



EWT RESEARCH & TECHNICAL PAPER NO. 1

THE POTENTIAL IMPACTS OF ANTHROPOGENIC NOISE ON MARINE ANIMALS AND RECOMMENDATIONS FOR RESEARCH IN SOUTH AFRICA

R. P. KOPER AND S. PLÖN



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ACRONYMS

ABR	Auditory Brainstem Response
ACCOBAMS	Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area
ADD	Acoustic Deterrent Device
AEI	Acoustic Ecology Institute
AHD	Acoustic Harassment Device
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
ASHA	American Speech-Language-Hearing Association
AWI	Animal Welfare Institute
Coega IDZ	Coega Industrial Development Zone
CSIR	Council for Scientific and Industrial Research
CTBT	Comprehensive Test Ban Treaty
dB	Decibel
EPBCA	Environmental Protection and Biodiversity Conservation Act
GRSA	Government of the Republic of South Africa
Hz	Hertz
ICES	International Council for the Exploration of the Sea
IMO	International Maritime Organization
IOCN	International Ocean Noise Coalition
JNCC	Joint Nature Conservation Committee
LACS	Low Level Acoustic Combustion Source

LFA sonar	Low Frequency Active sonar
MCAA	Marine and Coastal Access Act
MLPA	Marine Life Protection Act
MLRA	Marine Living Resources Act
MMC	Marine Mammals Commission
MMPA	Marine Mammal Protection Act
NATO	North Atlantic Treaty Organization
NGO	Non-Governmental Organization
NMFS	U.S. National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRDC	Natural Resources Defence Council
OMP	Office of Marine Programs
PAM	Passive Acoustic Monitoring
PASA	Petroleum Agency South Africa
PCAD	Population Consequences of Acoustic Disturbance
PPC	Public Process Consultants
PPO	Public Participation Office
PTS	Permanent Threshold Shift
RBM	Richards Bay Minerals'
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SIL	Sound Intensity Level
SPL	Sound Pressure Level
SURTASS	Surveillance Towed Array Sensor System
TTS	Temporary Threshold Shift
UNCLOS	United Nations Convention on the Law of the Sea
WCA	Wildlife and Countryside Act
WDCS	Whale and Dolphin Conservation Society
μPa	Micropascal

EXECUTIVE SUMMARY

The oceans are often thought of as a silent world. However, in reality the oceans are filled with sounds from both natural and anthropogenic (i.e. human generated) sound sources. In fact, during the last five decades, ocean ambient noise levels have increased with at least 10-12 dB within the 30-50 Hz frequency band. This frequency band falls within the hearing range of baleen whales, of which 42% of all species are endangered. As a result, there is a currently growing concern that anthropogenic sounds in the marine environment potentially have a substantial impact on marine organisms. Sounds generated by large container vessels, small recreational and fishing vessels, seismic surveys, naval sonar, and construction activities have all been related to negative impacts on a variety of marine animals. These negative impacts include direct effects, such as physical injury (i.e. auditory and non-auditory), stress, perceptual interference, behavioural changes, and chronic responses, and indirect effects on predator species as a consequence of a change in prey distribution or abundance due to direct effects of sound on the prey. Some anthropogenic sound sources produce noise as a simple byproduct, while others produce noise intentionally. Unfortunately, the production of either type of noise cannot be prevented, but several mitigation measures have been developed to potentially reduce harm to marine life.

Effective management of ocean noise pollution necessitates the evaluation of each sound source separately, followed by the application of appropriate mitigation measures. Current mitigation measures include geographic and temporal restrictions (i.e. activity restricted to specific areas or a time of year), source based mitigation (i.e. sound containment and improvement or replacement of current equipment used), and operational mitigation (i.e. to follow a protocol of operation). These existing mitigation measures are highly valuable for a country such as South Africa, which has a rich coastal biodiversity and is an important habitat for threatened marine species (e.g. the humpback dolphin), while experiencing a rapid increase in coastal industrial developments as well as oil and gas exploration. However, to date, no formal research on the effects of ocean noise on marine animals has been conducted in South Africa. The industrial development in South African coastal and offshore habitats must occur in conjunction with the conservation of marine organisms and ecosystems. To achieve this, the initiation of research on the negative impacts of noise on marine life is required, while implementation of existing as well as development of new, effective mitigation measures is necessary. In addition, best practice guidelines need to be developed and applied. Priority research sites along the coastline of South Africa are therefore recommended to initiate dedicated research in areas known to experience elevated noise levels due to anthropogenic activities, such as ports, seismic

survey areas, oil production areas, Naval test sites, and construction sites. Studies should be conducted on a wide variety of marine species, from the largest charismatic marine mammals to the planktonic larvae of marine fish species. Preferably, research should adopt a multi-species approach within the priority areas to quantify the species' spatial distribution and changes in behaviour in relation to levels of sound at the source, levels of sound at set distances from the source, and received sound levels.

The results of this research, together with the experience from international researchers, can then be used to assist industry to mitigate the potential impacts of anthropogenic noise on marine fauna. Development of best-practice guidelines will help industry to follow a standard mitigation approach, starting with careful site selection and the consideration of temporal activity restrictions. Furthermore, South Africa should encourage the import of existing and the development of new engineering solutions, such as skewed propeller blades and bubble curtains to reduce sound levels at the source. These engineering solutions should be adequately tested and, when found to be efficient, promoted to be used by industry. All resolutions and mitigation measures regarding ocean noise pollution should be listed by the South African Government in a White Paper for effective management of ocean noise pollution. These recommendations will enable the establishment of a balance between human industrial developments and marine wildlife conservation and management.

PART 1: INTRODUCTION

The environment is filled with a wide variety of sounds. These sounds can come from natural sources, such as a gentle breeze, a bird singing in the tree, or waves rolling onto the beach. However, there are also a number of anthropogenic (i.e. produced by humans) sounds, such as kids playing on a street, music from a radio, or construction work on a road. Some of these sounds are potentially harmful and therefore equate to pollution, where pollution is defined as the release of a potentially harmful chemical, physical, or biological agent into the environment as a result of human activity (Weilgart 2007). The same conditions apply in our oceans, where anthropogenic sound can be defined as an energy introduced by man, either directly or indirectly, into the marine environment, which results, or is likely to result, in such deleterious effects as harm to living resources and marine life (UNCLOS 1982). According to the 1982 United Nations Convention on the Law of the Sea, this definition equals the definition of “pollution of the marine environment” (UNCLOS 1982). Although the problem of marine sound pollution has not received much interest in the past, currently there is a growing concern that anthropogenic sounds in the marine environment may potentially have a substantial impact on marine organisms (Richardson 1995, Hildebrand 2004, Simmonds *et al.* 2004, Weilgart 2007, NRDC 2011).

Studies in the Northeast Pacific (i.e. California) have indicated that ambient noise levels (i.e. background noise originating from multiple unidentified sources) have increased by 10-12 decibels (dB) at the 30-50 Hertz (Hz) range between 1960 and 2004, suggesting a 2.5-3 dB increase per decade (NRC 2003, McDonald *et al.* 2006). This increase is most probably related to a doubling in the amount of commercial vessel traffic, together with an increase in tonnage and speed of vessels. However, commercial vessel traffic is not the only anthropogenic sound source in our oceans today. Other sound sources include seismic exploration, drilling and dredging, active sonar, explosions, and acoustic deterrent devices (ADDs) (Green Jr. and Moore 1995, NRC 2003, Hildebrand 2004, 2005, 2009). Together, these sources generate sounds covering the sound spectrum between 2 Hz and 200 kHz, which in turn is frequently used by the majority of marine animals for all important aspects of their life. In addition, several of these sound sources operate in coastal and continental shelf waters, which are areas that represent important marine habitats for many marine species (Hildebrand 2009). Therefore, there is a current growing concern that human induced sounds may have a negative impact on marine animals, resulting in disrupted behaviour, physical damage, and even death (Richardson 1995). The extent of this impact was highlighted in a review by Weilgart (2011), who reported that at least 55 marine species have been shown to be impacted by ocean noise pollution to at least some degree.

Despite the growing concern among scientific experts on ocean noise, this concern has not pervaded the general public, who is largely unaware of the potential threats to the marine environment. This report is therefore intended to give a summary on the basic concepts of sound, the importance of sound to marine animals, sound sources within the marine environment, on reported disturbance of marine animals by ocean noise, possible mitigation measures, and current global legislation. The final sections explore the potential impacts of ocean noise in South Africa, and provide recommendations for ocean noise studies in this region.

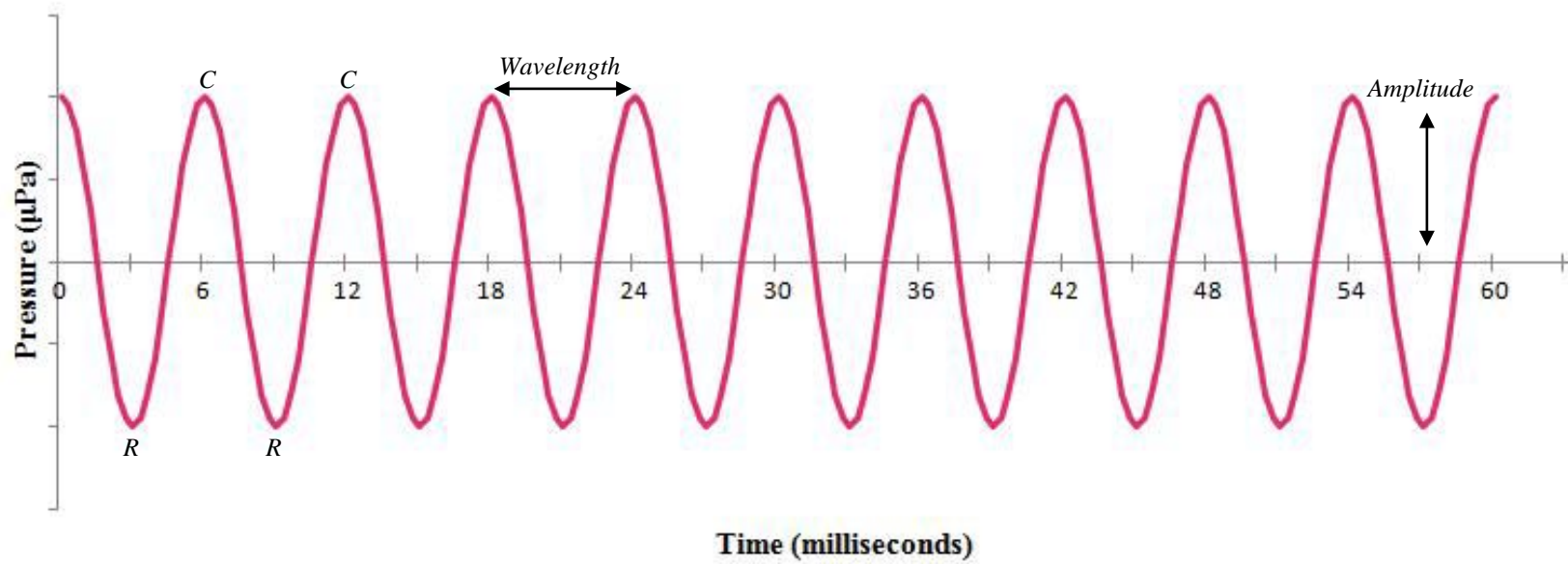
PART 2: BASIC PROPERTIES OF UNDERWATER SOUND

2.1. THE FREQUENCY OF SOUND

Sound is produced by a vibrating object, which changes the pressure of the medium in which the sound is generated. The change in pressure generates a pressure wave that causes molecules to move (Bradley and Stern 2008). Therefore, the pressure wave contains energy (Bradley and Stern 2008). A pressure wave propagates by means of the compression (i.e. an increase in density and pressure) and rarefaction (i.e. a decrease in density and pressure) of molecules within a medium (Simmonds *et al.* 2004) (Figure 1). However, with every compression and rarefaction energy is lost, with consequent attenuation of sound (i.e. loss of sound) (Bradley and Stern 2008). The distance between two compressions (or two rarefactions) is called the wavelength, whereas the number of complete wavelengths per second represents the sound frequency, which is measured in Hertz (Hz) (Green Jr. 1995a). Low frequency sounds correspond to long wavelengths with only a few compressions over time, and thus relatively little energy loss. Consequently, low frequency sound can travel over hundreds of kilometres or even more, depending on the medium (Dudzinski *et al.* 2008). In contrast, high frequency sounds correspond to short wavelengths with frequent compressions over time (i.e. high energy loss) and may only be detected over a few kilometres (MMC 2007).

The human audible range of hearing extends from 20 Hz to 20 kHz, while sounds below and above this range are called infrasonic and ultrasonic, respectively (Green Jr. 1995a). Based on modelling (baleen whales) and hearing tests (shellfish, fishes, sea turtles, sharks, seals, and toothed whales) we know that the hearing range for marine animals extends from as low as 5 Hz in baleen whales (i.e. mysticetes) (Weilgart 2007) to at least 200 kHz in crustaceans (Au and Banks 1998).

Figure 1 Schematic overview of a sound wave illustrating its wavelength and amplitude. "C" represents compressions, while "R" represents rarefactions



2.2. SOUND INTENSITY

Sound waves transport energy. The amount of energy transported over a given area per unit of time is referred to as the sound intensity, which is represented by the sound wave's amplitude (Simmonds *et al.* 2004) (Figure 1). Higher amplitudes indicate a higher amount of energy transported and therefore a higher sound intensity (Simmonds *et al.* 2004). However, sound intensity is not the same as loudness (OMP 2010). Loudness describes how an individual perceives sound. In general, for each individual sound signals of the same frequency will sound louder with increasing intensity, while sound signals of different frequencies, but of similar intensity, do not, as a rule, sound as equally as loud (OMP 2010).

The sound intensity is rarely measured directly (Green Jr. 1995a). Moreover, most sound receivers measure changes in sound pressure, which is measured in micropascals (i.e. μPa) (Green Jr. 1995a). However, intensity as well as pressure can be converted into a Sound Intensity Level (SIL) or Sound Pressure Level (SPL), respectively, according to the following formulae:

Sound Intensity Level:

$$SIL \text{ (dB} \cdot \text{re. } 1\mu\text{Pa)} = 10 \log\left(\frac{I}{I_{ref}}\right)$$

and

Sound Pressure Level:

$$SPL \text{ (dB} \cdot \text{re. } 1\mu\text{Pa)} = 20 \log\left(\frac{\rho}{\rho_{ref}}\right)$$

where I is the measured intensity, I_{ref} the reference intensity (i.e. $6.7 \times 10^{-19} \text{ Wm}^{-2}$ in water), ρ the measured sound pressure, and ρ_{ref} the reference pressure (i.e. $1 \mu\text{Pa}$ in water) (Simmonds *et al.* 2004). Most underwater intensity levels are measured at the reference distance of one meter from the source (i.e. source level). Therefore the official notation of an underwater sound is “x dB re 1 μPa at 1 m”, where “dB” stands for decibel and “re” for reference. The decibel (dB) is a logarithmic scale of sound intensity, where zero dB corresponds to the threshold of human hearing (i.e. $1 \times 10^{-12} \text{ Wm}^{-2} = 20 \text{ Hz}$). Consequently, an increase in sound intensity by “xy” dB corresponds to a sound that is 10^{xy} times more intense. For example, an increase in sound intensity by 25 dB corresponds to a sound that is $10^{2.5}$ times more intense. For simplicity, all decibel levels cited in this report were measured relative to the reference pressure level of one μPa at the reference distance of one metre, unless stated otherwise.

It should be noted that currently efforts are undertaken to develop a global metric for ocean noise impact assessments on marine animals. This new metric will take into account the hearing characteristics of the species under consideration as well as the duration of exposure (M-weighted Sound Exposure Level (SEL_m)) (de Jong *et al.* 2011, Götz *et al.* 2009).

On an average day, humans are exposed to sound levels between 0-100 dB re 20 µPa at 1 m, while exposure to higher levels occurs on an occasional basis (e.g. rock concert: 115 dB re 20 µPa; ambulance: 125 dB re 20 µPa; fireworks: 145 dB re 20 µPa) (SCENIHR 2008, ASHA 2011, DD 2011) (Figure 2). Possible hearing damage in humans can occur at exposure to sounds of 85 dB re 20 µPa for a period of eight hours (SCENIHR 2008, DD 2011). For every 3 dB increase, the exposure time before initiation of hearing damage should be divided by two (e.g. the recommended maximum exposure time to a 88 or 91 dB re 20 µPa sound source corresponds to four and two hours, respectively) (SCENIHR 2008, DD 2011).

2.3. COMPARISON OF SOUND IN WATER AND AIR

There are two important differences between sound measurements made in water and in air. Firstly, the density of water is greater than the density of air. Consequently, there is a difference in the speed of sound in these two media, with sound travelling over four times faster in water than in air (at 1500 ms⁻¹ and 340 ms⁻¹, respectively) (OMP 2010). Secondly, different reference levels are used for the calculations of the SIL and SPL of sound in air (i.e. 20 µPa/Wm²). Therefore, intensity levels measured in air and water are not directly comparable. However, in order to make approximate comparisons it has been suggested to subtract 61.5 dB of a measurement made in water to obtain the equivalent value in air (Simmonds *et al.* 2004, OMP 2010).

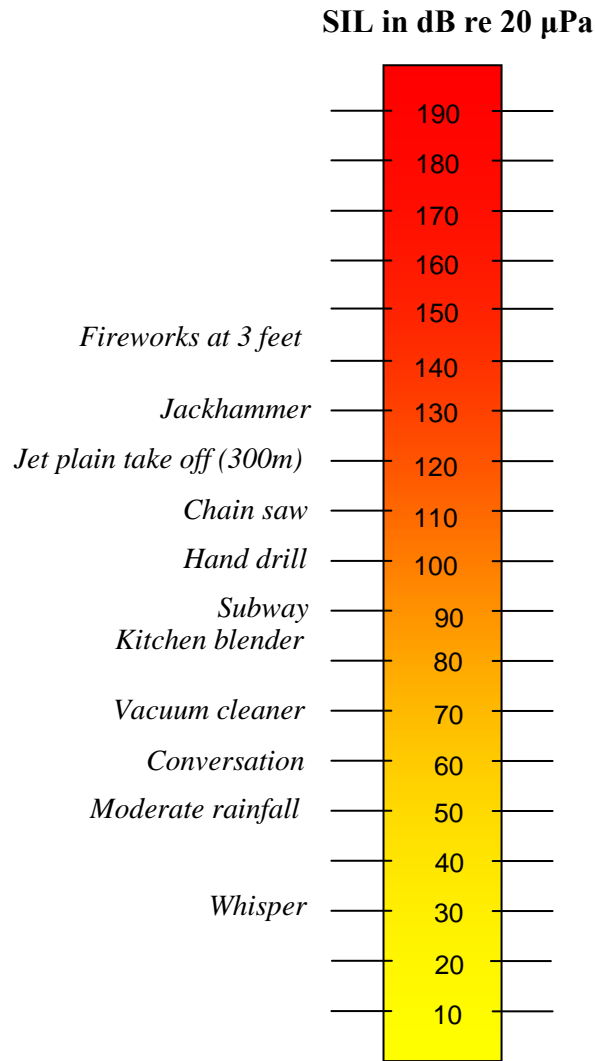


Figure 2 Sound intensity levels (SIL) of common airborne sounds measured in air (i.e. reference level 20 μ Pa/ Wm⁻²). Source: American Speech-Language-Hearing Association (ASHA 2011)

PART 3: SOUND AND MARINE ANIMALS

3.1. IMPORTANCE OF SOUND

In general, humans rely on vision and hearing for their daily lives. In addition, we make use of our three other senses of smell, taste, and touch. However, within the marine environment, visibility is severely limited due to the rapid absorption of light within the water column (Jasny *et al.* 2005). Light only penetrates into the upper layer of the water column referred to as the photic zone, which extends to a depth of 30 m in coastal areas, but up to a maximum of 150 m in the open ocean of the clearest waters (i.e. the Sargasso sea) (Barnes and Hughes 1999). Thereafter, visibility is severely limited, followed by complete darkness.

The development of the sense of smell of marine organisms varies among species. Species that have been reported to have an incredible sense of smell within the marine environment are sharks (Kalmijn 1971), rays (Kalmijn 1971), deep sea amphipods, and fish (Smith and Baldwin 1982, Wagner 2002, 2003). Similarly, sea lions and sea turtles are known to have maintained their olfactory receptor genes, thereby reflecting the importance of the terrestrial environment for these animals. However, whether sea lions and sea turtles make use of their sense of smell during aquatic activities has not been reported. In contrast, toothed whales appear to lack nervous structures that mediate olfaction (i.e. the ability to smell) (Oelschläger and Oelschläger 2008). In addition, the majority of the whales and dolphins have lost large numbers of their olfactory receptor genes (Kishida *et al.* 2007, McGrowen *et al.* 2008).

Taste buds in marine animals have been documented both behaviourally and physiologically for sea turtles, fish, sharks, manatees, dugongs, dolphins, and whales, but are only useful at short distances (Hamed *et al.* 1984, Dudzinski *et al.* 2008, Schwenk 2008, Würsig and Richardson 2008, Martin 2012b).

In contrast, sound is prevalent in the marine environment due to the fact that it can travel considerable distances in water. In addition, sound attenuation (i.e. loss of sound) is reduced due to the reflection of sound at the sea-air interface (i.e. sea surface) (Bradley and Stern 2008). Furthermore, in shallow waters sound will be partially reflected by the sea floor, while in deeper waters a drop in temperature will induce refraction (i.e. decrease in the speed of sound with consequent back bending of sound waves), effectively trapping the sound in the water column (Bradley and Stern 2008). Because of the ease with which sound travels in water and the large area over which sound can be transmitted in this medium, as opposed to in air, underwater acoustic signals

have evolved to be the principal mode of information transmission for fully aquatic animals as well as a predominant mode of communication for amphibious marine species (i.e. seals and sea turtles) (Dudzinski *et al.* 2008). This is especially apparent in the brain structure of marine mammals, which show an expansion of the neocortical areas for acoustic detection and acoustic memory (Oelschläger and Oelschläger 2008). For example, the female Subantarctic fur seal (*Arctocephalus tropicalis*) has been indicated to be able to recognize her pup's call after several weeks of separation, which is an important capability to increase breeding success (Mathevon *et al.* 2004).

3.2. USE OF SOUND BY MARINE ANIMALS

The exact relevance of sound to marine animals is only partially known. However, existing evidence suggests that there is an enormous variety in the use of sound, which also highlights the number of crucial roles that sound plays throughout the life cycle of many marine species (Jasny *et al.* 2005). The way in which marine animals make use of sound can be divided into two categories. Firstly, sound is used actively by producing sounds (Van Opzeeland 2010), such as male humpback whales (*Megaptera novaeangliae*) that advertise their reproductive status with a song (Tyack 1981). Secondly, sound is used passively by listening to biotic sounds (i.e. living, such as sound emitted by prey) and abiotic sounds (i.e. non-living, such as wave action on shorelines) for acoustic cues, which aid in orientation, navigation, and localization of prey, predators, and conspecifics (Clark *et al.* 2009, Van Opzeeland 2010). As an example, it is thought that baleen whales might navigate using a mental acoustic map of the sea floor that relies on memory of ambient noise (Scotsman 2005). Both categories of sound use will be explained in more detail below.

3.2.1. Active use of sound

Functions and examples of the active use of sound

Marine animals produce sound for communication (e.g. self advertisement in social as well as reproductive perspectives, aggression, group coordination etc.), orientation, navigation, and the localization and identification of prey.

In invertebrates, the social shrimp (*Synalpheus regalis*) uses coordinated concert snapping as a defence to warn potential intruders that the sponge which they occupy is already taken (Tóth and Duffy 2005).

Fish use sound for agonistic interactions in territorial fights, when competing for food, or when being attacked by a predator. However, fish primarily use sound to form spawning aggregations as well as in courtship interactions. Myrberg Jr. *et al.* (1986), for example, demonstrated that females of the bicolor damselfish (*Pomacentrus partitus*) use the courtship sounds of

conspecific males to locate male nest sites during the spawning period. In addition, females are able to make a distinction between sounds of different males, indicating the role of these sounds in mate recognition (Myrberg *et al.* 1986).

In toothed whales, orientation, navigation, and the localization and identification of prey is thought to be established through a special form of sound called echolocation. Echolocation is the use of directional forward-projecting pulsed sounds of high intensity and frequency (Thomson and Richardson 1995). Each pulse is very brief and pulses are spaced in a way that an echo from the target is received before the next pulse is emitted (Thomson and Richardson 1995). Despite experimental evidence of echolocation in toothed whales, such as the beluga whale (*Delphinapterus leucas*), killer whale, false killer whale (*Pseudorca crassidens*), Atlantic bottlenose dolphin (*Tursiops truncatus*), Atlantic spotted dolphin, white-beaked dolphin (*Lagenorhynchus albirostris*), dusky dolphin (*Lagenorhynchus obscurus*), harbour porpoise (*Phocoena phocoena*), and finless porpoise (*Neophocaena phocaenoides*), very little is known about its specific use and functional significance (Barrett-Lennard *et al.* 1996). Nevertheless, the bottlenose dolphin has been documented to use echolocation for obstacle avoidance (i.e. orientation and navigation) (Tyack 2000), to locate targets, such as prey, and to detect subtle changes in the location of an identified target (i.e. distance and angle to the target) (Au 1998). In addition, strong echolocation signals are potentially used to stun prey at close ranges (Thomson and Richardson 1995).

Overall, the use of echolocation is thought to be restricted to toothed whales. Nevertheless, bowhead whales might use the echoes of their low-frequency calls for under-ice navigation and avoidance of large multi-year ice floes (George *et al.* 1989). However, this type of navigation is not considered to be comparable with the mechanism of echolocation.

Furthermore, as previously mentioned, male humpback whales sing complex and long songs, which are assumed to function as advertising calls to attract reproductive females (Tyack 1981).

Sound frequencies produced by marine animals

Sounds produced by marine animals are closely related to their hearing frequencies (Table 1). Amongst the shellfish species, snapping shrimps (*Alpheus* spp. and *Synalpheus* spp.) are known to produce sounds from tens of Hertz to >200 kHz, with peak levels between 2 and 5 kHz (Au and Banks 1998), while male ghost crabs (*Ocyropode* spp.) only produce low frequency sounds between 150-800 Hz (Salmon 1983). Fishes produce one to five different sound types that show a considerable inter- as well as intra-specific variability (i.e. between and within species) (Amorim 1996). Nevertheless, all sound types together cover a wide frequency band, with frequency uses of 0.4-4 kHz and

0.1-2 kHz for gurnards and searobins (*Triglidae* spp.) and toadfishes (*Batrachoididae* spp.), respectively (Amorim 1996, Dos Santos *et al.* 2000). Manatees, dugongs, and seals produce sounds between 4-25 kHz and 1-4 kHz, respectively (Hildebrand 2005, Nummela 2008). Finally, toothed whales and dolphins produce mid- and high frequency sounds in the range of 0.05-200 kHz (Mathews *et al.* 1999), whereas baleen whales produce low- and mid frequency sounds of 0.01-28 kHz (Edds-Walton 1997).

3.2.2. Passive use of sound

Functions and examples of the passive use of sound

The passive use of sound can be described as hearing, which is the ability to perceive sound. Marine animals use sound passively to recognize and locate conspecifics (Clark *et al.* 2009, Van Opzeeland 2010). It is thought that female leopard (*Hydrurga leptonyx*), bearded (*Erignathus barbatus*), and Weddell seals (*Leptonychotes weddellii*) use the vocalization of males to select their partner (Stirling and Thomas 2003, Dudzinski *et al.* 2008). In addition, vocalizations of male seals function as a territory warning to other males (Stirling and Thomas 2003). Similarly, male humpback whales sing complex long songs, which are assumed to function as advertising calls to attract reproductive females (Tyack 1981). Alternatively, these songs might establish dominance or cooperative behaviour among males (Darling *et al.* 2006). The use of vocalizations in cow-calf bonding has been suggested for a variety of marine mammals, such as sea otters (*Enhydra lutris*) (Dudzinski *et al.* 2008), seals (Insley *et al.* 2003), manatees (*Trichechus* spp.) (Dudzinski *et al.* 2008), bottlenose dolphins (Sayigh *et al.* 1990, Smolker *et al.* 1993), and spotted dolphins (*Stenella frontalis*) (Herzing 1996).

Besides the recognition and location of conspecifics, sound can be used to identify and locate predators and prey. Passive listening for predators is probably used by the Atlantic herring (*Clupea harengus*), which was found to respond with vertical as well as horizontal escape reactions to playbacks of fish-eating killer whale feeding sounds (Dokseater *et al.* 2009). However, mammal-eating killer whales (*Orcinus orca*), are also known to passively listen for their prey (Heithaus and Dill 2008). In addition, Gannon *et al.* (2005) found that free ranging bottlenose dolphins in Sarasota Bay, Florida, changed their direction of travel in response to playbacks of fish sounds, while increasing their rate of echolocation. In contrast, this reaction was not observed during playbacks of sounds of snapping shrimp. Therefore, they concluded that bottlenose dolphins use passive listening extensively during the search phase of the foraging process, which could be a consequence of significant energetic or ecological costs to echolocation (Gannon *et al.* 2005).

Furthermore, several crab larvae as well as coral reef fish larvae have been indicated to, among other things, use the sound of reefs (i.e. fish calls and the

crackling and snapping of shellfish and other invertebrates) as a navigation cue for reef settlement (Montgomery *et al.* 2001, Simpson *et al.* 2004, Simpson *et al.* 2005a, Stanley *et al.* 2009). This behaviour indicates the importance of sound to crab and coral reef fish larvae during a critical stage of their life history.

Table 1 Known hearing frequency and sound production ranges of various marine taxa

Taxa	Order	Hearing frequency (kHz)	Sound production (kHz)	Reference
Shellfish	Crustaceans	0.1 – 3		(Horch 1971, Lagardère 1982, Lovell <i>et al.</i> 2005)
<i>Snapping shrimp</i>	<i>Alpheus/ Synalpheus</i> spp.		0.1 - >200	(Au and Banks 1998)
<i>Ghost crabs</i>	<i>Ocypode</i> spp.		0.15 – 0.8	(Salmon 1983)
Fish	Teleosts		0.4 – 4	(Popper 2003)
<i>Hearing specialists</i>		0.03 - >3		(Popper and Schilt 2008)
<i>Hearing generalists</i>		0.03 – 1		(Popper and Schilt 2008)
Sea turtles (based on the loggerhead turtle)	Chelonia	0.1 – 1	Unknown	(Bartol <i>et al.</i> 1999)
Sharks and skates	Elasmobranchs	0.1 – 1.5	Unknown	(Kritzler and Wood 1961, Casper <i>et al.</i> 2003, Casper 2006)
Seals	Pinnipeds	0.25 – 10	1 – 4	(Kastak and Schusterman 1998, Wolski <i>et al.</i> 2003, Hildebrand 2005)
<i>Northern elephant seal</i>	<i>Mirounga agurostris</i>	0.075 – 10		
Manatees and dugongs	Sirenians	0.4 – 46	4 – 25	(Gerstein <i>et al.</i> 1999)
Toothed whales	Odontocetes	0.1 – 180	0.05 – 200	(Tremel <i>et al.</i> 1998, Mathews <i>et al.</i> 1999, Kastelein <i>et al.</i> 2002)
Baleen whales	Mysticetes	0.005 – 30	0.01 – 28	(Edds-Walton 1997, Hildebrand 2005, Weilgart 2007)

Hearing frequency ranges of marine animals

The importance of sound to marine animals is reflected in their development of generally broader hearing frequency ranges in contrast to terrestrial animals (Hildebrand 2005). Unfortunately, there is only little information on the hearing abilities of shellfish. However, the common prawn (*Palaemon serratus*) has been found to be sensitive to sounds between 100 and 3000 Hz (Lovell *et al.* 2005), while the brown shrimp (*Crangon crangon*) and crayfish (*Astacidae* spp. and *Parastacidae* spp.) can probably only hear to 150 Hz (Lagardère 1982). Furthermore, ghost crabs (i.e. *Ocyropode* spp.) have been indicated to hear sounds between 800 and 3000 Hz (Horch 1971). Bony fish species (i.e. teleosts) can be divided in two different hearing groups: 1) hearing specialists, which are able to detect sounds between 30-3000 Hz and 2) hearing generalists, which only detect sounds between 30-1000 Hz (Popper and Schilt 2008). Furthermore, hearing frequency ranges of loggerhead (*Caretta caretta*), green (*Chelonia mydas*), and Kemp Ridley (*Lepidochelys kempfi*) sea turtles (i.e. chelonia) span from 5-900 Hz, depending on age (Ketten and Bartol 2006, Martin 2011). Sharks (i.e. elasmobranchs) hear within the frequency range of 10-1400 Hz (Casper 2006, Casper and Mann 2009), while seals (i.e. pinnipeds) hear well between 0.25 and 10 kHz (Kastak and Schusterman 1998, Wolski *et al.* 2003). Higher hearing frequency ranges are found within the manatees and dugongs (i.e. sirenians), which can hear frequencies from about 0.4-46 kHz (Gerstein *et al.* 1999). In addition, toothed whales have functional hearing from 0.1-180 kHz (Tremel *et al.* 1998, Kastelein *et al.* 2002), while baleen whale hearing probably ranges from 0.005-30 kHz (Hildebrand 2005, Weilgart 2007), based on models taking into account the call production and inner ear structure. See Table 1 for an overview of known hearing frequency ranges of various marine taxa.

In addition to large differences in hearing frequency ranges, large differences in hearing sensitivity can also be found, even between closely related taxa (e.g. *Triglidae* spp. and *Batrachoidae* spp.) (Ladich and Bass 2003, Popper and Schilt 2008). Studies on hearing frequency ranges and sensitivity often include the establishment of an audiogram, which is a graphical representation of auditory threshold values over a range of sound frequencies (i.e. minimum sound levels necessary to hear a sound of a specific frequency). These audiograms are typically U-shaped with steeply decreasing threshold values at lower frequencies, followed by a plateau within the most sensitive hearing range and a subsequent steep increase in threshold values at higher frequencies (Southall *et al.* 2007). Audiograms can be obtained from behavioural studies for which individuals are trained to respond to a sound stimulus by swimming to a different location upon hearing a signal (i.e. go/no-go response) or by choosing between two spots depending on whether the signal was heard or not (Nedwell *et al.* 2004). Alternatively, audiograms can be established from Auditory Evoked Potential (AEP) measurements. This method measures the activity of excited neurons within the acoustic pathway as a consequence of

acoustic signal detection (Cook 2006). Measurements are made with electrodes, which are either inserted in the individuals head to contact an auditory end organ or attached on the skin of the head (i.e. Auditory Brainstem Response, ABR) (Nedwell *et al.* 2004). To date, marine animal audiograms have been established for at least six teleost, three chelonian, seven elasmobranchs, seven pinniped, two sirenian, and 21 odontocete species. However, the majority of these audiograms are based on measurements on only one or two individuals and on captive animals. Previous studies on the audiograms of a population of wild bottlenose dolphins and beluga whales indicated a wide variation in hearing sensitivities among individuals (Finneran *et al.* 2005a, Cook 2006, Houser and Finneran 2006). Therefore, caution should be taken when extrapolating known figures to entire populations of wild animals.

Unfortunately, we know little on mysticete hearing as these species are too large to maintain in a controlled environment necessary for effective traditional measurement procedures (Houser *et al.* 2001). Nevertheless, a predicted audiogram for humpback whales has been established based on a mathematical function derived from known data on the cat and human (Houser *et al.* 2001). See Appendix A for an overview of accessible literature on hearing sensitivities for a variety of marine animals. Not all species for which hearing sensitivities have been measured are included as a consequence of inaccessibility to the relevant literature.

PART 4: SOURCES OF SOUND IN THE OCEAN

Sources of sound in the ocean can be divided into two categories: natural and anthropogenic. Both categories are explained in more detail below.

4.1. NATURAL SOUND SOURCES

Besides the sounds produced by various organisms in the ocean as described in section 3.2.1.2., there are a number of other natural sound sources in the ocean, such as wind and waves, rain and thunder, and earthquakes and volcanic eruptions.

4.1.1. Wind and waves

Weather can have an effect on noise in the ocean. The most dominant natural sound source below 10 Hz is a result of the natural movement of waves, driven by wind acting on the sea surface (NRC 2003, Hildebrand 2005). Ocean noise levels tend to increase with increasing wind speed at the sea surface (Chapman and Cornish 1993). However, along the shore surf noise might be the prominent source of sound, producing noise in the 100-700 Hz frequency band (Green Jr. 1995b).

4.1.2. Rain and thunder

Weather conditions, such as rain and thunder, can also have an effect on noise in the ocean. Rain can generate sound over a broad frequency band, ranging from 1-50 kHz for the largest rain drops (Nystuen 1999). In addition, thunder has been found to increase sound levels by 10 dB within the 10-250 Hz frequency band at a depth of 400 m and a distance between five and ten kilometres (Dubrovsky and Kosterin 1993). A lightning strike on the water can generate an instantaneous sound of 260 dB in the frequency range of ten to 1000 Hz, with peak SILs between 100 and 300 Hz (OMP 2010).

4.1.3. Earthquakes and volcanic eruptions

Earthquakes and volcanic eruptions can increase ocean sound levels significantly in the lower frequency range, producing frequencies below 100 Hz and peak SILs between 2 and 20 Hz (Green Jr. 1995b). In particular, the Pacific Ocean receives frequent noise from natural seismic activities with nearly 10,000 events per year (Fox *et al.* 2002). In contrast, the North Atlantic

receives approximately 3,500 natural seismic events per year (Fox *et al.* 2002). Source levels of these events exceed 200 dB (Fox *et al.* 2002).

4.2. ANTHROPOGENIC SOUND SOURCES

Anthropogenic sound sources in the ocean can be categorized as “transient” if it is a once-off sound of brief duration, such as sonar or explosions, which lasts for a couple of milliseconds to seconds, but is at high intensities (de Jong *et al.* 2011). However, sound sources are categorized as “repeated transient” when they repeatedly produce short sound pulses, such as pile driving or seismic airguns (de Jong *et al.* 2011). Anthropogenic sound sources persisting for longer durations at lower intensities, such as shipping noise, are categorized as “continuous” (Popper and Hastings 2009, de Jong *et al.* 2011). Nevertheless, these sounds often pervade a large area with ships being heard a day ahead of arrival or for a couple of hours at a time (Popper and Hastings 2009). Continuous sounds can further be subdivided as periodic (e.g. rotating machinery) or aperiodic (e.g. ship breaking ice) (Hildebrand 2005). The characteristics of anthropogenic sound sources are listed in Table 2. The sound levels of anthropogenic sound sources in the ocean relative to those produced on land are depicted at the end of this section in Figure 4, with the appropriate correction of subtracting 61.5 dB from sound levels measured in water according to OMP (2010) and Simmonds *et al.* (2004). However, this was only done for approximate comparison and converted underwater SIL levels should not be considered appropriate for direct comparison.

4.2.1. Ships, boats, and personal watercrafts

Vessels are considered to be continuous sound sources pervading large parts of the ocean, especially within the Northern Hemisphere (Würsig and Richardson 2008). The noise associated with all vessels originates primarily from bubble cavitation. Bubble cavitation is the sudden formation and collapse of low-pressure bubbles in the water, which is induced by the rotation of propeller blades (IMO 2008). Cavitation noise generally increases with vessel speed and has been indicated to account for 80-85% of ship radiated noise, peaking at 50-150 Hz (Hildebrand 2005, Spence *et al.* 2007). Moreover, propellers characterized by marine growth are likely to produce a higher level of cavitation noise (Spence *et al.* 2007). Similarly, damaged or asynchronously operating propellers can produce a strong tone between 100 and 1000 Hz called propeller singing (Green Jr. and Moore 1995). Furthermore, noise is created by the propulsion machinery inside the vessel, which is conducted into the water through the ship’s hull and by hydraulic flow over the hull (Hildebrand 2005, Jasny *et al.* 2005).

Table 2 Characteristics of anthropogenic sound sources

Sound source	Type of sound	Pulse duration (msec.)	Main frequency (kHz)	Source sound level (dB re 1 μ Pa)
<i>Cargo vessels</i>	Continuous	n.a.	0.0-0.5	195
<i>Small vessels</i>	Continuous	n.a.	1.0-10.0	160-170
<i>Seismic surveys</i>	Repeated transient	20-30	0.0-0.3	235-260
<i>Pile driving</i>	Repeated transient	40-50	0.1-0.2	170-260
<i>Drilling</i>	Continuous			
Island		n.a.	<0.1	124-150
Platform		n.a.	<0.1	>127
Vessel		n.a.	0.0-0.2	180-190
<i>Dredging</i>	Continuous	n.a.	0.0-0.5	160-180
<i>Sonar</i>	Transient			
Low frequency		6000-10000	0.1-0.5	235
Mid frequency		2500	2.0-10.0	235
High frequency		24	24.0-200.0	220
<i>Explosions</i>	Transient	<1	0.0-1.0	269-274 (i.e. charges of 0.1-1 kg)
<i>ADD</i>	Repeated transient	300	5.0-160	130-150
<i>AHD</i>	Repeated transient	2-12	5.0-160	185-196

Large commercial vessels are the main contributors to the current worldwide ocean noise levels within the 5-500 Hz frequency band (peak source levels of 195 dB) (Hildebrand 2005), which overlaps with the hearing frequency range of shellfish, fish, sea turtles, sharks, toothed whales, and baleen whales (see Table 1). In addition, small ships, boats, and personal watercrafts may be important noise sources on a local scale (Hildebrand 2005). The local sound production of these smaller vessels should not be neglected, as they can have a significant impact on coastal marine species. Small vessels, for example, have smaller propellers with a higher rotation rate in comparison to large shipping vessels. Consequently, cavitation noise is produced at higher frequencies (i.e. 350-1200 Hz, 145-150 dB) that fall within the hearing range of seals (Kastak and Schusterman 1998, Wolski *et al.* 2003), dugongs (Thomson and Richardson 1995), manatees (Popov and Supin 1990, Gerstein *et al.* 1999), and toothed whales (e.g. Tremel *et al.* 1998, Szymanski *et al.* 1999, Kastelein *et al.* 2002, Kastelein *et al.* 2003) and within the peak sensitivity range of fish, sea turtles, skates, and sharks (i.e. 15-500 Hz, 550-740 Hz, 200-550 Hz, and 20-800 Hz, respectively) (Casper *et al.* 2003, Casper 2006, Ketten and Bartol 2006, Codarin *et al.* 2009).

McDonald *et al.* (2006) indicated an increase in ambient noise levels of 2.5-3 dB per decade off Southern California due to an increase in commercial vessel traffic as well as an increase in gross tonnage transported per ship. This growth is expected to continue, based on the high economic pressure for oceanic shipping together with the lack of alternative modes for global gross tonnage transport (NRC 2003, Hildebrand 2004). In addition, coastal boating activities are likely to increase locally as has been reported in the United States, where boat registration numbers increased by 1.2 million between 1995 and 2001 (NRC 2003). The prospect of a further increase in vessel activities together with its worldwide occurrence makes vessel traffic one of the primary concerns regarding noise pollution in the oceans, despite the generally lower sound levels of individual vessels.

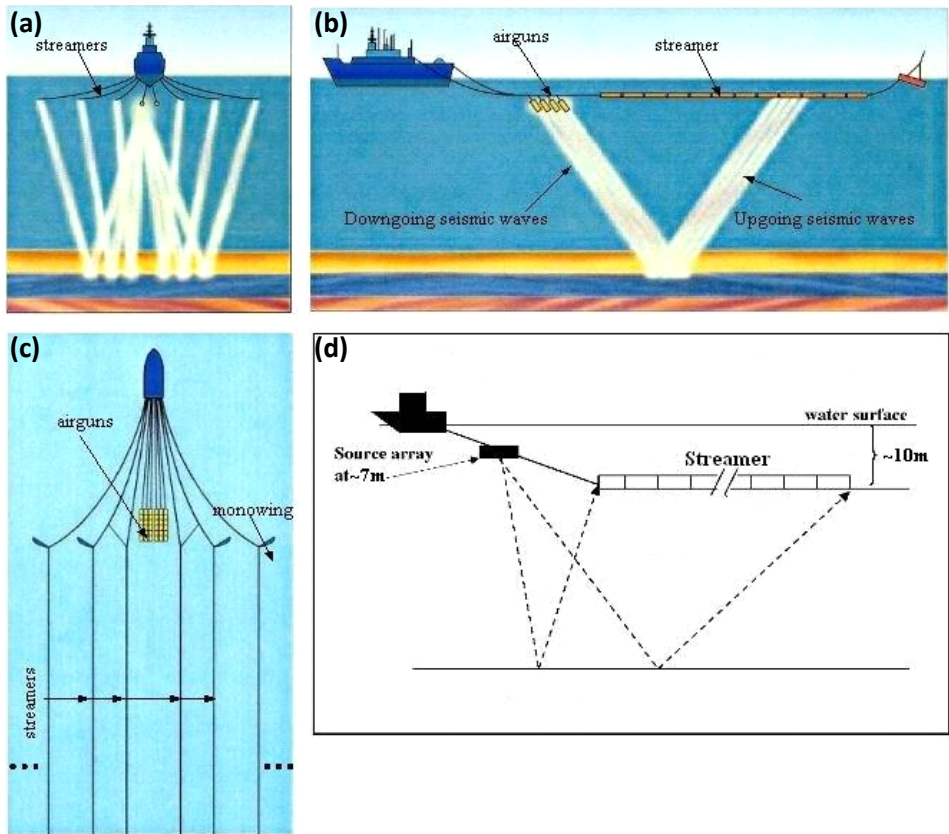


Figure 3 Diagram of a seismic survey vessel towing an airgun array with hydrophone streamers from the front (a), top (b), side (c), and schematic from the side (d) (Ikelle and Amundsen 2012)

4.2.2. Seismic exploration

Seismic explorations use high intensity sound to create an image of the structure and nature of soil layers of the ocean floor (Green Jr. and Moore 1995, Hildebrand 2005) and is primarily used for finding and monitoring natural reserves of oil and natural gas by the petroleum industries (Hildebrand 2005). Worldwide, a total of 156 seismic exploration vessels operate for the oil and gas industry, of which approximately 20% are operational on any given day (Offshore 2010). In addition, seismic exploration is conducted for geological research purposes to gather information on the earth's crust in an attempt to understand its origin as well as tectonic history (Hildebrand 2005).

Airgun arrays are primarily responsible for the production of sound during seismic operations. Each airgun releases a volume of air under high pressure, thereby creating a pressure sound wave that is able to penetrate into the seafloor (Hildebrand 2005). In general, an array of 12-48 airguns is towed behind a ship, while all airguns are fired with precise timing as to create a coherent pulse of sound (Hildebrand 2005) (Figure 3). These transient pulses are short in duration (i.e. 20-30 milliseconds) and generated every 10-20 seconds. Peak pressure levels are found between 5 and 300 Hz at 235-260 dB (Green Jr. and Moore 1995). Nevertheless, the full frequency spectrum ranges from as little as 1 Hz to more than 20 kHz, where sound pressure levels still exceed 110 dB (Lucke *et al.* 2009). Pulses reflected by the various sea bottom substrates are received by a hydrophone array, referred to as a streamer, towed behind the airgun array (Figure 3).

Airguns are towed at a depth of 4-8 m and focus downwards, emitting sound towards the sea floor (Green Jr. and Moore 1995) (Figure 3). Therefore, sound levels just below the surface (i.e. above the airguns) are slightly lower than at depth (MMC 2007). However, the horizontally dissipating sound pulses are still strong and have been shown to travel a considerable distance (i.e. as far as 28 km) (McCauley *et al.* 2000). Overall, Green Jr. and Moore (1995) reported that noise from seismic activities can be detected at 50 to 75 km from the sound source in waters between 25 and 50 m deep. In deeper waters and during conditions with optimal propagation, detection ranges can even exceed 100 km (Green Jr. and Moore 1995).

As mentioned above, peak intensity levels of seismic activities occur in the lower frequency range. Consequently, concerns about the impacts of seismic surveys is primarily directed towards baleen whales, which make extensive use of low frequency sound for several aspects of their life (e.g. communication, reproduction, navigation, and foraging) (Jasny *et al.* 2005, MMC 2007, Di Iorio and Clark 2010). However, sound levels at higher frequencies still reach considerable levels (Lucke *et al.* 2009) potentially impacting a much wider variety of marine species, including fish, sharks, seals, toothed whales, and baleen whales.

4.2.3. Construction, drilling, and dredging

Construction activities along the shore as well as on the seabed itself can contribute significantly to ocean noise levels (Green Jr. and Moore 1995). Prior to construction activities, part of the seabed might have to be removed by means of explosions, which are discussed in section 4.2.5. The actual construction activities, such as building bridges, wind farms, offshore oil platforms, and ports often involve pile driving (Popper and Hastings 2009). Pile driving produces transient sounds over a broad frequency band from 0 up to 200 kHz, with source levels of 235 dB (Lucke *et al.* 2009, Tougaard *et al.* 2009). The difficulty with pile driving arises from the multiple pile strikes that might have a cumulative sound effect on marine animals (Popper and Hastings 2009). The construction of an offshore oil platform is followed by drilling activities with source levels from 119-127 dB at near-field (i.e. within about two wavelengths from a sound source where there is no significant attenuation of sound) (Green Jr. and Moore 1995). While pile driving activities are usually completed within a couple of weeks, drilling and platform operations may be conducted for years, contributing continuously to increased ocean noise levels (Simmonds *et al.* 2004).

Dredging of the ocean floor is usually conducted to deepen shipping channels and harbours, to create platforms on land or submerged platforms, and for subsea mining operations (Green Jr. and Moore 1995). This activity often lasts for days or even weeks at a time within the same area, establishing a continuous noise source detectable at a distance of 20-25 km (Green Jr. and Moore 1995). The frequency of shipping channel dredging differs between locations. In Port Elizabeth, South Africa, for example, the harbour entrance of the Port of Ngqura is dredged only once every 12-18 months (Martin 2012a), while ongoing dredging is performed in Richards Bay further to the North (Ports and Ships 2011). The sounds produced with dredging cover the frequency band of 50-7000 Hz, with peak levels at 50-500 Hz of 150-180 dB (Green Jr. and Moore 1995).

Finally, it is worth mentioning that onshore wind farm construction and operation has caused widespread concern about the propagation of the sound generated during turbine installation into the sea (Langman 2011).

4.2.4. Active sonar

Active sonar is used for both military and civilian purposes (Hildebrand 2005). The basic principle consists of the emission of short pulses of sound and the reception of the echoes to provide information about objects either within the water column, on the sea bottom, or within the sediment (SeaBeam 2000). Based on their active frequencies, sonars can be divided into three different categories: 1) low frequency active (LFA) sonars, 2) mid-frequency sonars, and

3) high frequency sonars (Hildebrand 2005). LFA sonars are primarily used for military purposes to detect submarines over thousands of kilometers (Hildebrand 2005). One example of such a system is the SURTASS LFA, which operates in the 100-500 Hz frequency band at source levels of 235 dB (Prince 2007, SURTASS 2011). Mid-frequency sonars are also predominantly used for military purposes. Globally around 300 navy ships are deployed with this type of sonar, producing sounds within the 1-7 kHz frequency band (i.e. centre frequencies of 2.6 and 3.3 kHz) at source levels of more than 235 dB (Evans *et al.* 2001, Hildebrand 2005). High frequency sonars are used in weapons or weapon countermeasures and emit highly directional pulsed signals within the frequency range of 10 to 100 kHz (Hildebrand 2005).

Sonars available for commercial or recreational shipping span a wide range of frequencies from 3-200 kHz used for fish finding, depth sounding, and sub-bottom profiling (Hildebrand 2005). However, only a small frequency band is generated per sonar with source levels ranging from 150-235 dB (Hildebrand 2005).

4.2.5. Explosions

Explosions can be categorized as either nuclear or chemical in origin (Hildebrand 2005). Nuclear explosions in the sea used to result from the testing of nuclear weapons. However, these tests have been banned since 1996 by the Comprehensive Test Ban Treaty (CTBT) and to ensure worldwide conformity with the CTBT, an international monitoring system consisting of multiple hydrophone stations, continuously monitors the world's oceans to detect high-intensity sounds characteristic of nuclear explosions.

Chemical explosions are still occasionally used for the construction and removal of undersea structures. In addition, the Navy of various countries, such as the United States of America, The Netherlands, Germany, Canada, and South Africa, apply explosives in ship-shock trials (i.e. to test the ability of ships to withstand explosions), weapon testing, disposal of retrieved explosive weapons (i.e. mines), and to sink retired ships (Hildebrand 2004). Explosives produce sound within the frequency range of 10-1000 Hz, where the sound intensity mainly depends on the charge weight (Hildebrand 2005). In general, explosions are considered to be the strongest sources of transient sound in the sea as well as the most dangerous due to an extremely brief rising time in pressure (Green Jr. and Moore 1995). These characteristics guarantee a high potential for biological injuries (i.e. organ disruption, organ fractures, and haemorrhages) in a wide range of marine animals, such as fish (Klima *et al.* 1988), sea turtles (Klima *et al.* 1988), penguins (Cooper 1982), harbour porpoises (Ketten 2004), and dolphins (Ketten 2004).

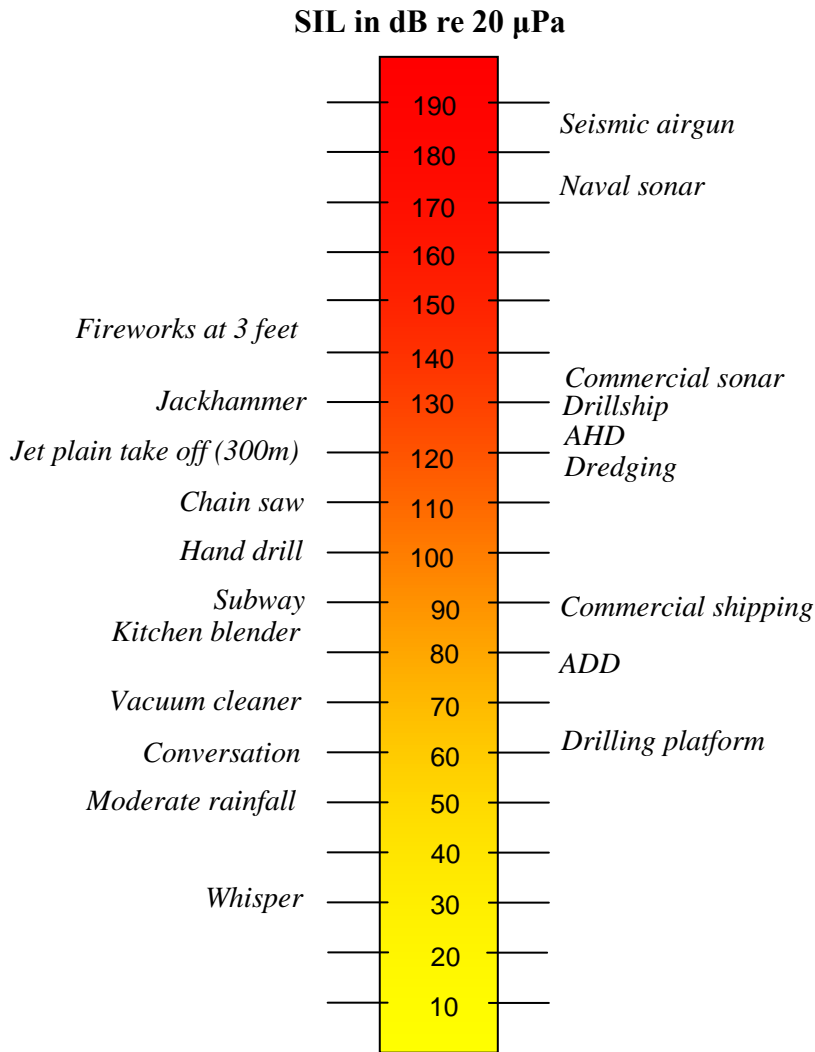


Figure 4 Sound intensity levels (SIL) of common airborne sounds as well as anthropogenic underwater sounds in dB re 20 μ Pa. The officially published underwater SILs were converted into an approximate airborne level by subtracting 61.5 dB

4.2.6. Acoustic deterrent (ADD) and harassment (AHD) devices

Fisherman and aquaculture industries use acoustic deterrent (i.e. ADD or pinger) and harassment (i.e. AHD) devices to keep marine mammals (i.e. seals, toothed whales, and baleen whales) away from fish nets and to prevent them from preying on fish caught in the nets, on hooks, or on lines (i.e. depredation) (Johnston and Woodley 1998). The fundamental difference between these two devices is that ADDs are used to protect marine mammals from potential danger by alerting them to the presence of unnatural objects, such as fishing nets (Johnston and Woodley 1998). These devices are low-powered, with source levels of 130-150 dB within the 5-160 kHz frequency band (Hildebrand 2004, 2005). In contrast, AHDs are deployed with the intention to cause pain to marine mammals, emitting pulsed sounds with source levels of 185-196 dB within the same frequency band as ADDs (Johnston and Woodley 1998, Hildebrand 2004, 2005).

Concerns about the effect of these devices is that there can be severe and long-term effects, such as physiological damage to marine mammal hearing or displacement of animals from important habitats (Johnston and Woodley 1998, Morton and Symonds 2002, Olesiuk *et al.* 2002, Hildebrand 2004). Furthermore, deterrent devices might affect non-targeted, acoustically sensitive marine species (Johnston and Woodley 1998, Morton and Symonds 2002). Killer whales in British Columbia, for example, were affected by AHDs that were installed in attempts to deter predation on salmon fish pens by harbour seals (*Phoca vitulina*) (Morton and Symonds 2002). The effect of ADDs and AHDs on non-targeted species is discussed in more detail below (see section 5.4.2).

PART 5: POTENTIAL IMPACTS OF ANTHROPOGENIC NOISE ON MARINE ANIMALS

As indicated previously, there is an increasing concern that anthropogenic ocean noise potentially harms marine animals. This concern has arisen from studies indicating a significant increase in ambient ocean noise by about 3 dB per decade as well as the increasing evidence of whale strandings being linked to military sonar exercises (Jasny *et al.* 2005). In recent years a doubling in research effort and improved abilities to study marine mammal behaviour have indicated a wide variety of potential effects of ocean noise on marine animals (Nowacek *et al.* 2007). Since the actual impact of anthropogenic noise on marine animals depends on a range of factors, including the properties of sound (e.g. sound level, frequency, and duration), the physical as well as behavioural state of the animal, and the acoustic and ecological features of the environment (e.g. natural sound sources and type of substratum) (Hildebrand 2005), an animal's response to one type of sound source might vary over time and space (NRC 2003). Therefore, the possible impacts of noise on marine animals will be discussed per type of response.

The type of response can be described as physical (e.g. non-auditory or auditory), stress (e.g. suppression of the immune system), perceptual (e.g. interference of sound from animals with sound from anthropogenic sources), behavioural (e.g. displacement from important habitats), chronic (e.g. sensitization or habituation), or indirect (e.g. reduced prey availability) (Dolman and Simmonds 2005). The following section discusses each of these possible effects in detail.

5.1. PHYSICAL RESPONSES

5.1.1. Non-auditory responses

The most severe non-auditory physical impacts of high levels of sound on marine animals include severe damage to body tissues or embolism (i.e. gas bubbles in the bloodstream), which often results in death (Dolman and Simmonds 2005). Explosions, for example, form a shockwave followed by intense oscillations of sound (Jasny *et al.* 2005). As these oscillations pass through an animal the pressure causes vibration of the lungs and viscera, around the natural pockets of air (Jasny *et al.* 2005). Consequently, body tissues may burst their walls and bleed into the cavities, causing internal bleeding and possibly resulting in death (Jasny *et al.* 2005). In addition, high

intensity sounds have the potential to permanently damage organs of balance, which has recently been indicated for octopi and squid (i.e. cephalopods) (André *et al.* 2011). For example, André *et al.* (2011) found that the common squid (*Loligo vulgaris*), cuttlefish (*Sepia officinalis*), octopus (*Octopus vulgaris*), and short-finned squid (*Illex coindetii*) suffered from permanent changes in the structure of their sensory haircells, which are responsible for the animals' sense of balance and position, when exposed to high intensity sounds (André *et al.* 2011). Klima *et al.* (1988) experimentally exposed sea turtles (i.e. four Kemp's ridley and four loggerhead sea turtles) to explosives at four different distances (229 m, 366 m, 549 m, and 915 m) (Klima *et al.* 1988). Five out of the eight individuals were retrieved unconscious and all four loggerhead sea turtles displayed pink coloration due to dilated blood vessels (Klima *et al.* 1988). Furthermore, high intensity sounds can cause severe concussions as indicated for the African penguin (*Spheniscus demersus*) and Southern Rockhopper (*Eudyptes chrysocome*) found floating unconscious close to blast sites in Saldhana Bay, South Africa (Cooper 1982) and at subantarctic Marion Island (Brown and Adams 1983), respectively.

Unfortunately, severe body damage can eventually result in death. This realization primarily originates from the strandings of beaked whales (*Ziphiidae*) related to military sonar exercises. Frantzis (1998) first brought attention to a mass stranding of Cuvier's beaked whales (*Ziphius cavirostris*) in the Ionian Sea, which were later related to tests of a Low Frequency Active Sonar (LFAS) by the North Atlantic Treaty Organization (NATO). The stranding locations and acoustic source tracks were closely associated in time and space, suggesting that these animals were affected by the sonar (Frantzis 1998). This sonar emitted sound signals between 450-700 Hz as well as 2.8-3.3 kHz at source levels of 226 dB (Frantzis 1998). However, it was the Bahamas' stranding event involving seventeen cetaceans, including Cuvier's beaked whales, Blainville's beaked whales (*Mesoplodon densirostris*), minke whales (*Balaenoptera acutorostrata*), and one Atlantic spotted dolphin, in March 2000 that raised immediate concern on the effects of sonar on marine mammals. All species from the Bahamas' stranding event provided clear evidence of acoustic trauma in relation to multiple military sonars operating between 2.6-8.2 kHz at 223-235 dB (Evans *et al.* 2001, Weilgart 2007). All of these animals appeared to be in good body condition without any sign of disease, ship strikes, blunt or other apparent contact trauma, or fishery related injuries. Nevertheless, there was clear evidence of haemorrhaging around the brain, in the inner ears, and in the acoustic fats located within the animals' head (Evans *et al.* 2001). Similar results were found in stranded animals in May 2000 on the Madeira Archipelago as well as in September 2002 on the Canary Islands (Hildebrand 2004), while a recent stranding at the beginning of December 2011 in the Ionian Sea is currently still under investigation (AEInews 2011). In addition, individuals from the Canary Islands showed gas bubble-associated lesions and fat embolism (i.e. nitrogen bubbles formed in the fatty marrow) in the blood

vessels and the tissue of vital organs (Fernández *et al.* 2005). These symptoms correspond to the presumed cause of decompression sickness in human divers, when nitrogen bubbles in the bloodstream, formed during rapid ascent to the sea surface, leave the bloodstream and block off smaller blood vessels (Fernández *et al.* 2005). Natural nitrogen levels in the tissues of diving whales and dolphins are likely to be insufficient to initiate bubble growth (Piantadosi and Thalmann 2004). However, Potter (2004) suggested that micro-bubble gas exchange could be activated by high intensity sounds resulting in bubble growth, sufficient to cause symptoms of decompression sickness. Other cases that revealed signs of decompression sickness involved stranded animals in Britain between October 1992 and January 2003 as well as animals stranded along the Spanish Costa del Sol in January 2006 (Jepson *et al.* 2003, Dalton 2006). Although decompression sickness is not always lethal, it can be rapidly fatal if severe. Alternatively, it can result in a more continuous syndrome leading to death, whereas gas and fat emboli can cause nervous and cardiovascular dysfunctions, respiratory distress, pain, and disorientation (Fernández *et al.* 2005). Currently, the development of decompression sickness and emboli has been hypothesized to be a consequence of abnormal diving behaviour, such as a more rapid surfacing than usual from a deep dive (Perrin and Geraci 2008). However, further research on the behavioural and physiological effects of sonar on whales and dolphins is important in order to elucidate the origin and development of this syndrome (Fernández *et al.* 2005).

High intensity sound has also caused mortality in a variety of other marine species. Intense noise has been indicated to increase the mortality rate in the brown shrimp (Lagardère 1982), for example, and might instantly kill fish larvae (Popper and Hastings 2009). In addition, juvenile and adult fish were found dead, floating around explosion sites with torn gas bladders and severe lesions of their abdominal organs (Klima *et al.* 1988), while the giant squid (*Architeuthis dux*) has been found stranded along the Spanish coast with severe internal injuries, probably resulting from offshore seismic surveys operating at frequencies below 100 Hz at 200 dB (MacKenzie 2004). Furthermore, Klima *et al.* (1988) reported a positive relationship between the frequency of offshore explosions and the number of dead Kemp's Ridley (*Lepidochelys kempi*) sea turtle strandings, characterized by lung haemorrhages and ruptures in the heart. In addition, penguins have been found dead, floating around blast sites in Saldhana Bay, South Africa (Cooper 1982) and at subantarctic Marion Island (Brown and Adams 1983). Finally, a variety of seal species, such as the California sea lion (*Zalophus californianus*) and the Northern fur seals (*Callorhinus ursinus*), have been found killed in the vicinity of explosion sites (Richardson 1995).

5.1.2. Auditory responses

Besides death and tissue damage, intense sounds have the potential to cause temporary (TTS) or permanent threshold shifts (PTS). The term threshold shift refers to an increase in the minimum sound level needed for an organism to hear the sound (i.e. audibility) (Hildebrand 2005). A TTS involves successful recovery to normal hearing thresholds after a given period of time unexposed, while during a PTS the sensory hair cells in the inner ear are permanently lost making recovery impossible (Weilgart 2007).

Temporary threshold shifts have been indicated for a variety of fish species as a consequence of exposure to white noise (i.e. signal covering all frequencies with an equal distribution of energy across all frequencies) (Amoser and Ladich 2003, Götz *et al.* 2009), various types of vessels (Scholik and Yan 2002), sonar (Popper *et al.* 2007), and seismic airguns (Popper *et al.* 2005). The goldfish (*Carassius auratus*), for example, showed significant temporary threshold shifts after only 10 minutes of exposure to white noise, with a peak shift of 28 dB after 24 hours (Smith *et al.* 2007). Furthermore, Moein *et al.* (1994) suggested a TTS in loggerhead sea turtles as a result of exposure to seismic airguns. TTS in marine mammals has been indicated for, among others, the beluga whale (Finneran *et al.* 2002), bottlenose dolphin (Finneran *et al.* 2005b), and harbour porpoise (Lucke *et al.* 2009). Possible PTS has been indicated for McCauley *et al.* (2003) in the pink snapper (*Pagrus auratus*) after exposure to sound from an airgun at 203 dB.

The effects of hearing loss, although not directly fatal, can have important consequences for the instant as well as future survival of the organism. Hearing loss reduces the potential for communication with conspecifics, interferes with foraging capabilities, increases vulnerability to predators, and may cause erratic behaviour with respect to migration, mating, and stranding (Hildebrand 2005, Jasny *et al.* 2005). The increased entanglement rate of humpback whales in fishing nets around Newfoundland, for example, has been hypothesized to be caused by hearing damage (Todd *et al.* 1996). Furthermore, sperm whales (*Physeter macrocephalus*) off the Canary Islands that had been struck and killed by ships, showed signs of hearing loss, such as reduced auditory nerve volumes (André *et al.* 1998). However, the detailed impacts of hearing loss remain to be explored (Hildebrand 2005).

5.2. STRESS

Animals that do not show any obvious signs of physical damage or behavioural disturbance due to excessive sound exposure might still experience changes in bodychemistry associated with stress (Jasny *et al.* 2005). Stress is of concern since it potentially inhibits growth, sexual maturation, reproduction and survival of an organism (Pickering 1992, McCormick 1999, Consten *et al.* 2001).

Unfortunately, we have little scientific evidence on the effects of stress on marine animals, with only a few studies published.

In invertebrates, the brown shrimp showed a significant reduction in growth and reproductive rate as well as a minor increase in aggression and mortality (Lagardère 1982). These symptoms correspond to symptoms induced by adaptation to stress (Lagardère 1982). Furthermore, fish embryos exposed to sounds between 100-1200 Hz at sound levels of 80-150 dB revealed signs of stress as well as an increase in hearing sensitivity with more than 50 dB (Simpson *et al.* 2005b). Similarly, the goldfish exhibited elevated cortisol levels within 10 minutes of exposure to white noise (i.e. 160-170 dB), while TTS became evident only after those 10 initial minutes (Smith *et al.* 2007). Furthermore, in cetaceans, Romano *et al.* (2004) found increased catecholamines (i.e. norepinephrine, epinephrine, and dopamine) that are indicative of stress in a captive beluga whale and bottlenose dolphin exposed to seismic pulses (i.e. 200-225 dB) and sonar pings (i.e. 3 kHz at 130-201 dB).

Nevertheless, studies on fish have indicated that not all types of sound necessarily induce a stress response. Wysocki *et al.* (2006) found that three fresh water fish species (i.e. common carp *Cyprinus carpio*, gudgeon *Gobio gobio*, and European perch *Perca fluviatilis*) responded with increased cortisol secretion when exposed to ship noise, but not when exposed to continuous white noise. Therefore, it seems likely that a less predictable stimulus characterized by fluctuating amplitudes and frequencies has a higher probability to induce stress than a continuous predictable sound stimulus (Wysocki *et al.* 2006).

5.3. PERCEPTUAL EFFECTS

A second effect of noise that can occur without any obvious signs displayed by the organism is masking. Masking occurs when sound emitted or received by the animal is obscured by interfering sounds (Würsig and Richardson 2008). In general, sounds are heard when sound levels reach the audibility threshold level. Masking is defined as an increase in the audibility threshold as a consequence of the presence of another sound (Moore 1982, in Clark *et al.* 2009). In the presence of masking noise, the original signal will only be audible when the 'critical ratio' is reached, which is the lowest signal-to-noise ratio at which a subject can detect a tonal signal over broadband masking noise (Fletcher 1940, in Southall *et al.* 2007). Complete or even partial masking of a signal reduces an animals' accessibility to information, which is essential for communication, navigation, and predator/prey detection and predator avoidance (Clark *et al.* 2009).

Long term masking on breeding grounds will result in a decreased reproductive success as a consequence of the inability to communicate with conspecifics in order to form social groups (Erbe 2001, Vasconcelos *et al.* 2007, Clark *et al.*

2009). This has been suggested for the Lusitanian toadfish (*Halobatrachus didactylus*), whose sounds to attract females and to defend nests is masked by ferryboat noise (Vasconcelos *et al.* 2007). Marine animals also use sound to navigate. A special case are coral reef fish larvae, which use sound as a cue to navigate to reefs for settlement (Simpson *et al.* 2008). This is an important stage of their life-cycle during which masking could result in reduced survival (Simpson *et al.* 2008). In addition, short- as well as long-term masking of navigational cues might cause animals to strand and possibly die (Erbe 2001). Reduced survival rates could also result from a decreased foraging efficiency due to masking (Erbe 2001). Soto *et al.* (2006), for example, reported a decreased duration of the vocal phase, indicative of prey capture attempts, in diving Cuvier's beaked whales coinciding with the passage of a noisy vessel. A reduction in echolocation range due to the masking of echoes from prey as well as the masking of acoustic signals used to coordinate the group behaviour of Cuvier's beaked whales diving together, were suggested as possible explanations (Soto *et al.* 2006). However, either explanation will result in a decreased foraging efficiency due to masking.

Some animals are probably capable of minor adaptations to elevated noise levels by changing aspects of their behaviour, which is discussed in section 5.4. below. Nevertheless, these adaptations could result in higher energetic costs (Tyack 2008). In addition, under continuously increasing noise levels, animals will reach the physical limit to their compensation abilities (Parks *et al.* 2011).

Difficulties in the prediction of long-term consequences of masking arise from the temporal and spatial variation in detectable masking sounds. In addition, the effect of masking depends on the vocalization, hearing, behavioural state, and adaptation capabilities of the species involved. Therefore, the interpretation of the significance of masking necessitates understanding of the function of a call or cue as well as the potential degree of adaptation for each species individually (Weilgart 2007).

5.4. BEHAVIOURAL RESPONSES

Behavioural responses depend on several factors, such as the behavioural state of the animal, sex, age, presence of offspring, the animals' previous experiences with a sound source, and location (Weilgart 2007). In addition, the eventual response varies from subtle changes to active avoidance or even abandonment of critical habitats (Hildebrand 2004). This variety makes it difficult to translate behavioural responses into biologically significant effects at the individual as well as the population level (NRC 2005). In general, behavioural responses are considered to be biologically significant when it affects the animals' ability to grow, survive, and reproduce (NRC 2005). These effects can work on a population level when several individuals are affected at the same time and thus, decreasing the survival of the species (NRC 2005). The

NRC (2005) developed a Population Consequences of Acoustic Disturbance (PCAD) model to assist in the translation of acoustic disturbance to population effects (Figure 5). The model contains five levels of variables, namely characteristics of the acoustic stimuli, behavioural response, life function affected, effect on vital rates, and consequences at the population level. These five levels of variables are linked by four transfer functions: 1) relation between acoustic stimuli and behavioural response, 2) translation of behavioural response into effect on critical life function (i.e. feeding/breeding), 3) identification of the resulting change in vital rate (e.g. life span, reproduction rate etc.), and 4) translation of changes in vital rates into consequences on population level. However, this model will take years to implement due to insufficient data (NRC 2005). Therefore, to date, no conclusions on the significant population effects of behavioural changes related to ocean noise can be drawn and are unlikely to emerge in the near future (OSPAR 2009). Nevertheless, the amount of studies reporting behavioural responses in response to acoustic stimuli increases continuously. In general, behavioural responses can be divided into: modification of vocal behaviour, displacement from important habitats, and other behavioural responses. These various responses are discussed in more detail below.

5.4.1. Modification of vocal behaviour

Animals have been reported to change their vocal behaviour in response to masking by anthropogenic sound or as an indicator of a change in behaviour (e.g. from foraging to travelling). A recent study on captive bottlenose dolphins indicated that metabolic rates increased by approximately 25-30% during vocal periods (Holt *et al.* 2011). Therefore, an increase in intensity, duration, and/or repetition of vocalizations by marine animals in response to increased anthropogenic noise might involve increased energetic costs (Holt *et al.* 2011).

Changes in vocal behaviour have particularly been documented for cetaceans. Beluga whales, for example, were found to decrease their calling rate in response to outboard motorboats and ferries (Lesage *et al.* 1999). The authors suggested that the decreased calling rate was possibly due to an overlap between sound frequencies of the beluga whale calls and vessels. Furthermore, the beluga whales slightly shifted the sound frequency of their calls to avoid the frequency band used by ferries (Lesage *et al.* 1999). A Cuvier's beaked whale shortened its vocal phase, which is indicative of foraging, by 20% in response to a passing modern cargo ship emitting sound at 30 kHz with a source level of 150 dB (Soto *et al.* 2006). This response suggests that Cuvier's beaked whales cease foraging in response to noise disturbance (Soto *et al.* 2006), thereby decreasing their energy intake. In contrast, killer whales in nearshore waters of the Washington state elongated their call durations after a period of increasing boat traffic. Foote *et al.* (2004) suggested that this change in vocal behaviour compensated for the increased amount of

anthropogenic noise. Humpback dolphins increased their whistle rate after a boat moved through the area they were occupying (Van Parijs and Corkeron 2001). The increase in whistle rate was significantly higher in groups with mother-calf pairs (Van Parijs and Corkeron 2001). Therefore, the authors suggested that noise affects dolphin group cohesion, resulting in high whistling rates to re-establish or maintain vocal contact. In reaction to pingers, sperm whales ceased the emission of clicks characteristic of their diving behaviour, although still swimming at the same speed and direction (Watkins and Schevill 1975). Blue whales (*Balaenoptera musculus*) increased their calling rate on days of seismic surveys as well as during the surveys in comparison to non-seismic survey days (Di Iorio and Clark 2010). Since these calls are normally associated with social encounters and feeding, the increased calling rate probably compensated for the elevated noise from seismic survey operations. Miller *et al.* (2000) suggested that humpback whales sang longer songs in response to LFA sonar transmissions to compensate for acoustic interference.

5.4.2. Displacement from important habitats

Animals might choose to avoid or even displace themselves from an habitat when they are exposed to disturbing factors, such as anthropogenic noise. Displacement from areas where seismic surveys are carried out, for example, has been indicated for a variety of fish species, such as cod (*Gadus morhua*) (Engås *et al.* 1996), haddock (*Melanogrammus aeglefinus*) (Engås *et al.* 1996), rockfish (*Sebastes* spp.) (Skalski *et al.* 1992), herring (*Clupea* spp.), blue whiting (*Micromesistius poutassou*), and mesopelagic fish species (Slotte *et al.* 2004), with a consequent decrease in catch rates of commercial fisheries. In addition, ringed seals (*Pusa hispida*) abandoned important habitats as a consequence of seismic activities (Kelly *et al.* 1986), while Parente *et al.* (2007) reported a decrease in overall species diversity along the Brazilian coast during seismic activities, which was primarily a consequence of the displacement of non-resident delphinid species.

Killer whales abandoned an area after the deployment of AHDs, which intended to deter harbour seals from salmon farms (Morton and Symonds 2002). However, whale occurrence returned to initial levels after the removal of these deterrent devices (Morton and Symonds 2002). Similarly, harbour porpoises have been indicated to abandon areas with AHDs as well as construction sites of an offshore windfarm (Olesiuk *et al.* 2002, Carstensen *et al.* 2006). Previously identified individuals of Cuvier's beaked whales have not been re-sighted after the sonar related stranding in the Bahamas (Malakoff 2001). However, it is unknown whether this is a consequence of mortality of all previously present individuals or of the displacement of the entire population to a different area. Furthermore, hourglass dolphins (*Lagenorhynchus cruciger*), minke whales, and southern bottlenose whales (*Hyperoodon planifrons*) were reported to change their distribution during the Heard Island

Feasibility Test- a trial to test the feasibility of measuring average ocean temperatures by emitting sound through the deep sound channel (Bowles *et al.* 1994, Simmonds *et al.* 2004).

Displacement from an habitat might not be of concern, provided that the quality of the area from which the animals were displaced from is poor or, alternatively, that the area where they have moved to is of equal quality (Nowacek *et al.* 2007). However, an animals' wellbeing can be negatively influenced when it is forced to leave a previously preferred habitat (i.e. good quality habitat), with a consequent increase in energetic costs (Costa 1998). On the other hand, animals might still suffer from physical injuries or stress even though they choose to stay in a preferred area with high quality (e.g. an area with a high prey availability) (Beale and Monaghan 2004). In other words, the animals may appear undisturbed despite experiencing an impact of anthropogenic sound.

5.4.3. Other behavioural responses

Other behavioural responses in marine mammals include both subtle and obvious responses, such as an increased breathing synchrony or swimming speed, alteration in dive duration, increased time spent at the surface, rapid and erratic movement, and movement away from the sound source (Bowles *et al.* 1994, Lesage *et al.* 1999, Williams *et al.* 2002, Hastie *et al.* 2003, Ng and Leung 2003, Soto *et al.* 2006). These short-term behavioural responses might result in considerable energetic costs. Williams *et al.* (2006), for example, indicated that the killer whales in British Columbia changed their behaviour from feeding to travel/forage in response to boat traffic, with a consequent increase in energy demand as well as a reduction in energy intake.

Squid (i.e. southern calamari *Sepioteuthis australis*) displayed a strong startle response to a nearby airgun, while remaining close to the water surface where sound levels are less, throughout the trial (McCauley *et al.* 2000). Species, such as bluefin tuna (*Thunnus thynnus*), have been found to respond with restless behaviour, rapid changes in speed, and abrupt turns upon exposure to noise from small boats. Furthermore, the tuna increased their vertical movement towards the surface or the bottom, where sound levels are generally less, when a boat approached (Sarà *et al.* 2007). In addition, the tuna actively tried to avoid ferries by swimming in the opposite direction (Sarà *et al.* 2007). Finally, green (*Chelonia mydas*) and loggerhead sea turtles increased their swimming speed and displayed erratic behaviour in response to sound from low frequency seismic airguns (McCauley *et al.* 2000). In addition, both species attempted to maintain themselves at maximum distances from the sound source (McCauley *et al.* 2000).

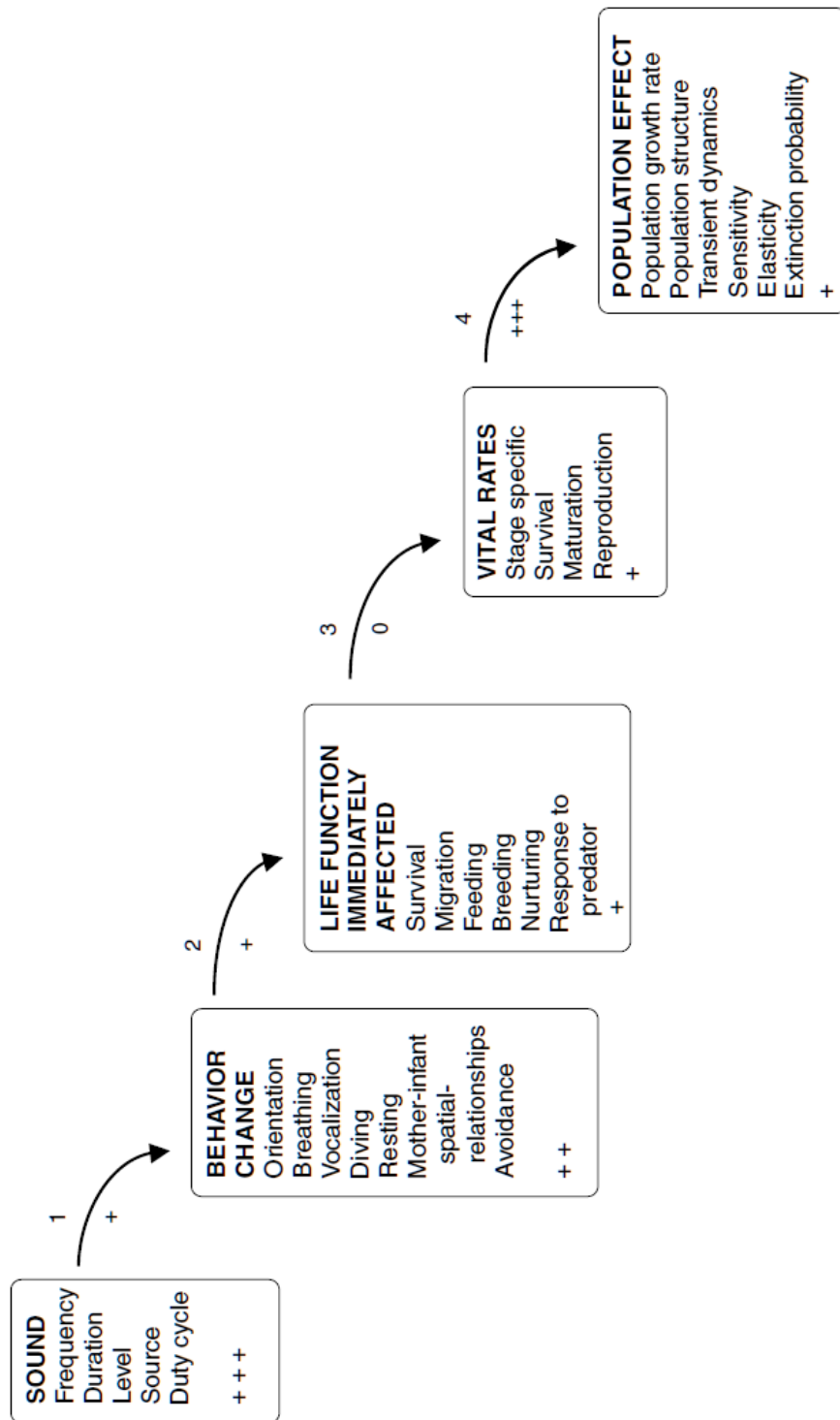


Figure 5 Population Consequences of Acoustic Disturbance (PCAD) from the NRC (2005): the number of + signs show the relative level of knowledge

5.5. CHRONIC RESPONSES

Chronic responses refer to sensitization and habituation as well as cumulative and synergistic effects. To be able to indicate chronic responses, animals have to be exposed to controlled stimuli to obtain longitudinal, sequential measurements (Nisbet 2000). Therefore, there is very little scientific evidence to date that marine animals adopt this type of response.

5.5.1. Sensitization

Sensitization refers to the process during which animals display an elevated responsiveness to noise over time (Richardson 1995). Richardson (1995) provides a list of examples where prior severe and harmful exposure to human activities have resulted in an increased responsiveness to sound in marine mammals. Northern fur seals (*Callorhinus ursinus*), for example, avoided ships that were engaged in seal hunting, while bottlenose dolphins avoided a boat that had previously been used for dolphin capture-and-release programs.

5.5.2. Habituation

Habituation refers to the process by which animals become accustomed to a particular noise over time (i.e. decreased responsiveness) (Richardson 1995, Hildebrand 2005). However, caution should be taken in the application of the term habituation. Decreased responsiveness to sound could in actual fact be a result of hearing damage and can therefore not be categorized as habituation (Weilgart 2007). Similarly, the most sensitive animals might leave an area of sound exposure, while the least sensitive animals remain (Beale and Monaghan 2004, Bejder *et al.* 2006). The gradual displacement of sensitive individuals might be perceived as a decrease in responsiveness of the whole population (Bejder *et al.* 2006). Incorrect applications of the term habituation can mislead wildlife managers to conclude that anthropogenic sounds have neutral or benign consequences for wildlife, and thus, can seriously underestimate their impacts and undermine management plans and conservation efforts (Bejder *et al.* 2006).

Nevertheless, several studies have documented habituation. Jacobs and Terhune (2002), for example, suggested that harbour seals in the Bay of Fundy, eastern Canada, habituated to the sounds of AHDs that were placed to deter these animals from Atlantic salmon (*Salmo salar*) aquaculture cage sites. Similarly, the harbour porpoises inhabiting this area habituated to the sound of ADDs (i.e. pingers) that were placed to reduce the bycatch of this species in gillnet fisheries (Cox *et al.* 2001). Furthermore, common minke, fin (*Balaenoptera physalus*), humpback, and gray whales (*Eschrichtius robustus*) seem to habituate to noise from whale watching vessels by changing their

behaviour from curiosity into disinterest or, in contrast, from avoidance into disinterest or curiosity (Watkins 1986).

5.5.3. Cumulative and synergistic effects

Multiple stressors can act simultaneously with a consequent cumulative or synergistic effect (Weilgart 2007). Cumulative stressors are stressors that might individually be insignificant, but that become significant when repeated over time or combined with the effects of other sound sources (MMC 2007). The combination of hearing impairment and an increased shipping activity, for example, may increase the risk of whale-ship collisions (Dolman *et al.* 2006). Synergistic stressors are stressors that facilitate each other's effect. For example, the effect of sound may be intensified when the animals exposed are in bad health conditions due to chemical pollution and therefore are unable to flee from or to avoid a particular sound source (Sih *et al.* 2004).

The assessment of cumulative and synergistic effects may take many years (Jasny *et al.* 2005). Therefore, to date these effects have not yet been addressed in a meaningful way (Jasny *et al.* 2005). Finding ways to assess cumulative and synergistic impacts of anthropogenic sound on marine animals should be considered as a conservation research priority (Jasny *et al.* 2005).

5.6. INDIRECT EFFECTS

As mentioned above, a variety of marine animals, such as shrimp, crab, squid, octopi, fish species, sea turtles, penguins, sharks, seals, toothed whales, and baleen whales are affected by anthropogenic noise. Therefore, it becomes evident that ocean noise might have ecosystem-scale effects (Hildebrand 2005). When shellfishes are affected by sound, for example, negative effects might have “knock-on” effects on squid or fish, which feed on them, and, in turn, on marine animals even higher up the food chain. In this scenario shellfishes are directly influenced by sound, while squid, fish, and higher orders of marine animals are indirectly affected. Furthermore, negative impacts of anthropogenic sound on key-species lower down the food chain will lead to a trophic cascade in which the impact of sound on the key-species alone will be enough to effect the entire food-chain (Smee 2010). In addition, a different type of stressor, such as chemical pollution, might cause a decrease in prey abundance (not to be confused with the accumulative effect of chemical pollution, which refers to the intake of polluted prey affecting an animals' health). Consequently, the predators' health condition might decrease and therefore increase the potential for negative impacts from anthropogenic noise pollution (Sih *et al.* 2004). However, to date the majority of ocean noise studies have been conducted on marine mammals. The full understanding of ecosystem-scale effects of anthropogenic ocean noise necessitates further research on the impact of noise on lower trophic levels, involving a variety of marine taxa.

PART 6: POSSIBLE MITIGATION MEASURES

Some sound sources produce noise as a simple byproduct (e.g. shipping), while others produce noise intentionally (e.g. AHD/ADD) (Jasny *et al.* 2005). Therefore, several different mitigation measures have been developed to reduce potential harm to marine life. Effective management of ocean noise pollution necessitates the evaluation of each sound source separately, followed by the application of appropriate mitigation measures. This section will briefly discuss the currently proposed and available mitigation approaches to minimize impact on marine animals.

6.1. GEOGRAPHIC AND TEMPORAL MITIGATION

6.1.1. Restrictions at important habitats

To protect marine animals, anthropogenic activities, such as shipping, seismic exploration, construction, drilling, dredging, active sonar, explosions, and the use of ADD's and AHD's should not be conducted in areas: that provide potential year-round critical habitat to endangered species; that have a high abundance of vulnerable species; that have a high species diversity; where species are displaced from a significant proportion of their feeding grounds; where the noise is in confined waters, on a migratory route, and is of sufficient duration that a significant proportion of a migratory period would be blocked; which geographically facilitate sound propagation, thereby affecting a larger area (e.g. bays and channels); and when noise on marine mammals itself has an economic impact (ICES 2005, Jasny *et al.* 2005, Götz *et al.* 2009). This approach, in combination with temporal restrictions discussed in the following section, has been adopted in Australia (Australian Government 2008), Europe (ACCOBAMS 2010, JNCC 2010), North America (IWC 2012), and Asia (IWC 2012).

For the protection of fish in particular, the Royal Norwegian Navy has implemented the restriction of naval exercises involving transmissions below 5 kHz in spawning areas, areas with large numbers of herring and brisling, and areas with intense fishing for herring and brisling (Götz *et al.* 2009).

6.1.2. Temporal restrictions

Seasonal restrictions

Some areas function as an important seasonal habitat for marine animals (Jasny *et al.* 2005). One obvious example is the migration of large whales (e.g. humpback, southern right, and gray whales *Eschrichtius robustus*) from their winter feeding grounds to their summer breeding grounds. Another example is the annual South African sardine run during the austral winter (i.e. May-October), which attracts a variety of marine predators, such as dolphins, sharks, seals, and sea birds (Van der Lingen *et al.* 2010). One oceanographic area in which seasonal restrictions have recently been implemented is the area around the Sakhalin Islands in the North Pacific near Russia (WWF 2011). Off-shore oil and gas platforms are not permitted to operate from June to mid-November, when endangered adult gray whales and their calves use this area as their primary feeding ground (WWF 2011).

Daily restrictions

Daily restrictions can be applied in areas where animals are known to obtain a daily pattern of occurrence (Jasny *et al.* 2005), such as the Hawaiian spinner dolphins (*Stenella longirostris*), which rest inshore during the day and forage offshore during the night (Norris and Dohl 1980). Operation of sound sources should be restricted at the time of the day during which animals might be engaged in crucial behaviours (e.g. foraging in early morning and late afternoon for the humpback dolphins in Algoa Bay, South Africa) (Götz *et al.* 2009, Koper 2011). Furthermore, if visual monitoring for marine animals is part of the mitigation strategy during anthropogenic sound polluting activities, operations need to be restricted when environmental conditions, such as darkness, mist, rain, and high sea state, obscure the efficiency of visual monitoring during anthropogenic sound polluting activities (Jasny *et al.* 2005).

6.2. SOURCE BASED MITIGATION

6.2.1. Activity reduction

A reduction in the amount of time a particular sound source is active might be achieved by more careful planning of the activity through the insurance of good service or the necessary equipment, or by following an effective work schedule (Jasny *et al.* 2005). In addition, seismic survey vessels that follow a transect survey, consisting out of multiple parallel transect lines, could shut the power of their airguns off when changing lines (EPBCA 2012). The employment of experienced crew might prevent the necessity for elongated trial periods as well as duplicate measurements (Jasny *et al.* 2005). Reduction of noise pollution by ADDs and AHDs can be achieved by using devices that are triggered by echolocation activities of dolphins and porpoises as well as by

manually reducing the duty cycle of the device (Götz *et al.* 2009). Furthermore, floating platforms should consider to secure themselves to a mooring station or a temporary anchor to reduce the amount of time the thrusters are running (Spence *et al.* 2007).

6.2.2. Sound containment

Sound containment intends to partially enclose the produced sound within a certain area around the sound source (Würsig *et al.* 2000). This mitigation measure seems appropriate for most of the potential sound sources. Blasting mats, for example, are rubber mats that can be placed over an explosive charge to reduce long range noise propagation (Spence *et al.* 2007). Ramming piles and machinery (e.g. onboard a ship) can be enclosed with acoustically-insulating material, such as fibre glass, mineral wool, and plastic (Spence *et al.* 2007, Götz *et al.* 2009). However, the most widely discussed containment device is known as the “bubble curtain” (Spence *et al.* 2007). A bubble curtain is a wall of bubbles around the location of the sound source created by forcing compressed air through perforated metal or PVC rings, that are surrounding the sound source, using air compressors (Spence *et al.* 2007). This device reduces sound transmission through a difference in density between seawater and air (i.e. 1020 – 1029 kg/m³ for seawater, depending on temperature and salinity, and 1.29 kg/m³ for air) as well as through the reflection and absorption of sound by the air bubbles (Cutnell and Johnson 1995, Würsig *et al.* 2000). Bubble curtains are primarily applied during pile driving and construction activities, but increasing efforts are being put into the potential use of this device around airguns, explosives, and vessel propellers (Spence *et al.* 2007).

The realization that currents might disrupt a single wall of bubbles has led to the development of “bubble trees”, which consist of several layers of bubbles (Figure 6) (Petrie 2005). Alternatively, a sheet of fabric or other solid material can be used to guide bubbles and prevent bubble dispersion. This latter system is referred to as a “confined bubble curtain” (Reyff 2005, Spence *et al.* 2007).

Bubble curtains have been proven to be highly effective, particularly with reducing sound resulting from pile driving. Würsig *et al.* (2000) reported a decrease of 3-5 dB, 8-10 dB, and 15-20 dB for the overall broadband frequency range, 400-800 Hz range, and 1.6-6.4 kHz range, respectively. Lucke *et al.* (2011) found a decrease of 13 dB between SEL levels measured in front and behind a bubble curtain. In addition, harbour porpoises held in an enclosure showed immediate strong behavioural responses (i.e. speed swimming and porpoising) when piling was carried out without the use of a bubble curtain. These reactions were not observed when the bubble curtain was used. However, a bubble curtain needs to cover the whole water column from sea bottom to sea surface to be effective and can therefore only be used in relatively shallow waters (CSA 2004, Laughlin 2005, Spence *et al.* 2007).

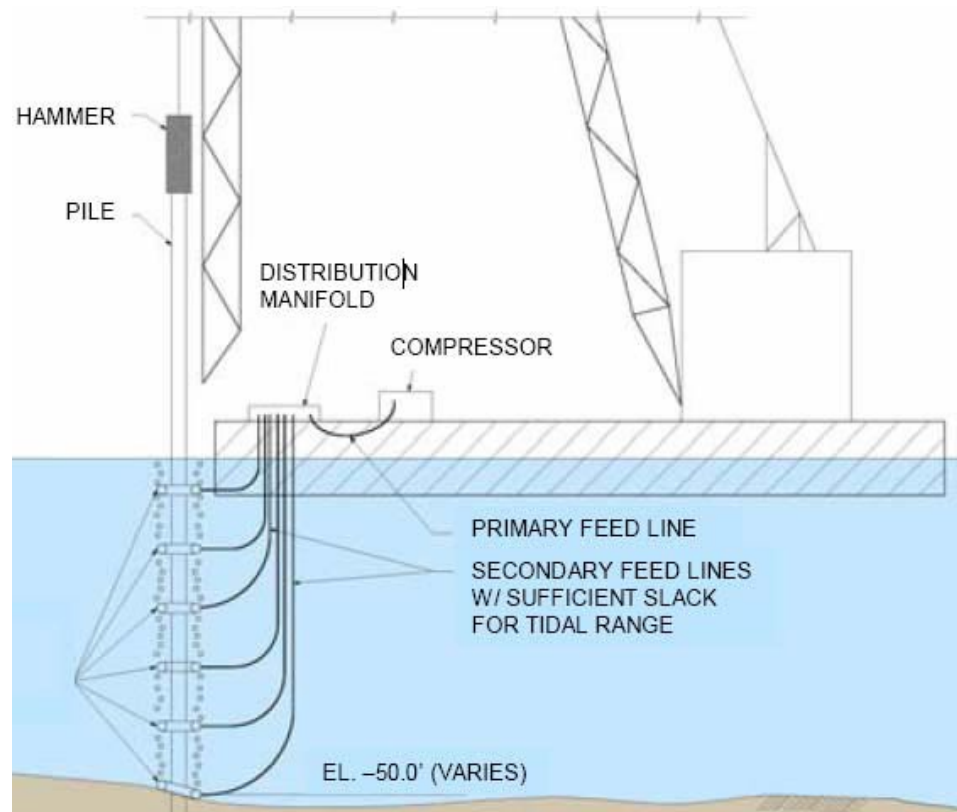


Figure 6 Example of a “bubble curtain tree” application in pile driving (Petrie 2005 credited to KPFF Consulting Engineers). Multiple bubble curtain rings are placed around the pile as to create a multi-layer bubble curtain. In contrast, an ordinary bubble curtain would consist of only one ring

6.2.3. Engineering and mechanical modifications

Engineering and mechanical modifications are sound source specific mitigation measures. Each sound source is discussed separately below.

Ships, boats, and personal watercrafts

Noise from vessel traffic is the dominant sound source within our oceans (Andrew *et al.* 2002). However, it is probably also the most likely sound source to undergo efficient mechanical modifications in the near future (Jasny *et al.* 2005). For years, the navy devoted money and time to the development of quieter ships and submarines (Götz *et al.* 2009). Therefore, the application of noise mitigation measures to commercial and recreational vessels is within reach.

The main process involved in the production of vessel noise is bubble cavitation generated by the propellers. As mentioned under section 4.2.1, propellers affected by marine growth are likely to produce a higher level of cavitation noise (Spence *et al.* 2007). Therefore, regular maintenance to keep

the propeller clean is an important common practice to keep sound levels resulting from cavitation to a minimum (Spence *et al.* 2007). Furthermore, cavitation noise can largely be reduced by increasing the uniformity of the flow conditions in and out of the propeller by improved propeller blade design as well as by reducing the sensitivity to variations in the flow and ship load (Spence *et al.* 2007). One promising example is the “forward-skew” blade design (Figure 7). This design has been shown to reduce noise by 5-18 dB around the 1000 Hz frequency band (Spence *et al.* 2007). Placing the propeller in a position where there are better flow characteristics might also help to reduce noise from cavitation (Spence *et al.* 2007).

The noise originating from the machinery aboard a ship can be reduced by selecting low-noise or low-vibrating equipment, by using vibration isolation systems or diesel-electric driven vessels (instead of diesel-gear driven vessels), and again by proper maintenance, such as the tightening of loose screws (Spence *et al.* 2007). In addition, exhaust silencers, which reduce airborne sounds by 20-30 dB re 20 μ Pa above 125 Hz, should always be used on any type of machinery (Spence *et al.* 2007).



Figure 7 Forward skew propeller with sharp tip called “bird beak” (Spence *et al.* 2007)

Seismic exploration

Seismic exploration activities generate broad band frequency noise (i.e. 5-20,000 Hz), of which only a small range (i.e. 5-100 Hz) is relevant for the collection of the required information (Goold and Fish 1998). One tool to reduce noise at the higher frequencies is known as an “airgun silencer,” which

is made from acoustically absorbent foam rubber (Nedwell J. and Edwards B. E. 2005, in Spence *et al.* 2007). This tool significantly reduces noise levels above 700 Hz to a maximum of 6 dB with an additional increase in sound levels around 100 Hz (Spence *et al.* 2007). Therefore, it has been hypothesized that fewer airguns might be needed when conducting seismic surveys with an airgun silencer in comparison to the current system (Spence *et al.* 2007). Systems proposed to replace airguns include a Low Level Acoustic Combustion Source (LACS) (Askeland *et al.* 2006), marine vibrators (Tenghamn 2006), and an underwater piston system (i.e. organ-pipe) generating sound at a single frequency (Morozov and Webb 2007). These alternatives have been indicated to severely reduce the sound levels above 100 Hz with an additional decrease in peak source levels of approximately 15 dB (Spence *et al.* 2007).

Alternatively, natural sounds, such as small seismic events, could potentially replace the artificially generated sound wave currently used during seismic exploration activities (Spence *et al.* 2007). However, this technique requires long acquisition times and is therefore not yet used by the oil and gas industry (Spence *et al.* 2007).

Construction, drilling, and dredging

The most promising tool for decreasing noise from pile driving activities is the bubble curtain discussed in section 6.2.2. Alternatively, or in addition, SILs (i.e. sound intensity levels) can be reduced by using steel casings lined with internal foam or *H*-shaped steel piles instead of round piles (Laughlin 2005, 2007). Furthermore, Laughlin (2006) suggests to place wooden, nylon, conbest (i.e. canvas based laminate combined with an aluminum alloy), or micarta (i.e. layers of material, such as paper or linen, bonded with resin) pile caps between the pile and piling hammer (Figure 8). Furthermore, the impact piling technique (i.e. use of pile hammer) could be replaced by vibratory pile driving or press-in piling, which use vibrations or weight alone to move the pile through the sediment (Spence *et al.* 2007).

Drilling activities are usually conducted from either fixed platforms or floating structures (Green Jr. and Moore 1995). Fixed platforms can reduce emitted sound levels by using a stiff foundation, such as multi-pile foundations. In addition, both platform types should use thrusters, fibre glass insulation, or damping techniques, such as the use of damping tiles, around machinery to reduce vibration noise (Spence *et al.* 2007).

Since dredging activities include the use of ships, decreasing engine noise, as described in section 6.2.3.1., is the first option that should be considered. In addition, all machinery should be mounted with the use of inflexible material to prevent vibration noise (Spence *et al.* 2007).



Figure 8 Left: circular steel casing with internal foam lining (Laughlin 2007). Right: wooden, micarta, and nylon pile caps at left, right, and bottom, respectively (Laughlin 2006)

Active sonar

Only little information is available on engineering mitigation of active sonar. However, when the species of concern has a well-defined hearing sensitivity, it may be possible to operate at frequencies to which the animals are relatively insensitive (ICES 2005). The development of more engineering modifications necessitates knowledge on the characteristics of sonar systems that cause negative impacts on beaked whales (ICES 2005).

Explosions

Although explosions only occur on an occasional basis, the possible impacts of explosions are severe. Therefore, efforts have been taken to develop mitigation measures that minimize the required charge weight for a given task (Spence *et al.* 2007). These measures include, for example, shape charges (Spence *et al.* 2007) and shock wave focusing charges. Shock wave focusing charges are hollow charges flexible enough to be wrapped around tubular constructions, focusing the energy of the shock-wave through a steel piling (CSA 2004). This technique has even been proven to reduce the charge weight by 90% (CSA 2004). In addition, explosives could be entirely replaced by cutting techniques, such as wire-, abrasive-, mechanical-, and torch cutting, which produce sound levels that are 80 dB less than the sound levels produced by normal blasting (TSB 2000, Spence *et al.* 2007). Furthermore, the use of thick bubble curtains (see section 6.2.2.) to contain sound from explosions has been effectively tested (Keevin and Hempen 1997), which resulted in decreased sound levels by more than 90 %.

Acoustic deterrent (ADD) and harassment (AHD) devices

As explained under section 4.2.6., ADDs and AHDs are deployed with the intention to negatively affect marine animals by causing discomfort or pain (Johnston and Woodley 1998). Unfortunately, there are not many engineering or mechanical modifications available for these devices. In general, these devices should be banned or at least prohibited to be used in areas where

endangered or threatened species occur permanently as well as temporarily (Jasny *et al.* 2005). However, when in use, both ADDs and AHDs have the potential to affect animals species other than the target population (Morton and Symonds 2002, Olesiuk *et al.* 2002). This could be prevented by pulsed directional sounds that are directly beamed towards the target population (Jasny *et al.* 2005). In addition, noise reduction can be achieved by using devices that are triggered by echolocation activities of dolphins and porpoises as well as by manually reducing the duty cycle of the device (Götz *et al.* 2009).

6.3. OPERATIONAL MITIGATION

6.3.1. Safety zones

Safety zones cover a radius around the sound source, which is visually and/or acoustically observed for the detection of marine mammals (e.g. whales, dolphins, seals) as well as sharks and sea turtles (MMC 2007, Weilgart 2007). The size of the radius should be established based on noise exposure criteria that identify the sound level above which there is a scientific basis for expecting that exposure would cause auditory injury or behavioural disturbance to occur (Southall *et al.* 2007). In 1995, the US National Marine Fisheries Service (NMFS) set “do not exceed” criteria for exposure of marine mammals to sound under the assumption that no physical injury would occur under these criteria. However, limited data availability led to uncertainty. Consequently, the “do not exceed” criteria were adapted over time to the current sound levels of 180 dB re 1 μ Pa for mysticetes and odontocetes and 190 dB re 1 μ Pa for pinnipeds exposed to pulsed sounds (Southall *et al.* 2007). In addition, a 160 dB re 1 μ Pa exposure criteria was set for behavioural disturbance. To date, these criteria levels are primarily used to establish safety zones during sonar and seismic surveys in the United States (HESS 1999, Lecky 2011, SURTASS 2011), Australia (Australian Government 2008), and New Zealand (Department of Conservation 2006). Nevertheless, recent data on TTS and behavioural reactions of marine mammals to sound appeared inconsistent with the above mentioned criteria. Therefore, the NMFS convened an expert panel of scientists to develop science-based underwater noise criteria (Barlow and Gentry 2004). Noise criteria were aimed to be assessed for the onset of physical injury as well as behavioural disturbance (Southall *et al.* 2007). Furthermore, sound sources were divided into three types according to acoustic characteristics: single pulse, multi pulses, and non-pulses. Animal species were divided into five categories based on their functional hearing frequencies:

1. Low-frequency cetaceans (0.007 to 22 kHz)
2. Mid-frequency cetaceans (0.15 to 160 kHz)
3. High-frequency cetaceans (0.2 to 180 kHz)

4. Pinnipeds in water (0.075 to 75 kHz), and
5. Pinnipeds in air (0.075 to 30 kHz) (Southall *et al.* 2007).

The minimum exposure criterion for injury resemble the levels at which a single exposure is estimated to cause PTS. Regarding behavioural disturbance criteria, Southall *et al.* (2007) were unable to derive explicit and broadly applicable numerical threshold values. Nevertheless, for single pulses the lowest level of noise exposure that has a measurable transient effect on hearing (i.e. TTS onset) was proposed as the most suitable threshold value until better measures are identified (Southall *et al.* 2007). The eventual radius covered by sound levels exceeding the noise exposure criteria should be calculated for each sound emitting activity separately, based on the characteristics of the sound source, animals in the area, and local propagation features (ACCOBAMS 2010).

Although safety zones help to protect some marine animals from exposure to sound levels near the source, there are several points to consider. First of all, not all animals will be detected by visual observation, and not all animals vocalize and therefore cannot be detected by passive acoustic monitoring (Jasny *et al.* 2005). In fact, fish as well as shellfish cannot be detected by either visual or acoustic monitoring, consequently these taxa are not adequately monitored by this mitigation measurement. Secondly, the effectiveness of visual observations is weather dependent. Furthermore, the radius of a safety zone is source dependent and sound levels might exceed the criteria values up to tens of kilometres from the sound source, which is impossible to cover with visual observations (HESS 1999). Therefore, it is recommended that the implementation of safety zones is practiced in combination with other measurements, such as engineering and mechanical modifications (Jasny *et al.* 2005).

6.3.2. Warning sounds

Warning sounds are sounds that intend to deter animals away from the sound source. A commonly used protocol is known as “ramp-up” or “slow-starts” (Jasny *et al.* 2005). During ramp-up, the sound intensity produced by the sound source is gradually increased in order to give animals the opportunity to move away (Jasny *et al.* 2005). However, this method has never been proven to be effective, with additional evidence suggesting that some animals might not move away (Stone 2003). This could be explained by the possibility that slow starts do not provide the animal with sufficient information to ascertain the direction of where the sound is coming from (Weilgart 2007). Furthermore, a slow start might even attract some animals out of curiosity (Weilgart 2007).

6.3.3. Power limits

In general, the lowest possible power levels should be used during any kind of anthropogenic activities known to contribute to ocean noise pollution (ACCOBAMS 2010, JNCC 2010, EPBCA 2012). In addition, power limits can be restricted by shutting down the power of non-operational systems prior as well as after usage (EPBCA 2012). Vessels should reduce their speed in order to reduce cavitation and consequently noise output (Spence *et al.* 2007). These measurements can either be achieved through decisions from the sound source operator or through governmental regulations (Jasny *et al.* 2005).

PART 7: LEGISLATION

Legislation stands for the act of making a law as well as for an already enacted law. Regarding the protection of marine animals from anthropogenic ocean noise, legislation is a complex matter. Although there are several international as well as national Acts for the protection of marine animals from harassment, hunt, capture, and kill (e.g. UNCLOS 1982, Government Gazette 1998, MLPA 2004, MMPA 2007, WCA 2010, EPBCA 2012 etc.), there is no specific Act to date for the protection of marine animals from anthropogenic noise (AWI 2012). However, based on these previously mentioned Acts that are in place, several governmental bodies as well as international and national organizations have recognized the concern about the effects of ocean noise on marine animals and are aiming to assess and mitigate its impacts (e.g. IMO 2011, ACCOBAMS 2012, ASCOBANS 2012, AWI 2012, JNCC 2012, NOAA 2012, NRDC 2012, WDCCS 2012 etc.). In addition, several guidelines, especially regarding the conduction of seismic surveys and naval sonar exercises (ACCOBAMS 2010, JNCC 2010, EPBCA 2012), have been established. These guidelines are primarily based on the protection of marine mammals and more knowledge on the effect of noise on other taxa is required to establish guidelines for a wider variety of animal species. A rough outline of the current measures for the protection of marine animals from anthropogenic noise is described below.

7.1. INTERNATIONAL LEGISLATION

The United Nations Convention on the Law of the Sea (UNCLOS) is an international Act implemented in 1994 that defines the rights and responsibilities of all participating nations in their use of the oceans (UNCLOS 1982). However, the issue of ocean noise and its effect on marine animals was not recognized until March 2008, when the convention noted to encourage further studies and consideration of the impacts on ocean noise on marine living resources (UNCLOS 2008). In addition, the convention requested the Secretariat to continue to compile peer-reviewed scientific studies it receives from Member States and to make them available on its website (UNCLOS 2008). To date, sources of noise in the marine environment are not regulated internationally (AWI 2012), but the recognition of concern is a step forward in developing international legislation.

7.2. GOVERNMENTAL NATIONAL LEGISLATION

There are a number of governmental national Acts in a number of specific countries regarding the protection of marine animals, especially marine mammals, from harassment, hunt, capture, or kill. For example, the United

States Marine Mammal Protection Act (MMPA 2007) and Marine Life Protection Act (MLPA 2004), the United Kingdom Wildlife and Countryside Act (WCA 2010) and Marine and Coastal Access Act (MCAA 2009), the Australian Environment Protection and Biodiversity Conservation Act (EPBCA 2012), and the South African Marine Living Resources Act (Government Gazette 1998). In summary, all these Acts aim to protect and conserve the marine environment, including marine life. However, as with the international legislation, none of these Acts specifically outlines the protection of marine animals from negative impacts of anthropogenic ocean noise.

7.3. LINKING MARINE ANIMAL RESEARCH, INDUSTRY, AND ENGINEERING MITIGATION FOR OCEAN NOISE LEGISLATION

The potential negative impacts of anthropogenic ocean noise is of increasing concern for a variety of governmental bodies as well as for international and national environmental non-governmental organizations (NGO's). All of these parties aim to assess the impact of ocean noise on marine life, identify anthropogenic sources generating ocean noise, develop mitigation measures, and establish a global approach in the mitigation of ocean noise pollution. Some of the well-known governmental agencies are the International Maritime Organization (IMO 2011) for the United Nations, the National Oceanic and Atmospheric Administration (NOAA 2012) in the USA, and the Joint Nature Conservation Committee (JNCC 2012) in the UK. In Europe, the governments of Southern and Northern European Countries have signed the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area (ACCOBAMS 2012) and the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS 2012), respectively. In addition, there are some non-governmental organizations (NGO's), such as the National Resources Defense Council (NRDC 2012), the Whale and Dolphin Conservation Society (WDACS 2012), Ocean Care (Ocean Care 2012), and the International Ocean Noise Coalition (IOCN) (AWI 2012). All these parties function as an essential link between marine research, industry, engineering (of mitigation tools), and the process of legislation. The primary progress achieved by these parties is the establishment of guidelines for specific anthropogenic activities, as is discussed below under section 7.4. These guidelines form the basis for adequate legislation for the protection of marine animals from anthropogenic noise pollution.

7.4. GUIDELINES

Current guidelines have mainly been established for seismic surveys and military exercises, with a few additional guidelines for offshore and onshore construction activities as well as the use of explosives.

7.4.1. Seismic surveys

Guidelines for the conduction of seismic surveys are provided by the Australian Government under the EPBCA (EPBCA 2012) (Table 3). In addition, agreements such as ACCOBAMS (2010) and JNCC (2010), have established guidelines (separate from the agreement or a governmental Act) for the Mediterranean, Black Sea, Contiguous Atlantic Area and United Kingdom waters (Table 3). These guidelines are aimed to prevent harm to marine mammals, especially cetaceans, and are therefore not regarded as adequate for the protection of fish, sea turtles, and sharks. Furthermore, it becomes evident that different regions apply different guidelines, probably as a consequence of the difference in animal species present. However, these differences highlight the necessity for careful selection of appropriate mitigation measures based on the area in which the activity is to be conducted and the expected potentially affected species.

Table 3 Guidelines for the conduction of seismic surveys from the EPBCA (2012), ACCOBAMS (2010) and JNCC (2010)

Mitigation measure	EPBCA	ACCOBAMS	JNCC
Pre-phase			
Site selection	X	X	X
Assessment			
Species affected			X
Likelihood of injury			X
Safe and harmful exposure levels		X	
Area affected		X	
Observation zone	X		
Low level zone	X		
Exclusion/shut down zone	X	X	X
Activity phase			
Use of lowest possible power level		X	X
Marine mammal observers		X	X
Continuous visual observation		X	
Continuous Passive Acoustic Monitoring (PAM)		X	
Pre-activity observation			

Mitigation measure	EPBCA	ACCOBAMS	JNCC
30 minutes	X	X	X
60 minutes *			X
120 minutes *		X	
Ramp-up	X	X	X
Lower power level when animal observed in low-power zone (i.e. 2 km)	X		
Shut down power when animal observed in exclusion/shut down zone:			
To be determined		X	
500 m	X		X
Restrict activity during the night and with bad visibility to systems that use PAM	X	X	X
Additional observations for marine animals from separate vessels or aircrafts	X		
When several surveys in one area: acquire minimal separation distance to allow for an escape route for marine animals		X	
Shut down power when changing survey lines/not active	X		X
Stop all activities in case of strandings, mortality, or observation of abnormal behaviour		X	
Post-phase			
Monitor populations after exposure for any negative effects		X	
Report on mitigation measure used and observations on marine animals.	X		X

* Represents pre-observation periods applied in areas where beaked whales are expected to occur.

7.4.2. Sonar exercises

Guidelines for the use of sonar in military exercises have been established by, amongst others, ACCOBAMS and NOAA (Prince 2007, ACCOBAMS 2010, UNS 2011) (Table 4). These guidelines are aimed to prevent harm to marine mammals (including whales and dolphins) as well as sharks and sea turtles. Therefore, these guidelines are not regarded as adequate for the protection of fish.

Table 4 Guidelines for the conduction of naval sonar exercises from ACCOBAMS (2010) and NOAA (UNS 2011)

Mitigation measure	ACCOBAMS	NOAA
Pre-phase		
Site selection	X	
Assessment:		
Safe and harmful exposure levels	X	
Area affected	X	
Exclusion/shut down zone	X	X
Activity phase		
Use of lowest possible power level	X	
Marine mammal observers	X	X
Continuous visual observation	X	
Continuous Passive Acoustic Monitoring (PAM)	X	
Pre-activity observation		
30 minutes	X	
120 minutes*	X	
Ramp up	X	
Shut down power when animal observed in exclusion/shut down zone		
To be determined	X	
500 m		
Restrict activity during the night and with bad visibility to systems that use PAM	X	
Stop all activities in case of strandings, mortality, or observation of abnormal behaviour	X	
Post-phase		
Monitor populations after exposure for any negative effects	X	
Report on mitigation measure used and observations on marine animals.	X	

* Represents pre-observation periods applied in areas where beaked whales are expected to occur.

7.4.3. Additional guidelines

Additional guidelines have been established for offshore as well as onshore construction activities and the use of explosives. For the construction of offshore wind farms the application of seasonal restrictions, the use of Acoustic Deterrent Devices, marine mammal observers, ramp-ups, and sound level restrictions have been recommended (ICES 2010). Furthermore, guidelines from ACCOBAMS include temporal restrictions, the usage of bubble-

or physical curtains, a 30-120 minute pre-activity observation period to ensure the absence of marine mammals near the sound source, and continuous visual observation during offshore construction activities, such as pile driving (ACCOBAMS 2010). In addition, onshore constructions should involve the set up of several noise monitoring stations at various distances from the source to monitor for local and long range noise levels and to verify if predicted sound levels are reached or not (ACCOBAMS 2010). Regarding explosions, guidelines from ACCOBAMS include the assessment of an exclusion/shut down zone, the usage of bubble curtains, the presence of marine mammal observers, and a 30-120 minute pre-activity observation period to ensure the absence of marine animals near the explosion site (ACCOBAMS 2010).

PART 8: CURRENT AND PLANNED ACTIVITIES IN SOUTH AFRICA

8.1. PORTS

South Africa is currently operating seven major ports for commercial shipping activities: Saldhana Bay, Cape Town, Port Elizabeth, Port of Ngqura (i.e. Coega), East London, Durban, and Richards Bay (Figure 9) (Table 5) (Ports and Ships 2011, Transnet 2012). The port of Durban is the largest, receiving over 4500 ships, carrying more than 130.000.000 Gt per year (Transnet 2012). The arrival and departure of large shipping containers is the primary source of noise around these ports. In addition, maintenance of the shipping lanes entering and exiting the ports includes dredging activities, for which the levels vary greatly from port to port and from year to year (UK MSACP 2011). Furthermore, ports might be subject to expansion projects. Saldhana Bay, for example, is planning to expand the ports' facilities with an extra container terminal (Engineering News 2011). The port of Cape Town is continuously expanding in order to increase ship handling capacity (Buthelezi 2011). The new port of Ngqura in the vicinity of Port Elizabeth is planning to build a new bulk liquid storage and handling facilities, which will involve dredging activities (PPC 2011). Finally, the port of Durban has finished the widening as well as dredging of the channel entrance and has now started excavating the basin leading to the terminal and dredging of the berths (Black 2011). In addition, the construction of a second harbour in Durban has not been ruled out (Black 2011).

A secondary, but well known, harbour frequently used by the fishing industry and petroleum industries is Mossel Bay (Transnet 2012).

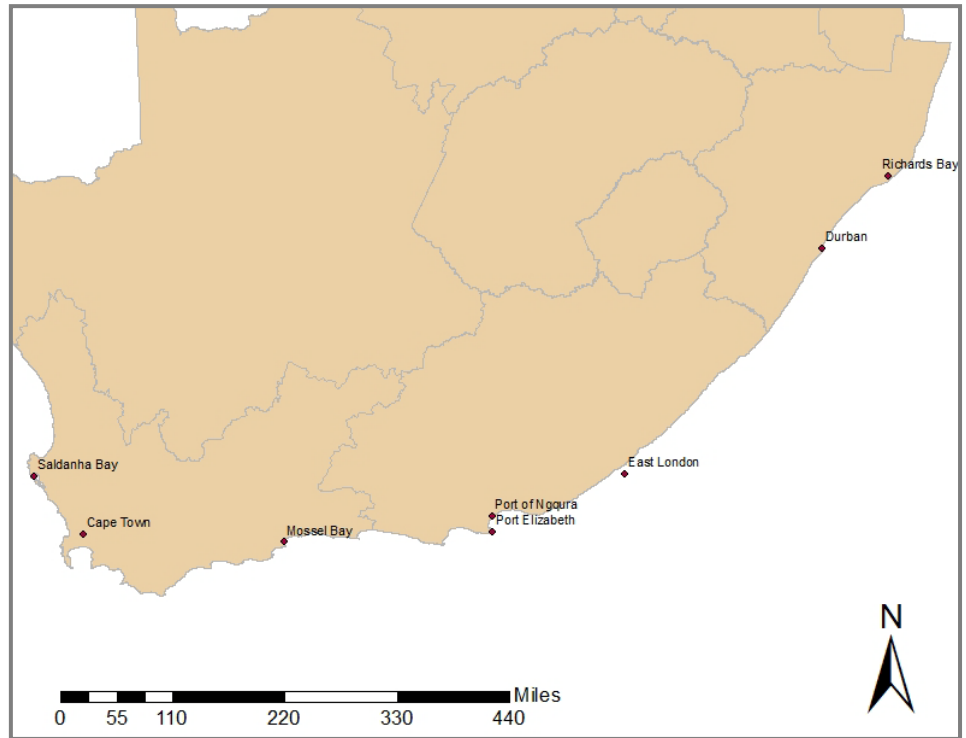


Figure 9 The major commercial ports of South Africa, including the smaller port of Mossel Bay

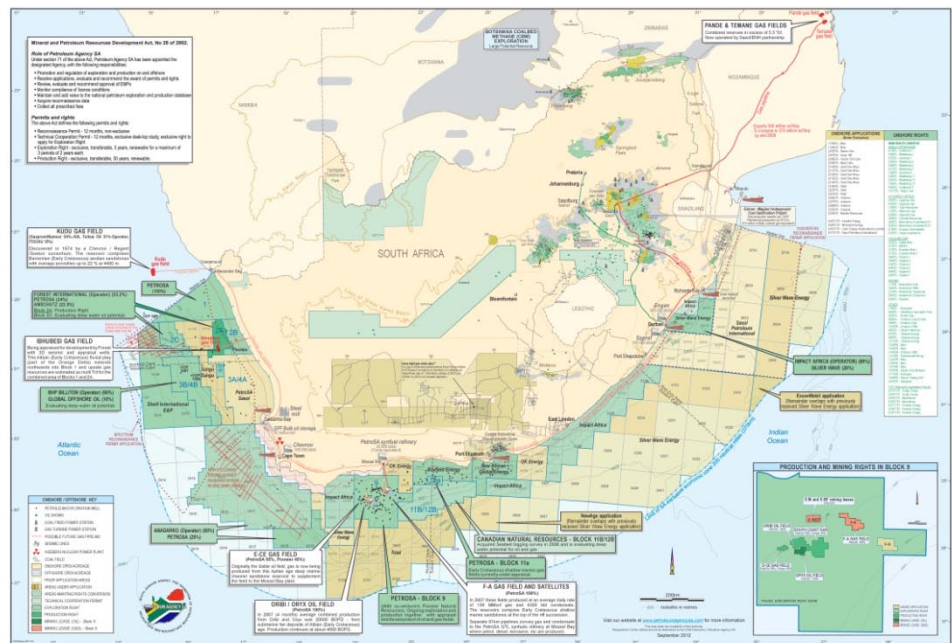


Figure 10 Current and planned seismic activities in South Africa. Dark green blocks represent areas with production rights, while brown areas represent areas currently under exploration application (PASA 2012)

Table 5 Major ports of South Africa with their corresponding annual amount of arriving container vessels, annual received gross tonnage, and port expansion plans (Transnet 2012)

Port	No. of vessels	Gross tonnage	Expansion
Saldhana Bay	505	33,600,791	Yes
Cape Town	2764	50,913,159	Yes
Port Elizabeth	1155	26,815,921	No
Port of Ngqura	358	15,469,577	Yes
East London	294	7,343,35	No
Durban	4633	131,708,314	Yes
Richards Bay	1871	63,625,727	No
Mossel Bay	1019	3,103,417	No

8.2. SEISMIC ACTIVITIES

South Africa is expanding its oil and gas exploration, with currently ten areas of oil production activities and continued seismic exploration activities (PASA 2012). In addition, seven areas around the coast are at present awaiting approval to conduct seismic surveys (Figure 10, obtained from the Petroleum Agency South Africa), four of which include inshore waters (PASA 2012). In Algoa Bay, for example, seismic surveys are planned to be conducted within a 1277.25 m² block reaching from approximately 15 km offshore (i.e. near Bird Island, which is a Marine Protected Area) to 65 km offshore (Fig. 11) (ERM 2011). Humpback whale mother-calf pairs are frequently spotted near Bird Island during the migration season. Furthermore, Bird Island is used as a breeding ground by the largest breeding colony of Cape gannets (*Morus capensis*) in the world as well as the African penguin and roseate terns (*Sterna dougallii*) (SANPARKS 2012). Seal Island, which is situated near Bird Island, supports a breeding colony of Cape fur Seals (*Arctocephalus pusillus*) (SANPARKS 2012). The presence of these vulnerable species has raised concern that seismic surveys at this relatively inshore location might have a negative impact on marine life (ERM 2011). In addition, seismic activities at inshore locations have a higher chance of interference with commercial as well as recreational fishing operations (ERM 2011).

Similarly to Algoa Bay, three seismic survey blocks are under proposal along the coast between Struisbaai and Mosselbaai (PPO 2010), an area which includes the De Hoop Marine Protected Area.

8.3. PIPELINE CONSTRUCTION

Pipeline constructions are planned to be conducted within a 300 m wide marine servitude near the Coega Industrial Development Zone (IDZ) in Algoa Bay (see Figure 11 for potential pipeline sites) (CSIR 2011b). Initially three pipelines will be constructed, of which two will account for seawater intake, while one pipeline will account for discharge purposes. These pipelines will be used for the discharge of waste water from cooling processes of onshore industrial activities, desalination, and mariculture. In addition, a pump station with headworks as well as dry and wet wells will be established onshore. The construction activities for this project are expected to take at least 24 months and include the clearing of land, excavation, pipe laying, embedment (i.e. covering the pipeline with bottom sediment), anchoring, and, if needed, blasting. In addition, the establishment of a temporary construction jetty has been proposed. These activities will produce potentially damaging noises for marine animals through the presence of a tug/work boat as well as a small work boat, drilling, dredging, and blasting. Consequently, there is concern on the effects of these noises on marine mammals and birds. Of particular concern is the effect on the South African penguin that breeds on the nearby Island of St. Croix (SANPARKS 2012). Fifty percent of the global population is located in Algoa Bay and this species was proclaimed as Endangered by the IUCN in 2010 (BirdLife International 2010).

A second location of potential pipe line construction is Thyspunt between Oyster Bay and St. Francis Bay in the Eastern Cape (Arcus GIBB 2001). Askom Holdings Limited applied for the establishment of a new nuclear power plant at Thyspunt, including pipelines for cooling processes as well as discharge of waste water and offshore disposal of sediment.

8.4. ONSHORE WIND TURBINES

The construction and operation of onshore wind turbines has previously raised concerns in Chile (Langman 2011). Depending on a range of factors (such as the pile driving technique used during construction, the bottom substrate, and the difference in density between bottom substrate and sea water), noise from digging and drilling as well as vibrations of operating wind turbines might be propagated through the bedrock and in this way penetrate into the sea (Lucke 2012). Two wind turbines have already been constructed in the Coega IDZ near Port Elizabeth. However, they are situated relatively inland (i.e. five-six kilometres) (CSIR 2011a) and are therefore unlikely to produce and propagate significant sound levels into the sea. Nevertheless, these two wind turbines are only the start of a bigger project, including a total of 25 turbines, of which eight are planned to be constructed in close proximity to the sea (i.e. within 3km) (zone 10 in Figure 11). Therefore, the construction and operation of

these turbines might potentially affect marine animals that live close to shore (i.e. within 1000 m), such as humpback dolphins and southern right whales.

8.5. ONSHORE MINERAL MINING

Richards Bay Minerals (RBM) continuously extract and process heavy minerals found in the dune sand along the coastline in the Zulti North and Tisand mineral lease areas (GAA 2012). Activities take place from approximately 200m off the high water mark, extending further inland (GAA 2012). However, mining activities primarily involve dredge mining processes, for which a freshwater pond is created in the dunes to host a dredger (GAA 2012). As mentioned under section 4.2.3., dredging activities can create a substantial amount of noise. These noise levels (i.e. 150-180 dB) together with the proximity to the ocean (i.e. 200 m) and the speed of sound in water-saturated sand (i.e. 1700 m/s^{-1}) (Chotiros 1995) indicate the potential for sound propagation into the ocean. However, our current knowledge on sound propagation in sandy material is too limited to make any conclusive statements.

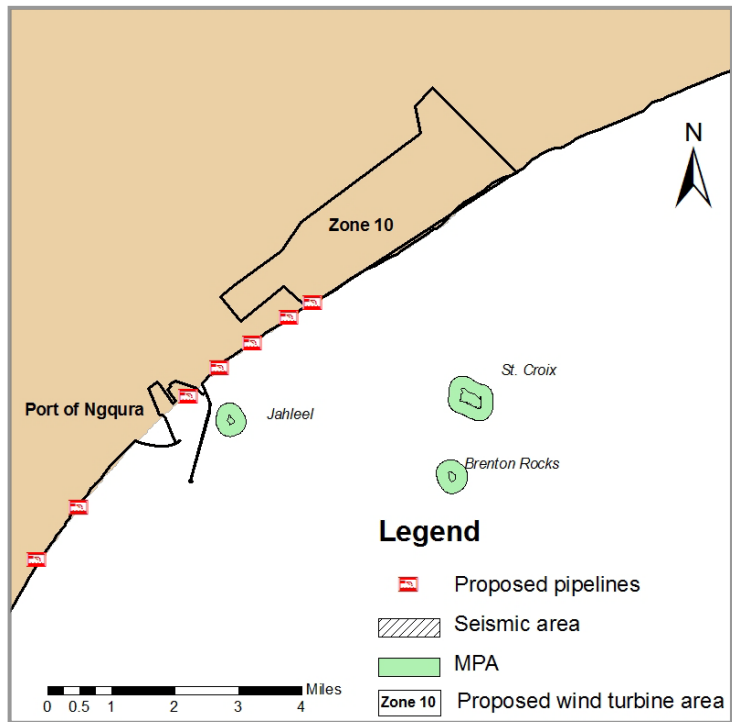
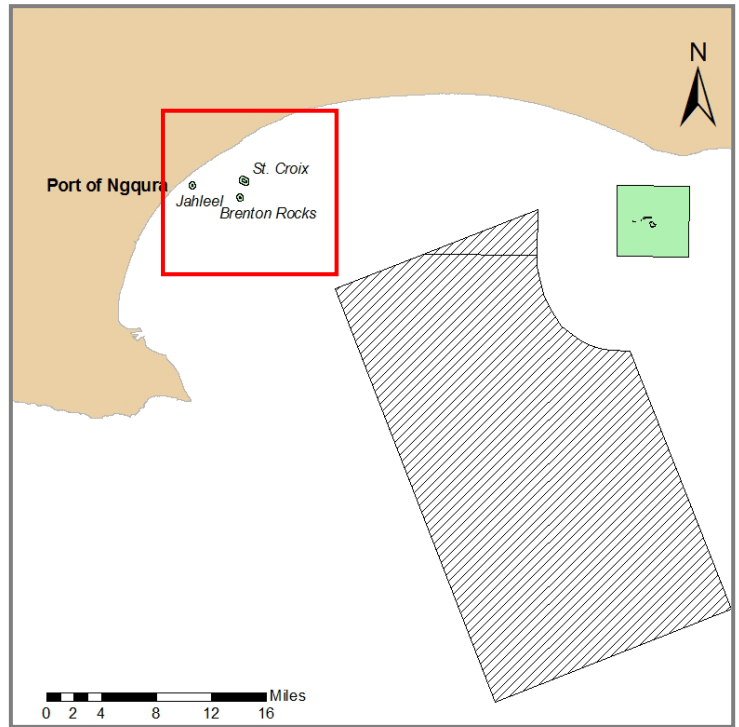


Figure 11 Top: Algoa Bay with proposed seismic survey area near the Marine Protected Area around Bird Island. Bottom: Close-up of the Port of Ngqura in Algoa Bay indicating the proposed marine pipeline sites as well as the proposed area for the construction of eight wind turbines (i.e. Zone 10)

PART 9: RECOMMENDATIONS FOR OCEAN NOISE STUDIES IN SOUTH AFRICA

9.1. NECESSITY TO INITIATE RESEARCH

The increasing concerns on the effect of anthropogenic ocean noise on marine animals has resulted in a rapid increase of interest in marine bioacoustics (i.e. sound produced by or affecting marine animals), with additional focus on the animals' physical and behavioural response to anthropogenic sounds. Since 2003, annual reports on ocean noise and marine animals have been published by a variety of organizations, such as the Whale and Dolphin Conservation Society (WDCS), and the National Research Council (NRC). Numerous marine biology related conferences and meetings in the past have included concerns on ocean noise, especially in 2011 (Appendix B). One of the most recent conferences, the 19th Biennial Conference on the Biology of Marine Mammals in Tampa, Florida, in November 2011, for example, included numerous posters and talks discussing the effect of sound on the vocal behaviour of blue, fin, humpback, northern right (*Eubalaena glacialis*), minke, bowhead, Cuvier's beaked, and killer whales, bottlenose dolphins, harbour porpoises, and the Pacific walrus (*Odobenus rosmarus divergens*). Behavioural responses were discussed for blue, bowhead, pilot (*Globicephala macrorhynchus*), and killer whales, and bottlenose dolphins. In addition, stress, increased energetic costs, and displacement was discussed for northern right whales, bottlenose dolphins, and bowhead whales, respectively.

Ocean noise continues to be an important topic of discussion, with at least ten conferences and meetings including this topic scheduled for 2012 (Appendix B). However, none of these past or future conferences and meetings have taken place in South Africa. Furthermore, research results presented during these events originated primarily from the United States of America, Europe, and Australia. Even studies conducted elsewhere still included researchers from these three regions. To date, no formal research on the effects of ocean noise on marine animals has been conducted in South Africa (as illustrated by the absence of South African-based institutions in Appendix B). However, reactions of marine animals to noise might differ between regions due to a variety of factors, including a variety of physical factors (such as bottom topography, salinity, water temperature etc.) as well as biological factors (such as species specific reaction, an animals' previous experiences with sound etc.). Therefore, South Africa currently lags behind in its knowledge on the impacts

of anthropogenic sounds on its marine life. Although the development of industry is often seen as a positive initiative to create job opportunities, the long-term effects of these developments on the marine environment can be overlooked. Tourism in South Africa has been identified as a growing industry, with the potential to create job opportunities. However, one of the biggest attractions of South Africa as a destination for tourists is the country's beautiful scenery, including the impressive coastlines with its opportunities for diving, snorkelling, and whale watching. Therefore, degradation of this environment by coastal development as well as disturbance of marine animals will not only negatively impact on the entire marine ecosystems, but also on the tourism-based economy, with a consequent loss of employment. Therefore, the development of industry in conjunction with the conservation of marine organisms in South Africa necessitates the initiation of dedicated research on the impact of ocean noise on marine life and the subsequent application of best-practice guidelines.

9.2. RECOMMENDED RESEARCH APPROACH

9.2.1. Identification of spatially and temporally affected areas

A crucial starting point for the research on the effects of ocean noise on marine life in South Africa is the identification of areas that receive elevated noise levels due to anthropogenic activities, such as ports, seismic survey areas, oil production areas, naval test sites, construction sites, and mining sites. During this process, a distinction should be made between areas receiving low intensity, but continuous noise, such as ports, and areas receiving high intensity transient noise, such as naval test sites.

9.2.2. Research on potentially impacted animals

Assessment of overlap between affected areas and previously identified biodiversity priority sites is the second step, which will help to identify research priority sites. Studies should be conducted on a wide variety of marine species, including whales, dolphins, seals, sharks, sea turtles, fish, cephalopods, and other invertebrates. Preferably, multiple species should be covered within the same area and aim to assess animal distribution in relation to sound source levels, distance to sound source, and received exposure levels. In addition, measured noise exposure levels with known hearing frequencies and sound use ranges of animals could provide valuable information on the potential effect of masking.

Instant changes in animal behaviour as well as changes in animal distribution over time should be covered. Potential effects of noise on marine mammal reproduction can be assessed in the field by keeping annual records of

offspring and numbers in conjunction with noise measurements in the area. However, a more scientific approach for smaller species, such as fish and sea turtles, includes controlled noise exposure experiments. If possible (i.e. not highly invasive), animal stress levels should be assessed and play-back experiments of various levels of anthropogenic sound should be considered.

In addition, the animal stranding network is advised to concentrate efforts on the collection of hearing organs from stranded animals, so as to facilitate research on potential hearing damage. In addition, strandings allow access to data on the health status of animals in a given area, which provide the opportunity to establish potential effects of cumulative impacts of sound on marine animals (e.g. metal/PCB pollution in conjunction with ocean noise).

9.2.3. Mitigation measures

Prior to the commencement of noise generating activities, it is of importance to carefully select the site of action and to consider temporal restrictions. The first step in site-selection is the identification of important marine habitats, which are characterized by a high biodiversity, the presence of endangered species, or signs of being an important nursery area. Year-round important marine habitats should be designated as fully protected marine reserves, protecting any living organism from harm. The distance from these reserve, at which sound generating anthropogenic activities are allowed to take place should be determined by the sound source levels. Each activity should keep a minimum distance at which the received sound levels within the reserve are unlikely to cause significant harm to marine animals. Seasonally important habitats, such as whale nursery grounds, should receive a similar approach within the period of time that the animals are present.

Once a suitable site for the anthropogenic activity has been selected, it is recommended to follow known operational mitigation measures as described under section 6.3. Furthermore, South Africa should invest in the implementation of existing and the development of new engineering modifications, such as skewed propeller blades and bubble curtains. These engineering modifications should be adequately tested to assess their suitability within the South African environment and, if proven to be effective, promoted to be used by industry. Once mitigation measures have been applied it is recommended to continuously monitor their effectiveness as to adjust strategies when needed.

In addition, it is advisable that the South African Government generates a White Paper for effective management of ocean noise pollution as has recently been done for an effective climate change response (GRSA 2011). This paper should list all resolutions and mitigation measures regarding ocean noise pollution. Furthermore, a local dedicated organization should be established

that aims to achieve the resolutions stipulated in the ocean noise White Paper and to communicate with international organizations to contribute to the establishment of a global approach for effective management of ocean noise pollution.

PART 10: CONCLUSION

Many marine animals use sound as the primary tool to communicate as well as to navigate and orientate within the relatively dark environment of the ocean. However, anthropogenic noise levels in the ocean have increased with more than 10 dB over the last five decades within the 30-50 Hz frequency band. Therefore, there is an increasing concern that anthropogenic noise might negatively affect marine animals through interference with important aspects of their lives (e.g. mating, foraging, migration). Especially noise from commercial shipping, seismic surveys, construction, drilling, dredging, and active sonar are frequently discussed in debates on the effects of ocean noise pollution. The increase in concern is based on scientific evidence of physical damage (i.e. death, organ damage, TTS, and PTS), stress, perceptual interference (i.e. masking), behavioural responses (i.e. change in vocalization and displacement from important habitats), chronic responses (i.e. sensitization, habituation, and cumulative and synergistic effects), and indirect effects on a broad spectrum of marine species, including whales, dolphins, seals, sharks, sea turtles, fish, octopi, squid, and shellfish. Fortunately, geographic, source based, and operational mitigation measures have been developed in order to assist in managing ocean noise pollution, including geographic and temporal mitigation, source based mitigation, and operational mitigation. These existing mitigation measures are also highly valuable for a country such as South Africa, which is experiencing a rapid increase in coastal industrial developments as well as oil and gas exploration. To date, no formal research on the effects of ocean noise on marine animals has been conducted in South Africa. Therefore, South Africa currently lags behind in its knowledge of the impacts of anthropogenic sounds on its marine life. If future development of the South African industry is to occur in conjunction with the conservation of marine organisms and their ecosystems, the initiation of dedicated research on the impacts of noise on marine life as well as development of new mitigation measures is necessary. To achieve this aim, it is recommended to initiate research on the effects of local sound sources on potentially impacted marine species in South Africa. In addition, mitigation measures, such as site selection and operational mitigation, should be applied during every anthropogenic activity with the potential to produce significantly elevated sound levels. Furthermore, it is considered crucial that a White Paper on the effective management of ocean noise pollution is published, supported by the establishment of a dedicated organization that aims to ensure effective management and to communicate with international organizations to contribute to the establishment of a global approach for effective management of ocean noise pollution.

CITED LITERATURE

- ACCOBAMS. 2010. Guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area. Report-ACCOBAMS Permanent Secretariat. 9 pp.
- ACCOBAMS. 2012. Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area (ACCOBAMS). Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area (ACCOBAMS). Accessed on: 28-02-2012. <http://www.accobams.org>.
- AEInews. 2011. Mass whale stranding during Italian Navy exercises: sonar heard. The Acoustic Ecology Institute. Accessed on: 23-12-2011. <http://aeinews.org/archives/1698>.
- Amorim, M. C. P. 1996. Diversity of sound production in fish. p. 71-105 *in* F. Ladich, S. P. Collin, P. Moller and B. G. Kapoor (Eds.). *Communication in Fishes*. Science Publishers, Enfield, United States of America.
- Amoser, S., and F. Ladich. 2003. Diversity in noise-induced temporary hearing loss in otophysine fishes. *Journal of the Acoustical Society of America* 113: 2170-2179.
- André, M., C. Kamminga, and D. Ketten. 1998. Are low frequency sounds a marine hearing hazard: a case study in the Canary Islands [abstract]. *Bioacoustics* 9: 220.
- André M., M. Solé, M. Lenoir, M. Durfort, C. Quero, A. Lombarte, M. Van der Schaar, M. López-Bejar, M. Morell, S. Zaugg, and L. Houégnigan. 2011. Low-frequency sounds induce acoustic trauma in cephalopods. Downloadable from *Frontiers in Ecology and the Environment*: www.frontiersinecology.org
- Andrew, R. K., B. M. Howe, J. A. Mercer, and M. A. Dzieciuch. 2002. Ocean ambient sound: Comparing the 1960s with the 1990s for a receiver off the California coast. *Acoustics Research Letters Online* 3: 65-70.
- Arcus GIBB. 2001. Revised draft environmental impact assessment report for the Eskom nuclear power station and associated infrastructure (Nuclear-1). Report prepared for Eskom Holdings Limited and the Department of Environmental Affairs (DEA) by Arcus Gibb (Pty) Ltd. Report number: 12/12/20/944. 19 pp.
- ASCOBANS. 2012. Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS). Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS). Accessed on: 29-02-2012. <http://www.ascobans.org>.

- ASHA. 2011. Noise. Accessed on: 13-12-2011. <http://www.asha.org/public/hearing/Noise/>.
- Askeland, B., B. Ruud, H. Hobaek, and R. Mjelde. 2006. A seismic field test with a Low Level Acoustic Combustion Source and pseudo noise codes. Report prepared for Marine Geophysical Researches. 21 pp.
- Au, W. W. L. 1998. Echolocation. p. 348-357 in W. F. Perrin, B. Würsig and J. G. M. Thewissen (Eds). Encyclopedia of Marine Mammals. Academic Press Elsevier, San Diego, United States of America.
- Au, W. W. L., and K. Banks. 1998. The acoustics of the snapping shrimp *Synalpheus parneomeris* in Kaneohe Bay. Journal of the Acoustical Society of America 103: 41-47.
- AWI. 2012. Ocean noise. Animal Welfare Institute. Accessed on: 28-02-2012. <http://www.awionline.org/content/ocean-noise-0>.
- Barlow, J., and R. Gentry. 2004. Report of the NOAA workshop on anthropogenic sound and marine mammals, 19-20 February 2004, 28 pp. Prepared for the U.S. Department of Commerce. Report number: NOAA-TM-NMFS-SWFSC-361.
- Barnes, R. S. K., and R. N. Hughes. 1999. An Introduction to Marine Ecology. Blackwell Publishing, United Kingdom. 286pp.
- Barrett-Lennard, L. G., J. K. B. Ford, and K. A. Heise. 1996. The mixed blessing of echolocation: differences in sonar use by fish-eating and mammal-eating killer whales. Animal Behaviour 51: 553-565.
- Bartol, S. M., J. A. Musick, and M. L. Lenhardt. 1999. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). Copeia 3: 836-840.
- Beale, C. M., and P. Monaghan. 2004. Behavioural responses to human disturbance: a matter of choice? Animal Behaviour 68: 1065-1069.
- Bejder, L., A. Samuels, H. Whitehead, and N. Gales. 2006. Interpreting short-term behavioural responses to disturbance within a longitudinal perspective. Animal Behaviour 72: 1149-1158.
- BirdLife International. 2010. *Speniscus demersus*. IUCN 2010. IUCN Red List of Threatened Species Version 2011.2. Accessed on: 06-02-2012. www.iucnredlist.org.
- Black, A. 2011. Durban port expansion project. ISIZA construction for development. 11. Available from: http://www.isiza.co.za/archive_issues/issue11/1059640.htm.
- Bowles, A. E., M. Smultea, B. Würsig, D. P. DeMaster, and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. Journal of the Acoustical Society of America 96: 2469-2484.

- Bradley, D. L., and R. Stern. 2008. Underwater sound and the marine mammal acoustic environment: a guide to fundamental principles. Report prepared for the U. S. Marine Mammal Commission (MMC). 68 pp.
- Brown, C. R., and N. J. Adams. 1983. The effect of underwater explosions on rockhopper penguins *Eudyptes chrysocome*. *Cormorant* 11: 68.
- Buthelezi, L. 2011. Cape port expansion on track. Accessed on: 06-01-2012. <https://www.iol.co.za/business/business-news/cape-port-expansion-on-track-1.1066471>.
- Carstensen, J., O. D. Henriksen, and J. Teilmann. 2006. Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). *Marine Ecology Progress Series* 321: 295-308.
- Casper, B. M. 2006. The hearing abilities of elasmobranch fishes. Ph.D. University of South Florida. pp 146.
- Casper, B. M., P. S. Lobel, and H. Y. Yan. 2003. The hearing sensitivity of the little skate, *Raja erinacea*: A comparison of two methods. *Environmental Biology of Fishes* 68: 371-379.
- Casper, B. M., and D. A. Mann. 2009. Field hearing measurements of the Atlantic sharpnose shark *Rhizoprionodon terraenovae*. *Journal of Fish Biology* 75: 2768-2776.
- Chapman, N. R., and J. W. Cornish. 1993. Wind dependence of deep ocean ambient noise at low frequencies. *Journal of the Acoustical Society of America* 93: 782-789.
- Chotiros, N. P. 1995. Bio-model of sound propagation in water-saturated sand [abstract]. *Journal of the Acoustical Society of America* 97: 199-214.
- Clark, C. W., W. T. Ellison, B. L. Southall, L. Hatch, S. M. Van Parijs, A. Frankel, and D. Ponirakis. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. *Marine Ecology Progress Series* 395: 201-222.
- Codarin, A., L. E. Wysocki, F. Ladich, and M. Picciulin. 2009. Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy). *Marine Pollution Bulletin* 58: 1880-1887.
- Consten, D., J. Bogerd, J. Komen, J. G. D. Lambert, and H. J. T. Goos. 2001. Long-term cortisol treatment inhibit pubertal development in male common carp, *Cyprinus carpio* L. *Biology of Reproduction* 64: 1063-1071.
- Cook, M. L. H. 2006. Behavioral and auditory evoked potential (AEP) hearing measurements in odontocete cetaceans. Ph.D. University of South Florida. 123pp.

- Cooper, J. 1982. Methods of reducing mortality of seabirds caused by underwater blasting. *Cormorant* 10: 109-113.
- Costa, D. P. 1998. Energetics. P. 383-391 in W. F. Perrin, B. Würsig and J. G. M. Thewissen (Eds) *Encyclopedia of Marine Mammals*. Academic Press Elsevier, San Diego, United States of America.
- Cox, T. M., A. J. Read, A. Solow, and N. Tregenza. 2001. Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? *Journal of Cetacean Research and Management* 3: 81-86.
- CSA. 2004. Explosive removal of offshore structures: Information synthesis report. Report prepared for the U. S. Department of the Interior, Minerals Management Service Gulf of Mexico OCS Region by Continental Shelf Associates, Inc. March, New Orleans, United States of America. Report number: *OCS Study MMS 2003-070*.
- CSIR. 2011a. Draft scoping report for the proposed Universal Wind Energy Project in Zone 12 of the Coega Industrial Development Zone (IDZ), Nelson Mandela Bay Municipality, Eastern Cape province. Report prepared for the Coega Development Corporation by the Council for Scientific and Industrial Research. Report number: *CSIR/CAS/EMS/ER/2011/0002/B*. 66pp.
- CSIR. 2011b. Scoping and environmental impact assessment for a proposed marine servitude and pipelines in the Coega Industrial Development Zone, Nelson Mandela Bay Municipality, Eastern Cape province. Report prepared for the Coega Development Corporation by the Council for Scientific and Industrial Research. Report number: *CSIR/CAS/EMS/ER/2011/0002/B*. 102pp.
- Cutnell, J. D., and K. W. Johnson. 1995. *Physics*. Wiley, New York, United States of America. 1038pp.
- Dalton, R. 2006. More whale strandings are linked to sonar. *Nature* 440: 593.
- Darling, J. D., M. E. Jones, and C. P. Nicklin. 2006. Humpback whale songs: do they organize males during the breeding season? *Behaviour* 143: 1051-1101.
- DD. 2011. Decibel exposure time guidelines; How loud is too loud? *Dangerous Decibels*. Accessed on: 15-12-2011. <http://www.dangerousdecibels.org/education/information-center/decibel-exposure-time-guidelines/>.
- de Jong, C. A. F., M. A. Ainslie, and G. Blacquièrre. 2011. Standard for measurements and monitoring of underwater noise, Part II: procedures for measuring underwater noise in connection with offshore wind farm licensing. TNO. The Hague, The Netherlands. Report number: TNO-DV 2011 C251. 56pp.

- Department of Conservation. 2006. Reference document: guidelines for minimising acoustic disturbance to marine mammals from seismic surveys. Wellington, New Zealand. 13pp.
- Di Iorio, L., and C. W. Clark. 2010. Exposure to seismic survey alters blue whale acoustic communication. *Biology Letters* 6: 51-54.
- Dokseater, L., O. R. Godø, N. O. Handegard, P. H. Kvalsheim, F. P. A. Lam, C. Donovan, and P. J. O. Miller. 2009. Behavioral responses of herring (*Clupea harengus*) to 1-2 and 6-7 kHz sonar signals and killer whale feeding sounds. *Journal of the Acoustical Society of America* 125: 554-564.
- Dolman, S., V. Williams-Grey, R. Asmutis-Silvia, and S. Isaac. 2006. Vessel collisions and cetaceans: what happens when they don't miss the boat. A science report prepared by the Whale and Dolphin Conservation Society (WDCS). Wiltshire, United Kingdom. 24pp.
- Dolman, S. J., and M. P. Simmonds. 2005. An updated note on the vulnerability of cetaceans to acoustic disturbance. Report prepared for the International Whaling Commission (IWC) by the Whale and Dolphin Conservation Society (WDCS). Wiltshire, United Kingdom. Report number: SC/58/E22. 11pp.
- Dos Santos, M. E., T. Modesto, R. J. Matos, M. S. Grober, R. F. Oliveira, and A. Canário. 2000. Sound production by the Lusitanian toadfish, *Halobatrachus didactylus*. *Bioacoustics* 11: 309-321.
- Dubrovsky, N. A., and S. V. Kosterin. 1993. Noise in the ocean caused by lightning strokes. p. 697-710 in B. R. Kerman, Eds. *Natural physical sources of underwater sound*. Kluwer Academic Publishers, Dordrecht, the Netherlands.
- Dudzinski, K. M., A. Thomas, and J. D. Gregg. 2008. Communication in marine mammals. p. 260-269 in W. F. Perrin, B. Würsig and J. G. M. Thewissen, Eds. *Encyclopedia of Marine Mammals*. Academic Press Elsevier, San Diego, United States of America.
- Edds-Walton, P. L. 1997. Acoustic communication signals of mysticete whales. *Bioacoustics* 8: 47-60.
- Engås, A., S. Løkkeborg, E. Ona, and A. V. Soldal. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). *Canadian Journal of Fisheries and Aquatic Sciences* 53: 2238-2249.
- Engineering News. 2011. Saldanha IDZ to generate own power. Creamer Media (Pty) Ltd. Accessed on: 06-01-2012. <http://www.engineeringnews.co.za/article/idz-to-generate-on-power-2011-03-04>.

- EPBCA. 2012. Environment Protection and Biodiversity Conservation Act 1999, as amended. Australian Government: Department of Sustainability, Environment, Water, Population and Communities. 19 February 2012, Act No. 91 Volume 2. 618pp.
- Erbe, C. 2001. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. Report prepared for Fisheries and Oceans Canada. April. 27pp.
- ERM. 2011. NewAGE Seismic survey EMPr Algoa/Gamtoos Block, Part A: General information, description of environment and impact assessment. An Environmental Management Programme (EMPR) report prepared for NewAge by Environmental Resources Management (ERM). 189pp.
- Evans, D. L., G. R. England, C. C. Lautenbacher Jr., S. M. Livingstone, W. T. Hogarth, and H. T. Johnson. 2001. Joint interim report Bahamas marine mammal stranding event of 14-16 March 2000. Report prepared by the National Oceanic and Atmospheric Administration (NOAA) and Department of the Navy. United States of America. 59pp.
- Fernández, A., Edwards, J. F., Rodriguez, F., Espinosa de los Monteros, A., Herráez, P., Castro, P., Jabber, J. R., Martin, V. and M. Arbelo. 2005. "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (family *Ziphiidae*) exposed to anthropogenic sonar signals. *Veterinary Pathology* 42: 446-457.
- Finneran, J. J., D. A. Carder, R. Dear, T. Belting, J. McBain, L. Dalton, and S. H. Ridgway. 2005a. Pure tone audiograms and possible aminoglycoside-induced hearing loss in belugas (*Delphinapterus leucas*). *Journal of the Acoustical Society of America* 117: 3936-3943.
- Finneran, J. J., D. A. Carder, C. E. Schlundt, and S. H. Ridgway. 2005b. Temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. *Journal of the Acoustical Society of America* 118: 2696-2705.
- Finneran, J. J., C. E. Schlundt, R. Dear, D. A. Carder, and S. H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. *Journal of the Acoustical Society of America* 111: 2929-2940.
- Foote, A. D., R. W. Osborne, and A. R. Hoelzel. 2004. Whale-call response to masking boat noise. *Nature* 428: 910.
- Fox, C. G., R. P. Dziak, and Matsumoto. 2002. NOAA efforts in monitoring of low frequency sound in the global ocean [abstract]. *Journal of the Acoustical Society of America* 112: 2260.
- Frantzis, A. 1998. Does acoustic testing strand whales? *Nature* 392: 29.

- GAA. 2012. Draft environmental impact report: EIA for listed activities triggered by Richards Bay Minerals' mining activities in Zulti North, Richards Bay, KwaZulu-Natal. Golder Associates Africa (Pty) Ltd. Kloof, KwaZulu-Natal, South Africa. Report number: 10612861-10396-1. 77pp.
- Gannon, D. P., N. B. Barros, D. P. Nowacek, A. J. Read, D. M. Waples, and R. S. Wells. 2005. Prey detection by bottlenose dolphins, *Tursiops truncatus*: an experimental test of the passive listening hypothesis. *Animal Behaviour* 69: 709-720.
- George, J. C., C. Clark, G. M. Carroll, and W. T. Ellison. 1989. Observations on the ice-breaking and ice navigation behavior of migrating bowhead whales (*Balaena mysticetus*) near Point Barrow, Alaska, spring 1985. *Arctic* 42: 24-30.
- Gerstein, E. R., L. Gerstein, S. E. Forsythe, and J. E. Blue. 1999. The underwater audiogram of the West Indian manatee (*Trichechus manatus*). *Journal of the Acoustical Society of America* 105: 3575-3583.
- Goold, J. C., and P. J. Fish. 1998. Broadband spectra of seismic survey air-gun emissions, with reference to dolphin auditory thresholds [abstract]. *Journal of the Acoustical Society of America* 103: 2177-2184.
- Götz, T., G. Hastie, L. T. Hatch, O. Raustein, B. L. Southall, M. Tasker, and F. Thomsen. 2009. Overview of the impacts of anthropogenic underwater sound in the marine environment. Report prepared by the OSPAR Commission. Report number: 441/2009. 133pp.
- Government Gazette. 1998. Government Gazette: Marine Living Resources Act (18/1998). Government of the Republic of South Africa. 19-10-1998, Gazette Number: 18930 Volume 395. 66pp.
- Green Jr., C. R. 1995a. Acoustic concepts and terminology. p. 15-32 in W. J. Richardson, C. R. Green Jr., C. I. Malme and D. H. Thomson (Eds). *Marine mammals and noise*. Academic Press, Inc., San Diego, United States of America.
- Green Jr., C. R. 1995b. Ambient noise. p. 87-100 in W. J. Richardson, C. R. Green Jr., C. I. Malme and D. H. Thomson (Eds). *Marine mammals and noise*. Academic Press, Inc., San Diego, United States of America.
- Green Jr., C. R., and S. E. Moore. 1995. Man-made noise. p. 101-158 in W. J. Richardson, C. R. Green Jr., C. I. Malme and D. H. Thomson (Eds). *Marine mammals and noise*. Academic Press, Inc., San Diego, United States of America.
- Greenhow, D. R., M. Brodsky, R. Lingenfelter, and D. Mann. 2012. Hearing threshold measurements using auditory evoked potentials of four stranded short-finned pilot whales (*Globicephala macrorhynchus*) in Key Largo, FL (Poster). University of Florida (USF) College of marine science.

- GRSA. 2011. National climate change response white paper. The Government of the Republic of South Africa. October.48pp.
- Hall, J. D., and C. S. Johnson. 1971. Auditory thresholds of a killer whale *Orcinus orca* Linnaeus. *Journal of the Acoustical Society of America* 4.1: 515-517.
- Hamed, M. S., O. M. Gabr, and M. M. H. Ghoneum. 1984. Development and distribution of taste buds in *Oryzias latipes* and their functional significance. *Japanese Journal of Ichthyology* 31: 335-337.
- Hastie, G. D., B. Wilson, L. H. Tufft, and P. M. Thompson. 2003. Bottlenose dolphins increase breathing synchrony in response to boat traffic. *Marine Mammal Science* 19: 74-84.
- Heithaus, M. R., and L. M. Dill. 2008. Feeding strategies and tactics. p. 414-423 in W. F. Perrin, B. Würsig and J. G. M. Thewissen (Eds). *Encyclopedia of Marine Mammals*. Academic Press Elsevier, San Diego, United States of America.
- Herzing, D. L. 1996. Vocalizations and associated underwater behavior of free-ranging Atlantic spotted dolphins, *Stenella frontalis* and bottlenose dolphins, *Tursiops truncatus*. *Aquatic Mammals* 22: 61-79.
- HESS. 1999. High energy seismic survey review process and interim operational guidelines for marine surveys offshore South California. Prepared for The California State Lands Commission and The U.S. Minerals Management Service, Pacific Outer Continental Shelf Region. 18-02-1999. 39pp.
- Hildebrand, J. 2004. Impacts of anthropogenic sound on cetaceans. Report prepared for the International Whaling Commission (IWC). Report number: *IWC/SC/56/E13*. 32pp.
- Hildebrand, J. A. 2005. Impacts of anthropogenic sound. p. 101-124 in J. E. Reynolds, W. F. Perrin, R. R. Reeves, S. Montgomery and T. J. Ragen (Eds). *Marine mammal research: conservation beyond crisis*. The Johns Hopkins University Press, Baltimore, Maryland, United States of America.
- Hildebrand, J. A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series* 395: 5-20.
- Holt, M. M., D. P. Noren, and T. M. Williams. 2011. Metabolic cost of sound production in dolphins: assessing the energetic impact of vocal compensation in noise habitats [abstract]. in Presentation at the 19th Biennial Conference on the Biology of Marine Mammals. Tampa, Florida, United States of America.
- Horch, K. 1971. An organ for hearing and vibration sense in the ghost crab *Ocypode*. *Journal of Comparative Psychology* A 73: 1-21.

- Houser, D. S., and J. J. Finneran. 2006. Variation in the hearing sensitivity of a dolphin population determined through the use of evoked potential audiometry. *Journal of the Acoustical Society of America* 120: 4090-4099.
- Houser, D. S., A. Gomez-Rubio, and J. J. Finneran. 2008. Evoked potential audiometry of 13 Pacific bottlenose dolphins (*Tursiops truncatus gilli*). *Marine Mammal Science* 24: 28-41.
- Houser, D. S., D. A. Helweg, and P. W. B. Moore. 2001. A bandpass filter-bank model of auditory sensitivity in the humpback whale. *Aquatic Mammals* 27: 82-91.
- ICES. 2005. Answer to DG Environment request on scientific information concerning impact of sonar activities on cetacean populations. Report for the European Commission, DG Environment from the International Council for the Exploration of the Sea (ICES). February 2005, Copenhagen, Denmark. 5pp.
- ICES. 2010. Report of the Working Group on Marine Mammal Ecology (WGMME), 12-15 April 2010, Horta, The Azores. Report number: ICES CM 2010/ACOM: 24. 212pp.
- Ikelle, L. T., and L. Amundsen. 2012. Towed-streamer acquisition. *Petroleum Seismology*. <http://petroleumgeophysics.com/images/Chapter-7>. Accessed on: 27-02-2012.
- IMO. 2011. International Maritime Organization. International Maritime Organization (IMO). <http://www.imo.org/Pages/home.aspx>. Accessed on: 29-02-2012.
- Insley, S. J., A. V. Phillips, and I. Charrier. 2003. A review of social recognition in pinnipeds. *Aquatic Mammals* 29: 181-201.
- IWC. 2012. Report of the scientific committee; Annex K: report of the stranding working group on environmental concerns. Report from the IWC Scientific Committee. 28-06-2012, Panama City, Panama. Report number: IWC/64/Rep 1. 26pp.
- Jacobs, S. R., and J. M. Terhune. 2002. The effectiveness of acoustic harassment devices in the Bay of Fundy, Canada: seal reactions and a noise exposure model. *Aquatic Mammals* 28: 147-158.
- Jasny, M., J. Reynolds, C. Horowitz, and A. Wetzler. 2005. Sounding the depths II: The rising toll of sonar, shipping, and industrial noise on marine life. Report prepared by the Natural Resources Defense Council. California, United States of America. 76pp.
- Jepson P. D., Arbelo, M., Deaville R., Patterson I. A. P., Castro P., Baker J. R., Degollada E., Ross H. M., Herráez P., Pocknell A. M., Rodriguez F., Howie F. E., Espinosa A., Reid R. J., Jaber J. R., Martin V., Cunningham A. A. and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans. *Was*

- sonar responsible for a spate of whale deaths after an Atlantic military exercise? *Nature* 425: 575.
- JNCC. 2010. JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys. Joint Nature Conservation Committee (JNCC). August, Aberdeen, United Kingdom. 15pp.
- JNCC. 2012. Joint Nature Conservation Committee. Joint Nature Conservation Committee (JNCC). Accessed on: 28-02-2012. <http://jncc.defra.gov.uk>.
- Johnston, D. W., and T. H. Woodley. 1998. A survey of acoustic harassment device (AHD) use in the Bay of Fundy, NB, Canada. *Aquatic Mammals* 24: 51-61.
- Kalmijn, A. J. 1971. The electric sense of sharks and rays. *Journal of Experimental Biology* 55: 371-383.
- Kastak, D., and R. J. Schusterman. 1998. Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise, and ecology. *Journal of the Acoustical Society of America* 103: 2216-2228.
- Kastak, D., and R. J. Schusterman. 2002. Changes in auditory sensitivity with depth in a free-diving California sea lion (*Zalophus californianus*). *Journal of the Acoustical Society of America* 112: 329-333.
- Kastelein, R. A., P. Bunshoek, M. Hagedoorn, W. W. L. Au, and D. d. Haan. 2002a. Audiogram of a harbor porpoise (*Phocoena phocoena*). *Journal of the Acoustical Society of America* 112: 334-344.
- Kastelein, R. A., M. Hagedoorn, W. W. L. Au, and D. d. Haan. 2003. Audiogram of a striped dolphin (*Stenella coeruleoalba*). *Journal of the Acoustical Society of America* 113: 1130-1137.
- Kastelein, R. A., P. Mosterd, B. v. Santen, M. Hagedoorn, and D. d. Haan. 2002b. Underwater audiogram of a Pacific walrus (*Odobenus rosmarus divergens*) measured with narrow-band frequency-modulated signals. *Journal of the Acoustical Society of America* 112: 2173-2182.
- Kevin, T. M., and G. L. Hempen. 1997. The environmental effects of underwater explosions with methods to mitigate impacts. Report from the U. S. Army Corps of Engineers. August 1997, Missouri, United States of America. 98pp.
- Kelly, B. P., L. T. Quakenbush, and J. R. Rose. 1986. Ringed seal winter ecology and effects of noise disturbance. Final report prepared by the Outer Continental Shelf Environmental Assessment Program. December. Report number: *Research Unit 232*. 85pp.
- Ketten, D. R. 2004. Experimental measures of blast and acoustic trauma in marine mammals. Report prepared for the Office of Naval Research (ONR). Report number: *N000149711030*. 12pp.

- Ketten, D. R., and S. M. Bartol. 2006. Functional measures of sea turtle hearing. Woods Hole Oceanographic Institution (WHOI). Woods Hole, Massachusetts, United States of America. Report number: OMB NO. 0704-0188. 5pp.
- Kishida, T., S. Kubota, Y. Shirayama, and H. Fukami. 2007. The olfactory receptor gene repertoires in secondary-adapted marine vertebrates: evidence for reduction of the functional proportions in cetaceans. *Biology Letters* 3: 428-430.
- Klima, E. F., G. R. Gitschlag, and M. L. Renaud. 1988. Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. *Marine Fisheries Review* 50: 33-42.
- Klishin, V. O., V. V. Popov, and A. Y. Supin. 2000. Hearing capabilities of a beluga whale, *Delphinapterus leucas*. *Aquatic Mammals* 26: 212-228.
- Koper, R. P. 2011. Occurrence, group size, and habitat use of the Indo-Pacific humpback dolphin (*Sousa chinensis*) in Algoa Bay, South Africa. M.Sc. thesis. University of Groningen, The Netherlands. pp 79.
- Kritzler, H., and L. Wood. 1961. Provisional audiogram for the shark, *Carcharhinus leucas*. *Science, New Series* 133: 1480-1482.
- Ladich, F., and A. H. Bass. 2003. Sound generation and reception in fishes. p. 173-193 in S. P. Collin and N. J. Marshall (Eds). *Sensory processing in aquatic environments*. Springer-Verlag New York, Inc., New York, United States of America.
- Lagardère, J. P. 1982. Effects of noise on growth and reproduction of *Crangon crangon* in rearing tanks. *Marine Biology* 71: 177-185.
- Langman, J. 2011. Chilean wind farm faces turbulence over whales. *National Geographic Daily News*. Accessed on: 30-12-2011. <http://news.nationalgeographic.com/news/energy/2011/11/111129-chile-wind-farm-impact-on-the-blue-whale/>.
- Laughlin, J. 2005. Underwater sound levels associated with pile driving at the Bainbridge Island ferry terminal preservation project. Underwater noise technical report prepared for the WSF Bainbridge Island ferry terminal preservation project. November. 44pp.
- Laughlin, J. 2006. Underwater sound levels associated with pile driving at the Cape disappointment boat launch facility, wave barrier project. Report prepared for the Washington State Parks Cape Disappointment Wave Barrier Project. 42pp.
- Laughlin, J. 2007. Underwater sound levels associated with driving steel and concrete piles near the Mukilteo ferry terminal. Report prepared for the WSF Mukilteo test pile project. 64pp.

- Lecky, J. H. 2011. Takes of marine mammals incidental to specified activities; taking marine mammals incidental to seismic survey in Cook Inlet, Alaska. Federal register: the daily journal of the United States government. Accessed on: 31-01-2012.
<https://www.federalregister.gov/articles/2011/09/21/2011-24241/takes-of-marine-mammals-incidental-to-specified-activities-taking-marine-mammals-incidental-to#h-33>.
- Lesage, V., C. Barrette, M. C. S. Kingsley, and S. B. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence river estuary, Canada. *Marine Mammal Science* 15: 65-84.
- Li S., D. Wang, K. Wang, E.A. Taylor, E. Cros, W. Shi, Z. Wang, L. Fang, Y. Chen, and F. Kong. 2012. Evoked-potential audiogram of an Indo-Pacific humpback dolphin (*Sousa chinensis*). *Journal of Experimental Biology* 215: 3055-3063.
- Ljungblad, D. K., P. D. Scroggins, and W. G. Gilmartin. 1982. Auditory thresholds of a captive Eastern Pacific bottle-nosed dolphin, *Tursiops spp.* *Journal of the Acoustical Society of America* 72: 1726-1729.
- Lovell, J. M., M. M. Findlay, R. M. Moate, and H. Y. Yan. 2005. The hearing abilities of the prawn *Palaemon serratus*. *Comparative Biochemistry and Physiology, Part A* 140: 89-100.
- Lucke, K. 2012. Researcher, Wageningen University and research centre; institute for marine resources and ecosystem studies. 't Horntje, Texel, The Netherlands. Personal communication.
- Lucke, K., P. A. Lepper, M. A. Blanchet, and U. Siebert. 2011. The use of an air bubble curtain to reduce the received sound levels for harbor porpoises (*Phocoena phocoena*). *Journal of the Acoustical Society of America* 130: 3406-3412.
- Lucke, K., U. Siebert, P. A. Lepper, and M. A. Blachet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. *Journal of the Acoustical Society of America* 125: 4060-4070.
- Mackenzie, D. 2004. Seismic surveys may kill giant squid. *NewScientist.com news service*. Accessed on: 17-10-2011.
<http://www.newscientist.com/article/dn6437-seismic-surveys-may-kill-giant-squid.html>.
- Malakoff, D. 2001. A roaring debate over ocean noise. *Science, New Series* 291: 576-578.
- Martin, K. 2011. Underwater hearing in the loggerhead turtle (*Caretta caretta*): A comparison of behavioral and auditory evoked potential audiograms. M.Sc. University of South Florida. pp 38.

- Martin, P. 2012a. Environmental Control Officer Coega IDZ/Port of Ngqura. Port Elizabeth.
- Martin, R. A. 2012b. Biology of sharks and rays: smell and taste. ReefQuest Centre for Shark Research. Accessed on: 26-09-2012. http://www.elasmo-research.org/education/white_shark/smell.htm.
- Mathevon, N., I. Charrier, and T. Aubin. 2004. A memory like a female fur seal: long-lasting recognition of pup's voice by mothers. *Annals of the Brazilian Academy of Sciences* 76: 237-241.
- Mathews, J. N., L. E. Rendall, J. C. D. Gordon, and D. W. Macdonald. 1999. A review of frequency and time parameters of cetacean tonal calls. *Bioacoustics* 10: 47-71.
- MCAA. 2009. Marine and Coastal Access Act 2009. Marine Management Organisation. 12 November 2009. 347pp.
- McCauley R. D., Fewtrell J., Duncan A. J., Jenner C., Jenner M. N., Penrose J. D., Prince R. I. T., Adhitya A., Murdoch J. and K. McCabe. 2000. Marine seismic surveys - a study of environmental implications. *Australia Petroleum Production and Exploration Association Journal* 40: 692-708.
- McCauley, R. D., J. Fewtrell, and A. N. Popper. 2003. High intensity anthropogenic sound damages fish ears. *Journal of the Acoustical Society of America* 113: 638-642.
- McCormick, M. I. 1999. Experimental test of the effect of maternal hormones on larval quality of coral reef fish. *Oecologia* 118: 412-422.
- McDonald, M. A., J. A. Hildebrand, and S. M. Wiggins. 2006. Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California. *Journal of the Acoustical Society of America* 120: 711-718.
- McGrowen, M. R., C. Clark, and J. Gatesy. 2008. The vestigial olfactory receptor subgenome of odontocete whales: phylogenetic congruence between gene-tree reconciliation and supermatrix methods. *Systematic Biology* 57: 574-590.
- Miller, P. J. O., N. Biassoni, A. Samuels, and P. L. Tyack. 2000. Whale songs lengthen in response to sonar. *Nature* 405: 903.
- MLPA. 2004. Marine Life Protection Act 1999, as amended 2004. Department of Fish and Game. July 2004, Fish and Game Code, Sections: 2850-2863. 8pp.
- MMC. 2007. Marine mammals and noise: A sound approach to research and management. A report prepared for the congress by the Marine Mammal Commission. 370pp. Available at: <http://mmc.gov/sound/fullsoundreport.pdf>.

- MMPA. 2007. The Marine Mammal Protection Act 1982, as amended 2007. Marine Mammal Commission and NOAA's National Marine Fisheries Service. Code: 16 U.S.C. 1362. 114pp.
- Moein, S. E., J. A. Musick, J. A. Keinath, D. E. Barnard, M. Lenhardt, and R. George. 1994. Evaluation of seismic sources for repelling sea turtles from hopper dredges. Report prepared for the U.S. Army Corps of Engineers Waterways Experiment Station by the Virginia Institute of Marine Science College of William and Mary. 41pp.
- Montgomery, J. C., N. Tolimieri, and O. S. Haine. 2001. Active habitat selection by pre-settlement reef fishes. *Fish and Fisheries* 2: 261-277.
- Moore, P. W. B., and R. J. Schusterman. 1987. Audiometric assessment of northern fur seals, *Callorhinus ursinus*. *Marine Mammal Science* 3: 31-53
- Morozov, A. K., and D. C. Webb. 2007. Underwater tunable organ-pipe sound source [abstract]. *Journal of the Acoustical Society of America* 122: 777-785.
- Morton, A. B., and H. K. Symonds. 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. *ICES Journal of Marine Sciences* 59: 71-80.
- Myrberg, A. A. J., M. Mohler, and J. D. Catala. 1986. Sound production by males of a coral reef fish (*Pomacentrus partitus*): its significance to females. *Animal Behaviour* 34: 913-923.
- Nachtigall, P. E., T. A. Mooney, K. A. Taylor, L. A. Miller, M. H. Rasmussen, T. Akamatsu, J. Teilmann, M. Linnenschmidt, and G. A. Vikingsson 2008. Shipboard measurements of the hearing of the white-beaked dolphin *Lagenorhynchus albirostris*. *Journal of Experimental Biology* 211: 642-647.
- Nachtigall, P. E., M. M. L. Yuen, T. A. Mooney, and K. A. Taylor. 2005. Hearing measurements from a stranded infant Risso's dolphin, *Grampus griseus*. *Journal of Experimental Biology* 208: 4181-4188.
- Nedwell, J. R., B. Edwards, A. W. H. Turnpenny, and J. Gordon. 2004. Fish and marine mammal audiograms: a summary of available information. Subacoustech. 03-09-2004, Hampshire, United Kingdom. Report number: 534R0214. 278pp.
- Nelson, D. R. 1967. Hearing thresholds, frequency discrimination, and acoustic orientation in the lemon shark, *Negaprion brevirostris* (Poey). *Bulletin of Marine Science* 17: 741-768.
- Ng, S. L., and S. Leung. 2003. Behavioral response of Indo-Pacific humpback dolphin (*Sousa chinensis*) to vessel traffic. *Marine Environmental Research* 56: 555-567.

- Nisbet, I. C. T. 2000. Disturbance, habituation, and management of waterbird colonies. *Waterbirds: the International Journal of Waterbird Biology* 23: 312-332.
- NOAA. 2012. NOAA Office of the General Counsel, U. S. Department of Commerce. National Oceanic and Atmospheric Administration (NOAA). Accessed on: 28-02-2012. http://www.gc.noaa.gov/gcil_sound.html.
- Norris, K. S., and T. P. Dohl. 1980. Behavior of the Hawaiian spinner dolphin, *Stenella longirostris*. *Fishery Bulletin* 77: 821-849.
- Nowacek, D. P., L. H. Thorne, D. W. Johnston, and P. L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review* 37: 81-115.
- NRC. 2003. Ocean noise and marine mammals. Committee on potential impacts of ambient noise in the ocean on marine mammals, National Research Council (NRC). National Academies Press, Washington, United States of America. 208pp.
- NRC 2005. Marine mammal population and ocean noise: determining when noise causes biologically significant effects. National Research Council (NRC). National Academies Press, Washington, United States of America. 142pp.
- NRDC. 2011. NRDC opening statement- International Whaling Commission 63rd annual meeting. National Resources Defense Council (NRDC), Report prepared for the International Whaling Commission (IWC). Channel Isle of Jersey. Report number: *IWC/63/OS NRDC*. 3pp.
- NRDC. 2012. Natural Resources Defense Council, The earth's best defense. Natural Resources Defense Council (NRDC). Accessed on: 29-02-2012. <http://www.nrdc.org>.
- Nummela, S. 2008. Hearing. p. 553-562 in W. F. Perrin, B. Würsig and J. G. M. Thewissen (Eds). *Encyclopedia of Marine Mammals*. Academic Press Elsevier, San Diego, United States of America.
- Nystuen, J. A. 1999. Listening to raindrops. <http://www.personal.umich.edu/~copyright/image/solstice/win99/janystuen/LISTEN.html>
- Ocean Care. 2012. Ocean Care. Accessed on: 29-02-2012. <http://www.oceancare.org/en/index.php>.
- Oelschläger, H. H. A., and J. S. Oelschläger. 2008. Brain. p. 134-149 in W. F. Perrin, B. Würsig and J. G. M. Thewissen (Eds). *Encyclopedia of Marine Mammals*. Academic Press Elsevier, San Diego, United States of America.
- Offshore. 2010. Worldwide seismic vessel survey. PennWell Corporation. Accessed on: 21-12-2011. http://www.offshore-mag.com/etc/medialib/platform-7/offshore/maps-and_posters.Par.16333.File.dat/1003off-vessel-survey.pdf.

- Offutt, G. C. 1974. Structures for the detection of acoustic stimuli in the Atlantic codfish, *Gadus morhua*. *Journal of the Acoustical Society of America* 56: 665-671.
- Olesiuk, P. F., L. M. Nichol, M. J. Sowden, and J. K. B. Ford. 2002. Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbor porpoises (*Phocoena phocoena*) in retreat passage, British Columbia. *Marine Mammal Science* 18: 843-862.
- OMP. 2010. Discovery of sound in the sea. Office of Marine Programs (OMP), University of Rhode Island. Accessed on: 13-12-2011. <http://www.dosits.org>.
- OSPAR. 2009. Overview of the impacts of anthropogenic underwater sound in the marine environment. OSPAR Convention for the protection of the marine environment of the North-East Atlantic. Report number: 441/2009. 134pp.
- Pacini, A. F., P. E. Nachtigall, L. N. Kloepper, M. Linnenschmidt, A. Sogorb, and S. Matias. 2010. Audiogram of a formerly stranded long-finned pilot whale (*Globicephala melas*) measured using auditory evoked potentials. *Journal of Experimental Biology* 213: 3138-3143.
- Pacini, A. F., P. E. Nachtigall, C. T. Quintons, T. D. Schofield, D. A. Look, G. A. Levine, and J. P. Turner. 2011. Audiogram of a stranded Blainville's beaked whale (*Mesoplodon densirostris*) measured using auditory evoked potentials. *Journal of Experimental Biology* 214: 2409-2015
- Parks, S. E., M. Johnson, D. Nowacek, and P. L. Tyack. 2011. Individual right whales call louder in increased environmental noise. *Biology Letters* 7: 33-35.
- Parmentier, E., K. Mann, and D. Mann. 2011. Hearing and morphological specializations of the mojarra (*Eucinostomus argenteus*). *Journal of Experimental Biology* 24: 2697-2701.
- PASA. 2012. Petroleum exploration and production activities in South Africa. Petroleum Agency South Africa (PASA). Accessed on: September 2012. Available from: <http://www.petroleumagencyrsa.com>.
- Perrin, W. F., and J. R. Geraci. 2008. Stranding. p. 1118-1123 in W. F. Perrin, B. Würsig and J. G. M. Thewissen (Eds). *Encyclopedia of Marine Mammals*. Academic Press Elsevier, San Diego, United States of America.
- Petrie, F. S. 2005. Washington state ferries' experience with bubble curtains: purpose, hardware, and use. in Powerpoint presentation for the 2005 Summer/meeting conference of the transportation research board ADC40 (A1F04) Noise & Vibration Committee.
- Piantadosi, C. A., and E. D. Thalmann. 2004. Pathology: Whales, sonar and decompression sickness. *Nature* 428: 716.

- Pickering, A. D. 1992. Rainbow trout husbandry: management of the stress response. *Aquaculture* 100: 125-139.
- Popov, V., and A. Supin. 1990. Electrophysiological studies of hearing in some cetaceans and a manatee. p. 405-415 in J. Thomas and R. Kastelein (Eds). *Sensory abilities of cetaceans*. Plenum Press, New York, United States of America.
- Popov, V. V., and V. O. Klishin. 1998. EEG study of hearing in the common dolphin, *Delphinus delphis*. *Aquatic Mammals* 24: 13-20.
- Popov, V. V., A. Y. Supin, D. Wang, K. Wang, J. Xiao, and S. Li. 2005. Evoked-potential audiogram of the Yangtze finless porpoise *Neophocaena phocaenoides asiaeorientalis* (L). *Journal of the Acoustical Society of America* 117: 2728-2731.
- Popper, A. N. 2003. Effects of anthropogenic sounds on fishes. *Fisheries* 28: 24-31.
- Popper A. N., Halvorsen M. B., Kane A., Miller D. L., Smith M. E., Song J., Stein P. and L. E. Wysocki. 2007. The effects of high-intensity, low-frequency active sonar on rainbow trout. *Journal of the Acoustical Society of America* 122: 623-635.
- Popper, A. N., and M. C. Hastings. 2009. The effects of human-generated sound on fish. *Integrative Zoology* 4: 43-52.
- Popper, A. N., and C. R. Schilt. 2008. Hearing and acoustic behavior: basic and applied considerations. p. 17-48 in J. F. Webb, A. N. Popper and R. R. Fay (Eds). *Fish bioacoustics*. Springer Science and Business Media, LLC, New York, United States of America.
- Popper, A. N., M. E. Smith, P. A. Cott, B. W. Hanna, A. O. MacGillivray, M. E. Austin, and D. A. Mann. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. *Journal of the Acoustical Society of America* 117: 3958-3971.
- Ports, and Ships. 2011. Ports & Ships: shipping and harbour news out of Africa. Accessed on: 15-12-2011. <http://ports.co.za>.
- Potter, J. R. 2004. A possible mechanism for acoustic triggering of decompression sickness symptoms in deep-diving marine mammals. Report from the Acoustic Research Laboratory, Tropical Marine Science Institute. Singapore. 7pp.
- PPC. 2011. Scoping and environmental impact assessment: Bulk liquid storage and handling facility, Coega Industrial Development Zone (IDZ). Background information document prepared by the Public Process Consultants (PPC).
- PPO. 2010. Invitation to participate: environmental management programme for exploration of natural gas in various areas in the Western Cape

(12679). Background information document prepared by the Public Participation Office.

Prince, D. S. 2007. Final comprehensive report for the operation of the Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) sonar onboard the R/V *Cory Chouest* and USNS IMPECCABLE (T-AGOS 23) under the National Marine Fisheries Service Regulations 50 CFR 216 subpart Q. Report prepared for the National Marine Fisheries Services (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) by the Department of the Navy, United States of America. 53pp.

Reyff, J. A. 2005. Underwater sound pressure levels associated with marine pile driving: assessment of impacts and evaluation of control measures [abstract]. Transportation Research Record: Journal of the Transportation Research Board.

Richardson, W. J. 1995. Documented disturbance reactions. p. 241-324 in W. J. Richardson, C. R. Green Jr., C. I. Malme and D. H. Thomson (Eds). Marine mammals and noise. Academic Press, Inc., San Diego, United States of America.

Romano T. A., Keogh M. J., Kelly C., Feng K. P., Berk L., Schlundt C. E., Carder D. A. and J.J. Finneran. 2004. Anthropogenic sound and marine mammal health: measures of the nervous and immune systems before and after intense sound exposure. Canadian Journal of Fisheries and Aquatic Sciences 61: 1124-1134.

Salmon, M. 1983. Acoustic 'calling' by fiddler and ghost crabs. p. 63-76 in J. K. Lowry (Ed.). Conference on the Biology and Evolution of Crustacea. The Australian Museum, Sydney, Australia in 1980. The Australian Museum.

SANPARKS. 2012. Marine and Coastal. South African National Parks. Accessed on: 01-03-2012.
<http://www.sanparks.org/parks/addo/conservation/ff/marine.php>.

Sarà G., Dean J. M., D'Amato D., Buscaino G., Oliveri A., Genovese S., Ferro S., Buffa G., Lo Martire M. and S. Mazzola. 2007. Effect of boat noise on the behaviour of bluefin tuna *Thunnus thynnus* in the Mediterranean Sea. Marine Ecology Progress Series 331: 243-253.

Sauerland, M., and G. Dehnhardt. 1997. Underwater audiogram of a tucuxi (*Sotalia fluviatilis guianensis*). Journal of the Acoustical Society of America 103: 1199-1204.

Sayigh, L. S., P. L. Tyack, R. S. Wells, and M. D. Scott. 1990. Signature whistles of free-ranging bottlenose dolphins *Tursiops truncatus*: stability and mother-offspring comparisons. Behavioural Ecology and Sociobiology 26: 247-260.

- SCENIHR. 2008. Health risks from exposure to noise from personal music players and mobile phoned including a music playing function. Report prepared by the Scientific Committee on Emerging and Newly Identified Health Risks. September. 81pp.
- Schlundt, C. E., R. L. Dear, L. Green, D. S. Houser, and J. J. Finneran. 2007. Simultaneously measured behavioral and electrophysiological hearing thresholds in a bottlenose dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America* 122: 615-622.
- Schlundt, C. E., R. L. Dear, D. S. Houser, A. E. Bowles, T. Reidarson, and J. J. Finneran. 2011. Auditory evoked potentials in two short-finned pilot whales (*Globicephala macrorhynchus*). *Journal of the Acoustical Society of America* 129: 1111-1116.
- Scholik, A. R., and H. Y. Yan. 2002. Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas*. *Environmental Biology of Fishes* 63: 203-209.
- Schusterman, R. J. 1974. Auditory sensitivity of a California sea lion to airborne sound. *Journal of the Acoustical Society of America* 56: 1248-1251.
- Schwenk, K. 2008. Comparative anatomy and physiology of chemical senses in Nonavian aquatic reptiles. p. 65-81 in J. G. M. Thewissen and S. Nummela (Eds). *Sensory evolution on the threshold adaptations in secondarily aquatic vertebrates*. University of California Press, Berkeley, California, United States of America.
- Scotsman, T. 2005. Whales use 'sound map' to navigate. CIESM The Mediterranean Science Commission. Accessed on: 24-01-2012. <http://www.ciesm.org/news/mscience/2003.htm>.
- SeaBeam. 2000. Multibeam sonar, theory of operation. L-3 Communications SeaBeam Instruments. East Walpole, Massachutes, United States of America. 105pp.
- Sih, A., A. M. Bell, and J. L. Kerby. 2004. Two stressors are far deadlier than one. *Trends in Ecology and Evolution* 19: 274-276.
- Simmonds, M., S. Dolman, and L. Weilgart. 2004. *Oceans of Noise*. Science report prepared by the Whale and Dolphin Conservation Society (WDCS). Chippenham, United Kingdom. 168pp.
- Simpson, S. D., M. G. Meekan, A. Jeffs, J. C. Montgomery, and R. D. McCauley. 2008. Settlement-stage coral reef fish prefer the higher-frequency invertebrate-generated audible component of reef noise. *Animal Behaviour* 75: 1861-1868.
- Simpson, S. D., M. G. Meekan, R. D. McCauley, and A. Jeffs. 2004. Attraction of settlement-stage coral reef fishes to reef noise. *Marine Ecology Progress Series* 276: 263-268.

- Simpson, S. D., M. G. Meekan, J. Montgomery, R. McCauley, and A. Jeffs. 2005a. Homeward sound. *Science* 308: 221.
- Simpson, S. D., H. Y. Yan, M. L. Wittenrich, and M. G. Meekan. 2005b. Response of embryonic coral reef fishes (Pomacentridae: *Amphiprion* spp.) to noise. *Marine Ecology Progress Series* 287: 201-208.
- Skalski, J. R., W. H. Pearson, and C. I. Malme. 1992. Effect of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). *Canadian Journal of Fisheries and Aquatic Sciences* 49: 1357-1365.
- Slotte, A., K. Hansen, J. Dalen, and E. Ona. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. *Fisheries Research* 67: 143-150.
- Smee, D. L. 2010. Species with a large impact on community structure. *Nature Education Knowledge* 1: 18.
- Smith, K. L., and R. J. Baldwin. 1982. Scavenging deep-sea amphipods: effects of food odor on oxygen consumption and a proposed metabolic strategy. *Marine Biology* 68: 287-298.
- Smith, M. E., A. S. Kane, and A. N. Popper. 2007. Noise-induced stress response and hearing loss in goldfish (*Carassius auratus*). *Journal of Experimental Biology* 207: 427-435.
- Smolker, R. A., J. Mann, and B. B. Smuts. 1993. Use of signature whistles during separations and reunions by wild bottlenose dolphin mothers and infants. *Behavioural Ecology and Sociobiology* 33: 393-402.
- Soto, N. A., M. Johnson, P. T. Madsen, P. L. Tyack, A. Bocconcelli, and J. F. Borsani. 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? *Marine Mammal Science* 22: 690-699.
- Southall B. L., Bowles A. E., Ellison W. T., Finneran J. J., Gentry R. L., Green Jr C. R., Kastak D., Ketten D. R., Miller J. H., Nachtigall P. E., Richardson W. J., Thomas J. A. and P.L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. *Aquatic Mammals* 33: 1-522.
- Spence, J., R. Fischer, M. Bahtiarian, L. Boroditsky, N. Jones, and R. Dempsey. 2007. Review of existing and future potential treatments for reducing underwater sound from oil and gas industry activities. Report prepared for the Joint Industry Programme on E&P Sound and Marine Life by the Noise Control Engineering, Inc. Report number: *NCE REPORT 07-001*. 185pp.
- Stanley, J. A., C. A. Radford, and A. G. Jeffs. 2009. Induction of settlement in crab megalopae by ambient underwater reef sound. *Behavioral Ecology* 24: 113-120.

- Stirling, I., and J. A. Thomas. 2003. Relationship between underwater vocalizations and mating systems in phocid seals. *Aquatic Mammals* 33: 411-521.
- Stone, C. J. 2003. The effects of seismic activity on marine mammals in UK waters, 1998-2000. Report prepared by the Joint Nature Conservation Committee (JNCC). Report number: *JNCC Report No. 323*. 78pp.
- SURTASS, L. 2011. SURTASS LFA. Department of the Navy, United States of America. Accessed on: 21-12-2011. <http://www.surtass-lfa-eis.com/Highlights/index.htm>.
- Szymanski, M. D., D. E. Bain, K. Kiehl, S. Pennington, S. Wong, and K. R. Henry. 1999. Killer whale (*Orcinus orca*) hearing: auditory brainstem response and behavioral audiograms. *Journal of the Acoustical Society of America* 106: 1134-1141.
- Tenghamn, R. 2006. An electrical marine vibrator with a flextensional shell [abstract]. *Exploration Geophysics* 37: 286-291.
- Terhune, J. M., and K. Ronald. 1975. Underwater hearing sensitivity of two ringed seals (*Pusa hispida*) [abstract]. *Canadian Journal of Zoology* 53.
- Thomas, J., N. Chun, and W. Au. 1988. Underwater audiogram of a false killer whale (*Pseudorca crassidens*). *Journal of the Acoustical Society of America* 84: 936-940.
- Thomas, J., P. Moore, R. Withrow, and M. Stoermer. 1990. Underwater audiogram of a Hawaiian monk seal (*Monachus schauinslandi*). *Journal of the Acoustical Society of America* 87: 417-420.
- Thomson, D. H., and W. J. Richardson. 1995. Marine mammal sounds. p. 159-204 in W. J. Richardson, C. R. Green Jr., C. I. Malme and D. H. Thomson (Eds). *Marine mammals and sound*. Academic Press, Inc., San Diego, United States of America.
- Todd, S., P. Stevick, J. Lien, F. Marques, and D. Ketten. 1996. Behavioural effects of exposure to underwater explosions in humpback whales (*Megaptera novaeangliae*). *Canadian Journal of Zoology* 74: 1661-1672.
- Tóth, E., and J. E. Duffy. 2005. Coordinated group response to nest intruders in social shrimp. *Biology Letters* 1: 49-52.
- Tougaard, J., J. Carstensen, J. Teilmann, H. Skov, and P. Rasmussen. 2009. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)). *Journal of the Acoustical Society of America* 126: 11-14.
- Transnet. 2012. Transnet National Ports Authority. Transnet. Accessed on: 31-01-2012. <http://www.transnetnationalportsauthority.net>.
- Tremel, D. P., J. A. Thomas, K. T. Ramirez, G. S. Dye, W. A. Bachman, A. N. Orban, and K. K. Grimm. 1998. Underwater hearing sensitivity of a

- Pacific white-sided dolphin, *Lagenorhynchus obliquidens*. Aquatic Mammals 24: 63-69.
- TSB. 2000. State of the art of removing large platforms located in deep water. Final report prepared for the United States Minerals Management Service by Twachtman Snyder & Byrd, Inc. November. Report number: MMS-372. 251pp.
- Tyack, P. 1981. Interactions between singing Hawaiian humpback whales and conspecifics nearby. Behavioural Ecology and Sociobiology 8: 105-116.
- Tyack, P. L. 2000. Functional aspects of cetacean communication. p. 270-307 in J. Mann, R. C. Connor, P. L. Tyack and H. Whitehead (Eds). Cetacean societies: field studies of dolphins and whales. The University of Chicago Press, United States of America.
- Tyack, P. L. 2008. Implications for marine mammals of large-scale changes in the marine acoustic environment. Journal of Mammalogy 89: 549-558.
- UK MSACP. 2011. Dredging and disposal. UK Marine Special Areas of Conservation (UK Marine SACs Project). Accessed on: 31-01-2012. <http://www.ukmarinesac.org.uk/activities/ports/ph5.htm>.
- UNCLOS. 1982. United Nations Convention on the Law of the Sea of 10 December 1982. Oceans and Law of the Sea: Division for ocean affairs and the law of the sea. Accessed on: 30-12-2011. http://www.un.org/depts/los/convention_agreements/convention_overview_convention.htm.
- UNCLOS. 2008. Resolution adopted by the General Assembly: Oceans and the law of the sea (62/1982). United Nations Convention on the Law of the Sea (UNCLOS). 14 March 2008, Code: A/RES/62/215, Section 120. 25pp.
- Van der Lingen, C. D., J. C. Coetzee, and L. Hutchings. 2010. Overview of the KwaZulu-Natal sardine run. African Journal of Marine Science 32: 271-277.
- Van Opzeeland, I. 2010. Acoustic ecology of marine mammals in polar oceans. PhD thesis. Alfred-Wegener Institute for Polar & Marine Research and the University of Bremen, Germany. 363pp.
- Van Parijs, S. M., and P. J. Corkeron. 2001. Boat traffic affects the acoustic behaviour of Pacific humpback dolphins, *Sousa chinensis*. Journal of the Marine Biological Association of the United Kingdom 81: 533-538.
- Vasconcelos, R. O., M. C. P. Amorim, and F. Ladich. 2007. Effects of ship noise on the detectability of communication signals in the Lusitanian toadfish. Journal of Experimental Biology 210: 2104-2111.
- Wagner, H. J. 2002. Sensory brain areas in three families of deep-sea fish (slickheads, eels and grenadiers): comparison of mesopelagic and demersal species. Marine Biology 141: 807-817.

- Wagner, H. J. 2003. Volumetric analysis of brain areas indicates a shift in sensory orientation during development in the deep-sea grenadier *Coryphaenoides armatus*. *Marine Biology* 142: 791-797.
- Wang, D., K. Wang, Y. Xiao, and G. Sheng. 1992. Auditory sensitivity of a Chinese river dolphin, *Lipotes vexillifer*. p. 213-221 in J. Thomas, (Eds). *Marine mammal sensory systems*. Plenum Press, New York, United States of America.
- Watkins, W. A. 1986. Whale reactions to human activities in Cape Cod waters. *Marine Mammal Science* 2: 251-262.
- Watkins, W. A., and W. E. Schevill. 1975. Sperm whales (*Physeter catodon*) react to pingers. *Deep-Sea Research* 22: 123-129.
- WCA. 2010. *Wildlife Countryside: The conservation of habitats and species regulations 1981, as amended 2010*. No. 490. 96pp.
- WDCS. 2012. *Whale and Dolphin Conservation Society International*. Whale and Dolphin Conservation Society (WDCS). Accessed on: 29-02-2012. <http://www.wdcs.org>.
- Weilgart, L. S. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology* 85: 1091-1116.
- Weilgart, L. S. 2011. The impact of ocean noise pollution on marine biodiversity. Accessed on: 09-12-2011. http://pacificenvironment.org/downloads/Lindy_s%20Biodiversity%20paper.pdf.
- Williams, R., D. Lusseau, and P. S. Hammond. 2006. Estimating relative energetic costs of human disturbance to killer whales (*Orcinus orca*). *Biological Conservation* 133: 301-311.
- Williams, R., A. W. Trites, and D. E. Bain. 2002. Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats: opportunistic observation and experimental approaches. *Journal of Zoology London* 256: 255-270.
- Wolski, L. F., R. C. Anderson, A. E. Bowles, and P. K. Yochem. 2003. Measuring hearing in the harbor seal (*Phoca vitulina*): Comparison of the behavioral and auditory brainstem response techniques. *Journal of the Acoustical Society of America* 113: 629-637.
- Würsig, B., C. R. Greene, and T. A. Jefferson. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. *Marine Environmental Research* 49: 79-93.
- Würsig, B., and W. J. Richardson. 2008. Effects of Noise. p. 765-773 in W. F. Perrin, B. Würsig and J. G. M. Thewissen (Eds). *Encyclopedia of Marine Mammals*. Academic Press Elsevier, San Diego, United States of America.

- WWF. 2011. Russian government moves to protect critically endangered whales. World Wildlife Fund. Accessed on: 30-01-2012. http://wwf.panda.org/what_we_do/successes/?200431/Russian-government-moves-to-protect-critically-endangered-whales.
- Wysocki, L. E., J. P. Dittami, and F. Ladich. 2006. Ship noise and cortisol secretion in European freshwater fishes. *Biological Conservation* 128: 501-508.
- Yan, H. Y. 2001. A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. *Proceedings of the Royal Society B.: Biological Sciences* 23: 15-26.
- Yuen, M. M. L., P. E. Nachtigall, M. Breese, and A. Y. Supin. 2005. Behavioral and auditory evoked potential audiograms of a false killer whale (*Pseudorca crassidens*). *Journal of the Acoustical Society of America* 118: 2688-2695.

APPENDICES

Appendix A Known maximum hearing sensitivity ranges for various marine taxa. Maximum hearing sensitivity ranges correspond to ranges where hearing threshold values fall within 10 dB of the minimum hearing threshold level. All threshold levels are measured with a reference level of 1 μPa , except measurements marked by a *, which are threshold levels measured with a reference level of 20 μPa

Appendix B Selected list of conferences, workshops and meetings concerned with aspects of ocean noise pollution

Appendix A Known maximum hearing sensitivity ranges for various marine taxa. Maximum hearing sensitivity ranges correspond to ranges where hearing threshold values fall within 10 dB of the minimum hearing threshold level. All threshold levels are measured with a reference level of 1 μ Pa, except measurements marked by a *, which are threshold levels measured with a reference level of 20 μ Pa

Species	Estimated hearing range (kHz)	Measured frequency (kHz)	Best hearing sensitivity (kHz)	Minimum threshold (dB re 1 μ Pa)	Captive / wild (C/W)	Behavioural / AEP	Sample size	References
<u>Teleosts</u>								
Atlantic codfish (<i>Gadus morhua</i>)	0.01-0.6	0.01-0.6	0.015-0.032	57	W	Behavioural	20	(Offutt 1974)
Oyster toadfish (<i>Opsanus tau</i>)	0.1-0.8	0.1-0.8	0.1-0.5	117	?	AEP (water)	5	(Yan 2001)
Brown meagre (<i>Sciaena umbra</i>)	0.1-3.0	0.1-3.0	0.2-0.5	82	W	AEP (water)	6	(Codarin <i>et al.</i> 2009)
Mediterranean damselfish (<i>Chromis chromis</i>)	0.1-0.6	0.1-3.0	0.1-0.3	102	W	AEP (water)	6	(Codarin <i>et al.</i> 2009)
Red-mouthed goby (<i>Gobius cruentatus</i>)	0.1-0.7	0.1-3.0	0.1-0.5	107	W	AEP (water)	6	(Codarin <i>et al.</i> 2009)
Mojorra (<i>Eucinostomus argenteus</i>)	0.1-1.8	0.075-3.6	0.15-0.6	78	W	AEP (water)	15	(Parmentier <i>et al.</i> 2011)

Species	Estimated hearing range (kHz)	Measured frequency (kHz)	Best hearing sensitivity (kHz)	Minimum threshold (dB re 1 μ Pa)	Captive / wild (C/W)	Behavioural / AEP	Sample size	References
<i>Chelonians</i>								
Loggerhead turtle (<i>Caretta caretta</i>)	0.1-0.9 (hatchling)	0.1-0.9	0.4-0.65	82	?	AEP (water)	2	(Ketten and Bartol 2006, Martin 2011)
	0.1-0.7 (2 yr old)	0.1-0.9	0.1-0.65	86	?	AEP (water)	2	
	0.1-0.4 (3 yr old)	0.1-0.9	0.1-0.4	93	?	AEP (water)	2	
	0.1-3.2 (adult)	0.05-3.2	0.1-0.4	110	C	AEP (water)	1	
	0.05-0.8 (adult)	0.05-1.1	0.1-0.4	98	C	Behavioural	1	
Green turtle (<i>Chelonia mydas</i>)	0.1-0.8 (juvenile)	0.1-0.9	0.55-0.74	94	?	AEP (water)	2	(Ketten and Bartol 2006)
	0.1-0.5 (subadult)	0.1-0.9	0.1-0.42	91	?	AEP (water)	2	
Kemp Ridley (<i>Lepidochelys kempii</i>)	0.1-0.5 (juvenile)	0.1-0.9	0.1-0.5	110	?	AEP (water)	2	(Ketten and Bartol 2006)

Species	Estimated hearing range (kHz)	Measured frequency (kHz)	Best hearing sensitivity (kHz)	Minimum threshold (dB re 1 μ Pa)	Captive / wild (C/W)	Behavioural / AEP	Sample size	References
<i>Elasmobranchs</i>								
Little skate (<i>Raja erinacea</i>)	0.1-0.8	0.2-0.8	0.2-0.55	122	C	Behavioural (water)	4	(Casper <i>et al.</i> 2003)
		0.1-0.8	0.1-0.3	124	C	AEP (water)	4	
Lemon shark (<i>Negaprion brevirostris</i>)	0.01-0.64	0.01-0.64	0.04-0.32	90	C	Behavioural	3	(Nelson 1967)
Atlantic sharpnose shark (<i>Rhizoprionodon terraenovae</i>)	0.02-1.4	0.02-2.0	0.02	83	W	AEP (water)	3	(Casper 2006, Casper and Mann 2009)
Nurse shark (<i>Ginglymostoma cirratum</i>)	0.1-1.0	0.1-1.0	0.2-0.8	134	C	AEP (water)	4	(Casper 2006)
Yellow stingray (<i>Urobatis jamaicensis</i>)	0.1-1.0	0.1-1.0	0.2-0.8	139	W	AEP (water)	5	(Casper 2006)
<i>Pinnipeds</i>								
Harbor seal (<i>Phoca vitulina</i>)	0.25-30	0.25-30	6.0-12	11	C	Behavioural (water)	1	(Wolski <i>et al.</i> 2003)
		0.2-22	8.0-16	15	C	AEP (water)	1	

Species	Estimated hearing range (kHz)	Measured frequency (kHz)	Best hearing sensitivity (kHz)	Minimum threshold (dB re 1 μ Pa)	Captive / wild (C/W)	Behavioural / AEP	Sample size	References
Ringed seal (<i>Pusa hispida</i>)	1.0-90	1.0-90	1.0-45	68	C	Behavioural (water)	1	(Terhune and Ronald 1975, Nedwell <i>et al.</i> 2004)
Hawaiian monk seal (<i>Monachus schauinslandi</i>)	2.0-48	2.0-48	16-24	65	C	Behavioural (water)	1	(Thomas <i>et al.</i> 1990)
Northern fur seal (<i>Callorhinus ursinus</i>)	0.5-32	0.5-32	2.0	10*	C	Behavioural (air)	2	(Moore and Schusterman 1987)
California sea lion (<i>Zalophus californianus</i>)	0.5-32	4.0-32	4.0-28	32*	C	Behavioural (air)	1	(Schusterman 1974, Moore and Schusterman 1987, Kastak and Schusterman 1998, 2002, Nedwell <i>et al.</i> 2004)
		0.5-32	2.0-8.0	16*	C	Behavioural (air)	1	
	0.1-35	2.5-35	2.5-10 (i.e. 10 m depth)	79	C	Behavioural (water)	1	
		0.25-64	8.0-27	77	C	Behavioural (water)	1	
Pacific walrus (<i>Odobenus rosmarus divergens</i>)	0.125-15	0.125-32	1.0-12	67	C	Behavioural (water)	1	(Kastelein <i>et al.</i> 2002b)

Species	Estimated hearing range (kHz)	Measured frequency (kHz)	Best hearing sensitivity (kHz)	Minimum threshold (dB re 1 μ Pa)	Captive / wild (C/W)	Behavioural / AEP	Sample size	References
<u>Sirenians</u>								
West Indian manatee (<i>Trichechus manatus</i>)	0.4-46	0.4-46	6.0-20	50	C	Behavioural	2	(Gerstein <i>et al.</i> 1999)
Amazonian manatee (<i>Trichechus inunquis</i>)	5.0-40	5.0-40	5.0-20	85	?	AEP (water)	1	(Popov and Supin 1990)
<u>Odontocetes</u>								
Harbour porpoise (<i>Phocoena phocoena</i>)	0.25-180	0.25-180	16-140	32	C	Behavioural	1	(Kastelein <i>et al.</i> 2002a)
Indo-Pacific Humpback dolphin (<i>Sousa chinensis</i>)	5.6-152	5.6-152	32-45	47	C	AEP (water)	1	(Li <i>et al.</i> 2012)
Common bottlenose dolphin (<i>Tursiops truncatus</i>)	2.0-180	1.0-160	25-80	47	C	Behavioural	1	(Ljungblad <i>et al.</i> 1982, Popov and Supin 1990, Cook 2006, Houser and Finneran 2006, Schlundt <i>et al.</i> 2007, Houser <i>et al.</i> 2008)
		5.0-140	40-90	57	C	AEP (water)	4	
		10-150	10-50	80	C	AEP (air)	42	
		5.0-80	20-40	79	C	Behavioural	1	
		5.0-80	40-80	68	C	AEP (air)	1	
		5.0-80	40-80	73	C	AEP (water)	1	
	5.0-120	35-120	68	W	AEP (air)	62		

Species	Estimated hearing range (kHz)	Measured frequency (kHz)	Best hearing sensitivity (kHz)	Minimum threshold (dB re 1 μ Pa)	Captive / wild (C/W)	Behavioural / AEP	Sample size	References
		10-150	10-50	68	C	Behavioural	1	
		10-150	20-50	70	C	AEP (air)	1	
		10-180	40-115	61	C	AEP (air)	13	
Short-beaked common dolphin (<i>Delphinus delphis</i>)	10-152	5.0-152	45-85	53	W (sick)	AEP (water)	1	(Popov and Klishin 1998)
Striped dolphin (<i>Stenella coeruleoalba</i>)	0.5-160	0.5-160	29-123	42	C	Behavioural	1	(Kastelein <i>et al.</i> 2003)
Risso's dolphin (<i>Grampus griseus</i>)	4.0-150	4.0-150	22.5-90	51	C	AEP (water)	1	(Nachtigall <i>et al.</i> 2005)
Marine tucuxi dolphin (<i>Sotalia fluviatilis guianensis</i>)	4.0-140	5.0-140	32-98	59	W	AEP (water)	2	(Popov and Supin 1990, Sauerland and Dehnhardt 1997)
		4.0-135	64-105	50	C	Behavioural	1	
White-beaked dolphin (<i>Lagenorhynchus albirostris</i>)	16-140	16-215	45-128	45	W	AEP (water)	1	(Nachtigall <i>et al.</i> 2008)
Pacific white-sided dolphin (<i>Lagenorhynchus obliquidens</i>)	0.1-140	0.075-150	4-64	64	C	Behavioural	1	(Tremel <i>et al.</i> 1998)
		4.0-45	15-27	70	C	Behavioural	1	
		4.0-45	9.5-22.5	81	C	AEP (water)	1	

Species	Estimated hearing range (kHz)	Measured frequency (kHz)	Best hearing sensitivity (kHz)	Minimum threshold (dB re 1 μ Pa)	Captive / wild (C/W)	Behavioural / AEP	Sample size	References
Short-finned pilot whale (<i>Globicephala macrorhynchus</i>)	10-100	5.0-160	30-70	79	C	AEP (water)	1	(Schlundt <i>et al.</i> 2011, Greenhow <i>et al.</i> 2012)
Long-finned pilot whale (<i>Globicephala melas</i>)	4.0-100	4.0-100	22.5-40	53	C	AEP (water)	1	(Pacini <i>et al.</i> 2010)
False killer whale (<i>Pseudorca crassidens</i>)	2.0-115	2.0-115	16-64	39	C	Behavioural	1	(Thomas <i>et al.</i> 1988, Yuen <i>et al.</i> 2005)
		4.0-45	15-27	70	C	Behavioural	1	
		4.0-45	9.5-22.5	81	C	AEP (water)	1	
Killer whale (<i>Orcinus orca</i>)	0.5-120	0.5-31	12-20	30	C	Behavioural	1	(Hall and Johnson 1971, Szymanski <i>et al.</i> 1999, Nedwell <i>et al.</i> 2004)
		1.0-120	18-28	33	C	Behavioural	2	
		1.0-120	18-42	37	C	AEP (water)	2	
Beluga whale (<i>Delphinapterus leucas</i>)	1.0-130	15-110	50-80	67	W	AEP (water)	2	(Popov and Supin 1990, Klishin <i>et al.</i> 2000, Finneran <i>et al.</i> 2005)
		8.0-128	40-100	55	C	AEP (air)	1	
		2.0-130	48-70	43	C	Behavioural	1	
		1.0-120	8.0-98	52	C	Behavioural	7	
Yangtze finless porpoise (<i>Neophocaena phocaenoides asiaeorientalis</i>)	8.0-152	8.0-152	45-128	47	C	AEP (water)	2	(Popov <i>et al.</i> 2005)

Species	Estimated hearing range (kHz)	Measured frequency (kHz)	Best hearing sensitivity (kHz)	Minimum threshold (dB re 1 μ Pa)	Captive / wild (C/W)	Behavioural / AEP	Sample size	References
Chinese/Yangtze River dolphin (<i>Lipotes vexillifer</i>)	1.0-200	1.0-200	16-48	55	C	Behavioural	1	(Wang <i>et al.</i> 1992 in, Nedwell <i>et al.</i> 2004)
Gervais' beaked whale (<i>Mesoplodon europaeus</i>)	5.0-80	5.0-80	50-80	87	W (sick)	AEP (water)	1	(Cook 2006)
Blainville's beaked whale (<i>Mesoplodon densirostris</i>)	5.6-160	5.6-160	40-50	49	W (sick)	AEP (water)	1	(Pacini <i>et al.</i> 2011)

Appendix B Selected list of conferences, workshops and meetings concerned with aspects of ocean noise pollution

Type	Title	Institution / agency	Year	Available from
Conference	Pacific rim underwater acoustics conference 2007, October 3-5, Vancouver, Canada	University of Washington and Victoria and Acoustical Society of America	2007	http://pruac.apl.washington.edu/
Conference	19th Biennial conference on the Biology of marine mammals, November 27 - December 2, Florida, USA.	NOAA and Society for Marine Mammalogy	2011	http://marinemammalscience.org/index.php?option=com_content&view=article&id=549&Itemid=65
Conference	Sustainable Ocean Summit (SOS), June 15-17, Belfast, Northern Ireland	Sustainable Ocean Summit (SOC)	2011	http://oceancouncil.org/site/summit/index.php?page=overview
Conference	26th Conference of the European Cetacean Society, March 26-28, Galway, Ireland.	Irish Whale and Dolphin Group (IWDG) and Galway-Mayo Institute of Technology (GMIT)	2012	http://iwdg.ie/ecs/
Conference	Acoustics 2012 conference, April 23-27, Nantes, France.	Institute of Acoustics (IOA) and French Acoustical Society (SFA)	2012	http://acoustics2012-nantes.org
Conference	Acoustics 2012 Hong Kong - multiple society conference, May 13-18, Hong Kong.	Hong Kong Institute of Acoustics (HKIOA)	2012	http://acoustics2012hk.org/
Conference	11th European conference on underwater acoustics, July 2-6, Edinburgh, Scotland.	IOA	2012	http://ecua2012.com/
Conference	SPE/APPEA International conference on health, safety and environment in oil and gas exploration and production, September 11-13, Perth, Australia	Society of Petroleum Engineers (SPE) and Australian Petroleum Production & Exploration (APPEA)	2012	http://spe.org/events/hse/2012

Type	Title	Institution / agency	Year	Available from
Conference	The effects of noise on aquatic life	Arthur Popper and Anthony Hawkins	2007, 2010, 2013	http://aquaticnoise.org/
Congress	19th International congress on sound and vibration, July 8-12, Vilnius, Lithuania.	International Institute of Acoustics and Vibration (IIAV) and Vilnius University	2012	http://icsv19.org/
Symposium	Symposium on environmental consequences of underwater sound (ECOUS), May 12-16, San Antonio, Texas, USA	Life Sciences Research Organization, Inc.	2003	http://lsro.org/workshops/ecous.html
Symposium	Potential application of quieting technology on large commercial vessels, May 1-2, 2007, Maryland, USA	National Oceanic and Atmospheric Administration (NOAA) Ocean Acoustics Program	2007	http://nmfs.noaa.gov/pr/acoustics/shipnoise.htm
Meeting	Open science meeting for an international quiet ocean experiment, August 30 - September 1, UNESCO headquarters, Paris, France	Scientific Committee on Oceanic Research (SCOR) and Partnership for Observation of the Global Oceans (POGO)	2011	http://iqoe-2011.org/main.cfm?cid=2473
Meeting	Ambient noise in north-European seas: monitoring, impact and management, October 3-5, National Oceanography Centre, Southampton, UK.	IOA	2011	http://ioa.org.uk/events/event.asp?id=119
Meeting	The XXIII meeting of the International Bioacoustics Council (IBAC), September 12-16, La Rochelle, France	International Bioacoustics Council (IBAC)	2011	http://cb.u-psud.fr/ibac2011/
Meeting	International Association of Geophysical Contractors (IAGC) annual meeting, February 21, Texas, USA	International Association of Geophysical Contractors (IAGC)	2012	http://iagc.org/en/cev/233

Type	Title	Institution / agency	Year	Available from
Meeting	US Office of Naval Research Biennial Program Review Meeting, April 16-20, Washington DC, USA.	US Navy	2012	http://iagc.org/en/cms/966/
Meeting	IWC Scientific Committee meeting, June 11-23, Panama City, Panama.	International Whaling Commission (IWC)	2012	http://iwcoffice.org/meetings/meeting2012.htm
Meeting	164th Meeting of the Acoustical Society of America, October 22-26, Missouri, USA.	Acoustical Society of America (ASA)	2012	http://acousticalsociety.org/meetings
Meeting	Arctic ocean open water meeting, March 6-8, Alaska, USA.	NOAA	Annually	http://nmfs.noaa.gov/pr/permits/openwater.htm
Workshop	Effects of noise on fish fisheries, and invertebrates; A BOEM workshop on data gaps and research needs, March 19-22, California, USA.	Bureau of Ocean Energy Management (BOEM)	2012	http://boemsoundworkshop.com
Report	Marine mammals and low-frequency sound: progress since 1994	NRC	2000	http://nap.edu/catalog.php?record_id=9756
Report	Ocean noise and marine mammals	National Research Council (NRC)	2003	http://nap.edu/catalog.php?record_id=10564
Report	Seismic suveys: what we don't know can hurt	AEI	2003	http://acousticecology.org/oceanairgunexecsumm.html
Report	Oceans of noise	Whale and Dolphin Conservation Society (WDCS)	2004	http://wdcs.org/submissions_bin/OceansofNoise.pdf

Type	Title	Institution / agency	Year	Available from
Report	Annex K: Report of the standing working group on environmental concerns (May 2004) Mini-Symposium on acoustics	IWC	2004	http://acousticecology.org/science/conferences.html
Report	Marine mammal populations and ocean noise: determining when noise causes biologically significant effects	NRC	2005	http://nap.edu/catalog.php?record_id=11147
Report	Sounding the depths: the rising toll of sonar, shipping and industrial ocean noise on marine life	National Resource Defense Council (NRDC)	2005	http://nrdc.org/wildlife/marine/sound/sound.pdf
Report	Underwater sound and marine life	Inter-Agency Committee on Marine Science and Technology	2006	http://marine.gov.uk/NOC_IACMST_Report_1.pdf
Report	Marine mammals and noise: A sound approach to research and management	Marine Mammal Commission (MMC)	2007	http://mmc.gov/sound/fullsoundreport.pdf
Report	Position Paper 13: The effects of anthropogenic sound on marine mammals. A draft research strategy	European Science Foundation, Marine Board (ESF)	2008	http://esf.org/marineboard/publications
Report	AEI special report: Ocean noise 2009. Science, policy, legal developments.	Acoustic Ecology Institute (AEI)	2009	http://acousticecology.org/docs/AEI_OceanNoise2009.pdf
Report	Summaries of the International Whaling Commission Scientific Committee annual reports provided by the Acoustic Ecology Institute	AEI	Annually	http://acousticecology.org
Website	International Association of Geophysical Contractors (IAGC); Marine environment	IAGC	2004	http://iagc.org/MarineEnvironment/

Type	Title	Institution / agency	Year	Available from
Website	Ocean Mammal Institute research with focus on the impact of engine noise on Hawaii's humpback whales	Marine Mammal Institute (MMI)	2011	http://oceanmammalinst.org/index.html
Website	Antarctic and Southern Ocean Coalition, Issues and advocacy, acoustic pollution	Antarctic and Southern Ocean Coalition (ASOC)	2011	http://asoc.org/issues-and-advocacy/antarctic-wildlife-conservation/acoustic-pollution
Website	Discovery of sound in the sea	University of Rhode Island	2011	http://dosits.org
Email alert	MARMAM mailing list: daily digital issues with notifications of conferences, meetings, new publications, online lectures etc. in the field of marine biology. Weekly messages under the topic of ocean acoustics and ocean noise	Marine Mammals Research and Conservation Discussion (MARMAM)	Daily	https://lists.uvic.ca/mailman/listinfo/marmam

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