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

CMS

ACCOBAMS

ASCOBANS

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Parties to the Convention on Migratory Species (CMS), the Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS) and the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) have recognized underwater noise as a major threat to many marine species. Several resolutions have been passed calling for effective measures to mitigate and minimize the impact of noise pollution on marine life.

CMS, ACCOBAMS and ASCOBANS decisions also recognize that addressing this issue effectively requires that noise-related considerations should be taken into account starting with the planning stage of activities, especially by making effective use of Environmental Impact Assessments (EIA). The Convention on Biological Diversity Decision XII/23 encourages governments to require EIAs for noise-generating offshore activities and to combine acoustic mapping with habitat mapping to identify areas where these species may be exposed to noise impacts.

A considerable number of national and regional operational guidelines detail the impacts to be avoided and mitigation measures to be taken during proposed operations. For the most part, these focus on cetaceans. Few guidelines cover other species, and almost none has been developed for the specific content that should be provided in EIAs before approvals and permits are granted.

Thanks to a voluntary contribution from the Principality of Monaco under the Migratory Species Champions programme, and an additional contribution from OceanCare, the CMS, ASCOBANS and ACCOBAMS Secretariats are pleased to have developed guidelines for Environmental Impact Assessment for noise-generating offshore industries, providing a clear pathway to implementing the Best Available Techniques (BAT) and Best Environmental Practice (BEP).

This Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities is structured to stand as one complete unit or to be used as discrete modules, tailored for national and agreement approaches.

The full document and the stand-alone modules are online at cms.int/guidelines/cms-family-guidelines-EIAs-marine-noise

The Government of the Principality of Monaco were recognized as Champion for their generous support and commitment towards marine species conservation for the period 2015–2017. The development of this Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities has been funded with the contribution granted by Monaco under the Migratory Species Champion Programme.

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Acronyms

ACCOBAMS	Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
BAT	Best Available Techniques
BEP	Best Environmental Practice
CBD	Convention on Biological Diversity
CMS	Convention on the Conservation of Migratory Species of Wild Animals or Convention on Migratory Species
dB	decibels
DSC	deep sound channel
EEH	Equal Energy Hypothesis
EIA	Environmental Impact Assessment
IMO	International Maritime Organization
IWC	International Whaling Commission
NOAA	National Oceanic and Atmospheric Administration (US)
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PTS	permanent threshold shift
RMS	root mean squared
SEA	Strategic Environmental Assessment
SEL	sound exposure level
SEL_{cum}	cumulative sound exposure level
SIL	Sound Intensity Level
SOCAL-BRS	Biological and Behavioural Response Studies of Marine Mammals in Southern California
SOFAR	Sound Fixing and Ranging Channels
SPL	Sound Pressure Level
TTS	temporary threshold shift
UK	United Kingdom of Great Britain and Northern Ireland
US	United States of America

Tables

Executive Summary

The sea is the interconnected system of all the Earth's oceanic waters, including the five named 'oceans' - the Atlantic, Pacific, Indian, Southern and Arctic Oceans - a connected body of salty water that covers over 70 percent of the Earth's surface.

This vast environment is home to a broader spectrum of higher animal taxa than exists on land. Many marine species have yet to be discovered, and the number known to science is expanding annually. The sea also provides people with substantial supplies of food, mainly fish, shellfish and seaweed, in addition to marine resource extraction. It is a shared resource for us all.

Levels of anthropogenic marine noise have doubled in some areas of the world, every decade, for the past 60 years. When considered in addition to the number other anthropogenic threats in the marine environment, increasing noise can be a life-threatening trend for many marine species.

Marine wildlife rely on sound for vital life functions, including communication, prey and predator detection, orientation and for sensing surroundings. While the ocean is certainly a sound-filled environment and many natural (or biological) sounds are very loud; wildlife is not adapted to anthropogenic noise.

Animals exposed to elevated or prolonged anthropogenic noise can suffer direct injury and temporary or permanent auditory threshold shifts. Noise can mask important natural sounds, such as the call of a mate, the sound made by prey or a predator. They can be displaced from important habitats. These impacts are experienced by a wide range of species including fish, crustaceans and cephalopods, pinnipeds (seals, sea lions and walrus), sirenians (dugong and manatee), sea turtles, the polar bear, marine otters and cetaceans (whales, dolphins and porpoises).

The *Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities* has been developed to present the Best Available Techniques (BAT) and Best Environmental Practice (BEP). The document is structured to stand as one complete unit or to be used as discrete modules, tailored for national and agreement approaches.

The modules that follow are structured to cover species area, as follows:

'**Module A: Sound in Water is Complex**' provides an insight into the characteristics of sound propagation and dispersal. This module is designed to provide decision-makers with necessary foundation knowledge to interpret the other modules in these guidelines and any impact assessments that are presented to them for consideration.

'**Module B: Expert Advice on Specific Species Groups**' presents 12 separate detailed sub-modules covering each of the CMS species groups, focusing on species' vulnerabilities, habitat considerations, the impact of exposure levels and assessment criteria.

'**Module C: Decompression Stress**' provides important information on bubble formation in marine mammals, source of decompression stress, source frequency, level and duration, and assessment criteria.

'**Module D: Exposure Levels**' presents a summary of the current state of knowledge about general exposure levels.

'**Module E: Marine Noise-generating Activities**' provides a summary of military sonar, seismic surveys, civil high-powered sonar, coastal and offshore construction works, offshore platforms, playback and sound exposure experiments, shipping and vessel traffic, pingers and other noise-generating activities. Each section presents

current knowledge about sound intensity level, frequency range and the general characteristics of activities. The information is summarized in a table within the module.
'**Module F: Related Intergovernmental or Regional Economic Organisation Decisions**' presents the series of intergovernmental decisions that have determined the direction for regulation of anthropogenic marine noise.
'**Module G: Principles of EIAs**' establishes basic principles including strategic environmental assessments, transparency, natural justice, independent peer review, consultation and burden of proof.
'**Module H: CMS-Listed Species Potentially Impacted by Anthropogenic Marine Noise**' provides the list of relevant CMS listed as of CMS CoP11.

The Technical *Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities* is structured to stand as one complete unit or to be used as discrete modules, tailored for national and agreement approaches.

The complete document and the discrete modules are online at: cms.int/guidelines/cms-family-guidelines-EIAs-marine-noise

A. Sound in Water is Complex

Geoff Prideaux
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 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 'independent, scientific modelling of sound propagation' of the proposed activity in the region and under the conditions they plan to operate.

Understanding what basic concepts 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 specialised and technical field. Professional acousticians will consider much 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 the water at 22°C, travel at around 1,484ms^{-1}. (Brekhovskikh and Lysanov 2006, Au and Hastings 2009, Ross 2013) Temperature also affects 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, Transmission Loss and Absorption 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 seafloor, 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. (Lurton 2010, Jensen *et al* 2011)

Absorption is a form of loss that obeys a different law of variation with range than the loss due to spreading. It involves a process of conversion of acoustic energy into heat and thereby represents a true loss of acoustic energy where the propagation is taking place. (Urick 1983) Absorption losses are less for lower frequencies noise relative to higher frequency noise; that is lower frequency noise generally propagates further in the marine environment.

However, all of these characteristics must be known to model accurately, as should the water depth and the rise and fall of the seabed surrounding it.

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 the pressure in the ocean increases with depth, but the 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 as 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 the reflection of the sea surface and seafloor. 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 made by people that are unfamiair with the dB scale is to assume that 10dB is half as loud as 20dB and a third of 30dB.

To explain, 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 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 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 dB.

This example shows one feature of decibel scales that are 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 should be provided with impulsive (also known as plosive, explosive and pulsive) 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 should be provided with constant non-impulsive (also known as non-plosive or continuous) 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)

This is important to note as attempts to establish noise thresholds based on one pressure metric when modelling has utilised another, will produce errors that can reduce the effectiveness of any proposed mitigation measures. For example, noise measured in RMS can be ~10 dB less than the peak level and ~16 dB less than the peak-to-peak level.

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.1.7. MicroPascals (µPa)

The pascal (Pa) is the standard measure for pressure. Scientists have agreed to use 1 microPascal (1µPa) as the reference pressure for underwater sound. This figure will usually be represented at one meter from a noise source (ie 1µPa @ 1m)

Most anthropogenic sound in the marine environment is produced across a large area. Sound measured in the acoustic ‘near-field’ environment tends to be highly variable, and if the sound is intense, can be physically impossible to measure.

To overcome this, sound modelling often makes source level measurements in the acoustic ‘far-field’ at sufficient distance from the source that the field has settled down. Source levels are then calculated back by a measured or modelled transmission loss to present a µPa measurement. This can introduce some assumptions/errors.

A.2. Necessity of Modelling

A.2.1. Sound Exposure Level cumulative (SEL_{cum})

Sound exposure level (SEL) is an important parameter when considering the impact of anthropogenic noise on marine species. SEL is a measure of the total energy contained within a noise signature; it depends on both amplitude of the sound and duration. This is often normalised to 1 second and is reported as 1 $\mu Pa^2 s$.

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 many 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 (SEL_{cum}) by which a time component is extended beyond 1 second. (NOAA, 2016)

NOAA has set a default time of 24 hours for SEL_{cum}. An alternate prescribed time can be applied to SEL_{cum} if stated. Within the SEL_{cum} metric, a reference to sound intensity level (0 to peak, peak to peak or rms) is not relevant due to the extended time parameter. (NOAA, 2016)

A.2.2. Independent, scientific modelling of sound propagation

These complexities illustrate the necessity for 'independent, scientific modelling of sound propagation' 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)

Independent, scientific modelling of sound propagation of each noise-generating activity proposal should be impartially conducted to provide decision-makers with credible and defensible information. The accuracy (i.e. bias) of models of sound propagation depends heavily on the accuracy of their inputs. Similarly, quantification of the precision (i.e. variability) of sound propagation models is rarely acknowledged but is also heavily dependent on the precision of the inputs into these models.

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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B. Expert Advice on Specific Species Groups

The sea is the interconnected system of all the Earth's oceanic waters, including the five named 'oceans' - the Atlantic, Pacific, Indian, Southern and Arctic Oceans - a connected body of salty water that covers over 70 percent of the Earth's surface.

This vast environment is home to a broader spectrum of higher animal taxa than exists on land. Many marine species have yet to be discovered, and the number known to science is expanding annually. The sea also provides people with substantial supplies of food, mainly fish, shellfish and seaweed. It is a shared resource for us all.

Levels of anthropogenic marine noise have doubled in some areas of the world, every decade, for the past 60 years. (McDonald and Hildebrand *et al* 2006, Weilgart 2007) When considered in addition to the number other anthropogenic threats in the marine environment, increasing noise can be a life-threatening trend for many marine species.

Marine wildlife rely on sound for its vital life functions, including communication, prey and predator detection, orientation and for sensing surroundings. (Hawkins and Popper 2014, Simmonds, Dolman *et al* 2014) While the ocean is certainly a sound-filled environment and many natural (or biological) sounds are very loud, wildlife is not adapted to anthropogenic noise.

The species groups covered in the following sub-modules are:

- Inshore Odontocetes
- Offshore Odontocetes
- Beaked Whales
- Mysticetes
- Pinnipeds
- Polar Bears
- Sirenians
- Marine and Sea Otters
- Marine Turtles
- Fin-fish
- Elasmobranchs
- Marine Invertebrates

General principles

Building on the information from module section A.1, sound waves move through a medium by transferring kinetic energy from one molecule to the next. Animals that are exposed to elevated or prolonged anthropogenic noise may experience passive resonance (particle motion) resulting in direct injury ranging from bruising to organ rupture and death (barotrauma). This damage can also include permanent or temporary auditory threshold shifts, compromising the animal's communication and ability to detect threats. Animals can be displaced from important habitats. Finally, noise can mask important natural sounds, such as the call of a mate, the sound made by prey or a predator.

These mechanisms, as well as factors such as stress, distraction, confusion and panic, can affect reproduction, death and growth rates, in turn affecting the long-term welfare of the population. (Southall, Schusterman *et al* 2000, Southall, Bowles *et al* 2007, Clark, Ellison *et al* 2009, Popper *et al* 2014, Hawkins and Popper 2016)

These impacts are experienced by a wide range of species including fish, crustaceans and cephalopods, pinnipeds (seals, sea lions and walrus), sirenians (dugong and manatee), sea turtles, the polar bear, marine otters and cetaceans (whales, dolphins and porpoises)–the most studied group of marine species when considering the impact of marine noise.

The NOAA acoustic guidelines (NOAA 2016), which employ the most up-to-date scientific information on the effects of noise on marine mammals, for impulsive and non-impulsive noise sources, are based on a dual metric–dB peak for instantaneous sound pressure and SEL accumulated over 24 h for both impulsive and non-impulsive, whichever is reached first. It is important to note that some jurisdictions, notably Germany, require appropriate sound intensity level metrics (0 to peak) in addition to SEL at a specified distance. Their duel requirement is because the way the energy is delivered–regarding both the duty cycle and the energy within the individual pulses of sound–influences the effects of sound exposure.

Sound exposure levels work well for marine mammals but not well for a number of other marine species, including crustaceans, bivalves and cephalopods, because these species detect sound through particle motion

(the organism resonating in sympathy with the surrounding sound waves) rather than through a tympanic mechanism of marine mammals or swim-bladders of some fish species. (Mooney, et.al., 2010; André, et.al., 2011; NOAA, 2016) Where sound pressure acts in all directions, particle pressure is an oscillation back and forth in a particular direction.
The detection of particle motion requires different types of sensors than those utilized by a conventional hydrophone. These sensors must specify the particle motion regarding the particle displacement, or its time derivatives (particle velocity or particle acceleration).

There is the need for a coordinated effort by biologists and physicists to quantify (through both dedicated measurements and modelling) particle motion in the marine environment to assess noise impacts on fish and invertebrates. Dedicated measurements need to be carried out to collect data on particle motion at different depths and locations for the different sound sources.

While specific metrics about the impact of sound pressure are presented, where available, impact metrics (standard specifications and measurements) have not yet been developed for particle motion impact on marine species. Decisions makers are urged to use their judgement about the potential impact of particle motion, in the absence of well-defined guidelines.

The thresholds used in many jurisdictions consider only the onset of Permanent Threshold Shift (PTS) as an auditory injury, whereas in Germany, the onset of Temporary Threshold Shift (TTS) is considered the threshold of injury. This is based on the finding that in the long term even a TTS can result in neuron degeneration of synaptic contacts between hair cells and nerves (Kujawa and Liberman 2009; Kujawa and Liberman, 2015)

Table 1: Potential results of sound exposure (from Hawkins and Popper 2016)

Impact	Effects on animal
Mortality	Death from damage sustained during sound exposure
Injury to tissues; disruption of physiology	Damage to body tissue, e.g internal haemorrhaging, disruption of gas-filled organs like the swim bladder, consequent damage to surrounding tissues
Damage to the auditory system	Rupture of accessory hearing organs, damage to hair cells, permanent threshold shift, temporary threshold shift
Masking	Masking of biologically important sounds including sounds from conspecifics
Behavioural changes	Interruption of normal activities including feeding, schooling, spawning, migration, and displacement from favoured areas
These effects will vary depending on the sound level and distance	

The current knowledge base is summarized in the following modules. If the Technical Background Information is revised at a later stage, the inclusion of diving seabirds would be a helpful addition.

This important volume of information should guide the assessment of Environmental Impact Assessment proposals.

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B.1. Inshore Odontocetes

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Odontocetes close to shore or in shallow waters

Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)
- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)

Related modules

- Refer also to modules B.10, B.12 and C when assessing impact to inshore odontocetes

B.1.1. Species Vulnerabilities

Close-range, acute noise exposure is known to generate spatial displacement, often extended over the duration of the noise exposure (Anderwald *et al* 2013, Pirotta *et al* 2013), temporary hearing impairment (temporary threshold shifts or TTS)(e.g. Kastelein *et al* 2015, Lucke *et al* 2009) reduction in both occurrence and efficiency, or even cessation, of foraging behaviour (e.g. Pirotta *et al* 2014).

Permanent hearing impairment (permanent threshold shifts or PTS) has not been documented empirically (unethical) but is expected to occur and exposure thresholds have been predicted (e.g. Southall *et al* 2007, NOAA 2016) , see table 2.

Long-range (and therefore of wider spatial magnitude), chronic noise exposure is also known to generate spatial displacement, often extended over the duration of the noise exposure (Campana *et al* 2015). Masking of communication and other biologically important acoustic signals also occurs (e.g. Gervaise *et al* 2012).

Spatial displacement can cause the temporary loss of important habitat, such as prime feeding ground, forcing individuals to exploit suboptimal foraging areas. This effect is of significant concern if foraging behaviour is seasonal and/or if foraging habitat is limited or patched. Similarly, displacement can reduce breeding opportunities if it occurs during the mating season. Therefore, foraging habitat and breeding season are particularly sensitive components to noise impact.

B.1.2. Habitat Considerations

Inshore odontocetes often feed on opportunistic, seasonally abundant prey (e.g. Shane *et al* 1986). Habitat is often degraded due to proximity to highly populated coastal areas, and are particularly exposed to higher levels of existing anthropogenic underwater noise (associated with coastal development, commercial ports, recreational boat ramps, etc.) in parts of their habitat range. Thus, populations have been fragmented or are in the process of being fragmented. For these reasons, suboptimal habitat should be available to perform the biological tasks that will be disturbed by the introduction of noise. Population structure should be known in enough detail to allow evaluation of the population's resilience to the disturbance. Some odontocetes show diel (24 hour cycle) movement patterns from offshore to inshore regions for resting (Thorne *et al* 2012), or prey accessibility (Goodwin 2008). Similarly, seasonal patterns have been described for inshore odontocetes mainly driven by their prey's life cycle (Pirotta *et al* 2014) or seasonality in human disturbance (Castellote *et al* 2015). These movement patterns and co-occurring disturbances should be considered to minimize odontocetes' exposure to noise or reduce cumulative impact. Some species have small home ranges or show high site fidelity with low connectivity. They therefore may be more vulnerable to population level impacts, particularly in areas of repeated anthropogenic activity. Caution should be taken to minimise overlaps with such areas. Appropriate scheduling of noise-generating activities at periods with the lowest presence of odontocetes should be prioritized. Feeding can be concentrated in habitat specific features such as river mouths (Goetz *et al* 2007) or canyons (Moors-Murphy 2014). These spatial particularities of habitat should also be considered and their disturbance minimized.

B.1.3. Impact of Exposure Levels

The harbour porpoise has been described as the inshore odontocete most sensitive to noise exposure among the species of which we have data (Lucke *et al* 2009, Dekeling *et al* 2014, but see Popov *et al* 2011).

Based on the NOAA acoustic guidelines (NOAA 2016), which employ the most up-to-date scientific information on the effects of noise on marine mammals, onset of physiological effects, that is TTS and PTS, for impulsive and non-impulsive noise sources is based on a dual metric (dB peak for instantaneous sound pressure and SEL accumulated over 24 h for both impulsive and non-impulsive, whichever is reached first) and is summarized in the table (below) for high frequency hearing specialists, which includes the harbour porpoise.

These thresholds are based on weighted measurements, which take into consideration hearing sensitivity across frequencies for each hearing functional group. For more details please see NOAA (2016).

A more restrictive decision from the German Federal Maritime and Hydrographic Agency on the onset for physiological effects on harbour porpoises must also be considered in this context. This Agency has implemented a different threshold since 2003, specifically for pile driving operations. Criteria consist of a dual metric, SEL = 160dB re 1 mPa^2/s and SPL(peak-peak) = 190 dB re 1µPa. Both measures should not be exceeded at a distance of 750 m from the piling site.

Regarding onset of behavioural disruption, NOAA has not yet updated its guidelines, and a threshold of 120 dB RMS for non-impulsive and 160 dB RMS for impulsive noise remain as the onset thresholds for all cetacean species. New information obtained through controlled noise exposure studies on offshore cetacean species (e.g. SOCAL-BRS, 3S), suggests that onset of behavioural disruption is context dependent, and not only received levels but also distance to the source might play an important role in triggering a reaction. Few studies have been focused on behavioural reaction to noise on inshore odontocetes. These show how the onset of a response is triggered by the perceived loudness of the sound, not just received levels (Dyndo *et al* 2015). At least for harbour porpoises, this finding lends weight to the recent proposal by Tougaard *et al* (2015) that behavioural responses can be predicted from a certain level above their threshold at any given frequency (e.g. in the range of 40–50 dB above the hearing threshold for harbour porpoise).

For loud noise sources such as large diameter pile driving or seismic surveys commonly found in inshore odontocete habitat, the onset for behavioural response can occur at very substantial distances (e.g. Tougaard *et al* 2009, Thompson *et al* 2013).

B.1.4. Assessment Criteria

Several key characteristics on the biology of a species should be adequately assessed in an EIA. Population stock structure is a critical element to allow evaluating potential negative effects outside the scope of the individual level. This information is often unavailable for inshore odontocetes, and regulators or decision makers should adopt a much stricter position regarding this criterion for impact assessment decisions. Correct impact evaluation cannot be accomplished without understanding the extent of a potentially impacted population. Because spatial displacement is by far the most prominent effect to occur in noisy activities occurring in inshore odontocete habitat, sufficient information on habitat use and the availability of unaffected suboptimal habitat should be addressed in the evaluation. Other more general points should not be forgotten when determining if this species group has been adequately considered by an EIA, such as the correct relationship between the spectral content of the noise source and hearing information for the affected species, and the integration of both behavioural and physiological effects for the estimated proportion of the population to be affected by the activity. One more important point to consider, is the

Table 2: TTS and PTS from impulsive and non-impulsive noise sources for inshore odontocetes (from NOAA 2016, based on high frequency functional group.)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
LE,24h	140 dB	153 dB	155 dB	173 dB
Lpk,flat	196 dB	n/a	202 dB	202 dB

potential for cumulative effects, due to the coastal exposure of these populations of inshore odontocetes. The introduction of new anthropogenic noise should be assessed in consideration with other already occurring stressors in their habitat, such as other noise sources, chemical pollutants, or physical disturbance, among others.

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B.2. Offshore Odontocetes

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Odontocetes in deeper waters

Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)
- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)

Related modules

- Beaked whales are considered separately in module B.3.
- Refer also to modules B.10, B.12 and C when assessing impact to offshore odontocetes

B.2.1. Species Vulnerabilities

While spatial displacement has been well documented in several inshore odontocetes species, little data is available for offshore odontocetes (other than beaked whale species), but similar behavioural responses are expected. Few direct measures of displacement are available (e.g. Goold 1996, Bowles *et al* 1994), and some indirect measures of disturbance exist, such as changes in vocal behaviour in short beaked common dolphins, Atlantic spotted dolphins and striped dolphins in the presence of anthropogenic noise (Papale *et al* 2015). Sperm whales exposed to tactical active sonar reduced energy intake or showed significant displacement with no immediate compensation (Isojunno *et al* 2016, Miller *et al* 2012). However, sperm whales chronically exposed to seismic airgun survey noise in the Gulf of Mexico did not appear to avoid a seismic airgun survey, though they significantly reduced their swimming effort during noise exposure along with a tendency toward reduced foraging (Miller *et al* 2009). Changes in vocal behaviour are normally associated with displacement in other odontocetes (e.g. Holt *et al* 2009, Lesage 1999).

Physiological impact by close-range, acute noise exposure, such as temporary threshold shift, has never been described in offshore odontocetes due to the difficulty to maintain these species in captivity. There is just one anecdotal description of physiological injury due to airgun noise exposure on a pantropical spotted dolphin (Graya and Van Waerebeek, 2011).

This lack of evidence should not be considered conclusive but rather as reflecting the absence of studies. Furthermore, due to similarities in sound functionality, hearing anatomy and physiology between offshore and inshore odontocetes, the vulnerabilities described for inshore species are expected to be very similar for offshore species.

Because of the lack of knowledge on offshore odontocete habitat seasonal preferences (e.g. it is not known whether reproduction occurs in similar habitats as where foraging occurs), noise impact on these species cannot be broken into lifecycle components.

B.2.2. Habitat Considerations

Little survey effort has been dedicated to offshore waters in most exclusive economic offshore zones and even less in international waters. As a consequence, data on offshore odontocete occurrence, distribution and habitat preferences is scarce for most species. However, some generalizations can be highlighted: Sperm whales do not use offshore regions uniformly, topography plays a key role in shaping their distribution (e.g Pirotta *et al* 2011). Moreover, solitary individuals use the habitat differently from groups (Whitehead 2003).

The occurrence of eddies, often associated with numerous seafloor topographic structures (canyons and seamounts), are known to favour ecosystem richness and consequently, cetacean occurrence (Ballance *et al* 2006, Hoyt 2011, Redfern *et al* 2006, Correia *et al* 2015). Therefore, areas where eddies are known to occur, particularly those related to underwater topography features, should be taken into special consideration when assessing impact to offshore odontocetes, even if no knowledge on cetacean occurrence is available.

B.2.3. Impact of Exposure Levels

Offshore odontocetes fall in their majority into the mid frequency hearing specialists. This group was considered for noise impact assessments during an international panel review (Southall *et al* 2007). This review has been updated in recent efforts by the U.S. Navy and NOAA. NOAA's most updated draft on acoustic guidelines (NOAA 2016) considers TTS and PTS, for impulsive and non-impulsive noise sources is based on a dual metric (dB peak for unweighted instantaneous sound pressure (Lpk) and SEL accumulated over 24 h (LE,24h) for both impulsive and non-impulsive, whichever is reached first) and is summarized in the table below for mid frequency hearing specialists (Table 3).

Table 3: TTS and PTS from impulsive and non-impulsive noise sources for offshore odontocetes, excluding beaked whales (from NOAA 2016, based on mid frequency functional group)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
LE,24h	170 dB	178 dB	185 dB	198 dB
Lpk,flat	224 dB	n/a	230 dB	230 dB

Please note cummulative thresholds are based on weighted measurements, which take into consideration hearing sensitivity across frequencies for each hearing functional group. For more details please see NOAA (2016).

Regarding onset of behavioural disruption, NOAA has not yet updated its guidelines, and a threshold of 120 dB RMS for non-impulsive and 160 dB RMS for impulsive noise remains as the onset thresholds for all cetacean species. Recent results from one of the few behavioural response studies where offshore odontocetes, other than beaked whales, are targeted identified higher thresholds than expected for avoidance of military tactic sonar by free-ranging long-finned pilot whales (Antunes *et al* 2015). The US Navy currently uses a generic dose–response relationship to predict the responses of cetaceans to naval active sonar (US Navy 2008), which has been found to underestimate behavioural impacts on killer whales and beaked whales in multiple studies (Tyack *et al* 2011, DeRuiter *et al* 2013, Miller *et al* 2012 and 2014, Kuningas *et al* 2013). The navy curve appears to match more closely results with long-finned pilot whales, though the authors of this study suggest that the probability of avoidance for pilot whales at long distances from sonar sources could well be underestimated. These results highlight how functional hearing grouping, particularly for offshore odontocete species, might not be the most conservative approach for noise mitigation purposes. Behavioural responses of cetaceans to sound stimuli often are strongly affected by the context of the exposure, which implies that species and the received sound level alone is not enough to predict type and strength of a response. Although limited in sample size, this new information has not yet been profiled in EIA procedures. Contextual variables are important and should be included in the assessment of the effects of noise on cetaceans (see Ellison *et al* 2012 for a context-based proposed approach).

B.2.4. Assessment Criteria

Because our limited knowledge on offshore odontocete ecology and their seasonal habitat preferences, common sense mitigation procedures such as avoiding the season of higher odontocete occurrence might be difficult to implement. However, habitat predictive modelling is often applicable with limited data (Redfern *et al* 2006), and should be encouraged in situations where impact assessments suffer from odontocete data deficit.

It should also be noted that in some particular cases, spatial displacement has generated drastic indirect effects at the population level. Good examples are the several episodes of large numbers of narwhals entrapped in ice in Canada and West Greenland attributed to displacement caused by seismic surveys (Heide –Jørgensen *et al* 2013). Displacement in offshore areas could drive odontocetes towards fishing grounds, increasing the risk of entanglement. In cases where planned offshore disturbance is proposed near potential risk areas for odontocetes, this indirect impact mechanism must be evaluated. In the case of sperm whales, regulations tend to be made assuming that animals avoid areas with high sound levels. Thus some policies assume benefits of avoidance in terms of reduced sound exposure, even in the absence of evidence that it occurs for some noise sources (Madsen *et al* 2006). Avoidance can also have adverse effects, with the biological significance depending upon whether important activities are affected by animal movement away from an aversive sound.

Other more general points should not be forgotten when determining if this species group has been adequately considered by an EIA, such as the correct relationship between the spectral content of the noise source and hearing information for the affected species, and the integration of both behavioural and physiological effects for the estimated proportion of the population to be affected by the activity.

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B.3. Beaked Whales

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)

Related modules

- Refer also to modules B.10, B.12 and C when assessing impact to beaked whales

B.3.1. Species Vulnerabilities

Beaked whales (Ziphiids) became widely known to the public due to mass mortalities of whales stranded with gas/fat emboli when exposed to submarine-detection naval sonar or underwater explosions (Jepson *et al* 2003, Fernández *et al* 2005). Most researchers agree that a 'fight or flight' stress response is responsible for the deaths of whales following noise disturbances (Cox *et al* 2006). Interruption of foraging and avoidance at high speed have been found in different species of beaked whales subject to playbacks of naval sonar at 1/3rd octave RMS received levels as low as 89–127 dB re 1 µPa (Tyack *et al* 2011, DeRuiter *et al* 2013, Miller *et al* 2015). Beaked whales may also be sensitive to other sources of anthropogenic noise, as suggested by the effectiveness of acoustic pingers in reducing the bycatch of beaked whales in deep-water fisheries, much higher than for other species (Carretta *et al* 2011), and by their apparent response to low levels of ship noise (Aguilar de Soto *et al* 2006). There has been a number of mass-strandings of beaked whales coincident in time and space with seismic activities (Malakof 2001, Castellote and Llorens 2016), but the lack of adequate post-mortem examinations has prevented assessing possible cause-effects relationships in these cases. This means that any intense underwater anthropogenic noise can be considered as of concern for beaked whales: blasting, intense naval and scientific sonar, seismics, pingers, etc.

It is still unknown why beaked whales are more sensitive to noise than many other marine mammal species. The reasons may lie in their specialized way of life. Ziphiids stretch their physiological capabilities to perform dives comparable to sperm whales, but with a much smaller body size (Tyack *et al* 2006). Their poor social defences from predators such as highly vocal killer whales may explain why beaked whales limit their vocal output (Aguilar de Soto *et al* 2012) and respond behaviourally to sound at relatively low received levels. The combination of a low threshold of response and a potentially delicate physiological balance may explain why behavioural responses can cause mortalities (Cox *et al* 2006).

Population data for beaked whales are scarce offshore, but long-term monitoring shows that local populations in nearshore deep-waters are small (<100-150 individuals), have high site-fidelity and apparently low connectivity and calving rate (Claridge, 2013, Reyes *et al* 2015). These characteristics generally reduce animal resilience to population-level impacts. Differences in population structure, with a reduced number of young, have been found between beaked whales inhabiting a naval training range and a semi-pristine neighbouring area in the Bahamas (Claridge, 2013). In summary, while discrete noise activities are of concern due to potential acute exposures/responses, there is a risk for population-level effects of noise on beaked whales inhabiting areas where impacts are repetitive.

B.3.2. Habitat Considerations

Some of the 22 species of the Ziphiidae family can be found in the deep waters of all oceans. However, beaked whales have a low probability of visual and acoustic detection (Barlow *et al* 2006, Barlow *et al* 2013) and knowledge about their distribution and abundance is poor, preventing identification of hot-spots offshore. Until more data exist, the assumption is that any area with deep waters is potential beaked whale habitat year-round.

Most mass-strandings related to naval sonar or underwater explosives have been recorded when the activities occurred in nearshore areas of steep bathymetry, suggesting that whales might die due to the stranding process. However, there is at least one mass-stranding case indicating that animals can die offshore before stranding: the naval exercise “Majestic Eagle”. This exercise occurred > 100 km offshore from the Canary Islands and dead whales were carried to the shore by the current and winds. The whales showed the same pathological findings identified previously as symptomatic of whales stranded alive in coincidence to naval exposure (Fernández *et al* 2012).

Thus, the vulnerability of beaked whales and their wide distribution make EIA relevant whenever human activities emitting intense sound occur near the slope or in abyssal waters offshore.

B.3.3. Impact of Exposure Levels

Beaked whales show strong avoidance reactions to a variety of anthropogenic sounds with the most sensitive fraction of the population responding at received levels of naval sonar below 100 dB re 1 μPa, and most of the animals tested responding at received levels of 140 dB re 1 μPa. This corresponds to ranges of several km from the ship operating the sonar (Miller *et al* 2015, Tyack *et al* 2011).

There are no data for thresholds of response for other noise sources. The range at which beaked whales may be expected to be at risk of disturbance from a given anthropogenic noise can be estimated from the characteristics of the sound source, acoustic propagation modelling and the dose: response data provided by behavioural response studies. For example, Tolstoy *et al* (2009) present broadband calibrated acoustic data on a seismic survey performed in shallow waters and received at deep (1600 m) and shallow water (50 m) sites. The line fit to have 95% of the received levels falling below a given received level (RL) was RL = 175.64 – 29.21 $\log_{10}$(range in km) for the deep water site and RL = 183.62 – 19 $\log_{10}$(range in km) at the shallow site. Solving the equation for shallow water and a RL of 140 dB at which beaked whales may be expected to be disturbed, the potential disturbance range would be range = $10^{43.62/19}$ = 197 km. The range predicted to disturb more sensitive individuals within the population would be greater.

The spectrum of the air gun sounds reported by Tolstoy *et al* (2009) is highest below 80 Hz, well below the naval sonars whose effects have been studied for dose-response curves, and in a frequency range where beaked whales are expected to have less sensitive hearing. It is difficult to weight the level of air guns by the hearing of beaked whale given the data available, but it is possible to make a rough estimate of the energy from air guns in the third octave band (which roughly match the frequency bands over which the mammalian ear integrates energy) of the naval sonars whose effects have been measured. The broadband SEL measured at 1 km for shallow water was 175 dB re 1 μPa^2s. Third octave levels were also reported for a shot recorded in shallow water at 1 km range. The third octave level for this shot at the 3 kHz sonar frequency was about 130 dB re1 μPa^2s, suggesting that this frequency band was about 45 dB lower than the broadband source level (SL). This suggests using a sound pressure level of 183.62 - 45 dB to estimate received level in this frequency band at 1 km range. In addition, seawater absorbs sound at about 0.18 dB/km at the 3 kHz sonar frequencies, and this absorption must be accounted for in the transmission loss. Therefore Transmission Loss (TL)= 19 $\log_{10}$(range) + 0.18*range. The range at which sensitive beaked whales, which respond at 100 dB re 1 μPa may respond, given that TL = SL – RL, i.e. 19 $\log_{10}$(range) + 0.18*range = 183.62-45-100 = 38.62, is estimated at 43 km.

These rough calculations show that beaked whales could be expected to be disturbed by exposure to airguns at ranges of 43-197+ km, assuming conditions as found by Tolstoy *et al* (2009). The actual values will depend upon the actual signature of the air gun array to be used, and the propagation conditions in the area. This guidance coupled with current data on beaked whale responses to anthropogenic noise suggests that each proposer should assess how sound is expected to propagate from the survey site to any beaked whale habitat with hundreds of km. If any of this habitat is expected to be exposed to levels of sound above those shown to disturb beaked whales (i.e. 100 dB re 1 μPa for the most sensitive individuals tested), then a further assessment should be made of the number of animals likely to be disturbed.

B.3.4. Assessment Criteria

EIA should consider different types of impacts, ranging from exposure of whales to intense received levels causing hearing damage to behavioural reactions with potential physiological consequences in some cases, to displacement and ecological effects (e.g. reduction in feeding rates or displacement from preferred habitat due to avoidance behaviour resulting in lower fitness).

A framework for mitigation targeted to reduce risk of the different impacts above needs to be included in the EIA, including actions during the planning-phase, real-time mitigation protocols and post-activity reporting to inform future planning and mitigation (e.g. Aguilar de Soto *et al* 2015). An effective mitigation method is spatio-temporal avoidance of high density areas (Dolman *et al* 2011). This is informed by surveys and habitat modelling and can be aided by simulation engines. However, the scarcity of data supporting density maps for beaked whales increases uncertainty about the number of whales to be expected in a given area and the identification of high density areas. Thus, planning-phase mitigation is essential but it does not eliminate the possibility of encountering and affecting/harming beaked whales. Another aspect of planning-phase mitigation is the choice of acoustic devices to be used during the activity, as well as the source levels required to achieve the objectives of the activity. *In situ* measurements of sound transmission loss shortly before the activity may allow adjustment of source level to below the maximum, so that the maximum is not used by default. A protocol towards reducing total acoustic energy and peak source levels transmitted to the environment should be defined before the activity, for any activity, within workable limits.

Depending on the activity, EIA may require updated information of the density of beaked whales and other vulnerable species, before the activity, in order to allow current data to be compared with existing density maps and to improve their accuracy. Also, if a choice of locations is evaluated, it would be possible to decide locating the activity in the place with lower concentration of vulnerable species.

A powerful and cost-effective way to monitor the effects would be to moor passive acoustic recorders in the beaked whale habitats exposed to sound levels above 100 dB re 1 µPa and to monitor both the actual levels of anthropogenic sound and also to monitor for the rates at which beaked whale echolocation clicks are detected. In the case of seismic, modern seismic surveys often include the deployment of cabled geophones at the seabed. These could be easily equipped with high frequency hydrophones to record beaked whales and other marine fauna.

Given the low probability of visual detection of beaked whales even in good sea conditions, real-time mitigation methods proposed in the EIA require increasing probability of detection by using passive acoustic monitoring systems with detectors programmed for automated classification of beaked whale vocalizations. Automatic detections can then be checked by trained personnel to take decisions about initiation of mitigation protocols.

B.3.5. Species not listed on the CMS Appendices that should also be considered during assessments

All beaked whales not currently listed by CMS seem to be particularly vulnerable to anthropogenic marine noise.

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B.4. Mysticetes

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and Sound Exposure Experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)

Related modules

- Refer also to modules B.12 and C when assessing impact to mysticetes

B.4.1. Species Vulnerabilities

Mysticete whales are all known to rely upon acoustic communication to mediate critical life history activities, including social interactions associated with breeding, raising young, migration and foraging (Edds-Walton 1997, Clark 1990). Research into the hearing capabilities of mysticetes, based primarily on anatomical modelling, indicate that mysticetes, as a group, are possibly capable of hearing signals from a minimum of approximately 7 Hz up to 35 kHz (Southall *et al* 2007). This range of frequencies spans many sources of anthropogenic noise in the ocean, excluding only the highest frequency sonar systems and pinger systems > 25 kHz (Hildebrand *et al* 2009). Previous research has documented impacts of noise exposure to physiology, behaviour, and habitat usage in mysticetes (Richardson *et al* 1995, Nowacek *et al* 2007, Tyack 2008).

Physiological impacts have been documented in mysticetes in response to noise exposure. This includes evidence of a decrease in physiological stress levels in North Atlantic right whale associated with a reduction in shipping noise (Rolland *et al* 2012). Techniques are currently under development to allow testing of acute stress responses to short-term high amplitude noise exposure (Hunt *et al* 2013).

Behavioral impacts have been documented in mysticetes in response to a variety of noise sources over the past three decades. This includes evidence of military sonar affecting movement, foraging and acoustic behaviour (Miller et a. 2000, Tyack 2009, Goldbogen *et al* 2013), seismic survey and air guns affecting movement and acoustic behaviour (Malme *et al* 1988, Di Iorio and Clark 2010, Castellote *et al* 2012), vessel noise affecting foraging, social and acoustic behaviour (Melcon *et al* 2012), and response to playback of predator and/or alarm stimuli (Cummings and Thompson 1971, Dunlop *et al* 2013, Nowacek *et al* 2004)

Habitat usage impacts have been documented in a number of cases. Previous studies have documented abandonment of habitat areas during periods of intense noise. One of the earliest documented cases occurred when commercial dredging and shipping activities resulted in abandonment of a critical calving ground in gray whales for the duration of human activities in an enclosed shallow water bay (Bryant *et al* 1984). Seismic surveys have resulted in large-scale, temporary, displacements of mysticete whales away from regions of seismic exploration in the Mediterranean (Castellote *et al* 2012). A further concern, of long-standing (Payne and Webb 1971), is the potential for even relatively low amplitude anthropogenic noise raising the background noise to a degree that it significantly reduces the range of communication for mysticetes. Recent studies have demonstrated the potential degree of masking experienced by mysticetes in urbanized habitat areas due to vessel traffic (Clark *et al* 2009, Hatch *et al* 2012). This is a major concern to result in chronic erosion of suitable habitat conditions through raising the baseline background noise levels.

B.4.2. Habitat Considerations

Based on previous studies, mysticetes show variable response to noise exposures in different habitat areas, possibly linked to differences in the behavioural states and/or the availability of suitable alternative habitats (Nowacek *et al* 2007). Most mysticete whales show some level of seasonal migratory behaviours (Corkeron and Connor 1999), therefore many habitats may seasonably pose relatively higher or lower risk depending on presence or absence of particular species. Calving grounds, breeding grounds, and foraging grounds are seasonally vulnerable areas for which there may not be suitable alternate habitat for many species, and would be of particular concern to highly endangered populations with limited available critical habitat areas.

Studies of responsiveness to noise exposure have been conducted on calving and breeding grounds (Miller *et al* 2000), on migratory corridors (e.g. Malme *et al* 1988, Tyack 2009, Dunlop *et al* 2013), and on foraging grounds for a variety of species (Di Iorio and Clark 2010, Parks *et al* 2011, Goldbogen *et al* 2013). Studies of migrating whales indicate that individuals may be highly responsive to noise exposure during migration, but may be able to deviate around acoustic disturbance without significant changes to the migratory distance (Malme *et al* 1988, Tyack 2009, Dunlop *et al* 2013).

The greatest data gaps regarding relative risk by h

abitat and season come from the facts that a) many species only have been tested in one type of habitat area and b) detection of an overt behavioural response may not truly indicate disturbance if animals are unable or unwilling to leave the habitat for foraging or breeding purposes. Also, for several species there is little known on the location of biologically important habitats (breeding, calving and foraging grounds).Future research to assess physiological responses to the same acoustic disturbance in multiple habitat areas are needed to have a high level of confidence regarding the actual impacts of noise exposure to mysticetes.

B.4.3. Impact of Exposure Levels

Relatively little data are available regarding the hearing abilities of mysticetes. Much of the current level of understanding comes from either anatomical modelling studies (Ketten 2000) or indirectly through interpretation of behavioural responses of mysticetes to controlled exposure experiments (Mooney *et al* 2012). A thorough review of exposure criteria for behavioural responses for mysticetes is summarized in Southall *et al* (2007). The thresholds for detectable behavioural responses to noise exposure varied by species, location and time of year, giving a wide range of thresholds for responses to multiple pulses and non-pulse signals.

Table 4: TTS and PTS from impulsive and non-impulsive noise sources for mysticetes (NOAA 2016)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
SEL cum 24h	168 dB	179 dB	183 dB	199 dB
dB peak	213 dB	n/a	219 dB	n/a

Peak sound pressure (dB peak) has a reference value of 1 µPa, and the 24 hour cumulative sound exposure level (SEL cum 24h) has a reference value of $1 \mu Pa^2 s$.

B.4.4. Assessment Criteria

Based on an extensive body of literature on the effects of noise on mysticetes (including physiology, behaviour and temporary habitat abandonment), a number of detailed criteria should be considered to assess potential risk of an signal generating activity. These include:

- Amplitudes, signal structure (pulse, multi-pulse, non-pulse), and anticipated cumulative time of exposure.
- Vulnerability of the species or sustainable ‘take’ – Some mysticete species and stocks are highly endangered, and warrant additional consideration if proposed activities have any potential to cause impacts at any level.
- Seasonal variability in the potential risk due to migratory timing of occupancy (can activities be seasonally shifted to minimize overlap with mysticete presence in critical habitat areas?).
- Data on noise exposure studies of target species, or closely related species, with similar signal type
- Comparison of the proposed acoustic exposure relative to the ambient, background levels and spectra of environmental noise (i.e. relatively low level noise exposure may be more significant in acoustically ‘pristine’ habitats).
- Consideration of potential cumulative effects of an additional introduction of sound into the environment (i.e. increase in potential for masking, increase in duration of exposure on daily and/or seasonal scales).

B.4.5. Species not listed on the CMS Appendices that should also be considered during assessments

Several of the CMS Appendix I and II species have not previously been studied regarding responses to noise exposure.

In particular, relatively little is known regarding the acoustic behaviours of sei whale, *Balaenoptera borealis*, Antarctic minke whale, *Balaenoptera bonaerensis*, Bryde's whale, *Balaenoptera edeni* and Omura's whale, *Balaenoptera omurai.*

In addition to the species listed in CMS Appendix I and II gray whale, *Eschrichtius robustus*, should be considered, due to recent documentation of individuals in 'novel' habitats including multiple confirmed sightings in the Atlantic Ocean (McKeon *et al* 2016) and severely threatened stocks in the Eastern Pacific (Rugh 2005).

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B.5. Pinnipeds

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Seals in the Wadden Sea (Wadden Sea seals)
- MOU Concerning Conservation Measures for the Eastern Atlantic Populations of the Mediterranean Monk Seal (*Monachus monachus*) (Atlantic monk seals)

Related modules

- Refer also to modules B.10, B.12 and C when assessing impact to pinnipeds

B.5.1. Species Vulnerabilities

Pinnipeds are sensitive to sound in both air and under water, therefore, they are likely to be susceptible to the harmful effects of loud noise in both media. Recent research has revealed that many pinnipeds have a better hearing sensitivity in water than was previously believed. (Southall *et al* 2000, 2008, Reichmuth *et al* 2013)

In developing guidelines for underwater acoustic threshold levels for the onset of permanent and temporary threshold shifts in marine mammals, NOAA has been considering two pinniped families: Phocidae and Otariidae. Phocid species have consistently been found to have a more acute underwater acoustic sensitivity than otariids, especially in the higher frequency range. This reflects the fact that phocid ears are better adapted underwater for hearing than those of otariids, with larger, more dense middle ear ossicles. (NOAA, 2016) The effective auditory bandwidth in water of typical Phocid pinnipeds (underwater) is thought to be 50 Hz to 86 kHz while for Otariid pinnipeds (underwater) it is 60 Hz to 39 kHz (NOAA, 2016). The draft NOAA guidelines do not pertain to marine mammal species under the U.S. Fish and Wildlife Service's jurisdiction, including the third family of pinnipeds: Odobenidae (walrus), which means there is no update on the auditory bandwidth of walrus.

Behavioural responses to anthropogenic noise have been documented in a number of different pinnipeds at considerable ranges indicating the need for precautionary mitigation (Kelly *et al* 1988) In addition to noise-induced threshold shifts, behavioural responses have included seals hauling out (possibly to avoid the noise) (Bohne *et al* 1985, 1986, Kastak *et al* 1999) and cessation of feeding (Harris *et al* 2001).

It is likely that pinniped foraging strategies also place them at risk from anthropogenic noise. Some pinnipeds forage at night, others transit to foraging locations by swimming along the bottom, and many dive to significant depths or forage over significant distances (Fowler *et al* 2007, Villegas-Amtmann *et al* 2013, Cronin *et al* 2013) with Australian sea lions foraging offshore out to 189 km (Lowther *et al* 2011).

In most respects, noise-induced threshold shifts in pinnipeds follow trends similar to those observed in odontocete cetaceans. Unique to pinnipeds are their vibrissae (whiskers), which are well supplied with nerves, blood vessels and muscles, functioning as a highly sensitive hydrodynamic receptor system (Miersch *et al* 2011). Vibrissae have been shown to be sufficiently sensitive to low frequency waterborne vibrations to be able to detect even the subtle movements of fish and other aquatic organisms (Renouf, 1979, Hanke *et al* 2012, Shatz and Groot, 2013). Ongoing masking through ensonification may impede the sensitivity of vibrissae and the animal's ability to forage.

It is possible that even if no behavioural reaction to anthropogenic noise is evident, masking of intraspecific signals may occur. (Kastak and Schusterman, 1998)

B.5.2. Habitat Considerations

Spatial displacement of pinnipeds by noise has been observed (e.g Harris *et al* 2001), however observations are too sparse and definitely require greater attention to be understood in ways that can inform management. Such displacement is likely to have serious consequences if affecting endangered species in their critical habitats, such as Mediterranean monk seals in Greece or Turkey. Displacement can cause the temporary loss of important habitat, such as feeding grounds, forcing individuals to either move to sub-optimal feeding location, or to abandon feeding altogether. Noise can also reduce the abundance of prey (refer to modules on fin-fish and cephalopods in these guidelines).

Displacement can also reduce breeding opportunities, especially during mating seasons. Foraging habitat and breeding seasons are therefore important lifecycle components of pinniped vulnerabilities. In particular, the periods of suckling and weaning are vulnerable times for both mothers and pups.

Many pinnipeds species exhibit high site fidelity. For some there is little or no interchange of females between breeding colonies, even between those separated by short distances, such as in Australian sea lions, *Neophoca cinerea* (Campbell *et al* 2008). The site fidelity of these animals increases their risk of local extinction, especially at sites with low population numbers (e.g monk seals).

Some species of pinnipeds can range far offshore and because they are difficult to sight and identify at sea their offshore foraging may only be revealed by telemetry studies. These studies usually involve tagging individuals that might come ashore hundreds or even thousands of miles from offshore foraging habitats.

B.5.3. Impact of Exposure Levels

Onset of temporary threshold shift (TTS) and permanent threshold shift (PTS) for impulsive and non-impulsive noise, and at peak levels (for instantaneous impact) as well as sound exposure levels (SEL) accumulated over a 24 hour period based on the latest updates of the NOAA acoustic guidelines (NOAA, 2016), are summarized in the tables that follow (right).

Walrus, *Odobenus rosmarus*, hearing is relatively sensitive to low frequency sound, thus the species is likely to be susceptible to anthropogenic noise. (Kastelein *et al* 2002) TTS and PTS levels can be inferred from Southall *et al* (2007) for Odobenidae.

Kastelein *et al* 2002 has drawn useful general observations by comparing hearing studies of the California sea lion, *Zalophus californianus*, harbour seal, *Phoca vitulina*, ringed seal, *Pusa hispida*, harp seal, *Pagophilus groenlandicus*, northern fur seal, *Callorhinus ursinus*, gray seal, *Halichoerus grypus*, Hawaiian monk seal, *Monachus schauinslandi* and northern elephant seal, *Mirounga angustirostris* to those of walrus. The high frequency cut-off of walrus hearing is much lower than other pinnipeds tested so far. The hearing sensitivity of the walrus *Odobenus rosmarus*, between 500 Hz and 12 kHz is similar to that of some phocids. The walrus, is much more sensitive to frequencies below 1 kHz than sea lion species tested. (Kastelein *et al* 2002) Other sensitive pinnipeds such as harbour seals (about 20 dB more sensitive to signals at 100 Hz than California sea lions) and elephant seal, *Mirounga angustirostris* and *Mirounga leonine*, are also more likely to hear low-frequency anthropogenic noise. (Kastak and Schusterman, 1998)

Assessment should consider that routine deep-divers, that dive to or below the deep sound channels, may be exposed to higher sound levels than would be predicted based on simple propagation models. Assessment should also consider convergence zones which may result in areas with higher sound levels at greater ranges.

Table 5: TTS and PTS from impulsive and non-impulsive noise sources for phocidae (from NOAA 2016)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
SEL cum 24h	170dB	181dB	185dB	201dB
dB peak	212dB	n/a	218dB	218dB

Table 6: TTS and PTS from impulsive and non-impulsive noise sources for otariidae (from NOAA 2016)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
SEL cum 24h	188dB	199dB	203dB	219dB
dB peak	226dB	n/a	232dB	232dB

Table 7: TTS and PTS from impulsive and non-impulsive noise sources for odobenidae (from Southall *et al* 2007)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
SEL cum 24h	171dB	171dB	186dB	203dB
dB peak	212dB	212dB	218dB	218dB

B.5.4. Assessment Criteria

There have been surprisingly few studies of the effects of anthropogenic noise, particularly from seismic surveys, on pinnipeds (Gordon *et al* 2003).

The lack of evidence of dramatic effects of anthropogenic noise on pinnipeds, in contrast to the well-known mortality incidents with some cetaceans, does not necessarily mean that noise has negligible consequences on pinniped conservation, and more attention should be dedicated to achieving a better understanding of possible impacts. For instance, some pinnipeds may not appear to have been physically displaced by loud noise, moving instead to the sea surface, but these animals may be effectively prevented from foraging, due to an ensonified foraging environment.

It is important that assessment of impact for pinnipeds considers both the physiological impact (TTS and PTS) as well as the very real possibility of masking, causing both behavioural responses and making prey less available.

B.5.5. Species not listed on the CMS Appendices that should also be considered during assessments

The following species are also sensitive to anthropogenic marine noise:

- walrus, *Odobenus rosmarus*
- harbour seal, *Phoca vitulina*
- northern elephant seal, *Mirounga angustirostris*
- southern elephant seal, *Mirounga leonine*
- Caspian seal, *Phoca caspica*
- Australian sea lion, *Neophoca cinerea*
- Hawaiian monk seal, *Neomonachus schauinslandi*

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B.6. Polar Bears

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Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Pingers and other noise-generating activities

Related modules

- Refer also to modules B.1 and B.5 when assessing impact to polar bears

B.6.1. Species Vulnerabilities

There are two studies of polar bear hearing, showing that polar bears have hearing similar to humans, and that best sensitivity was shown between 11.2 – 22.5 kHz (Nachtigall *et al* 2007), and 8 – 14 kHz (Owen and Bowles 2011).

There have not been many specific studies of polar bears and noise. It has been shown that polar bears in Spitsbergen are disturbed by snowmobiles and can show strong behavioural reactions on a distance of 2-3 km, females with cubs showing stronger reactions at longer distance than adult males (Andersen and Aars 2008).

Polar bear would be highly vulnerable when hunting, as they are hunting for seals and depend on stealth, either by sneaking up on seals or by waiting at seal breathing holes in the ice (Stirling 1974, Stirling and Latour 1978). Studies indicate that denning females could be somewhat protected from noise from seismic air guns, although they could be vulnerable if sound sources are within close proximity of the den (less than 100 m) (Blix and Lentfer 1992).

B.6.2. Habitat Considerations

Polar bear's essential habitat is sea ice. Polar bears would prefer to stay on sea ice covering shallow and productive shelf areas (Durner *et al* 2009, Schliebe *et al* 2006). There would be particular concerns associated with all activities that have an impact in areas which resource selection functions have shown are preferred sea ice habitat for polar bears (Durner *et al* 2009).

Some models project an ice-free Arctic Basin in summer in just a few years from now, before 2020 (Maslowski *et al* 2012), and modelling studies have shown that most subpopulations will be reduced and experience large environmental stress (Amstrup *et al* 2008, Hamilton *et al* 2014).

Although not exclusively associated with specific habitats, there are certain activities that might be a concern. Some industrial activities are located in important habitat, of special concern is oil drilling activities on sea ice in productive sea areas, and the prospect of new developments of petroleum exploration in critical habitat, especially in North America. It must be noted that there are little or no specific studies of the effect of noise or manmade sound on polar bears, thus the level of impact is to a large degree inferred from general expert knowledge of the effect of disturbance on these animals.

Future impact from disturbance from sound exposure needs to be focused on denning areas in spring, and areas of sea ice and glacier fronts that are used by females with cubs-of-the-year to find food immediately after den emergence. Arctic areas in northern Canada, bordering to the Arctic Basin are generally the areas where one expects sea ice habitat to persist for the longest period (Amstrup *et al* 2007).

B.6.3. Impact of Exposure Levels

Given the specific vulnerability of polar bears to habitat loss, the exposure level of polar bears, especially in denning areas in spring, and areas of sea ice and glacier fronts that are used by females with cubs-of-the-year to find food immediately after den emergence should be prioritized.

B.6.4. Assessment Criteria

An assessment of the future impact of noise would have to take into account the dramatically decreasing area of critical sea ice habitat, in some areas the length of the ice-free period from ice melt in spring till ice freeze-up in fall, has increased by more than 140 days in the period 1979-2015 (Laidre *et al* 2015).

A minimum would be that EIAs on impact of sound would assess to what extent sound exposure would be detrimental to reproductive success by directly considering the effect of sound in denning areas and productive sea ice areas in the vicinity of denning areas, and also areas of sea ice over productive shelf areas.

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B.7. Sirenians

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal construction works
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)
- MOU on the Conservation and Management of Dugongs (*Dugong dugon*) and their Habitats throughout their Range (Dugong)

B.7.1. Species Vulnerabilities

Even though traditional ecological knowledge and field observations (Marsh *et al* 1978, Hartman 1979) suggest that sirenians (manatees and dugongs) have 'exceptional acoustic sensitivity', scientific research on their hearing and reactions to marine noise is relatively sparse. Published hearing studies are based on the Florida manatee, *Trichechus manatus latirostis*, while behavioural studies on reactions to noise are limited to the Florida manatee, the Antillean manatee, *Trichechus manatus,* and the dugong, *Dugong dugon*. Although most of this research is limited to sounds in water, behavioural observations indicate that sirenians are capable of detecting some sounds in air above the surface (Hartman 1979).

Evoked potentials recorded for Florida manatees (Bullock *et al* 1982, Mann *et al* 2005) demonstrated variable sensitivity over a range of frequencies from about 200Hz to 35–40 kHz with greatest sensitivity in the lower range at 1–1.5 kHz. In-water behavioural audiograms of four captive Florida manatees identified the frequency range of best hearing as 6 to 32 kHz (Gerstein *et al* 1999, Gerstein 2002, Gaspard *et al* 2012), with individual variation within this range. Peak hearing sensitivity has been variously reported as 16-18 kHz (Gerstein *et al* 1999, Gerstein 2002) and 8 kHz (Gaspard *et al* 2012). Gaspard *et al* (2012) also reported that one of their test animals appeared to be able to hear loud sounds as low as 0.25 kHz and ultrasonic frequencies as high as 90.5 kHz. Gerstein *et al* (1999) speculated that the greater sensitivity to higher frequencies observed in their audiogram research may be an adaptation that enabled manatees to avoid the complications associated with perceiving sound reflections propagated from the water–air interface (Lloyd mirror effect) in the shallow depths typical of their habitats, raising the interesting question of what these animals can hear when at the surface.

Both Gerstein (1999) and Gaspard *et al* (2012) conducted in-water behavioural experiments on captive Florida manatees to measure critical ratios. The differences in their results likely reflect both their different experimental protocols and individual differences in the manatees' responses. Gaspard *et al* (2012) found that the manatees have relatively narrow auditory filters and struggle to hear lower and higher pitched sounds above background noise. However, manatee hearing was much sharper at 8 kHz – the frequency at which manatees communicate – where they could still distinguish tones that were only 18.3 dB louder than the background. This estimate of the manatee's critical ratio (8 kHz) is among the lowest measured in mammals (Gaspard *et al* 2012) suggesting that generic marine mammal impact guidelines may not be appropriate for sirenians.

Field studies show that both the Florida manatee (Miksis-Olds *et al* 2007) and the dugong (Hodgson and Marsh 2007) exhibit short-term behavioural responses to noise. Miksis-Olds and Wagner (2010) showed that elevated sound levels affect the patterns of behaviour of the Florida manatee and that the response is a function of the manatee's behavioural state. When ambient sounds were highest, the manatees spent more time feeding and less time milling. In contrast, Hodgson and Marsh's (2007) experimental and behavioural studies showed that the time that dugongs spent feeding and travelling was unaffected by boat presence, the number of boat passes and whether a pass included a stop and restart. However, focal dugongs were less likely to continue feeding if the boat passed within 50 m, than if the boat passed at a greater distance. Boats passing at a range of speeds, and at distances of less than 50 m to over 500 m evoked mass movements of dugong feeding herds, but such movements only lasted a couple of minutes. Castelblanco-Martínez and Arévalo-González (2015) experimentally studied the effects of side-scan sonar operating 455 kHz on the behaviour of 12 captive Antillean manatees. All the observed manatees variously showed behavioural changes including stopping foraging and feeding, significantly reducing displacement and remaining still at the bottom or at the surface, and increasing displacement behaviour. One male displayed continuous spinning movements for almost the entire experimental session. Most animals avoided the area nearest to the transducer.

Sirenians are not wilderness animals (Marsh *et al* 2011). Manatees occur in the inshore waters of Florida and have continued to use the intra-coastal waterway and residential canal estates, despite a high level of vessel activity (for references see Marsh *et al* 2011). Dugongs continue to use Johore Strait between Singapore and Peninsula area, one of the most heavily-used coastal waterways in the world, and are often detected in ports and military training areas along the Queensland east coast on the basis of their feeding trails and satellite tracking (Marsh *et al* 2011, Cleguer *et al* 2016). Hodgson *et al* (2007) experimentally tested the behavioural responses of dugongs to 4 and 10 kHz acoustic alarms (pingers). The rate of decline of the number of dugongs within the focal arena did not change significantly while pingers were activated. Dugongs passed between the pingers irrespective of whether the alarms were active or inactive, fed throughout the experiments and did not change their orientation to investigate pinger noise, or their likelihood of vocalizing. Thus despite the short-term behavioural responses noted above, there is no evidence that wild dugongs or Florida manatees are displaced by underwater noise, including side scan sonar (Gonzalez-Socoloske *et al* 2009). The reaction of dugongs and manatees to impulsive sounds does not appear to have been formally tested.

Both manatees and dugongs use underwater sound for communication. There have been numerous studies of sirenian communication sounds (see Marsh *et al* 2011) Characteristics of individual call notes seem fairly similar among the species of sirenians. Frequency ranges are typically from 1 to 18 kHz, often with harmonics and non-harmonically related overtones (e.g Anderson and Barclay 1995, Sousa-Lima *et al* 2002, O'Shea and Poche 2006).

Adults of both sexes produce vocalizations, but exchanges of communication calls are most common between cows and their nursing calves. Florida manatee calves vocalize at much greater rates than adults (Sousa-Lima *et al* 2002, O'Shea and Poche 2006). Manatees other than cows and calves vocalize at rates that vary with activity and behavioural context, and are lowest during resting, intermediate while travelling, and highest at nursing and other social situations (Reynolds 1981, Bengtson and Fitzgerald 1985, Williams 2005, O'Shea and Poche 2006, Miksis-Olds and Tyack 2009). Dugongs seem to vocalize more often during dark, early morning hours (Ichikawa *et al* 2006). No data are available on vocal communication in African manatees, *Trichechus senegalensis*, although recordings and sound spectrograms of calls of an isolated captive calf in Cote d'Ivoire were similar to those of some Florida and Amazonian manatee calves (TJ O'Shea unpublished). Florida manatees may alter vocalization parameters in response to environmental noise levels (Miksis-Olds and Tyack 2009). Sakamoto *et al* (2006) attempted to quantify the effect of vessel noise on the vocal characteristics of dugongs (number of call per minute, dominant frequency and call duration). None of the changes was significant.

We know of no information regarding PTS, TTS or noise-induced auditory damage in sirenians.

B.7.2. Habitat Considerations

In the marine environment, both manatees and dugongs mostly occur in shallow waters because of their dependence of seagrass communities (Marsh *et al* 2011). Antillean and African manatees are both riverine and estuarine and in the marine environment mainly occur in water less than 5 m deep. Dugongs are strictly marine, feeding in waters up to about 35 m deep. They may occasionally cross ocean trenches (see Marsh *et al* 2011), but typically spend most of their lives in much shallower inshore coastal and island waters often commuting with the tide to or from intertidal seagrass meadows (Marsh *et al* 2011). There is increasing evidence that dugong migration corridors follow topographic features such as coastlines (Zeh *et al* 2016 in press) or reef crests (Cleguer 2015).

B.7.3. Impact of Exposure Levels

Given that the available evidence suggests that manatees and dugongs are unlikely to be displaced by noise, the most practical approach to reducing the risk of impacts is avoidance of the overlap of acute sound impacts with seasonal aggregation sites and periods when the animals are likely to be under stress. Seasonal aggregation sites are most likely at the high latitude limits of the ranges of dugongs and manatees and typically occur as a behavioural repose to thermal conditions or prolonged periods of rough weather (see Marsh *et al* 2002 and 2011 for details of some well-known sites in Florida, Australia and the Arabian region). Site-specific information on this topic should be a focus of the Environmental Impact Assessment process. Extreme weather events such as cyclones or prolonged cold fronts can cause substantial increases in mortality (Marsh *et al* 2011, Meager and Limpus 2013) and noisy construction impacts should be planned to avoid times of likely environmental stress.

B.7.4. Assessment Criteria

We know of no field studies on the effects of anthropogenic noise, other than vessel noise on sirenians. The effect of vessel noise *per se* seems much less than that of vessel collisions. This lack of evidence does not prove that noise has negligible consequences for sirenian conservation, and more attention should be dedicated to a better understanding of possible impacts and ways to ameliorate them. A precautionary approach to the exposure of manatees and dugongs to noise, especially at key habitats and aggregation sites, is warranted.

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B.8. Marine and Sea Otters

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Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related modules

- Refer also to modules B.10, B.12 and C when assessing impact to marine and sea otters

B.8.1. Species Vulnerabilities

The marine otter, *Lontra feline*, and sea otter, *Enhydra lutris*, are amphibious marine mammals that may be vulnerable to coastal anthropogenic disturbance. Auditory thresholds for sea otters have been measured in air and underwater from 125 Hz to 40 kHz. Critical ratios data indicate that although sea otters can detect underwater sounds, their hearing appears to be primarily air adapted and not specialized for detecting signals in background noise. (Ghoul and Reichmuth 2012, 2014, 2016)

B.8.2. Habitat Considerations

There is little definitive research available about the specific anthropogenic noise vulnerabilities of this species group, but given the frequency range of hearing and the knowledge that these animals are social communicators and benthic foragers, (McShane *et al* 1995, Leuchtenberger *et al* 2014, Lemasson *et al* 2014, Thometz *et al* 2015) this species group should be considered. Their dependence on restricted nearshore habitats puts sea otters at risk from acoustic disturbance and activities occurring both on land and at sea. (Ghoul and Reichmuth 2016)

B.8.3. Impact of Exposure Levels

Ghoul and Reichmuth (2016) have conducted the only known assessment of sea otter hearing sensitivity. They found that hearing was most sensitive at 8 and 16 kHz, where measured thresholds were the lowest at 69 dB re 1 μPa. The range of best sensitivity in water spanned ~4.5 octaves, from 4 to 22.6 kHz. The roll-off in high-frequency hearing was typically steep and had a 28-dB increase within a half-octave frequency step. Low-frequency hearing (0.125–1 kHz) was notably poor. The sea otter was unable to detect signals below 100 dB re 1 μPa within this frequency range. Noise spectral density levels in the underwater testing enclosure were sufficiently low to ensure that the measured thresholds were not influenced by background noise, especially at frequencies above 0.5 kHz, where noise levels were below 60 dB re 1 μPa/√Hz. (Ghoul and Reichmuth 2016)

B.8.4. Assessment Criteria

Regulators estimating zones of auditory masking for sea otters should follow the guidance given for other marine mammals and opt for conservative estimates until additional data are available. (Southall *et al* 2000)

B.8.5. Species not listed on the CMS Appendices that should also be considered during assessments

Sea otters, *Enhydra lutris*, are classified by IUCN as Endangered, and should also be considered during assessments.

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B.9. Marine Turtles

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- MOU Concerning Conservation Measures for Marine Turtles of the Atlantic Coast of Africa (Atlantic marine turtles)
- MOU on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA)

Related modules

- Refer also to modules B.12 and C when assessing impact to marine turtles

B.9.1. Species Vulnerabilities

Although the ecological role of hearing has not been well studied for sea turtles, hearing capacity has been inferred from morphological and electrophysiological studies. (Southwood *et al* 2008)

Sea turtles do not have an external ear, in fact, the tympanum is simply a continuation of the facial tissue. Researchers have speculated that the cochlea and saccule are not optimized for hearing in air, but rather are adapted for sound conduction through two media, bone and water. Recent imaging data strongly suggest that the fats adjacent to the tympanal plates in at least three sea turtle species are highly specialized for underwater sound conduction. (Moein Bartol and Musick, 2003)

Hearing range (50-1200 Hz: Viada *et al* 2008, Martin *et al* 2012, Popper *et al* 2014) coincides with the predominant frequencies of anthropogenic noise, increasing the likelihood that sea turtles might experience negative effects from noise exposure.

At present, sea turtles are known to sense low frequency sound, however, little is known about the extent of noise exposure from anthropogenic sources in their natural habitats, or the potential impacts of increased anthropogenic noise exposure on sea turtle biology. Behaviour responses have been clearly demonstrated. (Samuel *et al* 2005)

Prolonged exposure could be highly disruptive to the health and ecology of the animals, encouraging avoidance behaviour, increasing stress and aggression levels, causing physiological damage through either temporary or even permanent threshold shifts, altering surfacing and diving rates, or masking orientation cues. (Samuel *et al* 2005)

B.9.2. Habitat Considerations

Sea turtles have been shown to exhibit strong fidelity to fixed migratory corridors, habitual foraging grounds, and nesting areas (Avens *et al* 2003), and such apparent inflexibility could prevent sea turtles from selecting alternate, quieter habitats.

The potential of noise for displacing turtles from their favoured or optimal habitat is unknown, but if it were to occur it could have negative consequences on growth, orientation, etc.

B.9.3. Impact of Exposure Levels

Sea turtles are low frequency specialists, but their range appears to differ between populations. Animals belonging to one population of subadult green turtles have been shown to detect frequencies between 100-500 Hz with their most sensitive hearing between 200-400Hz. Another responded to sounds from 100-800 Hz, with their most sensitive range being 600-700Hz. Juvenile Kemp's ridley turtles had a range of 100-500Hz, with their most sensitive hearing been 110-200Hz. (Moein Bartol and Ketten, 2006)

B.9.4. Assessment Criteria

It is important that assessment of impact for sea turtles both considers the physiological impact (TTS and PTS) as well as the very real possibility of masking prey movements, and impacts to nesting behaviour, in particular during inter-nesting resting. Some sea turtles may not appear to noise-generating industries to have been physically displaced by loud noise but these animals may be effectively prevented from foraging, due to an ensonified foraging environment.

Possible effects of distribution (avoidance behaviour) orientation, and even communication (e.g in the hatching phase) cannot be discounted.

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B.10. Fin-fish

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Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)
- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)
- Agreement on the Conservation of Seals in the Wadden Sea (Wadden Sea seals)
- MOU Concerning Conservation Measures for the Eastern Atlantic Populations of the Mediterranean Monk Seal (*Monachus monachus*) (Atlantic monk seals)
- MOU Concerning Conservation Measures for Marine Turtles of the Atlantic Coast of Africa (Atlantic marine turtles)
- MOU on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA)
- MOU on the Conservation of Migratory Sharks (Sharks)

Related modules

- Refer also to modules B.12 when assessing impact to fish

B.10.1. Species Vulnerabilities

The use of explosives will kill fin-fish inside a certain range (Yelverton *et al* 1975), with impact zones given in Popper *et al* (2014). Intense non-explosive, impulse noise such as pile driving or seismic surveys may impact adult fin-fish by: a) creating physiological damage such as rupturing gas spaces (ie. Halverson *et al* 2012), b) damaging sensory systems (McCauley *et al* 2003), c) creating adverse behavioural responses (e.g. Pearson *et al* 1996, McCauley *et al* 2003, Slotte *et al* 2004, Fewtrell and McCauley 2012, Hawkings *et al* 2014), d) masking the reception of signals of interest, or e) disrupting prey physiology, behaviour or abundance. For fin-fish the sustained but less intense noise from vessels or offshore construction activities may commonly produce behavioural impacts or masking of communication signals as indicated above. Fin-fish exposed to lower level, man-made noise for suitable time periods may receive damage to hearing systems and so suffer a loss of fitness.

There is an enormous amount of variability in the degree of sophistication of fin-fish hearing systems and habits which may pre-dispose or protect them from impacts of man-made noise sources, thus it is difficult to generalize known impacts across all fin-fish species with a high degree of confidence. In general terms: explosives routinely cause fin-fish deaths out to some range and sub-lethal injuries beyond this, pile driving is known to produce serious physiological and organ damage to fin-fish at short range, in some cases marine seismic surveys with air guns have produced hearing damage to fin-fish while in other cases such damage has not been observed, and most man-made noise sources are capable of producing fin-fish behavioural or masking impacts to some degree. Behavioural response to an approaching noise source by fin-fish seems to be reasonably generic, pelagic fin-fish tend to move downwards to eventually lie close to the seabed or flee laterally while site-attached fish may initially seek shelter in refuges or flee. At least some species of fin-fish do habituate to continual and stationary low level noise as they readily colonize man-made offshore facilities. The longer-term implications of consistent behaviour changes or slight physiological impairment from intense signals produced by seismic surveys are not well understood.

Many fin-fish form aggregations at specific times and places to spawn and produce fertilized eggs. Such aggregations may be spaced across several months or may occur only on few occasions per season. Many fin-fish species produce communication sounds as part of such aggregations (ie. McCauley 2001). Disruptions to such fin-fish spawning aggregations by excessive noise causing physiological or behavioural changes and which overlaps a large fraction of the species' seasonal spawning period will have deleterious impacts on the following years reproductive output.

All fin-fish are dependent on smaller prey species which may be impacted by man-made noise sources. Prey may include fin-fish or invertebrates. In general terms small, common, fin-fish prey species, such as sardines, herring or pilchards, have well developed sensory systems thus may be equally or more vulnerable to exposure to intense man-made noise than the larger fin-fish which prey on them. The response of marine invertebrates to intense signals such as seismic survey noise, are poorly known so it is difficult to draw conclusions or comparisons on how invertebrate prey fields will be impacted by noise exposure. Any changes to prey fields induced by a man-made noise source will impact fauna, possibly negatively, higher up the food chain.

All impacts of man-made noise sources on fin-fish need to be gauged at the population level. Noise sources which produce short term impacts, localized impacts compared with a species range, or which do not overlap well with habitats or time and spatial overlap of spawning periods would be expected to be of low severity form a population perspective, and vice versa.

B.10.2. Habitat Considerations

Fin-fish occupy an enormous variety of habitats, from deep ocean depths, pelagic systems, reefs and shoals, estuarine waters to inland waterways. Some fish may utilize multiple habitats on a seasonal or life cycle basis. In general terms habitats which are enclosed, such as estuaries, bays or reefs for site attached fin-fish, may be more susceptible to exposure by intense sound sources as the fin-fish have little options to escape the source. By contrast fin-fish that occupy physically larger spaces, such as oceanic species, have more options of where to flee and may be less constrained by the implications of moving geographical regions to avoid a noise source.

B.10.3. Impact of Exposure Levels

Known impacts of intense impulse noise exposure on fin-fish include consistencies in fish behavioural response to sound, but many anomalies. For high-energy impulse signals, such as seismic survey signals, the following can be said:

Fish behaviour most often changes at some range near to an approaching seismic vessel and generalized changes include diving, lateral spread or fleeing an area (e.g. Pearson *et al* 1996, McCauley *et al* 2003, Slotte *et al* 2004, Fewtrell and McCauley 2012, Hawkings *et al* 2014).

Fish behaviour is strongly impacted by an approaching seismic source above received levels of 145–150 dB re 1 µPa^2.s (SEL) (McCauley *et al* 2003), which equates to around 2–10 km using measured air gun arrays > 2000 cui.

Avoidance to an approaching seismic vessel by fish may be partly driven by the fish behavioural state, with feeding fishes appearing to be more tolerant and in one instance not showing avoidance to an approaching seismic survey vessel (Penä *et al* 2013).

Catch rates in some fisheries are altered during and after seismic operations, prolonged seismic can cause large-scale displacement of fish resulting in decreased fish abundance in and near a seismic operations area and increased fish abundance at long range (tens of km) from the seismic operations area (Engås *et al* 1996, Slotte *et al* 2004),

Long-term monitoring of reef fish community structure before and after a seismic survey programme showed no large-scale change in community structure (Miller and Cripps 2013) and fish sound production behaviour (chorusing) continued after a seismic programme with no apparent long-term change (McCauley 2011),

Exposure to accurately emulated repeated pile driving signals suggest physical injury (organ damage) arises at levels equivalent to 1920 strikes at 179 dB re 1 µPa^2.s or 960 strikes at 182 dB re 1 µPa^2.s, or an equivalent single strike SEL of 210–211 dB re 1 µPa^2.s (Halvorsen *et al* 2012).

In a review of experimental findings of sound on fishes Popper *et al* (2014) present sound exposure guidelines for fin-fish in the form of estimated levels at which the following occur: 1) mortality and potential mortal injury, 2) impairment – recoverable injury, 3) impairment – TTS, 4) impairment – masking, and 5) behavioural changes. They present these impacts for three categories of fin-fish, 1) no swim bladder, 2) swim bladder present but no links to otolith system, or 3) swim bladder present with links to otolith system, plus sea turtles and eggs/larvae. Popper *et al* (2014) present this data for sources of explosives, pile driving, air gun arrays, sonar and shipping. Given the lack of experimental evidence for most of these categories they were forced to: 1) either extrapolate from another exposure type, animal group or both, and 2) rather than presenting threshold levels often present the subjectively evaluated likelihood of an impact type occurring at 'near' (tens of m), 'intermediate' (hundreds of m) and 'far' (thousands of m) ranges. The thresholds listed for physical injury (mortality and impairment-recoverable injury) for pile driving and seismic air gun signals are the same, being primarily based on the pile driving work of Halverson *et al* (2012). Readers are referred to Popper *et al* (2014) for the particular thresholds for a fin-fish and sound exposure type as the reader should see their text for the reasoning and caveats behind the values presented.

B.10.4. Assessment Criteria

In assessing impacts of a noise source on fin-fish any EIA document should consider species which:

- are important for commercial fisheries,
- are listed as threatened, vulnerable or are endemic to an area,
- can be considered as important 'bait fish' or are important as prey species for higher order fauna,
- have limited ability to flee an intense noise source,
- utilize a noise impacted area for specific purposes such as feeding or spawning events.

In considering impacts of underwater noise on a species of fin-fish, factors which must be taken into account include:

- hearing capabilities of the species in question including knowledge of morphological adaptations to increase hearing capability, noting fin-fish primarily respond to motion of the water particles and less to measures of sound pressure. Fin-fish have a diverse range of morphological adaptations to improve hearing capability,
- studies of known impacts on this species,
- studies of known impacts on related species either taxonomically, morphologically or in general terms if no other comparison is available (ie. pelagic fishes, benthic fishes etc),
- particular spatial and temporal features which are critical to that fin-fish population's survival (ie. specific feeding areas or prey types, spawning locations and periods).

For migratory fin-fish impact assessment must consider if a noise producing action may cause a species to leave an area and if so, the consequences of this to the species in question, for other fauna and for commercial fisheries which target that species.

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B.11. Elasmobranchs

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- MOU on the Conservation of Migratory Sharks (Sharks)

Related modules

- Refer also to modules B.10 and B.12 when assessing impact to elasmobranchs

B.11.1. Species Vulnerabilities

Elasmobranchs as a group are poorly studied in relation to the potential impact of anthropogenic sounds, although several studies over time have been directed at particular species of shark to improve knowledge of their hearing mechanisms, abilities and implications for management. From as early as the 1960s (e.g. Nelson and Gruber, 1963), studies have shown that large sharks (*Carcharhinidae*, *Sphyrnidae*), in their natural environment, were attracted to low-frequency (predominantly 20 to 60 Hz) pulsed sounds, but apparently not to higher frequency (400 to 600 Hz) pulsed sounds, or to low-frequency continuous sounds. More recent research has established the hearing range of sharks to be between 40 Hz to approximately 800 Hz (Myrberg 2001), with possible limits for elasmobranchs in general at 20–1000 Hz (Casper and Mann, 2006, 2010).

Noise within the sharks' audible range may be produced by several anthropogenic sources such as shipping, underwater construction, pile driving, dredging, power stations and sonic surveys. It has been suggested that loud sounds in their audible range may repel sharks whereas low sounds may attract them (Francis and Lyon, 2013), probably as these latter mimics sounds emitted by struggling prey. Response likely depends on its distance from the source and the volume of the source.

Although more recent research in elasmobranch hearing and impacts in the wild have been sparse at best, and nonexistent for most species, there is evidence of habituation or at least no negative reaction to noise levels and frequencies from small boats operating recreational diving or from SCUBA divers' noises, even when these are regularly present and arising from many sources (Lobel, 2009 and personal observations by the author of this summary).

It is likely that elasmobranchs might suffer more impacts from noise through the effects it has on its prey species (Popper and Hastings, 2009, Carlson, 2012), and perhaps through acute events that impact concentration sites such as social groupings of hammerhead sharks, *Sphyrna* spp., and white sharks, *Carcharodon carcharias*, around offshore islands, as well as those gathering at coral reef habitats, in these cases, displacement may occur, either temporary or permanent, although again lack of adequate field research prevents any definitive conclusions. Several studies (eg Klimley and Myrberg 1979, Banner 1972, Myrberg *et al* 1978) indicate that elasmobranchs show consistent withdrawal from sources that are at close range and when confronted with sudden onset of transmissions. However they may habituate to these too if events become frequent (Myrberg, 2001). Seismic activities, pylon-driving operations, explosive construction work and activities involving similar pulsed sound emissions are likely therefore to have the most impact on elasmobranch species directly.

B.11.2. Habitat Considerations

Several species of elasmobranchs exhibit some type of site-fidelity, either permanent or seasonal. This has been observed in particular regarding species of interest to the dive industry. Some species of shark (eg whitetip, *Triaenodon obesus*, blacktip, *Carcharinus melanopterus*, and grey reef, *Carcharhinus amblyrhynchos*) and the reef manta, *Manta alfredi*, are particularly attached to coral reef environments, while others exhibit seasonal concentration around offshore islands (eg hammerheads, *Sphyrna lewini*, at Galápagos, Cocos and Malpelo Islands, white sharks, *Carcharodon carcharias*, at Guadalupe and Farallon Islands, whale sharks, *Rhincodon typus*, at Holbox, Mexico, and several other sites). Giant mantas *Manta birostris* also can be found in seasonal concentrations such as in Revillagigedo Islands in Mexico, Laje de Santos in Brazil and La Plata in Ecuador.

Seasons for these aggregations vary from site to site and by species and need to be assessed on a case by case basis.

Acoustic impacts which might severely affect vulnerable or complex habitats such as coral reefs or mangrove forests (essential nursery areas for some shark and ray species) are certain to have an effect on its elasmobranch fauna if it includes displacement or damage to prey species and any physical disruption of the habitat. Seasonal concentration areas for sharks and rays can be particularly vulnerable to acute acoustic disturbance, which may result in abandonment of the area or disruption of gregarious behaviour whose implications are yet not fully understood. Acute acoustic disturbances such as seismic or sonic surveys and any activity involving explosives in or around these critical habitats (coral reefs, offshore islands and other known seasonal concentration sites, key feeding grounds) are likely to have serious impacts on elasmobranch populations.

Although migration paths are still poorly understood for most species, recent satellite tagging research (e.g. Domeier and Nasby-Lucas, 2008) has begun to reveal some consistent patterns and as yet unknown concentration areas away from above-water topographic features. These areas likely represent additional vulnerability corridors where protection from acute acoustic disturbance should be incorporated into management actions.

B.11.3. Impact of Exposure Levels

As a group, elasmobranchs have been poorly represented in field studies on acoustics, with most knowledge available for more "visible" species such as large sharks. For these, observed impacts refer mostly to short-term avoidance responses to loud, sudden bursts of sound in their audible range, although there´s evidence that the regularity of such sounds might lead to habituation (see references above).

Given that bony fish, which make the majority of prey species for most sharks, may be severely impacted by sound (Slabekoorn et al., 2010), especially in loud bursts (eg Carlson, 2012), it is perhaps this indirect effect on prey that holds the most severe potential for generating impacts on shark populations.

There is insufficient information to assess long-term impacts or behavioral changes in elasmobranchs from anthropogenic noise that might affect survivability of species. Existing studies indicate that the most direct negative impact on the animals seems to be displacement by sonic outbursts, while longer-term exposure often seems to lead to habituation (Lobel, 2009; Myrberg, 2001; Myrberg at al., 1972).

B.11.4. Assessment Criteria

From available data it seems that there are two main aspects of potential impacts on elasmobranchs that merit particular consideration: displacement or elimination of prey species and displacement or disruption of behaviour associated with specific sites by sound bursts. Given that detailed studies are mostly lacking, a precautionary approach to the exposure of elasmobranchs to noise, especially at key habitats and aggregation sites, is warranted. In particular activities involving the use of equipment or methods that generate loud sonic outbursts near known or estimated aggregation areas, or which might physically injure or displace prey, need to be carried out with adequate assessment (including baseline surveys for elasmobranch species and their prey) and mitigation measures as feasible and appropriate. Also, proposed activities that alter or impact key habitats such as coral reefs, mangroves or offshore islands with known aggregations of elasmobranch species should be carried out with extreme caution and this group of species should be explicitly considered in studies and proposed management measures to reduce potential impacts.

B.11.5. Species not listed on the CMS Appendices that should also be considered during assessments

In general, listed species include those for which several acoustic and hearing studies exist, but as for the entire group detailed acoustic impact studies are lacking. The development and collation of more detailed data on a species by species basis could greatly help improve our understanding of the impacts of anthropogenic noise on their physiology and life cycles. Lack of information on most elasmobranch species is an impediment to the provision of any meaningful advice on species not listed on the CMS Appendices,

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B.12. Marine Invertebrates

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Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)
- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)
- Agreement on the Conservation of Seals in the Wadden Sea (Wadden Sea seals)
- MOU Concerning Conservation Measures for the Eastern Atlantic Populations of the Mediterranean Monk Seal (*Monachus monachus*) (Atlantic monk seals)
- MOU Concerning Conservation Measures for Marine Turtles of the Atlantic Coast of Africa (Atlantic marine turtles)
- MOU on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA)
- MOU on the Conservation of Migratory Sharks (Sharks)

Related modules

- Refer also to modules B.10 when assessing impact to marine invertebrates

B.12.1. Species Vulnerabilities

Very little is known about effects of anthropogenic noise on invertebrates (Morley *et al* 2014). This includes more than 170,000 described species of multicellular marine invertebrates in spite of their ecological and economic importance worldwide (Anderson *et al* 2011). Most research targets molluscs (e.g. cephalopods, shellfish) and crustaceans (e.g. crabs, shrimps, barnacles) (reviewed in Aguilar de Soto, 2016).

Molluscs:

Two atypical mass-strandings involving nine giant squids, *Architeuthis dux*, were associated with seismic surveys co-occurring in nearby underwater canyons where this species concentrates (Guerra *et al* 2004, 2011). Two specimens suffered extensive multiorganic damage to internal muscle fibres, gills, ovaries, stomach and digestive tract. Other squids were probably disoriented due to extensive damage in their statocysts. Damage to the sensory epithelium was also observed in four species of coastal cephalopods (*Sepia officinalis*, *Loligo vulgaris*, *Illex coindetii* and *Octopus vulgaris*) by exposure to two hours of low-frequency sweeps at 100 per cent duty cycle (André *et al* 2011, Solé, 2012, Solé *et al* 2013). Fewtrell and McCauley (2012) reported that squid, *Sepioteuthis australis*, exposed to seismic pulses from a single air gun showed signs of stress such as significant increases in the number of startle and alarm responses, with ink ejection in many cases, increased activity and changing position in the water column.

Delayed and abnormal development as well as an increase in mortality rates in eggs and larvae of shellfish exposed to noise have been recorded in two species. New Zealand scallop larvae, *Pecten novaezelandiae*, exposed to playbacks of low frequency pulses in the laboratory showed significant developmental delays and developed body abnormalities (Aguilar de Soto *et al* 2013). The number of eggs of sea hares, *Stylocheilus striatus*, that failed to develop at the cleavage stage, as well as the number that died shortly after hatching, were significantly higher in a group exposed to boat noise playback at sea compared with playback of ambient noise (Nedelec *et al* 2014). In contrast, playbacks of ship-noise enhanced larval settlement in the mussel, *Perna canaliculus* (Wilkens *et al* 2012) while seemed to increase biochemical indicators of stress in adult mussels (*Mytilus edulis*) (Wale *et al* 2016).

Crustaceans:

Stress responses were observed in aquarium-dwelling brown shrimp, *Crangon crangon*, exposed to ambient noise of some 30 dB higher than normal at 25–400 Hz (Lagardere, 1982, Regnault and Lagardere, 1983). Shrimps did not seem to habituate throughout the experiment. Similarly, shore crabs, *Carcinus maenas*, increased metabolic consumption and showed signals of stress when exposed to playbacks of ship noise in the laboratory. Crustacean larvae seem to differ in their sensitivity to noise: larval dungeness crabs, *Metacarcinus magister,* did not show significant differences in survival nor in time-to-moult when exposed to a single pulse from a seven air gun array, even at the higher received level of 231 dB re 1µPa (Pearson *et al* 1994). In contrast, larvae of other crab species, *Austrohelice crassa* and *Hemigrapsus crenulatus* megalopae, exposed to playbacks of noise from tidal turbines tended to suffer significant delays in time-to-moult (Pine *et al* 2012) and low-frequency noise exposure inhibited settlement of early larvae of barnacle, *Balanus amphitrite* (Branscomb and Rittschof, 1984). The apparent contradiction in the larval responses from different species of crustaceans may be due, among other things, to the experimental set-up (wild versus laboratory, one pulse versus a continuous exposure), the biology of the species, or the characteristics of the sound treatment. Cellular and humoral immune responses of marine invertebrates to noise have also been examined. In the European spiny lobster, *Palinurus elephas*, exposure to sounds resembling shipping noise in the laboratory affected various haematological and immunological parameters considered to be potential health or disease markers in crustaceans (Celi *et al* 2014).

B.12.2. Habitat Considerations

Marine invertebrates inhabit a range of habitats. Mainly, they may live associated to the seafloor (benthic or bentho-pelagic species) or free in the water column (pelagic). Many species have an initial pelagic phase as larvae, useful for dispersion, before finding suitable habitat for settling into their adult life. Sound from preferred habitats is one of the cues used by larvae to find a suitable location to settle (Stanley *et al* 2012). Once they settle, many species have limited capabilities to move fast enough at distances required to avoid noise exposure, due to morphological constrains or to territorial behaviour.

Species associated to the seafloor will be more exposed to ground-transmission of noise. This is especially relevant for intense low frequency sounds directed towards the seafloor, typical of seismic surveys. Seismic pulses coupled with the seafloor and low frequency vibrations can travel long distances through the ground and can re-radiate to the water depending on the structure and composition of the seafloor. Marine invertebrates are sensitive to the particle motion component of sound, more than to the pressure wave, they are well suited to detect low frequency vibrations because these are used, for example, to identify predators and prey.

The variability in the extent of barotrauma experienced by different giant squid stranding at the same time, in coincidence with the same seismic survey (Guerra *et al* 2004, 2011), underlines the difficulties inherent in predicting noise-induced damage to animals in the wild. Here, some giant squid suffered direct mortality from barotrauma, while the death of others seemed to be caused by indirect effects of physiological and behavioural responses to noise exposure. Direct injury (barotrauma) can be explained by some animals being exposed to higher sound levels due to complex patterns of sound radiation creating zones of convergence (Urick, 1983) of the seismic sound waves reflected by the sea surface/sea floor, and possibly by the walls of the steep underwater canyons in the area where the seismic survey took place.

Marine invertebrates often have discrete spawning periods. It is unknown if eggs/larvae have a greater vulnerability to sound-mediated physiological or mechanical stress, or even particular phases of larval development when larvae undergo metamorphosis.

Metamorphosis involves selective expression of genes mediating changes in body arrangement, gene expression is susceptible to stress, including from noise. Spawning periods are key for the recruitment of marine invertebrates and thus should be considered when planning activities.

B.12.3. Impact of Exposure Levels

There are no data about thresholds of pressure or particle motion initiating noise impacts on marine invertebrates. Studies have found a range of physiological effects (reviewed in Aguilar de Soto and Kight 2016) but there are no dose-response curves identifying levels of impact onset. Moreover, most studies report only sound pressure level, while particle motion is relevant for the effects of noise on these species. At a distance from an acoustic source (in the far-field) the pressure and particle motion components of sound are easily predicted in a free homogeneous environment such as the water column. In contrast, in the near-field animals may experience higher particle motions than would be expected for the same pressure level in the far-field. Intense underwater sound sources such as air guns, pile driving, sonar and blasting have back-calculated peak source levels ranging from 230 to, in the case of blasting, >300 dB re 1 µPa at 1m. These activities routinely ensonify large areas with sound pressure levels higher than the thresholds of response observed in different studies of noise-impacts on marine invertebrates. For example, a seismic array with an equivalent source level of 260 dB pk-p re 1 µPa at 1m will produce levels in excess of 160 dB_{rms} over hundreds of km-squared. This level was measured in an experiment reporting noise-induced developmental delays and malformations in scallop larvae (Aguilar de Soto *et al* 2013). But the particle velocities experienced by the larvae in the experiment (about 4-6 mm s^{-1} RMS) imply higher far-field pressure levels of some 195-200 dB_{rms} re 1 µPa, reducing the potential impact zone to only short ranges from the source. However, there are several reasons why larvae in the wild may be impacted over larger distances than these approximate levels suggest. Given the strong disruption of larval development reported, weaker but still significant effects can be expected at lower exposure levels and shorter exposure durations. Moreover, low frequency sounds propagate in complex sound fields in which convergence zones and re-radiation of sound transmitted through the sea-floor can create regions with high sound levels far from the source (Madsen *et al* 2006). The sound field experienced by an organism is a complex function of its location with respect to the sound source and acoustic boundaries in the ocean necessitating *in situ* measurements to establish the precise exposure level.

B.12.4. Assessment Criteria

Benthic marine invertebrates often have little movement capabilities further than a few metres, limiting their options to avoid exposure to anthropogenic noise. In the case of intense low frequency noise, e.g. seismic or pile driving, it is essential to consider ground-transmission. For example, during a seismic survey animals will be exposed to sound received from the air gun array passing over the location of the animals, but these invertebrates will be receiving at the same time ground-transmitted vibrations originated by previous seismic pulses. Thus, animals will experience waves arising from the water and from the ground, differing in phase and other parameters. Complex patterns of wave addition mean that in some cases vibrations will sum, increasing the levels of sound exposure to the animals. Because ground vibrations may travel tens of kilometres or more, the time that benthic invertebrates will be exposed to a given threshold of pressure or particle motion will be increased when we consider seafloor transmission. An alternative source for seismic surveys (©Vibroseis) is currently being tested. In contrast to usual seismic surveys transmitting pulses every 6 to 15 s from an air gun array towed by a ship near the sea-surface, Vibroseis is towed near the seafloor and emits continuously, but at lower peak level. Thus, duty cycle increases to 100 per cent. EIA of Vibroseis and other low frequency sound sources should include modelling particle motion in the target area and consider exposures to benthic fauna.

Results of experiments about effects of noise on catch rates of marine invertebrates have not shown significant effects: Andriguetto-Filho *et al* (2005) did not find changes on catches of shrimps after the passage of a small air gun array. No effects of seismic activities on catches of rock-lobsters were found either by Parry *et al* (2006) performing a long-term analysis of commercial data. In contrast, fishermen have blamed seismic sources for mortalities of scallops and economic losses due to reduced catch rates.

Despite uncertainties about how noise may affect marine fauna and fisheries, several countries have already implemented regulations that reduce overlap between seismic surveys and fishing activities (mainly of fin-fish). However, these regulations do not address concerns of noise effects on eggs and larvae, i.e. that noise might affect stock recruitment and thereby cause delayed reductions in catch rates.

Marine invertebrates form the base of the trophic-web in the oceans, providing an important food source for fish, marine mammals and humans. In addition to direct effects to adults, noise exposure during critical growth intervals may contribute to stock vulnerability, underlining the urgency to investigate potential effects of acoustic pollution on marine invertebrates at different ontogenetic stages. Moreover, recent results investigating the effects of noise on a range of marine invertebrate species call for applying the precautionary principle when planning activities involving high-intensity sound sources, such as explosions, construction, pile driving or seismic exploration, in spawning areas/times of marine invertebrates with high natural and economic value.

B.12.5. Species not listed on the CMS Appendices that should also be considered during assessments

Some large cephalopods are migratory, including the giant squid, *Architeuthis sp* (Winkelmann *et al* 2013). Given the vulnerability of this species to acoustic sources, it should also be considered during assessments.

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C. Decompression Stress

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Decompression sickness (DCS, 'the bends') is a disease associated with gas uptake at pressure. As hydrostatic pressure increases with depth, the amount of nitrogen (N_2) that is absorbed by the blood and tissues increases, resulting in higher dissolved gas tensions that could at maximum reach equilibrium with the partial pressure of N_2 in the lungs. This is a long-known problem for human divers breathing pressurized air, but has often been discounted as a problem for breath-hold divers since they dive on only a single inhalation (Scholander 1940). However, for free-diving humans and other air-breathing animals, tissues can become highly saturated under certain circumstances depending on the iterative process of loading during diving and washout at the surface (Paulev 1967, Lemaitre *et al* 2009). During decompression, if the dissolved gas tension in the tissues cannot equilibrate fast enough with the reducing partial pressure of N_2 in the lungs, tissues will become supersaturated, with the potential for gas-bubble formation (Francis and Mitchell 2003).

Breath-hold diving vertebrates were previously thought to be relatively immune to DCS due to their multiple anatomical, physiological and behavioural adaptations (Fahlman *et al* 2006, Fahlman *et al* 2009, Hooker *et al* 2012). However, recent observations have shown that marine mammals and turtles may be affected by decompression sickness under certain circumstances (Jepson *et al* 2005, Dennison *et al* 2012, Van Bonn *et al* 2013, Garcia-Parraga *et al* 2014). Of most concern, however, are the beaked whales, which appear to be particularly vulnerable to anthropogenic stressors that may cause decompression sickness (Jepson *et al* 2003, Cox *et al* 2006, D'Amico *et al* 2009, Hooker *et al* 2009, Hooker *et al* 2012).

C.1.1. Bubble Formation

Among marine mammals, both acute and chronic gas emboli have been observed. The formation of bubbles has been suggested as a potential explanation for lesions coincident with intravascular and major organ gas emboli in beaked whales that mass stranded in conjunction with military exercises deploying sonar (Jepson *et al* 2003, Fernandez *et al* 2005). There is some controversy about the exact behaviour leading to the gas emboli (Hooker *et al* 2012). However it is widely agreed that this outcome was linked to man-made acoustic disturbance. These types of lesions have also been reported in some single-stranded cetaceans for which they do not appear to have been immediately fatal (Jepson *et al* 2005, Bernaldo de Quirós *et al* 2012, Bernaldo de Quirós *et al* 2013). Looking at species-specific variability in bubble presence among stranded animals, the deeper divers (Kogia, Physeter, Ziphius, Mesoplodon, Globicephala, and Grampus) appeared to have higher abundances of bubbles, suggesting that deep-diving behaviour may lead to a higher likelihood of decompression stress (Bernaldo de Quirós *et al* 2012).

In addition, osteonecrosis-type surface lesions have been reported in sperm whales (Moore and Early 2004). These were hypothesized to have been caused by repetitive formation of asymptomatic N_2 emboli over time and suggest that sperm whales live with sub-lethal decompression induced bubbles on a regular basis, but with long-term impacts on bone health. Bubbles have also been observed from marine mammals bycaught in fishing nets, which died at depth (Moore *et al* 2009, Bernaldo de Quirós *et al* 2013). These bubbles suggested the animals' tissues were supersaturated sufficiently to cause bubble formation when depressurized (as nets were hauled). B-mode ultrasound has detected bubbles in stranded (common and white-sided) dolphins, which showed normal behaviour after release and did not re-strand, and so appeared to tolerate this bubble formation (Dennison *et al* 2012). Cerebral gas lesions have also been observed using Magnetic Resonance Imaging in California sea lions, *Zalophus californianus*, admitted to a rehabilitation facility (Van Bonn *et al* 2011, Van Bonn *et al* 2013).

It therefore appears that gas supersaturation and bubble formation may occur more routinely than previously thought. These cases highlight a growing body of evidence that marine mammals are living with blood and tissue N_2 tensions that exceed ambient levels (Moore *et al* 2009, Bernaldo de Quirós *et al* 2013). However, our understanding of how marine mammals manage their blood gases during diving, and the mechanism causing these levels to become dangerous is very rudimentary (Hooker *et al* 2012). Some perceived threats appear to cause a behavioural response that may override normal N_2 management, resulting in decompression sickness, stranding and death.

C.1.2. Sources of Decompression Stress

Most evidence for both beaked whale fatalities and for behavioural modification (thought to be the precursor to further effects) has suggested an anthropogenic sound source. There is a documented association between naval active sonar exercises (particularly mid-frequency active sonar) and beaked whale mass strandings (Frantzis 1998, Evans and England 2001, Jepson *et al* 2003). Spatial and temporal correlations between active sonar and beaked whale strandings support this conclusion but suggest a role for specific bathymetric topography leading some areas to show correlations while others do not (Filadelfo *et al* 2009). A comprehensive review of beaked whale mass strandings (D'Amico *et al* 2009) suggested that some strandings might be associated with other source events. However, the evidence is less comprehensive in support for high-intensity underwater sounds other than mid-frequency sonar causing fatalities for these species (Taylor *et al* 2004; Barlow and Gisiner 2006). In terms of other sources causing behavioural modification, ship-noise appears to cause a behavioural response disrupting foraging behaviour in Cuvier's beaked whales, *Ziphius cavirostris* (Soto *et al* 2006).

Another form of decompression stress is the oxidative stress caused by diving (Hermes-Lima and Zenteno-Savin 2002). Episodic regional lack of oxygen and abrupt reperfusion upon re-surfacing creates a situation where post-ischemic reactive oxygen species (ROS) and physiological oxidative stress are likely to occur. Decompression sickness likely has a multifactorial origin, but this oxidative stress could be a contributor (Wang *et al* 2015).

C.1.3. Source Frequency, Level and Duration

Understanding the responses of cetaceans to noise is a two-stage process: (1) understanding the noise required to cause the behavioural modification and (2) understanding the physiological mechanism by which that behavioural modification causes harm to the animal. At present, almost all research has focussed on the first of these, i.e. work evaluating playback and response, and almost nothing is known about how this response then leads to decompression stress.

Several recent studies have found similar behavioural responses of a small number of beaked whales to sonar signals (Tyack *et al* 2011, DeRuiter *et al* 2013, Stimpert *et al* 2014, Miller *et al* 2015). These studies have shown that beaked whales respond behaviourally to sonar and other human and natural stimuli, typically showing a combination of avoidance and cessation of noise-production associated with foraging (Table 8). Responses to simulated sonar have started at low received levels. These types of behavioural changes were also documented in work monitoring vocal activity using Navy range hydrophones (Tyack *et al* 2011, Moretti *et al* 2014).

C.1.4. Assessment Criteria

At the planning stage, the primary mitigation method to reduce issues of decompression stress would be to reduce the interactions of stressor and animals (i.e. to reduce the number of "takes"). Acknowledging that there might be other planning issues that limit flexibility, this could be done by placing high-intensity noise into areas without high densities of species of concern. Thus proposals should take account of all survey and modelling information sources to predict areas of likelihood of high/low species density, and attempt to reduce the number of impacted animals by designing operations within areas of lower animal density.

To supplement this, or in areas in which such species densities are unknown, baseline studies will be needed. Beaked whales are particularly difficult to monitor visually (surfacing for as little as 8 per cent of the time), but have more reliable detection acoustically (vocalising for 20 per cent of the time, de Soto *et al* 2012). Hydrophone arrays can detect animals at 2-6km distances (eg Moretti *et al* 2010, Von Benda-Beckmann *et al* 2010).

During the activity, real-time monitoring of animal presence should be conducted using visual and acoustic monitoring, with detections within a specified range of the activity resulting in cessation of the sound source. Mitigation measures such as 'ramp-up' may be effective, although some beaked whale species show curiosity toward novel sounds which may increase the likelihood of impact (Miller et al. 2015).

Monitoring over a wider area can sometimes be achieved using hydrophone arrays on the seafloor (Moretti *et al* 2010). Such hydrophone arrays allow detection over a wide but static area. Dynamic monitoring over a wide area is not currently feasible.

Modelling of animal likelihood and distance from the source should be carried out in order to minimize received levels (Table 8), thus reducing the risk of animals receiving too high a dose which might incur DCS/death.

Table 8: Responses of beaked whales to sound sources

Species	Sound source	Response observed at received level (dB re. 1µPa)
Cuvier's beaked whale, *Ziphius cavirostris* (DeRuiter *et al* 2013)	30 min playback of 1.6s MFA sonar signal repeated every 25 sec. Initial source level of 160 dB re 1 mPa-m was increased ('ramped up') by 3 dB per transmission to a maximum of 210 dB re 1 mPa-m.	89-127
Cuvier's beaked whale, *Ziphius cavirostris* (Soto *et al* 2006)	Maximum broadband (356 Hz–44.8 kHz) level received during the ship passage was 136 dB $_{rms}$ re 1 µPa, approx. 700m away.	106 (in click frequency range)
Northern bottlenose whale, *Hyperoodon ampullatus* (Miller *et al* 2015)	104 1-s duration 1–2 kHz upsweep pulses (naval sonar signals) at 20s intervals. The source level of the sonar pulses increased by 1 dB per pulse from 152 to 214 dB re 1 µPam over 20min (61 pulses), and the remaining pulses were transmitted for 15min at a source level of 214 dB re 1 µPa m.	107
Baird's beaked whale, *Berardius bairdii* (Stimpert *et al* 2014)	Simulated mid-frequency active (MFA) military sonar signal at 3.5-4 kHz, transmitting 1.6 s signal every 25 s. The initial source level of 160 dB re: 1 mPa was increased by 3 dB per transmission for the first 8 minutes to a maximum of 210 dB for 22 additional minutes (72 transmissions total over 30 minutes).	127
Blainville's beaked whale, *Mesoplodon densirostris* (Tyack *et al* 2011)	Simulated 1.4 s MFA sonar, killer whale and noise signals. MFA sonar had both constant frequency and frequency modulated tonal components in the 3–4 kHz band repeated every 25 s. Initial source level of 160 dB re 1 mPa-m was increased ('ramped up') by 3 dB per transmission to a maximum of 210 dB re 1 mPa-m.	138

C.1.5. Species not listed on the CMS Appendices that should also be considered during assessments

Beaked whales, *Ziphius cavirostris* (Appendix I) and *Hyperoodon* spp and *Berardius* spp (Appendix II) require additional consideration. These species appear particularly vulnerable to noise impacts. 20 species of *Mesoplodon* are currently missing from the CMS Appendices and yet are likely to also be vulnerable to noise impacts. All of these species are likely to be particularly sensitive to decompression stress.

Of other deep diving species which may potentially be at increased risk of decompression stress, *Kogia* are currently not listed on either of the CMS Appendices, *Physeter* is listed on Appendices I and II, *Globicephala* on Appendix II, and Grampus should also be considered during assessments.

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D. Exposure Levels

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D.1. Impact of Exposure Levels and Exposure Duration

One of the first comprehensive definitions of exposure criteria for noise impact on marine mammals considering two types of impacts, namely auditory injury and behavioural disturbances by three sound types (single pulse, multiple pulse and nonpulse) has been published by Southall *et al* (2007). Just recently, the National Oceanic and Atmospheric Administration (NOAA) compiled and synthesized best available science to guide the assessment of effects of anthropogenic noise on marine mammals (NOAA, 2016). Both guidance documents consider cetaceans and pinnipeds assigned to five functional hearing groups (i.e. low-frequency cetaceans, mid-frequency cetaceans, high-frequency cetaceans, pinniped in water, pinnipeds in air and low-frequency cetaceans, mid-frequency cetaceans, high-frequency cetaceans, phocid pinnipeds underwater, otariid pinnipeds underwater respectively). The assignment to functional hearing groups was based on functional hearing characteristics of the species (e.g. frequency range of hearing, auditory morphology) and with reference to Southall *et al* as well the medium in which the amphibious living pinnipeds were exposed to sound. The developed noise exposure criteria do not address polar bears, sirenians, and sea otters due to the absence of necessary data in these species. To account for different hearing bandwidths and thus differences in impacts of identical noise exposure frequency-weighting functions were developed for each functional hearing group and considered in the formulation of the noise exposure criteria. Southall *et al* and NOAA applied dual criteria for noise exposure using peak sound pressure level (SPL) and sound exposure level (SEL) in each of the considered functional hearing groups in order to account for all relevant acoustic features such as sound level, sound energy, and exposure duration that influence the impacts of noise on marine mammals.

The onset of a permanent threshold shift (PTS-onset) has been considered as the onset of auditory injury (Southall *et al* 2007, NOAA 2016, Finneran 2015). PTS-onset estimates are applied in order to formulate dual noise exposure levels. The PTS-onset thresholds were estimated from measured TTS-onset thresholds (=threshold where temporary change in auditory sensitivity occurs without tissue damage) in very few mid-frequency odontocetes (i.e. bottlenose dolphin and beluga) and pinnipeds (i.e. California sea lion, northern elephant seal, and harbour seal) and extrapolated to other marine mammals due to the scarcity of available TTS data. It has been noted, that this extrapolation from mid-frequency cetaceans and the subsequent formulation of exposure criteria may be delicate in particular for high-frequency cetaceans due to their generally lower hearing threshold as compared to other cetaceans. The growth rates of TTS were estimated based on data in terrestrial and marine mammals exposed to increasing noise levels. Noise exposure levels for single pulse, multipulse and nonpulse sounds were expressed for SPL and SEL whereby the latter has been frequency weighted to compensate for the differential frequency sensitivity in each functional marine mammal hearing group as described above. No noise exposure criteria were developed by Southall *et al* (2007) or NOAA (2016) for the occurrence of non-auditory injuries (e.g. altered immune response, energy reserves, reproductive efforts due to stress, tissue injury by gas and fat emboli), due to a lack of conclusive scientific data to formulate quantitative criteria for any other than auditory injuries caused by noise.

Additionally to auditory injuries Southall *et al* (2007) presented also explicit sound exposure levels for noise impacts on behaviour resulting in significant biological responses (e.g. altered survival, growth, reproduction) for single pulse noise. For the latter it has been assumed that given the nature (high peak and short duration) of a single pulse behavioural disturbance may result from transient effects on hearing (i.e. TTS). Therefore, TTS values for SPL and SEL were proposed as noise exposure levels. In contrast, for multiple and nonpulse sounds it has been taken into account that behavioural reactions to sounds are highly context-dependent (e.g. activity animals are engaged at the time of noise exposure, habituation to sound) and depending also among others on environmental conditions and physiological characteristics such as age and sex. Thus noise impact on behaviour is less predictable and quantifiable than effects of noise on hearing. Moreover, adverse behavioural effects are expected to occur below noise exposure levels causing temporary loss of hearing sensitivity. Therefore, a descriptive method has been developed by Southall et.al. (2007) to assess the severity of behavioural responses to multipulse and nonpulse sound. This method encompasses a quantitative scoring paradigm which numerically ranks (scores) the severity of behavioural responses. Noise exposure levels have been identified in a scoring analysis based on a thorough review of empirical studies on behavioural responses of marine mammals to noise. Reviewed cases with adequate information on measured noise levels and behavioural effects were then considered in a severity scoring table with the two dimensions, severity score and received SPL.

In contrast to former sound exposure assessment attempts Southall *et al* (2007) and NOAA (2016) account for differences in functional hearing bandwidth between marine mammal groups through the developed frequency-weighting functions. Thus, this approach allows to assess the effects of intense sounds on marine mammals under the consideration of existing differences in auditory capabilities across species and groups respectively. Furthermore, as compared to the widely used RMS sound pressure Southall *et al* (2007) and NOAA (2016) propose dual criteria sound metrics (SPL and SEL) to assess the impact of noise on marine mammals, accounting not only for sound pressure but also for sound energy, duration and high-energy transients.

All these aspects are certainly major accomplishment as compared to earlier attempts to assess noise effects on marine mammals. However, it has also to be noted that due to the absence of data noise exposure criteria had to be based on extrapolations and assumptions and therefore, as Southall *et al* (2007) and Finneran (2015) pointed out, caution is needed regarding the direct application of the criteria presented and that it is expected that criteria would change as better data basis becomes available.

D.2. Species Vulnerabilities

The best documented vulnerabilities to noise in marine mammals in terms of number of studies and species involved are certainly behavioural responses to noise. Only a few studies considering a few species exist regarding noise impacts on hearing and hearing sensitivity and physiology in marine mammals and therefore the respective knowledge on specific vulnerabilities of noise is rather scarce.

Auditory effects resulting from intense noise exposure comprise temporary threshold shift (TTS) and permanent threshold shift (PTS) in hearing sensitivity. For marine mammals TTS measurements exist for only a few species and individuals whereas for PTS no such data exist (Southall *et al* 2007, Finneran 2015). Furthermore, noise may cause auditory masking, the reduction in audibility of biological important signals, as has been shown for pinniped species in air and water (Southall *et al* 2000, 2003) and in killer whales (Foote *et al* 2004) for example.

Physiological stress reactions induced by noise may occur in cetaceans as has been shown for few odontocete species where altered neuro-endocrine and cardiovascular functions occurred after high level noise exposure (Romano *et al* 2004, Thomas *et al* 1990c). Furthermore, regarding noise-related physiological effects it has to be noted that scientific evidence indicates that in particular beaked whales experience physiological trauma after military sonar exposure (Jepson *et al* 2003, Fernandez *et al* 2004, 2005) due to in vivo nitrogen gas bubble formation.

The magnitude of the effects of noise on behaviour may differ from biological insignificant to significant (= potential to affect vital activities such as foraging and reproduction). Noise-induced behaviour response may not only vary between individuals but also intra-individually and depends on a great variety of contextual (e.g. biological activity animals are engaged in such as feeding, mating), physiological (e.g. fitness, age, sex), sensory (e.g. hearing sensitivity), psychological (e.g. motivation, previous history with the sound) environmental (e.g. season, habitat type, sound transmission characteristics) and operational (e.g. sound type, sound source is moving / stationary, sound level, duration of exposure) variables (Wartzok *et al* 2004).

Observable behavioural responses to noise include orientation reaction, change in vocal behaviour or respiration rates, changes in locomotion (speed, direction, dive profile), changes in group composition (aggregation, separation), aggressive behaviour related to noise exposure and/or towards conspecifics, cessation of reproductive behaviour, feeding or social interaction, startle response, separation of females and offspring, anti-predator response, avoidance of sound source, attraction by sound source, panic, flight, stampede, stranding, long term avoidance of area, habituation, sensitization, and tolerance (Richardson *et al* 1995, Gordon *et al* 2004, Nowacek *et al* 2007, Wartzok *et al* 2004).

Studies have shown that in mysticetes the reaction to the same received level of noise depends on the activity in which whales are engaged in at the time of exposure. For migrating bowhead whales strong avoidance behaviour to seismic air gun noise has been observed at received levels of noise around 120 dB re 1 µPa while engaged in migration. In contrast, strong behavioural disturbance in other mysticetes such as gray and humpback whales as well as feeding bowhead whales has been observed at higher received levels around 150-160 dB re 1 µPa (Richardson *et al* 1985, 1999, Malme *et al* 1983, 1984, Ljungblad *et al* 1988, Todd *et al* 1996, McCauley *et al* 1998, Miller *et al* 2005). Furthermore, in different dolphin species reactions to boat noise varied from avoidance, ignorance and attraction dependant on the activity state during exposure (Richardson *et al* 1995).

Noise-induced vocal modulation may include cessation of vocalization as observed in right whales (Watkins 1986), sperm whales and pilot whales (Watkins and Schevill 1975, Bowles *et al* 1994) for example. Furthermore, vocal response may include changes in output frequency and sound level as well as in signal duration (Au *et al* 1985, Miller *et al* 2000, Biassoni *et al* 2000).

Noise-induced behaviour depends on the characteristics of the area where animals are during exposure and/or of prior history with that sound. In belugas for example a series of strong responses to ship noise such as flight, abandonment of pod structure and vocal modifications, changes in surfacing, diving and respiration patterns has been observed at relatively low received sound levels of 94-105 dB re 1 µPa in a partially confined area but the animals returned after some days while ship noise was higher than before (LGL and Greeneridge 1986, Finley *et al* 1990).

The distance of a noise source or its movement pattern influences the nature of behavioural responses. For instance, in sperm whales, changes in respiration and surfacing rates has been observed in the vicinity of ships (Gordon *et al* 1992) and dependant on whether a ship is moving or not different reactions of bowhead whales and other cetaceans have been observed (Richardson *et al* 1995, Wartzok *et al* 2004)

D.2.1. Species not listed on the CMS Appendices that should also be considered during assessments

- Deep-diving cetaceans, in particular beaked whales need special consideration regarding noise exposure levels due to the risk for tissue trauma due to gas and fat emboli under certain noise conditions.
- Due to their lower overall hearing thresholds, high-frequency hearing cetaceans (true porpoises, river dolphins, *Pontoporia blainvillei*, *Kogia breviceps*, *Kogia sima*, *cephalorhynchids*) may need additional consideration as their sensitivity to absolute levels of noise exposure may be higher than other cetacean hearing groups.
- Southall *et al* pointed out that due to a lack of data they could not formulate noise exposure levels for polar bears, sea otters, and sirenians. Certainly a point which needs consideration when dealing with areas where these marine mammal taxa occur.

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E. Marine Noise-generating Activities

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Wild Migration

E.1. Military Sonar

E.1.1. Low-Frequency Active Sonar

The evolution of lower frequency active (LFA) sonar came from two needs. First, to increase detection ranges to overcome passive sonar systems and second, to compensate for the improvements of stealth designs in submarine hulls, part of which was an anechoic coating that absorbed incident waves. It was discovered this coating was less efficient when exposed to longer wave lengths.

LFA sonars work below the 1kHz range. For transmitting long distances efficiently, high-powered modulated signals, typically 240 dB in water at 1m, peak value, (240 dB re 1µPa @ 1m peak) are produced lasting from tens of seconds to sometimes minutes. An example of this technology is the SURTASS-LFA of the US navy that operates within 100-500Hz range. (Lurton, 2010)

E.1.2. Mid-Frequency Active Sonar

Mid-frequency active (MFA) sonar is used for detecting submarines at moderate range, typically less than 10km.

MFA operates between 1-5 KHz range, with a sound intensity level typically 235 dB in water at 1m, peak value, (235 dB re 1µPa @ 1m peak) with a pulse duration of 1-2 seconds. (Hildebrand, 2009, Fildelfo *et al* 2009)

E.1.3. Continuous Active Sonar

The concept of continuous active sonar (CAS) is generating interest in the anti-submarine warfare community, largely due to its 100 per cent duty cycle offering the potential for rapid, continuous detection updates. CAS operates between 500Hz to 3KHz range with sound intensity levels typically 182 dB in water at 1m, peak value, (182 dB re 1µPa @ 1m peak) with a signal duration of 18 seconds (Murphy and Hines, 2015)

E.1.4. Mine Counter Measures Sonar

Underwater mines have proven, over time, to be very effective. Their prevalence led to the development of the Mine Counter Measures (MCM) sonar. This system works at very high frequency, usually between 100-500kHz, to achieve high-quality acoustic imaging of the sea floor and water column. Targets, semi-buried or suspended from the sea floor, are easily identified. (Lurton, 2010)

E.1.5. Acoustic Minesweeping Systems

Acoustic Minesweeping Systems are another mine counter-measure that produces a low-frequency broadband transmission, mimicking the sound produced by certain vessels whereby detonating the mine. (Lurton, 2010)

E.2. Seismic Surveys

The commonly used surveying method for offshore petroleum exploration is ‘seismic reflection’. This is simply sound energy emitted from a sound source (air gun array) several metres below the sea surface that penetrates subsurface layers of the seabed and is reflected and refracted to the surface where it is detected by acoustic receivers (accelerometers and geophones).

These surveys are typically conducted using specially equipped vessels that tow one or more cables (streamers) with geophones at constant intervals. Air guns vary in size, and in conjunction with the charge pressure, determine the sound intensity level and frequency.

Frequencies used for seismic surveys are between 10-200Hz and down to 4-5Hz for the larger air guns. However, there are unused high-frequency components up to 150kHz, with a very high discharge at the onset of the pulse. (Goold and Coates, 2006)

The typical discharge sound intensity level of each pulse of an air gun array is around 260-262 dB in water at 1m, peak to peak value, (260-262 dB re 1µPa @ 1m p-p)

(OSPAR, 2009) every 10-15 seconds, and surveys typically run more or less continuously over many weeks. (Urick, 1983, Clay and Medwin, 1997, Caldwell and Dragoset, 2000, Dragoset, 2000, Lurton, 2010, Prideaux and Prideaux, 2015)

E.3. Civil High Power Sonar

Seafloor mapping sonar systems are probably one of the most prolific forms of underwater noise generation. The main application is coastal navigation for the production of bathymetric charts. Other applications include geology, geophysics, underwater cables and oil industry exploration. Three examples are Single Beam Sounders (SBES), Sidescan Sonars and Multibeam Echosounders (MBES).

E.3.1. Single Beam Sounders

Single beam sounders point vertically below the vessel and transmit a short signal, typically 0.1ms. The frequencies vary on their application. For deep water, the frequency would be around 12kHz and increase to 200, 400 and even 700KHz for shallow water. The sound intensity level is usually around 240 dB in water at 1m, peak value (240 dB *re* 1µPa @ 1m peak). (Lurton, 2010)

E.3.2. Sidescan Sonar

Sidescan sonar system structures are similar to single-beam sonars. This sonar differs as it is installed on a platform or "towfish" and towed behind a vessel close to the seabed. Two antennae are placed perpendicularly to the body of the towfish, pointing fractionally to the sea floor. The transmission of the sidescan sonar insonifies the sea floor with a very narrow perpendicular band. The echo received along time reflects the irregularities of the sea floor. A simple analogy is the scan mechanism of a photo copier. The operating frequency is usually in the range of many hundreds of kHz with the pulse duration 0.1ms or less. (Lurton, 2010)

E.3.3. Multibeam Echosounder

Multibeam echosounders are the major tool for seafloor mapping, for hydrography and offshore industry applications. The transmission and receiving arrays are mounted on the vessel to create a narrow beam, fan-like 150º spread, perpendicular to the keel.

Multibeam sounders can be put into three main categories depending on their system structure and varied uses:

- deep water systems, designed for regional mapping, 12khz for deep ocean, 30khz for continental slopes;
- shallow water systems designed for mapping continental shelves, 70-200kHz; and
- high-resolution systems for hydrography, shipwreck location and underwater structural inspection, 300-500khz.

The attraction for multibeam systems is the scale of area that can be covered over time. For instance, a deep water configured multibeam sounder with a 20km fan/spread can cover 10,000km² per day. (Lurton, 2010)

E.3.4. Boomers, Sparkers and Chirps

Sparkers and boomers are devices used to determine shallow features in sediments. These devices may also be towed behind a survey vessel, with their signals penetrating several tens (boomer) or hundred (sparker) of metres of sediments. Typical sound intensity levels of sparkers are approximately 204-210 dB in water at 1m, rms value (204-210 dB re 1 µPa @ 1 m). Deep-tow boomer sound intensity levels are approximately 220 dB in water at 1m, rms value (220 dB re 1 µPa @ 1 m). The frequency range of both is 80Hz-10kHz, and the pulse length is 0.2 ms. (Aiello *et al* 2012, OSPAR, 2009)

Chirps produce sound in the upper-frequency range around 20Hz-20 kHz. (Mosher and Simpkin, 1999) The sound intensity level for these devices is about 210-230 dB in water at 1m, peak value, (210-230 dB re 1 µPa @ 1 m) and the pulse length is 250ms. (Dybedal and Boe, 1994, Lee *et al* 2008, OSPAR, 2009)

E.4. Coastal and Offshore Construction Works

E.4.1. Explosions

Explosions are used in construction and for the removal of unwanted seabed structures. Underwater explosions are one the strongest anthropogenic sound sources and can travel great distances. (Richardson *et al* 1995) Sound intensity levels vary with the type and amount of explosive used and the depth to which it is detonated. TNT, 1-100lbs, can produce a sound intensity level from 272-287 dB in water at 1m, zero to peak value, (272-287 dB re 1µPa 0 to peak @ 1m) with a frequency range of 2-~1000Hz for a duration of <1-10ms. The core energy is between 6-21Hz. (Richardson *et al* 1995, NRC, 2003)

E.4.2. Pile driving

Pile driving is associated with harbour work, bridge construction and wind farm foundations. Sound intensity levels vary depending on pile size and type of hammer. There are two types of hammers, an impact type (diesel or hydraulic) and vibratory type. Vibratory type hammers generate lower source levels, but the signal is continuous, where impact hammers are louder and impulsive. The upper range is around 228 dB in water at 1m, peak value or 248-257 dB in water at 1m, peak to peak value, (228 dB re 1µPa peak @ 1 m/248-257 dB re 1µPa peak to peak @ 1m) with frequencies ranging within 20Hz-20kHz and a duration of 50ms. (Nedwell *et al* 2003, Nedwell and Howell, 2004, Thomsen *et al* 2006, OSPAR, 2009)

E.4.3. Dredging

Dredging is used to extract sand and gravel, to maintain shipping lanes and to route pipelines. The sound intensity level produced is approximately 168-186 dB in water at 1m, rms value, (168-186 dB re 1µPa @ 1m $_{rms}$) with frequencies ranging from 20Hz->1kHz with the main concentration below 500Hz.

The majority of this sound is constant and non-impulsive. (Richardson *et al* 1995, OSPAR, 2009)

E.5. Offshore Platforms

E.5.1. Drilling

Drilling can be done from natural or manmade islands, platforms, drilling vessels, semi-submersibles or drill ships.

For natural or manmade islands, the underwater sound intensity level has been measured at 145 dB in water at 1m, rms value, (145 dB re 1µPa @1m $_{rms}$) with frequencies below 100Hz. (Richardson *et al* 1995)

The sound intensity level transmitted down the caissons with platform drilling has been measured at approximately 150 dB in water at 1m, rms value, (150 dB re 1µPa $_{rms}$ @ 1m) at 30-40Hz frequency. (Richardson *et al* 1995)

Drill ships seem to emit the highest sound intensity level, 190 dB in water at 1m, rms value, (190 dB re 1µPa @ 1m $_{rms}$) with the frequencies ranging between 10Hz-10kHz, due to the efficient transmission of sound through the ship's hull. Additionally, ships use their location thrusters to keep them on target, combining propeller, dynamic positioning transponder (placed on the hull and sea floor) pingers (see below), and drill noise. (Richardson *et al* 1995, OSPAR, 2009, Kyhn *et al* 2014)

E.5.2. Positioning Transponders

Positioning transponders are used to dynamically position drill ships and other offshore platforms. Each system uses a concatenation of master and slave transponders. These systems have been recorded to have a sound intensity level of 100 dB in water at 2km, rms value (100 dB re 1µPa @ 2km $_{rms}$) with the frequencies ranging between 20kHz to 35kHz. (Kyhn *et al* 2014)

E.5.3. Related Production Activities

During production, noise sources include seafloor equipment such as separators, injectors and multi-phase pumps operating at very high pressures.

There have also been studies to measure the sound intensity levels during production maintenance operations. Sound intensity levels of 190dB rms from the drill ship (distance unknown) with a frequency range between 20Hz-10kHz were recorded. (Kyhn *et al* 2014) In another instance, well head (choke valves) were recorded as producing continuous noise 159 dB re 1 µPa @ 1m from the source (RMS) (McCauley, 2002)

There have been few systematic studies to measure the source levels of production maintenance. It is likely the sound intensity level is high. This is an area that needs focused attention.

E.6. Playback and Sound Exposure Experiments

Ocean science uses a variety of sound sources. These include explosives, air guns and underwater sound projectors.

Where studies involve the intentional exposure of animals to a particular noise source, the impact assessments (and ethics requirements) should refer to the information available in this Technical Background Information about the noise-generating activity and the species concerned (Modules B-D).

E.6.1. Ocean Tomography

Ocean tomography measures the physical properties of the ocean using frequencies between 50-200Hz with a sound intensity level of 165-220 dB in water at 1m (165-220 dB re 1µPa @ 1m). The *Acoustic Thermometry of Ocean Climate* research programme emitted a sound source of 195 dB in water at 1m, peak value, (195 dB re 1µPa @ 1m peak) at a frequency of 75Hz.

Geophysical research activities, one of which is the study of sediments in shallow water, also use typical mid or low-frequency sonar systems or echo-sounders. (OSPAR, 2009) These are discussed under Civil High Power Sonar.

E.7. Shipping and Vessel Traffic

Marine vessels, small to large, contribute significantly to anthropogenic noise in the oceans. The trend is usually, the larger the vessel, the lower the frequencies produced resulting in the noise emitted travelling greater distances. The sound characteristics produced by individual vessels are determined by the vessels class/type, size, power plant, propulsion type/design and hull shape with relation to speed. Also, the vessel's age regarding mechanical condition and the cleanliness of the hull: Less drag means less noise.

E.7.1. Small Vessels

Small vessels (leisure and commercial) for this paper are vessels up to 50m in length. These include planing hull designs such as jet skis, speed boats, light commercial runabouts as well as displacement hull designs like motor yachts, fishing vessels and small trawlers.

The greater portion of sound produced by these vessels is mainly above 1kHz mostly from propeller cavitation. Factors that generate frequencies below 1kHz are engine and gearbox noise as well as propeller resonance. The sound intensity level produced is approximately 160-180 dB in water at 1m, rms value, (160-180 dB re 1µPa @ 1m $_{rms}$) with frequencies ranging 20Hz ->10kHz. This, however, is dependent on the vessel's speed in relation to hull efficiency and economic speed to power settings. (Richardson *et al* 1995, OSPAR, 2009)

E.7.2. Medium Vessels

Medium vessels for this paper are vessels between 50-100m, such as tugboats, crew-boats, larger fishing/trawler and research vessels. These vessels tend to have slower revving engines and power trains. The frequencies produced tend to mimic large vessels with the majority of sound energy below 1kHz. The sound intensity level produced is approximately 165-180 dB in water at 1m, rms value (165-180 dB re 1µPa @ 1m $_{rms}$). (Richardson *et al* 1995, OSPAR, 2009)

E.7.3. Large Vessels

Large vessels for this paper are vessel lengths greater than 100m, such as container/cargo ships, super-tankers and cruise liners.

Large vessels, depending on type, size and operational mode, produce their strongest sound intensity level of approximately 180-190 dB in water at 1m, rms value, (180-190 dB re 1µPa @ 1m $_{rms}$) at a few hundred Hz. (Richardson *et al* 1995, Arvenson and Vendittis, 2000) In addition, a significant amount of high-frequency sound, 150 dB in water @ 1m, rms value, (150 dB re 1µPa @ 1m $_{rms}$) or broadband frequencies, 0.354-44.8 kHz of 136 dB in water at 700m distance, rms value, (136 dB re: 1µPa @ >700m $_{rms}$) can be generated through propeller cavitation. This near-field source of high-frequency sound is of concern particularly within shipping corridors, shallow coastal waters, waterways/canals and/or ports. (Arveson and Vendettis, 2000, Aguilar Soto *et al* 2006, OSPAR, 2009)

E.8. Pingers

E.8.1. Acoustic Navigation Beacons

Acoustic navigation beacons mark the position of an object and measure its height above the seabed. Most underwater beacons emit a short continuous wave tone, commonly 8-16 kHz octave band, with a stable ping rate. Typical sound intensity levels are around 160-190 dB in water at 1m, peak value (160-190 dB *re* 1µPa @ 1m peak). They are designed to be omnidirectional to be heard from any direction. Simple systems are programmed to transmit a fixed ping rate while more sophisticated systems transmit after receiving an interrogating signal. (Lurton, 2010)

E.8.2. Acoustic Deterrent Devices

Acoustic Deterrent Devices (ADDs) are a low powered device, 130-135 dB in water at 1m, peak value, (130-135 dB *re* 1µPa @ 1m peak) designed to deter fish from entering places of harm such as water inlets to power stations. The frequencies range from 9-15kHz for a duration 100-300ms every 3-4 seconds. (Carretta *et al* 2008, Lepper *et al* 2004, Lurton, 2010, OSPAR Commission, 2009)

E.8.3. Acoustic harassment devices

Acoustic Harassment Devices (AHDs) are a higher powered device, 190 dB in water at 1m, peak value, (190 dB *re* 1µPa @ 1m peak) originally designed to keep marine mammals away from fish farms by causing them pain. Frequencies range from 5-20kHz for repelling pinnipeds and 30-160KHz for delphinids. (Carretta *et al* 2008, Lepper *et al* 2004, Lurton, 2010, OSPAR, 2009)

E.9. Other Noise-generating Activities

E.9.1. Acoustic Data Transmission

Acoustic modems are used as an interface for subsurface data transmission. Frequencies range around 18-40kHz with a sound intensity level around 185-196dB in water at 1m (185-196 dB re 1µPa @ 1m). (OSPAR, 2009)

E.9.2. Offshore Tidal and Wave Energy Turbines

Offshore tidal and wave energy turbines are new, so acoustic information is limited. However, they appear to emit a frequency range of 10Hz-50kHz and a sound intensity level between 165-175dB in water at 1m, rms value, (165-175 dB re 1µPa @ 1m $_{rms}$) depending on size. (OSPAR, 2009)

E.9.3. Wind turbines

The operational sound intensity levels for wind generators depend on construction type, size, environmental conditions, type of foundation, wind speed and the accumulative effect from neighbouring turbines. A 1.5MW turbine in 5-10m of water with a wind speed of 12m/s has been recorded producing 90-112 dB in water at 110m, rms value, (90-112 dB re 1µPa @ 110m $_{rms}$) with frequencies ranging 50Hz-20kHz. (Thomsen *et al* 2006, OSPAR, 2009)

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Table 9: Noise-generating activity, sound intensity level, bandwidth, major amplitude, duration and directionality (summary of E.1-E.9)

Sound	Sound Intensity Level (dB re1 ìPa)	Bandwidth	Major Amplitude	Duration	Directionality
Military					
Military Low-Frequency Active Sonar	240 Peak @ 1m	<1kHz- 1khz	[unknown]	600-1,000ms	Horizontally focused
Military Mid-Frequency Active Sonar	235 Peak @ 1m	1-5kHz	[unknown]	1-2s	Horizontally focused (3 degrees down)
Continuous Active Sonar	182 Peak @ 1m	500Hz – 3kHz	[unknown]	18 seconds	Horizontally focused
Military Mine Counter Measures Sonar	[unknown]	100kHz-500kHz	[unknown]	[unknown]	[unknown]
Seismic Surveys					
Seismic Surveys	260-262 Peak to Peak @ 1m	10Hz-150kHz	10-120Hz also 120dB up to 100kHz	30-60ms	Vertically focused
Civil High Power Sonar					
Single Beam Sounders	240 Peak @ 1m	12kHz-700kHz depending on the application	[unknown]	0.1ms	Vertically focused
Sidescan Sonar	240 Peak @ 1m	12kHz-700kHz depending on the application	[unknown]	0.1ms	Vertically focused fan spread
Multibeam Echosounders	240 Peak @ 1m	12kHz-30kHz, 70kHz-200kHz, 300kHz-500kHz depending on the application	[unknown]	0.1ms	Vertically focused fan spread
Sparkers and Boomers	$204\text{-}220_{rms}$ @ 1m	80Hz-10kHz	[unknown]	0.2ms	[unknown]
Chirps	210-230 Peak @ 1m	20Hz-20kHz	[unknown]	250ms	[unknown]
Coastal and Offshore Construction Works					
Explosions, TNT 1-100lbs	272-287 Peak @ 1m	2Hz-~1,000Hz	6-21Hz	<1-10ms	Omnidirectional
Pile Driving	248-257 Peak to Peak @ 1m	20Hz-20kHz	100Hz-500Hz	50ms	Omnidirectional
Dredging	$168\text{-}186_{rms}$ @ 1m	20Hz-1kHz	500Hz	Continuous	Omnidirectional
Offshore Platforms					
Platform Drilling	150_{rms} @1m	30Hz-40Hz	[unknown]	Continuous	Omnidirectional
Drill Ships (including maintenance)	190_{rms} @ 1m	10Hz-10kHz	[unknown]	Continuous	Omnidirectional
Positioning transponders	100_{rms} @ 2km	20kHz – 35kHz	[unknown]	Continuous	Omnidirectional

Sound	Sound Intensity Level (dB re1 ìPa)	Bandwidth	Major Amplitude	Duration	Directionality
Playback and Sound Exposure Experiments					
Ocean Tomography	165-220 Peak @ 1m	50Hz-200Hz	[unknown]	[unknown]	Omnidirectional
Shipping and Vessel Traffic					
Small Vessels	160-180 $_{rms}$ @ 1m	20Hz-10kHz	[unknown]	Continuous	Omnidirectional
Medium Vessels	165-180 $_{rms}$ @1m	Below 1kHz	[unknown]	Continuous	Omnidirectional
Large Vessels	Low Frequency 180-190 $_{rms}$ @ 1m High Frequency 136 $_{rms}$ @ 700m	Low Frequency A few hundred Hz High Frequency 0.354khz-44.8khz	[unknown]	Continuous	Omnidirectional
Pingers					
Acoustic Navigation Beacons	160-190 Peak @ 1m	8kHz-16kHz	[unknown]	[unknown]	Omnidirectional
Acoustic Deterrent Devices	130-135 Peak @ 1m	9kHz-15kHz	[unknown]	100-300ms	Omnidirectional
Acoustic Harassment Devices	190 Peak @ 1m	5khz-20kHz, 30kHz-160kHz depending on the application	[unknown]	[unknown]	Omnidirectional
Other Noise-generating Activities					
Acoustic Data Transmission	185-196 @ 1m	18kHz-40kHz	[unknown]	[unknown]	Omnidirectional
Offshore Tidal and Wave Energy Turbines	165-175 $_{rms}$ @ 1m	10Hz-50kHz	[unknown]	Continuous	Omnidirectional
Wind Turbines	90-112 $_{rms}$ @ 110m	50Hz-20kHz	[unknown]	Continuous	Omnidirectional

F. Related Decisions of Intergovernmental Bodies or Regional Economic Organisations

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A series of relevant intergovernmental decisions have already determined the direction for regulating anthropogenic marine noise through EIAs. The following decisions are the latest from each of Multi-lateral Environment Agreement (MEA).

F.1.1. CMS

'CMS Resolution 9.19: Adverse Anthropogenic Marine/Ocean Noise Impacts on Cetaceans and Other Biota' encourages Parties to:

> *'…to endeavour to control the impact of emission of man-made noise pollution in habitat of vulnerable species and in areas where marine mammals or other endangered species may be concentrated, and where appropriate, to undertake relevant environmental assessments on the introduction of systems which may lead to noise associated risks for marine mammals.'*

'CMS Resolution 10.24: Further Steps to Abate Underwater Noise Pollution for the Protection of Cetaceans and Other Migratory Species' encourages CMS Parties to:

> *'…prevent adverse effects on cetaceans and on other migratory marine species by restricting the emission of underwater noise, understood as keeping it to the lowest necessary level with particular priority given to situations where the impacts on cetaceans are known to be heavy"* and
> *"[u]rges Parties to ensure that Environmental Impact Assessments take full account of the effects of activities on cetaceans and to consider potential impacts on marine biota and their migration routes ...'*

'Resolution 10.24' further articulates that CMS Parties should ensure that Environmental Impact Assessments take full account of the impact of anthropogenic marine noise on marine species, apply Best Available Techniques (BAT) and Best Environmental Practice (BEP), and integrate the issue of anthropogenic noise into the management plans of marine protected areas. 'Resolution 10.24' also 'invites the private sector to assist in developing …alternative techniques and technologies for coastal, offshore and maritime activities'.

F.1.2. ACCOBAMS

'ACCOBAMS Resolution 5.13: Conservation of Cuvier's beaked whales in the Mediterranean' and 'Resolution 5.15: Addressing the impact of anthropogenic noise' reinforces the commitments made in 'Resolution 4.17: Guidelines to Address the Impact of Anthropogenic Noise on Cetaceans in the ACCOBAMS Area (ACCOBAMS Noise Guidelines)' that urges ACCOBAMS Parties to:

> *'[r]ecogniz[e] that anthropogenic ocean noise is a form of pollution, caused by the introduction of energy into the marine environment, that can have adverse effects on marine life, ranging from disturbance to injury and death.'*

This Resolution also encourages ACCOBAMS Parties to:

> *' ... address fully the issue of anthropogenic noise in the marine environment, including cumulative effects, in the light of the best scientific information available and taking into consideration the applicable legislation of the Parties, particularly as regards the need for thorough environmental impact assessments being undertaken before granting approval to proposed noise-producing activities.'*

The ACCOBAMS Noise Guidelines provide further comprehensive detail-specific considerations relating to military sonar, seismic surveys and offshore drilling, shipping and offshore renewable energy developments.

F.1.3. ASCOBANS

'ASCOBANS Resolution 5.4: Adverse Effects of Sound, Vessels and other Forms of Disturbance on Small Cetaceans', urges ASCOBANS Parties to:

> *'… develop, with military and other relevant authorities, effective mitigation measures including environmental impact assessments and relevant standing orders to reduce disturbance of, and potential physical damage to, small cetaceans, and to develop and implement procedures to assess the effectiveness of any guidelines or management measures introduced.'*

'ASCOBANS Resolution 6.2: Adverse Effects of Underwater Noise on Marine Mammals during Offshore Construction Activities for Renewable Energy Production', further recommends that Parties:

> *'… include Strategic Environmental Assessments and Environmental Impact Assessments carried out prior to the construction of marine renewable energy developments and taking into account the construction phase and cumulative impacts'*

and to:

> *'… introduce precautionary guidance on measures and procedures for all activities surrounding the development of renewable energy production in order to minimise risks to populations …* [that include] *measures for avoiding construction activities with high underwater noise source levels during the periods of the year with the highest densities of small cetaceans, and in so doing limiting the number of animals exposed, if potentially significant adverse effects on small cetaceans cannot be avoided by other measures;* [to include] *Measures for avoiding construction activities with high underwater noise source levels when small cetaceans are present in the vicinity of the construction site;* [and] *technical measures for reducing the sound emission during construction works, if potentially significant adverse effects on small cetaceans cannot be avoided by other measures.'*

F.1.4. CBD

'CBD Decisions VIII/28: CBD Voluntary Guidelines on Biodiversity-inclusive Impact Assessment'provides detailed guidance on whether, when and how to consider biodiversity in both project level and strategic levels assessments. The document articulates screening, scoping, assessment and evaluation of impacts, development and alternatives; transparency and consultation, reporting, review and decision-making. The guidelines suggest that environmental impact assessments should be mandatory for activities in habitats for threatened species and activities resulting in noise emissions in areas that provide key ecosystem services.

'CBD Decision XII/23: Marine and coastal biodiversity: Impacts on marine and coastal biodiversity of anthropogenic underwater noise' encourages CBD Parties and others:

> *'… to take appropriate measures, as appropriate and within competencies and in accordance with national and international laws, such as gathering additional data about noise intensity and noise types; and building capacity in developing regions where scientific capacity can be strengthened.'*

In 'Decision XII/23' CBD Parties have agreed to a significant list of technical commitments, including gathering additional data about noise intensity and noise types, and building capacity in developing regions where scientific capacity can be strengthened.

The CBD Parties also encouraged Parties to take appropriate measures, including:

> *'… (e) Combining acoustic mapping with habitat mapping of sound-sensitive species with regard to spatial risk assessments in order to identify areas where those species may be exposed to noise impacts,*
> *(f) Mitigating and managing anthropogenic underwater noise through the use of spatio-temporal management of activities, relying on sufficiently detailed temporal and spatial knowledge of species or population distribution patterns combined with the ability to avoid generating noise in the area at those times,*
> *(g) Conducting impact assessments, where appropriate, for activities that may have significant adverse impacts on noise-sensitive species, and carrying out monitoring, where appropriate.'*

'Decision XII/23' urges the transfer to quieter technologies and applying the best available practice in all relevant activities.

F.1.5. IMO

The International Maritime Organization (IMO), through 'Resolution A 28/Res.1061', has requested that the Marine Environment Protection Committee (MEPC) keep under review measures to reduce adverse impact on the marine environment by ships, including developing:

> *'[g]uidance for the reduction of noise from commercial shipping and its adverse impacts on marine life'*

F.1.6. IWC

The Scientific Committee of the International Whaling Commission (IWC) continues to monitor and discuss the impacts of noise on cetaceans.

F.1.7. OSPAR

The Convention for the Protection of the Marine Environment of the North-East-Atlantic (OSPAR) has reached agreement on an 'OSPAR Monitoring Strategy for Ambient Underwater Noise'.

The OSPAR Intersessional Correspondence Group on Noise (ICG-NOISE) is currently working closely with the International Council for the Exploration of the Sea (ICES) data team to produce the 2017 OSPAR Intermediate Assessment for impulsive noise. This is the first regional assessment of its kind and will give policy-makers and regulators a regional overview of cumulative impulsive noise activity in the Northeast Atlantic, including the noise source type (e.g. pile driver, explosion) and intensity. The 2017 Intermediate Assessment will serve as a 'roof report' to inform the subsequent 2018 MSFD assessments of EU Member States within the OSPAR region.

F.1.8. Espoo (EIA) Convention

In 'Decision II/8' Espoo Parties endorsed the Good Practice Recommendations on Public Participation in Strategic Environmental Assessment set out in document 'ECE/MP.EIA/SEA/2014/2', including and requirement that

> *'… the public to be given an opportunity to comment on draft plans or programmes and the associated environmental reports,'*

and that:

> *'[p]eople who are affected by a plan or programme and are interested in participating must be given access to all necessary information and be able to participate in meetings and hearings related to the SEA process.'*

This applies during the different stages of the assessment, including screening, scoping, availability of the draft plan/programme and environmental report, opportunity for the public to express its opinions and decision.

F.1.9. HELCOM

The Baltic Marine Environment Protection Commission - Helsinki Commission (HELCOM) has two important programmes in development. The Baltic Sea Information on the Acoustic Soundscape Project surveyed national needs and requirements of information on noise and will recommend monitoring of ambient noise in the Baltic Sea. A registry of impulsive sounds project is also being considered.

F.1.10. Regional Seas Programmes

Most of the six UNEP administered Regional Seas Programmes including the Wider Caribbean Region, East Asian Seas, Eastern Africa Region, Mediterranean Region, North-West Pacific Region and the Western Africa Region and seven non-UNEP Administered Regional Seas Programmes including the Black Sea Region, North-East Pacific Region, Red Sea and the Gulf of Aden, ROPME Sea Area, South Asian Seas, South-East Pacific Region and the Pacific Islands Region suggest some form of impact assessment should be conducted to mitigate threats to the marine environment.

F.1.11. European Union Legislation and Implementation

Some pieces of EU legislation on environmental impact assessment and nature protection are relevant and contain specific references to the marine environment and wildlife and noise.

Recital 12 of Directive 2014/52/EU of the European Parliament and the Council, which amends Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment, specifically mentions the marine environment and gives the example of one source of noise-generating activity:

'With a view to ensuring a high level of protection of the marine environment, especially species and habitats, <u>environmental impact assessment</u> and screening procedures for projects in the marine[1] environment should take into account the characteristics of those projects with particular regard to the technologies used (for example seismic surveys using active sonars).'

In addition, Recital 33 of this Directive also requires that:

'Experts involved in the preparation of environmental impact assessment reports should be qualified and competent. Sufficient expertise, in the relevant field of the project concerned, is required for the purpose of its examination by the competent authorities in order to ensure that the information provided by the developer is complete and of a high level of quality.'

The marine environment is mentioned in Annex III paragraph 2 (ii) related to legal article 4(3), and noise and vibration are listed in Annex IV paragraphs 1 (d) and 5 (c) among information to be supplied according to Article 5 (1).

The EIA Directive applies to all Member States and requires that, for certain types of projects listed in its Annexes, public and private projects likely to have significant effects on the environment by virtue *inter alia* of their size, nature or location are made subject to an assessment of their environmental effects.

Under the EIA Directive "project" means '*the execution of construction works or of other installations or schemes*' and '*other interventions in the natural surroundings and landscape including those involving the extraction of mineral resources*'.

For projects listed in Annex I of the EIA Directive an assessment should always be carried out, whereas, for projects listed in Annex II, Member States have to determine whether an assessment is to be carried out through a case-by-case examination or according to thresholds or criteria set by the Member State.

The so-called EU nature directives (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitats Directive) and Council and European Parliament Directive 2009/147/EC on the conservation of wild birds (Birds Directive) are also relevant. For the Natura 2000 sites designated for the protection of features such as marine animal species listed in Annex II of the Habitats Directive, measures are required under Art. 6(2) to avoid any significant disturbance of those species, while different human activities that are likely to have a significant effect on Natura 2000 sites need to be properly assessed and authorized in accordance with the provisions of article 6 (3) and (4) of the Habitats Directive. This provision also includes the obligation to assess the cumulative impacts of different activities on the conservation objectives of the site. Furthermore, the provisions of Article 12 of the Habitats Directive, which includes an obligation to prohibit deliberate disturbance of strictly protected species, are also particularly relevant in such situation, as all species of cetaceans and a number of marine vertebrates and invertebrates listed in Annex IV(a) benefit from a system of strict protection.

The Commission guidance document on *'establishing Natura 2000 sites in the marine environment'*[1] contains a specific section on noise pollution.

There is specific legislation on the marine environment. In 2008 the European Parliament and the Council adopted the Marine Strategy Framework Directive[2] which requires the Member States to achieve or maintain 'good environmental status' of European Union marine waters by 2020, by developing marine strategies. Marine strategies contain five main elements: the initial assessment, the determination of good environmental status, the establishment of environmental targets, the monitoring programmes and the programme of measures.

When determining 'good environmental status', the Member States shall determine a set of characteristics on the basis of 11 qualitative descriptors. One of these descriptors state:

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[1] Guidelines for the establishment of the Natura 2000 network in the marine environment: Application of the Habitats and Birds Directives (pp. 94-96)

[2] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive); Commission Directive (EU) 2017/845 of 17 May 2017 amending Directive 2008/56/EC of the European Parliament and of the Council as regards the indicative lists of elements to be taken into account for the preparation of marine strategies

"*Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.*"

This is further specified in Commission Decision (EU) 2017 /848[3]. Two types of criteria elements are defined for Descriptor 11: (a) anthropogenic impulsive sound in water and (b) anthropogenic continuous low-frequency sound in water. The primary criteria for both types are that the spatial distribution, temporal extent, and the levels of anthropogenic impulsive sound or continuous low-frequency sound sources do not affect populations of marine animals. In both cases the Member States shall establish threshold values for these levels through cooperation at Union level, taking into account regional and subregional specificities.

Methodological standards, as well as specifications and standardised methods for monitoring and assessment, are given in detail for both types of sound sources.

Within the context of the Marine Strategy Framework Directive, the Member States sharing a marine region or sub-region are also encouraged to cooperate to deliver on the objectives of the Directive.

[3] Commission Decision (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU.

G. Principles of EIAs

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The principle of Environmental Impact Assessment (EIA) was developed and introduced in the 1960s during a time where there was a growth of modern environmental concern, a drive for more rational, scientific and objective environmental decision-making and a desire for more public involvement in environmental decision-making. (Weston, 2002)

Conducting EIAs is now a well-established governance and environmental management process, institutionalised in most of the 193 United Nations Member States (Glasson *et al* 2013, Morrison-Saunders and Retief, 2012).

Some intergovernmental bodies have elaborated the principles of what EIAs should present (see Module F).

Through the process of their adoption, governments have individually committed to reflecting these decisions in their domestic law. The 'weight' of these decisions taken by governments at an international level is considerable and provides significant clarity about the expectations to conduct EIAs and effectively manage impacts of marine noise-generating activities.

Some jurisdictions have already developed national and regional operational guidelines about mitigating anthropogenic noise on marine fauna during activities. These began with the United Kingdom's Joint Nature Conservation Committee guidelines. Similar guidelines have been iteratively developed in the United States of America, Brazil, Canada, Australia and New Zealand (Castellote 2007, Weir and Dolman 2007). The European Espoo Convention also provides guidance. These are important and necessary operational guidelines. They form a part of but are not the totality of what should be considered within an EIA.

This Module provides some general principles to ensure environmental impacts (broadly defined to include the physical, life and social sciences) are an explicit and fundamental consideration both during the design of an activity and in the project authorisation by a regulator. (Cashmaore, 2004)

It is clear that there is sufficient international agreement that EIAs should be conducted. There are widespread national legal commitment and some detail in a few jurisdictions. What is now required is a change of practice: by regulators to insist thorough EIAs are presented, and by proponents to accept the same. (Morrison-Saunders and Retief, 2012, Prideaux and Prideaux, 2015)

G.1. The importance of early Strategic Environmental Assessment

There is strong value in governments' undergoing a level of assessment before inviting proponents to propose activities. Conducting proactive and early assessment of groups of activities, in the context of broader governmental vision, goals or objectives, can serve as a decision-support instrument that shapes as a process. (Morgan, 2012) Commonly called Strategic Environmental Assessments (SEA), these exercises can highlight the likely outcomes of anticipated activities and reduce stakeholder conflict by restricting or directing activity development before any commercial investment has been made. (Alshuwaikhat, 2005, Fundingsland Tetlow and Hanusch, 2012).

SEAs have the potential to act as a mediating instrument, bridging problem perceptions with technical solutions and steering the assessment to facilitate the integration of environmental values into decision-making processes. (Therivel, 2012, Fundingsland Tetlow and Hanusch, 2012)

SEA can enhance communication between different stakeholders, enabling discussion and agreement independently of different beliefs, convictions, social roles, values, accumulated experiences, individual needs or other factors. (Vicente and Partidário, 2006) SEAs can also guide regulators about the institutional requirements needed to assess proposals properly. This will include their internal organisational structure, staffing and capacity. (Therivel, 2012, Fundingsland Tetlow and Hanusch, 2012)

SEA design should reflect the core principles of the EIAs and the 'CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities'.

G.2. Basic Principles of EIAs

It is broadly accepted that the basic intent of EIAs is to anticipate the significant environmental impacts of development proposals before any commitment to a particular course of action. Often, the detail required within EIAs is poorly defined. Many legislative provisions for EIAs have been introduced without consideration of the institutional requirements, organizational structure, staffing and capacity development (Cashmore *et al* 2004, Devlin and Yap 2008, Jay *et al* 2007). Often the scientific basis and methods need sophisticated understanding.

Defensible EIAs, representing the Best Available Techniques (BAT) and Best Environmental Practice (BEP), should provide regulators with decision-making certainty by ensuring:

- Appropriate transparency
- Natural justice
- Independent peer-review
- Appropriate consultation

Each of these elements complements and supports the others.

G.2.1. Transparency and Commercial Sensitivity

Transparency is necessary for well-informed consultation, natural justice and independent peer-review.

The extent of transparency should complement the goals of natural justice and consultation, but does not need to provide information that is genuinely commercially or personally sensitive. However, far too often commercial sensitivity is a veil that industry proponents hide behind. (DiMento and Ingram, 2005, Sheaves *et al* 2015) Currently, a large body of data about public resources (the marine environment) is claimed as commercial-in-confidence with little justification. (Costanza *et al* 2006, Sheaves *et al* 2015)

The technical details of proposal for activities that generate noise should be fully and transparently available for comment before plans are submitted for approval to regulators.

Broadly, the information provided should include:

- a comprehensive description of the noise to be generated and the equipment to be used, including elements of the sound that is auxiliary to the need,
- a comprehensive description of the direct and surrounding area where the noise-generating activity is proposed and the species within this area,
- independent, scientific modelling of sound propagation of expected sound intensity levels and sound dispersal, the timeframe of the noise-generation,
- scientific monitoring programmes conducted during and after noise-generating activity.

The full extent of information that should be transparently available is detailed in the 'CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities'.

While there is some information that is, and should remain, commercially sensitive, none of the information listed above should be considered commercially sensitive, and proponents should not seek to hide it from view.

G.2.2. Natural Justice

Natural justice is both a legal and common concept with two parts: it ensures there is no bias, increasing public confidence, and enshrines a right to a fair hearing so that individuals are not unfairly impacted (penalised) by decisions that affect their rights or legitimate expectations.

In the case of decisions for activities in the marine environment, confidence that there is no hidden bias can be developed by ensuring there is full transparency and that all stakeholders are given reasonable notice of the plans, a fair opportunity to present their concerns and that these concerns will factor in the final decision that is made. (DiMento and Ingram, 2005)

Stakeholders with a rightful interest in the marine environment include: traditional communities with cultural or spiritual connections, marine users such as fishermen (commercial and recreational), shipping and boating and tourism operators, scientists, conservation organizations, and general marine users such as tourism and recreation, who advocate for the conservation of marine wildlife or marine ecosystems. Their interest must be considered.

G.2.3. Independent Peer-review

There is a concern in many countries over the poor quality of EIA information. Depending on the circumstance, this might reflect problems with institutional arrangements, low levels of commitment by proponents, or issues with the nature, extent and quality of training and capacity-building in the impact assessment, or elements of all of these. (Morgan, 2012) There is often a significant gap between the best practice thinking represented in the research and practice literature and the application of EIAs on the ground. (Morgan, 2012)

Proponent-funded independent peer-review of EIA proposals, before submission to regulators for assessment, is an important tool of BEP. (Sheaves *et al* 2015) Comprehensive, independent peer-review is a logical requirement for ensuring alignment of EIAs with scientific understanding and standards and ensuring that scientific understanding takes precedence over short-term benefits and political considerations. (Morrison-Saunders and Bailey, 2003, DiMento and Ingram, 2005, Sheaves *et al* 2015)

In the case of marine noise-generating activities, independent peer-reviewers should include species experts and expert sound modellers and acousticians, who can declare full and verifiable independence from the proposal. Their peer-review reports should be fully transparent and submitted to regulators, without influence from proponents.

G.2.4. Consultation and burden of proof

True consultation has two key components: participation in the outcome of a decision and that the burden of proof rests with the proponent.

Development actions may have wide-ranging impacts on the environment, affecting many different groups in society. There is increasing emphasis by governments at many levels on the importance of consultation and participation by key stakeholders in the planning and development of projects.

An EIA is an important vehicle for engaging with communities and stakeholders, helping those potentially affected by a proposed development to be much better informed and to influence the direction and precautions put in place by the proponent. This requires an appropriate exchange of information and a willingness by the proponent to be transparent about their likely impact. (O'Faircheallaigh, 2010, Glasson *et al* 2013)

The burden of proof is often associated with the Latin maxim *semper necessitas probandi incumbit ei qui agit*, which broadly means "*the necessity for proof always lies with the person who makes the claim*". In the case of proponents of marine noise-generating activities, they claim that the activities they propose to undertake – in a shared marine environment – will cause minimal harm. To satisfy the burden of proof, the proponent must provide sufficient evidence to demonstrate that there is a limited danger of damaging the marine environment or any species that have been highlighted as having importance.

Other stakeholders do not carry the burden of proof but instead carry the benefit of assumption, meaning they need no evidence to support their position of concern. It is up to the proponent to provide the assurance and bear all financial costs for doing so.

Despite the international concensus for robust EIA described in Module F, in many circumstances the burden of proof has been shifted to stakeholders. The CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities and these Modules of Technical Support Information provide regulators with the needed information to redress this imbalance.

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H. CMS-Listed Species Potentially Impacted by Anthropogenic Marine Noise

Pinnipeds				
Scientific name	**Common name**	**App I**	**II**	**CMS Instruments**
Arctocephalus australis	South American fur seal		1979	CMS
Halichoerus grypus	Grey seal		1985	CMS
Monachus monachus	Mediterranean monk seal	1979	1979	CMS, Monk Seal in the Atlantic
Otaria flavescens	South American sea lion		1979	CMS
Phoca vitulina	Harbour seal		1985	CMS, Wadden Sea Seals

Cetaceans				
Scientific name	**Common name**	**App I**	**II**	**CMS Instruments**
Balaena mysticetus	Bowhead whale	1979		CMS
Balaenoptera bonaerensis	Antarctic minke whale		2002	CMS, Pacific Cetaceans
Balaenoptera borealis	Sei whale	2002	2002	CMS , ACCOBAMS , Pacific Cetaceans
Balaenoptera edeni	Bryde's whale		2002	CMS , Pacific Cetaceans
Balaenoptera musculus	Blue whale	1979		CMS, ACCOBAMS, Pacific Cetaceans
Balaenoptera physalus	Fin whale	2002	2002	ACCOBAMS, CMS, Pacific Cetaceans
Berardius bairdii	Baird's beaked whale		1991	CMS, Pacific Cetaceans
Caperea marginata	Pygmy right whale		1979	CMS, Pacific Cetaceans
Cephalorhynchus commersonii	Commerson's dolphin		1991	CMS
Cephalorhynchus eutropia	Chilean dolphin		1979	CMS
Cephalorhynchus heavisidii	Heaviside's dolphin		1991	CMS, Western African Aquatic Mammals
Cephalorhynchus hectori	Hector's dolphin			Pacific Cetaceans
Delphinapterus leucas	Beluga		1979	CMS
Delphinus capensis	Long-beaked common dolphin			Western African Aquatic Mammals, Pacific Cetaceans
Delphinus delphis	Common dolphin	2005	1988	CMS, ASCOBANS, ACCOBAMS, Western African Aquatic Mammals, Pacific Cetaceans
Eubalaena australis	Southern right whale	1979		CMS, Pacific Cetaceans
Eubalaena glacialis	Northern right whale	1979		CMS, ACCOBAMS
Eubalaena japonica	North Pacific right whale	1979		CMS
Globicephala melas	Long-finned pilot whale		1988	CMS, ACCOBAMS, ASCOBANS, Pacific Cetaceans, Western African Aquatic Mammals
Grampus griseus	Risso's dolphin		1988	CMS, ACCOBAMS, ASCOBANS, Western African Aquatic Mammals, Pacific Cetaceans
Hyperoodon ampullatus	Northern bottlenose whale		1991	CMS, ASCOBANS, Western African Aquatic Mammals
Lagenodelphis hosei	Fraser's dolphin		1979	CMS , Western African Aquatic Mammals, Pacific Cetaceans
Lagenorhynchus acutus	Atlantic white-sided dolphin		1988	CMS , ASCOBANS
Lagenorhynchus albirostris	White-beaked dolphin		1988	CMS , ASCOBANS
Lagenorhynchus australis	Peale's dolphin		1991	CMS
Lagenorhynchus obscurus	Dusky dolphin		1979	CMS, Western African Aquatic Mammals, Pacific Cetaceans
Megaptera novaeangliae	Humpback whale	1979		CMS, ACCOBAMS, Pacific Cetaceans
Monodon monoceros	Narwhal		1991	CMS
Neophocaena phocaenoides	Finless porpoise		1979	CMS, Pacific Cetaceans
Orcaella brevirostris	Irrawaddy dolphin	2009	1991	CMS, Pacific Cetaceans
Orcaella heinsohni	Australian snubfin dolphin		1979	CMS, Pacific Cetaceans

Orcinus orca	Killer whale		1991	CMS, ACCOBAMS, ASCOBANS, Western African Aquatic Mammals, Pacific Cetaceans
Phocoena dioptrica	Spectacled porpoise		1979	CMS, Pacific Cetaceans
Phocoena phocoena	Harbour porpoise		1988	CMS, ASCOBANS, ACCOBAMS, Western African Aquatic Mammals
Phocoena spinipinnis	Burmeister porpoise		1979	CMS
Phocoenoides dalli	Dall's porpoise		1991	CMS
Physeter macrocephalus	Sperm whale	2002	2002	CMS, ACCOBAMS, Pacific Cetaceans
Platanista gangetica	Ganges River dolphin	2002	1991	CMS
Pontoporia blainvillei	Franciscana	1997	1991	CMS
Sotalia fluviatilis	Tucuxi		1979	CMS
Sousa chinensis	Indo-Pacific hump-backed dolphin		1991	CMS, Pacific Cetaceans
Sousa teuszii	Atlantic hump-backed dolphin	2009	1991	CMS, Western African Aquatic Mammals
Stenella attenuata	Pantropical spotted dolphin		1999	CMS, Western African Aquatic Mammals, Pacific Cetaceans
Stenella clymene	Clymene dolphin		2009	CMS , Western African Aquatic Mammals
Stenella coeruleoalba	Striped dolphin		2001	CMS, ASCOBANS, ACCOBAMS, Western African Aquatic Mammals, Pacific Cetaceans
Stenella longirostris	Spinner dolphin		1999	CMS, Western African Aquatic Mammals, Pacific Cetaceans
Tursiops aduncus	Indian bottlenose dolphin		1979	CMS
Tursiops truncatus	Bottlenose dolphin	2009	1991	CMS, ASCOBANS, ACCOBAMS, Western African Aquatic Mammals, Pacific Cetaceans
Ziphius cavirostris	Cuvier's Beaked whale	2014		CMS, ACCOBAMS

Sirenians

Scientific name	**Common name**	**App I**	**II**	**CMS Instruments**
Dugong dugon	Dugong		1979	CMS, Dugong
Trichechus manatus	Manatee	1999	1999	CMS
Trichechus senegalensis	West African manatee	2009	2002	CMS, Western African Aquatic Mammals

Sea turtles

Scientific name	**Common name**	**App I**	**II**	**CMS Instruments**
Caretta caretta	Loggerhead turtle	1985	1979	CMS, IOSEA Marine Turtles , Atlantic Turtles
Chelonia mydas	Green turtle	1979	1979	CMS, IOSEA Marine Turtles, Atlantic Turtles
Dermochelys coriacea	Leatherback turtle	1979	1979	CMS, IOSEA Marine Turtles, Atlantic Turtles
Eretmochelys imbricata	Hawksbill turtle	1985	1979	CMS, IOSEA Marine Turtles, Atlantic Turtles
Lepidochelys kempii	Kemp's ridley turtle	1979	1979	CMS, Atlantic Turtles
Lepidochelys olivacea	Olive ridley turtle	1985	1979	CMS, IOSEA Marine Turtles, Atlantic Turtles
Natator depressus	Flatback turtle		1979	CMS, IOSEA Marine Turtles

Fish, Crustaceans and Cephalopods

Fish, crustaceans and cephalopods are considered as listed CMS species as well as prey to CMS listed species.

Scientific name	**Common name**	**App I**	**II**	**CMS Instruments**
Carcharodon carcharias	Great white shark	2002	2002	CMS, Sharks
Cetorhinus maximus	Basking shark	2005	2005	CMS, Sharks
Isurus oxyrinchus	Shortfin mako shark		2008	CMS, Sharks
Isurus paucus	Longfin mako shark		2008	CMS, Sharks
Lamna nasus	Porbeagle		2008	CMS, Sharks
Alopias pelagicus	Pelagic thresher shark		2014	CMS
Alopias superciliosus	Bigeye thresher shark		2014	CMS
Alopias vulpinus	Common thresher shark		2014	CMS
Carcharhinus falciformis	Silky shark		2014	CMS
Sphyrna lewini	Scalloped hammerhead shark		2014	CMS
Sphyrna mokarran	Great hammerhead shark		2014	CMS
Manta alfredi	Reef manta ray	2014	2014	CMS
Manta birostris	Manta ray	2011	2011	CMS
Manta alfredi	Reef manta ray	2014	2014	CMS
Mobula eregoodootenkee	Pygmy devil ray	2014	2014	CMS
Mobula hypostoma	Atlantic devil ray	2014	2014	CMS

Mobula japanica	Spinetail mobula	2014	2014	CMS
Mobula kuhlii	Shortfin devil ray	2014	2014	CMS
Mobula mobular	Giant devil ray	2014	2014	CMS
Mobula munkiana	Munk's devil ray	2014	2014	CMS
Mobula rochebrunei	Lesser Guinean devil ray	2014	2014	CMS
Mobula tarapacana	Box ray	2014	2014	CMS
Mobula thurstoni	Bentfin devil ray	2014	2014	CMS
Squalus acanthias	Spiny dogfish		2008	CMS, Sharks

Otters				
Scientific name	**Common name**	**App I**	**II**	**CMS Instruments**
Lontra felina	Marine otter	1979		CMS

Polar bear				
Scientific name	**Common name**	**App I**	**II**	**CMS Instruments**
Ursus maritimus	Polar bear		2002	CMS