# Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities

## Module A.

## Sound in Water is Complex

The full CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities and the stand-alone modules are online at:

**cms.int/guidelines/cms-family-guidelines-EIAs-marine-noise**

# A. Sound in Water is Complex

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Wild Migration

The ocean environment is filled with natural sound from animals and physical processes. Species living in this environment are adapted to these sounds. Over the past century many anthropogenic marine activities have increased levels of noise. (André *et al* 2010, Hildebrand 2009) These modern anthropogenic noises have the potential for physical, physiological and behavioural impacts on marine fauna–mammals, reptiles, fish and invertebrates. (Southall *et al* 2007)

The propagation of sound in water is complex and requires many variables to be carefully considered before it can be known if a noise-generating activity is appropriate or not. It is inappropriate to generalize sound transmission without fully investigating propagation.

Often, statements are made in Environmental Impact Assessments that a noise-generating activity is 'X' distance from 'Y' species or habitat and therefore, will have no impact. In these cases distance is used as a basic proxy for impact but is rarely backed with scientifically modelled information. (Wright *et al* 2013, Prideaux and Prideaux 2015)

The behaviour of sound in the marine environment is different from sound in air. The extent and way that sound travels (propagation) is affected by many factors, including the frequency of the sound, water depth and density differences within the water column that vary with temperature, salinity and pressure. (Clay and Medwin 1997, Etter 2013, Lurton 2010, Wagstaff 1981) Seawater is roughly 800–1,500 times denser than air and sound travels around five times faster in this medium. (Lurton 2010) Consequently, a sound arriving at an animal is subject to propagation conditions that are complex. (Calambokidis *et al* 2002, Hildebrand 2009, Lurton 2010, McCauley *et al* 2000)

To present a defensible Environmental Impact Assessment for any noise-generating activity proposal, proponents need to have expertly modelled the noise of the proposed activity in the region and under the conditions they plan to operate.

Understanding the basic concepts that should be presented is important to assess if the Environmental Impact Assessment is defensible and sufficient.

## A.1. Basic concepts

The study of acoustics is a specialized and technical field. Professional acousticians will consider many more complexities beyond the scope of this paper.

The basic concepts that decision-makers may need to understand are outlined in a very simplified form, specifically to be accessible to a lay-audience.

### A.1.1. Elasticity

The speed of sound is not a fixed numerical value. Sound wave speed varies widely and depends on the medium, or material, it is transmitted through, such as solids, gas or liquids. Sound waves move through a medium by transferring kinetic energy from one molecule to the next. (Lurton 2010) Each medium has its own elasticity (or resistance to molecular deformity). This elasticity factor affects the sound wave's movement significantly. Solid mediums, such as metal, transmit sound waves extremely fast because the solid molecules are tightly packed together, providing only tiny spaces for vibration. Through this high-elasticity medium, solid molecules act like small springs aiding the wave's movement. The speed of sound through aluminium, for example, is around 6,319ms$^{-1}$. Gas, such as air, vibrates at a slower speed because of larger spaces between each molecule. This allows greater deformation and results in lower elasticity. Sound waves moving through air at a temperature of 20°C will only travel around 342ms$^{-1}$. Liquid molecules, such as seawater, bond together in a tighter formation compared with gas molecules. This results in less

deformation, creating a higher elasticity than gas. Sound waves moving through water at 22°C travel at around 1,484ms$^{-1}$. (Brekhovskikh and Lysanov 2006, Au and Hastings 2009, Ross 2013) Temperature also has an effect on molecules. Molecules move faster under higher temperatures, transmitting sound waves more rapidly across the medium. Conversely, decreasing temperatures cause the molecules to vibrate at a slower pace, hindering the sound wave's movement. (Brekhovskikh and Lysanov 2006, Au and Hastings 2009, Ross 2013) The temperature of seawater at different depths is therefore of importance to modelling.

### A.1.2. Spherical Spreading, Cylindrical Spreading and Transmission Loss

The way sound propagates is also important. Spherical spreading is simply sound leaving a point source in an expanding spherical shape. As sound waves reach the sea surface and sea floor, they can no longer maintain their spherical shape and they begin to resemble the shape of an expanding cheese wheel. This is called cylindrical spreading.

The transmission loss, or the decrease in the sound intensity levels, happens uniformly in all directions during spherical transmission. However, when sound is in a state of cylindrical transmission, it cannot propagate uniformly. The sound is effectively contained between the sea surface and the sea floor, while the radius still expands uniformly (the sides of the cheese wheel). The height is now fixed and so the sound intensity level decreases more slowly. (Urick 1983, Au and Hastings 2009, Lurton 2010, Jensen *et al* 2011)

In actuality, the seabed is rarely, if ever, flat and parallel to the sea surface. These natural variations add extra complexities to modelling cylindrical spreading. However, these characteristics must be known to model spreading accurately, as should the water depth and the rise and fall of the seabed surrounding it. (Lurton 2010, Jensen *et al* 2011)

### A.1.3. Sound Fixing and Ranging Channels (SOFAR)

As well as spherical and cylindrical spreading, another variable can impact how far sound will be transmitted. This is usually called a Sound Fixing and Ranging Channel (SOFAR) and is a horizontal layer of water in the ocean at which depth, the speed of sound is at its minimum.

The SOFAR channel is created through the interactive effect of temperature and water pressure (and, to a smaller extent, salinity). This occurs because pressure in the ocean increases with depth, but temperature is more variable, generally falling rapidly in the main thermocline from the surface to around a thousand metres deep and then remaining almost unchanged from there to the ocean floor. Near the surface, the rapidly falling temperature causes a decrease in sound speed (or a negative sound speed gradient). With increasing depth, the increasing pressure causes an increase in sound speed (or a positive sound speed gradient). The depth where the sound speed is at a minimum is called the sound channel axis. The speed gradient above and below the sound channel axis acts like a lens, bending sound towards the depth of minimum speed. The portion of sound that remains within the sound channel encounters no acoustic loss from reflection of the sea surface and sea floor. Because of this low transmission loss, very long distances can be obtained from moderate acoustic power. (Urick 1983, Brekhovskikh and Lysanov 2006, Lurton 2010, Jensen *et al* 2011)

### A.1.4. Decibels dB

The decibel (dB), 1/10th of a Bel, is used to measure sound level. It is the unit that will be presented in documentation.

The dB is a logarithmic unit used to describe a ratio. The ratio may be power, sound pressure or intensity.

The logarithm of a number is the exponent to which another fixed value, the base, must be raised to produce that number. For example, the logarithm of 1,000 to base 10 is 3, because 1,000 is 10 to the power 3:

$$1{,}000 = 10 \times 10 \times 10 = 10^3.$$

More generally, if $x = b^y$, then y is the logarithm of x to base b, and is written y = logb(x), so log10 (1,000) = 3. (Au and Hastings 2009, Jensen *et al* 2011, Ross, 2013)

A common mistake is to assume that 10dB is half as loud as 20dB and a third of 30dB.

To disprove this false assumption, suppose there are two loudspeakers, the first playing a sound with power P1, and another playing a louder version of the same sound with power P2, but everything else (distance and frequency) remains the same.

The difference in decibels between the two is defined as:

10 log (P2/P1) dB where the log is to base 10.

If the second produces twice as much power as the first, the difference in dB is:

$$10 \log (P2/P1) = 10 \log 2 = 3 \text{ dB}.$$

To continue the example, if the second has 10 times the power of the first, the difference in dB is:

$$10 \log (P2/P1) = 10 \log 10 = 10 \text{ dB.}$$

If the second has a million times the power of the first, the difference in dB is:

$$10 \log (P2/P1) = 10 \log 1{,}000{,}000 = 60 \text{ dB.}$$

This example shows one feature of decibel scales that is useful in discussing sound: they can describe very big ratios using manageable numbers.

### A.1.5. Peak and RMS values

Peak value, as the term implies, is the point of a sound wave with the greatest amplitude. Peak values are associated with plosive sounds like seismic air guns, pile driving, low frequency sonar and explosives. (Au and Hastings 2009)

RMS (root mean squared) is the formula used to calculate the mean of a sound wave over time. RMS values are associated with constant non-plosive sounds like shipping propeller and engine noise, oil rig operations, some mid to high frequency sonar and water based wind turbines. (Au and Hastings 2009)

### A.1.6. Phase

Phase can be best described as the relational alignment with two or more sound waves over time. Very simplistically, waves with the same phase will constructively interfere to produce a wave whose amplitude is the sum of the two interfering waves, while two waves which are 180 degrees out of phase will destructively interfere to cancel each other out. (Rossing and Fletcher 2013)

## A.2. Understanding Sound Exposure Levels

### A.2.1. Sound Exposure Level cumulative (SELcum)

Sound Exposure level (SEL) is generally referred to as dB 0 to peak or peak to peak (dB 0 to peak or dB p to p) for plosive or pulsive noise like air guns, military sonar etc and dB Root Mean Squared (dB rms) for non-plosive or non-pulsive noise such as ship noise, dredging, wind farms, constant drone (Au and Hastings 2009). These measurements are generally of a one second duration only. The question arises, is this a realistic measurement metric for understanding the effects on all marine species?

According to NOAA's paper, Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, (NOAA, 2016) sound exposure level works well for marine mammals but not well for other marine species (crustaceans, bivalves, cephalopods, finned fish, etc) because non-mammal marine species detect sound through particle motion (the organism resonating in sympathy with the surrounding sound waves) rather than through a tympanic mechanism as with marine mammals. A more informed measurement introduced to modelling is sound exposure level cumulative (SELcum) by which a time component is added into SEL enabling it to encompass all marine species.

While SEL has been acceptable in the past, with the use of SELcum modelling, species experts have documented noticeable impacts on species' welfare that have otherwise gone unnoticed.

NOAA has set a default time of 24 hours for SELcum. An alternate prescribed time can be applied to SELcum if stated. Within the SELcum metric, reference to sound intensity level (0 to peak, peak to peak or rms) is not appropriate due to the extended time parameter. It may be displayed as 190 dB SELcum *re* 1µPa @ 1m pulsive or non-pulsive depending.

### A.2.2. Equal Energy Hypothesis

NOAA also mentions the Equal Energy Hypothesis (EEH) which discusses the basic impact trends on marine species. They also comment that the EEH is pretty loose due to the complexity of all the potential factors, but it serves as a reasonable rule of thumb.
It states:

- Growth rate of threshold shift (TS) is higher for frequencies where hearing is more sensitive
- Non-impulsive intermittent exposures require higher SELcum to induce a TS compared to continuous exposures of the same duration
- Exposures for longer durations and lower levels induce TTS at a lower level than those exposed to a higher level and a shorter duration with the same duration SELcum
- With the same SELcum, longer exposures require longer recovery time.
- Intermittent exposures recover faster compared to continuous exposures of the same duration
- Animals may be exposed to multiple sound sources and stressors beyond acoustics during an activity. This also

may have a cumulative effect.

Also, pulsive/plosive SELcum noise will induce TS more quickly than a non-pulsive noise with the same SELcum due to the fast rise time characteristics of pulsive/plosive noise.

## A.3. Necessity of Modelling

These complexities illustrate the necessity for expert modelling of sound propagation from noise-generating activities. (Urick 1983, Etter 2013) While noise modelling is common for land-based anthropogenic noise-producing activities, it is less common for proposals in the marine environment. The lack of rigorous noise modelling in the marine setting needs to be urgently addressed. (Prideaux and Prideaux 2015)

Modelling of each noise-generating activity proposal should be expertly and impartially conducted to provide decision-makers with credible and defensible information. The modelling should provide a clear indication of sound dispersal characteristics, informed by local propagation features. (Urick 1983, Etter 2013)

With this information, the acoustic footprint of the noise-generating activity can be identified and informed decisions about levels of noise propagation can be made. (Prideaux and Prideaux 2015)

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