Chapter 23: Noise and Vibration (Underwater)

Co-financed by the European Union
Connecting Europe Facility

NorthConnect KS
Serviceboks 603, Lundsiden
N-4606 Kristiansand
Norway

Phone +47 38 60 70 00
Mail: post@northconnect.no
Web: www.northconnect.no

Contents

23 Noise and Vibration (Underwater)

23.1 Introduction

The relatively high density of water means that underwater noise is readily transmitted in the marine environment. This means there is the potential for underwater noise emissions resulting from the installation and operation of the NorthConnect HVDC marine cables to disturb, injure or kill noise sensitive receptors at extensive distances from the working areas. The noise sensitive receptors likely to be present in the vicinity of the Consenting Corridor include marine mammals and fish. This chapter will outline the predicted noise levels resulting from the installation and operation of the NorthConnect HVDC cables, ascertain the potential effects on marine mammals and fish that could result from the noise emissions, and estimate the range from source where each affect can be expected. This in turn will inform the detailed impact assessments on marine mammals and fish, provided in Chapters 15 and 16.

23.2 Sources of Information

23.2.1 Planning and Legislative Framework

The Scottish Government has released general policies as part of the Scotland's National Marine Plan in favour of sustainable development and use of the marine environment which include:

- ***GEN 13 Noise:*** *Development and use of the marine environment should avoid significant adverse effects of man-made noise and vibration, especially on species sensitive to such effects* [Scottish Government, 2015a].

The Scottish government has released a series of good environmental status descriptors within Scotland's National Marine Plan. These include:

- ***GES 11:*** *Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.* [Scottish Government, 2015c].

23.2.2 Relevant Guidance

There are no internationally agreed standards with regard to the assessment of underwater noise, but it is current practice to undertake assessments based on criteria provided in the scientific literature or guidance published by regulatory authorities. For this assessment, the criteria are based on:

- Southall et al. [2007] Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammals 33, 411 - 521.*
- Popper A N et al. [2014]. Sound Exposure Guidelines for Fishes and Sea Turtles.

23.3 Assessment Methodology

The aim of this this chapter is not to assess the potential impacts from underwater noise on ecological receptors; these assessments are provided in Chapters 15 & 16. Instead this chapter will identify the ranges to which marine ecological receptors may be affected by underwater noise resulting from the installation and operations of the proposed HVDC cables.

23.3.1 Baseline Data Collection

Ambient underwater noise levels are highly variable, depending on a range of both natural and anthropogenic factors. Natural factors include sea state, rain, currents, movement of seabed materials, as well as sounds and vocalisations from marine animals. These factors can result in seasonal and even daily changes in the baseline noise levels. Anthropogenic noise will also contribute to the background levels; however, the significance of this contribution is difficult to quantify (due to the variability in the natural sources).

Very little data is available regarding baseline underwater noise levels in the North Sea along the marine Consenting Corridor. However, the highly variable nature of the ambient noise levels in the vicinity of the Consenting Corridor, means that baseline noise monitoring would not add substantially to the current understanding of the existing sound scape. As such no monitoring has been undertaken, and the baseline is informed by a review of the available literature.

23.3.2 Impact Assessment Methodology

In order to assess the potential impacts of underwater noise generated during the installation and operation of the NorthConnect HVDC cables, it is necessary to understand whether the noise is in a frequency range that can be detected by the marine noise sensitive receptors likely to be present in the vicinity of the consenting corridor. Where a noise source is detectable, it is then necessary to ascertain the nature of the potential impact resulting from the receptor being exposed to the noise source, as well as the distance to which that impact is likely to be experienced.

The primary underwater noise sensitive receptors in the marine environment are marine mammals and fish. Southall et al. [2007] presents hearing frequency thresholds for marine mammals, as well as noise exposure criteria for sound pressure levels which have the potential to cause injury and disturbance. The scientific literature also provides similar information for fish [Popper et al., 2014 & Slabbekoorn et al., 2010]. The frequencies and sound pressure levels of the noise sources likely to be associated with the installation and operation of the HVDC cables will be compared against the exposure criteria, in order to ascertain whether a risk of injury or disturbance to marine mammals and fish exists. Where a risk of injury or disturbance exists for a noise source, the range from the source to which that effect could be expected to occur will be calculated.

23.3.2.1 Marine Mammals Sensitivity

Marine mammals have hearing sensitivity thresholds, which are the frequency bands in which they can detect and are sensitive to underwater noise (Southall et al, 2007). Southall et al., has published a table, detailing the hearing thresholds of different marine mammal species. This will be used to ascertain which noise sources associated with the installation and operation of the HVDC cables will be detected by the marine mammals likely to be present within the vicinity of the consenting corridor, and hence need to be considered further in the assessment. This information is summarised in Table 23.1.

Table 23.1. Hearing Thresholds of Marine Mammals. After Southall et al, 2007.

Species	Hearing Threshold (kHz)
Harbour Porpoise	0.2-180
Bottlenose Dolphin	0.15-160
Minke Whale	0.007-22
White Beaked Dolphin	0.15-160
Short-Beaked Common Dolphin	0.15-160
Atlantic White-Sided Dolphin	0.15-160
Long-Finned Pilot Whale	0.15-160
Killer Whale	0.15-160
Risso’s Dolphin	0.15-160
Grey & Common Seals	0.075-75

Southall et al, [2007] also propose precautionary noise exposure criteria for marine mammal disturbance and injury; where injury is defined as either Permanent or Temporary Threshold Shift (PTS and TTS respectively); these criteria are presented in Table 23.2.

Table 23.2. Auditory Injury and Disturbance Criteria for Marine Mammals. After Southall et al, 2007.

Effect		Exposure Limit (dB re 1 µPa)
Injury	PTS Onset Cetaceans	230
	PTS Onset Seals	218
	TTS Onset Cetaceans	224
	TTS Onset Seals	212
Disturbance	All marine mammals	160

23.3.2.2 Fish Sensitivity

Considerably less information is available for the hearing capabilities of fish, or their sensitivity to underwater noise. The current guidance and exposure criteria are based on very sparse information from limited field studies, and as such should be treated with caution, however it is thought that the current criteria are overly conservative, and as such the assessment can be taken as the worst case [Popper et al., 2014].

Fish hearing thresholds depend greatly on the hearing mechanisms of the species, and can be broadly grouped into two classes; fish that do not have a swim bladder (or have a swim bladder that is not involved in hearing), and hearing specialists which have a swim bladder that is linked to the hearing mechanism (including herring) [Slabbekoorn et al., 2010]. Both groups of fish are likely to be present within the vicinity of the Consenting Corridor, and will be considered in the assessment. A summary of the hearing thresholds is presented in Table 23.3.

Table 23.3. Hearing Thresholds of Fish. After Slabbekoorn et al., 2010.

Fishing Hearing Group	Hearing Threshold (kHz)
No swim bladder involved in hearing	0.03-1
Swim bladder involved in hearing	0.03-5

Currently there are no nationally accepted standard noise exposure criteria for fish, however the United States National Marine Fisheries Service (NMFS) developed a set of interim injury and disturbance criteria, which have been broadly adopted [Popper et al., 2014]. It should be noted that the literature strongly criticises the disturbance threshold, as the basis for setting the threshold is not provided, and further studies suggest it is significantly lower than the sound pressure level which results in a behavioural response [Popper et al., 2014]. However, no alternative threshold value has been suggested, due to a lack of empirical evidence in the area, so the NMFS value is used for information. A summary of the fish noise exposure criteria is provided in table 23.4.

Table 23.4. Auditory injury and disturbance criteria of fish. After Popper et al., 2014.

Effect	Exposure Limit (dB re 1 µPa)
Onset of physical injury in fish.	206
Onset of behavioural disturbance	150

23.3.2.3 Range Estimation

Where a noise source is detectable to marine mammals or fish, and has a sound pressure level which exceeds the disturbance criteria; a simple but conservative propagation loss model will be used to estimate the range of potential disturbance from the noise source. The propagation loss model used is:

$$PL = 15\log_{10}(R)$$

Where PL is propagation loss in dB re 1 µPa, and R is the distance from the noise source.

The use of 15 as the scaler in the above equation makes it a hybrid between the cylindrical spreading model and the spherical spreading model. The cylindrical model is appropriate for shallow water, and assumes more horizontal spreading than vertical, so uses 10 as the scaler, while the spherical spreading model is appropriate for deeper water, and assumes equal vertical and horizontal spreading, so uses 20 as the scaler. Since the majority of the consenting corridor is in waters greater than 100m in depth, the spherical model could be applied throughout, however using 15 as the scaler will result in a reduced propagation loss, and hence can be considered a conservative approach.

23.3.3 Identification and Assessment of Mitigation

This chapter only identifies the range to which there is potential for injury or disturbance to sensitive receptors, resulting from the installation and operation of the HVDC cables. No consideration is made to the significance of these impacts on an individual or population level. This assessment is conducted in Chapters 15 & 16, and where necessary, appropriate mitigation measures identified. As such, no mitigation will be presented in this chapter.

23.3.4 Assessment of Residual Effects

Since no mitigation is proposed in this chapter, the residual effects cannot be considered.

23.3.5 Limitations of Assessment

This assessment is based on predicted source noise levels, using data currently available in the literature. In addition, the propagation loss model is rather simplistic and does not take into account bathymetry and sediment types. As such there is a potential for the actual noise levels, and hence impact ranges to differ from those predicted. However, a conservative approach has been used throughout, so this assessment should be considered to be a worst-case scenario.

23.4 Baseline Information

The marine consenting corridor in general passes through open water, with only three main types of anthropogenic acoustic source. The predominant acoustic sources that are present along the cable corridor include: shipping, fishing grounds (and associated fishing vessels), and oil and gas installations.

The oil and gas installations are localised sources, which may generate high underwater noise levels in their vicinity. The oil and gas installation are concentrated along the UK-Norway median line, in the north east of the consenting corridor. This infrastructure has been avoided by a minimum of 500m during the initial cable routing, however it is likely that the baseline in the vicinity of oil and gas infrastructure will be elevated.

Shipping density is generally low throughout the cable corridor; however, there are localised areas of high vessel traffic. Shipping provides numerous transient, low intensity noise sources which in isolation have a negligible effect on baseline noise levels. However, in high traffic areas, shipping noise can result in a significantly elevated baseline. High traffic areas in the vicinity of the consenting corridor include route between Aberdeen and Peterhead, and the waters around the offshore oil and gas installations. Shipping is covered in more detail in Chapter 19.

The North Sea is an important region for the commercial fisheries, and the consenting corridor passes through numerous fishing grounds. Fishing grounds result in high densities of fishing vessels, focussed specific areas where the target species is located. The grounds are not targeted year-round, but instead the fleet follows the seasonal movements of their target species throughout the year. This results in transient areas of localised high fishing vessel density, and associated elevated baseline noise levels. Further information on commercial fisheries is available in Chapter 20.

McDonald et al. [2008] and Walker et al. [2018] suggest that shipping noise is resulting in a chronic increase in deep sea baseline noise levels. In the North Sea region, it is likely that anthropogenic noise, specifically from shipping, is prominent in the soundscape [Ainslie et al., 2009]. Due to propagation loss, the anthropogenic noise levels will vary from the distance to the noise sources, such as shipping routes, fishing grounds, and oil and gas areas. A review of the available literature indicates that underwater noise levels of between 100 to 130dB re 1μPa are representative baseline for the Northern North Sea region, in the vicinity of the consenting corridor [Bailey et al., 2010; Nedwell et al., 2007; Robinson et al., 2011; Theobald et al., 2010].

23.5 Noise Impact Assessment

This section will identify the noise sources that will be associated with the installation and operation of the HVDC cables. The ranges to which potential impacts on noise sensitive marine receptors could expected be will then be identified.

23.5.1 Installation

23.5.1.1 Noise Sources

Previous studies have demonstrated that the principal noise source associated with marine cable installation is vessel noise, and the acoustic devices utilised during the pre-installation surveys [NSN Link Limited, 2014 & Meißner et al., 2006]. However, all potential sources will be identified and discussed for completeness, following advice provided in the scoping opinion. The acoustic sources that may be associated with the marine cable installation process include:

- Vessel Noise;
- Subsea survey equipment including;
    - Multibeam Echo Sounder (MBES),
    - Side-Scan Sonar (SSS), and
    - Sub Bottom Profiler (SBP).
- Horizontal Directional Drilling (HDD);
- Cable Burial; and
- Installation of external protection.

Further information on the vessels and installation techniques is provided in Chapter 2.

23.5.1.1.1 Vessel Noise

Installation of the marine HVDC cables will require multiple vessels including cable lay vessels, support vessels (cable burial/trenching, rock placement, route clearance vessels etc), as well as guard vessels to protect exposed sections of cable. The cable laying and support vessels will be large, potentially exceeding 150m in length and will operate Dynamic Positioning 2 systems (DP). The guard vessels (usually fishing vessels appointed to the project) will be much smaller, <50m in length, and will operate conventional positioning systems. While the actual properties of the underwater vessel noise will depend on the vessels selected by the installation contractor, numerous studies have detailed the characteristics of various vessel types ranging from large DP vessels equivalent to the cable lay and support vessels, to smaller tugs and fishing vessels which are analogous to the guard vessels.

Vessel noise from large DP vessels is described as being a low frequency broadband sound, with some tonal components ranging from 30Hz to 3kHz, with sound pressure levels reported between 180 to 197 dB re 1µPa at 1m [Talisman Energy, 2006; Wyatt, 2008; & Xodus, 2014]. Noise from DP vessels does not vary significantly with speed, as a DP system relies on all thrusters working simultaneously, regardless of whether the vessel is moving or holding station. However, noise levels will vary with climatic and tidal conditions, which affect a vessels ability to maintain position, since these factors change the amount of thrust required to keep the vessel in position. In moderate wind, sea state and current; the noise levels can be expected to be lower than in more challenging conditions.

Smaller, non-DP vessels are reported as also emitting broadband noise with tonal components, however the bandwidth is generally lower, concentrated between 50Hz and 2kHz. The reported sound pressure levels are also lower than for the larger DP vessels, and range between 170 to 180 dB re 1µPa at 1m, for a selection of tugs boats and offshore fishing vessels [Richardson, 1995; Walker et al., 2018 & Wyatt, 2008]. Unlike DP vessels, the noise emission levels from these vessels are highly dependent on speed, and these figures are all for vessels at transit speed. As such the noise levels reported here are representative of those when the vessels are travelling between sites, but will overestimate the emission levels when the vessel is in position, since the guard vessels will generally hold a fixed position or only travel slowly around their station.

When compared to the marine mammal and fish hearing thresholds (Tables 23.1 & 23.3), it is clear that vessel noise from both the large DP2, and smaller vessels is detectable to both marine mammals and fish. This source will therefore be considered further in the assessment.

23.5.1.1.2 Subsea Survey Equipment

Pre-installation subsea surveys will be required in order to inform the final cable route design, within the Consenting Corridor. Several acoustic survey devices including multibeam echo sounder (MBES), side scan sonar (SSS), and sub-bottom profiler (SBP) will be utilised to locate natural and man-made objects on the sea bottom, identify geological formations, and determine sub bottom soil characteristics. Similar survey equipment will also be utilised during the installation works, in order to ensure the cables are properly installed. Routine post installation surveys will be utilised during the operational phase, in order to ensure the cables remain properly protected.

MBES is used to create detailed digital terrain models that can be used to define topography and assist in the planning the cable route identifying any constraints. The sound energy produced by a MBES is transmitted directly beneath the unit, in a fan shape. The return signal (echo) that has bounced off the seafloor or other objects is then analysed to produce the terrain model. MBES operates at a sound pressure level of approximately 215 dB re 1µPa at 1m with a peak frequency between 200-400kHz.

SSS is used to determine the texture, topography and character of the seabed sediments and to detect features such as boulders, outcrops, pipelines and other infrastructure lying on, attached to or buried immediately beneath the seafloor. The beam of sound energy produced by SSS is formed into the shape of a fan that sweeps the seafloor directly under the unit, and to either side, typically to a distance of 150m (depending on factors including water depth, and signal strength). The strength of the return echo is continuously recorded, creating a 'picture' of the sea floor. SSS operates in the frequency range 200 - 600kHz with a sound pressure level of between 200-210 dB re 1µPa at 1m.

SBP is used to investigate the shallow (generally < 10m) subsurface structure beneath the seabed, particularly with regard stratification, and soil densities. The SBP directs a focussed acoustic pulse toward the seafloor, parts of this pulse reflect off of the seafloor, while other parts penetrate the seafloor. The portions of the sound pulse that penetrate the seafloor are both reflected and refracted as they pass into different layers of sediment. It is likely that a Chirp SBP system will be used during the pre and post-installation surveys, which operates in a frequency range from 1kHz to 10kHz, with sound pressure levels of between 185-200dB re 1µPa at 1 m.

When compared to the marine mammal and fish hearing thresholds (Tables 23.1 & 23.3), it is clear that MBES and SSS bandwidths are out with the hearing capabilities of any receptor likely to be present in the vicinity of the Consenting Corridor, and hence will not be considered further in this assessment. The SBP however is within the hearing thresholds of both marine mammals and fish, and an impact range will be calculated for this source.

23.5.1.1.3 Horizontal Directional Drilling (HDD)

HDD will be used to link the onshore and marine elements of the cable route, passing underneath the sea cliffs at the UK landfall, to the marine HDD exit which is located approximately 200m from the shore, in 25m of water depth. A land-based rig will be used to drill the HDD ducts from the cliff tops out to sea.

Nedwell et al. [2012] details the findings of underwater noise monitoring conducted during HDD operations in a shallow riverine environment, while drilling was taking place directly below the riverbed. The environment was quiet, with no other potential noise sources, and the resulting underwater noise levels are reported as 129.5dB re 1µPa on the riverbed. The reported sound pressure levels can be considered comparable to those from the proposed NorthConnect HDD operation, and are within the range of the baseline noise levels expected in the area, as detailed in section 23.4. Due to the very low noise levels expected for the HDD operation, this source will not be considered further in this assessment.

23.5.1.1.4 Cable Burial

Once the HVDC cables are laid on the sea bed, they will be buried in order to provide protection from both anthropogenic and natural risks. A variety of tools may be used to bury the NorthConnect HVDC cables, including ploughs, jet trenchers and mechanical trenchers. Little empirical data is available for noise emission levels resulting from cable burial works, due to the fact that the potential impacts of such operations are generally considered to be minimal and hence construction noise monitoring is not a priority [Meißner et al., 2006].

Noise monitoring was conducted during the installation of the offshore transmission cable for the North Hoyle wind farm using a mechanical trencher. The source noise levels were reported to be 178dB re 1µPa at 1m, with a mixture of broadband noise, tonal components, and transients associated with rock breakage. The noise levels were highly variable, and were directly related to the seabed type [Nedwell et al., 2003]. This level is broadly similar to the noise resulting from dredging works (considered by other projects to be a similar activity to cable trenching), which is reported as between 172 - 185dB re 1µPa at 1m [NSN Link Limited, 2014; Richardson et al., 1995; & Xodus, 2014]. The broadband cable installation noise is within the hearing thresholds of both marine mammals and fish, hence an impact range will be calculated for this source.

23.5.1.1.5 Installation of External Protection

External protection will need to be installed over the cable in areas where it cannot be trenched, such as existing infrastructure crossings, and areas of hard ground where trenching cannot be achieved. External protection involves constructing rock berms over the cable (rock placement), or installing other materials such as concrete mattresses or grout bags. Rock placement is considered to be the nosiest external protection method, since the rocks fall down a fall pipe from the rock placement vessel, which may result in underwater noise. Other external protection measures such as mattresses and grout bags will be placed using an ROV or crane, and as such are unlikely to result in any significant underwater noise, so will not be considered further.

Noise monitoring was conducted of the rock placement vessel M/V Rollingstone, while she was working in Yell Sound [Nedwell & Edwards, 2003]. The Rollingstone is capable of placing rock to depths of 600m, and is representative of the rock placement vessels likely to be utilised in the Consenting Corridor. It was found that the noise of rock placement was not detectable over the vessel noise, since there was no determinable difference between measurements taken when rock placement was ongoing, and when the vessel was holding station without placing rock [Nedwell & Edwards, 2003]. Therefore, the noise from rock placement is accounted for under the assessment of vessel noise, and will not be considered further.

23.5.2 Operation and Maintenance

Since the NorthConnect Interconnector will utilise direct current for power transmission in the marine cables, no underwater noise will result from the normal operation of the cable. Periodic surveys, and repairs to the cable will be required, however this will involve similar activities to those detailed for the installation phase, although in much more limited areas. As such no separate assessment will be conducted for the operation and maintenance of the marine cables.

23.5.3 Decommissioning

The removal of the cable from the seabed will not require any equipment or techniques that have the potential to generate greater underwater noise emissions than those considered above. As such the acoustic impact ranges resulting from decommissioning will be equal to or lower those resulting from construction.

23.5.4 Impact Range Calculation

The maximum predicted source noise levels resulting from the installation and operation of the NorthConnect marine HVDC cables have been used together with the effect criteria exposure limits, and noise dissipation model, in order to calculate the maximum predicted impact ranges for marine mammals and fish. The results are summarised in Table 23.5.

Table 23.5. Maximum predicted impact ranges on marine mammals and fish resulting from underwater noise associated with the installation and operation of the marine HVDC cables.

Noise Sensitive Receptor	Effect Criteria	Exposure Limit (dB re 1 µPa)	Maximum Predicted Impact Ranges			
			DP Vessel Noise	Non-DP vessel Noise	Sub Bottom Profiler	Cable Burial
			Source Level 197dB re 1µPa	Source Level 180dB re 1µPa	Source Level 200dB re 1µPa	Source Level 185dB re 1µPa
Marine Mammals	PTS Onset - Cetaceans	230	*Effect Criteria Exposure Limit Not Reached*			
	PTS Onset - Seals	218	*Effect Criteria Exposure Limit Not Reached*			
	TTS Onset - Cetaceans	224	*Effect Criteria Exposure Limit Not Reached*			
	TTS Onset - Seals	212	*Effect Criteria Exposure Limit Not Reached*			
	Disturbance - All Groups	160	293m	22m	464m	46m
Fish	Physical Injury	206	*Effect Criteria Exposure Limit Not Reached*			
	Behavioural Disturbance	150	1359m	100m	2154m	215m

None of the noise sources associated with the installation or operation of the NorthConnect marine HVDC cables are predicted to exceed the injury criteria exposure limits for marine mammals or fish. Therefore, the underwater noise associated with the NorthConnect project poses no risk of injury to marine mammals or fish. However, the exposure limits for disturbance are exceeded for both marine mammals and fish.

For marine mammals, the maximum predicted disturbance range is 464m, resulting from the sub bottom profiler. DP vessel noise results in the next largest disturbance range of 293m, while the noise resulting from the cable burial and non-DP vessel activities have very small predicted disturbance ranges of 46m and 22m respectively.

The exposure limit for disturbance in fish is 10dB re 1µPa lower than that for marine mammals, as such the impact ranges are greater. The sub bottom profiler has the potential to disturb fish to a range of 2154m from the source, while the DP vessel noise has a maximum predicted disturbance range of 1359m. Cable burial and non-DP vessel activities could cause disturbance to maximum ranges of 215m and 100m respectively. It is noted that the 150dB re 1µPa exposure limit for fish disturbance is widely disputed, and considered to significantly over estimate fish sensitivity to noise [Popper et al., 2014]; therefore, these disturbance ranges are likely to be an extremely conservative over estimate.

23.6 Cumulative Effects

Details of the marine projects which could result in cumulative underwater noise effects are provided in Chapter 6. The underwater noise levels and resulting maximum impact range of 2.2km associated with the installation and operation of the NorthConnect HVDC cables are not great enough to result in any cumulative effect with these projects.

23.7 Summary of Effects

The predicted underwater noise emissions from the installation and operation of the NorthConnect marine HVDC cables do not pose any risk of injury to marine mammals or fish, however they do have the potential to cause disturbance to both. The greatest disturbance ranges result from the SBP, which could disturb fish to a range of 2.2km, and marine mammals to 0.5km.

The next largest disturbance ranges result from DP vessel thruster noise, which could disturb fish to a range of 1.4km, and marine mammals to 0.3km. It should be highlighted that the DP vessel thruster noise resulting from the NorthConnect project is set against the of the background of the North Sea oil and gas activities; DP vessels are utilised regularly by the oil and gas industry to support the offshore infrastructure in the North Sea. The Consenting Corridor passes through an area with numerous oil and gas assets, so DP vessels will regularly operate in the vicinity of the corridor, so this noise source is unlikely to be considered a significant change from baseline conditions.

The disturbance ranges resulting from the Cable installation works, and the non-DP vessel noise are all below 0.2km and hence are unlikely to result in any significant impact to marine mammals or fish.

23.8 References

Ainslie, M. A., de Jong, C. A. F., Dol, H. S., Blacquière, G. and Marasini, C., 2009. Assessment of natural and anthropogenic sound sources and acoustic propagation in the North Sea. TNO-report TNO-DV 2009 C085.

Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G., & Thompson, P. M., 2010. Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. Marine pollution bulletin, 60(6), 888-897.

McDonald, M.A., Hildebrand, J.A., Wiggins, S.M., Ross, D., 2008. A 50-year comparison of ambient ocean noise near San Clemente Island: a bathymetrically complex coastal region off Southern California. J. Acoust. Soc. Am. 124, 1985–1992.

Meißner K, Schabelon H, Bellebaum J, and Sordyl H, 2006. Impacts of submarine cables on the marine environment: a literature review. Federal Agency of Nature Conservation/ Institute of Applied Ecology Ltd.

Merchant, N. D. *et al*. 2016. Underwater noise levels in UK waters. *Sci. Rep*. **6**, 36942; doi: 10.1038/srep36942.

Nedwell J., & Edwards B., 2004. A review of the measurements of underwater man-made noise carried out by Subacoustech Ltd 1993 – 2003. Subacoustech 134.

Nedwell J., Langworthy J., & Howell D., 2003. Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore wind farms, and comparison with background noise. Report No. 544 R 0424.

Nedwell, J. R., Parvin, S. J., Edwards, B., Workman, R., Brooker, A. G., & Kynoch, J. E., 2007. Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters. Subacoustech Report to COWRIE Ltd.

Nedwell, J.R., Brooker A.G., and Barham R.J., 2012. Assessment of Underwater Noise During the Installation of Export Power Cables at the Beatrice Offshore Wind Farm. Report No. E318R0106.

NSN Link Limited, 2014. Norway - UK Interconnector. UK Marine Environmental Statement. National Grid.

Popper A N, Hawkins A D, Fay R R, Mann D A, Bartol S, Carlson T J, Coombs S, Ellison W T, Gentry R L, Halvorson M B, Løkkeborg S, Rogers P H, Southall B L, Zeddies D G, Tavolga W N, 2014. Sound Exposure Guidelines for Fishes and Sea Turtles. Springer Briefs in Oceanography, DOI 10. 1007/978-3-319-06659-2.

Richardson, W.J., Fraker, M.A., Wuersig, B., and Wells, R.S., 1995. Behaviour of bowhead whales, *Balaena mysticetus* summering in the Beaufort Sea: Reactions to industrial activities. Biological Conservation, 32: 195-230.

Robinson, S., Theobald, P., Hayman, G., Wang, L., Lepper, P., Humphrey, V., & Mumford, S. 2011. Measurement of noise arising from marine aggregate dredging operations. MALSF, 978 (0907545), 57.

Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., ten Cate, C., Popper, A.N., 2010. A noisy spring: The impact of globally rising underwater sound levels on fish. Trends in Ecology and Evolution 25 (7), 419–427.

Southall B. L., Bowles A. E., Ellison W. T., Finneran J. J., Gentry R. L., Greene Jr. C. R., Kastak D., Ketten D. R., Miller J. H., Nachtigall P. E., Richardson W. J., Thomas J. A., and Tyack P. L., 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33, 411 - 521.

Talisman Energy (UK) Ltd, 2006. Noise impact assessment for Beatrice Demonstration Wind Farm.

Theobald, P., Pangerc, T., Wang, L., & Lepper, P. 2013. Environmental Statement Chapter 13 Appendix H - NPL Underwater Noise Technical Report.

Walker T., Adebambo O., C Del M., Feijoo A., Elhaimer E., Hossain M.T., Johnston Edwards S., Morrison, C., Romo J., Sharma N., Taylor, S., & Zomorodi, S., 2018. Environmental Effects of Marine Transportation. 1-27. 10.1016/B978-0-12-805052-1.00030-9.

Wyatt, R., 2008. Joint Industry Programme on Sound and Marine Life Review of Existing Data on Underwater Sounds Produced by the Oil and Gas Industry - Issue 1. Ref. S186.

Xodus, 2014. Marine noise inputs. Technical Note on Underwater Noise for Statoil’s Hywind Project.