ST FERGUS NEARSHORE PIPELINE INSPECTION SURVEY

EIA Justification

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1.0 INTRODUCTION

Shell U.K. Limited (hereafter referred to as Shell) is planning to undertake a nearshore Acoustic Pipeline Inspection (API) survey of pipelines connecting to St Fergus Gas Terminal, which is located on the North Sea coast in Aberdeenshire between Peterhead and Fraserburgh (see Figure 1-1). The gas terminal complex consists of four major onshore receiving, processing, and transporting facility complexes.

The Shell terminal receives gas and condensate from a number of pipelines including;

- the 289 km 20-inch pipeline (PL208) Fulmar Gas Line, which runs from the Central North Sea (CNS);
- the 101 km 20-inch Goldeneye gas pipeline (PL1978), which has the 4-inch monoethylene glycol (MEG) pipeline (PL1979) piggy-backed onto it;
- the 448 km 36-inch Far North Liquids and Associated Gas System (FLAGS) pipeline (PL002), which runs from the Northern North Sea (NNS); and
- the WAGES 16-inch Atlantic gas line from the Atlantic manifold to St Fergus (PL2029), which has the Atlantic 4-inch MEG pipeline (PL2032) piggy-backed onto it.

The objective is to carry out a pipeline inspection survey along these pipelines. This will involve the use of a sub-bottom profiler (SBP), side-scan sonar (SSS) and multi-beam echosounder (MBES). The survey will identify exposures, free spans, debris, obstacles, scarring (trawl, anchor), damage, scour or sedimentation along the pipelines and determine height and length of free-spans and any protective measures such as rock dumps and mattresses. The inspection can also include additional areas of interest, including but not limited to; pipeline or cable crossings, anomalous free spans / exposures.

The proposed St Fergus survey will cover an area of approximately 8 km^2 and will transect the United Kingdom Continental Shelf (UKCS) Blocks 19/11 and 19/12 in the Central North Sea (CNS). The location of the proposed survey area is illustrated in Figure 1-1 and the co-ordinates are provided in Table 1-1. The survey vessel will acquire SBP, SSS and MBES acoustic data along each pipeline route within the survey area from the shore outwards (seaward) to allow any potentially disturbed cetaceans to be directed away from the shore rather than onshore.

The proposed survey activities will commence with an earliest start date of 7th of August 2020 and it is expected that the pipeline survey will be completed within a maximum of eight working days, with the SBP component of the survey expected to take a maximum of four working days (subject to weather and tidal conditions). For the purposes of this permit application, the latest completion date is the 30th September 2020 to allow for any delays or alteration to the schedule.

This document presents an assessment carried out to determine the potential environmental impact of underwater sound from the proposed pipeline inspection and provides justification to support the application for consent to undertake the survey and the application for a European Protected Species (EPS) license.

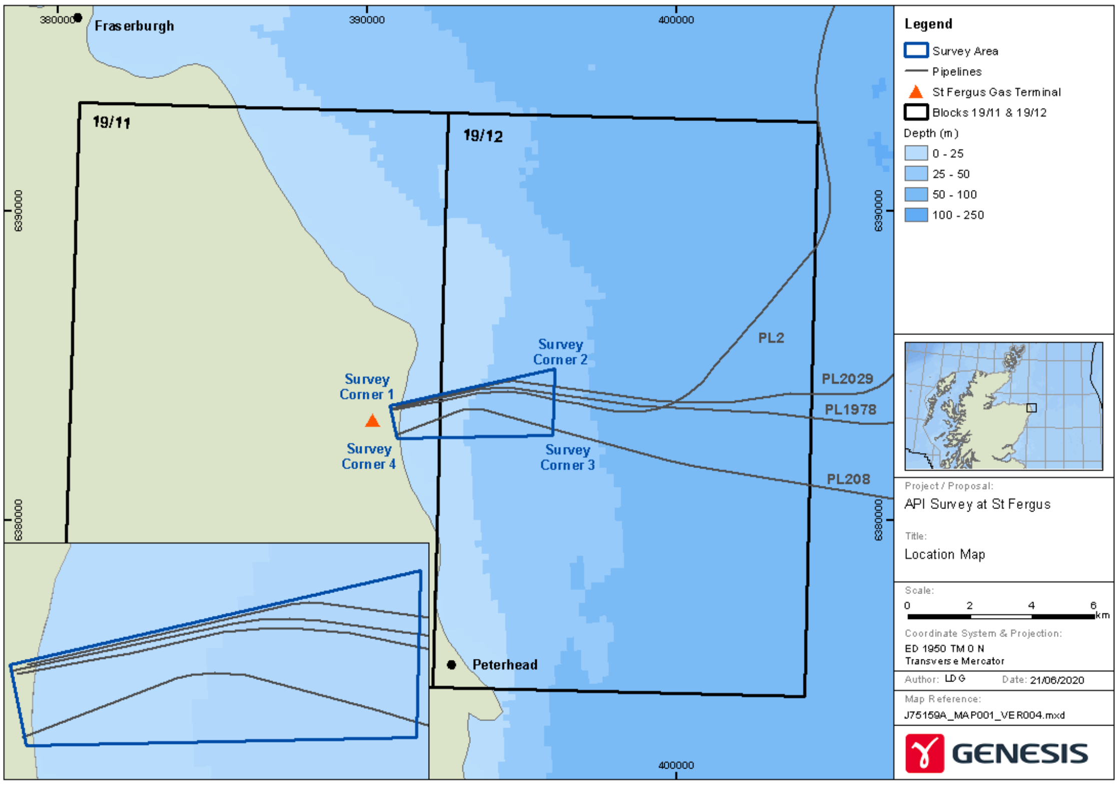

Figure 1-1: Location of the proposed survey area.

Table 1-1: Coordinates of the survey area.

Survey name	Location		Easting (m)	Northing (m)	Latitude (N)	Longitude (W)
St Fergus	Survey area	Survey Corner 1	390,842	6,383,758	57° 34' 51.82"	-01° 49' 37.85"
		Survey Corner 2	396,150	6,384,979	57° 35' 35.78"	-01° 44' 20.32"
		Survey Corner 3	396,097	6,382,821	57° 34' 25.99"	-01° 44' 20.18"
		Survey Corner 4	391,059	6,382,709	57° 34' 18.10"	-01° 49' 23.11"

Coordinate System: Easting and northing coordinates are provided using European Datum (ED) 1950 Universal Transverse Mercator (UTM) Zone TM0 coordinate system, whilst latitude and longitude coordinates are provided using World Geodetic System (WGS) 1984 coordinate system.

2.0 SURVEY EQUIPMENT

The primary sources of underwater sound associated with the proposed survey will be due to the SBP, SSS and MBES equipment that will be used, as well as sound from the survey vessel. The main sources of sound associated with the proposed pipeline inspection survey are described in the following sections.

2.1 Sub-bottom Profiler

Sub-bottom profiling is used to determine the stratification of soils beneath the sea floor. Various types of instrument may be used depending on the required resolution and seabed penetration (King, 2013; Danson, 2005). The majority of sound energy from SBPs is directed vertically downwards and the pulse duration is short (tens to hundreds of milliseconds). The actual source levels generated by a sub-bottom profiler depends on the type of equipment used and its operating specification.

The sub-bottom profiler that will be used during the proposed geophysical site survey will be a Innomar Medium Parametric SBP. The profiler is predicted to have a zero-to-peak SPL of 250 dB re 1 µPa-m, and an SEL of 243 dB re 1 µPa^{2}s-m. The SBP will emit a linear frequency modulated chirp signal over a frequency range of 5-15 kHz with a pulse interval of 0.1 s. Details of the SBP that will be used for the proposed pipeline inspection survey are summarised in Table 2-1.

Table 2-1: Sub-bottom profiler details.

Parameter		Value
Source		Innomar Medium Parametric SBP
Signal type		Linear frequency modulated chirp signal
Source Level	Zero-to-peak SPL	250 dB re 1 µPa-m
	SEL	243 dB re 1 µPa^{2}s-m
Frequency range (-3dB)		5 – 15 kHz
Pulse interval		0.1 s

2.2 Side Scan sonar

The proposed pipeline inspection survey will utilise SSS equipment. SSS data will be acquired using an EdgeTech 4200 system (EdgeTech, 2018), which is a dual-band source with selectable centre frequency pairings of 100/400 kHz, 300/600 kHz or 300/900 kHz. For the proposed pipeline inspection surveys, the SSS will be operated at a 300/600 kHz frequency pairing. Sound generated from the SSS will therefore be outside the main hearing range of any marine mammals that are likely to be in the survey area (NMFS, 2018; Southall *et al.,* 2019) and will unlikely have any significant impact.

2.3 Multi-beam Echosounder

The pipeline inspection survey will also employ a MBES. The MBES that will be used during the proposed pipeline inspection survey will be a dual-head Teledyne Reson 7125. The MBES will produce sound at a frequency of 400 kHz. The sound generated will therefore be outside the main hearing range of any marine mammals that are likely to be in the survey area (NMFS, 2018; Southall *et al.,* 2019) and will unlikely have any significant impact.

2.4 Survey Vessel

Vessel sound is generally continuous and results from narrowband tonal sounds at specific frequencies and broadband sounds (Richardson *et al.*, 1995). Acoustic energy from vessels is generally strongest at frequencies below 1 kHz. Whilst the survey vessel will contribute sound to the marine environment, the level of sound will not be high enough to cause any significant adverse effect to marine mammals or fish.

The pipeline inspection survey at St Fergus will be completed by the Fugro Seeker.

3.0 ENVIRONMENTAL BASELINE

This section outlines the main environmental sensitivities within the survey area that could be impacted by the proposed survey activities. This covers the main receptors sensitive to underwater sound such as marine mammals and fish.

3.1 Physical Environment

3.1.1 Bathymetry

Bathymetry can strongly influence the propagation of sound. Sound propagating in shallow waters interacts with the seabed, which typically results in stronger attenuation. In deeper waters, there is less interaction of sound with the seabed and attenuation due to bottom loss is generally lower than in shallow waters, which can result in longer range sound propagation (Jensen *et al.*, 2011).

Bathymetry around the proposed survey area at St Fergus is shown in Figure 3-1 (EMODnet, 2019). The water depth in the proposed St Fergus survey area ranges from less than 10 m to approximately 50 m in depth.

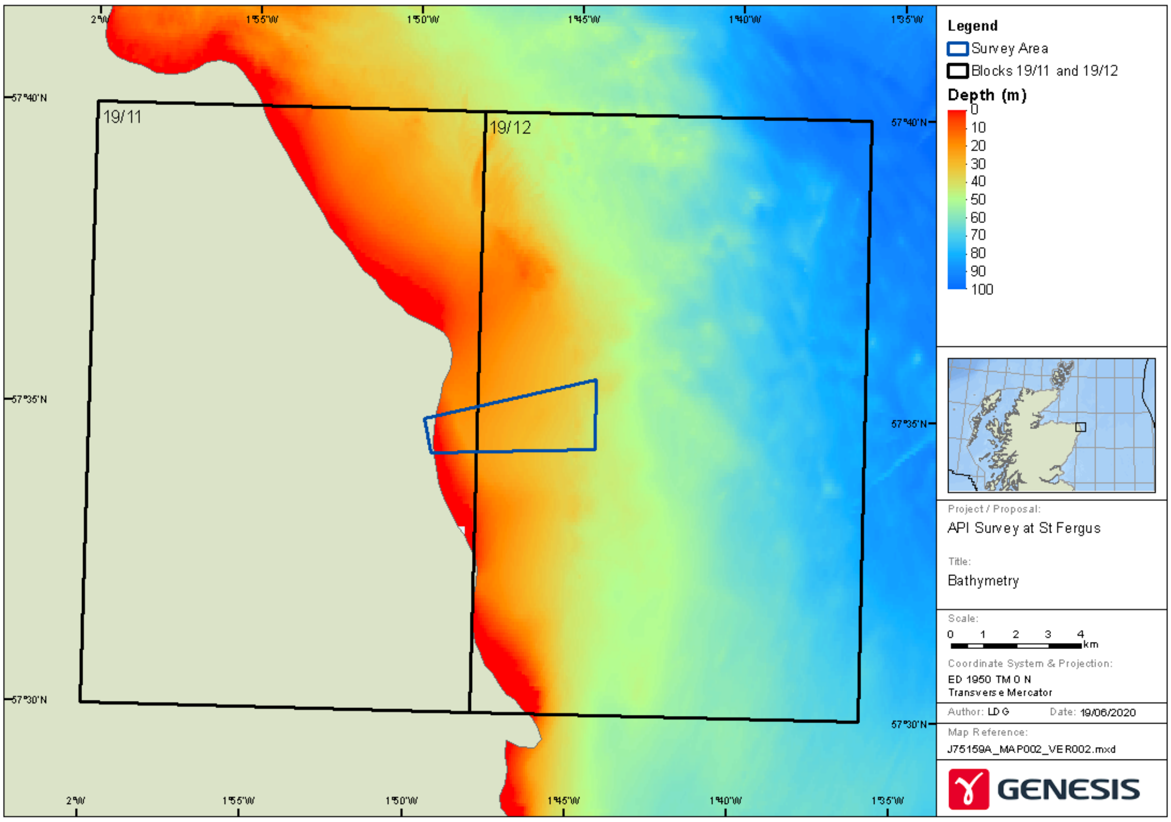

Figure 3-1: Bathymetry in the proposed survey area (EMODnet, 2019).

3.1.2 Seabed Sediments

The type of seabed sediments in an area can affect sound propagation through reflection, attenuation and scattering effects (Jensen *et al.*, 2011). An understanding of sediment distribution is therefore important for propagation modelling. Furthermore, the plant and animal species found in an area are often linked to the sediment type (particularly benthic species).

The seabed sediments around the proposed survey area are shown in Figure 3-2 (EMODnet, 2019). The sediments in the survey area predominantly comprise circalittoral sand.

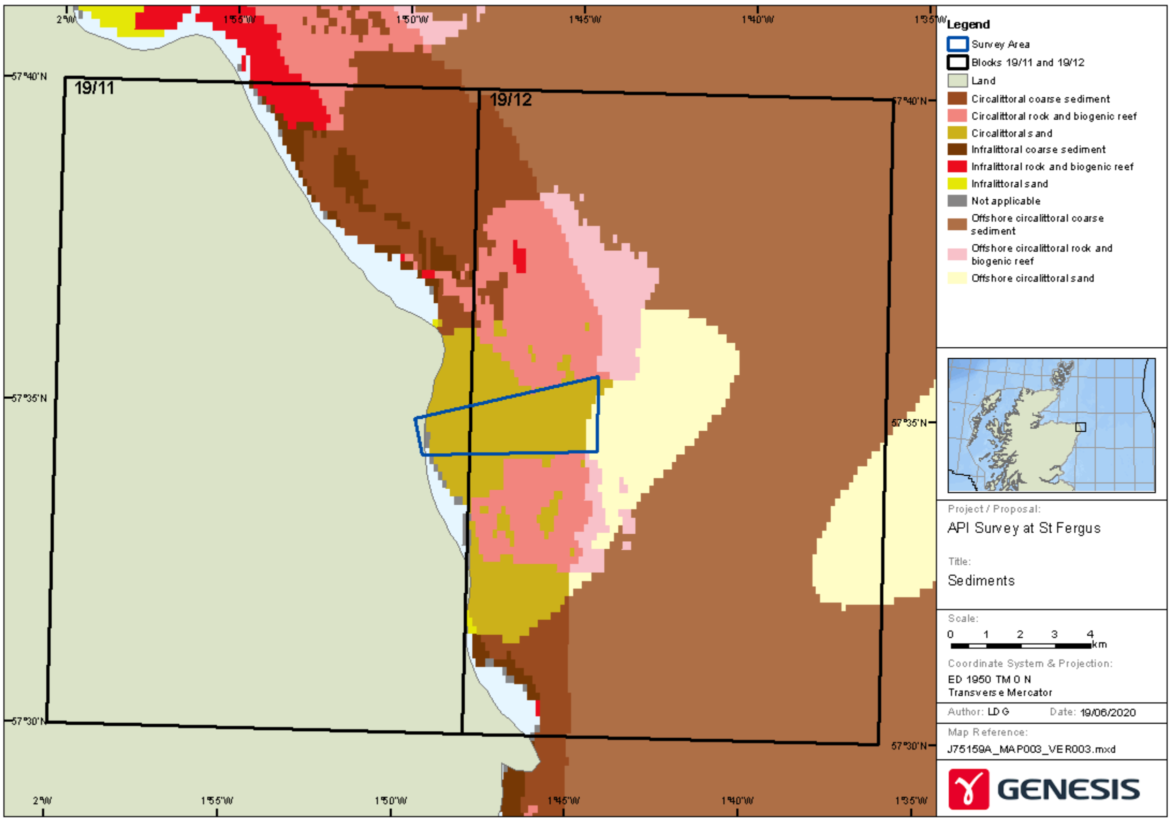

Figure 3-2: Seabed sediments in the proposed survey area (EMODnet, 2019).

3.2 Biological Environment

3.2.1 Cetaceans

A series of Small Cetacean Abundance in the North Sea (SCANS) surveys have been conducted to obtain an estimate of cetacean abundance in the North Sea and adjacent waters, the most recent of which is SCANS-III (Hammond *et al.*, 2017). Aerial and shipboard surveys were carried out during the summer of 2016 to collect abundance data for the most commonly occurring cetacean species in the North Sea. The proposed St Fergus survey lies within SCANS-III Block R (Figure 3-3). Aerial survey estimates of animal abundance and densities within this area are provided in Table 3-1. The data show that harbour porpoise, bottlenose dolphin, white-beaked dolphin, white-sided dolphin, and minke whale were observed in SCANS Block R during the SCANS-III survey.

Based on the 8 km^2 survey area, the number of animals which may be present in the survey area is noted in Table 3-1.

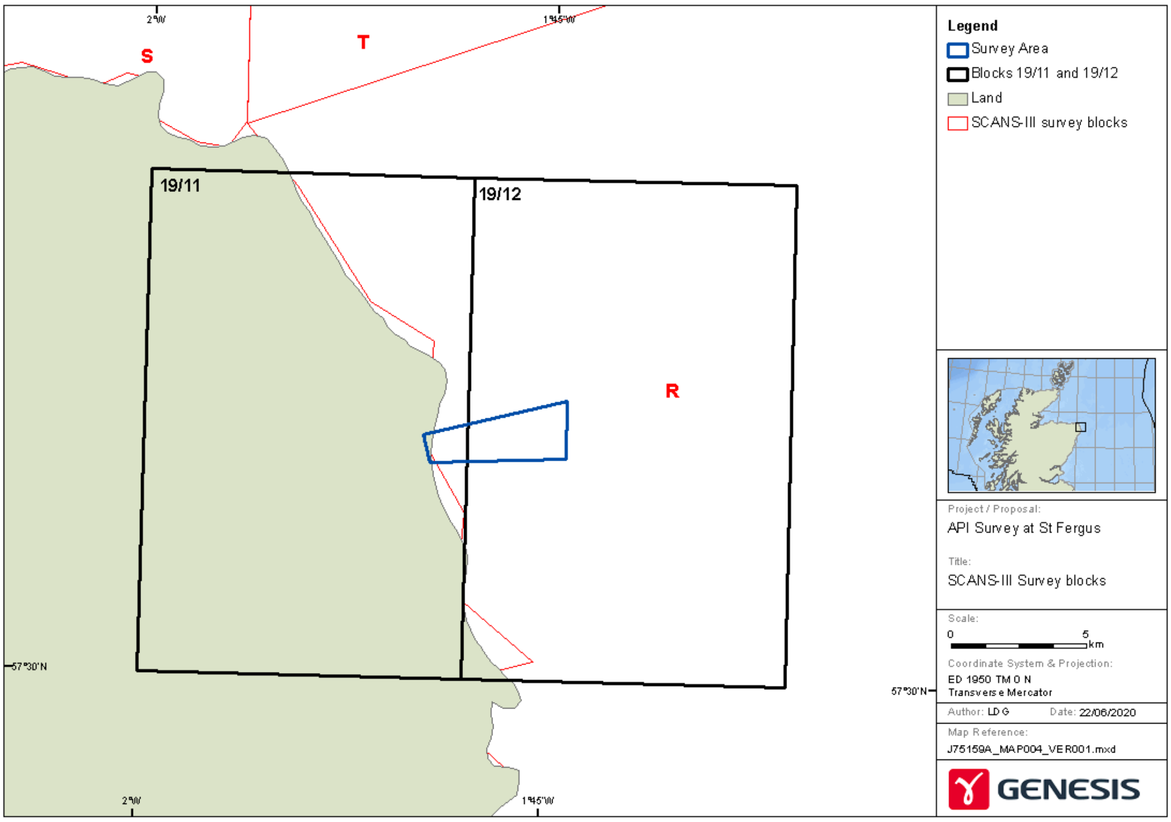

Figure 3-3: SCANS-III blocks in relation to survey area.

Table 3-1: Cetacean abundance in SCANS-III Survey Block R.

Species	Block R		Predicted number of animals present in the survey area (8km²), rounded to the nearest whole number
	Animal Abundance	Density (animals/km²)	
Harbour porpoise	38,646	0.599	5
Bottlenose dolphin	1,924	0.030	1
White-beaked dolphin	15,694	0.243	2
White-sided dolphin	644	0.010	1
Minke whale	2,498	0.039	1

The Joint Nature Conservation Committee (JNCC) has compiled an Atlas of Cetacean Distribution in Northwest European Waters (Reid *et al.*, 2003) which gives an indication of the seasonal distribution and abundance of cetacean species in the North Sea. In agreeance with the SCANS-III survey data, the Reid *et al.* (2003) data show that harbour porpoise, bottlenose dolphin, white-beaked dolphin, white-sided dolphin, and minke whale have been observed in the area of the proposed survey location (Table 3-2). All cetaceans are European Protected Species (EPS) and are listed under Annex IV of the European Union (EU) Habitats Directive. Harbour porpoise are granted further protection under Annex II of the EU Habitats Directive.

Table 3-2: Seasonal cetacean sightings within the proposed survey area.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Harbour porpoise	1	1	1	1	1	2	3	2	2	1	1	1
Bottlenose dolphin	1				1	1	1	1	1			
White-beaked dolphin		1	1			2	3	3	3	3		2
White-sided dolphin							1	1				
Minke whale						1	3	1	1			

Key: 1 = Low; 2 = Moderate; 3 = High;

Blue highlighting indicates possible period within which survey will take place.

3.2.2 Pinnipeds

Two species of pinnipeds (seals) are resident in British waters: the grey seal and the harbour seal. Although both species are Annex II species, they are not listed on Annex IV of the Habitats Directive, and as such are not classified as EPS. Seals are protected in the UK under the Conservation of Seals Act 1970. Both species are listed under Annex II of the EU Habitats Directive and are considered Scottish Priority Marine Features (PMFs).

Grey and harbour seals feed in inshore and offshore waters depending on the distribution of their prey, which changes seasonally and annually. Both species tend to be more concentrated close to shore, particularly during the pupping and moulting season. Seal tracking studies from the Moray Firth have indicated that the foraging movements of harbour seals are generally restricted to within a 40–50 km range of their haul-out sites (SCOS, 2013). The movements of grey seals can involve larger distances compared to harbour seals, with ranges of up to several hundred kilometres from one haul-out to another having been recorded (SMRU, 2017).

Distribution maps (Figure 3-4) based on telemetry data and count data indicate that harbour seals are not likely to occur in the St Fergus survey area. However, grey seals are likely to occur in the area at an average abundance of roughly 5 - 10 seals at any time within each 5 km x 5 km square (Russell *et al.*, 2017).

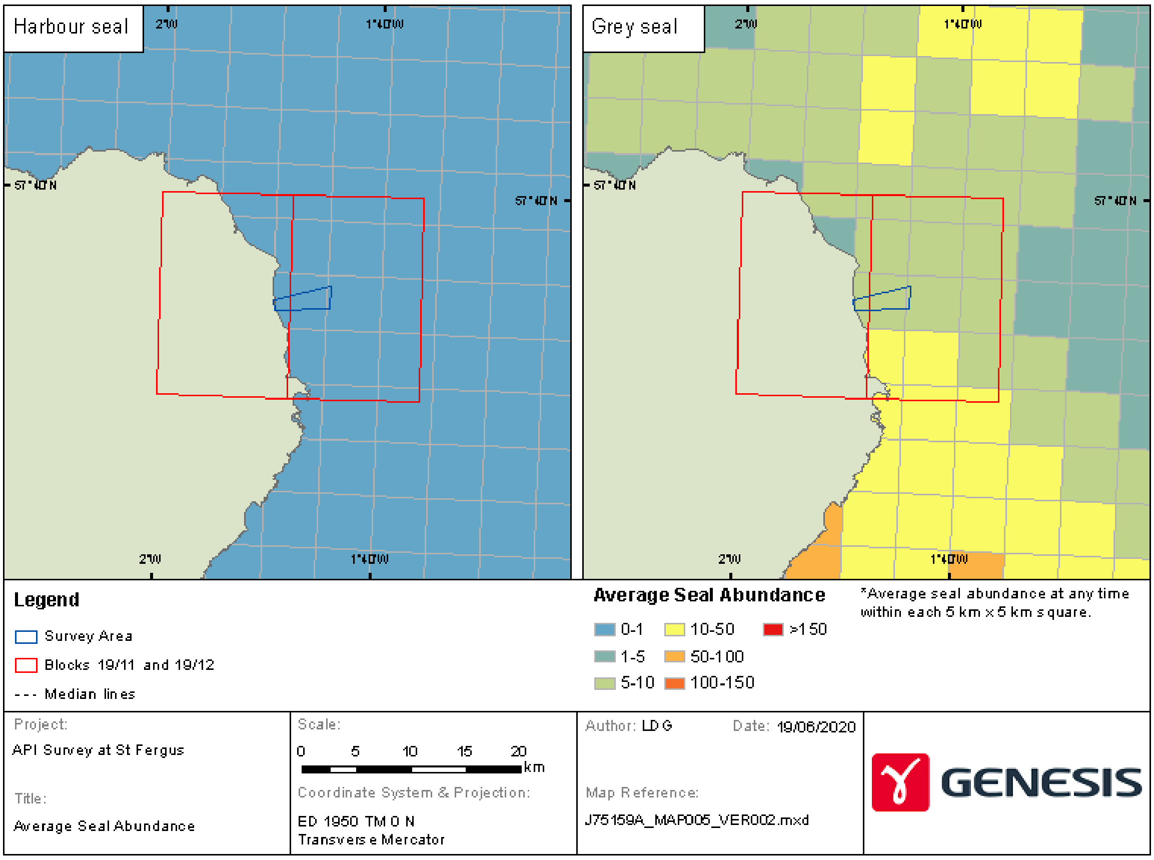

Figure 3-4: Average seal abundance near the survey area (Russell *et al.*, 2017).

3.2.3 Fish

More than 330 fish species are thought to inhabit the shelf seas of the UKCS (Pinnegar *et al.*, 2010). Finfish species can broadly be divided into pelagic and demersal species. Pelagic species (e.g. herring, mackerel, blue whiting and sprat) are found in mid-water and typically make extensive seasonal movements or migrations. Demersal species (e.g. cod, haddock, sand eels, sole and whiting) live on or near the seabed and, similar to pelagic species, are known to passively move (e.g. drifting eggs and larvae) and/or actively migrate (e.g. juveniles and adults) between areas during their lifecycle.

The proposed St Fergus survey area lies within International Council for the Exploration of the Seas (ICES) rectangle 44E8.

High intensity nursery grounds for herring and whiting were identified in the area. No peak spawning periods were identified at the proposed time of the survey (see Table 3-3) (Coull *et al.*, 1998, Ellis *et al.*, 2012). Low intensity spawning in the area was identified for herring, lemon sole, sprat, and *Nephrops* during the possible survey months (Figure 3-5). As shown in Figure 3-5, the survey area is located within these spawning areas. Although there is fish spawning and nursery activity in the vicinity at certain times of the year, the spawning and nursery areas tend to be transient, and are part of larger offshore areas (Coull *et al.*, 1998, Ellis *et al.*, 2012).

Aires *et al.* (2014) identified presence of juveniles in the area for whiting, haddock and cod (see Table 3-3).

Table 3-3: Spawning activity, nursery areas, and juvenile presence of commercial fish species within ICES rectangle 44E8.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Herring[1,2]	N	N	N	N	N	N	N	SN	SN	N	N	N
Whiting[1,2,3]	NJ	SNJ	SNJ	SNJ	SNJ	SNJ	NJ	NJ	NJ	NJ	NJ	NJ
Lemon sole[2]	-	-	-	S	S	S	S	S	S	-	-	-
Norway pout[2]	SN	S*N	S*N	SN	N	N	N	N	N	N	N	N
Sandeel[1,2]	SN	SN	N	N	N	N	N	N	N	N	SN	SN
Sprat[2]	N	N	N	N	S*N	S*N	SN	SN	N	N	N	N
Nephrops[2]	SN	SN	SN	S*N	S*N	S*N	SN	SN	SN	SN	SN	SN
Haddock[2,3]	NJ	NJ	NJ	NJ	NJ	NJ	NJ	NJ	NJ	NJ	NJ	NJ
Cod[1,3]	NJ	NJ	NJ	NJ	NJ	NJ	NJ	NJ	NJ	NJ	NJ	NJ

Key: S: Spawning; S*: Peak Spawning; N: Nursery; J: Juveniles (i.e. 0-group fish: < 1 year old)

Green highlighting indicates high intensity nursery ground

Blue highlighting indicates possible period within which survey will take place.

Sources: [1]Ellis, *et al.* (2012), [2]Coull, *et al.* (1998) and [3]Aires, *et al.* (2014)

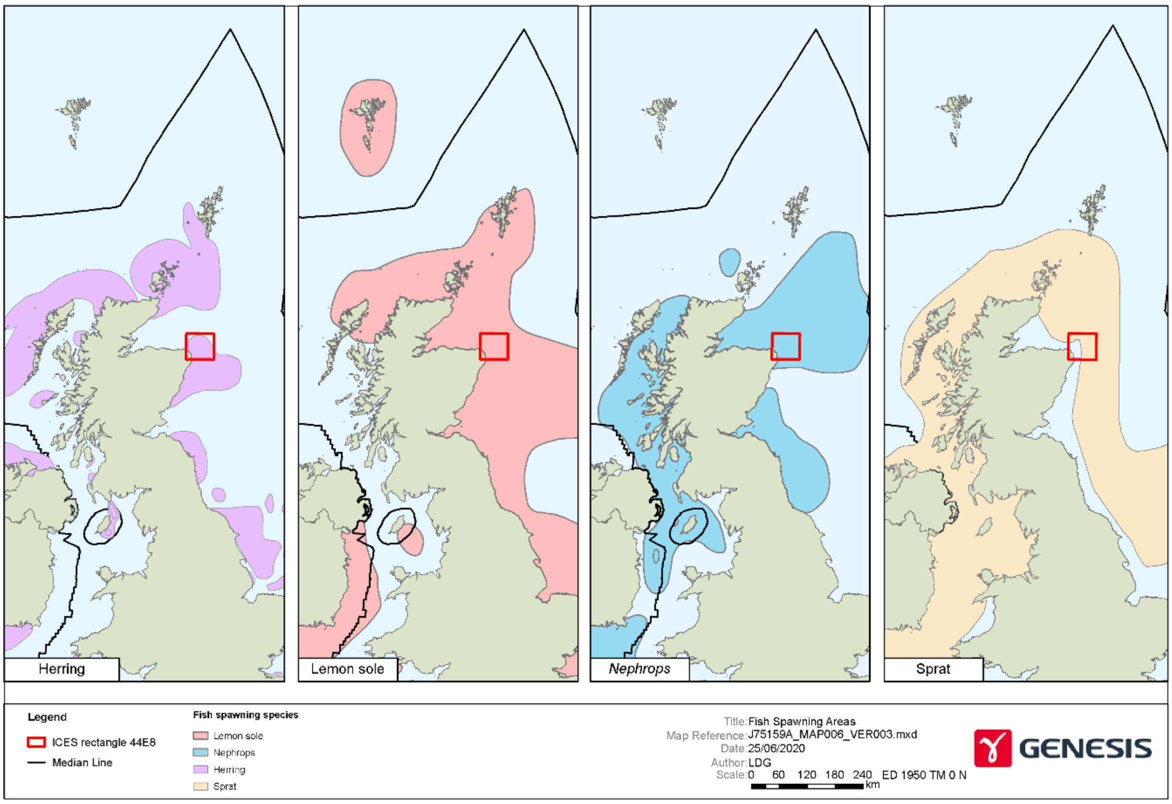

Figure 3-5: Spawning grounds of fish that spawn during the survey period.

3.2.4 Registered Concerns for Seismic Surveys

The Oil and Gas Authority (OGA) has published guidance (OGA, 2019), which includes advice from government departments and external agencies on seasonal concerns for fish spawning from offshore activities including seismic surveys. The St Fergus survey area lies within Blocks 19/11 and 19/12. There are identified periods of concern for seismic surveys during the survey period in these blocks, from January - February, August – September, and November – December. Furthermore, scientific fisheries advice has indicated that seabed surveys may be required before activities to confirm whether there are any herring spawning sites within a three-nautical mile radius of the proposed location.

3.2.5 Protected Areas

A network of Marine Protected Areas (MPAs) is in place to aid the protection of vulnerable and endangered species and habitats through structured legislation and policies. These sites include Special Areas of Conservation (SAC) and Special Protection Areas (SPA), designated under the EC Habitats Directive (92/43/EEC) and EC Birds Directive (2009/147/EC), respectively, along with Nature Conservation Marine Protected Areas (NCMPAs) designated under the Marine (Scotland) Act 2010 or the Marine and Coastal Access Act 2009. The Marine and Coastal Access Act 2009 (Part 5), enables the Department for Environment Food and Rural Affairs (Defra) to designate and protect Marine Conservation Zones (MCZs) in England and Wales. Figure 3-6 illustrates the protected areas within the vicinity of the proposed survey area.

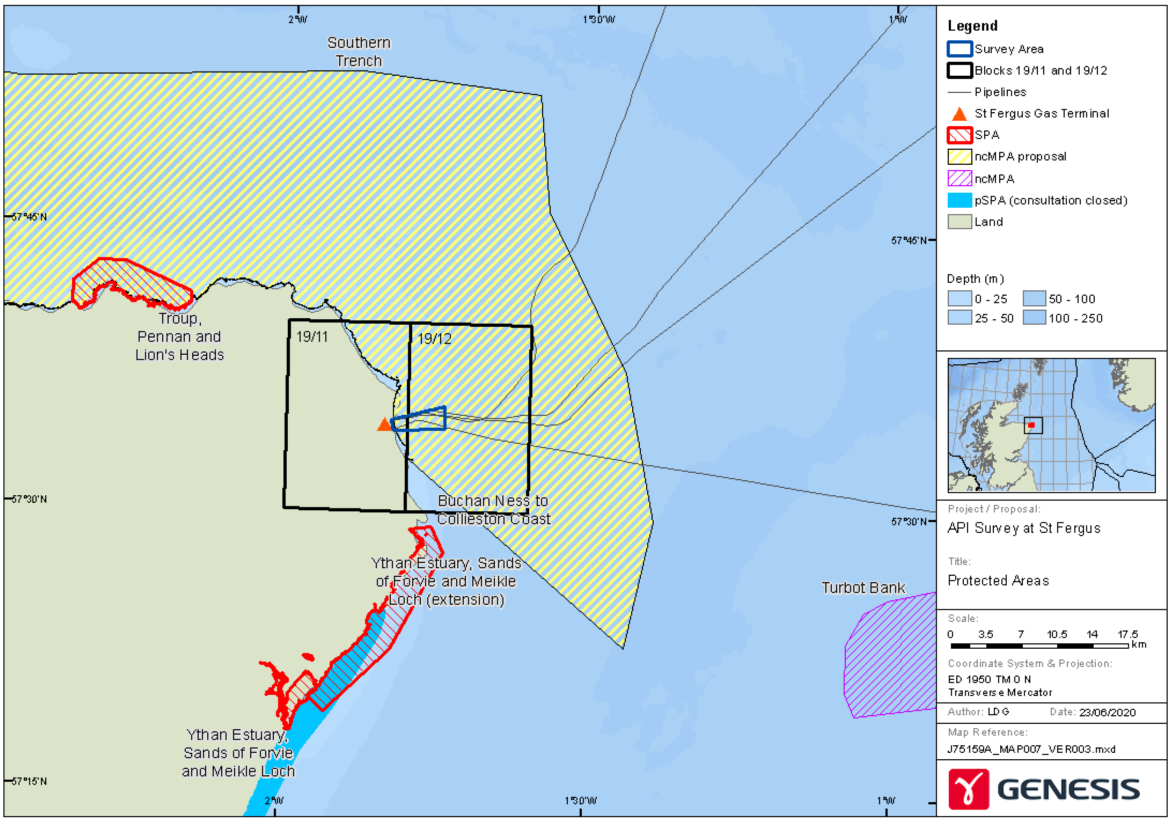

Figure 3-6: Sites of conservation interest in the vicinity of the proposed survey location.

3.2.5.1 Southern Trench pMPA

The Southern Trench is one of four possible MPAs (pMPA) which were submitted to the Scottish Government for consideration in 2014 for inclusion in the existing MPA network. The proposed survey area is within the Southern Trench pMPA. The Southern Trench pMPA is shaped around a large undersea valley consisting of an area of deep water (~200 m) extending along the coast between Banff and Peterhead. The Southern Trench is considered to be an exceptional example of an enclosed glacial seabed basin and is regarded as scientifically important in developing an understanding of ice sheet drainage patterns in this region (SNH, 2014).

There are shelf deeps within the pMPA, which are enclosed topographic depressions on the sea bed. Large numbers of juvenile fish have been recorded within the shelf deep, suggesting the shelf deep represents an important nursery area. In addition, the waters off Fraserburgh produce frontal zones with strong horizontal gradients in surface and/or bottom temperatures. These fronts can concentrate nutrients and plankton, which are associated with pelagic biodiversity hotspots as they attract prey assemblages and higher trophic level foragers such as cetaceans.

The following are protected features/species within the MPA proposal:

- Burrowed mud;
- Minke whale; and
- Shelf deeps.

3.2.5.2 Buchan Ness to Collieston Coast SPA

The Buchan Ness to Collieston Coast SPA lies *c.* 8.6 km to the south of the St Fergus survey area. This site has been designated for the conservation of vegetated sea cliffs of the Atlantic and Baltic Coasts. It is a 15 km stretch of south-east facing cliffs formed of granite, quartzite and other rocks running to the south of Peterhead. The low, broken cliffs show many erosion features (such as stacks, arches and caves), and provide an important nesting area for a number of seabird species, which feed outside the SPA in the nearby waters, as well as more distantly (JNCC, 2005). During the breeding season, the area regularly supports 95,000 individual seabirds, including: fulmar (*Fulmarus glacialis*), guillemot (*Uria aalge*), herring gull (*Larus argentatus*), kittiwake (*Rissa tridactyla*), and shag (*Phalacrocorax aristotelis*). Given that the qualifying features for Buchan Ness to Collieston Coast SPA have no sensitivity to underwater noise, no further assessment of potential impacts on these have been undertaken.

3.2.5.3 Other Protected Areas

Other SPAs close to the survey site are Troup, Pennan and Lion's Heads SPA (*c.* 23.5 km to the north west), which is designated for species Razorbill, Northern fulmar, Black-legged kittiwake, seabird assemblage, common guillemot, and herring gull, as well as marine area habitats. Ythan Estuary, Sands of Forvie and Meikle Loch is a proposed SPA (pSPA) (*c.* 18 km to the south) with the aim of protecting species Little tern, Waterfowl assemblage, common tern, Pink-footed goose, and Sandwich tern, as well as habitats tidal rivers, estuaries, mud flats, sand flats, lagoons, salt marshes, sand pastures, salt steppes. These are considered to be out-with the area of any potential disturbance associated with the pipeline surveys and so have not been assessed further.

4.0 NOISE IMPACT ASSESSMENT METHODOLOGY

The assessment method used here is largely based on the JNCC guidance on the protection of marine European Protected Species (EPS) from injury and disturbance (JNCC, 2010). The Conservation of Offshore Marine Habitats and Species Regulations 2017 have a revised definition of 'disturbance' to EPS. It is now an offence under UK Regulations to:

a) *deliberately capture, injure, or kill any wild animal of a European protected species;* (termed 'the injury offence'),
b) *deliberately disturb wild animals of any such species* (termed 'the disturbance offence').

Here, injury is defined as a permanent threshold shift (PTS; i.e. a permanent shift in the hearing of an EPS), and disturbance of animals includes any event that is likely:

a) *to impair their ability to survive, breed or reproduce, or to rear or nurture their young, or (in the case of animals hibernating or migratory species), to hibernate or migrate;*
b) *to affect significantly the local distribution or abundance of the species to which they belong.*

It has become increasingly evident that noise from human activities can have the potential to impact on marine species (OSPAR, 2009; Richardson, *et al*., 1995; Southall *et al*., 2007; NMFS, 2018; Popper *et al.,* 2014). Sound is important for marine mammals for navigation, communication and prey detection, and the introduction of anthropogenic sound therefore has the potential to impact marine mammals. Sound may also interfere with acoustic communication, predator avoidance, prey detection, reproduction and navigation in fish (Slabbekoorn *et al*., 2010).

The extent to which underwater sound might cause an adverse environmental impact is dependent on numerous factors. JNCC recommends considering the following factors when assessing the impact of sound exposure:

a) Duration and frequency of the activity;
b) Intensity and frequency of sound and extent of the area where disturbance and injury thresholds may be exceeded, taking into consideration species-specific sensitivities;
c) The interaction with other concurrent, preceding or subsequent activities in the area;
d) The most up to date thresholds for injury and behavioural responses; and
e) Whether the local abundance or distribution could significantly be affected.

The current assessment has followed these guidelines and considered the JNCC recommendations to assess the potential impacts of underwater sound.

4.1 Noise Modelling

To estimate potential impacts to marine mammals and fish, noise modelling has been conducted in order to predict received sound levels in the marine environment. The modelling focuses on predicting received sound levels from the SBP since this is the loudest sound source associated with the proposed pipeline inspection survey that will be within the hearing range of most marine mammals. The sound propagation model used for this assessment is the Genesis in-house model FARAM (Faunal Acoustic Risk Assessment Model), which utilises range-dependent parabolic equation and ray tracing algorithms. Both these propagation algorithms incorporate varying environmental conditions with depth and range, including site-specific bathymetry, a range-dependent sound speed depth profile and geo-acoustic model. By explicitly modelling these factors affecting sound propagation, results obtained are more relevant to the area of interest than would be obtained with simpler models. Full details of the adopted modelling methodology are provided in Appendix A of this report.

4.2 Impact Thresholds for Marine Mammals

Potential impacts to marine mammals have been assessed using thresholds for injury and disturbance. The thresholds used in this assessment are based on a comprehensive review of evidence for impacts of underwater sound on marine mammals.

4.2.1 Thresholds for Permanent Threshold Shift

Numerous studies have been conducted to estimate the sound levels that can potentially cause injury to marine mammals. Thresholds for estimating potential impacts to marine mammals have been suggested by the National Oceanic and Atmospheric Administration (NOAA) (NMFS, 2018) and Southall *et al.* (2019) based on the most recent studies and are now recognised as the appropriate criteria for assessing potential impacts to marine mammals as a result of underwater noise.

NOAA and Southall *et al.* (2019) proposed thresholds for marine mammals grouped into different functional hearing groups. It is noted that there is a slight difference in nomenclature between the NOAA guidance and that of Southall *et al.*: NOAA grouped marine mammals into low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, and phocid pinnipeds. Southall *et al.* (2019) proposed equivalent hearing groups but refers to them as LF cetaceans, HF cetaceans, very high-frequency (VHF) cetaceans and phocid pinnipeds, respectively. Table 4-1 shows the corresponding NOAA and Southall marine mammal hearing groups and lists marine mammal species that could potentially occur in the proposed survey areas categorised according to these hearing groups.

Table 4-1: Marine mammal species categorised according to the hearing groups proposed by NOAA (NMFS, 2018) and Southall *et al.* (2019).

Marine Mammal Hearing Group		Species in the vicinity of the survey areas
NOAA (NMFS, 2018)	**Southall *et al.* (2019)**	
LF cetaceans	LF cetaceans	Minke whale
MF cetaceans	HF cetaceans	White-beaked dolphin, Atlantic white-sided dolphin, Bottlenose dolphin
HF cetaceans	VHF cetaceans	Harbour porpoise
Phocid pinnipeds	Phocid pinnipeds	Grey seals

Despite the difference in the naming of the marine mammal hearing groups, the thresholds for PTS onset proposed by NOAA (NMFS, 2018) and Southall *et al.* (2019) are precisely the same and are shown in Table 4-2. It is noted that the thresholds shown in Table 4-2 are thresholds for impulsive sound sources. Depending on the operating conditions, the SBP may be characterised as a non-impulsive source. However, the impulsive thresholds proposed by NOAA (NMFS, 2018) and Southall *et al.* (2019) have been adopted for this assessment since they are more conservative. The thresholds are expressed in terms of both zero-to-peak SPL and cumulative SEL. As dual-metric criteria, the onset of PTS is considered to potentially occur when either of the thresholds are exceeded (NMFS, 2018; Southall *et al.,* 2019). The zero-to-peak SPL thresholds are used to assess the potential for injury to occur in marine mammals due to instantaneous sound pressure and do not take into consideration the hearing range of any marine mammals. In contrast, the cumulative SEL metric considers the hearing capability of the species under consideration by weighting the received SEL using generalised auditory weighting filters that have been derived for different marine mammal hearing groups. NOAA and Southall *et al.* (2019) proposed the same auditory weighting filters, which are shown in Figure 4-1 (note that the Southall *et al.,* 2019 marine mammal naming convention has been used in this figure).

In the rest of this impact assessment, the nomenclature used by Southall *et al.* (2019) for the marine mammal hearing groups is used.

Table 4-2: Thresholds for potential PTS onset to marine mammals.

Marine Mammal Hearing Group		Sound Metric	Threshold for PTS onset
NOAA (NMFS, 2018)	**Southall *et al.* (2019)**		
LF cetaceans	LF cetaceans	Zero-to-peak SPL	219 dB re 1 µPa
		Cumulative SEL	183 dB re 1 µPa²s
MF cetaceans	HF cetaceans	Zero-to-peak SPL	230 dB re 1 µPa
		Cumulative SEL	185 dB re 1 µPa²s
HF cetaceans	VHF cetaceans	Zero-to-peak SPL	202 dB re 1 µPa
		Cumulative SEL	155 dB re 1 µPa²s
Phocid pinnipeds	Phocid pinnipeds	Zero-to-peak SPL	218 dB re 1 µPa
		Cumulative SEL	185 dB re 1 µPa²s

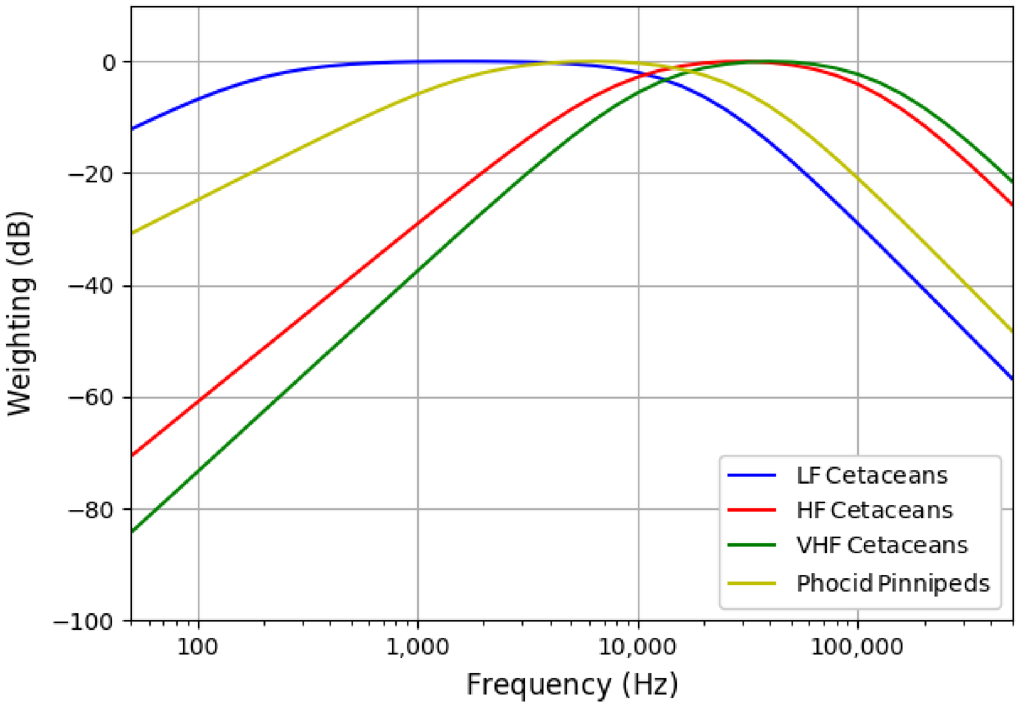

Figure 4-1: Auditory weighting functions for marine mammals.

4.2.2 Behavioural Disturbance Thresholds

Another important consideration in assessing the impacts of sound on marine mammals is the mammals' behavioural response. However, there are no well-established or accepted thresholds for behavioural disturbance to marine mammals (Southall *et al.*, 2007; Southall *et al.*, 2019; NMFS, 2018). This is because behavioural disturbance can range greatly from low level minor disturbance, such as changes in swimming behaviour and vocalisation, to higher levels of disturbance such as strong avoidance of an area. Southall *et al.* (2007) concluded that the available data on marine mammal behavioural responses were too variable and context-specific to justify proposing single disturbance criteria for all marine mammals. Instead, Southall recommended assessing whether a noise from a specific source could cause disturbance to a particular species by comparing the circumstances of the situation with empirical studies reporting similar circumstances.

The studies reviewed by Southall *et al.* (2007) suggest that LF cetaceans could exhibit behavioural responses at root mean square (rms) SPL's from 150–160 dB re 1 µPa and would likely show avoidance at rms SPLs above levels of 160 dB re 1 µPa.

There have been limited observations or measurements of sound levels that trigger behavioural responses in HF cetaceans and phocid pinnipeds. The studies reviewed by Southall *et al.* (2007) suggested that HF cetaceans would only show strong avoidance for rms SPL sound levels exceeding 170 dB re 1 µPa.

An rms SPL threshold of 140 dB re 1 µPa has been adopted in this assessment (see Table 4-3). This threshold is based on the studies reviewed by Southall *et al.* (2007) and is also a threshold of behavioural disturbance suggested by the National Marine Fisheries Service (NMFS, 1995).

Table 4-3: Behavioural disturbance thresholds used in this assessment

Marine Mammal Hearing Group	**Behavioural Disturbance Thresholds**	
	Rms SPL threshold	Response
LF cetaceans	140 dB re 1 µPa	Possible individual and/or group avoidance
HF cetaceans	140 dB re 1 µPa	Possible individual and/or group avoidance
VHF cetaceans	140 dB re 1 µPa	Possible individual and/or group avoidance
Phocid pinnipeds	140 dB re 1 µPa	Possible individual and/or group avoidance

4.3 Impact Thresholds for Fish

4.3.1 Fish Injury Thresholds

Popper *et al*. (2014) have defined criteria for injury to fish based on a review of publications related to impacts to fish, fish eggs and larvae from various sound sources. The review by Popper *et al.* (2014) is the most comprehensive available for potential impacts to fish species. The hearing capability of fish largely depends on the presence or absence of a swim bladder, which is taken into consideration in the thresholds derived by Popper *et al*. (2014). Different injury thresholds are derived in Popper *et al*. (2014) for the following categories:

- Fishes with no swim bladder or other gas chamber;
- Fishes with swim bladders in which hearing involves a swim bladder or other gas volume;
- Fishes with swim bladders in which hearing does not involve the swim bladder or other gas volume; and
- Fish eggs and larvae.

The thresholds for mortality and potential mortal injury proposed in Popper *et al*. (2014) that have been used in this assessment and are shown in Table 4-4.

Table 4-4: Popper *et al*. (2014) thresholds for potential mortal injury to fish.

Fish Group	Sound Metric	Threshold for potential mortal injury
Fishes with no swim bladder	Unweighted zero-to-peak SPL	213 dB re 1 µPa
	Unweighted cumulative SEL	219 dB re 1 µPa^{2}s
Fishes with swim bladder involved in hearing	Unweighted zero-to-peak SPL	207 dB re 1 µPa
	Unweighted cumulative SEL	207 dB re 1 µPa^{2}s
Fishes with swim bladder not involved in hearing	Unweighted zero-to-peak SPL	207 dB re 1 µPa
	Unweighted cumulative SEL	210 dB re 1 µPa^{2}s
Eggs and larvae	Unweighted zero-to-peak SPL	207 dB re 1 µPa
	Unweighted cumulative SEL	210 dB re 1 µPa^{2}s

4.3.2 Fish Disturbance Thresholds

Documented behavioural effects of sound on fish behaviour are variable, ranging from no discernible effect (Wardle *et al*., 2001) to startle reactions followed by immediate resumption of normal behaviour (Wardle *et al*., 2001; Hassel *et al*., 2004). Despite some documented behavioural effects there are no well-established criteria or thresholds for assessing behavioural disturbance to fish. In fact, it was concluded in Popper *et al*. (2014) that there lacked sufficient evidence to recommend thresholds that correspond to behavioural disturbance for fish.

5.0 ASSESSMENT OF POTENTIAL IMPACTS

This section presents the underwater noise modelling results and discusses any potential impacts to marine mammals and fish from the proposed pipeline inspection survey at St Fergus. The SSS and MBES equipment that will be used during the proposed survey will produce sound outside the main hearing range of marine mammals and fish species and will therefore not have any significant impact. The SBP that will be used during the pipeline inspection survey will produce the highest sound levels and is within the hearing group of most marine mammals and therefore the modelling and impact assessment has focussed on this sound source.

5.1 Potential Impacts to Marine Mammals

Potential impacts to have been predicted for marine mammals classified into the functional hearing groups proposed by Southall *et al.* (2019) (i.e. for marine mammals classed as LF cetaceans, HF cetaceans, VHF cetaceans and phocid pinnipeds).

5.1.1 PTS Onset

The potential for PTS onset to occur in marine mammals has been predicted by comparing estimated received sound levels to the Southall *et al.* (2019) zero-to-peak SPL and cumulative unweighted SEL thresholds. The potential onset of PTS is considered to have occurred when either the zero-to-peak SPL threshold or the corresponding cumulative SEL threshold is exceeded (Southall *et al.,* 2019; NMFS, 2018).

Zero-to-peak SPL

Received sound levels in terms of unweighted zero-to-peak SPL have been predicted for the SBP to identify potential areas where the instantaneous onset of PTS may occur to marine mammals. Figure 5-1 shows the predicted zero-to-peak SPL from the SBP. This figure shows the maximum unweighted zero-to-peak SPL over all depths. The contours in Figure 5-1 highlight the zero-to-peak SPL thresholds for the potential onset of PTS to marine mammals (see Table 4-2).

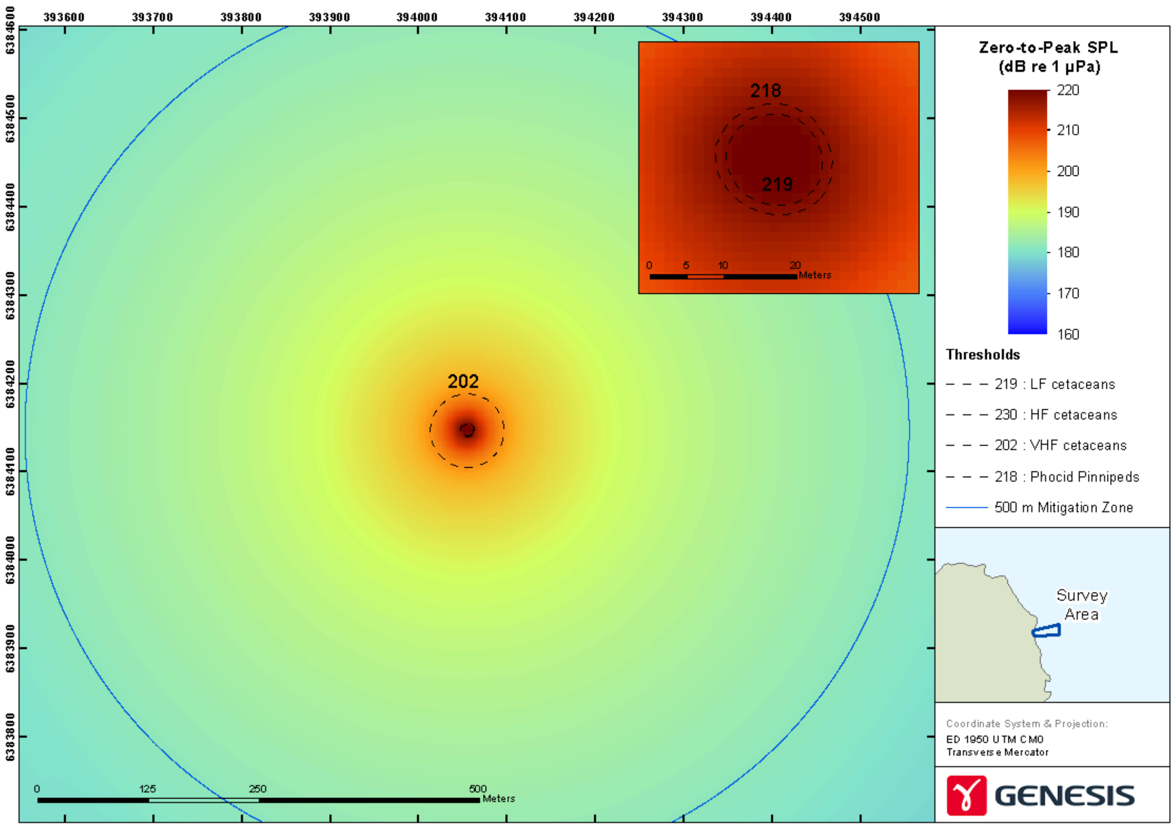

Figure 5-1: Predicted maximum zero-to-peak SPL for the SBP.

The predicted maximum distances where the adopted zero-to-peak SPL thresholds for PTS onset are exceeded are summarised in Table 5-1. The modelling predicts that the threshold for PTS onset to HF cetaceans will not be exceeded. It is predicted that the threshold for PTS onset to LF cetaceans and phocid pinnipeds will not be exceeded outside 10 m from the SBP. The predicted distance to PTS threshold exceedance for VHF cetaceans is 40 m. The predicted distances are well within the nominal 500 m mitigation zone suggested by JNCC for the mitigation of impacts from geophysical surveys (JNCC, 2017). The SBP will be activated using a soft-start where the power (and therefore sound levels) of the SBP will be initiated at a low level and increased over the soft-start duration. The soft-start of the SBP should allow any marine mammals in the area to move away from the SBP to distances where they will not suffer PTS onset.

Table 5-1: Predicted maximum distances from the SBP where the zero-to-peak SPL thresholds for potential PTS onset to marine mammals are exceeded.

Marine Mammal Hearing Group	PTS Threshold	Predicted Maximum Distance to Threshold Exceedance*
LF cetaceans (minke whale)	219 dB re 1 µPa	10 m
HF cetaceans (white-sided dolphin, white-beaked dolphin, bottlenose dolphin)	230 dB re 1 µPa	Threshold not exceeded
VHF cetaceans (harbour porpoise)	202 dB re 1 µPa	40 m
Phocid pinnipeds (grey seal)	218 dB re 1 µPa	10 m

*Predicted distances have been rounded up to the nearest 10 m.

Cumulative SEL

Potential impacts to marine mammals have also been assessed due to cumulative SEL from the SBP. Following the guidance by Southall *et al.* (2019) and NOAA (NMFS, 2018), potential impacts from cumulative SEL have been assessed by weighting received SEL sound levels with the auditory weighting filters shown in Figure 4-1 and calculating the weighted cumulative SEL received by marine mammals as the survey vessel traverses the pipeline route.

The cumulative SEL received by marine mammals has been estimated for mammals swimming away from the survey vessel. Results are presented showing the initial distances that marine mammals must be at the start of the SBP operation in order to not be exposed to weighted cumulative SEL exceeding the threshold for PTS.

Table 5-2 shows the maximum initial distances that marine mammals must be at the start of the SBP operation (i.e. safety distances) in order not to be exposed to cumulative SEL exceeding the thresholds for PTS when they swim away from the SBP at a swim speed of 2 m/s. The modelling predicts that the cumulative SEL thresholds will not be exceeded for HF cetaceans and phocid pinnipeds. The cumulative SEL thresholds for LF cetaceans and VHF cetaceans are predicted to be exceeded at distances of 50 m and 190 m, respectively. If a nominal mitigation zone of 500 m is employed during the survey, it is considered unlikely that the proposed pipeline inspection survey will cause PTS to any marine mammals. If any marine mammals are observed within the 500 m mitigation zone, the commencement of the surveys should be delayed for at least 20 minutes following the last sighting. Given this mitigation measure, it is expected that the risk of PTS onset to marine mammals will be low.

Table 5-2: Predicted distances from the SBP where the cumulative SEL thresholds for potential PTS onset to marine mammals are exceeded.

Marine Mammal Hearing Group	PTS Threshold	Predicted Distance to Threshold Exceedance*
Marine mammals swimming away from the SBP at 2 m/s		
LF cetaceans (minke whale)	183 dB re 1 µPa^{2}s	50 m
HF cetaceans (white-sided dolphin, white-beaked dolphin, bottlenose dolphin)	185 dB re 1 µPa^{2}s	Threshold not exceeded
VHF cetaceans (harbour porpoise)	155 dB re 1 µPa^{2}s	190 m
Phocid pinnipeds (grey seal)	185 dB re 1 µPa^{2}s	Threshold not exceeded
*Predicted distances have been rounded up to the nearest 10 m.		

5.1.2 Behavioural Disturbance

To predict potential behavioural disturbance to marine mammals, received sound levels in terms of rms SPL from the SBP have been estimated and compared to the adopted behavioural disturbance thresholds (see Table 4-3). The estimated rms SPL from the SBP is shown in Figure 5-2, which shows the maximum rms SPL over all depths and does not signify sound levels at any specific depth. The contour highlighted in Figure 5-2 corresponds to the adopted behavioural disturbance threshold for marine mammals (see Table 4-3).

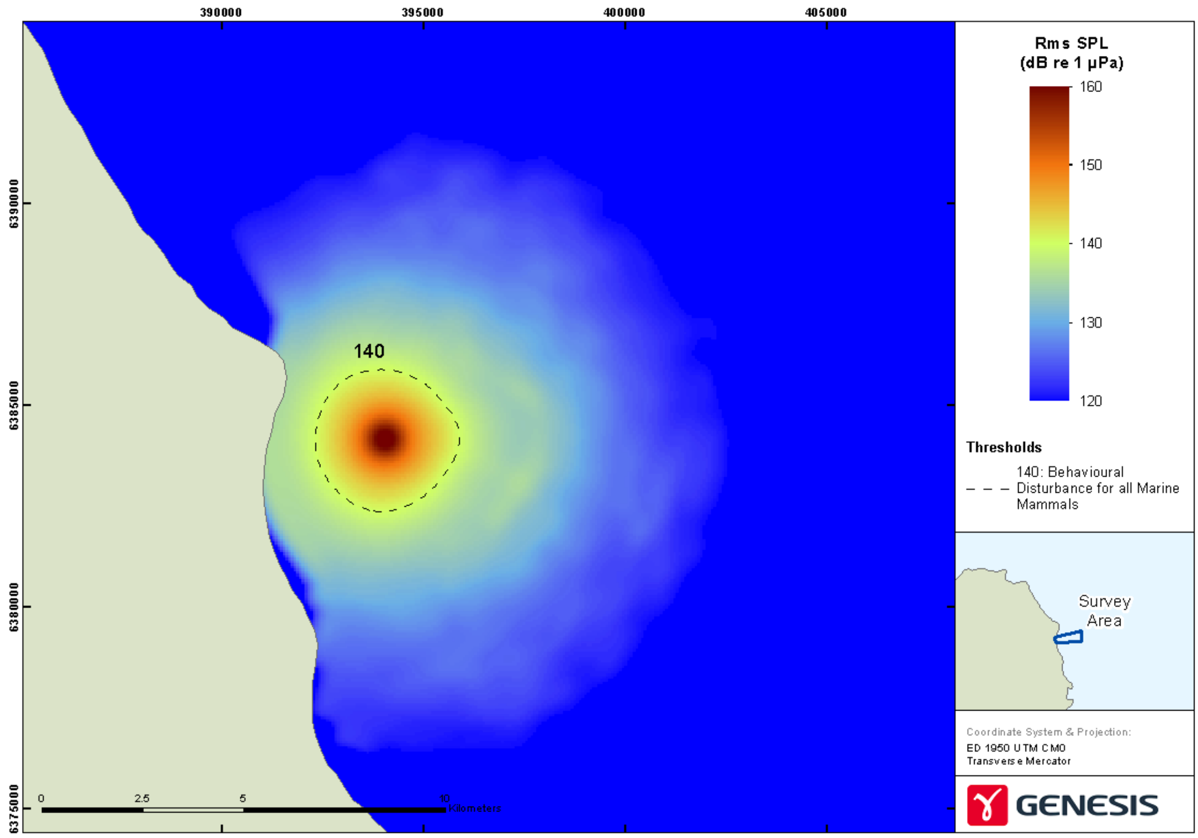

Figure 5-2: Predicted rms SPL for the SBP.

The predicted distances and areas where the adopted behavioural disturbance thresholds are exceeded are summarised in Table 5-3. The modelling predicts that marine mammals could experience behavioural disturbance within 1.8 km from the pipeline inspection survey.

Measurements made during a seismic survey in the Moray Firth (Thompson et *al.*, 2013) showed displacement of harbour porpoise (VHF cetaceans) out to 5–10 km from a 470 cu. in airgun array. The proposed SBP survey is predicted to have a smaller impact to marine mammals compared to those measured by Thompson *et al.* (2013) for seismic surveys.

Table 5-3: Predicted distances from the SBP and areas where the adopted marine mammal behavioural disturbance thresholds are exceeded.

Marine Mammal Hearing Group	Behavioural Disturbance Threshold	Possible Behavioural Response	Predicted Maximum Distance to Threshold Exceedance [1]	Predicted Area of Threshold Exceedance [2]
LF cetaceans (minke whale)	140 dB re 1 µPa	Possible individual and/or group avoidance	1.8 km	11 km^2
HF cetaceans (white-sided dolphin, white-beaked dolphin, bottlenose dolphin)	140 dB re 1 µPa	Possible individual and/or group avoidance	1.8 km	11 km^2
VHF cetaceans (harbour porpoise)	140 dB re 1 µPa	Possible individual and/or group avoidance	1.8 km	11 km^2
Phocid pinnipeds (grey seal)	140 dB re 1 µPa	Possible individual and/or group avoidance	1.8 km	11 km^2

[1] Predicted distances have been rounded *up* to the nearest 0.1 km.

[2] Predicted areas have been rounded *up* to the nearest 1 km^2.

The number of animals that could potentially be disturbed or exhibit behavioural responses due to the proposed pipeline inspection survey have been calculated based on the predicted disturbance zones and estimated densities of animals in the area taken from SCANS III (Hammond *et al.*, 2017). The estimated number of animals that could potentially be disturbed or exhibit behavioural responses is shown in Table 5-4.

The proposed pipeline inspection survey is expected to last a maximum of eight working days, with the SBP component of the survey expected to take a maximum of four working days. Therefore, any disturbance to marine mammals will be short term. It is expected that any marine mammals disturbed from the area will return shortly after cessation of activities. This is supported by studies undertaken during a seismic survey in the Moray Firth where displaced harbour porpoises were observed to return to the area within one day after the survey finished (Thompson *et al.*, 2013). Similar studies based on impacts arising from piling noise have indicated that marine mammals displaced by noise return to the area within relatively short periods of time, usually within three days once the activity causing the displacement has ceased (Tougaard *et al.*, 2006; Brandt *et al.*, 2016).

Table 5-4: Estimated number of cetaceans within predicted behavioural disturbance zones and percentage of MU population disturbed.

Species	Disturbance Area	Animal Density [1] (animals/km^2)	Number of Animals in Disturbance Zone	MU Population [2]	Percentage of MU Population Disturbed
Harbour porpoise	11 km^2	0.599	7	227,298	0.0004%
Bottlenose dolphin	11 km^2	0.030	1	195	0.5128%
White-beaked dolphin	11 km^2	0.243	3	15,895	0.0189%
White-sided dolphin	11 km^2	0.010	1	69,293	0.0014%
Minke whale	11 km^2	0.039	1	23,528	0.0043%

[1]Animal densities are from Hammond *et al*., (2017) SCANS-III Block Q.

[2] MU populations are from IAMMWG, (2015).

5.2 Potential Impacts to Fish

5.2.1 Injury

To assess any potential injury to fish from the proposed pipeline inspection survey, received sound levels in terms of unweighted zero-to-peak SPL and unweighted cumulative SEL have been predicted and compared to the Popper *et al*. (2014) thresholds for potential mortal injury (see Table 4-4).

Figure 5-3 shows the predicted zero-to-peak SPL from the SBP. This figure shows the maximum unweighted zero-to-peak SPL over all depths and does not signify the zero-to-peak SPL at any specific depth layer. The contours in this graphic highlight the Popper *et al*. (2014) zero-to-peak SPL thresholds for potential injury to fish species (see Table 4-4).

The predicted distances where the Popper zero-to-peak SPL thresholds are exceeded are shown in Table 5-5. The modelling predicts that injury to fish would be limited to a maximum distance of 40 m. It is expected that a soft-start activation of the SBP would disperse any fish in the vicinity of the survey to safe distances where they would be unlikely to suffer injury. The Popper cumulative SEL thresholds were predicted not to be exceeded.

The proposed survey could potentially be conducted during spawning of herring, lemon sole, Nephrops and sprat. However, given the small area of estimated potential impact to fish species, it is not expected that the proposed surveys will have a significant injurious impact on spawning fish, eggs or larvae.

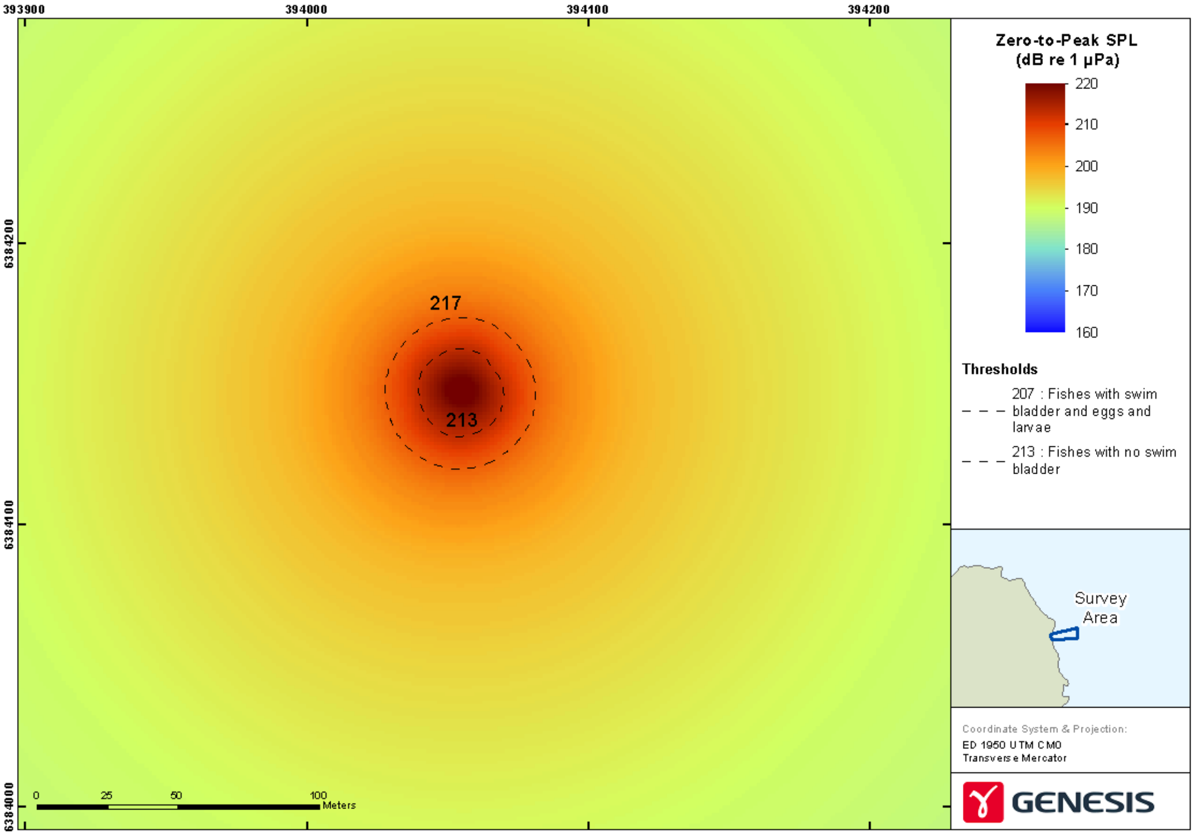

Figure 5-3: Predicted maximum zero-to-peak SPL for the SBP.

Table 5-5: Predicted maximum distances from the SBP where the Popper zero-to-peak SPL thresholds for fish injury/potential mortality are exceeded.

Fish Group	Threshold for Injury/Potential Mortality	Predicted Maximum Distance to Threshold Exceedance *
Fishes with no swim bladder (lemon sole)	213 dB re 1 µPa	30 m
Fishes with swim bladder involved in hearing (herring)	207 dB re 1 µPa	20 m
Fishes with swim bladder not involved in hearing (cod, sandeel, haddock, Nephrops, Norway pout, whiting, sprat)	207 dB re 1 µPa	20 m
Eggs and larvae	207 dB re 1 µPa	20 m

* Predicted distances have been rounded up to the nearest 10 m.

5.2.2 Behavioural Disturbance

Behavioural disturbance to fish could not be predicted from the propagation modelling since there are no established disturbance thresholds for fish. However, fish are mobile animals that would be expected to move away from a sound source that had the potential to cause them harm. If fish are disturbed by sound, evidence suggests they will return to an area once the activity generating the sound has ceased (Slabbekoorn *et al*., 2010). Any disturbance to fish is expected to be of a short duration and therefore it is concluded that the proposed surveys will not have a significant impact on any fish species.

5.3 Cumulative Noise

Figure 5-4 shows areas where known surveys are planned in 2020. There are no known surveys in the immediate vicinity of the proposed pipeline inspection survey at St Fergus and therefore the proposed survey will unlikely have any cumulative impact on any marine mammal population. Furthermore, the proposed survey is only expected to last a maximum of eight working days, of which the SBP will only be operated for up to four working days. Although cumulative impacts are expected to be minimal, any impacts will be further minimised by coordinating with other surveys (if Shell became aware of any surveys planned within the same area).

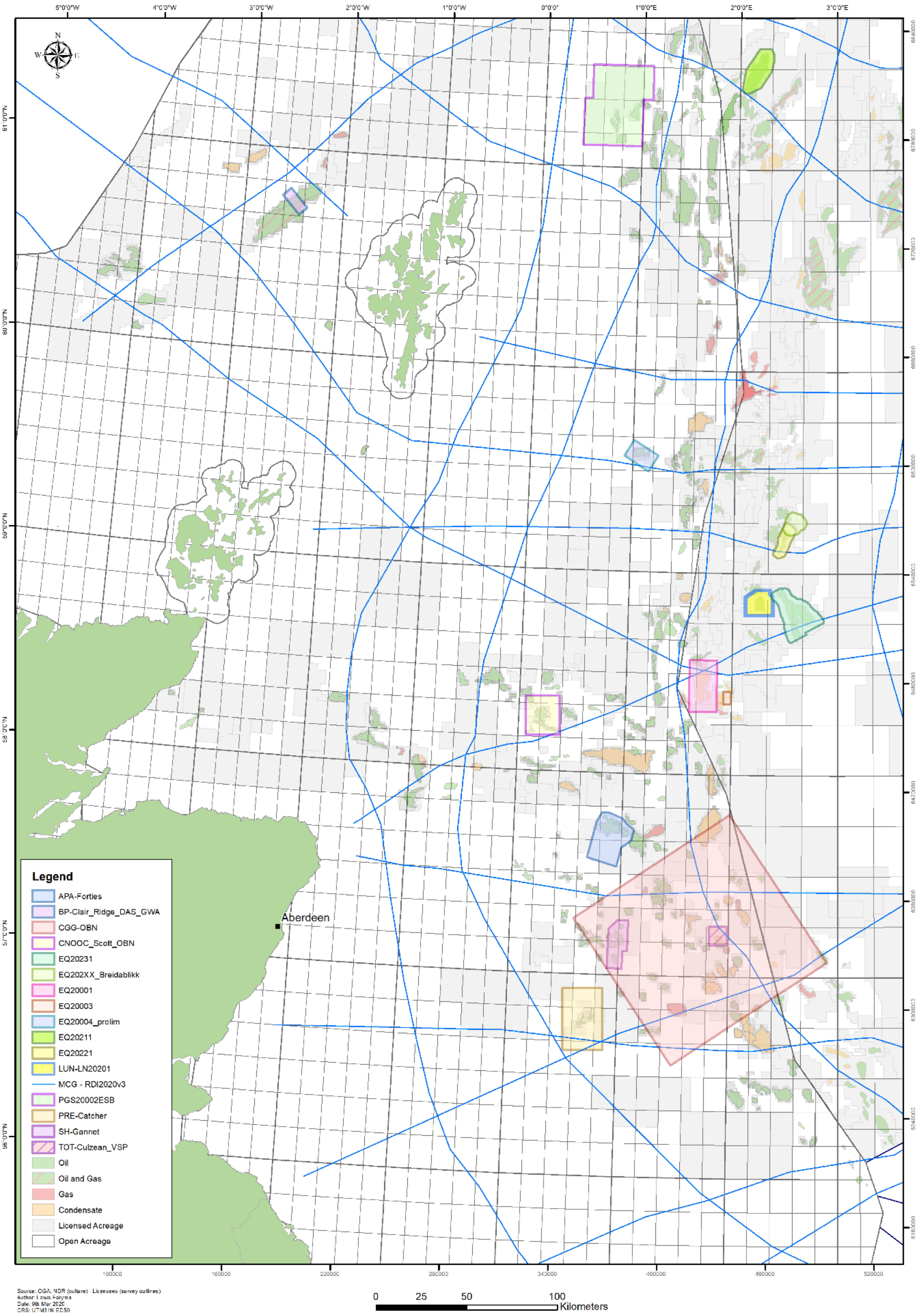

Figure 5-4: Possible surveys in the Central and Northern North Sea in 2020.

5.4 National Marine Plan

The proposed operations, as described in this application, have been assessed against the Scottish National Marine Plan (NMP) Objectives and General Policies (Scottish Government, 2015). Assessment of compliance with the relevant policies has been achieved through the impact assessment described throughout Section 5, specifically:

- **GEN 1 General Planning Principle**: Development and use of the marine area should be consistent with the Marine Plan, ensuring activities are undertaken in a sustainable manner that protects and enhances Scotland's natural and historic marine environment. Shell will ensure that any potential impacts are minimised.
- **GEN 4 Co-Existence:** Proposals which enable coexistence with other development sectors and activities within the Scottish marine area are encouraged in planning and decision-making processes, when consistent with policies and objectives of this Plan.
- **GEN 13 Noise:** Development and use in the marine environment should avoid significant adverse effects of man-made noise and vibration, especially on species sensitive to such effects.
- **GEN 21 Cumulative Impacts:** Cumulative impacts affecting the ecosystem of the marine plan area should be addressed in decision making and plan implementation. The operations are not expected to significantly increase cumulative impacts from surrounding oil and gas assets.

6.0 MITIGATION MEASURES

To minimise the risk of potential impacts of sound from the survey further, the JNCC (2017) "Guidelines for minimising the risk of injury to marine mammals from geophysical surveys" should be followed. The following mitigation measures are suggested:

- There will be a qualified MMO aboard the vessel during the entire survey, who will be following JNCC (2017) guidelines for minimising the risk of injury to marine mammals from geophysical surveys. When the MMO observation period is ongoing, the designated MMO will not be required to undertake any other duties on the vessel.
- The designated MMO will detect marine mammals within a 500 m mitigation zone. If any cetaceans are observed within 500 m from the source array, then the start of the seismic sources will be delayed for at least 20 minutes following last sighting.
- The designated MMO will carry out a 30-minute pre-data acquisition survey of the mitigation zone and, if an animal is detected, the soft-start of the seismic sources will be delayed until their passage, or the transit of the vessel, results in the marine mammals being more than 500 metres away from the source i.e. out with the 500 m mitigation zone.
- A soft-start activation of the SBP will be employed, whereby the source power will be incrementally increased over period of at least 20 minutes. This will allow any marine mammals to move away from the sound source and reduce the likelihood of exposing the animal to sounds that could potentially cause injury. A soft start will be employed whenever the SBP is used.
- If the SBP has been inactive for a period of 10 minutes or longer, the designated MMO will perform a visual inspection of the 500 m mitigation zone. If a mammal is detected within the 500 m mitigation zone, the restart of the survey will be delayed for at least 20 minutes following last sighting.

To minimise the risk of marine mammals being chased inshore, the survey vessel will acquire SBP, SSS and MBES acoustic data along each pipeline route within the survey area from the shore outwards (seaward) to allow any potentially disturbed cetaceans to be directed away from the shore rather than onshore.

7.0 CONCLUSIONS

This assessment has considered the potential impacts from the proposed pipeline inspection survey at St Fergus on marine mammals and fish. Sound propagation modelling was conducted to assess potential impacts to marine mammals and fish from the SBP that will be used during this survey since this activity will generate the highest sound levels in the marine environment during the proposed survey. The survey will also utilise SSS and MBES equipment, although these devices will produce sound that is outside the main hearing range of marine mammals and fish and therefore will have negligible impact.

Comparison of received sound levels to the Southall *et al.* (2019) and NOAA (NMFS, 2018) thresholds for potential PTS onset suggested that sound levels generated from the proposed survey would decrease to below the thresholds for any marine mammal species well within the nominal 500 m mitigation zone (the modelling predicted that the PTS thresholds for LF cetaceans such as minke whale would not be exceeded outside 50 m, whilst the threshold for VHF cetaceans would not be exceeded outside 190 m). If any marine mammals are observed within the 50 m mitigation zone by MMOs, the commencement of the survey will be delayed until all mammals have vacated the mitigation zones for at least 20 minutes following the last sighting. Given this mitigation measure, it is considered that the risk of any marine mammal experiencing the onset of PTS is low.

Possible areas of behavioural disturbance were also predicted from the underwater noise modelling. Although it was predicted that the proposed survey would result in potential behavioural disturbance to marine mammals, the estimated number of marine mammals that could potentially be disturbed was estimated to be very small compared to total abundances that could be in the area. It is expected that any marine mammals disturbed from the area would likely return after cessation of activities. The proposed pipeline inspection survey is expected to last for eight working days, of which the SBP will only be operated for four working days (subject to weather and tidal conditions). Therefore, any disturbance caused will be temporary.

The proposed survey area is located within the Southern Trench pMPA, which is designated for the protection of minke whale (as well as burrowed mud and shelf deeps). The modelling predicts that impacts to minke whale (which are LF cetaceans) will be low and the survey will not have a significant impact on this protected area or any other protected area.

The modelling predicted that injury to fish and their eggs and larvae would be limited to a maximum distance of 40 m from the SBP. It is expected that the soft start of the SBP would likely disperse any fish to safe distances where they would not experience sound levels that could cause injury. In addition, identified spawning areas are very extensive in comparison to the potential area of disturbance. It is concluded that the proposed survey will be unlikely to have any significant impact on spawning fish, their eggs or their larvae.

There are no known other surveys within the vicinity of the proposed pipeline inspection survey at St Fergus and therefore the proposed operations are unlikely to have a cumulative impact on any marine mammal or fish population.

It is concluded that the proposed survey will not have any significant impact on marine mammals or fish species.

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ACRONYMS AND ABBREVIATIONS

dB	Decibels
Defra	Department for Environment, Food and Rural Affairs
EC	European Commission
ED	European Datum
EEC	European Economic Community
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data network
EPS	European Protected Species
EU	European Union
FARAM	Faunal Acoustic Risk Assessment Model
GEBCO	General Bathymetric Chart of the Oceans
HF	High Frequency
IAMMWG	Inter-Agency Marine Mammal Working Group
ICES	International Council for the Exploration of the Seas
JNCC	Joint Nature Conservation Committee
kg/m^3	Kilograms per cubic metre
kHz	Kilo-Hertz
km	Kilometres
km^2	Square kilometres
LF	Low Frequency
m	Metres
m/s	Metres per second
MCZ	Marine Conservation Zone
MF	Mid Frequency
MMO	Marine Mammal Observer
MPA	Marine Protected Area

ms	Milli-seconds
MU	Management Unit
NCMPA	Nature Conservation Marine Protected Area
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OGA	Oil and Gas Authority
PE	Parabolic Equation
PMF	Priority Marine Feature
pMPA	Possible Marine Protected Area
pSPA	Possible Special Protection Area
PTS	Permanent Threshold Shift
RAM	Range-dependent Acoustic Model
rms	Root mean square
SAC	Special Area of Conservation
SCANS	Small Cetacean Abundance in the North Sea
SCOS	Special Committee on Seals
SEL	Sound exposure Level
SMRU	Sea Mammal Research Unit
SPA	Special Protection Area
SPA	Special Protection Area
SPL	Sound Pressure Level
UK	United Kingdom
UKCS	United Kingdom Continental Shelf
VHF	Very High Frequency
WGS	World Geodetic System
WOA	World Ocean Atlas

APPENDIX A: MODELLING METHODOLOGY

This appendix discusses the modelling methodology that has been adopted for this assessment. The noise modelling focuses on sound generated by the sub-bottom profiler since it is the loudest sound source associated with the proposed survey that is within the hearing range of marine mammals that are likely to be in the area.

A.1. SOURCE MODELLING

The sub-bottom profiler that will be used during the proposed geophysical site survey will be a Innomar Medium Parametric SBP. The profiler is predicted to have a zero-to-peak SPL of 250 dB re 1 µPa-m, and an SEL of 243 dB re 1 µPa^{2}s-m. The SBP will emit a linear frequency modulated chirp signal over a frequency range of 5-15 kHz. The estimated third octave band SEL spectra of the SBP is shown in Figure A-1. The pulse interval of the SBP is 0.1 s. Details of the sub-bottom profiler are summarised in Table A-1.

Table A-1: Sub-bottom profiler details.

Parameter		Value
Source		Innomar Medium Parametric SBP
Signal type		Linear frequency modulated chirp signal
Source Level	Zero-to-peak SPL	250 dB re 1 µPa-m
	SEL	243 dB re 1 µPa^{2}s-m
Frequency range (-3dB)		5 – 15 kHz
Pulse interval		0.1 s

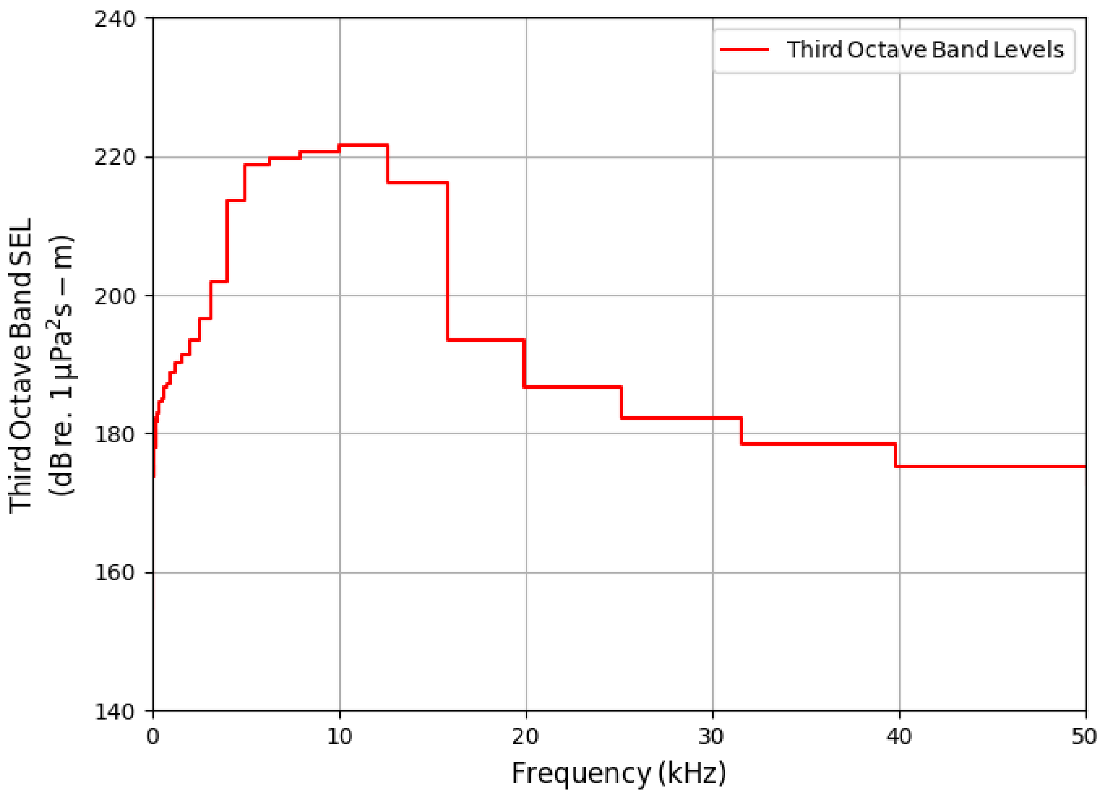

Figure A-1: Third octave band SEL for the SBP used in the modelling.

SBPs are highly directional sound sources, with the largest portion of energy being directed vertically downwards to the seabed. The directivity of these devices results on horizontal propagation being substantially reduced, and it is therefore important to account for the effects of such directionality. Neglecting directionality effects can lead to received sound levels (and consequently estimated impacts to marine life) being significantly overestimated. The Innomar Medium Parametric SBP is conservatively estimated to have a -3 dB beam-width of 40°. The beam pattern for the sub-bottom profiler that has been used in the modelling is shown in Figure A-2.

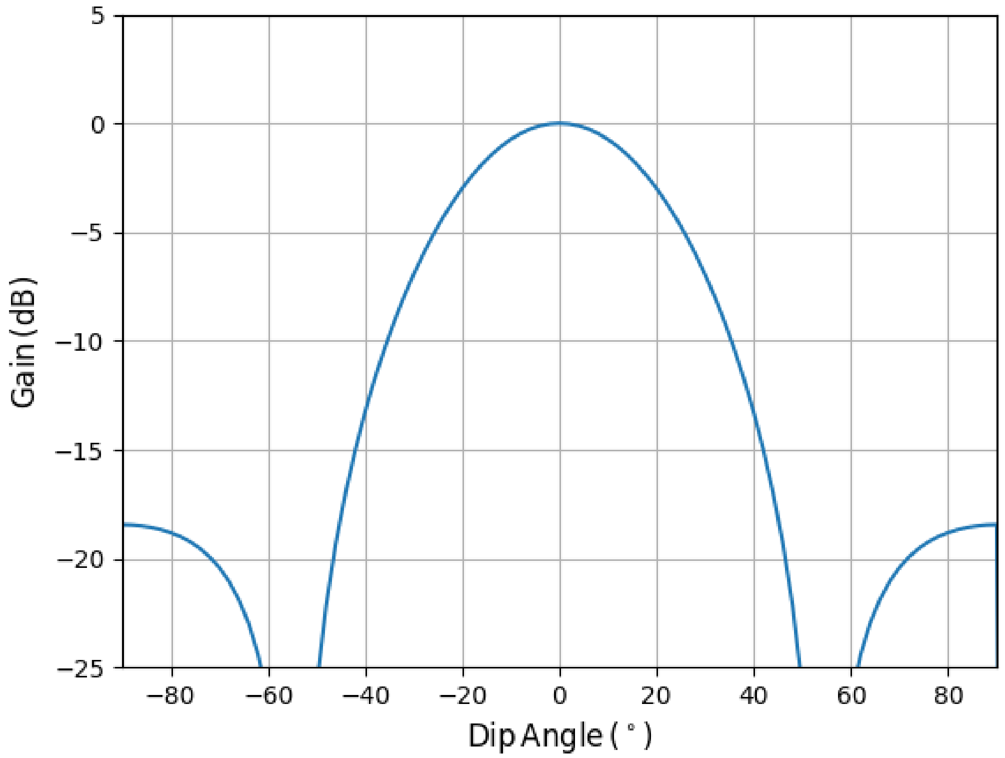

Figure A-2: Beam pattern for the sub-bottom profiler used in the modelling.

A.2 Propagation Model

The Genesis in-house software FARAM has been utilised for modelling sound propagation. FARAM is an underwater sound propagation model that incorporates site-specific environmental data such as a full bathymetric grid, varying water column temperature and salinity profiles, and geo-acoustic properties of the seabed. By explicitly modelling the factors affecting sound propagation, results can be obtained that are more accurate and relevant to the area of interest than would be obtained with more simplistic models (e.g. simple spreading models). FARAM contains implementations of a parabolic equation (PE) and ray tracing algorithms, which have been used to estimate received sound levels.

A.2.1 Parabolic Equation Algorithm

PE algorithms approximate the wave equation, allowing a solution to be found computationally (Jensen *et al.*, 2011). This is one of the most popular wave-theory techniques for modelling sound propagation in spatially-varying environments (Jensen *et al.*, 2011). The computational scheme used in this assessment is based on the Range-dependent Acoustic Model (RAM) implementation of the PE (Collins, 1993).

PE techniques are complex and require careful selection of environmental parameters (e.g. variation in bathymetry and sound speed profiles) and computational parameters (e.g. depth and range resolution) to ensure that the solution is accurate. The PE algorithm is best suited to calculation of low frequency sound propagation since the computational complexity (and hence implementation time) of the PE method significantly increases with frequency. The PE algorithm has been used to estimate the propagation of frequencies up to 500 Hz for the modelling conducted in this assessment. A ray tracing algorithm has been utilised for sound propagation of frequencies above 500 Hz.

A.2.2 Ray Tracing Algorithm

The ray tracing method that has been utilised for modelling higher frequencies is the Bellhop Gaussian beam ray tracing model (Porter and Liu, 1994). Bellhop is an efficient algorithm that is well suited for the modelling of higher frequency sound sources.

Similar to the RAM PE algorithm discussed previously, Bellhop also incorporates acoustic propagation effects resulting from range dependent sound speed depth profiles and geo-acoustic properties. However, in contrast to the RAM PE algorithms, Bellhop also accounts for increased sound attenuation due to volume absorption. This type of sound attenuation becomes more prominent at higher frequencies and cannot be neglected without significantly over estimating received levels at large distances from the sound source.

A.2.3 Environmental Input Data

The implemented propagation algorithms account for various site-specific environmental properties including a bathymetric grid, geographically and depth varying sound speed profiles and geo-acoustic properties of the sediment. To model the effects of these environmental properties, input data are required that describes the surrounding environment. The environmental input datasets that are utilised in the propagation model are discussed in the following sections.

Sound Speed Profile

A major factor that influences the propagation of sound in water is the speed of sound through the water column, which influences how an acoustic wave refracts. Sound speed data can be derived from measurements/modelling of temperature and salinity, which are more readily available. Sound speed profiles for the model location were derived from temperature and salinity profiles taken from the World Ocean Atlas (WOA; 2013). WOA is an objectively analysed 1° resolution database where temperature and salinity data are given based on historical data. Since the sound speed profile is a function of temperature, pressure (which is a function of depth) and salinity, this database can be used to calculate the sound speed profile. The empirical formula in (Jensen *et al*., 2011) has been used to calculate sound speed profiles based on temperature, salinity and depth.

Bathymetry and Seabed Properties

Seabed bathymetry strongly influences the propagation characteristics of sound; in shallow water regions, there is significant interaction of the sound with the seabed through reflections and scattering effects, which can result in strong attenuation. In deep water regions, there is typically less interaction of sound with the seabed and attenuation due to bottom loss is small, which can result in longer propagation distances.

The bathymetry data that have been used in the noise modelling is provided by the General Bathymetric Chart of the Oceans (GEBCO) 30 arc-second grid (GEBCO, 2014), which is a continuous terrain model for ocean and land with a spatial resolution of 30 arc seconds.

The implemented propagation model accounts for attenuation effects of sound due to interactions with the seabed. The modelling has assumed a sandy seabed in line with the expected sediments in the area) and the main geo-acoustic properties associated with the seabed that have been used in the modelling are shown in Table A-2 (Jensen *et al.*, 2011).

Table A-2: Geo-acoustic parameters that have been used in the model.

Geo-acoustic Parameter	Value
Predominant sediment	Sand
Sound speed in sediment	1650.0 m/s
Sound attenuation in sediment	0.8 dB/wavelength
Sediment density	1,900 kg/m^3