# Shannon Technology and Energy Park (STEP) Power Plant

## Appendix A7A.4: Acoustic Impact Assessment Report

Shannon LNG Limited

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# Impact Assessment of Potential Acoustic Effects of Shannon LNG Construction and Operation Activities on Marine Mammals and Fish in the Shannon Estuary, Ireland

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# Glossary

| | |
|---|---|
| CI | Confidence Interval |
| CHP | Combined Heat and Power |
| C-POD | hydrophone that passively monitors acoustic signals in the water |
| CV | Coefficient of Variation |
| dB | decibel |
| dB re 1 μPa | decibels relative to 1 micropascal |
| DPM | detection positive minutes |
| ESB | Electricity Supply Board |
| EU | European Union |
| FSRU | Floating Storage Regasification Unit |
| h | hour |
| Hz | hertz |
| HF | High-frequency cetacean |
| HF-weighting | Frequency weighting for high-frequency cetaceans, allowing for their functional hearing bandwidths and appropriate in characterizing auditory effects of sounds |
| IUCN | International Union for Conservation of Nature |
| IWDG | Irish Whale and Dolphin Group |
| kHz | kilohertz |
| $L_{\mathrm{E}}$ | sound exposure level |
| $L_{\mathrm{E,24}}$ | cumulative sound exposure level over a 24-h period |
| $L_{\mathrm{S,}}$ | sound pressure level at the source |
| $L_{\mathrm{S,E}}$ | sound exposure level at the source |
| $L_{\mathrm{p}}$ | sound pressure level, for underwater sound pressure, decibels are referenced to 1 μPa |
| $L_{\mathrm{p,0\text{-}pk}}$ | zero-to-peak sound pressure level (the largest deviation of the sound pressure from zero) |
| $L_{\mathrm{p,pk\text{-}pk}}$ | peak-to-peak sound pressure level |
| $L_{\mathrm{p,rms}}$ | root-mean-square sound pressure level |
| $L_{\mathrm{p,rms,MF}}$ | root-mean-square sound pressure level, weighted for mid-frequency cetaceans |
| MF | Mid-frequency cetacean |
| MF-weighting | Frequency weighting for mid-frequency cetaceans allowing for their functional hearing bandwidths to appropriately characterize potential auditory effects of sounds |
| MMscm/d | million metric standard cubic metres per day |
| MW | megawatt |
| LNG | Liquefied Natural Gas |
| LNGC | Liquefied Natural Gas Carrier |
| NBDC | National Biodiversity Data Centre |
| NMFS | (U.S.) National Marine Fisheries Service |
| NPWS | National Parks and Wildlife Service |
| TTS | Temporary Threshold Shift or hearing impairment |
| PTS | Permanent Threshold Shift or hearing impairment |
| PW | Phocid in water |
| PW-weighting | Frequency weighting for phocids in water allowing for their functional hearing bandwidths to appropriately characterize potential auditory effects of sounds |
| rms | root-mean-square, used to calculate an energy-based time averaged level |
| SAC | Special Area of Conservation |
| SCI | Sites of Community Importance |
| SD | Standard Deviation |
| SFPC | Shannon Foynes Port Company |
| VG | Vysus Group |

# Executive Summary

Shannon LNG is proposing a Liquefied Natural Gas (LNG) marine terminal and power plant in the Shannon Estuary, Ireland. The Lower River Shannon is a prime wildlife conservation area and has been designated as a Special Area of Conservation (SAC) for Annex I qualifying interests of large shallow inlets and bays, mudflats, sandflats, reefs, and the bottlenose dolphin (*Tursiops truncatus*), which is an Annex II species (NPWS 2012). Activities associated with the construction and operation of the LNG terminal (e.g., pile driving, vessel noise) have the potential to impact marine mammals and fish that occur within the SAC by introducing sound into the marine environment. The potential effects are assessed for several marine species occurring in the Shannon Estuary, with a particular focus on the resident population of bottlenose dolphin. The assessment of potential effects for the bottlenose dolphin was based on its occurrence in the estuary and the extent of the potentially affected area which was determined by underwater acoustic modeling and available sound threshold criteria.

Of the activities that were acoustically modeled, sound pressure levels (frequency-weighted for various marine mammal hearing groups) resulting from an approaching LNG carrier with four tugs were found to travel the farthest distance. Based on a behavioural disturbance threshold of $L_{\mathrm{p,rms}}$ 120 dB re 1 µPa for continuous sounds, the distances were 983 m for mid-frequency (MF) cetaceans such as the bottlenose dolphin, 988 m for high-frequency (HF) cetaceans such as the harbour porpoise (*Phocoena phocoena*), and 2.8 km for seals. The next largest impact area was for a cumulative sound scenario involving multiple project operations and other nearby vessel traffic. Sound pressure levels at or above the behavioural threshold of $L_{\mathrm{p,rms}}$ 160 dB for impulsive sound such as impact pile driving could occur up to 138 m away for MF cetaceans, 77 m for HF cetaceans, and 937 m for seals. The activities with the largest threshold distances would in turn be expected to have the greatest potential impact on marine mammals in the estuary. Based on the disturbance thresholds, 3 exposures annually were estimated for bottlenose dolphins during approaching or departing LNG carriers during the operational phase, and 12 annual exposures were estimated for the cumulative sound scenario during the operational phase. Only 4 exposures were estimated for all impact pile driving during construction.

For bottlenose dolphins, as well as seals, only sounds from impact pile driving have the potential to cause permanent threshold shift (PTS), with a total of two bottlenose dolphin exposures estimated for all impact pile driving activities combined. PTS would only be possible if a bottlenose dolphin were to approach within 94 m of the pile being driven and remain within that distance for the entire ~60 min of impact pile driving. Similarly, temporary threshold shift (TTS) would be possible if a dolphin remained within 786 m of impact pile driving for ~60 min. TTS was also determined to be a possibility for bottlenose dolphins within 41 m of some operational activities that emit continuous sounds. Although rarely observed in the estuary, harbour porpoise could theoretically be exposed above PTS/TTS threshold from impact pile driving activities. Activities that emit non-impulsive or continuous sounds have no potential for PTS in bottlenose dolphins, but they could elicit PTS in a harbour porpoise if the animal were to approach certain operational activities within 50 m and remain within that distance for the entire activity. However, PTS is considered highly unlikely to occur in marine mammals, as animals tend to move away from loud sound sources, and monitoring and mitigation measures would be implemented to minimize any impacts. The proposed activities likely would have no more than a minor impact, such as localized short-term avoidance of the area around the activities by individual marine mammals or potentially TTS, with no effect on the population.

Fish could also experience PTS/TTS or other injury from impact pile driving activities, with fish that use their swim bladder for hearing such as Twaite shad (*Allosa fallax fallax*) being slightly more susceptible to potential effects than other types of fish. Mortalities could occur within 142 m of impact pile driving, whereas TTS is possible within ~2 km of impact pile driving. The risk of injury within tens of metres from a continuous sound source is low for all fish types, and although TTS is unlikely, there could be a moderate risk within tens of metres from a continuous sound source.

## Introduction

Shannon LNG Limited is proposing to construct a Liquefied Natural Gas (LNG) marine import terminal and power station in the Shannon Estuary, Ireland. Offshore facilities would consist of a jetty and a Floating Storage Regasification Unit (FSRU). Activities associated with the construction and operation of the LNG terminal will create noise that has the potential to impact marine mammals and fish. In this report we assess how those sounds (e.g., pile driving, vessel traffic) could affect bottlenose dolphins that regularly occur in the Shannon Estuary, as well as other species of marine mammals and fish. The bottlenose dolphin population in the estuary is considered to be resident and consists of ~145 individuals (Baker et al. 2018a; Berrow et al. 2020). To assess potential effects of project activities on bottlenose dolphins, the number of acoustic exposures that may occur during the planned activities was calculated based on the occurrence of dolphins in the area and the extent of the potentially affected area which was determined by underwater acoustic modeling and available sound threshold criteria. In addition, the potential impact on other marine mammals and fish were also assessed, based on modeled distances to available sound threshold criteria. The results are discussed within the context of the project and in light of the monitoring and mitigation measures that are anticipated to be implemented.

## Project Area

The Shannon LNG terminal is proposed to be located at Ardmore Point on the southern shore of Shannon Estuary, on the west coast of Ireland (Figure 1) (Brown and Worbey 2020). The Lower River Shannon is a prime wildlife conservation area and has been designated as a Special Area of Conservation (SAC) for Annex I qualifying interests of large shallow inlets and bays, mudflats, sandflats, reefs, and the bottlenose dolphin (*Tursiops truncatus*), which is an Annex II species (NPWS 2012). The Shannon Estuary is the longest waterway in Ireland, with a distance of 100 km and 500 km$^2$ of navigable water (O'Brien et al. 2016; Blázquez et al. 2020; Brown and Worbey 2020). It is a busy industrialized waterway with a large variety of anthropogenic activities in and around it.

Major industrial developments in the region include a coal power station, oil-fired power station, aluminum refinery, and shipping facilities (Blázquez et al. 2020). Due to the bathymetry of the estuary, it is categorized as a deepwater berth allowing for some of the largest shipping vessels to use the area (Blázquez et al. 2020). The coal import facility is located along the outer estuary at the Electricity Supply Board (ESB) Moneypoint power generation station, across the estuary from the planned LNG terminal. The aluminum refinery (Rusal Aughinish) is situated ~26 km farther up river, and the oil-fired electricity generating power plant is located in Tarbert, ~5 km east of the proposed project site. Ireland has committed to end the burning of coal in ESB's Moneypoint generation plant by 2025 (Ireland's National Energy & Climate Plan 2021–2030). Furthermore, the oil-fired electricity generating power plant in Tarbert is expected to close by 2023 (Eirgrid: All-Island Generation Capacity Statement 2020–2029). The proposed activities are assessed in light of the current shipping activities associated with the Moneypoint and Tarbert power stations.

In 2020, there were six main shipping terminals handling 830 ships per year carrying a total dead weight tonnage of 10,000,000 in Shannon Estuary (Brown and Worbey 2020). With easy access to roads and railways, Shannon Foynes port is home to 37% of Ireland's bulk traffic (Brown and Worbey 2020). Shannon Foynes Port Company (SFPC) is responsible for all commercial marine activities on the Shannon Estuary between Shannon Bridge in Limerick City and the mouth of the estuary joining Loop Head in County Clare to Kerry Head in County Kerry. On a monthly basis, ~18 tankers and 103 dry cargo vessels operate along a well-defined passage along the main channel and past the proposed project area. Other vessel traffic includes 11 transits per month by small commercial and port services vessels; military vessels also transit through the area (Brown and Worbey 2020).

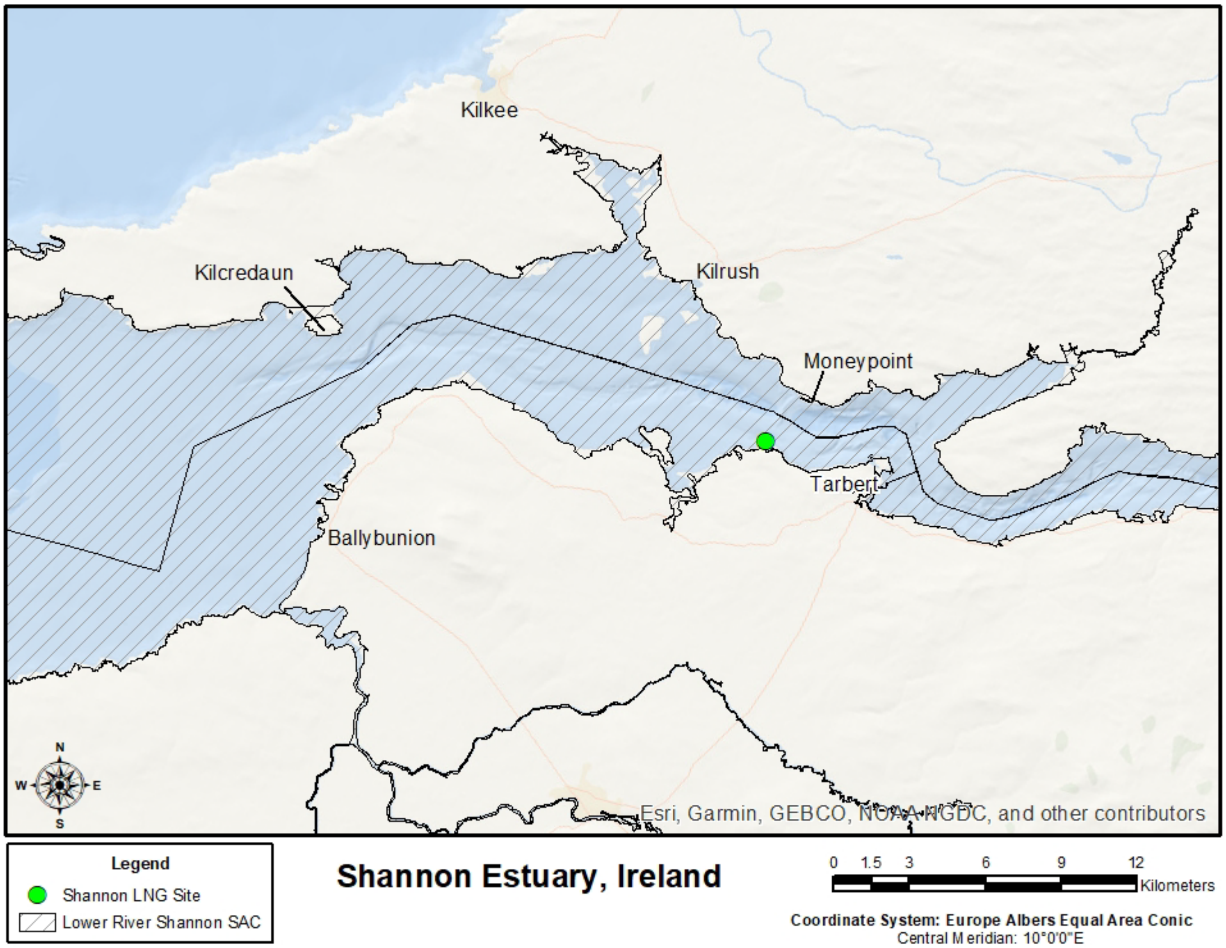

Figure 1. Location of the project site and Shannon Estuary region (Source: Halcrow 2007).

The estuary is also home to fishing activities, a car and passenger ferry which operates once every hour in each direction year-round, and dolphin watching vessels (O'Brien et al. 2016; Brown and Worbey 2020). According to Brown and Worbey (2020), as many as 500 dolphin watching boat trips occur annually within the estuary, including near the project area during July and August, and periodically during April–June and September–October. However, there may have been fewer trips (200–300) in recent years (S. Berrow, IWDG, pers. comm., 2 Nov. 2020).

Ambient noise in the estuary, consisting of natural sounds such as wave noise, as well as ship traffic, was measured in May 2020 (VG 2021). At night, unweighted root-mean-square sound pressure levels ($L_{\mathrm{p,rms}}$) ranged from 91.4 decibels referenced to 1 micropascal (dB re 1 µPa) to 109.1 dB re 1 µPa with a median exceedance level of 95.2 dB re 1 µPa. During the day, unweighted $L_{\mathrm{p,rms}}$ were noticeably higher and ranged from 95.5 dB re 1 µPa to 129.4 dB re 1 µPa with a median of 117.3 dB re 1 µPa. After applying MF-weighting to focus on frequencies that are audible to bottlenose dolphins, MF-weighted sound pressure levels ($L_{\mathrm{p,rms,MF}}$) at night ranged from 86.6 dB re 1 µPa to 98.5 dB re 1 µPa with a median of 88.8 dB re 1 μPa. Unlike the unweighted levels, daytime MF-weighted ambient noise had similar low end (86.2 dB re 1 μPa) and median (88.2 dB re 1 μPa) $L_{\mathrm{p,rms,MF}}$ as nighttime measurements, but the high end of the range did increase to $L_{\mathrm{p,rms,MF}}$ 109.0 dB re 1 μPa.

## Project Description

The Shannon LNG terminal would be located at Ardmore Point between Tarbert and Ballylongford on the southern shore of Shannon Estuary (Figure 1). The waters to the west of the location are considered the outer (or lower) estuary, whereas the inner (upper) estuary is located to the east of the site. One of the reasons this site was chosen is because it is a sheltered berthing area with water depths >15 m (Halcrow 2007; Brown and Worbey 2020). The LNG marine terminal would consist of an in-water jetty with tug docking berths and an FSRU, with an onshore nominal 500 MW high-efficiency Combined Heat and Power (CHP) plant (Shannon LNG 2020).

A 345-m jetty (or trestle) with a central loading platform, six mooring dolphins, and four breasting dolphins would be constructed to access the deeper waters of the estuary (Brown and Worbey 2020). Approximately 203 piles would be installed using a combination of techniques including a hydraulic impact hammer, vibratory hammer, and/or continuous flight auger (CFA) techniques. Piling for the construction of the jetty will commence initially from onshore (requiring approximately 4.5 months to complete) followed by approximately 11 months from the water. The jetty construction works will operate on a 24-h basis, 6 days a week with maintenance works on Sundays and over approximately 15.5 months. The exact number of piles is subject to the final design. The pile diameter would be ~1.067 m, and a 150 kJ impact hammer would be used. It will take approximately 1 day to install an individual pile with impact piling occurring for approximately 60 min per pile. Impact piling will not commence during night-time hours. Some onshore blasting related to site preparation may take place at locations 70 m or greater from the shoreline. Nonetheless, some sounds produced by onshore blasting could also enter the water.

The FSRU would not be permanently moored at the jetty and may depart the jetty on rare occasions in very poor weather conditions (wind speeds of approximately 60 knots or greater). Based on site-specific weather station data from 2007 to 2012, wind speeds greater than 60 knots were observed on only one occasion, for a duration of 60 h. This equates to an absence from the jetty of less than 0.001% over the total 5-year period. Loading of LNG onto the FSRU would be via ship-to-ship transfer from an LNG carrier berthed alongside. The FSRU would have an LNG storage capacity of up to 180,000 $m^3$. Up to one LNG carrier (LNGC) per week is expected to deliver its cargo to the FSRU. Upon arrival, mooring and berthing of the LNGC would require 12 h or less. A similar amount of time would be required to unmoor and unberth the LNGC upon departure. Once docked to the FSRU, offloading of the LNGC to the FSRU would require approximately 35 h. The LNGC is expected to have a capacity range of 130,000 to 180,000 $m^3$. At full operation, the LNG terminal would have a capacity of 22.6 MMscm/d (Shannon LNG 2020).

## Project Sounds

Impulsive and non-impulsive sounds affect marine life differently, especially in terms of their potential to cause injury (Southall et al. 2007, 2019; Popper et al. 2014). Consequently, most available effects criteria for in-water sounds are divided into those two broad categories based on the temporal characteristics of the sound. During the project, impulsive sounds include blasting and impact pile driving; non-impulsive sounds include ship noise, vibratory pile driving, and socket drilling for piling. Project activities and their sound characteristics are shown in Table 1 and described below by project phase.

## *Construction Phase*

### Impulsive Sounds

Impact pile driving produces impulsive sounds that have higher source levels than vibratory pile driving. Madsen et al. (2006) reported that hydraulic impact pile driving produces broadband sounds, with much of the energy below 500 Hz, and that received $L_{\mathrm{p,rms}}$ can exceed 200 dB re 1 µPa at 100 m. In the modeling of impact pile driving, VG (2021) assumed a single-strike broadband (50–1600 Hz) source level ($L_{\mathrm{S,E}}$) of 208 dB re 1 $\mu\mathrm{Pa}^2\mathrm{m}^2\cdot\mathrm{s}$ (Table 1).

Sounds from blasting are also categorized as impulsive and, depending on the size of the charge used, typically have higher source levels than impact pile driving. During this project blasting would only occur on land, although the sounds could emanate into the water. A source level of 232 dB re 1 $\mu\mathrm{Pa}^2\mathrm{m}^2\cdot\mathrm{s}$ ($L_{\mathrm{S,E}}$) was used for acoustic modeling of blasting (VG 2021), which was then corrected for the on-land location of an embedded blasting charge, resulting in a source level upon entering the water of 206 dB re 1 $\mu\mathrm{Pa}^2\mathrm{m}^2\cdot\mathrm{s}$ ($L_{\mathrm{S,E}}$) (Table 1).

### Non-Impulsive Sounds

Non-impulsive sounds (sometimes also referred to as continuous sounds) would also be produced during project construction by socket drilling and vibratory pile driving activities. In the acoustic modeling, the drilling source level ($L_{\mathrm{S}}$) was assumed to be 168 dB re 1 µPa·m. NPWS (2014) noted that pile driving generally produces low frequencies, but that some energy occurs at frequencies up to 20 kHz. The dominant frequency range of pile driving is most likely related to differences in the size, shape, and thickness of the piles. For modeling of vibratory pile driving, VG (2021) assumed a source level ($L_{\mathrm{S}}$) of 182 dB re 1 µPa·m.

Table 1. Types of construction and operational activities and their associated source levels.

| Project Phase | Activity | Type of Sound | Source Level[1] |
|---|---|---|---|
| Construction | Impact pile driving | Impulsive | $L_{\mathrm{S,E}}$: 208 dB re 1 $\mu\mathrm{Pa}^2\mathrm{m}^2\cdot\mathrm{s}$ |
| Construction | Blasting[2] | Impulsive | $L_{\mathrm{S,E}}$: 206 dB re 1 $\mu\mathrm{Pa}^2\mathrm{m}^2\cdot\mathrm{s}$ |
| Construction | Vibratory pile driving | Non-impulsive | $L_{\mathrm{S}}$: 182 dB re 1 µPa · m |
| Construction | Socket drilling | Non-impulsive | $L_{\mathrm{S}}$: 168 dB re 1 µPa · m |
| Construction | Support vessels[3] | Non-impulsive | $L_{\mathrm{S}}$: 168 dB re 1 µPa · m |
| Operations | FSRU hull-radiated noise[4] | Non-impulsive | $L_{\mathrm{S}}$: 176 dB re 1 µPa · m |
| Operations | FSRU cooling pumps | Non-impulsive | $L_{\mathrm{S}}$: 166 dB re 1 µPa · m |
| Operations | LNGC offloading | Non-impulsive | $L_{\mathrm{S}}$: 169 dB re 1 µPa · m |
| Operations | LNGC sailing | Non-impulsive | $L_{\mathrm{S}}$: 185 dB re 1 µPa · m |
| Operations | Tugboat idling | Non-impulsive | $L_{\mathrm{S}}$: 165 dB re 1 µPa · m |
| Operations | Tugboat sailing | Non-impulsive | $L_{\mathrm{S}}$: 181 dB re 1 µPa · m |
| Operations | Cargo ship transiting at 10 knots | Non-impulsive | $L_{\mathrm{S}}$: 187 dB re 1 µPa · m |
| Operations | Cargo ship docked at Moneypoint | Non-impulsive | $L_{\mathrm{S}}$: 160 dB re 1 µPa · m |

[1] See VG (2021)

[2] A source level ($L_{\mathrm{E}}$) of 232 dB re 1 $\mu\mathrm{Pa}^2\mathrm{m}^2\cdot\mathrm{s}$ was corrected for the on-land location of an embedded blasting charge, resulting in a source level ($L_{\mathrm{E}}$) upon entering the water of 206 dB re 1 $\mu\mathrm{Pa}^2\mathrm{m}^2\cdot\mathrm{s}$.

[3] Support vessels included 1 jack-up rig, 1 crane barge, 1 tug, and 1 crew boat.

[4] With engines on standard vibration mounts to reduce noise, but no cooling pumps.

### *Operations Phase*

#### Non-Impulsive Sounds

Shipping is a known source of non-impulsive anthropogenic sound with most energy in the low frequencies between 10 and 100 Hz (Erbe 2019); however, especially smaller vessels can produce frequencies up to 50 kHz (O'Brien et al. 2016). Most vessel noise is created by propellers spinning in the water and forming bubbles which then grow, vibrate, and collapse to produce this range of sound (O'Brien et al. 2016; Erbe 2019). The size, speed, gross tonnage, draft, and operating equipment of a vessel all influence characteristics of shipping noise (O'Brien et al. 2016). Source levels for vessels typically range from $L_S$ 130 to 160 dB µPa·m for small vessels (small fishing vessels and recreational boats) and up to $L_S$ 200 dB re 1 µPa·m or greater for larger vessels such as cargo ships and large ferries (Richardson et al. 1995; Erbe 2019). Some small ships, such as tugs, can have $L_S$ above 160 dB re 1 µPa·m (Richardson et al. 1995; VG 2021). However, estimated sound levels from a single tug are much lower relative to other sources of construction noise, such as impact pile driving.

In their modeling of FSRU and vessel sounds, VG (2021) assumed $L_S$ of ~187 dB re 1 µPa·m for a cargo ship transiting at 10 knots, $L_S$ 185 dB re 1 µPa·m for a sailing LNGC, and $L_S$ 181 dB re 1 µPa·m for a transiting tug. Other source levels used were $L_S$ 176 dB re 1 µPa·m for the FSRU hull-radiated noise (with engines on standard vibration mounts to reduce noise, but no cooling pumps), $L_S$ 166 dB re 1 µPa·m for the FSRU cooling pumps, $L_S$ 169 dB re 1 µPa·m for an offloading LNGC, $L_S$ 165 dB re 1 µPa·m for an idling tug, and $L_S$ 160 dB re 1 µPa·m for a cargo ship at Moneypoint (Table 1).

## Marine Mammal Species Assessed

### Occurrence in the Shannon Estuary

#### *Bottlenose Dolphins*

The bottlenose dolphin is considered least concern under the International Union for Conservation of Nature (IUCN) Red List and is listed in Annex II of the European Union's (EU) Habitats Directive. The Habitats Directive was adopted in 1992 and ensures the conservation of a wide range of rare, threatened, or endemic species in Europe. The core habitat areas for Annex II species, including the bottlenose dolphin, are designated as sites of community importance (SCIs), which can in turn be designated as SACs.

The Lower River Shannon, or outer part of the estuary, is one of two SACs designated for bottlenose dolphins in Irish waters (O'Brien et al. 2016; Rogan et al. 2018; Blázquez et al. 2020). Studies on the resident bottlenose dolphin population in Shannon Estuary have been occurring since 1993 by the Irish Whale and Dolphin Group (IWDG) and by the National Parks and Wildlife Service (NPWS) of Ireland as part of the EU's obligation to ensure conservation of this species (Blázquez et al. 2020). Data collected over 20 years show that the Shannon Estuary dolphin population is genetically and demographically isolated from other coastal dolphins (Mirimin et al. 2011; O'Brien et al. 2016; Rogan et al. 2018). Mark-recapture photo-identification studies indicate that bottlenose dolphins in the Shannon Estuary exhibit long-term site fidelity and seasonal residency (e.g., Ingram 2000; Ingram and Rogan 2002; Ingram and Rogan 2003; Englund et al. 2007, 2008; Berrow 2009; Rogan et al. 2018). The most recent photo-identification study occurred during June–October 2018, resulting in a mark-recapture abundance estimate of 139 individuals (CV=0.11, 95% CI=121–160) (Rogan et al. 2018). Baker et al. (2018a) provided an estimate of 145 individuals for 2015, based on direct counts. The median group size based on boat surveys throughout the estuary is 6 (e.g., Englund et al. 2007, 2008; Rogan et al. 2018), and the average group size has been reported as 9.71 (Barker and Berrow 2016). The mean group size (±SD) at the proposed LNG site at Ardmore Point was estimated at 6.2 ± 3.1 dolphins, based on watches from shore (Berrow et al. 2020).

Although the dolphins inhabit the Shannon Estuary year-round, the greatest number appear to occur there between June and August (Garagouni et al. 2019), with decreasing numbers during the winter (Ingram 2000; Englund et al. 2007; Rogan et al. 2018). The lower numbers during winter may be due to animals dispersing over a wider region in pursuit of prey affected by the seasonal changes (Garagouni et al. 2019), although data on the abundance and distribution of the population during winter is generally lacking. However, dolphin sightings were made off Ardmore Point each month during monitoring from October 2020 to March 2021 (Berrow 2020 a,b,c, 2021 a,b,c). One photo-identification study found that at least 62% of individuals from the Shannon bottlenose dolphin population also use waters outside of the Shannon Estuary during the summer (May–August), including Brandon Bay and Tralee Bay located adjacent to the estuary (Levesque et al. 2016).

Bottlenose dolphins in the Shannon Estuary prefer areas with the greatest slope and depth (Ingram and Rogan 2002). Two critical habitat areas occur within the Shannon Estuary that at least part of the population migrates between throughout the year; the larger of the two areas is located near the mouth of the estuary closest to Kilcredaun, and the smaller is located off Moneypoint (See Figure 1; Ingram and Rogan 2002; Rogan et al. 2018). In general, a smaller proportion of the population is found in the eastern part of the estuary compared to the western part (Baker et al. 2018b). The distribution of sightings in 2018 showed that dolphin presence throughout the estuary was similar to past studies, but noted greater activity within the inner estuary where it constricts near Tarbert/Killimer and farther upriver, near Glin (see Figure 1) (Ingram and Rogan 2002; Rogan et al. 2018). Baker et al. (2018b) found that only 25% of the population regularly uses the inner estuary; those dolphins were also seen in the outer estuary. Within the critical habitat areas, the dolphins appear to most commonly be found near northern-facing slopes (Garagouni et al. 2019). Dolphin distribution in the estuary is also correlated with tide level, with higher presence in bottleneck areas during ebb and slack low tides (Garagouni et al. 2019).

The location of the proposed in-water structures and immediate vicinity around them at the proposed LNG terminal at Ardmore Point has not been identified as a hot spot for bottlenose dolphin occurrence based on commercial dolphin-watching activities (see Berrow et al. 2020). However, sightings have been made in the area during several vessel-based surveys (e.g., Ingram and Rogan 2003; Englund et al. 2007, 2008; Berrow et al. 2012). Visual observations from shore at Ardmore Point show that the site is regularly used by the dolphins, which pass by the area but rarely stop and socialize or forage there; it is more likely used as a transition corridor to move between the outer and inner estuary (Berrow et al. 2020). During 23 days of observations from April through September 2020, 21 sightings of dolphins were made on 13 separate watch days. Most sightings were made off Moneypoint, near the ferry, near Scattery Island, and mid-channel; six sightings were made within 500 m of Ardmore Point, and a total of 22 individual dolphins were identified. During 23 observation days from October 2020 to March 2021, 20 dolphin sightings were made on 15 different watch days (Berrow 2020 a,b,c, 2021a,b,c). Thus, the encounter rates of bottlenose dolphin groups were similar during spring/ summer and autumn/winter, at 0.2 groups/hour of observation.

Passive acoustic monitoring with C-POD porpoise detectors was also conducted at two sites off Ardmore Point from August 2019 through May 2020; dolphin clicks were detected on 62% of monitoring days at each of the two sites (Berrow et al. 2020). The C-POD located closest to the LNG site (LNG1) had a mean detection positive minutes (DPM) per day of 4.4, whereas LNG2 had a DPM of 3.6; DPM was lower at LNG1 during the winter than during other seasons. The low DPM per day at these two sites supports evidence from visual monitoring that the area around Ardmore Point is primarily a transit corridor (Berrow et al. 2020). There were significantly more detections during the evening than during the day at LNG1, and significantly more detections in the evening and at night than during the day at LNG2 (Berrow et al. 2020).

The Shannon Estuary also acts as a calving area for the species, with neonates most frequently observed from July to September (Ingram 2000; Baker et al. 2018a), although Rogan et al. (2018) also reported neonates in October. An average of seven calves are born each year, with weaning taking place at a mean age of 2.9 years (Baker et al. 2018a). During watches from Ardmore Point, 10 calves were recorded, including four that were born in 2018 and 2019 (Berrow et al. 2020). However, it is not known whether this particular location is an important calving area within the estuary.

### *Other Marine Mammals*

Harbour porpoise, harbour seals (*Phoca vitulina*), and grey seals (*Halichoerus grypus*) are listed in Annex II of the EU's Habitats Directive and are considered least concern under the IUCN Red List. Although harbour porpoise occur regularly along the coast of Ireland (O'Brien 2016), they are rarely seen in the Shannon Estuary (O'Callaghan et al. 2021). Only two sightings have been reported in the inner estuary (Berrow 2020a, Berrow et al. 2020; O'Callaghan et al. 2021). One sighting was made on 22 October 2020 of a single harbour porpoise that was foraging for ~1 h near Moneypoint (Berrow 2020a; O'Callaghan et al. 2021). Another sighting of an adult and juvenile was made near Scattery Island in 2018 (O'Callaghan et al. 2021). One sighting of two porpoise was made in the outer estuary during July 2005 (O'Callaghan et al. 2021). In addition, six strandings have been reported in the Shannon Estuary (O'Callaghan et al. 2021). Possible porpoise clicks have also been detected during monitoring in summer/autumn 2018 at two sites off Ardmore Point (Berrow et al. 2020) and off Moneypoint (O'Brien et al. 2013). However, O'Callaghan et al. (2021) note that these high-frequency clicks could have been generated by dolphins.

Grey seals are common in the Shannon Estuary. The National Biodiversity Data Centre (NBDC) database contains 231 records of the species in the Shannon Estuary, 46 of which are within close proximity to the proposed project. Rogan et al. (2018) reported four sightings of grey seals in Shannon Estuary during dolphin surveys in the summer/autumn of 2018, including two pups hauled out on a beach. During shore-based observations from Ardmore Point from April to August 2020, individual grey seals were seen on six occasions, five of which occurred within 500 m of the site (Berrow et al. 2020). Sightings of individual grey seals were also made during monitoring in October 2020, January 2021, February 2021 (Berrow 2020a, 2021a,b). Cronin et al. (2011) also reported movement of grey seals from the outer coast into the estuary, and Cadhla and Strong (2007) documented a breeding site in the outer estuary. Duck and Morris (2013) reported two sightings in the Inner Shannon Estuary during summer surveys in 2003, but no sightings during surveys in 2012.

Cronin et al. (2010) reported a gap in harbour seal distribution in the Shannon Estuary. Sightings reported through the NBDC include three records for the Fergus Estuary, and seven records near the proposed project location — three at Kilrush, three at Scattery Island, and one at Tarbert. Duck and Morris (2013) reported one harbour seal sighting in the inner Shannon Estuary during surveys in 2012, and eight sightings during surveys in 2003; no sightings were made in the outer Shannon Estuary during either survey.

## Sound Production and Hearing

Bottlenose dolphins echolocate for navigating, foraging, coordinating group behaviour, and detecting and avoiding predators (Branstetter et al. 2018). Echolocation clicks typically have frequencies of 110–130 kHz while whistles are produced at frequencies of 1–24 kHz (Richardson et al. 1995). Bottlenose dolphins are classified as mid-frequency (MF) cetaceans meaning they can hear sounds in the frequency range of 150 Hz to 160 kHz (Southall et al. 2007; NMFS 2018) and their most sensitive hearing is between ~25 and 70 kHz (Ljungblad et al. 1982; Strahan et al. 2020). Frequencies lower than 30 kHz are important for social communication (Accomando et al. 2020). Because bottlenose dolphin hearing is most sensitive at mid-frequencies, noise disturbance from smaller vessels (e.g., recreational boats, fishing boats, and tour boats) are more likely to have an effect on their behaviour compared to larger vessels (O'Brien et al. 2016).

Similar to bottlenose dolphins, harbour porpoise also use echolocation to navigate and detect prey and predators. Their echolocation clicks are in the range of 110–150 kHz (Møhl and Andersen 1973; Teilmann et al. 2002). They also produce clicks at ~ 2 kHz (Richardson et al. 1995). Harbour porpoise are in the high-frequency (HF) hearing group, with a hearing range of 275 Hz to 160 kHz (NMFS 2018). Using auditory brainstem responses, Ruser et al. (2016) found that the harbour porpoise could hear best between 120 and 130 kHz. Kastelein et al. (2002) reported a broader "best" hearing range of 16–140 kHz, with maximum sensitivity between 100 and 140 kHz. Similarly, Kastelein et al. (2017) reported a maximum sensitivity for harbour porpoise at 125 kHz.

Harbour seals produce sounds such as clicks and growls at 0.1–150 kHz (Richardson et al. 1995). The functional hearing range for pinnipeds in water is generally considered to extend from 75 Hz to 75 kHz (Southall et al. 2007), although Cunningham and Reichmuth (2016) reported that a harbour seal was able to detect frequencies up to 180 kHz. In comparison with odontocetes, pinnipeds tend to hear best at lower frequencies, have lower high-frequency cutoffs, and poorer sensitivity at the best frequencies. Harbour seals hear well in water at frequencies from 1–60 kHz, with peak sensitivity at ~32 kHz (Kastak and Schusterman 1995). Below 30–50 kHz, the hearing thresholds of most pinniped species tested are essentially flat down to ~1 kHz and range between 60 and 85 dB re 1 µPa. Measurements for harbour seals indicate that below 1 kHz, their thresholds under quiet background conditions deteriorate gradually with decreasing frequency to ~75 dB re 1 µPa at 125 Hz (Kastelein et al. 2009).

## Potential Impacts of Anthropogenic Sounds

Noise produced during project construction and operation, including from pile driving, LNGCs, and tugboats, may elicit some type of response from marine mammals inhabiting the Shannon Estuary. The potential effects of sound sources could consist of masking natural sounds, behavioural disturbance, and in theory temporary or permanent hearing impairment, or non-auditory physical or physiological effects (e.g., Richardson et al. 1995; Erbe 2019). The impact would depend on the behaviour of the animal at the time of reception of the sound, as well as the distance and received level of sound, the hearing ability of the animal within the frequency range of the sounds, the age and activity of the animal at the time of exposures, and the bathymetry and water depth of the area.

With some exceptions (Erbe et al. 2016), in order for anthropogenic sounds to be detected by an animal, they must be greater than or equal to both the ambient noise level at the corresponding frequencies and the hearing threshold of the animal. With that being said, industrial sounds can be up to ~20–30 dB stronger than the detection thresholds and/or ambient noise levels before they elicit notable changes in behaviour or distribution of animals sensitive to those sounds (Richardson et al. 1995). Individuals frequently exposed to the same sounds can develop tolerance and become habituated to sound levels ~40 to 60 dB above ambient or detection levels before showing behavioural or distributional changes.

### *Masking*

Although masking of natural sounds, such as from conspecifics, can occur in noisy habitats (e.g., Pine et al. 2016; Morrison et al. 2020), cetaceans, including bottlenose dolphins and harbour porpoise, can change their vocal behaviour to avoid masking (e.g., Luís et al. 2014; Sairanen 2014; Gospić and Picciulin 2016; Gridley et al. 2016; Heiler et al. 2016; O'Brien et al. 2016; van Ginkel et al. 2018). Similarly, harbour seals have been shown to increase the minimum frequency and amplitude of their calls in response to vessel noise (Matthews 2017). Noise in the marine environment also has the potential to lessen a marine mammals' ability to detect targets through decreasing the sensitivity of their hearing system and causing changes in behaviour (Branstetter et al. 2018). However, studies have shown that bottlenose dolphins can decrease their hearing sensitivity in order to mitigate the impacts of exposure to loud sounds (e.g., Nachtigall and Supin 2014, 2015; Nachtigall et al. 2018).

Madsen et al. (2006) argued that substantial masking effects would be unlikely during impact pile driving given the intermittent nature of these sounds and short signal duration. In contrast, there could be potential masking effects during vibratory pile driving as the sound emitted is continuous. David (2006) speculated that noise generated by pile driving with a 6 t diesel hammer has the potential to mask bottlenose dolphin vocalizations at 9 kHz within 10 to 15 km from the source if the vocalization is strong and up to 40 km if the call is weak; masking potential reduced with increasing frequency. Masking could reduce an animal's ability to communicate which could then lead to a decrease in socializing activities (Paiva et al. 2015).

### *Behavioural Effects*

Marine mammal behavioural responses to vessels are presumably responses to the sounds produced by those vessels, but visual or other cues are also likely involved. Responses are variable and range from avoidance at long distances to little or no response or approach (Richardson et al. 1995). Responses depend on the speed, size, and direction of travel of the vessel relative to the marine mammal; slow vessel approaches tend to elicit fewer responses than fast, erratic approaches (Richardson et al. 1995).

Sini et al. (2005) found larger boats generally elicited positive reactions from bottlenose dolphins (e.g., approaching or following a boat, initiating bow riding, leaping or breaching), whereas smaller boats elicited more negative responses, including prolonged dives followed by increased respiration rate and longer inter-breath interval lengths, as well as active avoidance. Similarly, Nowacek (2001) found that when bottlenose dolphins were approached by boats in Sarasota, Florida, the dolphins decreased their group spacing, changed heading, and swam faster. Other behavioural responses of bottlenose dolphins to ships include interrupted feeding, resting, and social activities (Papale et al. 2011). A decrease in resting and socializing activities of bottlenose dolphins was also observed in the presence of vessel activity in Sicily, Italy, as well as an increase in time spent foraging and traveling, alterations in dive patterns, displays of breathing synchrony, changes in inter-animal distances, and increased travel speeds were also noted (Marley et al. 2017). Due to increased speeds during travel, high-energy demand paired with high metabolic rates could ultimately lead to induced stress and energetic consequences (Marley et al. 2017). A decrease in socializing activities is another concern due to the importance of socializing for young dolphins to develop their social behaviours, physical movements, problem solving skills, and foraging methods (Marley et al. 2017). The physical presence of vessels, not just ship noise, has been shown to disturb the foraging activity of bottlenose dolphins (Pirotta et al. 2015). Mullin et al. (1989) reported both attraction and avoidance of oil production platforms that operate drills by bottlenose dolphins in the Gulf of Mexico, depending on depth.

Vessel sounds have also been shown to elicit behavioural responses in harbour porpoise such as increased swimming speed and porpoising (e.g., Dyndo et al. 2015), and reduced foraging and echolocation (e.g., Teilmann et al. 2015; Wisniewska et al. 2018). Wisniewska et al. (2018) suggested that a decrease in foraging success could have long-term fitness consequences. However, Kastelein et al. (2019) surmised that if disturbance by noise would displace a harbour porpoise from a feeding area or otherwise impair foraging ability for a short period of time (e.g., 1 day), it would be able to compensate by increasing its food consumption following the disturbance. Harbour seals that are hauled out often enter the water when approached by vessels; responses of seals in the water are variable. Based on observations in the Arctic of ringed seals (*Phoca hispida*) and bearded seals (*Erignathus barbatus*) near drillships drilling, some seals tolerate drilling noise (Richardson et al. 1995).

Responses of marine mammals to pile driving can be similar to those described above for vessel presence. Avoidance is likely to be the primary behavioural response of marine mammals to pile driving. Currently, there is uncertainty regarding the extent to which marine mammals respond differently to impact pile driving versus vibratory pile driving (Graham et al. 2017). Based on sound levels measured during impact pile driving during wind turbine installation in northeastern Scotland and a disturbance threshold of 140 $\mathrm{dB_{p\text{-}p}}$ re 1 µPa, Bailey et al. (2010) suggested that behavioural disturbance from pile driving may occur up to 50 km away for bottlenose dolphins. Graham et al. (2017) reported that bottlenose dolphins spent less time in a construction area when impact or vibratory piling was occurring. Similarly, Paiva et al. (2015) reported a significant decrease in the number of Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) detections during pile driving activities, which included vibratory and impact driving. In another study, Indo-Pacific humpback dolphins (*Sousa chinensis*) exposed to $L_{\mathrm{p,rms}}$ of 170 dB remained within 300 to 500 m of the percussive pile driving area before, during, and after operations; although some dolphins temporarily abandoned the work area, their numbers returned close to those seen pre-construction during the follow-up survey seven months after construction activities ended (Würsig et al. 2000).

Harbour porpoises are known to be fairly responsive to anthropogenic sounds (reviewed in Richardson et al. 1995) and often avoid pile driving activities (e.g., Tougaard et al. 2009; Brandt et al. 2011; Haelters et al. 2015). Bailey et al. (2010) suggested that for harbour porpoise, behavioural disturbance from impact pile driving may occur up to 70 km away (based on a threshold of 90 $\mathrm{dB_{p\text{-}p}}$ re 1 µPa), with major disturbance at distances up to 20 km (based on a threshold of 155 $\mathrm{dB_{p\text{-}p}}$ re 1 µPa). During impact pile driving at Horns Rev I wind farm in the Danish North Sea, harbour porpoise acoustic activity decreased; however, it resumed to baseline levels 3 to 4.5 h after the cessation of pile driving activities (Tougaard et al. 2003, 2005). Tougaard et al. (2003) reported that effects of pile driving activity on harbour porpoises were documented at distances of 10–15 km from the activity and included a decrease in feeding behaviours and a decline in the number of porpoises in the Horns Rev area during the construction period as compared to periods before and after construction. There were fewer circling porpoises during pile driving and significantly more traveling within 15 km of the construction site (Tougaard et al. 2005). Based on Tougaard et al. (2005, 2009, 2011), behavioural effects extended as far as 20–25 km from the construction site. There was complete recovery of acoustic activity during the first year of regular operation of the wind farm; the acoustic activity was actually higher during operation than prior to construction (Tougaard et al. 2006b; Teilmann et al. 2008).

In contrast to the Before After Control Impact sampling design used during previous studies at Horn Rev wind farm, a gradient sampling design showed that the behavioural responses of harbour porpoises to pile driving were longer than previously reported. Brandt et al. (2011) recorded no porpoise clicks for at least 1 h at a distance of 2.6 km from the construction site at Horns Rev II, with reduced acoustic activity for 24–72 h. Out to a distance of 4.7 km, the recovery time was still longer than 16 h – the time between pile driving events; recovery time decreased with increasing distance from the construction site (Brandt et al. 2011). At a distance of ~22 km, negative effects were no longer detectable; rather, a temporary increase in click activity was apparent, possibly as a result of porpoises leaving the area near the construction site (Brandt et al. 2011).

During pile driving activities (using both vibratory and impact techniques) at the Nysted offshore wind farm off the coast of Denmark, a significant decrease in harbour porpoise echolocation activities and presumably abundance was reported within the construction area and in a reference area 10–15 km from the wind farm (Carstensen et al. 2006; Teilmann et al. 2008). Carstensen et al. (2006) reported a medium-term porpoise response to construction activities in general and a short-term response to ramming/vibration activities. Porpoises appeared to have left the area during piling but returned after several days (Tougaard et al. 2006a). Two years after construction, echolocation activity and presumably porpoise abundance were still significantly reduced in the wind farm but had returned to baseline levels at the reference sites (Tougaard et al. 2006a; Teilmann et al. 2008).

Teilmann et al. (2006) speculated as to the cause of the negative effect of construction persisting longer for porpoises at Nysted than at Horns Rev. Porpoises at Horns Rev may have been more tolerant to disturbance, since the area is thought to be important to porpoises as a feeding ground; the Horns Rev area has much higher densities of animals compared to Nysted (Teilmann et al. 2006). Another explanation proposed by Teilmann et al. (2006) took into account that the Nysted wind farm is located in a sheltered area whereas Horns Rev is exposed to wind and waves with higher background noise. Thus, noise from construction may be more audible to porpoises at Nysted compared to Horns Rev. Graham et al. (2017) reported that vibratory pile driving had a greater effect on reducing the probability of harbour porpoise occurrence in a construction area compared with impact pile driving.

Scheidat et al. (2011) suggested that harbour porpoise distribution was fairly quick to recover after construction of the Dutch offshore wind farm Egmond aan Zee, as acoustic activity of harbour porpoises was greater during the 3 years of operation than the 2 years prior to construction. In addition, Leopold and Camphuysen (2008) noted that construction of wind farm Egmond aan Zee did not lead to increased strandings in the area. Harbour porpoises near pile driving activities in Scotland may have exhibited a short-term response within 1–2 km of the installation site, but this was a short-term effect lasting no longer than 2–3 days (Thompson et al. 2010). During the construction of a harbour wall in Demark, which involved pile driving of 175 wooden piles, a 40 m-long air bubble curtain was constructed in hopes of reducing noise effects on three harbour porpoises in a facility on the opposite side of the harbour (Lucke et al. 2011). The bubble curtain was found to be helpful in reducing the piling noise, and the initial avoidance behaviour of the harbour porpoises to the piling sound was no longer apparent after installation of the bubble curtain (Lucke et al. 2011).

The effects of pile driving on the distribution and behaviour of pinnipeds may be small in comparison to the effects on cetaceans. Ringed seals exposed to pile driving pulses exhibited little or no reaction to impact pile driving sounds at a shallow water site in the Alaskan Beaufort Sea; at the closest point (63 m), received levels were 151 dB re 1 $\mu Pa_{rms}$ and 145 dB re 1 $\mu Pa^2 \cdot s$ $L_E$ (Blackwell et al. 2004). Other seal species seem less tolerant of pile driving, at least at their haul-out sites. Remote video monitoring showed that harbour seal haul-out behaviour was affected by pile driving at an offshore wind farm (Nysted) in the western Baltic (Edrén et al. 2004, 2010). The authors found a short-term reduction in the number of seals hauled out at nearby beaches during periods with pile driving vs. no pile driving. Sound levels were not measured, and observations of seals in the water were not made. The authors suggest that seals may have spent more time in the water because this is a typical response to disturbance, or the seals may have used an alternate haul-out site. However, both aerial surveys and remote video monitoring did not show a long-term decrease in the number of seals hauled out from baseline conditions to the construction period (Edrén et al. 2004, 2010; Thomsen et al. 2006). Harbour seals did not seem to be affected by pile driving noise during construction activities in San Francisco Bay (Caltrans 2004).

Similarly, Teilmann et al. (2006) noted that the reactions of harbour seals to construction activities appeared to be short-term because aerial surveys did not reveal any decrease in overall abundance during the 2002–2003 construction period or the 2004–2005 operation period (Teilmann et al. 2006). However, Skeate et al. (2012) suggested a likely link between windfarm construction (e.g., pile driving) and a statistically significant decrease in the number of hauled out harbour seals nearby. At the Horns Rev wind farm, no seals were observed during ship-based surveys in the wind farm during pile driving (Tougaard et al. 2006c). However, animals were sighted in the wind farm during other construction activities, although at apparently lower numbers than during baseline conditions (Tougaard et al. 2006c). Bailey et al. (2010) suggested minor disturbance within 14 km (based on a threshold of $L_{p,pk\text{-}pk}$ 160 dB re 1 μPa), and major disturbance within 215 m (based on a threshold of $L_{p,p\text{-}p}$ 200 dB re 1 μPa) of pile driving activities for harbour and grey seals. Russell et al. (2016) reported displacement of harbour seals during piling when received levels were between $L_{p,pk\text{-}pk}$ 166 and 178 re 1μPa. Although displaced during active pile driving, harbour seals were then observed to return to a normal distribution (distribution measured during the non-piling scenario) within 2 h of cessation of pile driving (Russell et al. 2016).

The limited available evidence indicates that marine mammals, like humans, show less annoyance to occasional noise pulses with a given peak level than they do to continuous noise at that same level (Richardson et al. 1995). Although blasting on land could have potential effects on marine mammals, small explosive charges were “not always effective” in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Captive false killer whales (*Pseudorca crassidens*) showed no obvious reaction to single noise pulses from small (10 g) charges (Akamatsu et al. 1993). Several additional studies found limited or no effects on odontocetes (Jefferson and Curry 1994) or baleen whales (Fitch and Young 1948; Payne 1970; Payne and McVay 1971; Lien et al. 1993).

### *Hearing Impairment*

Although it is unlikely that continuous noise from vessels, drilling, and vibratory pile driving would be strong enough to cause hearing damage or other injuries in marine mammals, impulsive sounds from pile driving and blasting could theoretically have auditory effects on marine mammals. There is a possibility some marine mammals could suffer from PTS or TTS when exposed to impact pile driving sounds. There are empirical data on the sound exposures that elicit onset of TTS in captive bottlenose dolphins, belugas, and porpoise. The majority of these data concern non-impulse sound, but there are some limited published data concerning TTS onset upon exposure to pile driving (e.g., Kastelein et al. 2015, 2016), a single pulse of sound from a watergun (Finneran et al. 2002), and to multiple pulses from an airgun

(Finneran et al. 2015). A detailed review of TTS data from marine mammals can be found in Southall et al. (2007, 2019).

Kastelein et al. (2015, 2016) reported TTS in the hearing threshold of a captive harbour porpoise during playbacks of pile driving sounds; although the pulses had most of their energy in the low frequencies, multiple pulses caused reduced hearing at higher frequencies in the porpoise. Unlike in the Kastelein et al. (2015, 2016) experiments, during project activities an animal would be able to move away from the sound source, as avoidance behaviour has been demonstrated for many marine mammals subjected to loud sounds, thereby reducing the potential for impacts to their hearing ability. There is no specific evidence that exposure to pulses from pile driving or other activities in unrestricted environments is likely to lead to PTS for any marine mammals. Similarly, Nowacek et al. (2013) concluded that current scientific data indicates that seismic airguns (an impulsive source like impact pile driving) have a low probability of directly harming marine life, except at close range.

The following summarizes some of the key results for sounds other than pile driving regarding bottlenose dolphins and porpoise. Recent information corroborates earlier expectations that the effect of exposure to strong transient sounds is closely related to the total amount of acoustic energy that is received. Finneran et al. (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones (non-impulsive) for periods of 1, 2, 4 or 8 s, with hearing tested at 4.5 kHz. For 1-s exposures, TTS occurred with sound exposure levels ($L_E$) of 197 dB, and for exposures >1 s, $L_E$ >195 dB resulted in TTS ($L_E$ is equivalent to energy flux, in dB re 1 μPa$^2 \cdot$ s). At an $L_E$ of 195 dB, the mean TTS (4 min after exposure) was 2.8 dB. Finneran et al. (2005) suggested that an $L_E$ of 195 dB is the likely threshold for the onset of TTS in dolphins exposed to tones of durations 1–8 s (i.e., TTS onset occurs at a near-constant $L_E$, independent of exposure duration). That implies that, at least for non-impulsive tones, a doubling of exposure time results in a 3 dB lower TTS threshold.

The assumption that, in marine mammals, the occurrence and magnitude of TTS is a function of cumulative acoustic energy ($L_E$) is probably an oversimplification (Finneran 2012). Kastak et al. (2005) reported preliminary evidence from pinnipeds that, for prolonged non-impulse noise, higher $L_E$s were required to elicit a given TTS if exposure duration was short than if it was longer, i.e., the results were not fully consistent with an equal-energy model to predict TTS onset. Mooney et al. (2009a) showed this in a bottlenose dolphin exposed to octave-band non-impulse noise ranging from 4–8 kHz at $L_p$ of 130–178 dB re 1 μPa for periods of 1.88–30 min. Higher $L_E$s were required to induce a given TTS if exposure duration was short than if it was longer. Exposure of the aforementioned bottlenose dolphin to a sequence of brief sonar signals showed that, with those brief (but non-impulse) sounds, the received energy ($L_E$) necessary to elicit TTS was higher than was the case with exposure to the more prolonged octave-band noise (Mooney et al. 2009b). Those authors concluded that, when using (non-impulse) acoustic signals of duration ~0.5 s, $L_E$ must be at least 210–214 dB re 1 μPa$^2 \cdot$ s to induce TTS in the bottlenose dolphin.

On the other hand, the TTS threshold for odontocetes exposed to a single impulse from a watergun (Finneran et al. 2002) appeared to be somewhat lower than for exposure to non-impulse sound. This was expected, based on evidence from terrestrial mammals showing that broadband pulsed sounds with rapid rise times have greater auditory effect than do non-impulse sounds (Southall et al. 2007). Schlundt et al. (2000) reported that stimuli levels between 192 and 201 dB 1 μPa were necessary to induce TTS in bottlenose dolphins when exposed to intense 1-s tones at various frequencies. The conclusion that the TTS threshold is higher for non-impulse sound than for impulse sound is somewhat speculative. The available TTS data for impulse sound are extremely limited, and the TTS data from the bottlenose dolphin exposed to non-pulse sound pertain to sounds at 3 kHz and above. Follow-on work has shown that the $L_E$ necessary to elicit TTS can depend substantially on frequency, with susceptibility to TTS increasing with increasing frequency above 3 kHz (Finneran and Schlundt 2010, 2011; Finneran 2012).

For one harbour porpoise tested, the received level of airgun sound that elicited onset of TTS was lower than for the bottlenose dolphin. The porpoise was exposed to single pulses from a small (20 $in^3$) airgun, and auditory evoked potential methods were used to test the animal's hearing sensitivity at frequencies of 4, 32, or 100 kHz after each exposure (Lucke et al. 2009). Based on the measurements at 4 kHz, TTS occurred upon exposure to one airgun pulse with received level $L_{p,p\text{-}p}$ ~200 dB re 1 $\mu Pa_{pk\text{-}pk}$ or an $L_E$ of 164.3 dB re 1 $\mu Pa^2 \cdot s$. If these results from a single animal are representative, it is inappropriate to assume that onset of TTS occurs at similar received levels in all odontocetes (*cf.* Southall et al. 2007). Some cetaceans may incur TTS at lower sound exposures than are necessary to elicit TTS in the bottlenose dolphin.

Insofar as we are aware, there are no published data confirming that the auditory effect of a sequence of sound pulses received by an odontocete is a function of their cumulative energy. Southall et al. (2007) considered that to be a reasonable, but probably somewhat precautionary, assumption. It is precautionary because, based on data from terrestrial mammals, one would expect that a given energy exposure would have somewhat less effect if separated into discrete pulses, with potential opportunity for partial auditory recovery between pulses. However, as yet there has been little study of the rate of recovery from TTS in marine mammals, and in humans and other terrestrial mammals the available data on recovery are quite variable. Southall et al. (2007) concluded that—until relevant data on recovery are available from marine mammals—it is appropriate not to allow for any assumed recovery during the intervals between pulses within a pulse sequence. However, recent data have shown that the $L_E$ required for TTS onset to occur increases with intermittent exposures, with some auditory recovery during silent periods between signals (Finneran et al. 2010; Finneran and Schlundt 2011). For example, Finneran et al. (2015) reported no measurable TTS in bottlenose dolphins after exposure to 10 impulses from a seismic airgun with a cumulative $L_{E,}$of ~195 dB re 1 $\mu Pa^2 \cdot s$. Additional data are needed to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated pulses with variable received levels. At the present state of knowledge, it is also necessary to assume that the effect is directly related to total received energy even though that energy is received in multiple pulses separated by gaps. A data gap remains concerning the exposure levels necessary to cause TTS in toothed whales when the signal is a series of pulsed sounds, separated by silent periods.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels of $L_p$ ~178 and 183 dB re 1 µPa and total energy fluxes ($L_E$) of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, initial evidence from more prolonged (non-pulse and pulse) exposures suggested that some pinnipeds (harbour seals in particular) incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001). Kastak et al. (2005) reported that the amount of threshold shift increased with increasing $L_E$ in a harbour seal. They noted that, for non-impulse sound, doubling the exposure duration from 25 to 50 min (i.e., a +3 dB change in $L_E$) had a greater effect on TTS than an increase of 15 dB (95 vs. 80 dB) in exposure level. Mean threshold shifts ranged from 2.9–12.2 dB, with full recovery within 24 h (Kastak et al. 2005). Kastak et al. (2005) suggested that, for non-impulse sound, exposure levels resulting in TTS onset in three species of pinnipeds may range from $L_E$ 183–206 dB re 1 $\mu Pa^2 \cdot s$, depending on the absolute hearing sensitivity. As noted above for odontocetes, it is expected that—for impulse as opposed to non-impulse sound—the onset of TTS would occur at a lower cumulative exposure level given the assumed greater auditory effect of broadband impulses with rapid rise times. Insofar as we are aware, there are no data to indicate whether the TTS thresholds of other pinniped species are more similar to those of the harbour seal or to those of the two less-sensitive species. Harbour seals may be able to decrease their exposure to underwater sound by swimming just below the surface where sound levels are typically lower than at depth (Kastelein et al. 2018).

### *Other Physiological Effects*

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that might (in theory) occur in mammals close to a strong sound source include stress, neurological effects, bubble formation, and other types of organ or tissue damage. Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). Intense shock waves, because of their high peak pressures and rapid changes in pressure, can cause severe damage to animals. The most severe damage takes place at boundaries between tissues of different density. Different velocities are imparted to tissues of different densities, and this can physically disrupt the tissues. Gas-containing organs, particularly the lungs and gastrointestinal tract, are especially susceptible (Yelverton et al. 1973; Hill 1978). Lung injuries can include laceration and rupture of the alveoli and blood vessels, which in turn can lead to hemorrhage, creation of air embolisms, and breathing difficulties. Intestinal walls can bruise or rupture, with subsequent hemorrhage and escape of gut contents into the body cavity. Although hearing damage and other physical injuries have been reported for cetaceans (e.g., (Ketten et al. 1993; Ketten 1995) and pinnipeds (Fitch and Young 1948; Danil and St. Leger 2011) subjected to explosions, the charges for the proposed project would be detonated on land and would not create shock waves in the water.

## Fish Species Assessed

A number of Ireland's native diadromous species pass through the Lower Shannon Estuary on their way to or from freshwater spawning grounds or reside there for feeding as they mature. These include four species of conservation interest in the area, namely twaite shad (*Allosa fallax fallax*), sea lamprey (*Petromyzon marinus*), river lamprey (*Lampetra fluviatilis*), and Atlantic salmon (*Salmo salar*). These are all listed on Annex II of Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (EU Habitats Directive). The Habitats Directive ensures the conservation of a wide range of rare, threatened, or endemic species in Europe. Core habitat areas for Annex II species are designated as SCIs, which must be managed corresponding to the species' ecological requirements. The SCIs for twaite shad, sea lamprey, river lamprey, and Atlantic salmon that occur in the Lower Shannon Estuary have in turn been designated as a SAC. Additionally, the twaite shad and the sea lamprey are listed under Annex V, which mandates that EU Member States are required to manage exploitation of the species so that conservation status remains favourable (EU Commission 2021).

Fish stock surveys were conducted by Inland Fisheries Ireland in September to November 2008 and in October 2014 in the Upper and Lower Shannon Estuary using either a beach seine, fyke net, or beam trawl (Kelly et al. 2015). Within the Upper Shannon Estuary, 15 and 22 species of fish were recorded during 2008 and 2014, respectively, and flounder, sprat and sandy goby were the most abundant species during the 2014 survey. Within the Lower Shannon Estuary, 31 fish species were recorded in a 2008 survey and 29 were recorded in 2014. Out of these species, sprat was the most abundant, followed by sand goby, thick-lipped mullet, and sand smelt (Kelly et al. 2015). European eels (*Anguilla anguilla*) were caught in the Upper Shannon Estuary in 2008 and 2014, and the Lower Shannon Estuary in 2014 only (Kelly et al. 2015).

### Twaite Shad

Twaite shad is an anadromous fish and member of the herring (Clupeidae) family that is distributed across the north-eastern Atlantic, with Iceland as the northernmost extent of its range, Morocco as the southernmost, and the Baltic Sea as the easternmost (Aprahamian et al. 2003). They are listed as least concern globally on the IUCN Red List (IUCN 2021) but as vulnerable in the Ireland Red List (King et al. 2011), a version of the IUCN Red List (using the same population status evaluations) in which regional species population statuses in Ireland are assessed, established by the National Parks and Wildlife Service. Adult twaite shad generally migrate from the marine environment into freshwater environments to spawn from February in the south of its range to May and June in the north (Davies et al. 2020). In Ireland, shad typically spawn during April–June (Quigley 2017). The river migration period can last for three months, and seaward migration occurs for surviving adults after spawning and for young-of-the-year in the summer and autumn (Maitland and Hatton-Ellis 2003; Davies et al. 2020). Four rivers in Ireland have been shown to support spawning grounds and spawning populations of twaite shad including the Munster Blackwater and the three rivers within the Barrow-Nore-Suir river system (King and Roche 2008; Quigley 2017; Davies et al. 2020; Gallagher et al. 2020), entries to which are located on the southwestern coast of Ireland.

### Sea Lamprey and River Lamprey

Sea lamprey and river lamprey are anadromous species found in the Northern Hemisphere. The sea lamprey is listed as near threatened in the Ireland Red List (King et al. 2011), but as least concern globally on the IUCN Red List (IUCN 2021), and the river lamprey is listed as least concern on both Red Lists. Their populations are declining in Ireland and Europe due to overharvesting, habitat destruction, and the loss of spawning and nursery grounds from the construction of anthropogenic barriers blocking upstream access (Igoe et al. 2004; Bracken et al. 2018). For example, Silva et al. (2019) found that sea lampreys in the River Ulla experience a mean delay of 6.3 days per river obstacle during upstream migration. Lampreys typically spend their first years (two to eight for sea lampreys, three to five for river lampreys) in freshwater before migrating out to sea following a period of metamorphosis (Igoe et al. 2004). During this period of metamorphosis, lampreys will spend up to ten months without feeding and will begin early feeding in estuarine or coastal waters (Silva et al. 2012). Sea and river lampreys return to freshwater as adults and will spawn in areas with fast-flowing water and gravel bottoms where they can create shallow depressions or nests. All lampreys are semelparous and will die after a single spawning event (Bracken et al. 2018).

Sea lampreys are found in all suitable rivers in Ireland and have been particularly noted in the River Shannon, River Suir, River Nore, River Moy, and the River Corrib (Igoe et al. 2004). On the Mulkear River, a main tributary of the River Shannon, adult sea lamprey have been found spawning over nests until mid-May, and most adults leave by early August (Igoe et al. 2004). A study by Bracken et al. (2018) used environmental DNA (eDNA) to identify critical habitat for sea lamprey in Ireland. The eDNA sampling technique allows for the detection of low-density species and enables more effective and accurate deployment of resources and time allocation when collecting biological samples. Over a three-year period (2015-2017), they surveyed two different catchments in Ireland that included the Munster Blackwater and the Mulkear, the latter of which forms part of the Lower River Shannon SAC. Sea lamprey spawning aggregations and habitat use within both catchment areas were confirmed following eDNA collection, and eDNA concentrations were higher within the Mulkear catchment (Bracken et al. 2018). River lampreys are less apparent than sea lampreys due to smaller body size, and documentation of distribution information in

Ireland is less thorough, although its riverine range seems to largely overlap with that of the sea lamprey (Igoe et al. 2004). Key populations of river lamprey have been documented in the Mulkear River, and large numbers have been recorded in the Lower River Shannon and its tributaries. Additionally, they inhabit rivers including the Slaney, Barrow, Nore, Munster Blackwater, Laune, and Boney (Igoe et al. 2004), and lamprey larvae have been found in the Mulkear and Munster Blackwater rivers (Gallagher et al. 2020).

### *Atlantic Salmon*

Atlantic salmon is an anadromous species that is found in Europe and North America. Adult salmon migrate from the sea into rivers to spawn, usually in the same river that they spent time as a juvenile (Cefas 2021). Salmon require clean, well oxygenated rivers with gravel beds for the female to bury her eggs in redds. Spawning in Europe typically takes place from November to December. Juveniles hatch as alevins, emerge from the redds as fry, and grow into parr. After approximately four years, parr become smolt through a process called smoltification and migrate to sea where they can mature (Cefas 2021). Atlantic Salmon are listed as vulnerable in Europe under the IUCN Red list (IUCN 2021) and in Ireland under the Ireland Red List (King et al. 2011). Atkinson et al. (2020) studied the effects of river obstacles to anadromous species including Atlantic salmon and concluded that the removal of river obstacles such as bridges, culverts, would improve connectivity between river catchments and habitats.

Atlantic salmon has been observed spawning in the Lower Shannon Estuary and its tributaries. Catch and release studies of Atlantic salmon have estimated that the annual rod catch between 2009-2013 in the Mulkear, a large tributary of the Shannon catchment, was 970 salmon, while the Feale had an annual catch average of 1,350 (Gargan et al. 2015). Salmon monitoring programs conducted in the Shannon River Basin district since 2007 have concluded that three rivers (the Feale, Kilmastula, and Old Shannon) meet the conservation threshold of 17 salmon fry/5 min during electrofishing surveys showing healthy juvenile salmon abundance (Gargan et al. 2020).

### European Eel

The European eel is not listed as part of the EU Habitats Directive; however, it is considered critically endangered on the IUCN Red List (IUCN 2021) and the Ireland Red List (King et al. 2011) and is listed as a CITES Appendix II species, meaning the species is not currently threatened with extinction but trade is controlled to prevent this from occurring (CITES 2021). European eels are a catadromous species that undergo five principal stages throughout their life history including the leptocephalus, glass eel, elver, yellow eel, and silver eel (adult) stages. Adult eels spawn in the Sargasso Sea, and larvae and leptocephali drift on the Gulf Stream until they are transported across the Atlantic Ocean (Arai et al. 2006). Leptocephali metamorphose into glass eels and then elvers, with both stages typically arriving on the Irish coast during December and increasing in numbers during spring (Moriarty 1999). At this point they typically migrate upstream, approximately six to eight months after hatching, with elvers using freshwater habitats to grow into yellow eels and mature as silver eels. O’Connor (2003) reported that the main movement of eels in the Shannon Estuary occurs during February and March.

Not all eels undergo full upstream migration and are instead estuary-dependent, relying entirely on the estuarine environment for food resources, shelter, and nursing grounds. The estuarine environments in Ireland, however, are limited by high altitude land patterns; therefore, most eels are constrained during their growth period to either freshwater or marine environments (Arai et al. 2006). Mature adults will then migrate downstream to the sea in autumn with possible continuation through late spring.

The River Shannon is Ireland's largest river system, and it has a network of lakes which are important habitats for the European eel. Within the river system, otolith analysis has determined that male silver eels are 11 years old on average, and females are 15 years old (McCarthy et al. 2008). Stocking programs of juvenile eel have been in place to address adverse effects of the Shannon hydropower structures on eel recruitment and were most successful during the 1970s and 1980s; however, there are still steady declines in both yellow and silver eel populations in the Shannon system (McCarthy et al. 2008). The fishery for European eel in the River Shannon is long established, with detailed records dating from 1960 onwards (McCarthy et al. 1999).

## Hearing

All fish have hearing and skin-based mechanosensory systems, such as the inner ear and the lateral line, that provide information about their surroundings (Popper et al. 2019a; Putland et al. 2019). While all fish are likely sensitive to particle motion, not all fish (e.g., cartilaginous fish, such as sharks and jawless fish) are sensitive to the sound pressure component. Potential effects of exposure to anthropogenic sound on fish can be behavioural, physiological, or pathological.

Several authors have reviewed the hearing ability of fish (e.g., Popper and Fay 1993, 2011; Popper et al. 2014, 2019a; Putland et al. 2019). At least two major pathways for sound transmittance between sound source and the inner ear have been identified for fish. The most primitive pathway involves direct transmission to the inner ear's otolith, a calcium carbonate mass enveloped by sensory hairs. The inertial difference between the dense otolith and the less-dense inner ear causes the otolith to stimulate the surrounding sensory hair cells. This motion differential is interpreted by the central nervous system as sound. The second transmission pathway between externally received sounds and the inner ear of fish is via the swim bladder, a gas-filled structure that is much less dense than the rest of the fish's body. The swim bladder, being more compressible and expandable than either water or fish tissue, will differentially contract and expand relative to the rest of the fish in a sound field. The pulsating swim bladder transmits this mechanical disturbance directly to the inner ear.

Some fish have been described as being hearing "generalists" or "specialists" where generalists conventionally detect sound to no more than 1-1.5 kHz and only detect the particle motion component of the sound field. Whereas specialists detect sounds above 1.5 kHz and detect both particle motion and pressure. However, Popper and Fay (2011) have suggested that the terms be dropped due to vagueness in the literature, and that the most common mode of hearing in fishes involves sensitivity to acoustic particle motion via direct inertial stimulation of the otolith organs. Additionally, they found that any possible sensitivities to pressure were the result of the presence of a swim bladder in the fish and that hearing sensitivity may be enhanced if the fish has a specific connection between the inner ear and the swim bladder (Popper and Fay 2011).

Popper and Fay (2011) have also noted that there is a range of hearing abilities across fish species that is like a continuum, presumably based on the relative contributions of pressure to the overall hearing abilities of a species. One end of this continuum is represented by fish that only detect particle displacement because they lack pressure-sensitive gas-filled body parts (e.g., swim bladder). These species include elasmobranchs (e.g., sharks) and jawless fish, and some teleosts including flatfish. Fish at this end of the continuum are typically capable of detecting sound frequencies <1.5 kHz (e.g., Casper et al. 2003; Casper and Mann 2006; 2007; 2009). The other end of the fish hearing continuum is represented by fishes with highly specialized otophysic connections between pressure receptive organs, such as the swim bladder, and the inner ear. These fishes include some squirrelfish, mormyrids, herrings, and otophysan fishes (freshwater fishes with Weberian apparatus, an articulated series of small bones that extend from the swim bladder to the inner ear). Rather than being limited to 1.5 kHz or less in hearing, these fishes can typically hear up to several kHz. One group of fish in the anadromous herring sub-family Alosinae (shads and menhaden) can detect sounds to well over 180 kHz (Mann et al. 1997, 1998, 2001). This is one of the widest hearing ranges of any vertebrate that has been studied to date. While the specific reason for this very high frequency hearing is not totally clear, there is strong evidence that this capability evolved for the detection of the ultrasonic sounds produced by echolocating dolphins to enable the fish to detect, and avoid, predation (Mann et al. 1997; Plachta and Popper 2003). All other fishes have hearing capabilities that fall somewhere between these two extremes of the continuum. Some have unconnected swim bladders located relatively far from the inner ear (e.g., salmonids, tuna) while others have unconnected swim bladders located relatively close to the inner ear (e.g., Atlantic cod, *Gadus morhua*).

## Potential Impacts of Anthropogenic Sounds

Anthropogenic sounds can have important negative consequences for fish survival and reproduction if they disrupt an individual's ability to sense its soundscape, which often tells of predation risk, prey items, or mating opportunities (Fay 2009). Potential negative effects include masking of key environmental sounds or social signals, displacement of fish from their habitat, or interference with sensory orientation and navigation. These effects can generally be classified as behavioural, physiological, or pathological.

Behavioural effects refer to temporary and (if they occur) permanent changes in behaviour (e.g., startle and avoidance behaviour). Behavioural effects include changes in the distribution, migration, mating, and catchability of fish. Physiological effects involve temporary and permanent primary and secondary stress responses, such as changes in levels of enzymes and proteins. Pathological effects involve lethal and temporary or permanent sub-lethal injury. The three categories are interrelated in complex ways. For example, it is possible that certain physiological and behavioural changes could potentially lead to an ultimate pathological effect on individuals (i.e., mortality).

### *Impulsive Noise*

In a review of studies on the effects of anthropogenic sound on fish, specifically those produced by pile driving, Hastings and Popper (2005) summarized behavioural, physiological, and pathological effects on multiple fish species, as well as gaps in knowledge in the context of fish, which is largely a topic that still requires further research. High intensity pile driving noise has potentially lethal and sublethal effects on fish, but previous studies often lack quantification, evidence of delayed mortality, or consistent results, as well as suggesting that results may be highly species-specific, thereby making extrapolation of results difficult (Hastings and Popper 2005; Popper and Hastings 2009).

The most common behavioural responses to anthropogenic noise are avoidance, alteration of swimming speed and direction, and alteration of schooling behaviour (Vabø et al. 2002; Handegard and Tjøstheim, 2005; Sarà et al. 2007; Becker et al. 2013). A study conducted by Harding et al. (2016) investigated the behavioural and physiological impacts to Atlantic salmon from additional noise of impact pile driving compared to ambient control conditions. Atlantic salmon have a swim bladder that only detects particle motion, and it is not used in hearing. This means that salmon are susceptible to barotrauma that involves particle motion, not sound pressure (Popper et al. 2014). Atlantic salmon are known to detect low frequency sounds below 380 Hz which coincides with the dominant frequencies produced during piling operations (100 Hz to 2 kHz). Therefore, construction projects using pile driving may have the potential to interact with multiple Atlantic salmon life stages (Harding et al. 2016). In the study, Harding et al. (2016)

performed laboratory-based experiments using underwater playback of pile driving noise to Atlantic salmon with a hydrophone positioned 10 cm above the bottom of the tank (water depth: 1 m) and a Sony PCM-M10 24-bit recorder (96 kHz sampling rate). Pile driving noise levels were between $L_p$ 149.4-153.7 dB re 1µPa. The results showed that there were no observed differences in salmon behaviour when exposed to additional piling noise during experiments (Harding et al. 2016). Similar studies have also found that juvenile coho salmon displayed no avoidance behaviour from exposure to a real impact-piling event when positioned in cages that were positioned close to the noise source (Ruggerone et al. 2008; Harding et al. 2016). However, other studies did show behavioural effects in response to impulsive pile driving sounds on European seabass (*Dicentrarchus labrax*), including increased startle responses, swimming speeds, diving behaviours, school cohesion (Neo et al. 2014), and increased opercula beat rates (a sign of stress), increased energy expenditure on alert and defensive behaviours (e.g. inspection of the experimental area), as well as decreased inspection of possible predators (Spiga et al. 2017).

Physiological effects in fish due to pile driving and other sounds reviewed by Hastings and Popper (2005), although difficult to quantify, suggest that sublethal acoustic stressors, including vibratory sounds and increased background noise, may lead to increased stress chemicals, reduced fitness, and increased vulnerability to predation or other environmental pressures. Significant tissue damage in several fish species has been recorded in response to pile driving, primarily to the swim bladder or any air-filled structures, similar to effects from blasting (Caltrans 2004), but these results have not been consistently reproduced (Hastings and Popper 2005). Various studies have reported trauma to brain and neurological tissues, eyes, and blood vessels, including quantified studies by Hastings (1990, 1995) showing mortalities of goldfish after 2-hour continuous wave exposure (250 Hz, 204 dB re 1 µPa - peak) and of blue gouramis after 0.5-hour continuous wave exposure (150 Hz, 198 dB re 1 µPa - peak). Laboratory pile driving studies demonstrated swim bladder damage in Chinook salmon and documented tissue damage in other species (Halvorsen et al., 2012). A similar study saw ruptured swim bladders and/or kidney hemorrhaging in fish which had been exposed to ~96 pile strikes with a single-strike $L_E$ of 183 dB (Casper et al. 2017). Casper et al. (2017) found that physical injuries sustained by the fish increased in both severity and number as the cumulative sound exposure level increased with a higher energy of each pile strike and total number of strikes.

Auditory structures have also been affected by pile driving sounds in the form of hearing loss as temporary or permanent threshold shifts, with observed losses in hearing and recovery times varying widely across species. While extreme caution in extrapolation of results is recommended by Hastings and Popper (2005), overall results suggest that limited exposure to high-intensity pile driving sounds is unlikely to result in mortality and any threshold shifts are likely to be temporary. Fish may also recover more quickly from hearing damage than other groups such as marine mammals due to the ability to regrow sensory hair cells (Simmonds and MacLennan 2005).

Blasting can produce high peak pressure waves that can cause immediate mortality and significant physical damage to fish, primarily to the swim bladder, as well as to the kidneys, liver, spleen, and sinus venosus. Effects are typically greater to fish with smaller body sizes, and damage can occur to fish eggs and larvae as well (Yelverton et al. 1975, Hastings and Popper 2005; Mahtab et al. 2005). Different types of pressure waves created by explosives decay at different rates, and distance and media through which the wave passes (e.g., onshore soil types) will affect attenuation and require detailed modeling to assess distances of disturbance (Mahtab et al. 2005).

### *Non-impulsive Noise*

Continuous low intensity sounds produce largely behavioural changes in fish. Neo et al. (2014), which showed behavioural effects on European seabass (*Dicentrarchus labrax*) due to impulsive pile driving sounds, showed the same effects in response to acoustically equivalent continuous pile drilling sounds, but behavioural recovery times were significantly slower from intermittent sounds (i.e., pile driving) compared to continuous sounds (i.e. drilling). This suggests that the timing of acoustic disturbances is an important factor in impacts, not just cumulative acoustic energy. Spiga et al. (2017) observed similar differences in behavioural effects on European seabass between impulsive pile driving and continuous drilling noise disturbances, with drilling sounds resulting in a lower frequency of startle responses and quicker recovery times of normal predator-related behaviours. Continuous vibratory pile driving sounds were monitored in a harbour in Scotland in order to assess potential impacts to Atlantic salmon in important adjacent riverine habitats, and these produced received $L_p$ between 142 and 155 dB re 1 µPa from source levels between $L_p$ 173 and 185 dB re 1µPa in the immediate harbour area (Hawkings 2005). Effects to salmon were not directly observed, but sound levels from vibratory pile driving sounds were within hearing ranges of fish and posed potential risk to normal migration behaviours of nearby Atlantic salmon.

Vessel noise, which typically occurs at low frequencies thereby largely overlapping with the hearing ranges of fish (Popper and Fay 2011, Duarte et al. 2021), is another source of non-impulse sound which may elicit behavioural changes in fish. Startle and avoidance responses to vessel noise have been well documented (Simmonds and MacLennon 2005). A study by Nedelec et al. (2016) on the threespot damselfish (*Dascyllus trimaculatus*) observed increased ventilation rates and hiding behaviours in response to playback of vessel noise recordings, but also recorded development of tolerance (i.e., a trend toward normalcy in ventilation and hiding behaviour) of the vessel sounds with time. Vessel sounds and the resultant increased background noise level have also produced reduced predator detection and consequent increased mortality via predation, masking of vocalizations and important auditory cues and messages, and increased physiological stress (Simpson et al. 2016; Stanley et al 2017; Duarte et al. 2021). de Jong et al. (2020) also surmised that continuous sounds, such as those from heavy ship traffic, were mostly likely to cause stress, masking, and hearing loss rather than intermittent sounds.

## Impact Assessment Methods

The proposed activities associated with the marine construction and operation of the LNG terminal have the potential to impact marine mammals and fish, mainly through the introduction of noise to the marine environment. In the sections below, we describe the methods used to determine the area within which animals may be exposed to sounds above threshold levels that could cause various levels of impact, such as potential injury or behavioural disturbance. For bottlenose dolphins, we then estimate the number of animals likely be present in this region of the Shannon Estuary. By applying that estimate to the area predicted to be exposed above threshold levels, we arrive at the number of potential disturbance or injurious exposures of bottlenose dolphins to the various project activities. This provides a quantitative measure of potential impacts upon which to base further assessment of overall impacts. Quantitative assessment of potential impacts to other species is limited by available data on the absolute abundance of those species in the project area, quantitative criteria for assessing impacts, or both. The main sources of data used in deriving the estimates are described in the next subsections.

Various assumptions had to be made to conduct the acoustic modeling regarding equipment and likely activity scenarios, as not all details were available at the time of the analysis. Similarly, we have made simplifying assumptions such as calculating a spatially uniform dolphin density and applying it throughout a year when there are likely spatial and seasonal differences in densities that would lead to, for example, lower exposure estimates during the winter compared with summer. In addition, it should be recognized that there are a number of limitations and uncertainties associated with TTS and PTS criteria for marine mammals (NMFS 2018). As described in the previous section (*Behavioural Effects*), behavioural responses can also be quite variable and influenced by the ecological context in which the sounds are encountered. Factors such as the life stage and activity state of the animal, nature and novelty of the sound, and spatial relationship to the sound can all affect the response of marine mammals (Ellison et al. 2012). Thus, as with all similar assessments, there are some uncertainties associated with the results of this study.

## Acoustic Modeling of Project Activities

Acoustic modeling specific to the project site and activities was conducted by VG (2021). Several different scenarios and project activities were modeled at various positions as summarized in Table 2. Further details can be found in VG (2021). The scenarios range in complexity from a single activity like impact pile driving during construction in Scenario C1 to Scenario E, which involves multiple sources during the operational phase that is based on the offloading scenario, with the addition of a transiting cargo ship and moored ship. It is important to note the temporal duration and frequency of occurrence for each of these scenarios, which are described in the final column of Table 2. Some activities may produce strong sounds but only for brief periods of time and relatively infrequently. The temporal aspects of these activities and the sounds they produce play and important role in interpreting potential impacts.

Acoustic modeling used VG’s survey mapping methodology, which calculates sound propagation along a number of transects (in this case, 15 transects from each of Position A and B) that are chosen to represent various bathymetric profiles with different sound propagation characteristics. Sound propagation took into account the bathymetry, tide level, seabed properties, and sound speed profile of the water column. The modeling resulted in sound propagation estimates for the various locations and activity scenarios. The distance along the various transects to the thresholds was determined, as well as the area to the thresholds. In general, the modeling results are expected to be representative of the vast majority of operations; however, there may be instances where either the equipment used or sound propagation conditions may vary from the modeling results.

## Marine Mammals

### *Density of Bottlenose Dolphins in the Project Area*

Since no bottlenose dolphin density estimates have been reported in previous studies and the available data collected from shore and via boat-based surveys do not lend themselves to determining a density using standard line-transect methodologies, we used the dolphin population size and areas in which they typically occur to calculate a density. Rogan et al. (2000) divided the Shannon Estuary into 4 Zones based on occurrence of dolphins. For our calculations, we used Zone 4, the zone farthest to the east where the proposed terminal would be constructed, as the area component to the density calculation (number of dolphins per unit area). Rogan et al. (2000) also reported that 13% of the dolphin population typically occurs within Zone 4. Thus, 13% of the current estimated population size of 145 individuals (as provided by Baker et al. 2018a) was assumed to occur in Zone 4. By dividing 13% of the current population (~19 animals) by the area of Zone 4 (35 km$^2$), we calculated a density of 0.54 dolphins/km$^2$ in Zone 4.

Table 2. Construction and operational scenarios that were modeled by VG (2021), and their associated activities and durations. Underlined activities produce impulsive sounds.

| **Project Phase** | **Acoustic Modeling Scenario[1]** | **Activities[2]** | **Modeling Location (Position)[3]** | **Activity Duration and Frequency of Occurrence** |
|---|---|---|---|---|
| Construction | C1 | Impact pile driving[4] | Marine Terminal (A) | 60 min per pile,<br>(2640 strikes per pile),<br>Up to one pile per day |
| Construction | C2 | Vibratory pile driving with support vessels | Marine Terminal (A) | *Vibratory piling*: 20 min per pile, up to one pile per day<br>*Support vessels*: 1 jack-up rig (100% operation time), 1 crane barge (100% operation time), 1 tug (20% sailing, 80% idling), 1 crew boat (10% operation time) |
| Construction | C3 | Socket drilling with support vessels | Marine Terminal (A) | Drilling: up to 25 h per pile, up to one pile per day<br>*Support vessels*: 1 jack-up rig (100% operation time), 1 crane barge (100% operation time), 1 tug (20% sailing, 80% idling), 1 crew boat (10% operation time) |
| Construction | C4 | Blasting – onshore[4] | Marine Terminal (A) | Single instantaneous event, up to one per day |
| Operations | A | Stationary FSRU emitting hull-radiated noise continuously, including noise from seawater cooling pumps | Marine Terminal (A) | Continuously for 24 h, 7 days a week. |
| Operations | B | FSRU with offloading LNGC tied to it and one idling tug | Marine Terminal (A) | Up to 35 h once per week |
| Operations | D | Approaching/Departing LNGC assisted by 4 transiting tugs, along with FSRU | LNGC and tugs:<br>1,150 m northwest of terminal (B)<br>FSRU: (A) | 15 min, one approach and one departure per week |
| Operations | E | FSRU together with an offloading LNGC and 4 sailing tugs, plus cargo ship sailing in the middle of the estuary at 10 knots and a ship moored at Moneypoint | FSRU and tugs: (A)<br>Sailing cargo ship: middle of estuary<br>Moored ship: Moneypoint | *FSRU*: continuously for 24 h<br>*Offloading LNGC and idling tug*: 24 h.<br>*Transiting LNGC and 4 sailing/engaged tugs*: 15 min<br>*Sailing cargo ship*: 15 min<br>*Moored ship*: 24 h<br>Event may occur for 15 min once per week |

[1] See VG (2021).

[2] Source levels are provided in Table 1.

[3] See Figure 1 *in* VG (2021).

[4] Impact piling and blasting were modeled without support vessels to avoid mixing impulsive and non-impulsive sounds.

We also considered an alternative source for the density calculation. Baker et al. (2018b) estimated ~25% of the population (~36 individuals) could use the inner estuary between Kilrush and Aughinish. As the inner estuary covers 338 km$^2$, the density based on this paper is 0.11 dolphins/km$^2$. To be conservative, we used the estimate derived from Rogan et al. (2000) described above, 0.54 dolphins/km$^2$.

### *Acoustic Thresholds*

The NPWS (2014) has published *Guidance to Manage the Risk to Marine Mammals from Man-made Sound Sources in Irish Waters*. Although this document discusses the acoustic threshold criteria recommended by Southall et al. (2007), it does not provide specific acoustic thresholds to be used in Irish waters. NPWS however does require a 1-km monitored/mitigation zone for marine mammals during pile driving activities, unless information specific to the project is available to inform the mitigation distance and is approved by the Regulatory Authority. The 1-km zone is to be monitored by an experienced and qualified marine mammal observer and pile driving cannot commence if marine mammals are detected within the 1-km zone around pile being driven. In this assessment, we have assumed the monitoring and mitigation measures described in NPWS (2014) for pile driving will be implemented during the relevant construction activities.

As there are no specific threshold criteria for use in Irish or EU waters at this time, for this assessment we use the threshold criteria set forth by the U.S. National Marine Fisheries Service (NMFS) in their *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing* (NMFS 2016, 2018) to assess the effects of noise on the hearing of marine mammals (Table 3). The thresholds for TTS and PTS onset (where PTS onset is considered the point at which injury or mortality becomes possible and is defined as "Level A" harassment in the U.S. Marine Mammal Protection Act) for marine mammals for impulsive sounds use dual metrics of cumulative sound exposure levels (over 24 h; expressed here as $L_{\mathrm{E,24h}}$) and peak sound pressure levels (expressed here as $L_{\mathrm{p,0\text{-}pk}}$). NMFS recommends that the largest distance of the dual criteria is used to calculate distances to potential injurious exposures. For non-impulsive sounds a single metric of $L_{\mathrm{E,24h}}$ is recommended (Table 3).

Different PTS and TTS thresholds are provided for various hearing groups and include the use of frequency weighting functions. Frequency weighting functions are used to assess potential auditory effects of sounds by taking into account the animal's hearing sensitivity to different frequencies (NMFS 2018). For example, MF-weighting is the auditory frequency-weighting function used for various species of marine mammals assigned to the "mid-frequency" category that includes bottlenose dolphins, HF-weighting is the function assigned to "high-frequency" species such as harbour porpoise, and PW-weighting is assigned to phocid pinnipeds underwater.

Also provided in Table 3 are the behavioural thresholds that are currently used by NMFS. The disturbance thresholds (termed "Level B" harassment in U.S. regulations) are unweighted (also referred to as "flat-weighted") received $L_{\mathrm{p,rms}}$ of 160 dB re 1 µPa for impulsive sounds and 120 dB re 1 µPa for non-impulsive sounds (NMFS 2019). However, NMFS has recently started to incorporate the use of frequency weighting into disturbance threshold calculations as well (NMFS 2021), since this approach allows more realistic assessment of potential behavioural responses.

Table 3. NMFS in-water acoustic thresholds for disturbance, TTS, and PTS for different marine mammal hearing groups (Source: NMFS 2018, 2019).

| | | **Acoustic Thresholds** | | | |
|---|---|---|---|---|---|
| | | **Impulsive Sounds** | | **Non-Impulsive Sounds** | |
| **Marine Mammal Hearing Group** | **Generalized Hearing Range** | **PTS Onset** | **TTS Onset** | **PTS Onset** | **TTS Onset** |
| **Level A Criterion – PTS Onset** | | | | | |
| Low-frequency cetaceans (LF) | 7 Hz to 35 kHz | $L_{p,0-pk}$: 219 dB<br>$L_{E,p,LF,24h}$: 183 dB | $L_{p,0-pk}$: 213 dB<br>$L_{E,p,LF,24h}$: 168 dB | $L_{E,p,LF,24h}$: 199 dB | $L_{E,p,LF,24h}$: 179 dB |
| Mid-frequency cetaceans (MF) | 150 Hz to 160 kHz | $L_{p,0-pk}$: 230 dB<br>$L_{E,p,MF,24h}$: 185 dB | $L_{p,0-pk}$: 224 dB<br>$L_{E,p,MF,24h}$: 170 dB | $L_{E,p,MF,24h}$: 198 dB | $L_{E,p,MF,24h}$: 178 dB |
| High-frequency cetaceans (HF) | 275 Hz to 160 kHz | $L_{p,0-pk}$: 202 dB<br>$L_{E,p,HF,24h}$: 155 dB | $L_{p,0-pk}$: 196 dB<br>$L_{E,p,HF,24h}$: 140 dB | $L_{E,p,HF,24h}$: 173 dB | $L_{E,p,HF,24h}$: 153 dB |
| Phocid pinnipeds Underwater (PW) | 75 Hz to 75 kHz | $L_{p,0-pk}$: 218 dB<br>$L_{E,p,PW,24h}$: 185 dB | $L_{p,0-pk}$: 212 dB<br>$L_{E,p,PW,24h}$: 170 dB | $L_{E,p,PW,24h}$: 201 dB | $L_{E,p,PW,24h}$: 181 dB |
| **Level B Criterion – Disturbance** | | | | | |
| Behavioural disruption for impulsive noise (e.g., impact pile driving, blasting) | | | $L_{p,rms}$: 160 dB | | |
| Behavioural disruption for continuous noise (e.g., vibratory pile driving, vessel noise, drilling) | | | $L_{p,rms}$: 120 dB | | |

The acoustic propagation modeling conducted by VG (2021) for this project applied weighting to $L_{p,rms}$ and $L_{E,24h}$ values. Even with the application of frequency-weighting functions to established disturbance thresholds, behavioural responses are complex and often context dependent, such that some individuals may respond at lower received levels, while others will not respond until received levels are above the threshold. Alternative threshold and approaches, including probability of response curves and multiple step functions to describe the likelihood and severity of responses are under consideration by regulatory bodies, but no new criteria have been finalized.

### *Estimation of Exposures*

To determine the number of individuals potentially exposed to the specified threshold levels we multiplied the estimated dolphin density by the area potentially exposed to sounds above the threshold levels. For example, the number of dolphins potentially exposed above disturbance thresholds, or "disturbance exposures", are calculated by multiplying the dolphin density (0.54 dolphins/km$^2$) by the area around the activity where received $L_{p,rms} \geq 160$ dB or $\geq 120$ dB are predicted to occur for impulsive and non-impulsive sound, respectively. Similarly, the number of individuals potentially exposed above PTS thresholds, or "PTS exposures" are based on the multiplication of the density of dolphins by the area around the activity where received levels of sound were modeled to exceed $L_{p,0-pk}$ 230 dB or $L_{E,MF,24h}$ 185 dB for impulsive sound and $L_{E,MF,24h}$ 198 dB for non-impulsive sound. The same calculations were made using the areas potentially exposed above TTS thresholds to calculate "TTS exposures".

In cases where the calculation results in a value of less than one individual it can be interpreted as the probability of an individual being exposed to a single occurrence of that event. For instance, if it is calculated that 0.1 dolphins may be exposed above the PTS threshold from a certain activity, then there is a 10% chance that a dolphin would be exposed during any single occurrence of that activity. And if that activity were to occur 10 times, then it would be reasonable to expect that a single dolphin might be exposed over the course of all ten occurrences combined.

However, since calculations that rely on density estimates do not always adequately reflect species that tend to occur in groups, we also provide estimates based on exposures of dolphin groups using the mean group size of ~6.2 ± 3.1 individuals as a worst-case scenario for potential exposures. As sightings of other marine mammal species in the Shannon Estuary are limited, meaningful densities, group sizes, or estimates of frequency of occurrence were not available. Thus, assessment of potential impacts to these species are qualitative in nature.

## Fish

### *Acoustic Thresholds*

Popper et al. (2014) provided acoustic thresholds for various impulsive sound sources, such as pile driving (Table 4). The sound levels expected to cause mortality and potential mortal injury during in-water explosions are $L_{p,0\text{-pk}}$ 229–234 dB (Popper et al. 2014). For non-impulsive sounds, Popper et al. (2014) only provides quantitative thresholds for fish with swim bladders involved in hearing; relative risks from continuous sounds for other fish groups are also provided as shown in Table 5.

Table 4. Acoustic thresholds and relative risk for impact pile driving for various fish hearing groups (Source: Popper et al. 2014).

| | **Acoustic Thresholds for Pile Driving** | | | |
|---|---|---|---|---|
| | **Mortality and Potential Mortal Injury** | **Impairment** | | |
| **Type of Fish** | | **Recoverable Injury** | **TTS** | **Behaviour** |
| No swim bladder (particle motion detection) | $L_{p,0\text{-pk}}$: >219 dB<br>$L_{E,p,24h}$: >213 dB | $L_{p,0\text{-pk}}$: >213 dB<br>$L_{E,p,24h}$: >216 dB | $L_{E,p,24h}$: *>>186 dB* | (N) High; (I) Moderate; (F) Low |
| Swim bladder is not involved in hearing (particle motion detection) | $L_{p,0\text{-pk}}$: >207 dB<br>$L_{E,p,24h}$: 210 dB | $L_{p,0\text{-pk}}$: >207 dB<br>$L_{E,p,24h}$: 203 dB | $L_{E,p,24h}$: *>186 dB* | (N) High; (I) Moderate; (F) Low |
| Swim bladder involved in hearing (primarily pressure detection) | $L_{p,0\text{-pk}}$: >207 dB<br>$L_{E,p,24h}$: 207 dB | $L_{p,0\text{-pk}}$: >207 dB<br>$L_{E,p,24h}$: 203 dB | $L_{E,p,24h}$: *186 dB* | (N) High; (I) High; (F) Moderate |
| Eggs and larvae | $L_{p,0\text{-pk}}$: >207 dB<br>$L_{E,p,24h}$: >210 dB | (N) Moderate; (I) Low; (F) Low | (N) Moderate; (I) Low; (F) Low | (N) Moderate; (I) Low; (F) Low |

(N) = near or tens of metres from the source; (I) = intermediate or hundreds of metres from the source; (F) = far or thousands of meters from the source.

Table 5. Acoustic thresholds or relative risk of continuous sounds such as shipping for various fish hearing groups (Source: Popper et al. 2014). Relative risk (high, moderate, low) is given for fish at three distances from the source.

| Type of Fish | Mortality and Potential Mortal Injury | Impairment |  | Behaviour |
|---|---|---|---|---|
|  |  | Recoverable Injury[1] | TTS[1] |  |
| No swim bladder (particle motion detection) | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Moderate<br>(F) Low |
| Swim bladder is not involved in hearing (particle motion detection) | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Moderate<br>(F) Low |
| Swim bladder involved in hearing (primarily pressure detection) | (N) Low<br>(I) Low<br>(F) Low | 170 $dB_{rms}$ re 1 µPa for 48 h | 158 $dB_{rms}$ re 1 µPa for 12 h | (N) High<br>(I) Moderate<br>(F) Low |
| Eggs and Larvae | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Moderate<br>(F) Low |

[1] Criteria are presented as sound pressure since no data are available for particle motion.

(N) = near or tens of metres from the source; (I) = intermediate or hundreds of metres from the source; (F) = far or thousands of meters from the source.

# Impact Assessment Results

Here we present results from the acoustic modeling of areas potentially exposed above the threshold levels and the number of animals potentially present within those areas. As noted in the Methods section, bottlenose dolphins were the only species with quantitative estimates of abundance in the project area. Thus, they are the only species for which estimates of the number of individuals that could potentially be exposed to sounds above disturbance thresholds during the construction and operational phases of the project are provided. The disturbance exposure estimates would primarily involve temporary changes in behaviour. Also provided are the exposure estimates for TTS. Although PTS or other injuries are not expected because of the relatively small distances and monitoring and mitigation measures that would be implemented, the results of those calculations are also presented for completeness.

## Marine Mammals

### *Construction*

Impulsive sounds from pile driving reached the PTS and TTS threshold criteria for bottlenose dolphins at distances up to 94 m and 786 m, respectively (Table 6). Given these relatively short distances and the low density of dolphins, daily (or per event) PTS and TTS exposures from impact pile driving were <1. As noted previously, when the calculated number of exposures from a given event is less than one, it should be interpreted as the probability of exposing a single animal during that given event. To understand the likelihood of exposure across all of the planned impact piling we multiplied the per event exposure estimates by the number of impact piling events (203); this resulted in 2 exposures above the PTS criterion and 88 exposures above the TTS criterion. Implementation of monitoring and mitigation measures (NPWS 2014) as planned will further reduce the very low potential for PTS or TTS exposures calculated here.

For harbour porpoise, impact pile driving activities also have the potential to cause auditory impairment, with PTS possible within 3163 m and TTS possible within 7640 m (Table 7). The same is true for harbour seals, but the distances are substantially shorter (Table 8). In both cases, these distances result from the cumulative sound exposure ($L_{E,P,24h}$) criteria, which means that individuals of these species would have to remain within those distances the entire 60 min duration of pile driving to experience such effects.

Neither of the non-impulsive sounds from construction activities (vibratory pile driving or socket drilling) reached the threshold criteria for potential PTS or TTS for bottlenose dolphins (Table 6). For harbour porpoise and harbour seal, the $L_{E,P,24h}$ TTS threshold distance extended to 604 m and 84 m for socket drilling (Scenario C3). As noted for the impact pile driving $L_{E,P,24h}$ thresholds, an individual animal would need to remain within those distances for the entire duration of the event, a full day (24 h) in this case, which is highly unlikely.

The very low likelihood that any marine mammals will be exposed above PTS or even TTS thresholds means that most potential impacts are likely to be through behavioural disturbance. For impact pile driving, the distance to the MF-weighted behavioural threshold of $L_{\mathrm{p,rms}}$ 160 dB occurred at locations up to 138 m away and over an area of ~0.04 km$^2$ (Table 6; Fig. 2c). A similar distance was estimated for the socket drilling scenario (118 m), and a negligible 2 m distance was estimated for vibratory pile driving (Table 6). When the areas exposed above these levels were multiplied by the bottlenose dolphin density, less than one daily disturbance exposure is expected to result from any of the construction activities (Table 6). If one pile is driven in a 24-h period and a total of 203 piles are expected to be driven during the project, then the exposure estimate for disturbance over the course of the construction period from all impact pile driving would sum to a total of four individuals. For socket drilling, it was estimated that there could be up to three total disturbance exposures over the course of pile installation.

Alternatively, if we assume that at least one exposure would occur each day of pile installation (203 days) and that each exposure would involve an entire group of dolphins (average of 6.2 ± 3.1 individuals), then there could be 1259 disturbance level exposures (range 629–1888) during pile installation activities.

The modeled distances to disturbance thresholds from construction activities for HF-cetaceans (Table 7) were similar to those of bottlenose dolphins, while quite a bit larger for seals (Table 8). Given the low frequency of occurrence of these species in the Shannon Estuary, it is likely that only a few individuals, if any, would be disturbed by sounds produced during construction activities.

Table 6. Threshold criteria, distances and areas to thresholds, and exposure estimates for bottlenose dolphins during various Shannon LNG project construction activities using <u>*MF-weighted*</u> modeling results for assessing potential PTS and disturbance. Impact pile driving and onshore blasting are impulsive sounds, whereas vibratory pile driving and drilling are continuous sounds.

| | **C1 - Impact Pile Driving** | **C4 - Onshore Blasting** | **C2 - Vibratory Pile Driving Plus Support Vessels** | **C3 - Socket Drilling Plus Support Vessels** |
|---|---|---|---|---|
| **Disturbance** | | | | |
| **Threshold MF-weighted (dB)** | 160 | 160 | 120 | 120 |
| **Max. distance to threshold (m)** | 138 | - | 2 | 118 |
| **Area within threshold (km$^2$)** | 0.038 | - | 2.369E-06 | 0.025 |
| **PTS** | | | | |
| **PTS threshold $L_{\mathrm{E,p,MF,24h}}$ (dB)** | 185 | 185 | 198 | 198 |
| **Max. Distance to PTS $L_{\mathrm{E,p,MF,24h}}$ threshold (m)** | 94 | - | - | - |
| **Area within $L_{\mathrm{E,p,MF,24h}}$ threshold (km$^2$)** | 0.020 | - | - | - |
| **PTS threshold $L_{\mathrm{p,0\text{-}pk}}$ (dB)** | 230 | 230 | - | - |
| **Max. Distance to PTS threshold $L_{\mathrm{p,0\text{-}pk}}$ (m)** | - | - | - | - |
| **Area within PTS $L_{\mathrm{p,0\text{-}pk}}$ threshold (km$^2$)** | - | - | - | - |
| **TTS** | | | | |
| **TTS threshold $L_{\mathrm{E,p,MF,24h}}$ (dB)** | 170 | 170 | 178 | 178 |
| **Max. Distance to TTS $L_{\mathrm{E,p,MF,24h}}$ threshold (m)** | 786 | - | - | - |
| **Area within $L_{\mathrm{E,p,MF,24h}}$ threshold (km$^2$)** | 0.808 | - | - | - |
| **TTS threshold $L_{\mathrm{p,0\text{-}pk}}$ (dB)** | 224 | 224 | - | - |
| **Max. Distance to TTS threshold $L_{\mathrm{p,0\text{-}pk}}$ (m)** | - | - | - | - |
| **Area within TTS $L_{\mathrm{p,0\text{-}pk}}$ threshold (km$^2$)** | - | - | - | - |
| **Occurrence of activity** | 1 pile per day; total 203 piles^ | 1 blasting event per day | 20 min per pile | 25 h per pile |
| **Disturbance Exposures*** | | | | |
| ***Daily exposures*** | 0.020 | 0 | 1.276E-06 | 0.013 |
| ***Total exposures*** | 4.140 | 0 | 2.590E-04 | 2.724 |
| **PTS exposures*** | | | | |
| **$L_{\mathrm{E,p,MF,24h}}$** | 0.011 | 0 | 0 | 0 |
| **$L_{\mathrm{p,0\text{-}pk}}$** | 0 | 0 | - | - |
| **TTS exposures*** | | | | |
| **$L_{\mathrm{E,p,MF,24h}}$** | 0.435 | 0 | 0 | 0 |
| **$L_{\mathrm{p,0\text{-}pk}}$** | 0 | 0 | - | - |

- not applicable or sounds did not reach threshold.

*Exposure calculations are based on the affected area x dolphin density of 0.54 dolphins/km$^2$.

^ Number of piles and piling rate are estimated and subject to weather, construction technology, and other considerations.

Table 7. Threshold criteria and distances to thresholds for high-frequency cetaceans during various Shannon LNG project activities for assessing potential harm and disturbance.

| | Construction | | | | Operation | | | |
|---|---|---|---|---|---|---|---|---|
| | C1 - Impact Pile Driving | C4 - Onshore Blasting | C2 - Vibratory Pile Driving Plus Support Vessels | C3 - Socket Drilling Plus Support Vessels | A - FSRU | B - FSRU with Offloading | D - LNGC Approach/ Depart | E - Cumulative Sound |
| **Disturbance** | | | | | | | | |
| **Threshold HF-weighted (dB)** | **160** | **160** | **120** | **120** | **120** | **120** | **120** | **120** |
| **Max. distance to threshold (m)** | 77 | - | - | 110 | 76 | 77 | 988 | 802 |
| **PTS** | | | | | | | | |
| **PTS threshold $L_{E,p,HF,24h}$ (dB)** | **155** | **155** | **173** | **173** | **173** | **173** | **173** | **173** |
| **Max. Distance to PTS $L_{E,p,HF,24h}$ threshold (m)** | 3163 | - | - | - | - | 50 | - | 50 |
| **PTS threshold $L_{p,0\text{-}pk}$ (dB)** | **202** | **202** | - | - | - | - | - | - |
| **Max. Distance to PTS threshold $L_{p,0\text{-}pk}$ (m)** | - | - | - | - | - | - | - | - |
| **TTS** | | | | | | | | |
| **TTS threshold $L_{E,p,HF,24h}$ (dB)** | **140** | **140** | **153** | **153** | **153** | **153** | **153** | **153** |
| **Max. Distance to TTS $L_{E,p,HF,24h}$ threshold (m)** | 7640 | - | - | 604 | 50 | 564 | 222 | 564 |
| **TTS threshold $L_{p,0\text{-}pk}$ (dB)** | **196** | **196** | - | - | - | - | - | - |
| **Max. Distance to TTS threshold $L_{p,0\text{-}pk}$ (m)** | - | - | - | - | - | - | - | - |

"-" means sounds did not reach above the threshold.

Table 9. Threshold criteria and distances to thresholds for phocid pinnipeds during various Shannon LNG project activities for assessing potential harm and disturbance.

| | Construction | | | | Operation | | | |
|---|---|---|---|---|---|---|---|---|
| | C1 - Impact Pile Driving | C4 - Onshore Blasting | C2 - Vibratory Pile Driving Plus Support Vessels | C3 - Socket Drilling Plus Support Vessels | A - FSRU | B - FSRU with Offloading | D - LNGC Approach/ Depart | E - Cumulative Sound |
| **Disturbance** | | | | | | | | |
| **Threshold PW-weighted (dB)** | **160** | **160** | **120** | **120** | **120** | **120** | **120** | **120** |
| **Max. distance to threshold (m)** | 937 | 75 | 737 | 368 | 549 | 554 | 2797 | 1922 |
| **PTS** | | | | | | | | |
| **PTS threshold $L_{E,p,PW,24h}$ (dB)** | **185** | **185** | **201** | **201** | **201** | **201** | **201** | **201** |
| **Max. Distance to PTS $L_{E,p,PW,24h}$ threshold (m)** | 590 | - | - | - | - | - | - | - |
| **PTS threshold $L_{p,0\text{-}pk}$ (dB)** | **218** | **218** | - | - | - | - | - | - |
| **Max. Distance to PTS threshold $L_{p,0\text{-}pk}$ (m)** | - | - | - | - | - | - | - | - |
| **TTS** | | | | | | | | |
| **TTS threshold $L_{E,p,PW,24h}$ (dB)** | **170** | **170** | **181** | **181** | **181** | **181** | **181** | **181** |
| **Max. Distance to TTS $L_{E,p,PW,24h}$ threshold (m)** | 4010 | - | - | 84 | - | 116 | - | 116 |
| **TTS threshold $L_{p,0\text{-}pk}$ (dB)** | **212** | **212** | - | - | - | - | - | - |
| **Max. Distance to TTS threshold $L_{p,0\text{-}pk}$ (m)** | - | - | - | - | - | - | - | - |

"-" means sounds did not reach above the threshold.

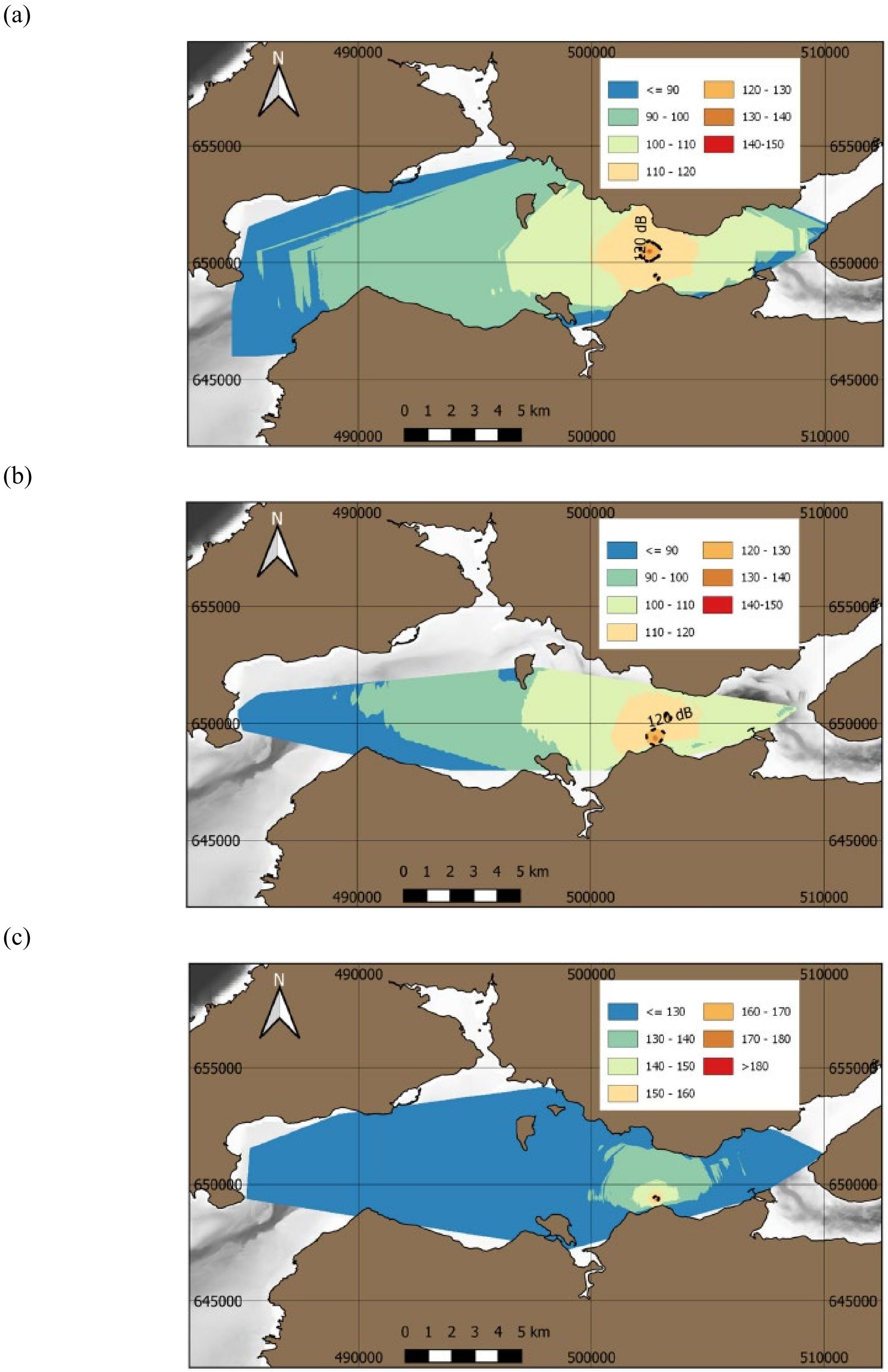

Figure 2. Sound contour map of $L_{p,rms}$ (MF-weighted, "Max-over-depth") for (a) Scenario D (FSRU with approaching LNGC and four tugs), (b) Scenario E (cumulative sound scenario), and (c) Scenario C1 (impact pile driving). Values in dB re 1 µPa.

## Operations

None of the non-impulsive sounds from operational activities reached the threshold criteria for potential PTS for bottlenose dolphins (Table 7). Although modeling estimated a slight possibility of TTS based on the $L_{E,p,MF,\ 24h}$ TTS criterion (within 41 m of the activity for the entire duration of the activity) on a daily basis from offloading activities (Scenario B) and the cumulative scenario (Scenario E), exposure estimates were still less than 1 individual when summed over the course of 1 year.

TTS is a possibility for harbour porpoise during all operational scenarios at distances ranging from 50 m to 564 m (Table 7), while PTS is only possible within 50 m of the offloading and cumulative scenarios (Scenarios B and E). No PTS is expected in seals from operational activities, but TTS may be possible within 116 m from the offloading and cumulative sound scenarios (Table 8).

Acoustic modeling estimated that out of all of the scenarios, Scenario D (an approaching LNGC with four tugs) would create the largest area ensonified above the MF-weighted behavioural threshold of $L_{\mathrm{p,rms}}$ 120 dB (Table 10; Fig. 2a). The area ensonified by sounds from the approaching LNGC and tugs is estimated to be ~0.6 km$^2$ as it travels along its path from a point 1,150 km from the FSRU. The next largest impact area was estimated for Scenario E (cumulative scenario), for which the behavioural threshold would be exceeded at locations up to 939 m away over an area of 0.4 km$^2$ (Table 10; Fig. 2b).

The disturbance exposures of bottlenose dolphins were higher for operational activities than for construction activities. Although daily exposures were still calculated to be less than 1, it was estimated that there could be between 1 and 34 individuals behaviourally disturbed each year across the four operational scenarios (Table 10). Alternatively, if we assume that at least 1 behavioural disturbance exposure of an average-sized group of dolphins could occur each day during the various operational activities, the disturbance exposures would be 2263 animals for the FSRU operation (Scenario A), 645 exposures during LNGC approach/departure (Scenario D), and 322 exposures for the offloading and cumulative sound scenarios (Scenarios B and E).

An approaching LNGC with four tugs (Scenario D) resulted in the longest estimated distance (up to 988 m away) to the HF-weighted behavioural disturbance threshold ($L_{\mathrm{p,rms}}$ 120 dB). The 802 m distance for the cumulative sound scenario (Scenario E) was the next largest. Similarly, for seals, the PW-weighted $L_{\mathrm{p,rms}}$ 120 dB distance resulting from the LNGC approach was the largest and could extend up to 2797 m away, which was followed by the cumulative scenario (Scenario E) at 1922 m (Table 10). As noted in the previous section, the infrequent occurrence of these species in the estuary makes the likelihood of disturbing individuals quite low, despite the longer distance to threshold levels compared to bottlenose dolphins.

Table 10. Threshold criteria, distances and areas to thresholds, and exposure estimates for bottlenose dolphins during various Shannon LNG project operations activities using *MF-weighted* modeling results for assessing potential disturbance, PTS, and TTS. All sounds produced by operational activities are considered continuous.

| | A - FSRU | B - FSRU with Offloading | D - LNGC Approach/ Depart | E - Cumulative Sound |
|---|---|---|---|---|
| **Disturbance** | | | | |
| **Threshold MF-weighted (dB)** | 120 | 120 | 120 | 120 |
| **Max. distance to threshold (m)** | 112 | 113 | 983 | 939 |
| **Area within threshold ($km^2$)** | 0.031 | 0.031 | 0.601 | 0.440 |
| **PTS** | | | | |
| **PTS threshold $L_{E,p,MF,24h}$ (dB)** | 198 | 198 | 198 | 198 |
| **Max. Distance to PTS $L_{E,p,MF,24h}$ threshold (m)** | - | - | - | - |
| **Area within $L_{E,p,MF,24h}$ threshold ($km^2$)** | - | - | - | - |
| **TTS** | | | | |
| **TTS threshold $L_{E,p,MF,24h}$ (dB)** | 178 | 178 | 178 | 178 |
| **Max. Distance to TTS $L_{E,p,MF,24h}$ threshold (m)** | - | 41 | - | 41 |
| **Area within $L_{E,p,MF,24h}$ threshold ($km^2$)** | - | 0.003 | - | 0.003 |
| **Occurrence of activity** | Continuous | Once per week | 15 min twice per week | Once per week at most |
| **Disturbance exposures*** | | | | |
| ***Daily exposures*** | 0.017 | 0.017 | 0.324 | 0.237 |
| ***Weekly exposures*** | 0.116 | 0.017 | 0.648 | 0.237 |
| ***Yearly exposures*** | 6.037 | 0.881 | 33.683 | 12.320 |
| **PTS $L_{E,p,MF,24h}$ exposures*** | 0 | 0 | 0 | 0 |
| **TTS $L_{E,p,MF,24h}$ exposures*** | 0 | 0.002 | 0 | 0.002 |

- sounds did not reach threshold.

*Exposure calculations are based on the affected area x dolphin density of 0.54 dolphins/$km^2$.

## Fish

### *Construction*

Fish could experience PTS, TTS or other injury from impact pile driving activities, with fish that use their swim bladder for hearing, such as Twaite shad, being more susceptible to potential effects than other types of fish. For fish that use their swim bladder for hearing, as well as for fish eggs and larvae, mortalities could occur within 142 m of impact pile driving, whereas TTS is possible within ~2 km of impact pile driving (Table 11). Blasting is expected to introduce sound pressure levels into the water of up to $L_{p,0\text{-}pk}$ 207 dB (VG 2021). As the threshold for mortality and potential mortal injury is $L_{p,0\text{-}pk}$ 229–234 dB, no mortalities are expected from blasting for fish in any hearing groups.

Fish without a swim bladder or those whose swim bladder is not involved in hearing have a moderate risk of behavioural disturbance within hundreds of metres during pile driving (Table 5). The risk of behavioural disturbance is also moderate for fish without a swim bladder exposed to blasting sounds. For fish that have a swim bladder involved in hearing, the risk becomes high within hundreds of metres from impact pile driving, whereas fish without swim bladders and those not involved in hearing are only at high risk of behavioural disturbance within tens of metres from impact pile driving (Table 5).

### *Operations*

Based on the thresholds for continuous sounds from Popper et al. (2014) for fish that have swim bladders involved in hearing, none of the sound levels from the modeled activities have the potential to cause injury. TTS is also unlikely during activities emitting non-impulsive sound, as sound levels would have to be $L_{p,rms}$ 158 dB for 12 h. The cumulative sound scenario is the only activity that is close to producing such levels (up to $L_{p,rms}$ 160 dB; see VG 2021), but as this is a multiple-source scenario, and not all the sources would be emitting sound for 12 h, it is unlikely that this threshold level would be reached. For fish eggs, larvae, and fish that have no swim bladders or their swim bladders are not involved in hearing, the risk of injury or TTS is low at distances of hundreds of metres from the source. At tens of metres, the risk of injury is still low, but the risk of TTS for those types of fish is moderate.

The risk of behavioural disturbance is low for all of the fish hearing groups, including eggs and larvae, when exposed to impulsive or continuous sounds thousands of metres from the source (Table 5). However, the potential for behavioural disturbance for all types of fish is moderate at hundreds of metres from a continuous sound source. For fish that use their swim bladder for hearing, the risk of behavioural disturbance within tens of metres from a continuous sound source is high.

Table 11. Distances to threshold criteria for fish during various Shannon LNG project activities using *unweighted* modeling results for assessing potential harm. Thresholds for pile driving from Popper et al. (2014).

| | **Impact Pile Driving** | | | | |
|---|---|---|---|---|---|
| | **Mortality and potential mortal injury** | | **Recoverable Injury** | | **TTS 186 dB** |
| | $L_{p,0\text{-}pk}$ | $L_{E,p,24h}$ | $L_{p,0\text{-}pk}$ | $L_{E,p,24h}$ | $L_{E,p,24h}$ |
| **No swim bladder (e.g., lampreys)** | **>213:** 42 m | **>219:** 25 m | **>213:** 42 m | **>216:** 46 m | 2041 m |
| **Swim bladder not used for hearing (e.g., salmon)** | **>207:** 85 m | **210:** 97 m | **>207:** 85 m | **203:** 232 m | 2041 m |
| **Swim bladder used for hearing (e.g., shad)** | **>207:** 85 m | **207:** 142 m | **>207:** 85 m | **203:** 232 m | 2041 m |

## Discussion

Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many marine mammals would be present within a particular distance of industrial activities and/or exposed to a particular level of industrial sound, as we have done here. In most cases, this approach likely overestimates the numbers of marine mammals that would be affected in some biologically important manner, as animals tend to move away from loud sound sources before the sound level is at or above the threshold.

Although two potential PTS exposures have been estimated for bottlenose dolphins from impact pile driving over the course of all pile driving activity, no PTS or other injuries would be expected because of the relatively short distance (94 m) to the threshold criteria and the monitoring and mitigation measures that would be implemented. Monitoring and mitigation measures would follow those in the NPWS (2014) guidance and would lower the likelihood of impacts from construction activities. Although PTS was modeled to be a possibility relatively far from impact pile driving (up to 3163 m) for harbour porpoise, these cetaceans rarely occur within the Shannon Estuary.

Monitoring and mitigation measures during project construction would include the use of qualified marine mammal observers to monitor during sub-tidal piling operations, and the commencement of piling would be delayed if the observers sight any marine mammals within 1,000 m of the site for 30 min prior to the planned start of piling. Since impact piling cannot always be stopped immediately if a marine mammal approaches once piling has commenced, some potential for impacts would remain, including potential for TTS. Nonetheless, the 1,000-m mitigation zone is overly precautionary given that the MF-weighted PTS threshold was modeled to occur out to a maximum distance of 94 m.

During operations, the PTS and TTS thresholds that could be exceeded by the activities are all based on accumulated sound over a period of time (sound exposure levels). This means that individuals would have to remain within the predicted distances for the entire duration of the activity, or for at least 24 h if the activity lasts longer than a day, in order to experience TTS or PTS. Additionally, the operational scenarios often involved multiple sources operating in different locations. This means that the distances calculated are not continuous in all directions around any one of the sources, resulting in gaps where received sound levels would be below the threshold levels. These factors, along with the highly mobile nature of marine mammals means that it is very unlikely that any marine mammals will experience PTS or even TTS from the planned activities.

Using the available information on dolphin abundance and distribution within the Shannon Estuary, we have estimated that there are likely to be very few daily instances of bottlenose dolphins (or other marine mammals) being affected via disturbance during either construction or operational activities associated with the Shannon LNG project. For all construction activities, and most of the operational scenarios, distances to disturbance thresholds would be less than 140 m. Since the location where the in-water structures will be installed and the immediate vicinity around that are not known to be important feeding or calving areas, temporary avoidance at these distances is not likely to have significant impacts. In addition, strong impulsive sounds from impact pile driving would occur over relatively short periods of time (1 h per day, or 4% of the time), leaving most of the time available for undisturbed movements through the area. Similarly, the two operational scenarios with disturbance threshold distances of almost 1 km, Scenarios D and E, would only occur for relatively short periods of time (less than 1 h per day) and infrequently (up to 3 times per week). The temporal aspects (limited duration and infrequent occurrence) of these most potentially behaviourally disruptive activities mean they are unlikely to substantially disrupt important marine mammal behaviours that might occur in this region of the estuary. Since dolphins are highly mobile within the estuary and operations will occur over many years, it is likely that all individuals in the population could be exposed at some point in time to noise from the project. Nonetheless, the potential disturbance exposures likely would have no more than a minor effect, such as localized short-term avoidance of the area around the activities by individual animals and no effect on the population.

Our analysis method used MF-weighting for estimating potential disturbance exposures since it emphasizes the frequencies that are of most relevance to bottlenose dolphins. However, Kastelein et al. (2015, 2016) reported that harbour porpoise (an HF cetacean) hearing sensitivity was reduced when exposed to multiple impulsive pile-driving sounds with most energy at low frequencies. These findings suggest that there could be potentially greater impacts of LF sounds on bottlenose dolphins than expected. Nonetheless, exposure estimates based on group size are almost certainly overestimates, and there is no indication that the project activities would be likely to cause significant harm to individuals or the population.

The population of bottlenose dolphins in the Shannon Estuary has remained stable for the past 20 years and has demonstrated evidence of long-term fidelity and seasonal residency despite inhabiting a busy and noisy region with various industrial activities, such as ferry traffic and shipping (Ingram 2000; Ingram and Rogan 2002; Englund et al. 2007, 2008; Rogan et al. 2018). Thus, it is anticipated that the dolphins in the vicinity of the project would likely habituate to the sounds produced during project activities as they have to other similar noise and vessel traffic in the estuary. Habituation of bottlenose dolphins to noise has been shown to occur elsewhere. For example, in Aberdeen Harbour, Scotland, an area with high vessel activity, bottlenose dolphins showed a change in normal behaviour around boats, but rarely left the area; this type of response suggested habituation and tolerance, especially due to the estuary's importance for prey availability (Sini et al. 2005).

Although there is some indication that fish (especially those with swim bladders used in hearing) within hundreds of metres of impact pile driving could be at high risk of disturbance or even potentially experience injury or TTS, impact piling would occur for a relatively short duration (60 min) for each pile, once per day. Thus, impact pile driving is unlikely to hinder fish migration, and for most fish, the distances within which mortality and/or mortal injuries could occur are relatively small and should not impact the overall populations if these types of effects were to take place. Although continuous sounds during project construction and operation have little likelihood of causing injury or TTS in fish, fish that use their swim bladder for hearing could potentially be at high risk of disturbance near those sound sources. It is possible that the continuous noise emission from the FSRU during project operation could cause fish to avoid the immediate area around the FSRU, but avoidance behaviour would likely be restricted within tens of metres from the FSRU.

In summary, the proposed construction and operational activities associated with Shannon LNG are similar to other activities that currently occur routinely within the estuary and are therefore unlikely to have adverse effects that could impact populations of marine mammals or fish in the long-term. The most potentially impactful activity on marine mammals and fish during construction would be impact pile driving because of the potential for PTS in marine mammals and injury or mortality in fish, but this would be of limited duration and impacts will be mitigated in multiple ways. Additionally, there is no evidence to suggest that the project site provides critical habitat for bottlenose dolphins (Berrow et al 2020) so avoidance of these activities would be unlikely to have significant impacts. During operations, underwater sounds would be created by vessel traffic and contribute to the pre-existing ambient noise within the estuary. The cumulative sound scenario and approaching/departing LNGC have the largest distances to behavioural disturbance thresholds during operations, but both scenarios would occur only briefly up to 3 times per week, and only if other vessels are located within the vicinity of the project site. Once the other power stations located in the Shannon Estuary shut down, there would be even less potential for cumulative effects from the proposed activities and existing shipping activities occurring in the estuary. In addition, harbour porpoise and grey seals rarely occur in the Shannon Estuary, and harbour seals are uncommon. Thus, any effects from project activities are expected to be minor, temporary, and localized to the area immediately around the terminal, with no long-term effects on marine mammal or fish populations.

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# Addendum

June 12, 2023

RE: Potential Impacts from Only Onshore Construction Activities.

This addendum was added to summarize the potential impacts after the scope of the project was reduced to involve only onshore construction activities. Specifically, the complete assessment in this report considered the potential impacts to bottlenose dolphins and other marine species from both in-water and onshore construction activities as well as vessels during plant operations. The two largest sources of potential impact were determined to be in-water impact pile driving related to jetty construction and vessel arrivals/departures during operations. Both of these are in-water activities that would no longer occur if only onshore construction activities are conducted. Blasting was the only onshore construction activity assumed to have potential acoustic impacts in the water. Since the blasting locations will be onshore the sound levels occurring in the water (after sound has transmitting through the ground) would be relatively low. In fact, the only predicted impact from blasting sounds would be potential behavioral disturbance of pinniped species within 75 m of the shoreline.

Our assessment of acoustic impacts from the full project, including in-water construction and operations activities, was that some short-term behavioral disturbances may occur, but that the project was unlikely to have adverse effects that could impact populations of marine mammals or fish in the long-term. Given the reduction in the project scope to only onshore construction activities, our previous conclusion is further supported and no meaningful impacts to marine mammals or fish are expected.