SCOTTISH EXECUTIVE

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Note: This document is only a section of the Final Environmental Report

Scottish Marine Renewables SEA
Environmental Report Section C SEA Assessment: Chapter C17 Noise

Scottish Executive
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Glossary & Abbreviations

Anthropogenic	Originating from human sources or activities
Cetacean	A member of the order Cetacea, which consists of mammals most adapted to a marine environment: Whales, Dolphins and Porpoises.
COWRIE	Collaborative Offshore Wind Research into the Environment - an independent company which aims to increase understanding and awareness of the potential environmental impacts of the UK offshore windfarm programme.
dB	Decibel
DRC	Dose response criteria
DTI	The Department of Trade and Industry
EIA	Environmental Impact Assessment
Farfield	Distances that are large compared to the dimensions of the sound source
Frequency	The number of sound pressure fluctuations per second
Hz	Hertz – The unit of measurement used to express frequency
KHz	Kilohertz
Km	Kilometer
Knot	a unit of water or air speed ideally equaling 1 nautical mile per hour, depending on the relative motion of the medium
m	Metre
MCT	Marine Current Turbines
MW	Megawatt
NAWR	Noise at Work Regulations
OPD	Ocean Power Delivery
Propagation	The act or process by which a disturbance, such as the motion of electromagnetic or sound waves, is transmitted through a medium such as air or water.
PTS	Permanent threshold shift – irreversible, physiological damage to the inner ear which results in permanent, partial hearing sensitivity loss
QinetiQ	Private company with expertise in noise and acoustics.
SPL	Sound pressure level
Swim bladder	An organ found in most fish species which enables them to control their buoyancy.
Topography	The three-dimensional arrangement of physical attributes (such as shape, height, and depth) of a land surface.
TTS	Temporary threshold shift - physiological damage to the inner ear which results in temporary and partial hearing sensitivity loss.
μPa	Micro pascal – a unit commonly used to quantify underwater noise

C17 Noise

C17.1 Introduction

This chapter of the report is dealt with in a different manner to the majority of the other chapters of Section C – The Level 1 Assessment. This is because the potential effect of noise emissions is generally gauged based on their effects on receptors such as fish and marine mammal species. Therefore, this section of the report is structured as follows:

- Baseline environment - ambient/background noise
- Device installation noise emissions and impact review
- Device operation noise emissions and impact review

The information in this chapter of the report informs the impact assessments for fish and marine mammals (Chapters C7 and C9 respectively).

There are a range of information sources. These include:

- work done for the DTI's SEA programme for oil and gas development
- the outputs of the Collaborative Offshore Wind Research Into the Environment (COWRIE) programme
- work done under the DTI's Energy Technology Support Unit Programme (ETSU), and
- a specialist study undertaken by QinetiQ specifically for this SEA project to investigate the ambient noise in the SEA study area and the noise emitted by arrays of operational devices.

It should be noted that, whilst the available information on noise emissions and impacts is useful and informative, much of it is not in directly comparable formats and there is not a consistent level of information available across all noise sources and receptor sensitivities.

Specifically, the units in which noise emissions are measured or described vary considerably depending on the characteristics of the sound emitted and effect that is being assessed. Good explanations of the issues associated with the measurement of underwater sound are given in "A Review of Offshore Windfarm Related Underwater Noise Sources" by Nedwell and Howell, 2004 and "Effects of Offshore Windfarm Noise on Marine Mammals and Fish" by Thomsen et al., 2006. Therefore, in the below text, units of measurement are specified wherever available.

It is normal to express sound levels in terms of decibels (dB). The decibel relates the measurement of noise to a reference unit and it expresses the ratio between the reference unit logarithmically. The reference unit for marine/underwater noise is typically 1 microPascal (1μPa) (Nedwell et al., 2003).

Sound (in dB) is often made up of various frequency components and therefore it is typical to note the frequency range that applies to a specific sound level. Frequency is the number of sound pressure fluctuations per second (Vella, et al., 2001) and the unit of measurement is the Hertz (Hz).

Receptors are sensitive to both sound pressure levels (expressed as dB re 1μPa for underwater noise) and the frequency of the sound (expressed as hertz (Hz) or kilo-hertz (kHz)).

C17.2 Baseline Environment - Ambient /Background Noise

A specialist study was commissioned by the Scottish Executive and undertaken by QinetiQ to inform this aspect of the SEA project. The information presented in this section is a summary of the full report which can be found in Appendix C17.A.

C17.2.1 Noise Sources in the SEA Study Area

Ambient (or background) noise can be made up of either natural (e.g. wind noise) or anthropogenic sources (e.g. shipping). These sounds combine to give a continuum of noise against which all acoustic receivers have to detect the signals they are looking for. Both natural and anthropogenic ambient noise can affect bioacoustic receivers. Therefore this section of the report gives an overview of the different contributors to ambient noise in the SEA study area. This information is important in determining the baseline environment against which noise emissions from installation and operation of marine renewable energy devices can be assessed.

The potential sources of ambient noise in the SEA study area are summarised below.

Table C17. 1: Potential Contributors to Ambient noise in the Study Area

Source	Indicative Frequency Range	Comments
Wind-sea noise	500Hz – 25kHz	Noise levels are dependant upon local wind speed.
Precipitation noise	1 – 100kHZ	In the winter months precipitation is likely to be a significant contributor to ambient noise
Shore and surf noise	1 Hz – 1000kHz	Shore and surf noise is likely to be a major contributor to ambient noise in coastal areas in the SEA study area - particularly at coastlines that are exposed to large waves such as the west coast of the Western Isles, Orkney and Shetland, the Fair Isles, the St Kilda Group and Flannan Isles.
Sediment transport noise	Mostly above 10kHz	Sediment transport mainly occurs in the intertidal zone but can also occur away from the coastline.
Commercial Shipping	50 – 300 Hz for large ships	Shipping noise is typically the dominant contributor to ambient noise in shallow water areas and close to shipping lanes in the study area. At higher frequencies than 300 Hz, the sounds of individual ships merge into a background continuum. At higher frequencies the dominant noise source is likely to be wind generated noise. In the shallower waters (e.g. tens of metres) of the SEA study area the water is too shallow to support long-range propagation of the very low frequencies. Different types of ships give different noise contributions from different sources. For a fast ferry the main source of noise is from the displaced water and the machinery. For a small coaster, virtually all of the noise is from the propulsion machinery.
Leisure craft	Various	Largely confined to coastal waters. In tourist areas it can be the dominant source of sound through the summer months.
Industrial noise: Offshore	Various	Includes noise generated from offshore wind farms, construction and oil and gas developments. There are no such developments in the sea study at present, but under the appropriate conditions (e.g. presence of a strong surface duct (see section C17.2.2 for a definition) with a calm flat surface) sound could propagate into the SEA study area.
Industrial noise: Onshore	<100Hz	Potential sources include traffic noise from roads or railways and quarry blast noise. Coupling through the substrate into the marine environment will generally only occur at low frequencies (i.e. less than 100 Hz).

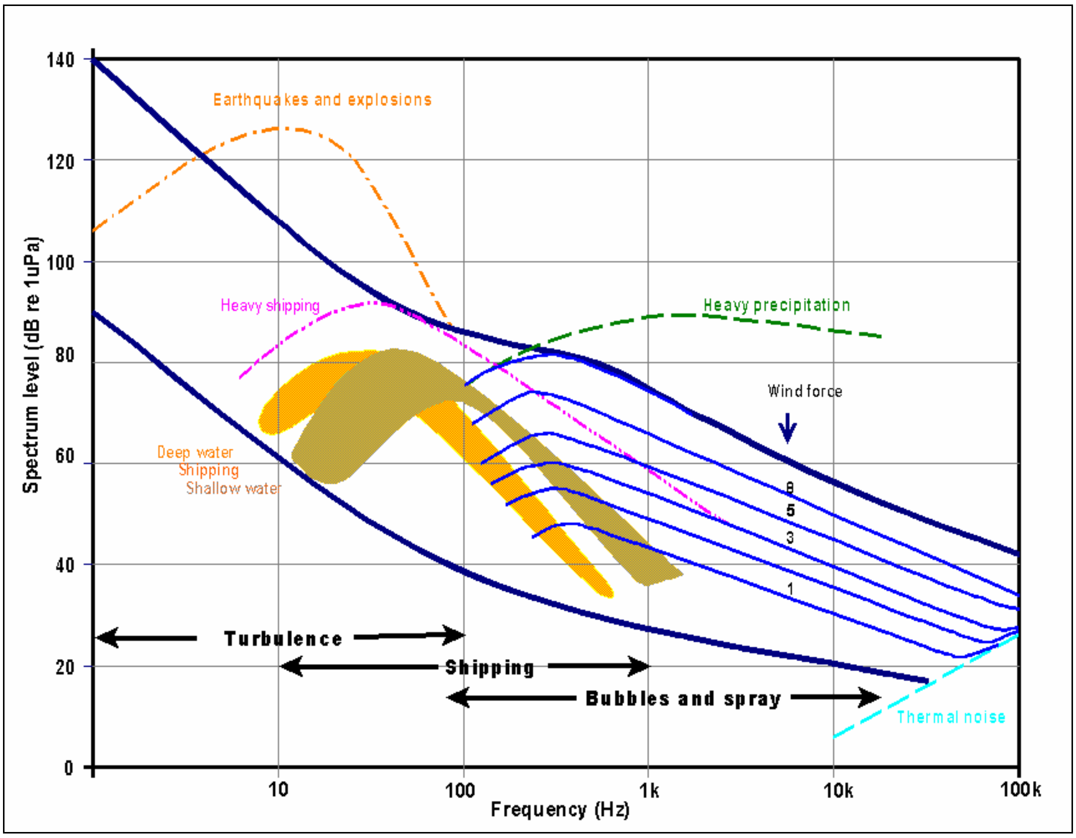
Source	**Indicative Frequency Range**	**Comments**
Military noise	Various	Military activities and exercises occur across the study area and noise sources include firing and bombing practice. Military shipping is generally very quiet and will only make a small contribution to overall shipping noise. Military sonar is covered below.
Sonar*	Echosounder: 26 kHz – 300kHz	Used by small leisure craft up to the largest commercial ships. The higher frequencies are attenuated over short distances by absorption but their contribution to ambient noise is significant due to the high numbers of such units.
	Fishing sonar: Lower frequencies than those for general echosounders noted above.	Their contribution is mainly restricted to fishing grounds, which can also be sensitive areas where there is a high density of fish and cetaceans.
	Acoustic modems: 2 -20kHz	Used to carry data from seabed installations to the surface. Likely to be used at discrete locations throughout the study area.
	Air guns: Centre frequency between 50 – 100 Hz	Used for seabed geological/geo physical survey work
	Military sonar: 1 – 300kHz	High frequencies above 80 kHz are used by mine hunters and the high acoustic absorption coefficient of seawater at such frequencies means that any impact is limited to a very small area around the ship, typically less than 3 km. Lower frequencies (<3 kHz) are used in the deeper waters and can fill a whole ocean basin with sound. In the shelf region to the west of the Hebrides, medium frequencies are most likely to be used (3 to 10 kHz).
Aircraft noise	Various	Aircraft noise from coastal airports such as Benbecula and noise from helicopters servicing oil and gas rigs may be locally significant.
Fishing Activity	Vessel: Less than 1 kHz	Noise can come from vessel, sonar or gear noise (e.g. trawl noise). No published information is available on noise levels/frequency ranges for fishing gear.
Biological Noise	Sperm whale echolocation: 2-40 kHz Bottle nose dolphin echolocation: 80 – 120 kHz Cetacean tonals: 2 – 25 kHz Harbour porpoise echolocation: 130 kHz	Fish, cetaceans and seals can all produce sound. Cetacean sounds are either tonal whistles in the range 2 to 25 kHz, or wideband echolocation clicks with maximum energy in the 40 to 140 kHz region. Seals are also very common in the waters around the Hebrides and northern islands, and, although not as vocal as the cetaceans, can make a significant contribution to ambient noise at certain times of the year, particularly during the breeding season (July to August) when the male harbour seals emit a broadband roar
Thermal Noise	More than 100kHz	Caused by thermal motion of molecules. This sound source is only relevant in the absence of all other sound sources.

Frequencies noted are those that are monitored. In respect to seismic survey, airguns will include frequencies outside of those monitored.

Figure C17.1 below gives a good indication of composite ambient noise spectrums in deep waters to the west of the SEA study area. However, in the shallower waters of the SEA study area the water is too shallow to support long-range propagation of the very low frequencies. Therefore, ambient noise at these frequencies will generally be lower than these curves suggest. Above about 100 Hz (depending on water depth) Figure C17.1 does give a good approximation of noise spectra away from the coastline.

Close to the coast, particularly around the Scottish islands, the ambient noise is likely to be modified by the shielding effect of the islands and the contribution from very local noise sources such as surf noise.

Figure C17. 1: Composite ambient noise spectrum



Adapted from Wenz, 1962

Figure 17.2(which accompanies this chapter) illustrates the geographical extent of dominant ambient noise sources in the SEA study area when there is little or no wind and precipitation. When weather conditions deteriorate, wind and precipitation noise will dominate over most of the study area and the region in which shore and surf noise dominates will extend further offshore. Additionally, some of the sea lochs will have very low levels of ambient noise when there is little or no wind or precipitation, and dominant contributions here are likely to be natural background noises, including biological sounds.

It should be noted that just because a particular noise source is dominant in a given area it does not necessarily mean that other sources may be neglected in that area. The total noise level from all sources may be significantly higher than the level due to the dominant source alone; different sources may dominate in different parts of the spectrum; and bio-receptors may be more sensitive to a less dominant noise source in a different frequency range.

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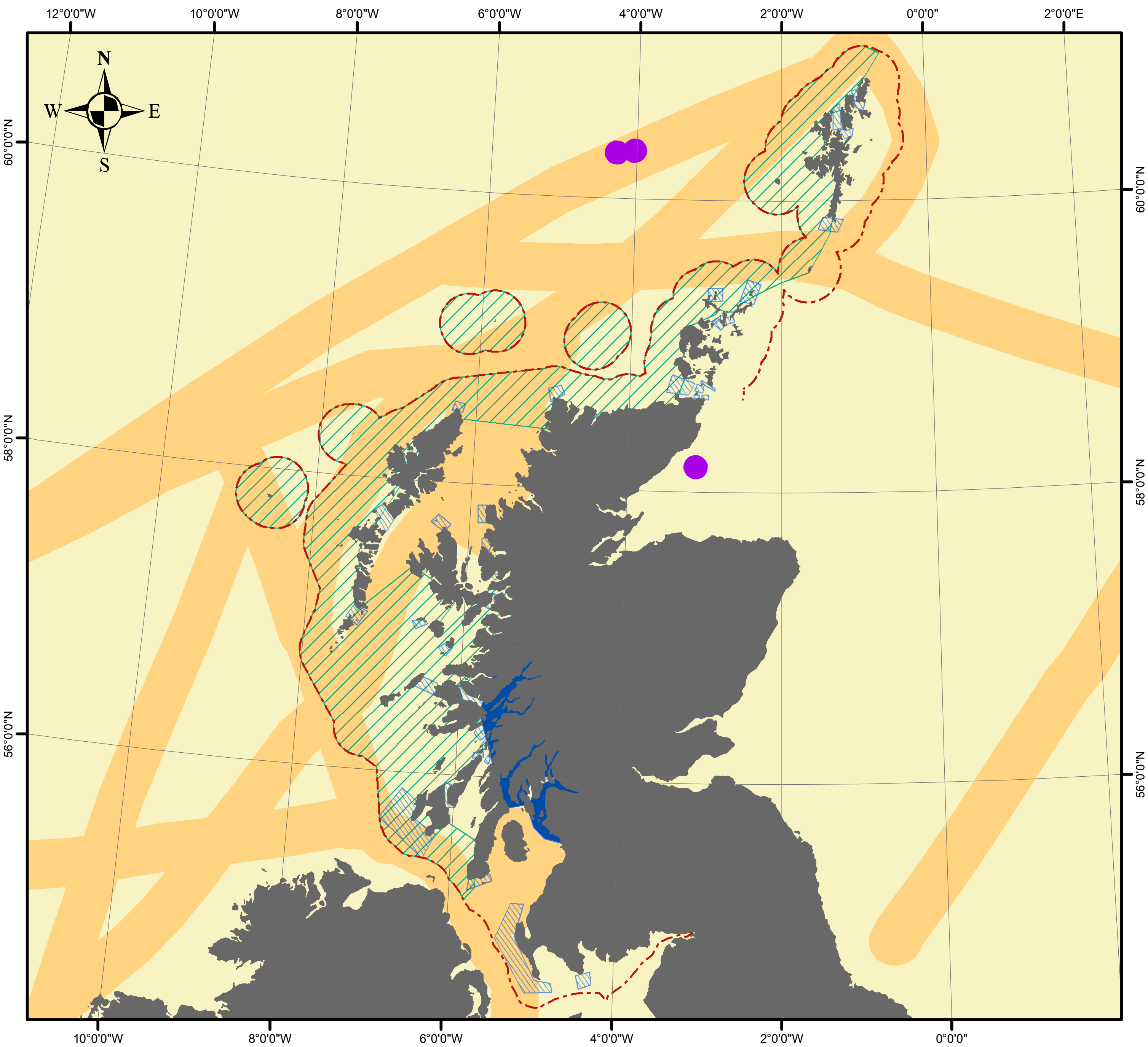
Figure C17.2 :Ambient Noise



Legend

- Shore and surf noise
- Industrial noise
- Loch noise
- Local shipping (>40,000 tons)
- Distant shipping

Potential development area

- Tidal resource
- Wave resource
- 12 Nautical mile limit (study area only)
- Land

Note: This map shows the dominant noise sources in the study area when there is little or no wind and precipitation. When weather conditions deteriorate wind and precipitation noise will dominate over most of the area and the region in which shore and surf noise dominates will extend further offshore.

Kilometeres
0 25 50 100 150 200

Date	17 January 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	SeaZone Solutions Ltd; QinetiQ	
File Reference	P736\GIS\Mxd\Scoping report\	
Checked	RM	GIS Specialist
	FLB	Project Manager

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C17.2.2 Ambient Noise Field Modifiers

Propagation - The propagation of sound in water can vary based on salinity, temperature, pressure and seabed type. Variations in salinity are generally very small, except perhaps at the mouth of major rivers, and pressure variations are due almost entirely to depth so temperature variations have the major effect on sound propagation in shallow water.

Under some conditions, a mixed isothermal layer forms close to the sea surface as a result of mixing initiated by waves and turbulence. The existence of a mixed layer, and its thickness (typically 25 m to 200 m), depend upon atmospheric factors such as the wind stress at the surface and the heat flux across the surface, and on fresh water exchange. The mixed layer acts as a surface duct which may trap the acoustic signals, because the sound speed profile within the duct tends to refract sound upwards and the surface acts as a reflector. A source and receiver located within this surface duct experience significantly less propagation loss than when there is no surface duct. During the day, the sea surface can heat up and introduce a temperature gradient close to the sea surface that causes downwards refraction of underwater sound and hence increased propagation loss for a receiver in the surface layer.

Because sound can interact strongly with the seabed, the sediment types and seabed roughness can affect propagation loss. For example, hard seabeds reflect noise effectively whereas soft silty or muddy sea beds absorb noise.

Similarly, waves on the surface can also affect propagation loss by scattering the sound interacting with the surface rather than just reflecting it.

Suspended sediments or bubbles can cause additional propagation loss.

Propagation loss varies on a diurnal basis, particularly during the early summer, and on an annual cycle, as the air temperature variations through the year warm and cool the water. A period of sustained strong wind can also disrupt the temperature structuring.

Multipath effects – Due to the surface and seabed reflections, sound can travel between a source and receiver by a multitude of paths. This has the effect of dispersing the arrived signal in time. This effect is particularly important for wideband (i.e. over a large frequency range) impulsive sounds such as explosions, pile driving or seismic exploration air guns. If any of the propagation effects are frequency sensitive then frequency dispersion will also occur. A common example of this is the sound of air guns operating at distances of 30 to 50 km from a receiver in which the low frequencies travel more slowly than the high frequencies so the single impulse at the source turns into a pronounced frequency sweep at the receiver. The effect of time dispersion is to reduce the peak energy in the received signal. The integrated level is unchanged by time dispersion, but the peak levels can be significantly reduced. When considering the contribution to ambient noise levels this can be an important factor. For narrowband signals, the effects of multipath propagation can cause large fluctuations in the received signal level.

Source and receiver depth - The vertical sound speed structure described above can lead to significant variations in the propagation loss between a sound source and the receiver as the depth of the source and/or the receiver is varied. The most extreme example is the surface duct where a shadow zone may form under the duct. Within the shadow zone levels from a distant sound source in the duct are much reduced compared with the level from the same source within the duct.

Tides - In the deep waters to be found to the west of the SEA area, the variations in depth at a given location due to tides are insignificant. However, in inshore waters the effect is much more pronounced and can significantly alter ambient noise fields through the tidal cycle.

Sand banks that dry at low water can also break acoustic paths so a receiver hearing a loud noise source across a sand bank at high tide may not receive it at low tide.

C17.2.3 Ambient Noise Study

The variety of types of water body (e.g. small inter-island channel, wide inter-island channels, open sea, sea lochs) in the SEA study area indicate that ambient noise is likely to be highly variable both in terms of the contributors to ambient noise and the factors that affect the propagation of sound.

When there is little or no wind, the shoreline areas of the study area will be dominated by shore and surf noise and the areas directly offshore of the coastline are likely to be dominated in many areas by shipping noise. The “quietest” areas of the study area are likely to be remote sea-lochs where biological sounds may be significant. No sources of offshore industrial noise have been identified in the study area but in specific environmental conditions the sound from these sources outside of the SEA study area may influence the ambient noise in the study area.

In addition to the various contributors to ambient noise in the study area ambient noise can also be affected by “modifiers”. The key modifiers and their potential effects in the SEA study area are summarised below:

- Propagation of sound can vary based on salinity, temperature pressure and seabed type. Propagation loss can also be increased by increased levels of suspended sediment and bubbles, and is affected by seabed types – hard sea beds (e.g. rock) are reflective whereas soft sea beds (e.g. mud or silt) absorb sound.
- Sound can travel by multiple paths and therefore sound signals can be dispersed in time affecting the frequency and sound level detected by a receiver.
- Topography can also alter propagation – islands can act as barriers to sound preventing it from propagating further out to sea.

All of the available information suggests that specific ambient noise studies will be required for individual project developments to give an indication of the baseline with regards to ambient noise, so that the impacts of device installation and operation noise can be accurately assessed.

C17.3 Construction Noise

The key sources of noise related to site preparation and device installation are broadly similar to those investigated for offshore wind farm construction – namely:

- Shipping and machinery
- Dredging
- Pile driving or drilling

Additionally, cable burial requires the use of trenching or jetting machinery in soft sediments, rock cutting machinery in hard sea-beds, or rock or concrete matress laying may be used to protect cables in areas where they cannot be buried.

Of all of the sources of noise noted above the noise emitted during pile driving is understood to have the greatest potential effects on marine wildlife (Thomsen, et al., 2006). This is due to the fact that pile driving generates very high sound pressure levels over a relatively broad frequency range (20 Hz - > 20 kHz; Madsen et al, 2006).

The most up-to-date information on noise associated with these sources (which has been drawn from a range of industries) has been assessed and drawn together in a recent study undertaken by Biola (Thomsen, et al., 2006) into the effects of offshore wind farm noise on marine mammals and fish. The COWRIE project commissioned a translation of this report into English so that it could inform the UK offshore wind industry.

This report provides the most recent review of studies undertaken in this area of research and focussed on the impacts upon a limited number of key marine mammal and fish species. Species for investigation were selected based on a series of factors including their status (e.g. protected status and distribution/abundance across the UK in areas of interest for wind farm development), their sensitivity, and availability of information and data. The species selected were harbour porpoise, harbour seals, cod, dab, salmon and herring.

In addition to the recent report noted above, COWRIE have commissioned several studies to investigate the impact of noise and vibration from the offshore wind industry (Nedwell. Et al. 2003, Nedwell and Howell, 2004). These reports draw on a wide range of subsea noise research, much of which has been carried out for sectors other than the offshore wind and marine renewable energy industry.

The information in sub-sections C17.3.1 to C17.3 .3 below draws mainly on the latest noise study (Thomsen, et al., 2006), with further input from other sources as appropriate.

C17.3.1 Review of Available Information

Following a review of the available information on impact piling, the most recent available study (undertaken by Biola and recently translated by the COWRIE project) used sound measurements from a 1.5 m diameter jacket-pile construction in the German Bight (water depth 30 m, sandy bottom, 60 beats per minute) to model the potential noise emissions from driving a 3.5 m pile (which is more representative of the diameter of wind farm/marine energy device piles). Mono-piles for wind turbines or marine energy devices are typically 20 – 30 m long and it usually takes approximately one to two hours to drive a pile into the seabed. Piles can be installed either by piling in soft sediments or a combination of piling or light hammering and drilling in harder sediments such as clays or rock. The level of piling noise is highly dependent on pile size and length (Nedwell et al., 2003) and substrate type (typically soft substrates absorb noise, whereas hard substrate types reflect noise).

Typically there are only relatively thin veneers of sediment over the bed rock in the SEA study area (see chapter C2 for details of the geology of the SEA study area) and therefore it can be assumed that often a combination of piling or hammering and drilling will be needed for devices that require piling for installation.

It should also be noted that piling is not required for many types of device as they can be secured to the seabed by an arrangement of anchors or a gravity structure (see Section B for further details on device installation methods).

Construction of a marine energy device array involves a considerable amount of shipping activity to transport parts, equipment and personnel to and from site. Sound pressure levels from ships are considerably lower than those from pile driving (Nedwell & Howell, 2004) and therefore the effects of pile driving are likely to overshadow the effects of ship noise during installation (Tomsen et al. 2006). However, ship noise may be an issue for maintenance activities undertaken during operation of the devices, particularly if the area has previously been subject to very little shipping. The source level of shipping noise assumed for the latest COWRIE assessment was 160 dB_{rms} re 1µPa at 1 m at 250 Hz and 150 dB_{rms} re 1µPa at 1 m at 2 kHz. These third octave band[1] sound levels were selected based on the two frequencies relevant for porpoises and seals.

There is little available information on noise emissions from drilling of piles, rock or mattress placement, installation of gravity bases or cable trenching in similar environments to which marine renewable energy devices are likely to be installed. However, the small amount of information that is available suggests that noise emissions for these activities are below those for pile driving (Nedwell & Howell, 2004). A summary of the level of understanding with regards to the impacts of these noise sources is presented in section C17.3.3 below.

[1] It is common to plot frequency ranges as bands of frequencies. 3 * 1/3 octave bands cover the same range as a single octave band therefore giving better frequency resolution.

There have been some suggestions that underwater explosives may be required for clearance of sites during decommissioning of device arrays but there is currently no available information on decommissioning plans for device arrays. If explosives are not used then the key source of noise will be from cutting equipment which is considered to be less noisy than piling (RPS, 2006). Impacts and issues associated with decommissioning are discussed in Chapter C21 – Decommissioning.

C17.3.2 Species Sensitivity to Noise

As discussed above, the latest work undertaken by Biola focussed on two species of marine mammals – harbour porpoise and harbour (or common) seals – drawing together information on species sensitivities from wide range of studies. Both species are widely distributed throughout the SEA study area (Hastie & Wilson, 2006) and have wide-ranging hearing abilities and sensitivities. The wide-ranging hearing abilities with regards to sound levels and frequencies, and the wide distribution throughout the study area of harbour seal and porpoise, provide a good strategic-level overview of the envelope of impacts of installation noise upon marine mammals (an overview of different marine mammal species sensitivity to noise is presented in Chapter C9 – Marine Mammals).

C17.3.2.1 Harbour Porpoise

Harbour porpoises are the most common cetacean species in European waters and rely heavily on sound for orientation and foraging. They have a very wide hearing range with relatively high hearing thresholds of 92 – 115 dB_{rms}[2] re 1 μPa below 1 kHz, good hearing with thresholds of 60 – 80 dB_{rms} re 1 μPa between 1 and 8 kHz, and excellent hearing abilities with thresholds of 32 – 46 dB_{rms} re 1 μPa between 16 and 140 kHz (Kastelein et al., 2002). These hearing abilities closely match sounds emitted by harbour porpoises which can be categorized as low frequency sounds (1.4 – 2.5 kHz) used for communication, sonar clicks (110 – 140 kHz) used for echolocation, low energy sounds (30 – 60 kHz), and broadband signals (13 – 100 kHz) (Verboom and Kastelein, 1995). However, it should be noted that there are no studies focusing on the lower part of the frequency spectrum for harbour porpoises and therefore the sensitivity of harbour porpoises to low frequency sound is not known at this time.

C17.3.2.2 Harbour (Common) Seal

Harbour seals are also common in European waters. They communicate using low-frequency calls when diving and have a well developed under-water hearing system (Riedmann, 1990; Kastak and Schustermann, 1998). The hearing range for harbour seals extends over a very wide frequency range. The area of best hearing is between 8 and 16 kHz with acute hearing at lower frequencies (Schustermann, 1998). The work undertaken by Schustermann also indicates that below 1 kHz harbour seals are more sensitive than harbour porpoises.

C17.3.2.3 Fish

The hearing ability of fish varies greatly across species types. Typically, fish sense sound via particle motion in the inner ear which is detected from sound-induced motions in the fish's body. The detection of sound pressure is restricted to those fish which have air filled swim bladders; however, particle motion (induced by sound) can be detected by fish without swim bladders.

[2] Root-mean-square pressure level – root-mean-squared pressures divided by the duration of the signal.

Fish with swim bladders that are coupled by mechanical means to the fishes inner ear have high sensitivity to variations in sound pressure (they can detect sounds over 3 kHz with best sensitivity between approximately 300 to 1000 Hz (Popper et al., 2003)), and can be categorized as sound specialists.

Fish that do not have a mechanical method of coupling the sound induced motions in the fishes body with the inner ear have relatively low sensitivity (they can detect sounds up to 500 – 1000 Hz) with best hearing between approximately 100 and 400 Hz (Popper et al., 2003) to sound pressure variations. These types of fish can be categorised as sound generalists.

The work commissioned by COWRIE selected four different fish species, representative of different hearing capabilities and the range of fish found in the North Sea. A summary of the available information is presented in Table C17.2 below.

Table C17. 2: Selected Fish Species' Sensitivity to Noise

Species	Hearing Mechanism/Sensitivity to Sound	Indicative Hearing Frequency Range	Indicative Hearing Threshold	Comments
Dab (*Limanda limanda)*	Low sensitivity to sound – no swim bladder	30 – 250Hz	89 dB re 1µPa at 110 Hz	Representative of other flat fish species. (Source: Chapman and Sand, 1974)
Atlantic Salmon (*Salmo Salar*)	Poor hearing ability – swim bladder is disconnected from skull/hearing system	<380Hz	95 dB re 1µPa at 160 Hz	Salmon was selected for investigation due to its protected status under the Habitats and Species Directive. (Source: Hawkins and Johnstone, 1978)
Atlantic Cod (Gadus morhua)	More sensitive to sound than dab and salmon. Can detect particle motion and sound pressure to determine direction of sound (Schuif and Hawkins, 1983). Gas filled swim bladder is close in proximity to the inner ear (Hawkins and Johnstone, 1978)	Not well defined	75 dB re 1µPa at 160 Hz	Cod are more sensitive to sound than dab and salmon. (Source: Hawkins and Johnstone, 1978)
Atlantic Herring (*Clupea harengus*)	Good hearing ability – swim bladder terminates within the inner ear.	30Hz – 4kHz	75 dB re 1µPa at 100 Hz	(Source: Enger, 1967)

C17.3.3 Impacts of Construction Noise

The latest COWRIE study (Thomsen et al. 2006) drew several conclusions with regards to the impacts of pile driving noise on harbour porpoise and common seal, which are summarised in Table C17.3 below.

Table C17. 3: Impacts of Pile Driving Noise on Harbour Seals and Porpoise

Effect	Harbour Seal	Harbour Porpoise
Audibility	Zone of audibility would extend beyond 80 km (perhaps up to hundreds of km) from the source.	
Behavioural responses	Possible over many kilometres, up to approximately 20 km.	
Masking	May occur for distances of up to 80 km from the source.	Masking of echolocation due to pile driving is unlikely as piling pulses have little energy.
Hearing loss (permanent threshold shift)	May be a concern[3] at up to 400 m from the sound source.	May be a concern[3] at up to 1.8 km from the sound source.

It should also be noted that studies during the construction of the Horns Reef offshore wind farm (Denmark) indicated that harbour porpoises left the area or decreased their acoustic activity during piling activities (Tougaard et al. 2003). This would suggest that behavioural responses to the noise (i.e. moving away from the noise source) could reduce the occurrence of permanent threshold shift effects.

With regards to fish, the conclusions of the COWRIE work are summarised in Table C17.4 below.

Table C17. 4: Impacts of Pile Driving Noise on Selected Fish Species

Effect	Cod and Herring	Dab and Salmon
Audibility and masking	Able to perceive pile driving pulses (and masking may occur) at distances of up to 80 km	May be able to detect pile driving pulses at considerable distances from the source. Insufficient information to define zone of influence.
Hearing loss (permanent threshold shift)	Permanent and temporary threshold shifts may occur in close proximity to pile-driving for all fish species. Insufficient information to define zone of influence.	

With regard to shipping noise, the recent work commissioned by COWRIE suggests that for harbour porpoises the zone of audibility ranges from 1 – 3 km depending on the frequency of noise emitted by the ship (Thomsen et al. 2006). For harbour porpoises the zone of audibility was calculated to range between 3 and 20 km, and a zone of masking may occur at distances of up to 15 km.

It is important to note that pile driving pulses are of short duration and therefore may be below the time where full detection of signals is possible in porpoises (Thomsen et al., 2006) and fish. This is in contrast to drilling and shipping noise which occurs over long periods of time (i.e. several hours to several days).

Additionally, it should be noted that many marine renewable devices are not piled into the seabed, but are fixed by anchors or gravity bases. Therefore the noise from installation of those types of devices is likely to be different (and potentially less) than that presented for the pile driving noted above. The impacts upon marine mammals are also likely to be different than that presented above as piling noise is typically for a short duration and the sound is emitted in pulses rather than the continuum of noise associated with other installation activities. A summary of understanding with regards to the impacts of other installation activities is given in Table C17.5 below.

[3] from a regulatory perspective injury is of concern when the received broad-band sound pressure level exceeds 180 dBrms re 1μPa for cetaceans and 190 dBrms re 1μPa for pinnipeds (NMFS, 2003)

Table C17.5: Summary of Information on Installation Methods Other than Piling

Noise Source	State of Knowledge	Behavioural Response
Drilling	Several deep water measurements, no shallow water measurements. Large range of levels.	Reported response to play back tests. Cetaceans avoid area when received level is high. EIA for a single tidal device predicted negligible impacts on fish.
Gravity foundation installation	No available measurements	No available observations
Rock layering	One inconclusive measurement	No available observations
Trenching	Measurements were taken for cable trenching at North Hoyle offshore Windfarm.	Typically noise levels were below the level at which a behavioural reaction would be expected.
Jet Cutting	No available measurements	No available observations
Diver Tools	One set of measurements available covering: drills wrenches, bolt guns, grinder and jack hammer.	No available observations

Adapted from Nedwell and Howell, 2004

C17.4 Device Operation Noise – Sources

C17.4.1 General Approach

A specialist study was commissioned by the Scottish Executive and undertaken by QinetiQ to inform this aspect of the SEA project. The information presented in this section is a summary of the full report which can be found in Appendix C17.A.

At this stage in the development of marine renewable energy devices there is a lack of data on the noise emissions from operational devices and there are currently no arrays of devices installed in UK waters. Therefore an initial qualitative assessment was made of the sources of noise in marine renewable energy devices based on assessment of their mechanical and non-mechanical components. Further, more detailed, assessment was then carried out based on underwater noise measurements taken for a single pre-commercial scale tidal turbine device, and detailed review of the mechanical components and some in-air measurements made available for a single wave device. This part of the assessment also investigated the potential noise emissions from multiple device arrays. This was done numerically (using modelling), and involved making necessary assumptions including array geometry.

Finally impact assessment was undertaken based on the available information.

It should be noted that although available information on specific devices was used, the aim of the study undertaken was to give (as far as is possible with current levels of information) a generic overview of the potential noise emissions from operating devices and an envelope of potential effect. Due to the limited information available and the wide range of devices currently in development, it was deemed appropriate to take a relatively precautionary approach for many aspects of the work.

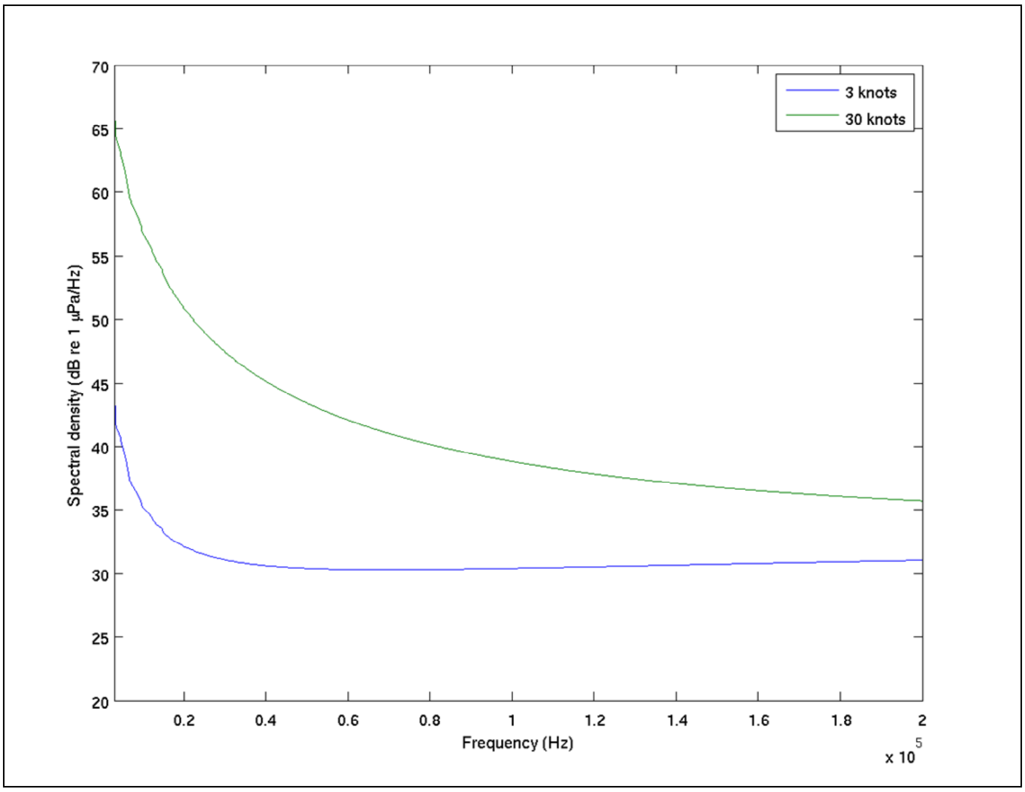
It is acknowledged that device specific assessments will be more refined and may present lower noise emissions and associated impacts.

C17.4.2 Ambient Noise Assumptions

To give an indication of the difference between ambient noise and device generated noise, the potential ambient noise in the SEA study area was modelled first. The model gave an indication of the noise generated by wind at the surface of the ocean, but did not include shipping, shore or surf noise.

Model predictions were carried out for a range of environments across the SEA study area including different water depths, sound speed profiles, seabed types and receiver depths (i.e. the depth at which the ambient noise spectrum is calculated). In analysing the results of the model runs it was found that the only parameter that significantly affected the ambient noise was wind speed. The results of the modelling study can therefore be summarized in Figure C17.3 below.

Figure C17. 3: Predicted Ambient Noise Levels in the SEA Study Area Owing to Surface-Generated Noise and Thermal Noise, for Wind Speeds of 3 knots and 30 knots



Source: Underwater Noise Study Supporting the Scottish Executive Strategic Environmental Assessment for Marine Renewables, QinetiQ, January 2007

The above graph does not include noise from shipping, which will dominate at low frequencies, or noise from precipitation, shore and surf noise. When device noise is compared with the ambient noise at low wind speeds, the effect of neglecting the shipping noise in particular will be more precautionary at low frequencies than an assessment which included these terms.

The model results showed good agreement with noise measurements taken by an autonomous recording unit (ARU) off Barra Head in 2004.[4]

[4] The (ARU) was deployed on the seabed in 40 m water depth. Sound was measured continuously over a period of approximately two weeks. Calibration data for ARUs are not available so the absolute sound level could not be determined.

C17.4.3 Sources of Renewable Energy Device Noise

The potential sources of noise in marine renewable energy devices are listed below:

- Rotating Machinery
- Flexing Joints
- Structural Noise
- Moving air
- Moving water
- Moorings
- Electrical Noise
- Instrumentation Noise

The noise generated by these elements of the devices can be coupled into the sea via a variety of paths that are summarized below.

Direct coupling - This results when the noise generator is in direct contact with the sea, e.g. the flexing joints of a wave generator or the rotating blades of a tidal current turbine. This mechanism is generally the most efficient coupling mechanism.

Mechanical coupling - This mechanism requires a mechanical path between the noise source and the sea. An example would be the rotational noise of an air-driven turbine being coupled via the turbine mounts into a metal shell which is then in direct contact with the sea. The path will generally modify the content of the sound.

Seabed coupling - For units firmly secured to the seabed, noise may be coupled through the structure into the substrate and thence into the water column.

Air coupling - Sound can also be generated from the in-air part of a generation system and coupled through the air-water interface into the water column. This is generally a very inefficient coupling system because of the acoustic impedance mismatch between air and water.

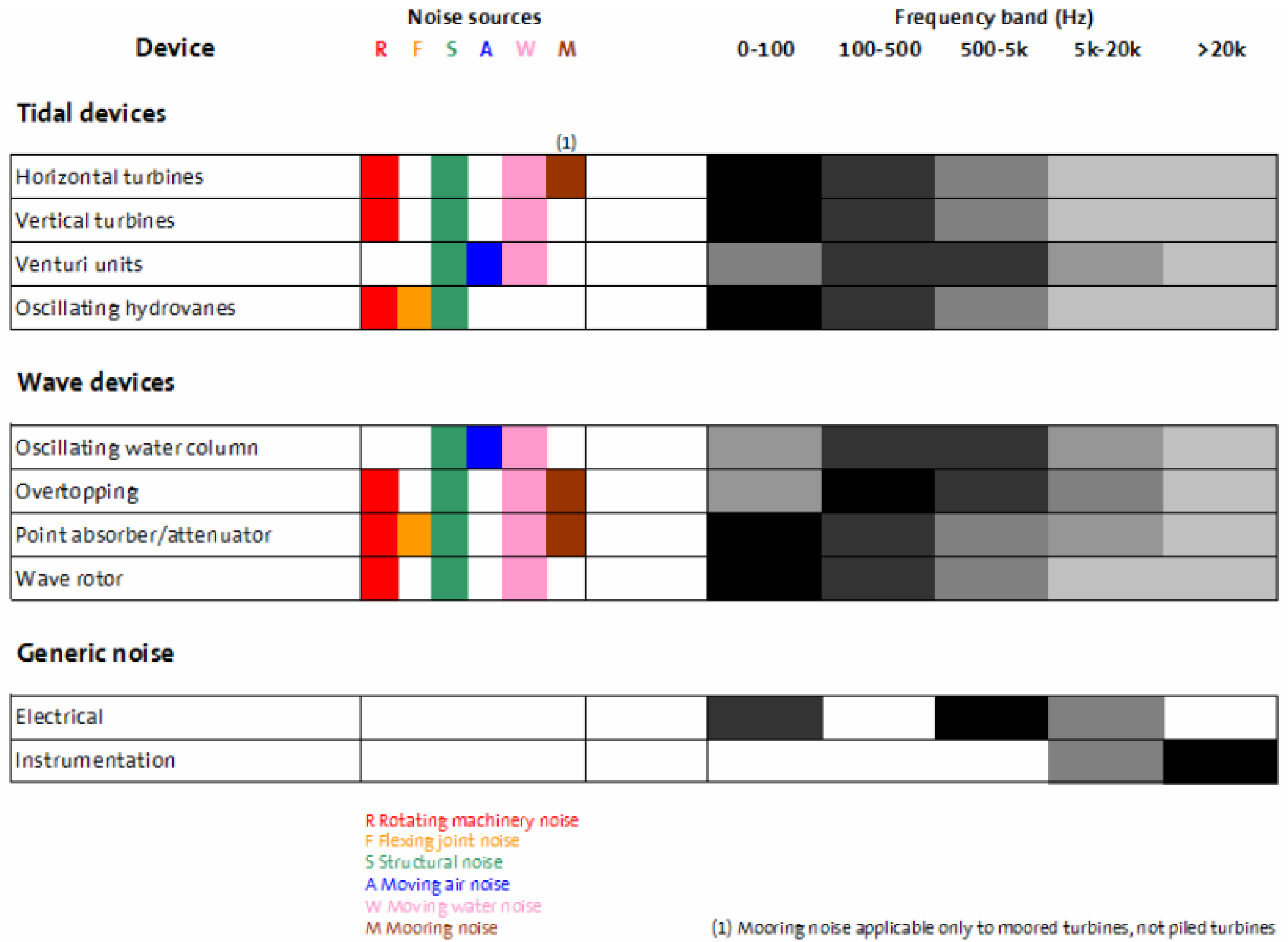
The main sources of noise associated with different device types are summarized in Table C17.6 below and Figure C17.4 on page 15.

Table C17. 6: Sources of Noise from Marine Renewable Energy Devices

Device Category	**Key Noise Generating Components**
Horizontal axis turbine	Rotating machinery noise; moving air noise; structural noise; mooring noise
Vertical axis turbine	Rotating machinery noise; moving air noise; structural noise; mooring noise
Venturi units	Moving water noise; moving air noise; structural noise
Oscillating Hydrovanes	Flexing joints; rotating machinery noise; structural noise
Oscillating water column devices	Moving water noise; moving air noise; structure noise (all of the rotating machinery is housed above the water line so coupling of the noise to the water will generally be low. The shoreline versions of this device are considered to be within the envelope of this summary)
Overtopping devices	Rotating machinery noise; moving water noise; mooring noise; structural noise
Point absorber/attenuator	Mooring noise; flexing joints; structural noise; rotating machinery noise (in some examples)
Wave rotor	Limited information available

Developers will always seek to minimize noise emissions from their devices as noise generation reduces efficiency. However, increased noise levels can also occur during fault conditions. Developers will obviously seek to reduce the occurrence of faults but in the hostile marine environment where such devices are deployed, it is inevitable that fault conditions will occur. Under these conditions noise output can rise significantly. A faulty bearing in rotating machinery can produce elevated levels of wideband noise – worn gear boxes can become progressively noisier and anti-vibration mounts can become worn and less efficient. A faulty bearing in a flexing joint can produce different tonals at the flexing cycle and joints can partially or fully seize resulting in a change in the way the unit interacts with the waves and thereby increasing wave noise. Rubber seals can become worn and start squeaking. With mooring noise as parts wear they will generally become noisier. This is likely to result in an increase in mechanical impact noise from the joints.

Figure C17.4: Summary of the Main Noise Sources Associated with Different Device Types. The greyscale indicates the relative noise level in each part of the spectrum, with black indicating the highest level and white indicating no or negligible noise.



Source: Underwater noise study supporting the Scottish Executive strategic environmental assessment for marine renewables, QinetiQ, January 2007

C17.5 Example Tidal and Wave Device Noise

Information and data on the sound produced by wave and tidal devices is currently very scarce due to the developing status of the industry. This chapter has drawn upon available information and data for a single wave and single tidal device to give an illustrative example of the level of sound emitted from a single marine renewable energy device and how sound emissions will increase for arrays of devices. As the industry develops it is expected that more data will be collected and knowledge and understanding will progress.

C17.5.1 Tidal Turbine

The only known underwater measurements in the vicinity of an operating wave or tide energy device were carried out at the site of the Marine Current Turbines (MCT) tidal current generator near Lynmouth in the Bristol Channel (Parvin, et al. 2005). These data have been kindly supplied by Subacoustech Ltd on behalf of MCT for use in the SEA to provide an indication of the noise generated by tidal energy devices. Sample measurements were taken both while the turbine was running and when it was not running to give an indication of the local ambient noise. The distance of the measurements locations from the device ranged from 100 m to 1300 m. All of the measurements were taken within a period of about four hours on the 9th March 2005. Therefore, the variation in ambient noise over time was not captured.

The noise measurements indicate that there was a large degree of variation in the sound pressure at similar distances from the device, and that in some cases, particularly at greater distances from the device; the ambient noise level is higher than the noise level from the turbine.

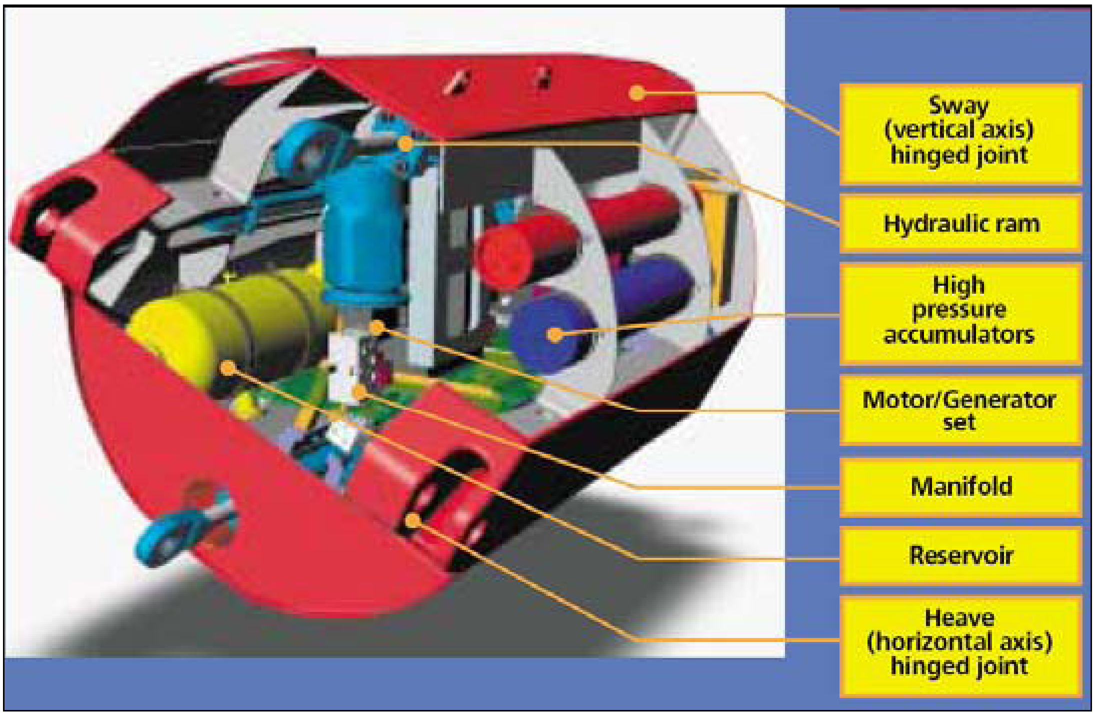
Listening to the recordings indicates that the ambient noise at the site contains a large amount of shore and surf noise, which is to be expected based on the close proximity of the device to the cliffs of the shoreline.

Assessment of the data implies an effective source level of 166 dB re 1μPa at 1 m. However, this sound source level should be treated with caution as there are likely to be large fluctuations in sound pressure level at short distances from the source.

C17.5.2 Wave Device

Information on the Pelamis wave device was kindly supplied by Ocean Power Delivery (OPD) to help inform this assessment. As it was not possible to undertake underwater noise measurements for a wave device with the SEA study timescales, experts from QinetiQ carried out an assessment of the likely underwater noise generated by the Pelamis wave device. This illustrative assessment was based on engineering information from OPD (OPD, 2003a), a pre-installation noise review (OPD, 2003b), and experience in measuring the radiated noise from similar types of marine mechanical systems. Figure C17.5 shows an internal view of one of the power conversion modules.

Figure C17. 5 Internal View of one of the Pelamis Power Conversion Module



Source: http://www.oceanpd.com/Development/conversionModule.html

The results of the pre-installation noise review supplied by OPD were not considered representative of the likely noise radiated by Pelamis in normal operation. This was due to the fact that during the measurement of noise emissions two hydraulic power packs were used to power the device. The noise from the power packs masked the noise from the device. The hydraulic power pack will not be present during operation at sea. For this reason, and due to the lack of other technical information, it was not possible to make any assessment of the likely underwater radiated noise based upon these measurements.

Based on QinetiQ's assessment of the device, the hydraulic motor generator packs, hydraulic rams and associated pipework, and wave noise were predicted to be the most significant contributors to underwater noise.

As no empirical data was available for the Pelamis wave device it was only possible to make an approximate indication of the expected underwater noise from data for machinery of similar type. Ship steering systems typically use electically-powered hydraulic pumps which drive rams that operate rudders that are similar to the motors used in Pelamis. Some scaling of the data was required as the hydraulic power of a steering system is not as high as the 250 KW Pelamis units. Farfield [5] radiated underwater noise from a steel-hulled vessel was used as source data for the estimate as it was considered to be closest to Pelamis in terms of its size, construction and transmission paths between the hydraulic pumps and the sea water. Some published literature suggests that it is possible to expect sound power to scale linearly with the rated power of the machine. This extrapolation introduces some error but it will hopefully be minimal as the machines are still within an order of magnitude in power rating terms. Underwater radiated noise measurements were taken from a number of nominally identical vessels when the steering pumps were operating under load.

The power-compensated values, which are expected to be representative of tones generated by the Pelamis hydraulic power packs, are shown in Table C17.7.

[5] Distances that are large compared to the dimensions of the sound source (Vella, et al, 2001).

Table C17. 7 EstimatedUunderwater Radiated Tonal Noise Levels Due to Pelamis Hydraulic Motors

Frequency Hz	**Level (dB re.1 1 µPa at 1m)**
175 (assuming 7 cylinder motor at 1500 rpm)	129 to 140
350 (assuming 7 cylinder motor at 1500 rpm)	127 to 141

Without a substantial program of experimental and/or theoretical work it would not be possible to predict accurately the additional wave noise generated by the operation of a wave device such as Pelamis. However, it is possible to produce a very approximate indication of the likely levels of broad band wave noise by comparison with the underwater radiated noise of a surface vessel underway.

Results were chosen from a vessel operating with propulsion shaft power levels higher than, but within an order of magnitude of 250 kW, the rated output of the Pelamis modules. The vessel was below its propeller cavitation inception speed, which means that the majority of noise was related to interactions between the waves and the ship. In the 1 kHz third octave band the measured level is approximately 140 dB re. 1 µPa at 1 m. The third octave band levels drop by approximately 10 dB per decade as the frequency increases such that the 10 kHz band level is approximately 130 dB re. 1 µPa at 1 m.

Relating these levels to a wave energy device such as Pelamis requires a number of sweeping assumptions. For this reason these levels can only be regarded as a tentative indicator of the possible high frequency broadband wave noise one might expect to be generated by a wave energy device in operation close to its rated load. This approach is considered appropriate for present purposes but a more detailed assessment would be required for individual devices and projects.

The estimated values given above are the best indication of noise emissions in the absence of any measured data. They do not take into account certain details of the construction of the device, for example the use of adhesives to fix internal bulkheads which may reduce structure-born noise transmission. On the other hand the transmission of noise and vibration into the water by the hydraulic/seawater cooling pipes could provide a very direct transmission path which is not available in the steering pump data. If this were the case, it could result in a device such as Pelamis generating considerably greater tonal levels of underwater radiated noise. Another factor which may introduce errors into the levels quoted above is the actual power levels in operation of the steering pump. This is a system with a certain redundancy built into it and the rated power may not be a good indication of the actual power consumed under load. This effect would also suggest that the actual radiated noise levels generated by Pelamis at full rated capacity could be higher than those given in Table C17.7.

It has not been possible in this study to estimate the noise levels due to structural resonances in Pelamis.

C17.6 Effects of Array Geometry

Commercial scale marine renewable energy developments will see multiple device arrays of varying size and configuration. Due to the current developing state of the industry, the majority of device developers have not fully addressed the design issues associated with large arrays of devices.

In order to assess the underwater noise field from an array of devices, it would be necessary to know the details of the array, i.e. the shape of the array and the spacing between the devices. It would also be necessary to know the acoustic environment (i.e. water depth, sound speed profile and seabed type) in order to compute the sound propagation between devices in the array, and from the array to the surrounding area. The data required for this approach are not available, nor would it be appropriate to investigate specific geometries in that level of detail in this strategic study.

It is likely that many arrays will be rectangular, or approximately rectangular, and it was therefore considered pragmatic to consider the two limiting cases: a linear array; and a square array. In such arrays the highest noise levels would be expected in the vicinity of the device which is located closest to the centre of the array. The dominant contribution would be from that device itself, the nearest neighbours might also contribute a significant amount of sound energy, depending on the element separation, with more distant devices contributing progressively lower levels as the distance increases, as a result of geometric spreading and absorption.

The following figures show estimates of the additional noise level at the central device of the array, due to the rest of the devices in the array. These levels have been computed assuming spherical spreading over the relatively short distances between units. This is a reasonable assumption for nearest neighbours, which contribute the most to the additional noise level. Although this may slightly underestimate the noise level from the more distant devices, their overall contribution is relatively weak.

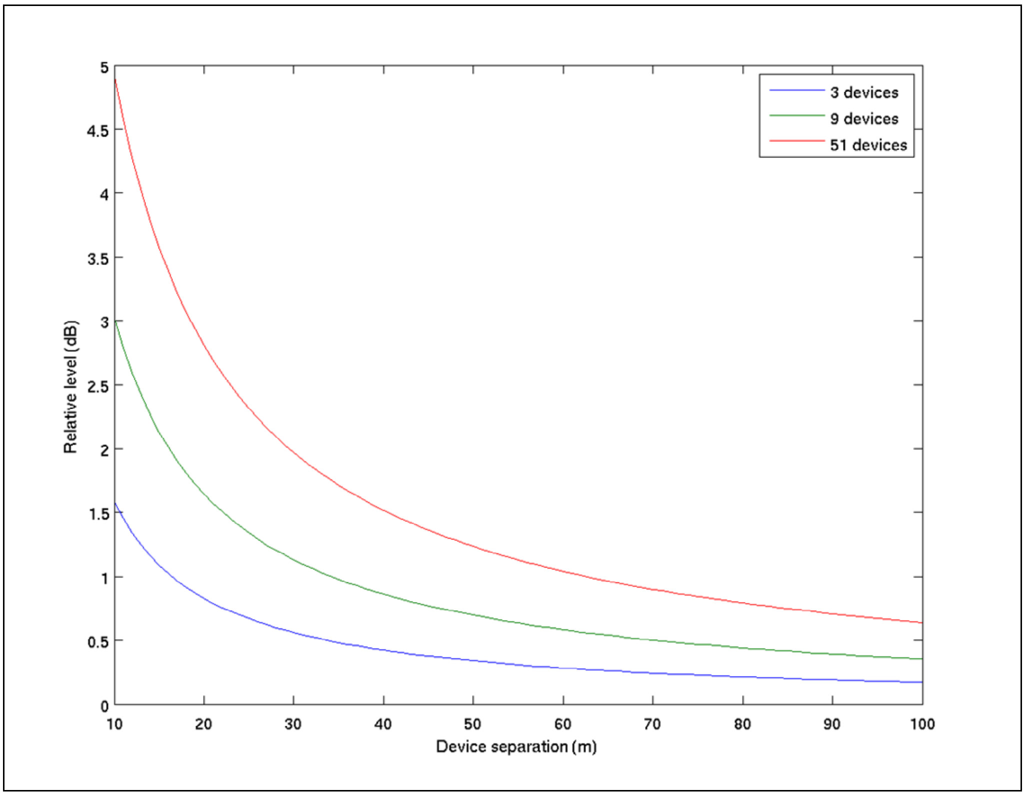
Figure C17.6 shows the increase in noise level at the central device of a linear array, due to the rest of the devices in the array, as a function of the separation between devices. Results are shown for arrays containing 3, 9 and 51 devices. This figure shows the noise level raised by up to 5 dB relative to the noise level of a single device, for a 51- device array with 10 m separation, and 3 dB for a 9-device array. In practice, device separations are likely to be greater than 10 m, and noise levels will therefore be lower. For separations greater than 20 m (see note[6]) the maximum noise level at the centre device will be less than 3 dB above that of a single device for arrays containing up to 51 devices.

Figure C17.7 shows the maximum noise level relative to the noise of a single device, at the centre device of a line array, as a function of the number of devices in the array, for separation of 10 m, 20 m, and 100 m. It can be seen that for separations of 20 m or greater the maximum noise level is less than 3 dB above the noise of a single device for arrays of up to 50 devices. For greater separations the maximum noise level is lower.

Figure C17.8 shows the maximum noise level relative to the noise of a single device, at the centre device of a square array, as a function of the orthogonal separation between devices, for arrays containing 9, 25 and 49 devices. The levels are generally higher than for a linear array owing to the larger number of devices within a given range, for a given separation. The maximum levels are less than 3 dB above that of a single device for separations greater than about 50 m, for arrays containing up to 49 devices.

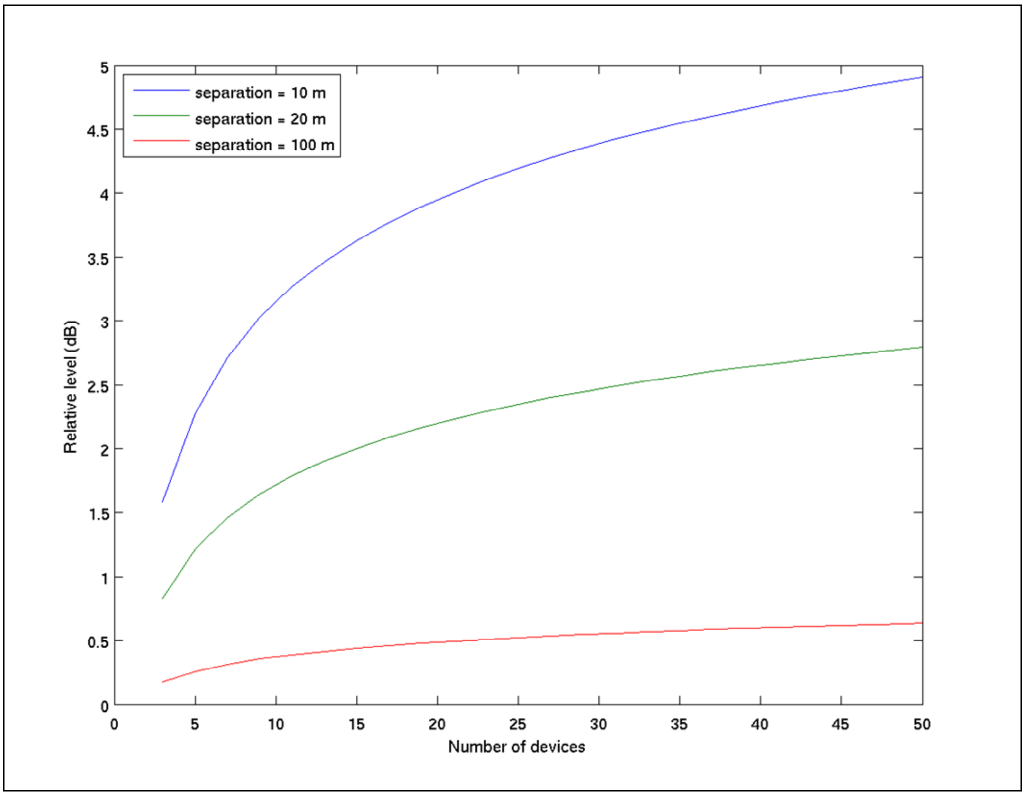
[6] In reality separation between devices is likely to be greater, these distances were determined based on their effect on noise emissions.

Figure C17.6: Noise Levels Relative to the Noise of a Single Device, at the Centre of a Linear Array as a Function of the Separation Between Devices



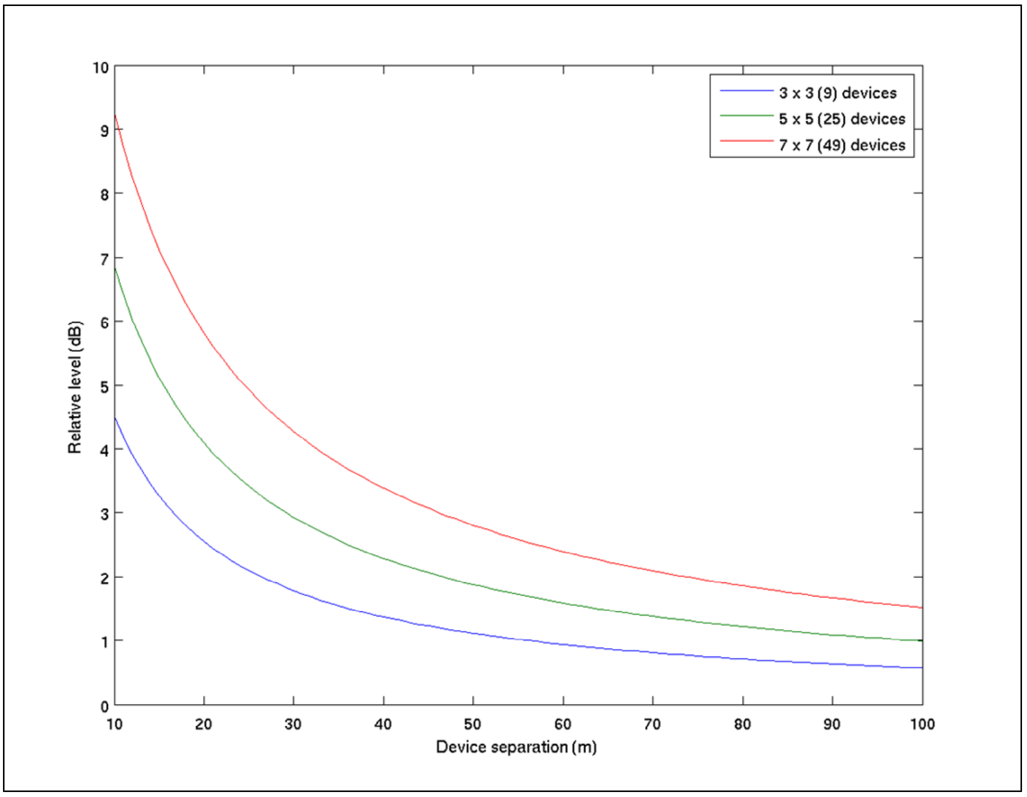
Source: Underwater Noise Study Supporting the Scottish Executive Strategic Environmental Assessment for Marine Renewables, QinetiQ, January 2007

Figure C17.7: Noise Level Relative to the Noise of a Single Device, at the Centre of a Linear Device Array, as a Function of the Number of Devices in the Array



Source: Underwater Noise Study Supporting the Scottish Executive Strategic Environmental Assessment for Marine Renewables, QinetiQ, January 2007

Figure C17.8: Noise Level Relative to the Noise of a Single Device, at the Centre of a Square Device Array, as a Function of the Separation between Devices



Source: Underwater Noise Study Supporting the Scottish Executive Strategic Environmental Assessment for Marine Renewables, QinetiQ, January 2007

All of the above estimates are for the noise level at the centre device in the array, as that is expected to be the noisiest position and therefore the one with the maximum potential physiological impact on receptors.

At large distances from an array of devices (i.e. at ranges much greater than the device separation) each device will contribute approximately equally to the total noise level. However, the overall level at these ranges will be small compared to the noise levels within the array.

Table C17.8 summarises the key results of this assessment of the effects of array geometry. This analysis suggests that for device separations greater than about 50 m the maximum noise level will be within 3 dB of the noise level from a single device.

Table C17. 8 Noise Level Relative to that of a Single Device, at the Centre Device of an Array, for Various Device Configurations

Device Separation (m)	Noise Level Relative to a Single Device (dB)					
	Linear Array			Square Array		
	3 devices	9 devices	51 device	9 devices	25 devices	49 devices
10	1.6	3.0	4.9	4.5	6.9	9.3
20	0.8	1.6	2.6	2.6	4.1	5.8
50	0.3	0.7	1.1	1.1	1.8	2.8
100	0.2	0.4	0.6	0.6	1.0	1.5

C17.7 Impacts of Device Operation Noise

C17.7.1 Method of Assessment

In order to assess the impact of underwater noise on the receptors likely to be encountered in the marine environment, it was necessary to define thresholds, corresponding to various levels of severity of impact. Thresholds for acoustic impact on fish, marine mammals and human beings were developed by QinetiQ (Heathershaw et al, 2001). The method used takes into account frequency, intensity and duration of sound, and further details can be found in Appendix C17.A.

The onset of permanent or temporary hearing damage in fish, marine mammals and submerged human beings in the marine environment is dependent on the intensity of the sound to which an organism is exposed, its hearing response, and the duration of exposure. Two levels of damage were considered in the work undertaken for this SEA:

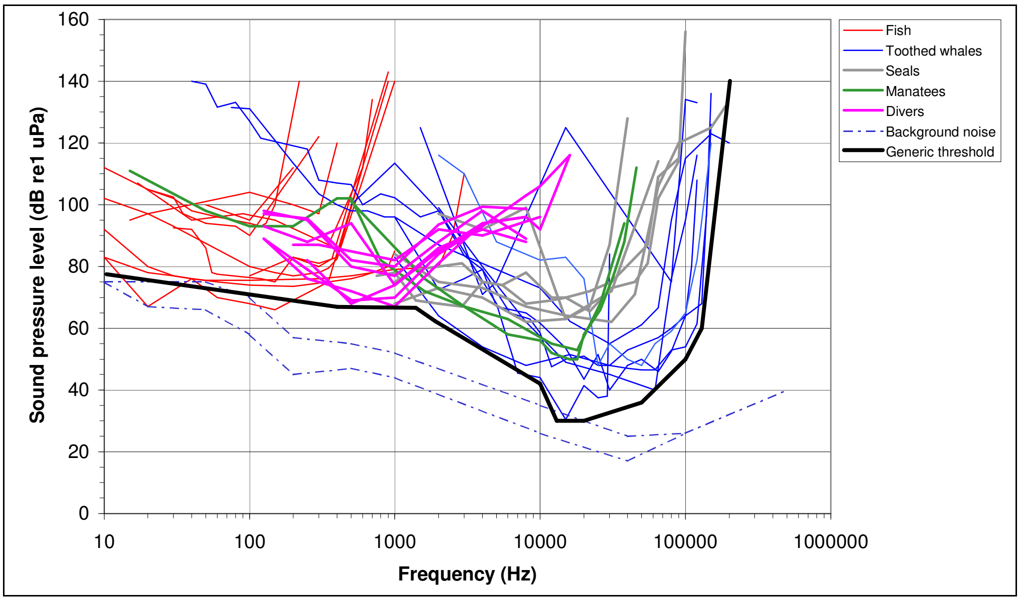
A. **permanent threshold shift (PTS)**. PTS constitutes irreversible physiological damage caused by rupture of the hair cells of the inner ear, resulting in a non-recoverable partial loss of hearing sensitivity; and

B. **temporary threshold shift (TTS)**. TTS constitutes a temporary loss in the efficiency of the mechanical–chemical–electrical transfer function in the inner ear, resulting in a temporary and partial loss of hearing sensitivity.

Investigation of published data (Heathershaw et al, 2001) indicates that the onset of PTS in fish, marine mammals or submerged human beings is possible at sound pressure levels (SPLs) greater than 95 dB above the threshold of hearing of the animal in question, for an exposure duration of 8 hours or more in any period of 24 hours. Similarly, the onset of TTS has been found to be possible for SPLs of 75 dB above the threshold of hearing, for the same exposure duration. The SPLs, at which onset of PTS and TTS might occur, increases as the duration of exposure decreases. These SPLs are, respectively, 10 dB below and 10 dB above an extrapolation of the UK Noise at Work Regulations (NAWR) dose response criteria (DRC) to the marine environment, for total durations of exposure between 10 s and 8 hours.

In order to assist in the determination of the distance from the source of noise at which a fish, marine mammal or human diver is likely to be subjected to any given impact criterion, a frequency-dependent generic threshold curve (Figure C17.9) has been produced, bounding the available audiograms and corresponding to the threshold of hearing of the most sensitive creature at any frequency. It may be seen that the lowest threshold (i.e. highest sensitivity) occurs at a sound pressure level of about 30 dB re 1 μPa between 10 and 11 kHz.

Figure C17.9: In-Water Threshold of Hearing for Fish, Man and Marine Mammals. Also Shown are Typical Ambient Noise Levels and the Generic Threshold Curve



Source: Underwater Noise Study Supporting the Scottish Executive Strategic Environmental Assessment for Marine Renewables, QinetiQ, January 2007

The generic hearing threshold curve seen above has been used in the impact assessment in conjunction with a TTS dosage threshold of 75 dB and a PTS dosage threshold of 95 dB above the threshold of hearing in order to estimate ranges of influence.

C17.7.2 *Summary of Impacts from Tidal Device*

PTS analysis was undertaken for the broadband noise spectrum of the tidal turbine, for an exposure duration of 30 minutes. The analysis was performed for a duration of 30 minutes as this is deemed representative of the dive time of many shallow-water marine mammal species. The sound source levels were scaled up for a 1 MW turbine based on the assumption that sound scales linearly with the generator power. This is a potential source of error in the analysis but is thought to give a 'worst case' and therefore precautionary assumption.

PTS – The assessment revealed that if the most sensitive receptor were to spend 30 minutes within a distance of 16 m of the device it might suffer permanent hearing damage. The 16 m relates to frequency of 19,953 Hz and source levels of 157.6 dB re 1μPa at 1 m and is estimated to be the maximum distance over which PTS could occur for the most sensitive species.

Evidence suggests that it is unlikely that an animal would choose to stay in close proximity to the source of a loud noise (Tougaard, et al. 2003).

TTS – TTS thresholds assumed exposure over a period of 8 hours. This exposure period takes into account the fact that the ear does not recover immediately but sound at a later time may add to the impact of the previous noise.

The assessment revealed that if the most sensitive receptor were to spend 8 hours within 934 m of the device it might suffer temporary, recoverable hearing damage. The 934 m relates to frequency of 15,849 Hz and source levels of 157.2 dB re 1μPa at 1 m and is estimated to be a maximum distance over which TTS could occur for the most sensitive species.

In comparison to the PTS, it is estimated TTS could occur over almost the full range of frequencies and sound source levels produced by an operational tidal device, but at smaller distances than the 934 m maximum distance of impact. It should also be noted that seabed type assumed for these calculations is a hard reflective seabed and the water depth is assumed to be relatively shallow. In deeper water with a less reflective seabed (e.g. a muddy seabed), the range of impact would be reduced to a maximum of 378 m for frequency of 15,849 Hz and source levels of 157.2 dB re 1μPa at 1 m.

C17.7.3 Summary of Impacts from Wave Device

The same assumptions and methodology were used to asses the impacts of the wave device as the tidal device. Although it should be noted that there was no measurement data to base the noise emissions of the wave device on and therefore the sound levels had to be estimated based on available data for similar machinery types. The tonals due to the hydraulic power packs were scaled up to a 1 MW generator, again assuming that acoustic power scales linearly with generator power. However, the third octave levels representing the broadband wave noise spectrum have not been scaled up. Although it may be expected that a physically larger device might generate somewhat higher levels of wave noise, this is not expected to scale linearly with generator power.

The estimated noise spectrum does not exceed the 30 minute PTS threshold at any frequency. Therefore, based on the limited data available, it is not expected that a wave energy device of this type would present any potential for causing PTS. The maximum predicted TTS range for an exposure of 8 hours is only 6 metres, so the risk of an animal experiencing TTS from a single 1 MW device of this type is insignificant. Note that this analysis does not include structural noise, which is unknown and may be significant.

C17.7.4 Impacts of Arrays

The analysis summarized above indicates that for commercial-scale arrays the maximum noise level is likely to be within 3 dB of the noise level for a single device. Therefore, the zones of influence for arrays of 1 MW devices have been estimated by increasing the source levels of a single 1 MW device by 3 dB. The maximum indicative ranges for the 30 minute PTS threshold for the tidal turbine, and the 8 hour TTS threshold for both devices, are shown in Table C17.9. There is no PTS impact from the wave attenuator array. The maximum PTS range for the tidal turbine array is just 24 m.

These results indicate that there is unlikely to be a significant PTS impact for commercial arrays of wave devices like Pelamis, and only a very small (less than 25 m) PTS zone around individual devices within a typical array of tidal current turbines.

Table C17. 9: Maximum Indicative Ranges for Arrays of 1 MW Devices

Frequency (Hz)	Source Level (dB re. 1 µPa at 1 m)	Hearing Threshold (generic threshold value) (dB)	Threshold (dB re. 1 µPa)	Threshold Excess (dB)	Indicative Range	
					20 log R	17 log R
N x 1 MW Tidal turbine array, PTS, 30 minute exposure						
19953	160.6	30.0	137.1	23.6	15	24
N x 1 MW Tidal turbine array, TTS, 8 hour exposure						
15849	160.2	30.0	105.0	55.2	517	1284
N x 1MW Pelamis array, TTS, 8 hour exposure						
10000	133.0	42.1	117.1	15.9	6	9

Note: The 20 log R figures assume spherical spreading and are most appropriate at short ranges and/or in deeper water or where the seabed is very lossy (e.g. mud), whilst the 17 log R numbers are appropriate for somewhat longer ranges and/or in shallower water or where the seabed is more reflective (e.g. sand or rock).

Biological receptors may exhibit avoidance reactions to underwater noise at levels much lower than the PTS and TTS thresholds. It should therefore be noted that arrays of devices may appear as impenetrable barriers to an animal, perhaps separating them from feeding grounds, even though there may be plenty of room between devices for the animal to pass without experiencing damaging noise levels.

C17.8 Likelihood of Occurrence

Installation and operation of marine renewable energy devices will generate noise and therefore noise impacts are likely to occur wherever a development takes place. However, as the information above suggests, noise emissions will be highly dependent on device types for both installation and operation of devices and the local ambient noise conditions. The characteristics of a site will also influence the likelihood of effects occurring – for example where installation or operation takes place in a sound, channel or entrance to a sea loch, marine mammals may be caused to avoid the area.

Additionally, the zone of influence of the noise emissions will vary depending on local and regional environmental conditions.

C17.9 Mitigation Measures

The following mitigation measures could be used to reduce noise emissions as appropriate.

Table C17.10: Mitigation Measures – Noise

Potential Effect	Project Phase	Mitigation Measure
Underwater noise – construction	CD	Minimise use of noisy activities such as pile driving where possible. Use sound insulation on equipment. Use a soft start/ramp up procedure (slowly increasing energy of emitted sound). However, it should be noted that this may make it more difficult for harbour porpoise and marine mammals to localize the sound. Avoid installation during sensitive periods. Use of bubble curtains (this is expensive and may only be effective in shallow water). Use acoustic deterrent or disturbance devices to scare sensitive species away*. Use of mammal observers or passive observation methods
Underwater noise – construction	CC	Minimise installation period Avoid installation during sensitive periods
Underwater noise – operation	OD	Device design. Underwater noise during operation may be beneficial in alerting species to the presence of the device reducing the risk of collisions. This requires further research.

*There are a number of issues and concerns with regard to the use of Acoustic Deterrent Devices (ADDs), which would need to be considered should ADDs be considered for use to mitigate potential collision impacts. The interaction of such devices with marine mammals is not well understood and may be based upon the delivery of painful doses of noise into the marine environment – which has issues both in respect of animal welfare and deliberate disturbance, and use of such devices may require a licence under the Wildlife and Countryside Act. Furthermore there is a lack of understanding as the efficacy of such devices (which may vary between individuals, populations and species) and, in respect of extended periods of deployment, how receptors may become habituated to such devices. COWRIE is currently commissioning work on acoustic deterrent devices in an attempt to further understand this issue.

CD = Construction/decommissioning impact – devices
CC = Construction/decommissioning impact – cables
OD = Operation impact – devices
OC = Operation impact – cables

Further more detailed information on mitigation methods is presented in a comprehensive study recently commissioned by a consortium of Outer Thames offshore wind farm developers that considers the effectiveness of the current methods available (RPS Energy, 2006).

C17.10 Confidence and Knowledge Gaps

C17.10.1 Installation of Devices

There is currently a lack of information on the noise emitted during several types of installation activity (drilling, dredging, installation of gravity structures, cable trenching) as research effort to date has focussed on the most “noisy” installation activity – pile driving.

However, it can be considered that there is a good degree of confidence in the data available on the noise emissions of pile driving as several field studies have been undertaken on this issue. Additionally, available literature (Thomsen et al., 2006; Nedwell and Howell, 2004) suggests that pile driving noise has the potential to cause the greatest environmental impacts.

C17.10.2 Operation of Individual Devices and Device Arrays

In general the emissions and associated effects of noise from wave and tidal energy device deployment are not well studied or understood, and although there is good confidence in the work reported, it is acknowledged throughout that assumptions have had to be made due to gaps in information. Therefore, it can be summarised that there is a moderate level of confidence in several aspects of the work reported above and further work is required to predict the noise emissions from different types of device arrays.

The main information shortfall identified is the lack of data available for radiated noise from marine renewable energy devices. At the time of writing, underwater noise measurements were only available for one single pre-commercial device (the tidal current turbine at Lynmouth) at one location, on one day. These measurements have therefore been used as the prime source of radiated noise information for analysis in this SEA. It must, however, be recognised that other types of device may have very different noise signatures.

Those devices having all of their major mechanical and electrical components submerged are likely to cause the highest overall levels of underwater noise - especially devices such as tidal current turbines having submerged rotors, gearboxes, generators and power conversion modules. Therefore, although noise data for other devices are not available, it is expected that their total contributions to the underwater noise field will be lower for a given generator power. However, depending on the details of the device they may contribute higher levels of sound in certain parts of the spectrum. For example, devices operating on the surface may contribute high levels of wave and splashing noise at frequencies up to around 100 kHz.

Additionally, no information is available on the directionality of sound emitted by marine renewable energy devices. Therefore, all assessments have been based on the assumption that the devices radiate omni-directionally. If there is any anisotropy in the radiation pattern this would lead to higher levels in some directions than those assumed in this report, and lower levels in other directions. Although the measurements of the tidal current turbine at Lynmouth were made at a number of positions around the device it would not be possible to decouple any azimuthal variability from other sources of spatial and temporal variability in this dataset.

Modelling was undertaken to investigate how noise emissions would scale up with an increase in the number of devices, but due to the fact that there are currently no arrays of devices deployed in UK waters it is not yet possible to validate these predictions.

However, the work undertaken for this SEA has investigated the limited information available and given an indication of how noise emissions will scale with an increase in the number of devices.

In terms of how noise emissions will interact and accumulate between device arrays across the study area, it has not been possible to make a prediction. This is because such predictions would require that the locations and array geometry of each development would need to be known in order to make any meaningful predictions.

For this SEA study there were also some information shortfalls with regards to ambient noise that were not considered imperative to the SEA study but may need more detailed assessment for EIA level impact studies. For example, more detailed assessment of local contributors to ambient noise such as local shipping, other marine activities and shore and surf noise would be required for development specific EIA.

C17.10.3 Cumulative Effects of Installation and Operation of Multiple Arrays

No attempt has been made to assess the noise issues and cumulative impacts associated with the simultaneous installation of multiple device arrays as there is currently insufficient data to carry out such an assessment. This will continue to be the case until device arrays begin to be developed. Additionally the varied environmental properties of the study area (varying water depths, topography, seabed types and ambient noise conditions) mean that an accurate assessment could not be made at this time. Should the situation arise where multiple developments are planned and operation will occur simultaneously it may be necessary for a detailed cumulative impact assessment to be undertaken that looks at noise emissions and potential effects during installation and operation. Such a study has recently been successfully undertaken for the Thames offshore wind farm developers to assess the impact of pile driving activities.

C17.10.4 Impacts on Biological Receptors

Much work has been done on the impacts of pile-driving noise on biological receptors related to the wind industry. However there are still several gaps in understanding with regards to the sensitivity of many species to different noise levels and frequencies and how the noise actually affects biological receptors such as fish and marine mammals.

Specific data gaps identified are listed below and apply to both installation and operation noise:

- There is not a standard methodology for undertaking underwater noise measurements and assessing the impacts upon marine wildlife which makes it very difficult to draw conclusions across the various information sources and research available.
- There are no generic studies focusing on the abilities of different species types to detect the range of noise emissions from marine renewable energy devices as there is currently very limited empirical data upon which to base such a study. Field measurement data is currently being collected for a 1:4.5 scale Wave Dragon type device off Denmark to support the consent application for the deployment of a commercial scale Wave Dragon device off the coast of Pembrokeshire in south Wales. In addition some preliminary work has been done to identify the issues with measuring the airborne, waterborne and rock borne noise from a shoreline wave device.
- The Scottish Association for Marine Science identified several gaps in information with regards to marine species hearing sensitivities which are summarised in Table C17.11 below.

Table C17. 11: Marine Mammals' Species Groups Use of Sound - Knowledge Gaps

Species Group	Knowledge Gap
Seals	Abilities to detect renewable device acoustic signatures
Porpoise	Perception of rotating objects using echolocation
Delphinids	Perception of rotating objects using echolocation
Large Odontocetes	Perception of rotating objects using echolocation Hearing abilities
Mysticetes	Hearing abilities

One particular point of note is that the assessment of TTS and PTS impacts for device operation were based on a generic threshold curve which is based on hearing thresholds of the most sensitive receptors – this gives a precautionary prediction of impacts. Specific assessments for individual developments based on hearing thresholds for the relevant species to that specific location may result in smaller zones of influence with regards to PTS and TTS.

In addition to gaps in information with regards to species sensitivity to noise there are specific gaps in information on species behavioural responses to device operation noise. Species could react to both the physical presence of a device and the noise emitted from it. Therefore, it is likely that monitoring will be required for the first generation of renewable energy device arrays to assess the impacts of device arrays operation on marine species – specifically marine mammals.

C17.11 Recommendations for Survey and Monitoring

C17.11.1 Survey

It is evident from the above information that there is currently a lack of data on the impacts of installation of devices and sound emitted from devices, and no data on the noise emissions from arrays of devices. Therefore as part of project specific investigations detailed consideration is likely to be required of noise impacts. This could be expected to involve investigation and modelling of noise levels and propagation of sound during installation and device specific operation noise measurements and analysis.

C17.11.2 Monitoring

Based on the gaps in data and information with regards to noise emissions from marine renewable energy devices and the impacts of noise on marine wildlife, the following monitoring is recommended.

- Monitoring of the behavioural impacts on marine mammals of noise from device operation. SMRU have been developing a monitoring protocol, covering both data collection and data analysis for marine turbine development areas. These studies are ongoing at Eday in Orkney, and in Strangford Narrows, Northern Ireland, with the aim that the protocols can be developed into an industry standard and will be applicable at any other location. It should be noted that such monitoring studies would have to take into account that the visual impacts of devices may also impact certain species behaviour.

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