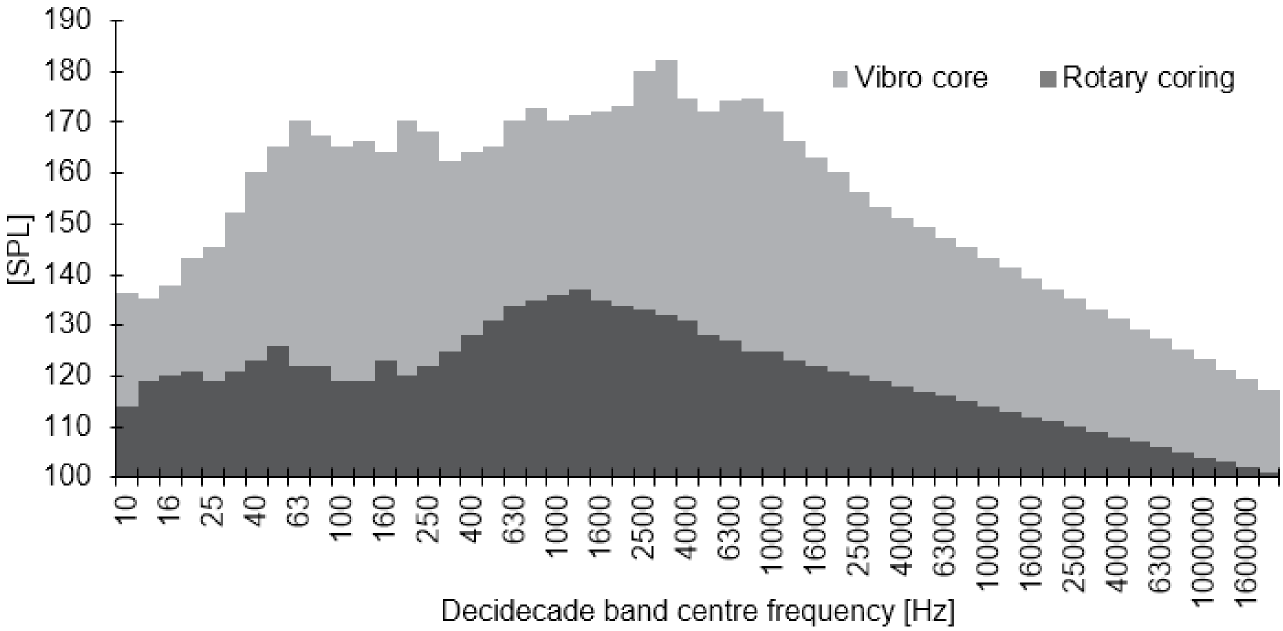


**Figure 4-8. Band levels for drilling/rotary/vibro/sonic coring. Levels above 25 kHz are extrapolated based on trend in bands at lower frequencies.**

### 4.1.2 Combined Sources

The relevant equipment for each survey type has been groups into six scenarios.

MBES and SSS is active for all combined sources of the geophysical survey.

#### 4.1.2.1 Geophysical Survey (Parametric SBP & USBL Active)

This scenario assumes the geophysical survey is using a parametric SBP and that a towfish is deployed requiring an active USBL.

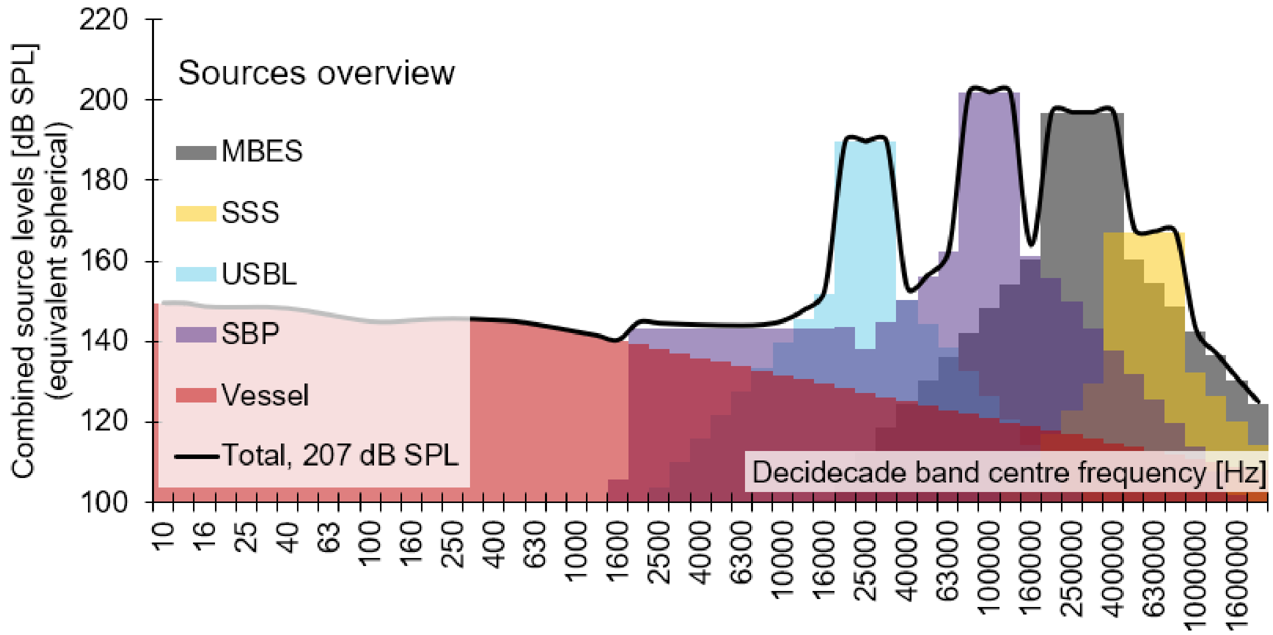


**Figure 4-9. Source band level during geophysical survey (parametric SBP & USBL active).**

### 4.1.2.2 Geophysical Survey (Parametric SBP & USBL Not Active)

This scenario assumes the geophysical survey is using a parametric SBP and that there is no need for a USBL (hull mounted SBP and SSS, with known positions).

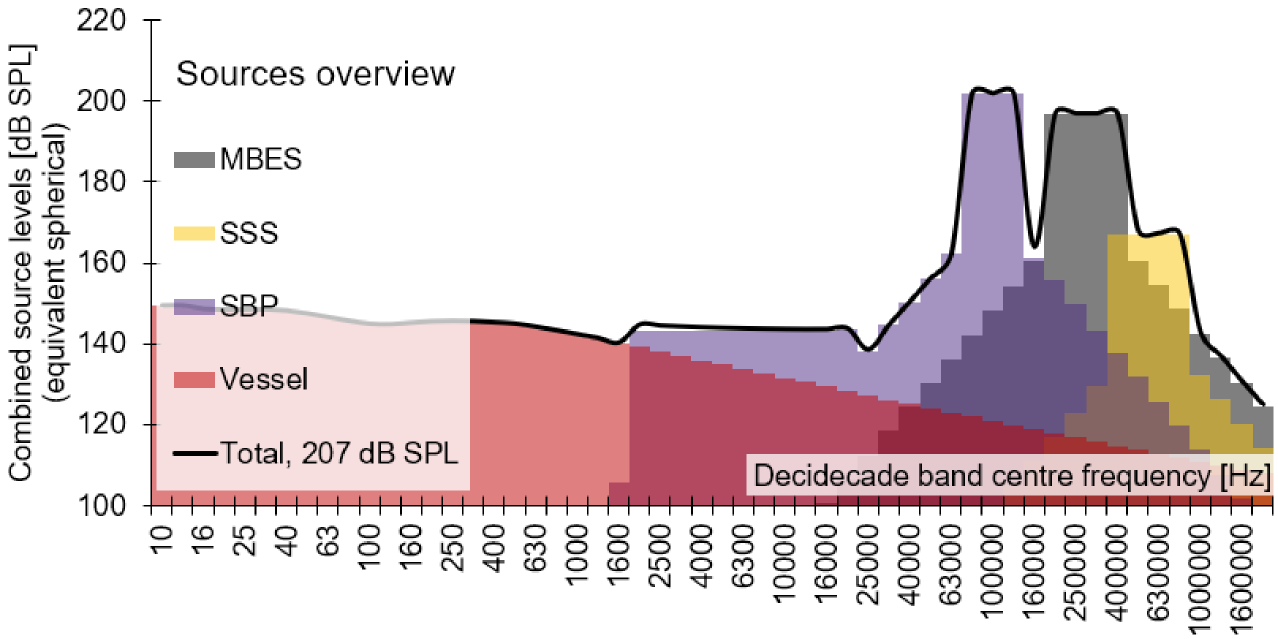


**Figure 4-10. Source band level during geophysical survey (parametric SBP & USBL not active).**

### 4.1.2.3 Geophysical Survey (Chirper/Pinger SBP & USBL Active)

This scenario assumes the geophysical survey is using a chirper or pinger type SBP and that a towfish is deployed requiring an active USBL.

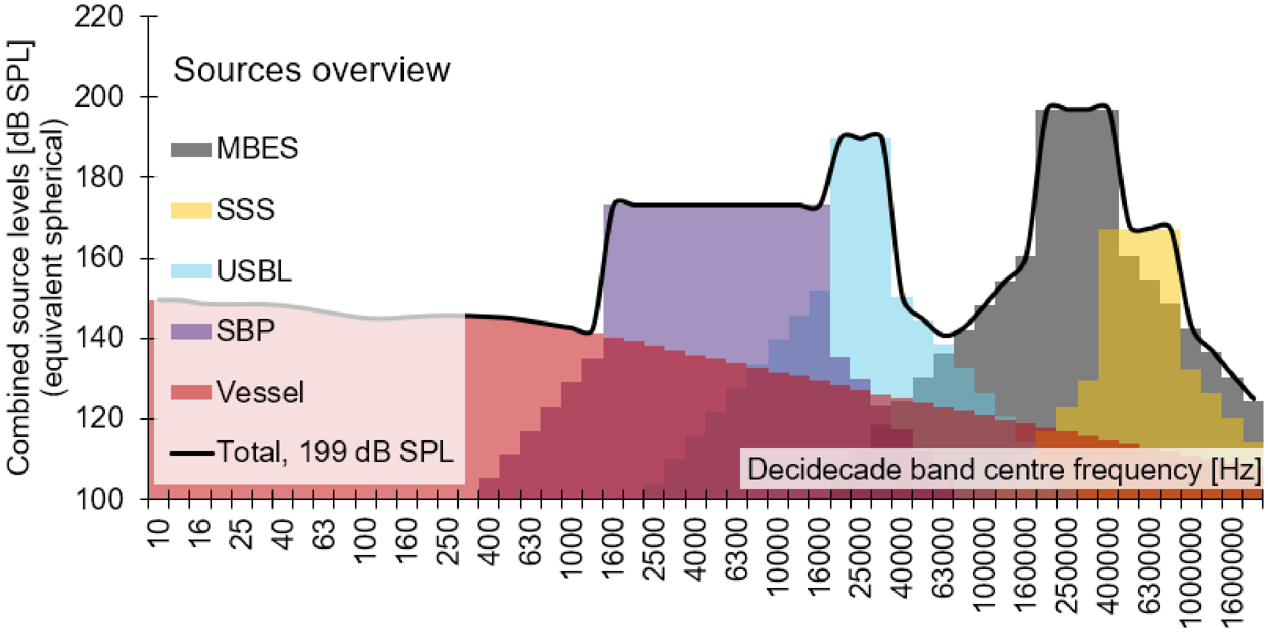


**Figure 4-11. Source band level during geophysical survey (chirper/pinger SBP & USBL active).**

### 4.1.2.4 Geophysical Survey (Chirper/Pinger SBP & USBL Not Active)

This scenario assumes the geophysical survey is using a chirper or pinger type SBP and that there is no need for a USBL (hull mounted SBP and SSS, with known positions).

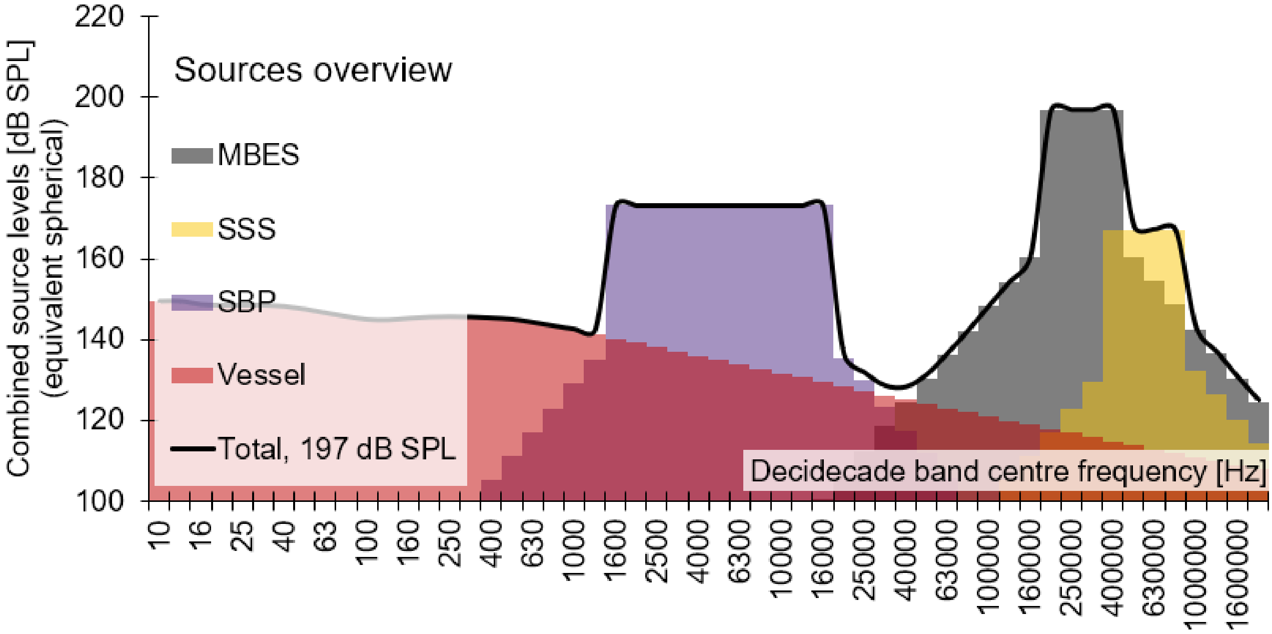


**Figure 4-12. Source band level during geophysical survey (chirper/pinger SBP & USBL not active).**

### 4.1.2.5 Soft Start Source

During soft starts it's assumed that any SBP and USBL will not be active but the MBES and/or the SSS will be active.

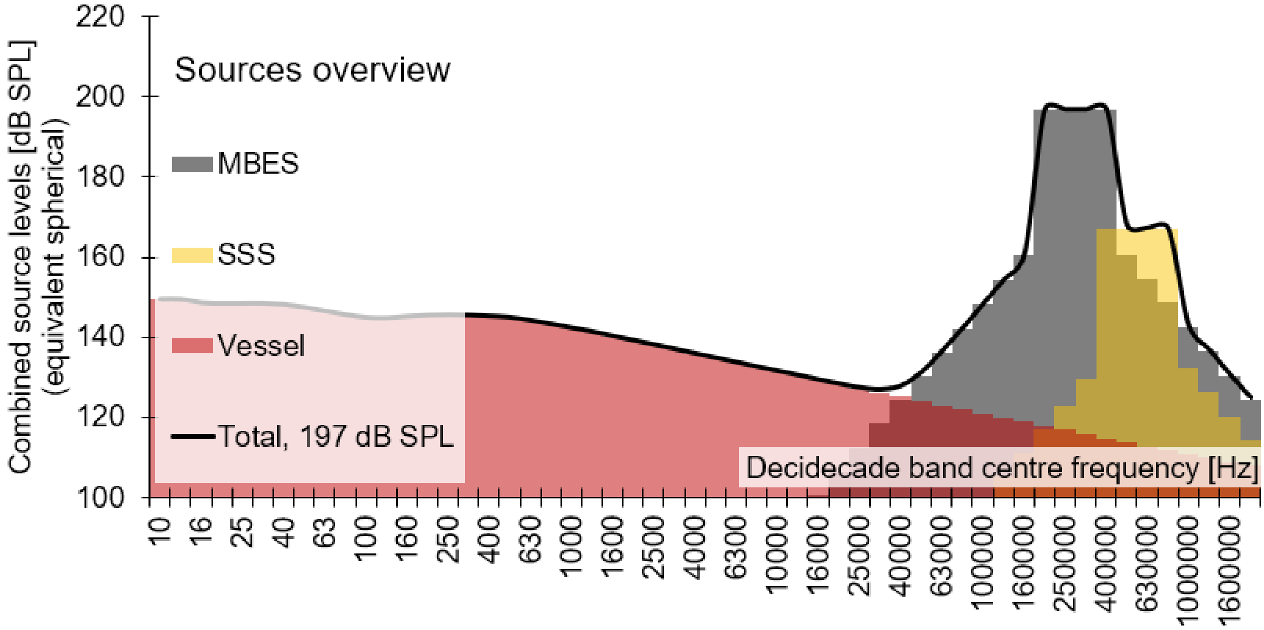


**Figure 4-13. Source band level during geophysical survey soft start.**

### 4.1.2.6 Geotechnical Survey

This scenario assumes all the vessel, rotary, sonic and vibro-coring is active.

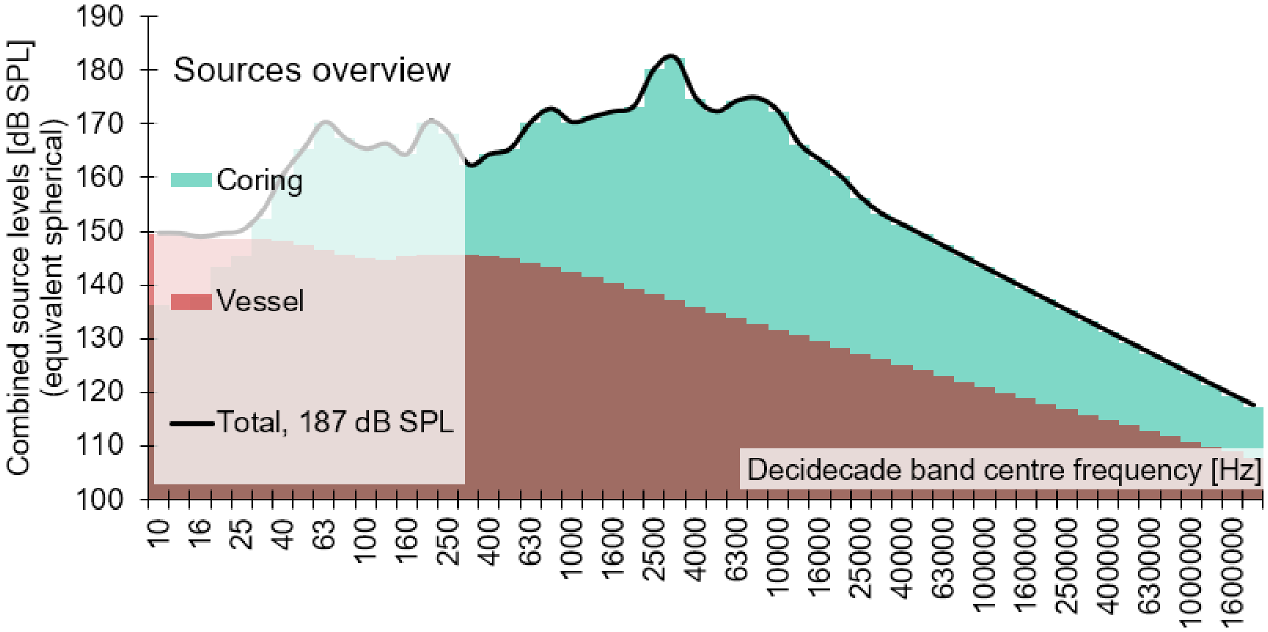


**Figure 4-14. Source band level during geotechnical survey.**

# 5 SOUND PROPAGATION MODELLING METHODOLOGY

There are several methods available for modelling the propagation of sound between a source and receiver ranging from very simple models which simply assume spreading according to a $10 \cdot \log_{10}$(range) or $20 \cdot \log_{10}$(range) relationship to full acoustic models (e.g., ray tracing, normal mode, parabolic equation, wavenumber integration and energy flux models). In addition, semi-empirical models are available which lie somewhere in between these two extremes in terms of complexity (e.g., (Rogers, 1981; Weston, 1971))[5].

For simpler scenarios, such as this one, where the sediment is relatively uniform and mostly flat or where great detail in the sound field is not needed, the speed of these simpler models is preferred over the higher accuracy of numerical models and are routinely used for these types of assessments. For this assessment we have used the “Roger’s” model (Rogers, 1981), which is suitable to depths of c. 200 m and generally softer sediments.

This model will tend to underestimate the transmission losses (leading to estimated greater than actual impact) due primarily to the omission of surface roughness, wind effects and shear waves in the sediment.

The main assumptions made for the modelling are:

1. A soft start where no SBP and no USBL is active, but MBES and/or SSS is active (section 4.1.2.5) is a feasible and practical option for the survey operator.
   This gives the VHF group a c. 9-18 dB reduction in received level for the duration of the soft start depending on exact equipment configuration.
2. Animals fleeing the area will not return within a 24-hour period.
3. Animals flee for up to 2 hours after which they will be up to 10.8 km & 3.6 km away, for marine mammals and fish respectively.
4. Modelling assumes high tide; this is a worst-case assumption.
5. Results assume a transition from impulsive (kurtosis >40) to non-impulsive (kurtosis <40) at 200-400 m range from the source. This mean all ranges greater than 400 m are assessed against the non-impulsive thresholds.
   This assumption is also applicable for the assessment of behavioural disturbance.

## 5.1 Exposure Calculations (dB SEL)

To compare modelled levels with the two impact assessment frameworks (Southall et al. 2019 & Popper et al. 2014) it’s necessary to calculate received levels as exposure levels, SEL, weighted for marine mammals, and unweighted for fishes. For ease of implementation sources have generally been converted to an SPL source level, meaning converting to SEL from SPL or from a number of events.
The conversion is relatively easy:

To convert from SPL to SEL the following relation can be used:

$$SEL = \mathrm{SPL} + 10 \cdot Log_{10}(t_2 - t_1) \qquad (1)$$

Or where it’s inappropriate to convert SEL from one event to SEL cumulative by relating to the number of events as:

$$SEL_{,n\ events} = SEL_{single\ event} + 10 \cdot Log_{10}(n) \qquad (2)$$

And SPL from SEL:

$$SPL = SEL_{single\ event} + 10 \cdot Log_{10}\left(\frac{n}{t_2 - t_1}\right) \qquad (3)$$

[5] This model is compared to measurements in the paper (Rogers, 1981) describing it and is capable of accurate modelling in acoustically simpler scenarios. Simpler meaning shallow in relation to the wavelengths and with no significant sound speed gradient in the water column.

As an animal swims away from the sound source, the noise it experiences will become progressively more attenuated; the cumulative, fleeing SEL is derived by logarithmically adding the SEL to which the mammal is exposed as it travels away from the source. This calculation is used to estimate the approximate minimum start distance for an animal in order for it to be exposed to sufficient sound energy to result in the exceedance of a threshold, or to check if a set exclusion zone is sufficient for an activity (e.g. will an exclusion zone of 500 m be sufficient to prevent exceeding a PTS threshold). It should be noted that the sound exposure calculations are based on the simplistic assumption that the animal will continue to swim away at a constant speed. The real-world situation is more complex, and the animal is likely to move in a more varied manner. Reported swim speeds are summarised in Table 5-1 along with the source papers for the assumptions.

For this assessment, we used a swim speed of 1.5 m/s for marine mammals, and 0.5 m/s for fishes including sharks.

For very long fleeing durations the ambient sound itself can exceed the thresholds, e.g., an ambient sound level of 117.5 dB, weighted for the VHF group, will exceed the non-impulsive TTS threshold of 153 dB SEL after 2 hour's exposure[6]. We here consider fleeing durations of 2 hours (7200 seconds, allowing 10800 m of fleeing), meaning that weighted levels of 117.5 dB SPL will exceed the VHF group's non-impulsive TTS threshold in the fleeing model.

**Table 5-1: Swim speed examples from literature**

| Species | Hearing Group | Swim Speed (m/s) | Source Reference |
|---|---|---|---|
| Harbour porpoise | VHF | 1.5 | Otani *et al.,* 2000 |
| Harbour seal | PCW | 1.8 | Thompson, 2015 |
| Grey seal | PCW | 1.8 | Thompson, 2015 |
| Minke whale | LF | 2.3 | Boisseau *et al.,* 2021 |
| Bottlenose dolphin | HF | 1.52 | Bailey and Thompson, 2010 |
| White-beaked dolphin | HF | 1.52 | Bailey and Thompson, 2010 |
| Basking shark | Fish (unweighted) | 1.0 | Sims, 2000 |
| All other fish groups | Fish (unweighted) | 0.5 | Popper *et al.,* 2014 |
| Sea turtles | Fish (unweighted) | 0.56-0.84 & 0.78-2.8 | (F, et al., 1997; SA, 2002) |

[6] 117.5 dB SPL + 10*$\log_{10}$(3600 seconds) = 153.1 dB SEL, TTS non-impulsive threshold for the VHF group is 153 dB SEL.

# 6 RESULTS AND ASSESSMENT

Results are presented here as the geographical “risk range” to an auditory threshold (TTS/PTS/Behavioural) as given in Sections 2.3 and 2.5. A given risk range specifies the expected range, within which, a receiver would exceed the relevant threshold. Risk ranges are given for the 90$^{th}$ percentile value.

## 6.1 Result types

Several result types are presented for each activity to inform this assessment and to provide flexibility in mitigation:

1. **“1 second exposure risk range”:**
   This is the range of acute risk of impact from the activity (a one second exposure) and is presented to indicate instantaneous risk and for comparison with other studies.
   This assumes a stationary animal (during the 1-seond exposure) with all equipment operating at full power and does not include a soft start.

2. **“Minimal starting range for a fleeing animal with no soft start”:**
   The minimal range a fleeing animal needs to start fleeing from to avoid being exposed to noise exceeding its TTS/PTS threshold. Animals are moving in a straight line away from the source at a constant speed of 1.5 m/s (0.5 m/s for fish incl. basking shark).

3. **“Minimal starting range for a fleeing animal with a 10 min soft start with no SBP and no USBL active”:**
   The minimal range a fleeing animal needs to start fleeing from to avoid being exposed to noise exceeding its TTS/PTS threshold. Animals are moving in a straight line away from the source at a constant speed of 1.5 m/s (0.5 m/s for fish incl. basking shark).

4. **“Minimal starting range for a fleeing animal with a 20 min soft start with no SBP and no USBL active”:**
   The minimal range a fleeing animal needs to start fleeing from to avoid being exposed to noise exceeding its TTS/PTS threshold. Animals are moving in a straight line away from the source at a constant speed of 1.5 m/s (0.5 m/s for fish incl. basking shark).

5. **“Behavioural response range”:**
   The range at which the behavioural limit for the marine mammals (160/120 dB SPL impulsive/non-impulsive) or the fishes (incl. sharks) (150 dB SPL) is exceeded.

## 6.2 Assumptions and Notes

The results should be read while keeping the following in mind:

- Results are rounded up to nearest 2 significant digits, this can lead to some curious appearing overlaps in risk ranges.
- Results for behavioural disturbance mainly rely on the non-impulsive threshold of 120 dB SPL (for marine mammals) as the noise transitions to non-impulsive in the range 200-400 m. This means large ranges of disturbance, but should be considered in relation to e.g., the radiated noise from common vessels which will also exceed this threshold to ranges of 500-5000 m (assuming 160-175 dB SPL source level).
- The soft start has little effect on the TTS ranges for the VHF group when the USBL is active, this is due to the relatively low threshold for TTS for the VHF group (153 dB SEL) and the logarithmic nature of transmission losses: A constant reduction of received level with a multiplication of range – a 3-6 dB reduction per doubling of distance, such as from 2 km to 4 km (until ranges become large enough for absorption to become significant) – means that fleeing is not very effective at reducing received level.

- Animals are modelled as fleeing in straight lines. Where sites are very confined, the maximal risk ranges will be restricted by line-of-sight ranges (and cut short where they meet land). Note that this simply means that animals leaving the confined area will also have left the activities' noise impact (as noise at relevant frequencies attenuates extremely rapidly by passing through land).
- Modelling assumed a maximal fleeing time of 7200 seconds (2 hours), this allows for 10.8 km of fleeing for marine mammals (3.6 km for fish).
- Modelling is limited to a range of 10 km from the source.
- No modelling of risk ranges for mortality for fishes as risk ranges to PTS (recoverable injury) are all smaller than 30 m.
- No results for assessment against the $L_P$ thresholds are included as for all scenarios the risk ranges to the PTS threshold were below 10 m.

  Results are thus *only* given in relation to the behavioural thresholds (SPL) and TTS/PTS thresholds for sound exposure level (SEL).
- The hearing group "Fish" includes sharks and are for unweighted received levels assessed against the lowest thresholds for fishes as found in guidance (Popper, et al., 2014).

## 6.3 Results

For all geophysical survey results, the vessel, SSS and MBES are active, only the type of SBP and presence of a USBL is changing between the scenarios modelled.

### 6.3.1 Geophysical Survey (Parametric SBP & USBL Active)

This scenario assumes the geophysical survey is using a parametric SBP and that a towfish is deployed requiring an active USBL (Section 4.1.2.1).

Risk ranges for exceeding PTS is below 140 meters for all groups except the VHF group, which risks exceeding the PTS threshold to a range of 670 m with no soft start.

A soft start of 10 minutes will allow sufficient time for the VHF group to swim away to reduce the PTS exceedance risk range to 270 m.

A soft start of 20 minutes will allow sufficient time for the VHF group to swim away to reduce the PTS exceedance risk range to 240 m.

The soft start itself has a PTS risk range of 240 m for the VHF group. Therefore, extension of the soft start duration will not decrease the PTS risk range further.

**Table 6-1: Risk ranges for exceeding the behavioural threshold for all hearing groups during Geophysical survey (Parametric SBP & USBL active).**

| Behavioural Threshold exceedance Risk ranges (SPL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| Non-impulsive | 4300 | 4300 | 4300 | 4300 | 4300 | 670 |

**Table 6-2: Risk ranges for exceeding the TTS threshold for all hearing groups during Geophysical survey (Parametric SBP & USBL active).**

| TTS Threshold Exceedance Risk ranges (SEL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| One second | 10 | 100 | 1500 | 20 | <10 | 20 |
| Fleeing receiver, no soft start | 260 | 400 | 3500* | 320 | <10 | 240 |
| Fleeing receiver, 10 min soft start | <10 | 80 | 3500* | <10 | <10 | 110 |
| Fleeing receiver, 20 min soft start | <10 | 70 | 3500* | <10 | <10 | 90 |

*See Comments, section 6.2 on results limitations.

**Table 6-3. Risk ranges for exceeding the PTS threshold for all hearing groups during Geophysical survey (Parametric SBP & USBL active).**

| PTS Threshold Exceedance Risk ranges (SEL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| One second | <10 | 10 | 420 | <10 | <10 | <10 |
| Fleeing receiver, no soft start | 20 | 140 | 670 | 30 | <10 | 30 |
| Fleeing receiver, 10 min soft start | <10 | <10 | 270 | <10 | <10 | <10 |
| Fleeing receiver, 20 min soft start | <10 | <10 | 240 | <10 | <10 | <10 |

### 6.3.2 Geophysical Survey (Parametric SBP & USBL Not Active)

This scenario assumes the geophysical survey is using a parametric SBP and that there is no need for a USBL as the SBP and SSS are hull mounted with known positions (Section 4.1.2.2).

Risk ranges for exceeding PTS is below 110 meters for all groups except the VHF group, which risks exceeding the PTS threshold to a range of 400 m with no soft start.

A soft start of 10 minutes will allow sufficient time for the VHF group to swim away to reduce the PTS exceedance risk range to 240 m.

A soft start of 20 minutes will allow sufficient time for the VHF group to swim away to reduce the PTS exceedance risk range to 240 m.

The soft start itself has a PTS risk range of 240 m for the VHF group. Therefore, extension of the soft starts will not decrease the PTS risk range further.

**Table 6-4: Risk ranges for exceeding the behavioural threshold for all hearing groups during Geophysical survey (Parametric SBP & USBL not active).**

| Behavioural Threshold exceedance Risk ranges (SPL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| Non-impulsive | 1300 | 1300 | 1300 | 1300 | 1300 | 490 |

**Table 6-5: Risk ranges for exceeding the TTS threshold for all hearing groups during Geophysical survey (Parametric SBP & USBL not active).**

| TTS Threshold Exceedance Risk ranges (SEL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| One second | <10 | 90 | 690 | 10 | <10 | 20 |
| Fleeing receiver, no soft start | 40 | 340 | 860 | 100 | <10 | 220 |
| Fleeing receiver, 10 min soft start | <10 | 70 | 390 | <10 | <10 | 100 |
| Fleeing receiver, 20 min soft start | <10 | 70 | 380 | <10 | <10 | 90 |

**Table 6-6. Risk ranges for exceeding the PTS threshold for all hearing groups during Geophysical survey (Parametric SBP & USBL not active).**

| PTS Threshold Exceedance Risk ranges (SEL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| One second | <10 | 10 | 340 | <10 | <10 | <10 |
| Fleeing receiver, no soft start | <10 | 110 | 400 | <10 | <10 | 30 |
| Fleeing receiver, 10 min soft start | <10 | <10 | 240 | <10 | <10 | <10 |
| Fleeing receiver, 20 min soft start | <10 | <10 | 240 | <10 | <10 | <10 |

### 6.3.3 Geophysical Survey (Chirper/Pinger SBP & USBL Active)

This scenario assumes the geophysical survey is using a chirper or pinger type SBP and that a towfish is deployed requiring an active USBL (Section 4.1.2.3).

Risk ranges for exceeding PTS is below 60 meters for all groups except the VHF group, which risks exceeding the PTS threshold to a range of 660 m with no soft start.

A soft start of 10 minutes will allow sufficient time for the VHF group to swim away to reduce the PTS exceedance risk range to 280 m.

A soft start of 20 minutes will allow sufficient time for the VHF group to swim away to reduce the PTS exceedance risk range to 240 m.

The soft start itself has a PTS risk range of 240 m for the VHF. Therefore, extension of the soft starts will not decrease the PTS risk range further.

**Table 6-7: Risk ranges for exceeding the behavioural threshold for all hearing groups during Geophysical survey (Chirper/pinger SBP & USBL active).**

| Behavioural Threshold exceedance Risk ranges (SPL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| Non-impulsive | 4300 | 4300 | 4300 | 4300 | 4300 | 640 |

**Table 6-8: Risk ranges for exceeding the TTS threshold for all hearing groups during Geophysical survey (Chirper/pinger SBP & USBL active).**

| TTS Threshold Exceedance Risk ranges (SEL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| One second | 20 | 40 | 1500 | 20 | <10 | 10 |
| Fleeing receiver, no soft start | 300 | 390 | 3700* | 330 | <10 | 150 |
| Fleeing receiver, 10 min soft start | <10 | 80 | 3700* | <10 | <10 | 90 |
| Fleeing receiver, 20 min soft start | <10 | 70 | 3700* | <10 | <10 | 90 |

*See Comments, section 6.2 on results limitations.

**Table 6-9. Risk ranges for exceeding the PTS threshold for all hearing groups during Geophysical survey (Chirper/pinger SBP & USBL active).**

| PTS Threshold Exceedance Risk ranges (SEL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| One second | <10 | <10 | 320 | <10 | <10 | <10 |
| Fleeing receiver, no soft start | 20 | 60 | 660 | 30 | <10 | <10 |
| Fleeing receiver, 10 min soft start | <10 | <10 | 280 | <10 | <10 | <10 |
| Fleeing receiver, 20 min soft start | <10 | <10 | 240 | <10 | <10 | <10 |

### 6.3.4 Geophysical Survey (Chirper/Pinger SBP & USBL Not Active)

This scenario assumes the geophysical survey is using a chirper or pinger type SBP and that there is no need for a USBL as the SBP and SSS are hull mounted with known positions (Section 4.1.2.4).

Risk ranges for exceeding PTS is below 10 meters for all groups except the VHF group, which risks exceeding the PTS threshold to a range of 320 m with no soft start.

A soft start of 10 minutes will allow sufficient time for the VHF group to swim away to reduce the PTS exceedance risk range to 240 m.

A soft start of 20 minutes will allow sufficient time for the VHF group to swim away to reduce the PTS exceedance risk range to 240 m.

The soft start itself has a PTS risk range of 240 m for the VHF group. Therefore, extensions of the soft starts will not decrease the PTS risk range further.

**Table 6-10: Risk ranges for exceeding the behavioural threshold for all hearing groups during Geophysical survey (Chirper/pinger SBP & USBL not active).**

| Behavioural Threshold exceedance Risk ranges (SPL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| Non-impulsive | 3600 | 3600 | 3600 | 3600 | 3600 | 260 |

**Table 6-11: Risk ranges for exceeding the TTS threshold for all hearing groups during Geophysical survey (Chirper/pinger SBP & USBL not active).**

| TTS Threshold Exceedance Risk ranges (SEL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| One second | <10 | 10 | 280 | <10 | <10 | 10 |
| Fleeing receiver, no soft start | 180 | 90 | 1700 | 130 | <10 | 90 |
| Fleeing receiver, 10 min soft start | <10 | 70 | 1700 | <10 | <10 | 90 |
| Fleeing receiver, 20 min soft start | <10 | 70 | 400 | <10 | <10 | 90 |

**Table 6-12. Risk ranges for exceeding the PTS threshold for all hearing groups during Geophysical survey (Chirper/pinger SBP & USBL not active).**

| PTS Threshold Exceedance Risk ranges (SEL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| One second | <10 | <10 | 100 | <10 | <10 | <10 |
| Fleeing receiver, no soft start | <10 | <10 | 320 | <10 | <10 | <10 |
| Fleeing receiver, 10 min soft start | <10 | <10 | 240 | <10 | <10 | <10 |
| Fleeing receiver, 20 min soft start | <10 | <10 | 240 | <10 | <10 | <10 |

### 6.3.5 Geotechnical Survey

This scenario assumes all the vessel, rotary, sonic and vibro-coring is active (Section 4.1.2.6).

No soft start has been modelled for the geotechnical survey; this is based on:

1. Risk ranges for exceeding PTS are below 10 meters for all groups.
2. The sampling platform (vessel or barge) will itself emit similar noise to the sampling activity and will serve as a type of soft start exceeding normal soft start durations.
3. The geotechnical equipment itself cannot easily be operated at reduced noise output.

**Table 6-13: Risk ranges for exceeding the behavioural threshold for all hearing groups during Geotechnical survey.**

| Behavioural Threshold exceedance Risk ranges (SPL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| Non-impulsive | 4700 | 4700 | 4700 | 4700 | 4700 | 290 |

**Table 6-14: Risk ranges for exceeding the TTS threshold for all hearing groups during Geotechnical survey.**

| TTS Threshold Exceedance Risk ranges (SEL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| One second | <10 | <10 | 20 | <10 | <10 | <10 |
| Fleeing receiver, no soft start | 50 | <10 | 1200 | 20 | <10 | <10 |

**Table 6-15. Risk ranges for exceeding the PTS threshold for all hearing groups during Geotechnical survey.**

| PTS Threshold Exceedance Risk ranges (SEL thresholds) | LF [m] | HF [m] | VHF [m] | PCW [m] | OCW [m] | Fish [m] |
|---|---|---|---|---|---|---|
| One second | <10 | <10 | <10 | <10 | <10 | <10 |
| Fleeing receiver, no soft start | <10 | <10 | <10 | <10 | <10 | <10 |

## 6.4 Results Summary

### 6.4.1 Geophysical Survey

**Parametric SBP & USBL**

The risk ranges to PTS exceedance for fleeing receivers of the VHF group is within 270 m with a 10-minute soft start.

The risk ranges for remaining groups are within 140 m, with no soft start.

**Parametric SBP & no USBL**

The risk ranges to PTS exceedance for fleeing receivers of the VHF group at or within 240 m with a 10-minute soft start.

The risk ranges for the remaining groups are within 110 m, with no soft start.

**Chirper or pinger SBP & USBL**

The risk ranges to PTS exceedance for fleeing receivers of the VHF group over 280 m with a 10-minute soft start.

The risk ranges for the remaining groups are within 60 m, with no soft start.

**Chirper or pinger SBP & no USBL**

The risk ranges to PTS exceedance for fleeing receivers (VHF group) over 240 m with a 10-minute soft start.

The risk ranges for the remaining groups are within 10 m, with no soft start.

### 6.4.2 Geotechnical Survey

The geotechnical survey has virtually no risk of exceeding PTS thresholds for any hearing group, with all ranges to PTS risk below 10 m.

# 7 CONCLUSIONS

This assessment concludes that with the application of a suitable soft start of 10 minutes where the sub-bottom profiler (SBP) and ultrashort baseline positioning system (USBL) is switched off, and the multibeam echosounder (MBES) and the side scan sonar (SSS) remains on, with a 500 m pre-survey search there is little to no risk of causing auditory injury to the assessed species groups (marine mammals and fishes).

The VHF hearing group containing harbour porpoises is the main driver of risk. All other hearing groups (i.e., marine mammals and fishes) have risk ranges for auditory injury below 140 m for any configuration of sub-bottom profiler and positioning system, even with no soft start.

Behavioural disturbance ranges of up to 4.7 km have been identified for marine mammals for the Geotechnical Survey. Behavioural disturbance ranges of 1.3 - 4.3 km for Geophysical Survey scenarios.

However, these behavioural disturbance ranges should be considered in the context of behavioural disturbance ranges for common vessels operating in the area. For medium to larger vessels, such as fast ferries or freight vessels, the behavioural ranges will be comparable to those from the survey.

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# Appendix A – Acoustic Concepts and Terminology

Sound travels through water as vibrations of the fluid particles in a series of pressure waves. The waves comprise a series of alternating compressions (positive pressure variations) and rarefactions (negative pressure fluctuations). Because sound consists of variations in pressure, the unit for measuring sound is usually referenced to a unit of pressure, the Pascal (Pa). The unit usually used to describe sound is the decibel (dB) and, in the case of underwater sound, the reference unit is taken as 1 µPa, one micro-pascal, whereas airborne sound is usually referenced to a pressure of 20 µPa. To convert from a sound pressure level referenced to 20 µPa to one referenced to 1 µPa, a factor of 20 log (20/1) i.e. 26 dB has to be added to the former quantity. Thus, a sound pressure of 60 dB re 20 µPa is the same as 86 dB re 1 µPa, although care also needs to be taken when converting from in air sound to in water sound levels due to the different sound speeds and densities of the two mediums resulting in a conversion factor of approximately 62 dB for comparing intensities (watt/m²), see Table 8-1 , below.

**Table 8-1: Comparing sound quantities between air and water.**

| | Constant intensity | | Constant pressure | |
|---|---|---|---|---|
| **Properties** | **Air** | **Water** | **Air** | **Water** |
| Soundspeed (C) [m/s] | 340 | 1500 | 340 | 1500 |
| Density (ρ) [kg/m³] | 1.293 | 1026 | 1.293 | 1026 |
| Acoustic impedance (Z=C·ρ) [kg/(m²·s) or (Pa·s)/m³] | 440 | 1539000 | 440 | 1539000 |
| Sound intensity (I=p²/Z) [Watt/m²] | 1 | 1 | 22.7469 | 0.0065 |
| Sound pressure (p=(I*Z)$^{½}$) [Pa] | 21 | 1241 | 100 | 100 |
| Particle velocity (I/p) [m/s] | 0.04769 | 0.00081 | 0.22747 | 0.00006 |
| dB re 1 µPa² | 146.4 | **181.9** | 160.0 | **160.0** |
| dB re 20 µPa² | **120.4** | 155.9 | **134.0** | 134.0 |
| | | | | |
| **Difference dB re 1 µPa² & dB re 20 µPa²** | **61.5** | | **26.0** | |

All underwater sound pressure levels in this report are described in dB re 1 µPa². In water, the sound source strength is defined by its sound pressure level in dB re 1 µPa², referenced back to a representative distance of 1m from an assumed (infinitesimally small) point source. This allows calculation of sound levels in the far-field. For large, distributed sources, the actual sound pressure level in the near-field will be lower than predicted.

There are several descriptors used to characterise a sound wave. The difference between the lowest pressure deviation (rarefaction) and the highest pressure deviation (compression) from ambient is the peak to peak (or pk-pk) sound pressure ($L_{P\text{-}P}$ for the level in dB), Note that $L_{P\text{-}P}$ can be hard to measure consistently, as the maximal duration between the lowest and highest pressure deviation is not standardised. The difference between the highest deviation (either positive or negative) and the ambient pressure is called the peak pressure ($L_P$ for the level in dB).  Lastly, the average sound pressure is used as a description of the average amplitude of the variations in pressure over a specific time window (SPL for the level in dB). SPL is equal to the $L_{eq}$ when the time window for the SPL is equal to the time window for the total duration of an event. The cumulative sound energy from pressure is the integrated squared pressure over a given period (SEL for the level in dB). These descriptions are shown graphically in Figure 8-1 and reflect the units as given in ISO 18405:2017, “Underwater Acoustics – Terminology”.

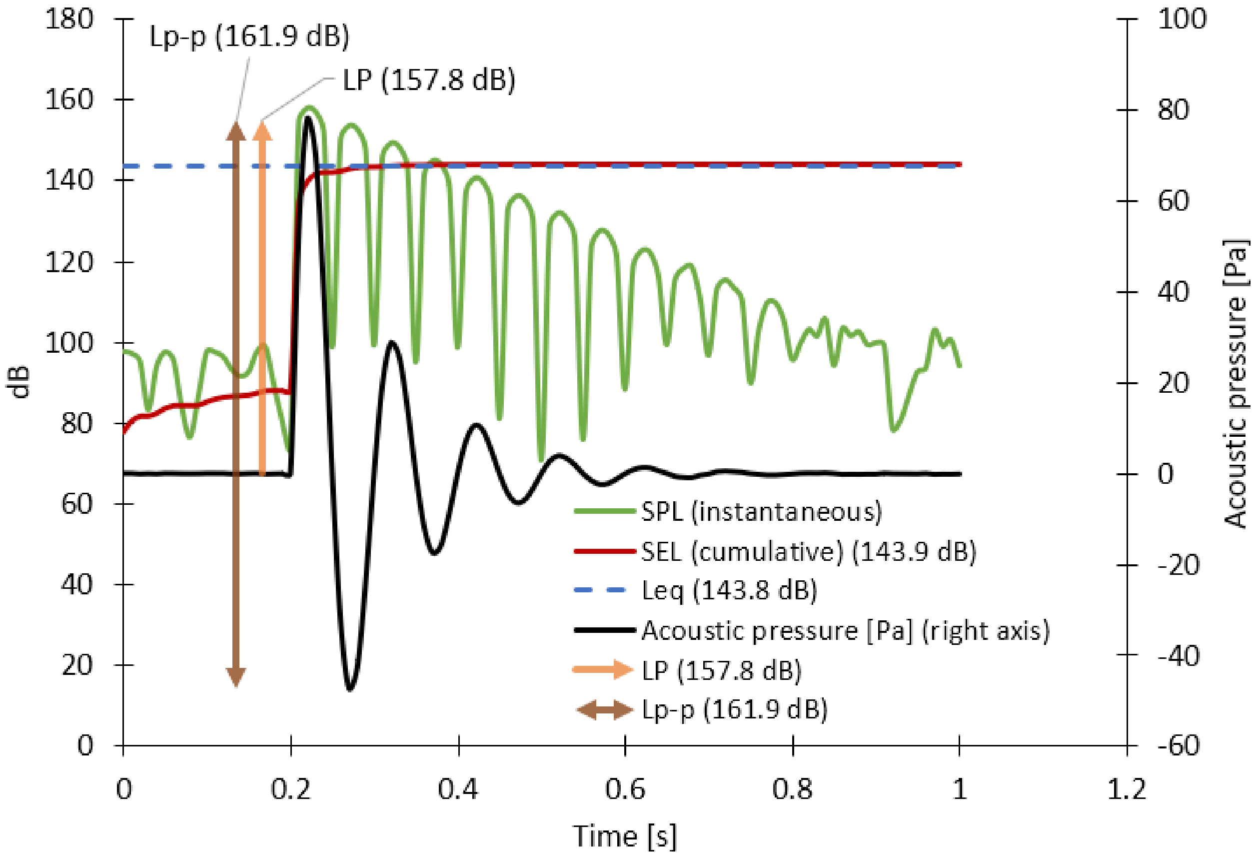


**Figure 8-1: Graphical representation of acoustic wave descriptors ("LE" = SEL).**

The sound pressure level (SPL[7]) is defined as follows (ISO 18405:2017, 3.2.1.1):

$$SPL = 10 \cdot Log_{10}\left(\frac{\overline{p^2}}{1 \cdot 10^{-12} Pa}\right) \qquad (1)$$

Here $\overline{p^2}$ is the arithmetic mean of the squared pressure values. Note that $L_P$ is simply the instantaneous SPL (ISO 18405:2017, 3.2.2.1).

The peak sound pressure level, $L_P$, is the instantaneous decibel level of the maximal deviation from ambient pressure and is defined in (ISO 18405:2017, 3.2.2.1) and can be calculated as:

$$L_P = 10 \cdot Log_{10}\left(\frac{max(p^2)}{1 \cdot 10^{-12} Pa}\right)$$

Another useful measure of sound used in underwater acoustics is the Exposure Level, or SEL. This descriptor is used as a measure of the total sound energy of a single event or a number of events (e.g. over the course of a day). This allows the total acoustic energy contained in events lasting a different amount of time to be compared on a like for like basis. Historically, use was primarily made of SPL and $L_P$ metrics for assessing the potential effects of sound on marine life. However, the SEL is increasingly being used as it allows exposure duration and the effect of exposure to multiple events over e.g. a 24-hour period to be taken into account. The SEL is defined as follows (ISO 18405:2017, 3.2.1.5):

$$SEL = 10 \cdot Log_{10}\left(\frac{\int_{t_1}^{t_2} p(t)^2 dt}{1 \cdot 10^{-12} Pa}\right) \qquad (2)$$

To convert from SEL to SPL the following relation can be used:

$$SEL = \text{SPL} + 10 \cdot Log_{10}(t_2 - t_1) \qquad (3)$$

[7] Equivalent to the commonly seen "RMS-level".

Converting from a single event to multiple events for SEL:

$$SEL_{n\ events} = SEL_{single\ event} + 10 \cdot Log_{10}(n) \quad (4)$$

The frequency, or pitch, of the sound is the rate at which these oscillations occur and is measured in cycles per second, or Hertz (Hz). When sound is measured in a way which approximates to how a human would perceive it using an A-weighting filter on a sound level meter, the resulting level is described in values of dB(A). However, the hearing faculties of marine mammals and fish are not the same as humans, with marine mammals hearing over a wider range of frequencies, fish over a typically smaller range of frequencies and both with different sensitivities. It is therefore important to understand how an animal's hearing varies over the entire frequency range to assess the effects of sound on marine life. Consequently, use can be made of frequency weighting scales to determine the level of the sound in comparison with the auditory response of the animal concerned. A comparison between the typical hearing response curves for fish, humans and marine mammals is shown in Figure 8-2. Note that hearing thresholds are sometimes shown as audiograms with sound level on the y axis rather than sensitivity, resulting in the graph shape being the inverse of the graph shown. It is also worth noting that some fish are sensitive to particle velocity rather than pressure, although paucity of data relating to particle velocity levels for anthropogenic sound sources means that it is often not possible to quantify this effect. Marine reptiles (mostly sea turtles) have relatively poor hearing underwater, lacking a good acoustic coupling mechanism from the sea water to the inner ear.

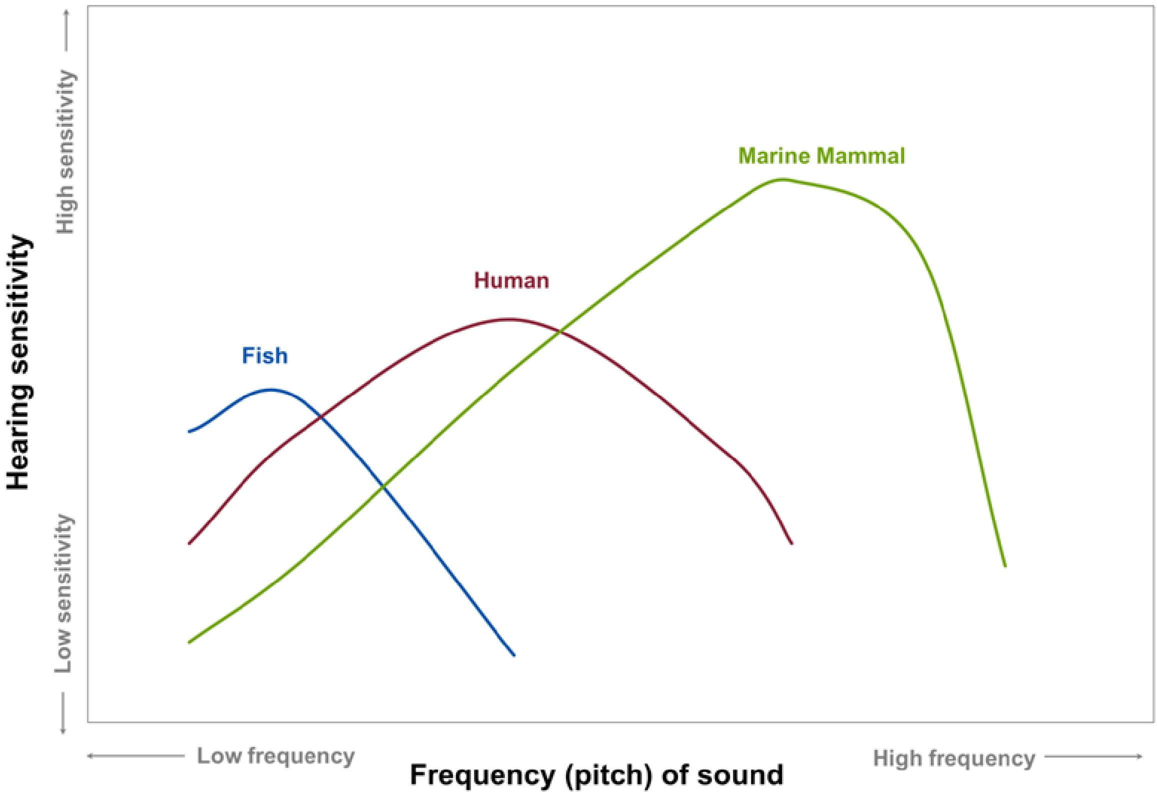


**Figure 8-2: Comparison between hearing thresholds of different marine animals and humans.**

## Impulsiveness

The impulsiveness of a source can be estimated from the kurtosis of the weighted signal (as suggested by Matin et al. in “Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals”, Journal of the Acoustical Society of America, 2020)

The consequence of this is that the same equipment can be both impulsive and non-impulsive, depending o marine mammal presence and the local environment.

Below is an example of a hull mounted echo sounder at 15 m depth and at 250 m depth.

In shallow water the ping rate can be high as reflections from the sediment return quickly, but the single pulse duration is usually shorter as less energy in the signal is required due to the short range the pulse must travel. This leads to high repetition rate (decreases kurtosis) and shorter pulses (increases kurtosis). Figure 8-3 shows an example where this leads to a non-impulsive source, to be compared to the thresholds for non-impulsive noise.

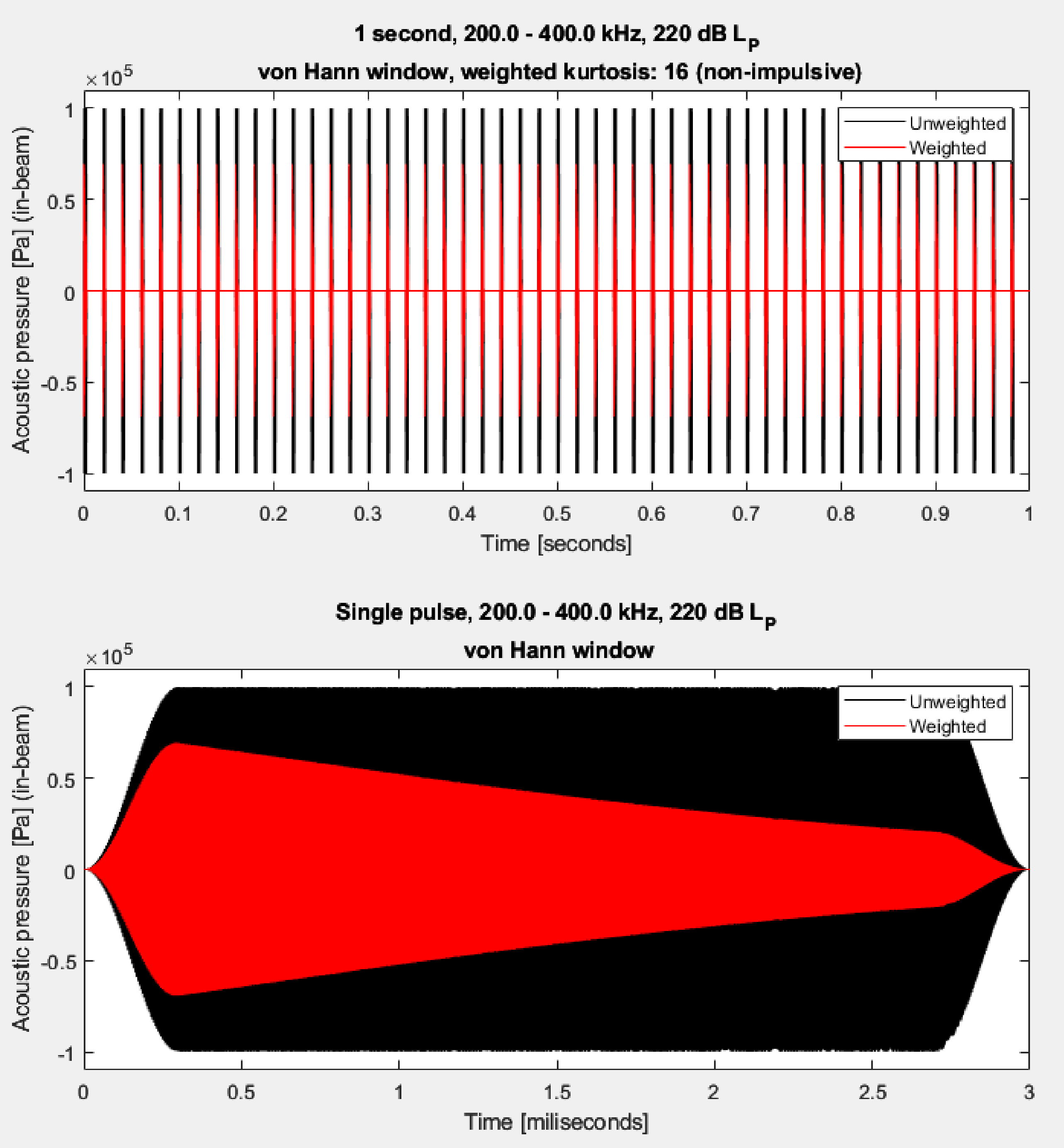


Figure 8-3. Example of a multibeam echosounder at 15 m depth (achieving 50 ping/sec) with a 3 ms ping duration. VHF-weighted kurtosis of 16 – non-impulsive.

In deeper water, the ping rate will usually be slower as echoes take longer to return to the sediment and the pulses will be longer to increase the energy in the pulses and make their echoes easier to detect. This leads to low repetition rate (increases kurtosis) and longer pulses (decreases kurtosis). Figure 8-4 shows an example where this combination resulted in an impulsive source, to be compared to the thresholds for impulsive noise.

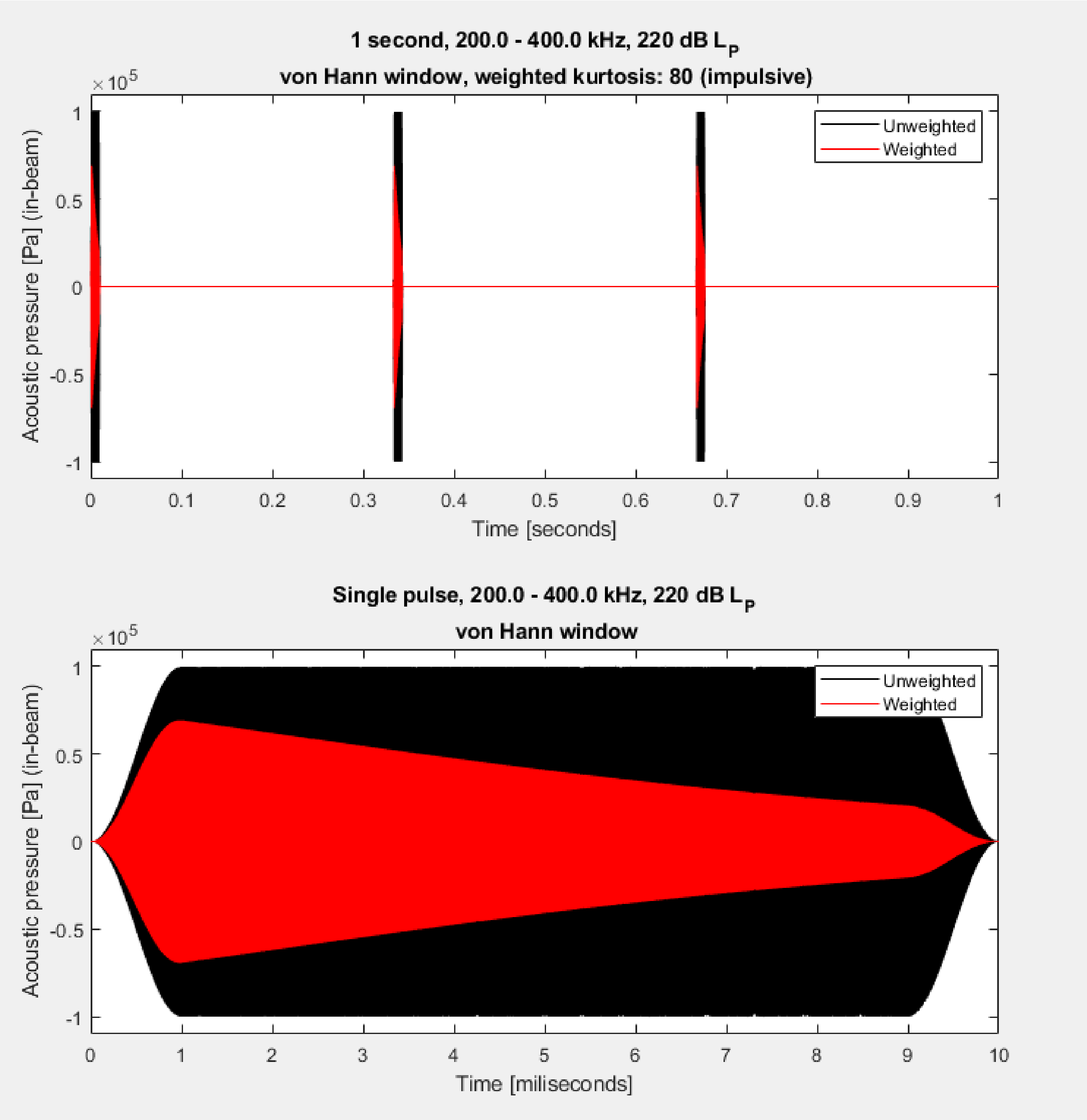


Figure 8-4. Example of a multibeam echosounder at 250 m depth (achieving 3 ping/sec) with a 10 ms ping duration. VHF-weighted kurtosis of 80 – impulsive.

With range, due to multiple reflections and scattering, the kurtosis will decrease with increased range, for shallow water this decrease will be quicker than for deeper water, compare Figure 8-5 & Figure 8-6, where a kurtosis <40 is reached at c. 200 m in 20 m depth, but at over 1000 m at 200 m depth.

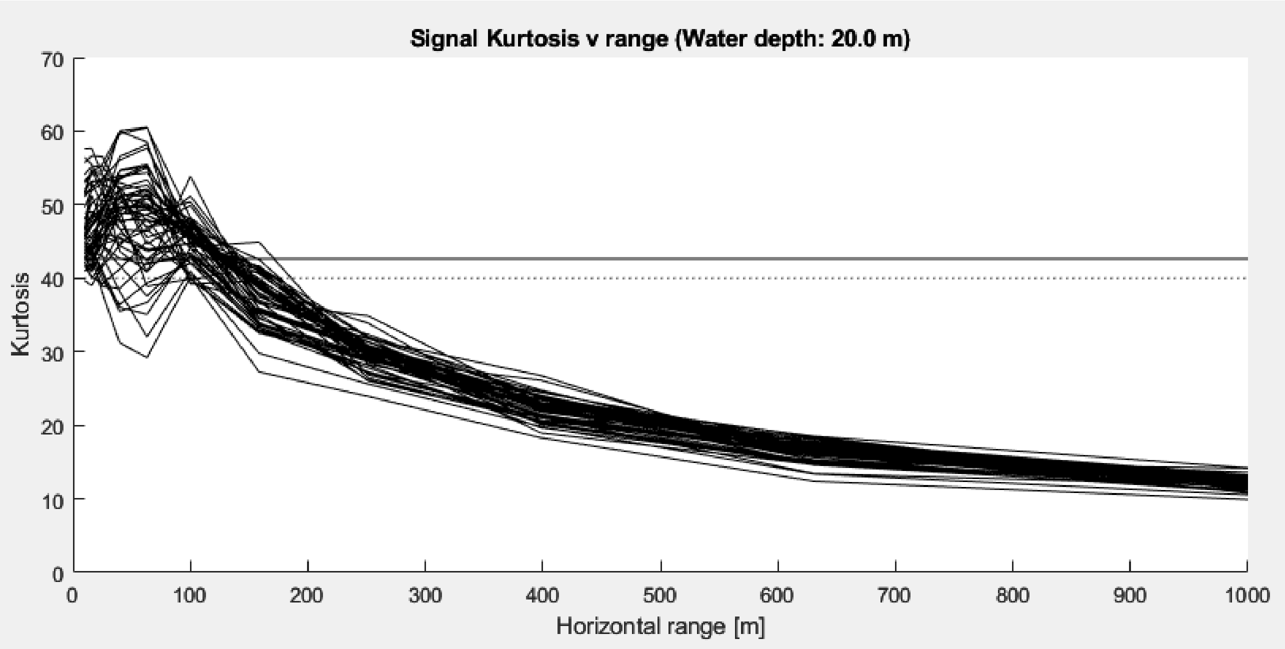


**Figure 8-5. Example of USBL signal kurtosis decreasing with range at 20 m depth. Multiple lines are various combinations of source and receiver depths.**

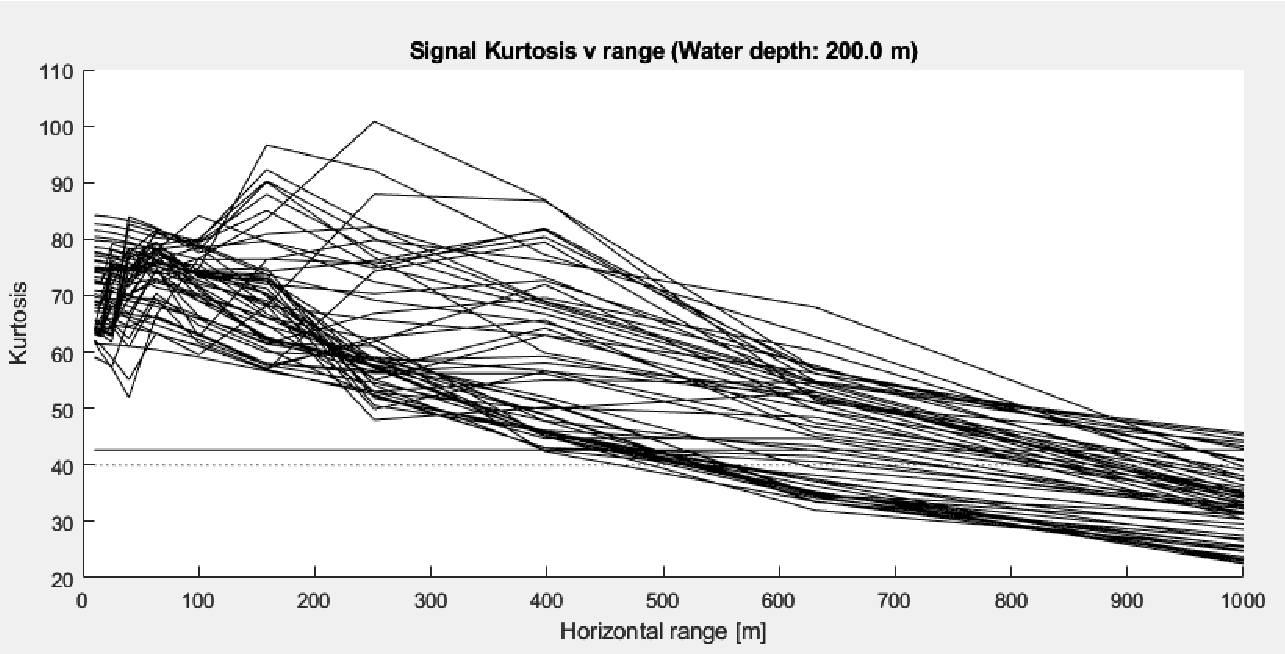


**Figure 8-6. Example of USBL signal kurtosis decreasing with range at 200 m depth. Multiple lines are various combinations of source and receiver depths.**

## Review of Sound Propagation Concepts

Increasing the distance from the sound source usually results in the level of sound getting lower, due primarily to the spreading of the sound energy with distance, analogous to the way in which the ripples in a pond spread after a stone has been thrown in.

The way that the sound spreads will depend upon several factors such as water column depth, pressure, temperature gradients, salinity, as well as water surface and seabed conditions. Thus, even for a given locality, there are temporal variations to the way that sound will propagate. However, in simple terms, the sound energy may spread out in a spherical pattern (close to the source, with no boundaries) or a cylindrical pattern (much further from the source, bounded by the surface and the sediment), although other factors mean that decay in sound energy may be somewhere between these two simplistic cases.

In acoustically shallow waters[8] in particular, the propagation mechanism is coloured by multiple interactions with the seabed and the water surface (Lurton, 2002; Etter, 2013; Urick, 1983; Brekhovskikh and Lysanov 2003, Kinsler et al., 1999). Whereas in deeper waters, the sound will propagate further without encountering the surface or bottom of the sea, in shallower waters the sound is reflected many times by the surface and sediment.

At the sea surface, the majority of sound is reflected back into the water due to the difference in acoustic impedance (i.e. sound speed and density) between air and water. However, scattering of sound at the surface of the sea is an important factor with respect to the propagation of sound from a source. In an ideal case (i.e. for a perfectly smooth sea surface), the majority of sound wave energy will be reflected back into the sea. However, for rough waters, much of the sound energy is scattered (Eckart, 1953; Fortuin, 1970; Marsh, Schulkin, and Kneale, 1961; Urick and Hoover, 1956). Scattering can also occur due to bubbles near the surface such as those generated by wind or fish or due to suspended solids in the water such as particulates and marine life. Scattering is more pronounced for higher frequencies than for low frequencies and is dependent on the sea state (i.e. wave height). However, the various factors affecting this mechanism are complex. Generally, the scattering effect at a particular frequency depends on the physical size of the roughness in relation to the wavelength of the frequency of interest.

As surface scattering results in differences in reflected sound, its effect will be more important at longer ranges from the source sound and in acoustically shallow water (i.e. where there are multiple reflections between the source and receiver). The degree of scattering will depend upon the water surface smoothness/wind speed, water depth, frequency of the sound, temperature gradient, grazing angle and range from source. Depending upon variations in the aforementioned factors, significant scattering could occur at sea state 3 or more for higher frequencies (e.g. 15 kHz or more). It should be noted that variations in propagation due to scattering will vary temporally (primarily due to different sea-states/wind speeds at different times) and that more sheltered areas (which are more likely to experience calmer waters) could experience surface scattering to a lesser extent, and less frequently, than less sheltered areas which are likely to encounter rougher waters. However, over shorter ranges (e.g. within 10-20 times the water depth) the sound will experience fewer reflections and so the effect of scattering should not be significant. Consequently, over the likely distances over which injury will occur, this effect is unlikely to significantly affect the injury ranges presented in this report, and not including this effect will overestimate the impact.

When sound waves encounter the seabed, the amount of sound reflected will depend on the geoacoustic properties of the seabed (e.g. grain size, porosity, density, sound speed, absorption coefficient and roughness) as well as the grazing angle (see Figure 8-7[9]) and frequency of the sound (Cole, 1965; Hamilton, 1970; Mackenzie, 1960; McKinney and Anderson, 1964; Etter, 2013; Lurton, 2002; Urick, 1983). Thus, seabeds comprising primarily of mud or other acoustically soft sediment will reflect less sound than acoustically harder seabeds such as rock or sand. This effect also depends on the profile of the seabed (e.g. the depth of the sediment layers and how the geoacoustic properties vary with depth below the sea floor). The sediment interaction is less pronounced at higher frequencies (a few kHz and above) where interaction is primarily with the top few cm of the sediment (related to the wavelength). A scattering effect (similar to that which occurs at the surface) also occurs at the seabed (Essen, 1994; Greaves and Stephen, 2003; McKinney and Anderson, 1964; Kuo, 1992), particularly on rough substrates (e.g. pebbles and larger).

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

[9] The density of “rays” indicate difference in effective propagation angle from the source, with acoustically harder sediments (gravel) having better reflection at steeper angles leading to more “rays” being effectively propagated (no significant bottom attenuation) in the waveguide. Beam shape indicated in left chart, with the black line showing the same received level.

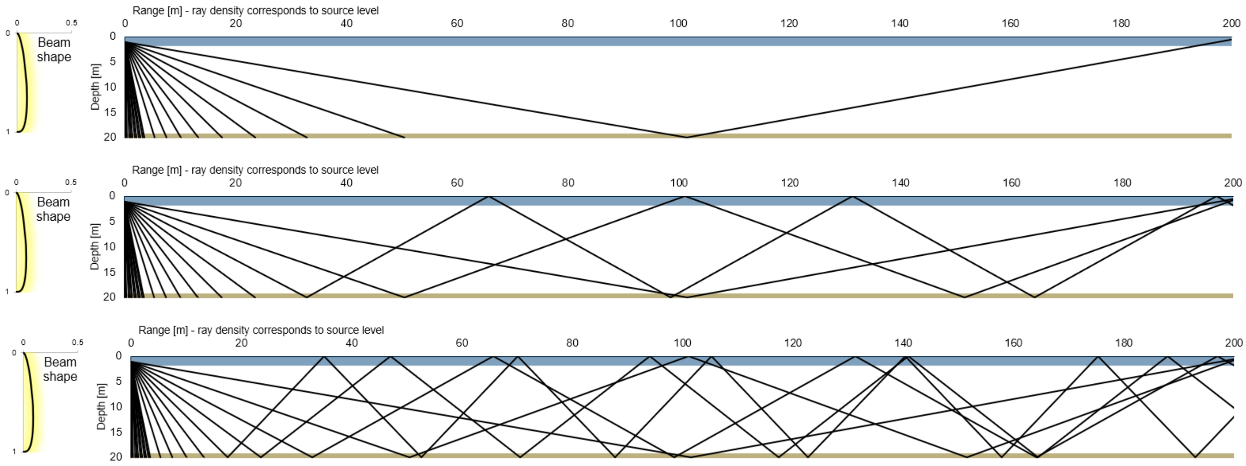


**Figure 8-7: Schematic of the effect of sediment on sources with narrow beams. Sediments range from fine silt (top panel), sand (middle panel), and gravel (lower panel).**

These sediment effects mean that the directivity of equipment such as sub-bottom profilers have a profound effect on the effective source level – the apparent source level to a far-away receiver.

A parametric SBP such as the “Innomar Medium” or “Standard” sub-bottom profiler use two higher frequencies (“primary frequencies”) to generate an interference pattern at lower frequencies (“secondary frequencies”). This means that the secondary beam can be made extraordinarily narrow, e.g. 5 degrees at -10 dB (Figure 8-8), versus c. 50 degrees for a chirper/pinger type, leading to a much smaller sound impact – even when a parametric sub-bottom profiler has higher sound output within the main beam. We account for these differences in beam pattern by including the sediment reflection loss at high incidence angles (Figure 8-7) to reduce the effective source level accordingly.

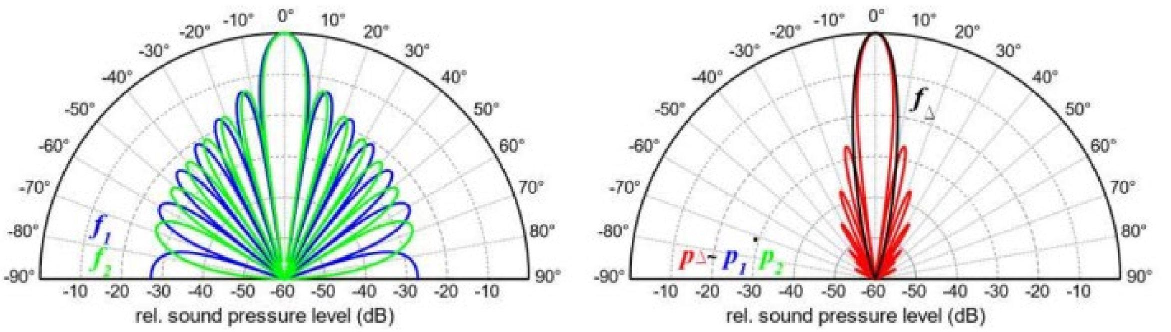


**Figure 8-8. Example of a beam pattern on an Innomar SES 2000. Primary frequencies left (f1 & f2), the interference pattern between the primary frequencies means that the beam pattern for the secondary frequency (right plot) is very narrow (Source: Innomar technical note TN-01).**

Another phenomenon is the waveguide effect which means that shallow water columns do not allow the propagation of low frequency sound (Urick, 1983; Etter, 2013). The cut-off frequency of the lowest mode in a channel can be calculated based on the water depth and knowledge of the sediment geoacoustic properties. Any sound below this frequency will not propagate far due to energy losses through multiple reflections. The cut-off frequency as a function of water depth is shown in Figure 8-9 for a range of seabed types. Thus, for a water depth of 10m (i.e. shallow waters typical of coastal areas and estuaries) the cut-off frequency would be approximately 70Hz for sand, 115Hz for silt, 155Hz for clay and 10Hz for bedrock.

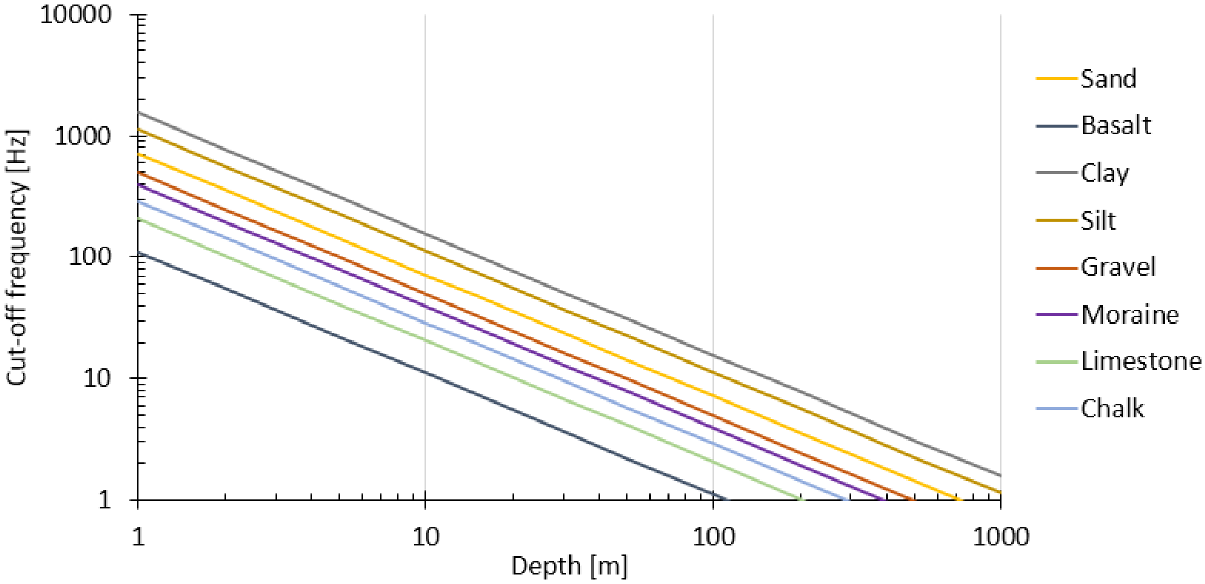


**Figure 8-9: Lower cut-off frequency as a function of depth for a range of seabed types.**

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

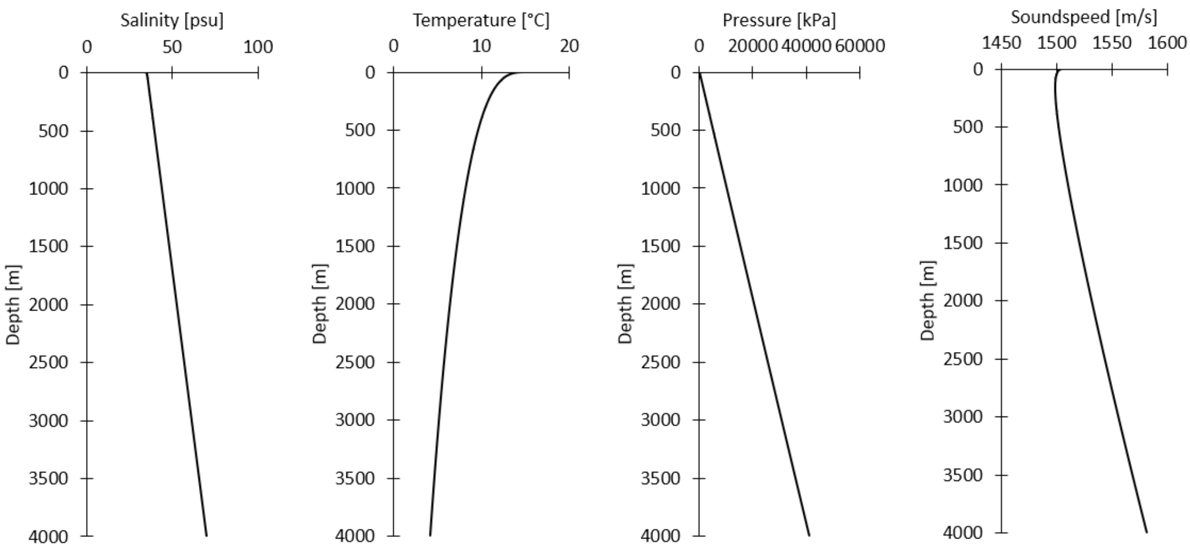


**Figure 8-10: Soundspeed profile as a function of salinity, temperature and pressure.**

Wind can make a significant difference to the soundspeed in the uppermost layers as the introductions of bubbles decreases the soundspeed and refracts (bends) the sound towards the surface, where the increased roughness and bubbles from the wind will cause increased transmission loss.

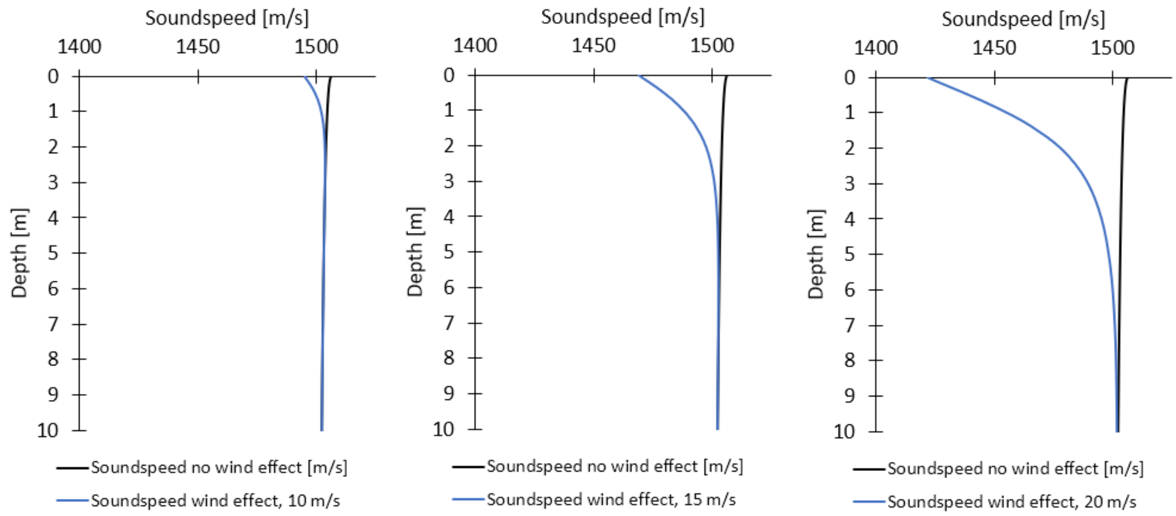


**Figure 8-11: Effect of wind (at 10 m height) on upper portion of soundspeed profile.**

Sound energy can also be absorbed due to interactions at the molecular level converting the acoustic energy into heat. This is another frequency dependent effect with higher frequencies experiencing much higher losses than lower frequencies. This is shown in Figure 8-12 where the variation of the absorption (sometimes called volume attenuation) is shown for various salinities and temperatures. As the effect is proportional to the wavelength, colder water, with slower soundspeed/period and being slightly more viscous, will have more absorption. Higher salinity slightly decreases absorption at low frequencies (mostly due to increase in soundspeed and wavelength/period), but much higher absorption at higher frequencies where interaction with pressure sensitive molecules of magnesium sulphite and boric acid increase the conversion acoustic energy to heat.

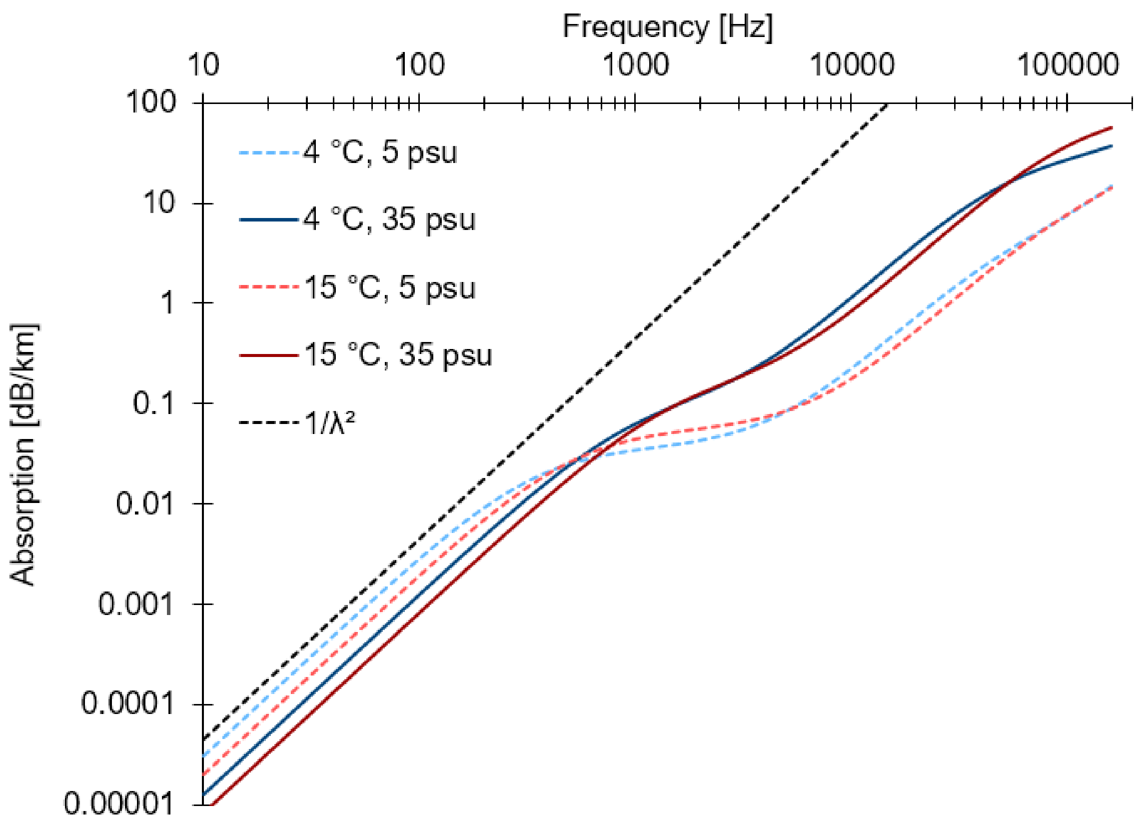


**Figure 8-12: Absorption loss coefficient (dB/km) for various salinities and temperature.**