Laboratory of Applied Bioacoustics (LAB)
Technical University of Catalonia (UPC)

Exp. CONAT150113NS2008029

Best Practices in Management, Assessment and Control of Underwater Noise Pollution

Written by Michel André, Maria Morell, Alex Mas, Marta Solé, Mike van der Schaar, Ludwig Houégnigan, Serge Zaugg and Joan V. Castell (on behalf of LAB), and by Cristina Álvarez Baquerizo and Liana Rodríguez Roch (on behalf of *Samara, servicios jurídicos ambientales s.c.)*

30 June, 2009

INDEX

TABLES

ANNEXES

Introduction; the purpose of this work and explanation of its content; difficulties and limitations.

The origin of this work can be found in the project *'Effects and Control of Anthropogenic Noise in Marine Ecosystems'* in the part relative to legal initiatives. In the first phase of the Report on this Project (December 2008) it was concluded that the level of complexity of marine issues, united by the fact that wide scientific gaps and difficulties still need to be covered and resolved, counseled against the immediate drawing up of legal projects concerning underwater acoustic pollution. Nevertheless, it was suggested that a document of 'Best Practices' be elaborated to focus on the 'state of the art' of this issue, and that it be used by public administrations and promoters of projects that will cause acoustic pollution, as much within the framework of environmental impact assessments as in management development plans in protected marine areas. It is of vital importance that activities, which generate acoustic pollution in the oceans, be monitored. Accordingly, this document could derive, in the short term, a Protocol of Applications which will in its own time open the way for the preparation of, if necessary, legislative initiatives within their own right.

Sources of sound produced by human activities manifest physical, physiological and behavioral effects on marine fauna; mammals, reptiles, fish and invertebrates, effects that can be diverse depending on the proximity to the signal source. These impacts, for example, include a reduction in the abundance of fish species of up to 50% in zones under exploration[1], changes in cetacean behavior and their migration routes[2], and a distinct range of physical injuries in both marine vertebrates and invertebrates[3]. There may be further long-term consequences due to chronic exposure and sound can indirectly affect animals due to changes in the accessibility of prey, which in turn may suffer the adverse effects of acoustic pollution. These damages could have a significant bearing on the conservation of species already endangered which use acoustically contaminated areas for migratory routes, reproduction and feeding.

For many reasons, nowadays, evaluating the acoustic impact of artificial sound sources in the marine realm is an expensive proposition. Firstly, we face the relative lack of information on the sound processing and analyses mechanisms in marine organisms. Although we are capable of cataloging and recording the majority of these signals, we still do not know enough about the important role they play in the balance and development of populations. Secondly, the possible impact of sound emissions may not only concern auditory reception systems but might also interfere on other sensorial and systemic levels, proving lethal for the affected animal. If to these heavyweight reasons one adds the fact that a prolonged or punctual exposure to a determined noise can have negative short, medium and long term consequences not immediately observed, the lack of provision and research resources are the greatest difficulty confronting the scientific community, in obtaining objective data that will allow the efficient control of anthropogenic noise in the ocean.

In addition, we find ourselves with a most pressing problem which relates to the homogenization of measurements. For now there is no protocol for measuring marine acoustic pollution, nor any agreement on the enunciation of these measurements. Whilst this problem resolves itself, gathered within this body of work are aspects relative to the expression of measurements as science has created them, with the idea that in some heterogeneous or fragmented way, these indications may be useful in orientating

[1] Engås *et al.* 1993, Skalski *et al.* 1992
[2] Richardson *et al.* 1995b, Gordon and Moscrop 1996
[3] Bohne *et al.* 1985, Gordon *et al.* 1998b, McCauley *et al.* 2000 ; Guerra *et al.* 2004.

preventative and precise management actions in the advancement of acoustic pollution control.

In this work Cetaceans have been designated as bio-indicators. Marine mammals, notably cetaceans, depend on acoustic exchange for a great number of activities and vital behaviors such as communication, geographical orientation, habitat relationships, feeding and a wide range endeavors within the broader social group (cohesive action, warnings and maternal rapports). On account of their fundamental role in the balance of the marine food chain, cetaceans will serve in this project as bio-indicators of the interaction with noise of anthropogenic origin.

Finally, with regard to the content of this Document, we would like to point out the following introductory aspects of interest:

- In the treatment of "Sound Sources", a distinction has been made between "Sources of noise" and "Acoustic signals". The reason for this separation lies in the following: human activities in the ocean can generate residual noise that is associated with that activity but does not contain or provide data. Shipping noise, oil and oceanographic platform construction, wind turbines or seabed drilling, for example, all fall into the category of "noise"; we are dealing with activities that "might" function without noise if they could rely on adequate available technology and practices. There are other activity groups which include military and industrial sonar, seismic and geographical surveys that are based on the usage of acoustic signals, i.e. sound sources introduced into the medium to extract information, and whose substitution would be very difficult, at the moment, to bring about. Lastly, we will consider as acoustic signals the biological sources produced by marine organisms.

- The first six sections of this Document try to summarize and set out the "state of the art" in underwater acoustic pollution and its environmental impact on species chosen as bio-indicators; i.e. cetaceans. In section 7 tools are put forth that could be applied to the elaboration of Environmental Impact Assessments or in Management plans of Marine Protected Areas (MPA's) or the Natura Marine 2000 program. All of these will call for a careful follow-up that will not only assess the need to correct their implementation but also improve the available scientific data.

This Document has been conceived as the first piece in an open process. Its authors wish that its content be analyzed and improved not only through peer reviews to which it will be submitted, but particularly, through the process of its application by public administrations, hypotheses or data of Environmental Impact Assessment Plans, Programs and Projects that involve underwater acoustic pollution or in the elaboration of Management Plans for Marine Protected Areas. It is therefore hoped that in the near future newer versions of the same will be made to permit the shaping of a Protocol of conduct in the strictest sense. For this to come about will depend, in the greater part, on the existing research needs being covered that are annexed, as an epilogue, at the culmination of this work.

1. The Problem of Marine acoustic pollution

In the past hundred years the scale of anthropogenic noise introduced into the marine environment has grown to unprecedented levels. There is no doubt that in recent history, the larger oceangoing organisms, particularly cetaceans, have not yet developed the ability to adapt their auditory capacities to these powerful sound sources, whose impact on the functioning of their vital systems remains unknown.

The sources of marine noise pollution produced by human activity, includes, amongst others, maritime transport, oil and gas exploration and exploitation, industrial and military sonar, experimental acoustic sources, undersea explosions; military and civilian, engineering activities, supersonic aircraft noise and the construction and operation of sea-based wind farms.

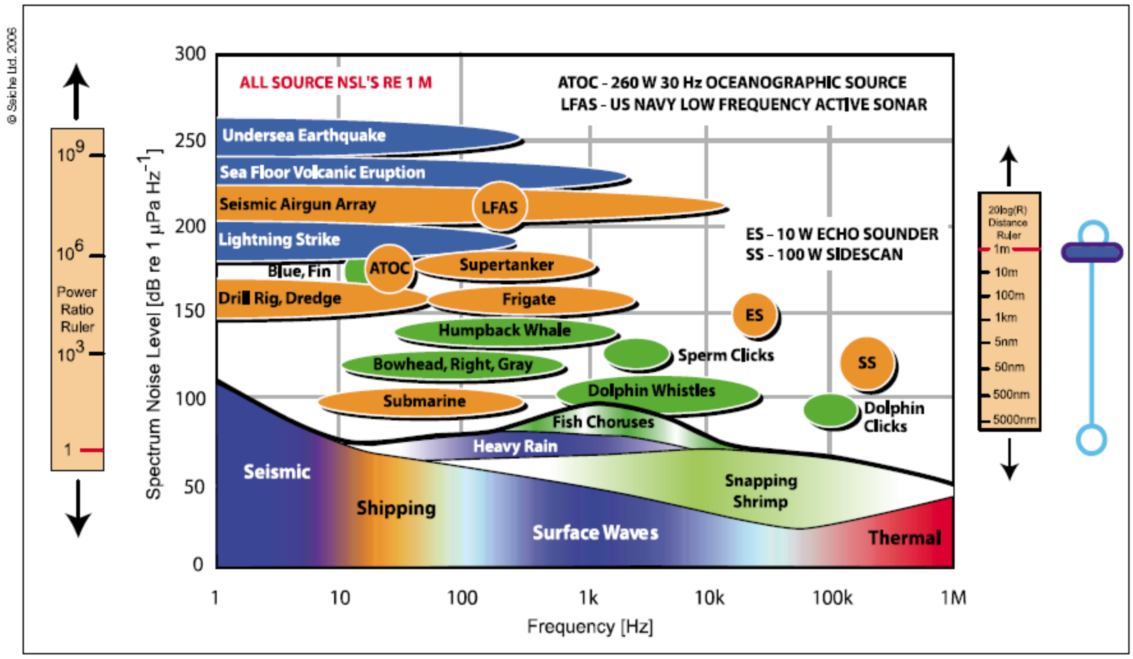


Figure 1. - Sound levels and frequencies from anthropogenic and natural sound sources in the marine environment[4].

These sound sources invade the acoustic and physical space of marine organisms (Figure 1) and there is no actual field of reference in which to foresee the negative consequences of these interactions on the ocean's natural equilibrium, and their short, medium and long term effects on marine biodiversity.

Sound sources as a result of human activity/action have shown physical, physiological and behavioral effects on marine fauna – mammals, reptiles, fish and invertebrates -, impacts whose distinct seriousness will depend on the proximity of an animal to the sound source. These impacts, as we have already mentioned in the introduction, include a reduction in the abundance of fish species of up to 50% in prospected zones[5],

[4] Boyd *et al.* 2008
[5] Engås *et al.* 1993, Skalski *et al.* 1992

changes in behavior and in the migratory routes of cetaceans[6] and damages of distinct orders, including physical, in marine invertebrates and vertebrates[7].

Even though land based environmental noise has been regulated since some time, only recently has marine acoustic pollution been introduced in legal international frameworks[8], becoming national regulations in countries such as the United Kingdom.

The Council of the European Cetacean Society, a society of some 500 European scientists dedicated to cetacean biology research, considers that[9]:

- There is an urgent need for research into the effects of man-made acoustic pollution in the sea, research that must be conducted under the highest standards of scientific credibility, avoiding all conflicts of interest.
- Non-intrusive mitigation measures must be developed and implemented as soon a possible.
- There will have to be a limitation put on the use of powerful underwater sound sources until the short, medium and log term effects on marine mammals are known and the use of such sources is avoided in areas where concentrations of these animals are found.
- Legislative instruments must be developed with regard to marine acoustic pollution that will permit compliance of European and national policies on the protection of marine biodiversity[10].

Still even more recently, the Convention on Migratory Species (CMS), recognizing that…

> *anthropogenic ocean noise constitutes a form of pollution which may degrade the marine environment and also have adverse effects on ocean fauna, even resulting in individual fatalities and reaffirming that the difficulty in determining the negative acoustic impact on cetaceans requires the drawing up of precautionary principles in cases where impact is possible,*

…has just published among other resolutions[11], one that urges bodies whom exercise jurisdiction over any species of marine organisms listed in the appendices of the CMS, to…

> *…develop methods of control on the impact of acoustic emissions arising from human activities in susceptible habitats that serve as gathering points or places of passage of endangered species, and to carry out environmental impact studies on the introduction of systems that may produce noise and their derived risks to marine mammal species.*

---

[6] Richardson *et al.* 1995b, Gordon and Moscrop 1996
[7] Bohne *et al.* 1985, Gordon *et al.* 1998, McCauley *et al.* 2000, Guerra *et al* 2004
[8] These regulations include articles 192, 194 (2.3), 206 and 235 of UNCLOS 1982 and UNCED 1992.
[9] Conclusions from the 17th International Conference held in Las Palmas, Canary Islands in March 2003, under the main theme of Marine Mammals and Sound.
[10] André and Nachtigall 2007
[11] Ninth meeting of the parties, Rome 2008

2. Basic Acoustic Concepts

It is important to take into account that the terms "sound", "noise" and "signal" are different and furthermore, could mean different things in different languages. The appellations "noise" and "sound" are not synonymous[12]. Sound is an allusive term to any acoustic energy. Noise, for its part, is a type of unwanted sound to whoever hears it. The opposite of noise is signal; i.e. a sound that contains some useful or desirable information. Thus, a particular sound can be noise for one and a signal for others[13] .

Sound is a physical phenomenon that resides in the mechanical oscillation of the particles in an elastic medium, produced by a vibrating element that is capable of provoking an auditory sensation, in function of the receptor's sensitivity. Sound travels at a different velocity depending on the medium in which it propagates. In the case of air, its speed is around 350 meters per second while in water (a fluid of far greater density where the particles are grouped closer together) it travels at roughly 1450 meters per second. This demonstrates a significant change in the behavior of sound waves in both scenarios, water being the medium where sound is transmitted with greater ease and therefore, over greater distances.

The oscillation of water particles (in this case the sea), happens at a standstill, meaning that the particles move themselves in relation to a position of equilibrium, transmitting this movement to their neighboring particles. This oscillation can be slow or fast producing what we differentiate between low pitch sounds (slow oscillation) or high pitch sounds (fast oscillation). The concept of frequency is used to put values on these oscillations which establish the oscillations per second that are produced in the particles from the medium with respect to their position of equilibrium. The magnitude for measuring said oscillations is Hertz (oscillations per second).

Sound propagates in the form of pressure waves. A wave is a physical magnitude that propagates in space and time. It is mathematically expressed as a "function" of space and time, analogous to magnitudes as disparate as the height of a wave of water, the electrical impulses that regulate heartbeat, or indeed the probability of finding a particle in quantum mechanics. Pressure waves corresponding to sound waves are thus, variations of pressure which are transmitted through space and time resulting from movement of the particles moving themselves from their position of equilibrium, which in turn transmit this movement to neighboring particles and so on.

To understand the magnitude of Sound Pressure we must start from the concept of "atmospheric pressure", i.e. the pressure exerted by the ambient air in the absence of sound. This is measured in units of SI (*Systéme International d'unités*) called Pascal (1 Pascal is equal to the force of 1 Newton applied uniformly over the surface of 1 square meter and is abbreviated 1 Pa). The Sound Pressure Level, which is expressed in the abbreviation "Lp", is the expression of the magnitude of sound pressure in dB referred to a concrete magnitude (more on this later). Sound Pressure values are in general far lower than those in atmospheric pressure. For example, the most intense sounds one can bear without experiencing severe auditory pain are around 20Pa, while those hardly audible at all are nearer 20µPa (µ is the symbol for micro-Pascal, i.e. a millionth part of one Pascal).

The Decibel (dB) is the unit measure of Sound Pressure Level. It is not an absolute value but relative to a reference measure. Decibels are used since, in mammals, perception

[12] "Energy producer's caucus" of the "Advisory Committee on Acoustic Impacts on Marine Mammals"
[13] ACAIMM 2006

on an auditory level in pressure variations is not linear, but rather, closer to a logarithmic scale from where decibels are derived. Decibel measurements are not absolute but are calculated in comparison to a reference that is different for measurements in air and measurements in water for which both cannot be directly compared. For all of this, it is fundamental to include in all measurements the reference with respect to which levels have been calculated. Any measure is useless without specifying this reference. Typical references are 20µPa in air and 1µPa in water.

The Sound Pressure Level (SPL) holds an advantage of being an objective and fairly comfortable measurement of the radiated sound, but has the disadvantage of being far from representing with precision what is really perceived. Given the human ear's sensitivity to certain frequencies, much depends on the components of the sound frequency perceived.
The logarithmic definition of the decibel scale implies that an increase of 10 times in the scale of sound pressure expressed in Pascal corresponds to a 20dB increase in the pressure level.

Increase of sound pressure Level corresponding to an increase in pressure.

Increase of sound pressure	Increase of sound pressure level
1 x	+ 0dB
2 x	+ 6 dB
10 x	+ 20 dB
100 x	+ 40 dB
1000 x	+ 60 dB
10000 x	+ 80 dB

While sound "levels" are universally measured with decibels, their calculation can be based on different methods of measurement or values of reference. There are different methods of measurement and units with the aim of quantifying the amplitude and the energy of the sound pressure's signal[14]:

- The difference of pressure between the maximum positive pressure and the minimum negative pressure in a wave is the "peak-to-peak" (p-p). The amplitude "peak-peak" can be measured directly from the maximums to the minimums expressed in dB_{p-p}.
- The positive pressure peak of a wave is known as "zero-to-peak" (0-p), roughly equates to the half of the "peak-to-peak" pressure. In any case, the difference between the two levels of corresponding pressures is approximately 6dB. The "zero-peak amplitude can be measured directly from the zero pressure line to the wave maximum, expressed in dB_{0-p}.
- The concept of "root-mean-square-(RMS)" or effective value refers to a statistic measurement on a variable magnitude. It is based on the mean of the squared signal, in a given time for when a short pulse is measured; the RMS sound values

[14] Johnston *et al.* 1988; Richardson *et al.* 1995b ; McCauley *et al.* 2000 ; LGL 2003, 2004

can change significantly depending on the time duration of the analysis. RMS amplitude is expressed in dB_{RMS} and should always be accompanied with the time frame decided to be used for this concrete measure, and the reference with which the measurement has been carried out. The values of a continuous signal measured in RMS or in peak value usually differ in 10-12 dB.

- The Spectral Density of energy or power, commonly called spectrum, provides information on the distribution of the energy contained in the signal in the different frequencies that they are composed of.
- Equivalent Sound Level (Leq): Leq is defined as the constant level which, if maintained for the same duration, will generate the same acoustic energy to the receptor as the studied signal. It is a comparative measure between different sounds of the same duration.
- Sound Exposure Level (SEL). To compare sounds of various types or durations, SEL is defined as the level of pressure of a constant wave which, if it is maintained for one second, will generate the same acoustic energy to the receptor as the studied sound.
- Loss of Transmission: Sound pressure diminishes over distance from the source due to the phenomena of absorption and dispersion of waves. In an "ideal" scenario, without reflections or obstacles, the sound pressure diminishes by a factor of 1 over the considered distance (1/r, where r = radius from the source). In realistic scenarios, due to differing layers of water, the propagation of sound and its attenuation may be very different. For example, the reduction of sound pressure could diminish if the sound is channeled due to seabed topography and/or water column stratification. The effects of topography and the characteristics of the water column to which we refer can induce very complex situations[15], which in turn should be taken into account at the time of establishing correct measurements of sound impacts.
- Source Levels (SL), describe the level of sound pressure referred to the nominal distance of 1 (one) meter from the source[16].

Before moving on to the remainder of this document, it is important to bear in mind that from a scientific viewpoint, there is no consensus in the modes of expressing "sound levels" and this is a problem. All values should be converted to the same values (points) of reference, averaged in the same time intervals and this should be expressed in all measures. This is not done, for the moment at least, in terms of marine acoustics. To be able to carry out conversions from one to another expression, additional information, available or not as is often the case, is nevertheless required. Even though the utmost effort had been made in being as consistent as possible in terms of expressing sound levels, it is imperative to take into account that throughout this Document we can find a great many variations of measures, values, references and units to communicate them, (particularly when magnitudes have been 'gleaned' from the world of scientific literature). The reader must exercise caution at the time of establishing comparisons between different values and magnitudes, on account of the above.

[15] Bain and Williams 2006; DeRuiter *et al.* 2006; Madsen *et al.* 2006b
[16] Urick 1983; Richardson *etal.* 1995b

3. Sound sources, the importance of the difference between noise sources and acoustic signals.

3.1 Sources of Noise

Maritime Traffic

Maritime traffic is the principal source of low frequency background noise (5-500 Hz)[17] in the world's oceans.

Ship noise is fundamentally generated from three elements: the engine, propeller and associated machinery and the flow of water over the hull. Ships can also provoke cavitation[18], i.e. the creation of cavities (hollow areas of water) or pressure zones inferior to the ambient underwater pressure, caused by the rapid movement of an object (vessel, propellers) through its medium. The subsequent "filling up" of these empty spaces produces sound. Cavitation accounts for up to 80-85% of all noise made by maritime shipping traffic[19].

Vessel traffic is not evenly distributed in the oceans, but rather over established routes and coastal areas; these are designed in order to minimize distances.

Seaports are also a source of noise; even though only a few dozen ports control the majority of the world's shipping, hundreds of additional smaller ports and harbors also make a significant impact, depending on their characteristics and location. In the same way small boats don't contribute a great deal in global marine noise, they do act as sources of local and coastal noise pollution.

Oil and gas exploration and exploitation

Oil and gas production activities produce low frequency sub-aquatic noise[20] in different phases of operation: drilling (perforations), installation and removal of open sea structures and associated transport. Of all of these, it is the drilling process phase[21] that produces the highest sound pressure levels.

The noise from drill ships is produced by perforating equipment, propellers and propulsion stabilizers deployed to maintain the ship's position. The most commonly used drilling equipment is called a "jack-up rig" (self-raising towers or platforms). In addition, drilling generates auxiliary noise through supply ships and helicopter support activities.

The activities associated with hydrocarbon industries have historically made up the greatest source of acoustic activity in shallow waters (<200m). In recent years these enterprises have moved into deeper waters (up to 3000m). Deep water production and drilling has the potential to create higher levels of noise than in shallow water due to the types of vessels and machinery engaged in this activity, including floating production

---

[17] Below 600 Hz (OSB 2003)
[18] Ross 1987, 1993.
[19] Vessel noise oscillates between minimum levels from 115 dB re 1 μPa at 1 m (meter) for small boats (Au and Green 2000) to 180-190 dB re 1μPa at 1 m for Supertankers (Hildebrand 2005). There is considerable information available in maritime traffic literature and source levels (Gray and Greely 1980; Institute of Shipping Economics and Logistics 1989; Jennete 1993; Lloyds Register of Ships 1989; Molinelli *et al.* 1990; Revello and Klingbeil 1990; Ross 197; Scrimger *et al.* 1990; Scrimger and Heitmeyer 1991, Richardson *et al.* 1995b; Erbe and Farmer 2000).
[20] <50 Hz
[21] Possibly reaching 185-191 dB re 1μPa at 1m (Richardson *et al.* 1995b; WDCS 2003).

platforms. Furthermore, noise generated in deeper waters can easily be caught up in a deep channel through which sound is propagated over great distances.

Dredging

Marine dredging is usually carried out in coastal areas and is normally concerned with deepening canals and channels, port and land reclamation or in the extraction of natural marine resources. In this field of operation we will encounter two sources of noise; dredging boats and the machinery deployed therein[22].

Marine wind farms

There are three phases involved in the life cycle of a marine wind farm; construction, exploitation and dismantling. In each of these phases underwater noise can arise from a wide variety of sources.

During construction, noise comes from re-installation activities, such as topographical studies, increased marine traffic, pile drives, dredging, the opening of ditches and drilling. The operational and exploitation phases produce further sources of noise, including aerodynamic alteration from the windmill blades and gearboxes. The dismantling of a wind turbine can involve hydraulic water-jet cutting equipment and explosives[23].

Explosions

Nuclear explosions having been banned, underwater explosions today are mainly used in the fields of marine construction, the elimination of underwater structures (foremost in the oil industry) and in military uses and are of a chemical nature[24].

---

[22] Noise levels involved in dredging have been registered from 160-180 dB re 1 μPa at 1m in 1/3 octave with a peak intensity between 50 and 500 Hz (Graneé and Moore 1995).
[23] The omni-directional source levels are often in the approximate range of 185-195 dB rms re 1 μPa at 1m, peak levels can reach up to 260 dB re 1 μPa at 1m in absence of noise reduction measures, the main part of the energy in low frequency ranges between 40-1000 (or 2000) Hz (CDoT 2001; Nedwell *et al.* 2003; Nedwell and Howell 2004; Rodkin and Reyff 2004).
[24] Some armed forces carry out tests to confirm the resistance of their ships to sub-aquatic explosions, and can use charges more than 1000 kg. (Hildebrand 2004), generating a low frequency sound, with pressure levels of up to 299 dB re 1 μPa at 1m.

3.2 Acoustic signals

3.2.1 Anthropogenic acoustic signals

Seismic studies

The realization of seismic studies in the marine environment has, in general, seabed composition analysis as its primary objective. This is also the foremost technique used in the search for oil and natural gas reserves. Explosives are also used in scientific research to gather information on the earth's origin and tectonic plate movement in the earth's crust.

The pressure waves necessary in the execution of a seismic survey are achieved through "pulses" of compressed air performed by airguns, which are in turn fed by powerful compressors. The airguns discharge a predetermined volume of air at high pressure, creating a pressure sound wave and the expansion/contraction of the released air bubble. The airguns can be mounted on a vessel or arranged in a device (from tens to hundreds of meters in length), towed along by a vessel (array). The towed device tends to include a number of sound sensors (hydrophones), which can detect the pressure waves reflected back up from the seabed, forming, in an adequate receptor, an image of the surface below. Furthermore, this image can contain information on the rock layers and sediments found below the seabed.

An underwater seismic reflection survey includes a series of passes in parallel across an area by a ship that tows the compressed airgun arrays and hydrophones.

Currently[25] there are around ninety boats dedicated to these types of studies around the world for industrial exploitation purposes[26].

A study of ambient noise in the North Atlantic has indicated that airgun activity developing along the continental shelf propagates significant low frequency[27] sound into the deep, having been detected with hydrophones in localities of over 3000km away.

Sonar

Sonar systems intentionally create acoustic energy to explore the ocean. They search for information on objects within the water column, on the seabed and in its sediment. Sonar emits high intensity acoustic energy and can either receive this reflected energy or disperse it. There is a wide range of sonar systems used in civilian and military applications. Sonar can be qualified as low frequency (<1 kHz), mid frequency (1-20 kHz) and high frequency (>20 kHz).

---

[25] IWC 2006a

[26] Signals emitted by compressed airgun arrays produce a maximum source level of 259 dB re 1 µPa at 1m of exit pressure (Greene and Moore 1995). These signals are low frequency (under 200-250 Hz) with the highest energy between 10-120 Hz and an energy peak at 50 Hz (Dragoset 1990; Richardson *et al.* 1995b; Gausland 2003; Tolstoy *et al.* 2004; Parkes and Hatton 1986; Caldwell and Dragoset 2000). Above 250 Hz the acoustic energy emitted diminishes with increasing frequency, although it can reach up to a 100 kHz Decruiter *et al.* 2006; Goold and Coates 2006; Bain and Williams 2006; Sodal 1999; Masden *et al.* 2006b).

[27] Nieukirk *et al.* 2004

Military sonar is used in the detection, finding and classification of targets. In general, it covers a very wide range of frequencies with higher levels used than in civilian sonar, operating as much in training exercises as in combat.

Active low frequency sonar (LFA) is used for surveillance on a broad scale; it is designed to sweep for submarines over distances into the hundreds of kilometers. Support ships specialized in deploying LFA use 'arrays', source elements which are suspended vertically below the ship[28].

Mid frequency Anti-submarine tactical sonar[29] is designed to detect submarines over many kilometers. The majority of Navy's operate mid frequency sonar for deep water sounding, communication between platforms, etc.

For its part, high frequency sonar tends to be incorporated in weaponry such as torpedoes and mines or in countermeasure systems (defense) against mines and anti-torpedo devices artifacts. These are designed to function over areas ranging from hundreds of meters to various kilometers. Such sonar is very precise and uses pulsed signals. Other types of high frequency military sonar includes side-scanning for seabed mapping and operate at frequencies near 100 kHz.

Naval ships and submarines use acoustics to communicate. At present, civil underwater communication systems are being developed, such as the Dutch ACME[30] system to help ships avoid running aground in coastal or port waters.

Commercial Sonar is used for fish finding, probing great depths and in profiling water columns. These deep water probes have been devised to focus the sound in one (pulse-beam) downward directed sound pulse. Deep-water sounders and other hardware that profiles the water column in medium depths have been designed for locating the seabed and to probe the area above it, respectively. They operate mainly in coastal and shallow waters. Sounds used in the detection of fish are used in both deep and shallow waters[31].

Sonar research systems are "civilian" sonar used in diverse research tasks such as depth measurement, finding objects, charting the seabed, sediment layer detection and locating fish shoals. Research sonar apparatuses can be installed in the ship's hull or towed behind it. Mid frequency[32] sonar is generally used depending on water depth and the object being sought. The length of the signal is relatively short, work cycles small and the density of the energy flow is low in comparison with military sonar.

[28] These Systems have been designed to project pulses of energy in a horizontal direction, the effective source levels of an LFA array can be from 235-240 dB re 1μPa at 1m in the horizontal axis (Zimmer 2003).

[29] For example, the sonar AN/SQS-53C and AN/SQS 56. The AN/SQS-53C is the most advanced vessel in the US Navy, generating modulated frequency pulses between 2 and 8 kHz at source levels of 235 dB rms re 1 μPa at 1m or more (Evans and England 2001). It is equipped with an array of transducers of 536 elements. The sonar AN/SQS 56 has a source level of 223 dB rms re 1μPa at 1m.

[30] At source levels of 235 dB rms re 1 μPa at 1m or more (Evans and England 2001). It is equipped with an array of transducers of 536 elements. The sonar AN/SQS 56 has a source level of 223 dB rms re 1μPa at 1m.

[31] Using frequencies around 12 kHz and source levels 125-133 dB (L_{eq} re 1 μPa (Kastelein *et al.* 2005, 2006)

[32] 12 kHz

Acoustic harassment and dissuasive devices

Acoustic dissuasive devices (ADD's) use sound to drive away marine mammals in commercial fishing areas. The aim of these is to keep animals away from fish by introducing local acoustic alert signals that result in discomfort for the animals. It is argued that these noise emissions called "pingers"[33] can be useful in reducing accidental capture of mammals by alerting them to the presence of driftnets and other fish catching material, sending them far from such materials that might cause them harm[34].

Acoustic harassment devices (AHD's) are used to reduce the hunting of fish stocks by mammals in the open sea and in fish farms. AHD's are high energy devices reaching source levels of 185-195 dB re 1 µPa ref 1m. These pingers have frequencies in the 5-160 kHz band whose pulses can last from 2-2000 ms.

Such devices have been only partially successful in reducing accidental capture of some mammal species[35], but require further long term research to confirm that their sound does no more than alert mammals to the presence of prey. Marine mammals have learned to perceive such AHD signals as a "dining bell" that teaches them to hunt with greater ease[36].

Other forms of underwater signals have been experimented with on marine mammals with the same objective of alerting cetaceans and impede their approach to fishing zones or trawlers[37]. Sounds produced by submarine communications equipment have also been tested in this area[38]. In this final case, acoustic devices are deployed as an axis in a communications network for the harvesting of data for maritime security. These devices produce diverse types of sound, including chirps and frequency sweeps.

Scientific Experiments

The use of sound is often employed in the research of underwater acoustic propagation and in oceanographic acoustics.

A broad range of bandwidth, source level and work cycle signals are transmitted during these projects. The spatial extension of the majority of these experiments is in the dozens of kilometers, but not to exclude the Acoustic Thermometry of Ocean Climate (ATOC) program which is on a far greater scale. Acoustic Thermometry studies the changes in oceanic temperature by measuring the speed of sound in the ocean[39], using low frequency sound, which can reach a great distance[40]. It emits at 4 hourly intervals with a 5-minute "ramp-up" period and a signal duration at maximum energy of 20 minutes[41].

Another large scale sonar research project carried out by European researchers[42] uses drifting float sources[43] called RAFOS (Ranging and Fixing of Sound), which drift at a

---

[33] Community Regulation no. 812/2004 of the European Union establishes some guidelines in the use of pingers
[34] Pingers use low energy source levels (130-150 dB re 1 µPa at 1m) in the wide band.
[35] Kraus *et al.* 1997, Culik *et al.* 2001, Bordino *et al.* 2002
[36] Geiger and Jeffries 1986; Mate and Harvey 1987; Jefferson and Curry 1994
[37] Nowacek *et al.* 2004
[38] Kastelein *et al.* 2005
[39] The ATOC source has a level of 195 dB re 1 µPa at 1m and a transmitted signal centered at 75 Hz with a wide band of 37.5 Hz (Au et al. 1997)
[40] Munk and Wunsch, 1979
[41] The generators are situated 15km from the island of Kauai, Hawaii and approx. 89 km southwest of San Francisco, California.
[42] NODC 1996; Lankhorst *et al.* 2004; Gascard and Rouault 2004; IfM-Geomar 2005; BODC 2006.

predetermined depth and periodically emit a high intensity signal[44] (tone) or a continuous signal of 80 s or longer. These sounds are picked up by distant receivers (min. 600km distance)[45] and the arrival time is used to calculate the position of the floats, and so derive information on the direction and or temperature of deep water currents[46].

Sound as an instrument of scientific ocean research has a great many uses and here we have mentioned but a few. As in the oil and gas industry, research vessels use sound to find and release submerged equipment by producing an acoustic transmission. The Acoustic Doppler Current Profiler (ACDP), installed in ship's hulls, measures the speed and direction of ocean currents, emitting a sequence of high frequency pulses using what is called the "Doppler effect" to analyze its transmission.
An Acoustic Current Meter (ACM) emits and receives sound pulses to study waves and currents.

All of these devices either use high frequencies with short sound propagation or have low level sources.

---

[43] Rossby *et al.* 1986
[44] 195 dB re 1 μPa at 1m, that is the frequency sweep of 200 to 300 Hz
[45] Rossby *et al.* 1986
[46] NODC 1996; Lankhorst *et al.* 2004; WHOI 2004; Gascard and Rosault 2004; IfM-Geomar 2005; BODC 2006

Table 1. Comparison of sub-aquatic sound sources of anthropogenic origin[47].

Source	SPL (dB re 1 µPa at 1m)	Ping Energy (dB re 1 µPa at 1m)	Ping Duration	Duty Cycle (%)	Peak Frequency (Hz)	Bandwidth (Hz)	Directionality
Ship Tests (10,000 lb TNT)	299	302	2 s	Inter-mittent	Low	Wide	Omni-directional
Military sonar (SURTASS /LFA)	235	243	6-1000 s	10	250	30	Horizontal
Airgun array (2000 psi, 8000 in.³	256	241	30 ms	0.3	50	150	Vertical
Mid frequency military sonar (SQS-53C)	235	232	0.5 s-2 s	6	2600-3300	Narrow	Horizontal
Super-Tanker (337m, 18 Knots)	185	-[AQ4]	Continuous	100	23	5-100	Omni-Directional
ATOC Sonar research	195	226	1200 s	8	75	37.5	Omni-Directional
AHD	185	185	0.5-2 s	50	10000	600	Omni-Directional
Echo Sounder (in hull)	235	218	20 ms	0.4	12000	Narrow	Vertical
RAFOS	195	216	120 s	Small	250	100	Omni-Directional
Trawler (12m length 7 knots)	151	-[AQ5]	Continuous	100	300	250-1000	Omni-Directional
ADD	132	127	300 ms	8	10000	2000	Omni-directional

[47] Table extracted from Hildebrand 2005.

3.2.2. Biological acoustic signals

Cetaceans

Cetaceans produce a wide range of acoustic signals to communicate with members of the same social group and echolocation (biological sonar) for targets. These signals vary within the two principal cetaceous groups, Odontocetes (toothed whales) and mysticetes (baleen whales).

Odontocetes make up around 80 very diverse species worldwide and are present in all the oceans and some rivers.[48].

Cetacean communication signals tend to include mid frequencies (1-20 KHz). The majority of these species have also developed a system of echolocation, which operates at high and very high (20-150 kHz) frequencies and is used in the detection and localizing of obstacles, prey and mates. The acoustic signals of ***odontocetes*** can be classified into three categories: tonal whistles, very brief short pulses used in echolocation and other less well defined pulsed signals such as weeps, growls and barks.

On the other hand, ***mysticetes*** or what are popularly known as "whales" make up a total of eleven species and are distributed in all the oceans [49]. It is believed that ***mysticetes*** are particularly sensitive to low and mid frequencies (12 Hz-8 kHz). It has yet to be proven if these signals can be used in echolocation. The acoustic repertoire of cetaceans is most diverse and can include inter-species and intra-species variations.

Invertebrates and fish

Perception of sounds

For small vertebrates and invertebrates, the perception of sounds and pressure respond to similar mechanisms due to the fact that sound propagation through water requires a variation in pressure, as in a slow or fast displacement of its particles. In teleostean (bony) fish the swimming bladder is clearly a potential pressure receiver, for it is flexible, gasified and reacts to pressure fluctuations by changing its volume. Furthermore, the swimming bladder of many fish species has been discovered to have a direct or indirect relation to the perilymph of the inner ear.

Fish lacking swim or gas bladders perceive nearby acoustic pressures , since these are transmitted by bone conduction, vibration of the otolith or by lateral linear reaction, and being insensitive to distant sounds that surpass 400 Hz. Fish equipped with swim or gas bladders without inner-ear connections posses excellent reflexes conditioned with frequencies inferior to 520 Hz. Some species have a direct connection which allows them to pick up varying frequency levels from 13 to 4000 Hz. If a fish remains at depths without varying, for compensation, the volume of the swim bladder, not only will it jeopardize its flotation system but also its ability to perceive sounds.
With regard to pressure, fish possessing a swim bladder can perceive equivalent variations of less than 0.5% of the hydrostatic environment, whilst those without can only perceive changes that vary between 2.5-10%. The distinction between frequencies in the case of 'bony' fish is similar to the process that takes place in the cochlea (the coiled part of the inner ear) of vertebrates, although the precise mechanism in the case of bony fish is unknown.

[48] See annex V guide to the cetaceans present in Spanish waters.
[49] As above footnote.

Sound emissions

Despite that fish do not possess a larynx, some fish produce sounds by rubbing serrated surface components on their skeletal structure. Many species produce very sharp sounds by grinding their teeth but it is the vibrations of the swim bladder wall, using specialized muscles, which emits the greatest range of sounds or repertoire of calls.

Sound produced by marine invertebrates has not been investigated to the same extent as that of fish or marine mammals. Nevertheless, the sounds produced by some 40 species of marine crustaceans (*Palinuridae*) and some shrimps (*Alpheus*) have been documented. Other mollusks such as *percebes* (goose barnacle) do emit sounds but the mechanisms involved have not been studied in great detail.

The majority of marine invertebrates known to produce sound do so by rubbing parts of their bodies. Shrimps, on the other hand, are an exception; by closing a specialized claw they produce a clicking sound creating 'cavitation' and making a bubble that generates acoustic pressure of 80 kPa at a distance of 4 cm from the claw when the bubble collapses. This pressure is sufficiently strong enough to be able to kill small fish[50].

Marine crayfish do not posses claws but produce harsh sounds through antennae friction, which is believed to be a method of repelling predators.

Mussels (*Mytilus edilus*) make sound with the *byssus*, the 'beard' that is used for adherence to hard surfaces. In temperatures above 10ºC mussels can produce clicking noises by stretching and breaking the byssus. It is uncertain whether these sounds are produced intentionally or not.

Fiddle or violin crabs make up 97% of the genus *Uca* whose males are renowned for their asymmetric claws. The larger of the claws is used to produce sound by hitting parts of its own body or the surface of the area where it is located. A great variety of sounds produced in this manner have been described as harsh noises, drumming, whistling or rapping. Sounds particular to each species have been identified based on different frequencies and time intervals. For example, the species *Uca pugilator* (fiddler crab) produces rapping sounds between 600 and 2400 Hz while the *Uca rapax's* sounds are between 300 and 600 Hz.

Tropical sea urchins (*Diadema setosum)* produce 'sparking' sounds with the rubbing of the spines as they move. These sounds can also be made from the chaffing between the 'Aristotle's Lantern' (a specialized masticating structure) and its exoskeleton during feeding and reproduction.

[50] Versluis *et al.* 2000

4. Cetaceans as bio-indicators; Acoustic signals and cetaceans: understanding of the environment

As was explained in the introduction, the choice of cetaceans as bio-indicators of oceanic acoustic pollution is not by chance. The marine environment, as with all environments, is organized on the basis of the balance of organisms inhabiting them; each one is positioned on a specific trophic level that allows the development of higher levels. Disruption in any of these levels unbalances the chain, in both senses. Faced with a problem of conservation, the challenge of scientists is to find an organism, sufficiently representative, that's to say, whose balance and development may have an influence on the balance and development of the rest of the food chain, and use it as a bio-indicator against a contaminating source. Cetaceans, for their vital dependence and almost exclusive relationship with sound information, represent, up until now, the best bio-indicators of marine acoustic pollution.

The auditory system of cetaceans is characterized by a series of unique morphological adaptations: one of the most interesting ones is the capacity to select frequencies in order to distinguish acoustic images across auditory channels which act as frequency filters.

In a healthy organism, this frequency selectivity of the ear (and of the acoustic signals which are produced and received therein) is evolvable and directly in relation with the specific use of its habitat, and as such, characterizes each cetacean species. On the other hand, within this frequency selectivity, the sensitivity of the ear in some species allows the measurement of the physiological or pathological condition of the auditory system in a predetermined individual, and to estimate its auditory capacity to use its habitat.

Each of the 80 species of cetaceans relies on a complex acoustic repertoire[51]. This diversity of acoustic signals, intra and interspecies, complicates any analysis we make and considerably limits our capacity to adequately estimate the effects of a polluting sound source.

Each of the species that make up the order of cetaceans offers a unique acoustic repertoire in direct relation with the habitat where it has evolved over millions of years. It is understood, that in order to detect prey, a coastal species will need to extract precise short distance details of the surrounding relief, while the absence of such relief will require pelagic cetaceans (those living in the open sea) to obtain information over medium and long distances to the presence of fish shoals or plankton blooms. Notwithstanding, all toothed cetaceans share the same acoustic production mechanism which includes the projection of air across nasal air ducts and its exit by vocal lips, situated on the top of the head. Throughout immersions or dives, this air is recycled and permits them to vocalize, with the aim of echolocation or communication depending on the social context at that time.

Another peculiarity along with the absence of vocal chords, also unique in mammals, is the non-use of the external auditory channel for hearing purposes. Auditory vibrations are received across fatty tissues situated at lower jaw level that direct information to the middle and inner ear where it is processed before arriving to the brain.

---

[51] See Table No. 2

Table 2. Functional groups according to the auditory characteristics of cetaceans, the estimated bandwidth and the genus that represents each group[52]

Functional groups according to auditory characteristics	Estimated Bandwidth	Genus represented
Low frequency	7Hz to 22 kHz	*Baleana, Caperea, Eschrichtius, Megaptera, Balaenptera* (13 species/subspecies)
Mid frequency	150 Hz to 160 kHz	*Steno, Sousa, Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Lissodelphis, Grampus, Peponocephala, Feresa, Pseudorca, Orcinus, Globicephala, Orcaella, Physeter, Delphinapterus, Monodon, Ziphius, Berardius, Tasmacetus, Hyperoodon, Mesoplodon* (57 species/subspecies)
High Frequency	200 Hz to 180 kHz	*Phocoena, Neophocaena,Phocoenoides, Plaanista, Inia, Kogia, Lipotes, Pontoporia, Cephalorhynchus* (20 species/subspecies)

[52] Even though the range of frequencies embrace a considerable bandwidth that makes classification in different groups difficult, we consider here the central energy to the auditory spectrum of the species studied.

5. Atypical strandings

A mass beaching is considered to involve two or more cetaceans, (excluding the unit formed by a mother and calf) alive or dead in a correlation of space and time.

A "typical" mass stranding is one that involves cetaceans of the same species that remain stranded in the same place, more or less, at the same time.
An unusual or atypical stranding is characterized by[53]:

- affecting different species temporarily or spatially, or
- occurring in a greater spatial range at the same time, or
- occurring in unusual places, or
- happening in an area encompassing a long time period, or
- affecting species not normally prone to strandings.

Some unusual mass strandings have occurred in a concurring space/time coinciding with the use of high intensity, mid frequency naval sonar or as a consequence of non-specific military activities. The species most affected in these atypical strandings are beaked whales (in 98% of cases), namely Cuvier's beaked whale which accounts for 81% of cases, followed by Blainville's beaked whale. In the Canary Islands in 1988 two pygmy sperm whales stranded themselves and in the Bahamas in 2000 two albino fin whales were seen to do the same.

In both these last cases, as in western Greece in 1996[54], the Bahamas in 2000 and the Canary islands in 2002[55] or in the Haro Strait, Washington State in 2003, it was confirmed that the strandings took place in areas at a time when mid frequency military sonar was in operation. This coincidence occurred in two other additional cases in 2004, in the Canary Islands and off the coast of Almeria[56]. During the incidence in Greece in 1996 new low frequency military sonar was undergoing tests along with the use of habitual mid frequency sonar[57] (see section 6.2).

[53] Frantzis 1998, Frantzis and Cebrian 1999; Franztis 2004; Martín 2002; Brownell 2005; Bownell *et al.* 2005; Hohn *et al.* 2006 ; Fernandez 2006b
[54] D' Amico 1998; Frantzis 1998, 2004
[55] Martín 2002; Martín *et al.* 2004
[56] Dalton 2006; Fernandez 2006b
[57] D' Amico 1998; Zimmer 2003; Frantzis 2004

6. Effects of anthropogenic acoustic pollution on cetaceans

There is a growing consensus about the potential impact of man-made sound on marine fauna. The conscious awareness of this issue has been reinforced by a series of strandings coinciding with the exposure to man-made sound sources. Anthropogenic originated sound can affect cetaceans in different ways, and these effects can be on an individual or group level. The question of how and why man-made sound affects marine mammals is controversial and it is therefore essential to consider that the control and adjustment of marine noise is a question that could demand great financial cost, and yet it remains vital for research into this area to be continued in the future. For now, the following associations can be established:

Table 3. Types of anthropogenic sound that can affect marine mammals[58]

Source	Effects of greatest concern
Ships	Masking Habitat displacement
Airguns (compressed air)	Masking Physical trauma Auditory loss Behavioral changes Habitat displacement Behavior conditioning effects
Intense low or mid frequency sonar activity	Physical trauma Auditory loss Behavioral change Behavior conditioning effects
Pile driving	Physical effects Auditory loss Behavioral change Behavior conditioning effects
Other types of sonar (deepwater soundings, trawlers, fishing boats)	Masking Auditory loss Behavioral change Behavior conditioning effects
Dredgers	Behavioral change Habitat displacement Behavioral conditioning effects
Drilling	Auditory loss Behavioral change Behavior conditioning effects
Towed fishing materials	Behavioral change Behavior conditioning effects Habitat displacement
Explosions	Physical trauma Auditory loss Behavioral change Behavior conditioning effects
Recreational boats	Masking Behavioral change Behavior conditioning effects
Acoustic hardware	Behavior conditioning effects
Airplanes	Behavior conditioning effects

[58] Boyd *et al. 2008*

6.1 Signal masking

The process known as auditory signal masking happens when noise reduces, partially or completely, the capacity to hear sound or signals. The scope of interference depends on the spectrum and the temporal-spatial relationship between the signals and the masking noise, among other factors[59].
In addition to the acoustic effects of "overlapping" from auditory masking, if a mammal can hear a sound, this sound, at a determined level, may injure the ear causing a reduction in sensitivity. The minimum level at which a sound can be perceived is called the auditory 'threshold'. If an individual needs a significantly greater sensitivity than is normal for its species to perceive a particular frequency, an auditory deficit marked by a change in the threshold level or *threshold shift* occurs. Any noise at a sufficient level may change the auditory threshold, whilst a different sound, produced at the same level, may not provoke equivalent changes If a change in auditory threshold is accompanied by lesions in the ear, this will be deemed acoustic trauma that may be temporary or permanent, depending on the duration of the exposure (see point 2).

We can conclude that masking is the increase of the auditory threshold for a sound due to the presence of another sound[60]. It has been confirmed[61] that signal masking is particularly pronounced if the spectral frequency of the masking noise superimposes the critical band surrounding the frequency of the signal.

The majority of underwater activities produce low frequency sound. This noise can potentially mask the communication signals of all baleen whale species that use frequencies below 1 kHz and some odontocetes, such as sperm whales. The direct consequences of this masking of communication and related signals can be diverse: group dispersal, reducing a fundamental part of their interaction with the natural environment (echolocation)[62], impaired feeding ability and the separation of mothers from young with usually fatal consequences for the calf. It is believed that continuous noise is more detrimental than temporal signals[63] and that low frequency sounds possess a greater masking effect than higher frequencies[64]. There is still no data on the effect of low frequency masking, nor direct measurements with baleen whales.

The responses of different species to the presence of ambient noise have different results, some of which have been documented. For example, sperm and pilot whales have been observed to cease vocalizations during the exposition of intense noise sources[65]. The contrary has also be shown as in the case of Beluga whales[66] and dolphins[67] which increase the intensity and frequency of their vocalizations to compensate for the presence of ambient noise. Despite these strategies, it is likely that the level of efficient communication has been reduced and that this reduction has limited their ability to react to stressful or dangerous situations[68]. However, the directionality of the auditory reception could compensate for some of the negative effects of masking. The directionality index of the bottlenose dolphin has been measured up to 20 dB[69].

---

59 Southall *et al.* 2007
60 Erbe 1997
61 Fletcher 1940, in Johnson *et al.* 1989
62 André and Natchtigall, 2007
63 Richardson *et al.* 1995b
64 Erbe 1997
65 André *et al.* 1997
66 Au *et al.* 1985; Lesage *et al.* 1993
67 Au 1993
68 Lesage *et al.* 1993
69 Au and Moore 1984

The capacity of an animal to hear directionally could indeed help it avoid masking, in that it is capable of differentiating between the signal's propagated direction and noise. The 20 dB directionality index measured in dolphins would mean that they could hear a signal coming from a certain direction as if this signal was ten times higher than ambient noise.

Grey whales also modify their vocalizations to optimize transmission and signal reception in response to growing noise levels[70]. It has been suggested that grey whales have evolved in function of an environment with a determined ambient noise, and will thus[71] be especially sensitive to changes in this environment. It has also been suggested[72] that the ability to detect low intensity sounds could be of great importance for the wellbeing of cetaceans. Table 4 summarizes these and other experiments related to the masking of signal on cetaceans.

[70] Dahlheim 1993
[71] Crane and Lashkari 1996
[72] Gordon and Moscrop 1996

Table 4. Summary of relevant articles on the masking of acoustic signals of cetaceans

Species	Experiment objectives	Results and conclusions	Source
Beluga (captivity)	Analyze the noise effects of icebreakers and the elaboration of *maskograms* to illustrate masking zones around various noises.	Masking radius: - 15 km for "bubbler system" of icebreakers (SPL 194 dB re 1µPa) - 22 km from propeller noise (SPL 203 dB re 1 µPa ref 1m) Melting ice does not seem to contribute to the masking of beluga signals.	Erbe 1997; Johnson *et al.* 1989
	Analyze the effects of icebreakers in masking noise and the construction of a model to process the effect.	The noise from the bubbler system in icebreakers and the "ramming" of the ice produces a noise masking signal rate of 15-29 dB. The masking zone for beluga vocalizations extends for over 40 km.	Erbe and Farmer 1998; 2000, Erbe *et al.* 1999, 2000
	Study the vocalizations of belugas when there is an increase in ambient noise.	Belugas change their vocalizations when there is an increase in ambient noise. With low frequency noises an animal increases the level and frequency of its vocalizations in a possible attempt to avoid masking.	Au *et al.* 1985
Beluga	Study the vocalizations of belugas as a response to boat noise.	The belugas increased the frequency of their vocalizations and change to higher in response to boat noise.	Lesage *et al.* 1999
Sperm whale	Study the behavioral responses in sperm whales after the emission of different acoustic sources with the objective of diverting them from shipping lanes and avoiding collision.	The sperm whales that were studied did not react to the majority of the emitted signals despite the very high level of the first exposure. They did momentarily cease making their 'clicking' echolocation signals after having been exposed to a series of artificial codas.	André *et al.* 1997
Long fin pilot whale	Study pilot whales vocalizations as a response to the "Head Island Feasibility Test/HIFT" 1991.	Pilot whales ceased all vocalizations when exposed to HIFT.	Bowles *et al.* 1994
Dolphins	Study the effect of masking noises in dolphins while using echolocation.	The capacity of distinguishing and detecting targets can be seen to be severely reduced by the introduction of masking noise.	
	Study the effects of ambient and anthropogenic noise in dolphins.	The capacity to distinguish and detect objects diminished severely upon the introduction of making noise. On many occasions dolphins compensated for the presence of masking noise by emitting more "clicks" by sweep.	Au 1993
Bottlenose dolphins	Demonstrate that natural sounds (shrimp) can degrade the detection range of dolphin prey by means of echolocation.	In an ambient noise of 55 dB re 1 $\mu Pa^2/Hz$ there is a reduction of 46% in the detection range (going from detecting a 28 cm cod from a distance of 173 m to detecting it from 93m away).	Au *et al* 2007
	Model the noise masking zone from pile driving and wind farms.	The masking zone for strong vocalizations is from 10-15 km, and up to 40 km for those weaker vocalizations.	David 2006
Harbor	Study the 3 types of	It's unlikely that this noise reaches	Tougaard *et al*

porpoise	wind power generators in Denmark and Sweden (Middelgrunden, Vindeby, and Bockstigen-Valar). The turbine noise was only measured above the ambient noise in frequencies below 500 Hz.	dangerous levels at any distance from the turbines, and this noise is not considered capable of masking porpoise communication.	2009
	50% of the detection of a porpoise's auditory threshold for a narrow band modulated frequency signal of 4.0 kHz where studied using behavioral methods, in the bottom noise level of a swimming pool and with two levels of masking noise.	The masking consisted in a noise in a 1/6 octave band with a frequency of 4.25 kHz. Its amplitude was reduced to 24 dB/octave on both sides of the respective spectrum plane. The auditory system of the animal responded in a linear form with the increase of the masking noise. Given that the narrow band noise was centered outside of the test frequency, the critical ratio of the porpoise for tonal signals of 4 kHz in target noise, can only be estimated to be between 18 and 21 dB re 1µPa.	Kastelein and Wensveen 2008
Narwhal	Study the reaction of the narwhal to icebreaker noise.	The narwhal exhibited a totally silent behavior in contrast to the known state of alarm behavior of belugas when they were exposed to icebreaker noise.	JCNB/NAMMCO 2005
Killer whales	Study the vocalizations of killer whales as a response to its interaction with whale watching boats.	It was suggested that the Killer whales change frequency and prolong their vocalizations in response to the presence of whale watching boats.	Foote *et al* 2004
Humpback whale	Study humpback vocalizations as a response to low frequency active sonar transmissions.	Some humpbacks were observed to cease vocalizations, while the songs of others were 29% longer at a maximum received level of 150 dB. Miller *et al*. 2000 signaled that perhaps this was to compensate for interference. Fristrup *et al* (2003) showed that humpback's songs were up to 10% longer, two hours after the exposure to sonar.	Miller *et al*. 2000; Fristrup *et al*. 2003

6.2. Acoustic trauma (TTS/PTS)

The influencing factors on the magnitude of auditory threshold change or threshold shift (TS) include amplitude, duration, and frequency content, temporal pattern and energy distribution of the exposure to noise. The changes in threshold are called acoustic traumas: which can be reversible or permanent.

TS magnitude normally decreases in time after the cessation of noise exposure. If the received emission causes a temporary loss, i.e. a temporary threshold shift (TTS), it will eventually return to normality sometime after exposure. The following physiological mechanisms are believed to play an important role in inducing TTS, also called auditory fatigue: effects on sensory hair cells in the inner ear which reduce their sensitivity, modification of the chemical environment within the sensory cells, residual muscular activity in the middle ear, some inner ear membrane displacement, increased blood flow and post-stimulatory reduction in both efferent and sensory neural-output[73].

If a received emission produces a permanent hearing loss (permanent change of auditory threshold) this is considered to be a permanent threshold shift (PTS).
A PTS is an auditory injury. Some of the apparent causes of PTS in mammals are severe extensions of the underlying effects of TTS (as in irreparable damage to hair cells). Other causes imply different mechanisms such as the exceeding of the elastic limits of some inner and middle ear tissues and membranes, and changes resulting in the chemical composition of inner ear fluids[74]. The relationship between TTS and PTS depends on a great number of variable complexities that concern the subject of study and the exposure to which it has been subjected. A PTS may arise after a long period of exposure[75] or immediately following an exposure to highly elevated sound levels, such as those caused by explosions[76]. Recent anatomical and behavioral studies suggest that cetaceans may be far more resistant to TTS than land mammals from having evolved in a relatively noisy environment[77]. It is important to bear in mind that cetaceans also suffer from hearing loss as a consequence of old age[78]. Finally, a severe change in threshold shift has been linked with hydrocephalic sickness in one example of a stranded striped dolphin, indicating that lesions in the central nervous system could be at the origin of a PTS[79].

Auditory loss, whether temporary or permanent, can affect these animals in many ways. A temporal loss can impede the animal in detecting its prey or predators or can cause it to venture into dangerous areas it would normally avoid. A permanent loss will have grave consequences in any cetacean within the framework of communication in order to feed, mate, nurse, and socialize. These damages have been deemed to be the result of receiving intense sound pressure[80] and could in turn be the cause of successive strandings. In the long term, any loss in hearing capacity of large numbers of individuals of any species may diminish its reproductive potential and thus its survival as species.

[73] Kryter 1994; Ward 1997
[74] Ward1997; Yost 2000
[75] Richardson *et al.* 1995b
[76] Scheifele 1997
[77] Perry 1998
[78] Ketten 1998; Ridgway and Carder 1997
[79] André *et al.* 2003 and André *et al.* 2007
[80] D'Amico 1998; Gordon *et al.* 1998b; Ketten 1998; Finneran *et al*. 2002; Degollada *et al.* 2003; Ketten and Finneran 2004; Ketten et al. 2004, Ketten 2004.

Data from PTS and TTS of land mammals has been used in developing safe exposure guidelines in the workplace[81]. Recently published data on sounds that cause light TTS (generally lower than 20 dB in auditory sensitivity) in toothed whales and pinnipeds has established a sound exposure level of 192-195 dB re 1 μPa^2s as the threshold beyond which a TTS is created in dolphins and belugas exposed to mid frequency tones[82]. Shift in the auditory medium threshold of 4 dB at 8 kHz and a change of 8 dB at 16 kHz have been observed following exposure to noise in the octave band centered in 7.5 kHz[83].

A similar change in threshold shift was observed with higher frequencies[84] in the case of cetaceans that have their maximum sensitivity in medium frequencies. In table 5 details are shown of up-to-date published works on hearing loss on cetaceans. It has also been noted that if octave band levels of a received signal noise are more than 96 dB above the central frequency of an audiogram, TTS could occur from 12 to 18 dB after an exposure of 30 minutes[85].

[81] Example, NIOSH 1998
[82] Ridgway *et al.* 1997; Schlundt *et al.* 2000; Finneran et al. 2005
[83] Nachtigall *et al.* 2004
[84] Schlundt *et al.* 2000 and Finneran *et al.* 2007
[85] Au *et al.* 1995

Table 5. Summary of the relevant articles on auditory loss on cetaceans.[86]

Species	Experiment objectives	Results and conclusions	Source
Belugas (in the wild)	Convert human Occupational Safety and Health Administration (OSHA) to sub-aquatic standards for cetaceans.	Levels of noise that can cause PTS in belugas (at frequencies of 500 Hz, 1 kHz and 10 kHz) occurred in 2 of the 3 areas researched in the Saint Lawrence river estuary. As noise level vary during the day it is unlikely that belugas were subjected to OSHA criteria (for PTS in humans). Scheifele witnessed that a number of assumptions made in the conversion were too conservative to reasonably expect that PTS would happen in noise levels lower than those forecast.	Scheifele 1997
Beluga	Model sounds produced by an icebreaker with a third octave centered at 5 kHz. The received levels would be from 81 dB_{RMS} re 1 µPa a 1 m (corresponding to the threshold perturbation).	The audible zones would include from 35 to 78 km and the masking would be in 14 km for the noise produced by the "bubbler system" and 40 km for "ramming" noises; TTS of 12-8 dB in a 30 minute exposure would be produced in the first 40 m for bubble noises and 120 m for "ramming", or of 4.8 dB for a 20 minute exposure between 1 and 2 km for the "bubbler system" and 2 to 4 km for the "ramming" noise.	Erbe and Farmer 2000
Sperm whale	Preliminary study of inner ear structures in 2 sperm whales killed in a Canary Islands ferry collision.	The results are consistent with auditory nerve degeneration and increased fibrousness in response to inner ear injury. Combined with the experimental playback results, these results suggest that low frequency sounds from ships may be affecting hearing and increasing the incidence of collisions around the Canary Islands.	André *et al.* 1997
Harbor porpoise	Measure the TTS in a porpoise after exposure to seismic air gun sounds stimulus (single pulses).	At 4 kHz the predefined TTS criteria exceeded 199.7 dBp-p re 1µPa a 1m (SPL) and a SEL of 164.3 dB re $1µPa^2s$ at 1 m. The elevated reference levels of auditory sensitivity indicate potentially masked thresholds. Therefore resulting TTS levels should be considered as temporary changes in threshold (MTTS).	Lucke *et al.* 2009
Striped dolphin	Electrophysiological measurements of the hearing of a stranded striped dolphin.	The PTS measured over 60 dB re 1µPa at 1m, in comparison with the species reference. The PTS was attributed to severe hydrocephaly which was revealed postmortem.	André *et al.* 2003, 2007
Bottlenose dolphin and Beluga	Subject 2 common dolphins and a beluga to single pulses in an "explosion simulator" (ES). The ES consisted of an array of electrode pole sound projectors that generated a similar	The pressure wave form was similar to the waves forecast in the Naval model of EUA REFMS (Britt *et al.* 1991). Nevertheless the ES failed to produce energy frequency below 1 kHz. No substantial changes were seen (≥ 6 dB) in the threshold of the subject exposed to single pulses with a	Finneran *et al.* 2002

[86] Abbreviations used: SEL, Sound exposure level; SPL, Source pressure level; PTS, Permanent threshold shift; TTS, Temporal threshold shift.

	pressure to that of a distant underwater explosion.	maximum received exposure level of (peak: 70 kPa, [10 psi]; peak-to-peak; 221 dB re: 1 μPa; SEL: 179 dB re: 1 μPa²s).	
	Repeat previous experiment with a water jet gun to produce only one acoustic pulse, at frequencies of 0.4, 4 and 30 kHz. The subjects were a harbor porpoise and a beluga.	The TTS measurements in the beluga were 7 and 8 dB at 0.4 and 30 kHz respectively, following an exposure length of 2 minutes of single intense pulses (peak: 160kPa [23psi]; peak-to - peak: 226 dB re: 1 μPa). The threshold returned at ±2 dB of the pre-exposure value after 4 minutes of exposure. No TTS was observed in the porpoise in maximum exposure conditions (peak: 207 kPa [30psi]; peak-to-peak: 228 dB re: 1 μPa: SEL: 188 dB re: 1 μPa²s). These studies show that in order to induce TTS in very short pulses, higher sound pressures than the ones observed for longer tones are required.	Finneran *et al.* 2002
Bottlenose dolphin	Study TTS in 5 dolphins and two belugas choosing tones of 1 s at 3, 10, 20 and 75 kHz.	The dolphins began to demonstrate measurable TTS as of received levels from 192-201 dB re 1μPa, depending on frequencies and individuals. One beluga did not show TTS at the maximum studied level (201 dB re1 μPa), while the other showed a TTS at a level of 198 dB re1 μPa.	Ridgeway *et al.* 1997
	Carry out controlled experimental studies to witness the effects of sonar in mid frequency.	Active and mid frequency sonar can induce TTS in harbor porpoises following repeated exposure to intense sonar pings with a SEL total of 214 dB re1 μPa²s. Light alterations were also observed in behavior associated to the exposures.	Mooney *et al.* 2009
	Measure TTS in 5 dolphins and two belugas exposed to pure tones of 1 second (non- pulsed). Also include the data analysis of TTS from Ridgeway *et al.*'s technical report 1997.	At frequencies of 3 kHz, 10 kHz and 20 kHz, the SPL's necessary to induce TTS were 192 to 201 dB re at 1μPa, (SEL: 192 to 201 dB re 1 μPa²s), with an average 195 dB re: 1 μPa (195 dB re: 1 μPa²s). At 0.4 kHz no subjects demonstrated any changes to exposures of 193 dB re: 1 μPa SPL, (193 dB re: 1 μPa²s SEL). The data at 75 kHz were not conclusive: a dolphin exhibited a TTS after an exposure of 182 dB SPL re: 1 μPa (182 dB re: 1 μPa²s) but not to superior levels. Another dolphin did not manifest TTS after maximum SPL levels of 193 dB re: 1 μPa (193 dB re: 1 μPa²s). These changes in threshold occurred more frequently at frequencies above stimulus fatigue.	Schlundt *et al.* 2000
Bottlenose dolphin	Measure TTS in dolphins exposed to sounds of 3 kHz with 1, 2, 4, 8 second durations and various SPL value levels using behavioral methods. The swimming pool where the animals were silent, with	One dolphin showed a light TTS (3-6 dB) following SEL exposure of 190 to 204 dB re: 1 μPa²s. The SPL values that generally caused TTS tended to diminish with the increase in exposure duration while SEL level values necessary to induce TTS were fairly consistent over all the range of	Finneran *et al.* 2005a

	ambient noise levels below 55 dB re 1 µPa/Hz at frequencies above 1 kHz.	exposure length times. The TTS magnitude correlated more with the SEL exposure than the SPL.	
	Study the increase of TTS and the recovery of a bottlenose dolphin exposed to tones of 3 kHz with SPL's of up to 200 dB re 1 µPa and time durations up to 128 s.	The maximum SEL that produced a TTS 4 de ~23 dB re 1 µPa was from 217 dB re 1 µPa ^{2}s. All thresholds recovered in the first 24 hours, the majority in the first 30 minutes. The growth of TTS 4 with an incremental SEL exposure was ~1 dB TTS for dB SEL for TTS 4 of ~15 to 18 dB.	Schlundt *et al.* 2006
	Measure TTS in a porpoise following single and multiple exposures at tones of 20 kHz. The threshold levels were estimated in multiple frequencies (from 10 to 70 kHz) using behavioral or electrophysiological methods. 3 experiments were carried out. The first two with single exposures (20 kHz tones of 64 s to 185 and 186 dB re µPa) and the third with exposures of 16 s to 20 kHz separated by 11 and 12 min. with an average SPL of 193 dB re µPa (SD = 0.8 dB).	The auditory loss was frequency dependent with greater TTS at 30 kHz, lesser at 40 kHz and at 20 kHz and very low or inexistent in the other frequencies measured. Threshold changes reached AEP were 40 to 45 dB, always greater with behavioral methods (of which were 19 to 33 dB). Full recovery needed up to 5 days with a recovery rate at 20 kHz of ~2 dB against a rate of 30 and 40 kHz of ~5 to 6 dB.	Finneran *et al.* 2007b
	Measure TTS in a harbor porpoise using AEP after 30 min. exposure to a fatiguing noise in a low frequency octave.	TTS was found between 4 to 8 dB after almost 50 minutes exposure with a central frequency of 7.5 kHz (max. 160 dB re: 1µPa SEL ~193 to 195 dB re: µPa^{2}s). Maximum TTS was reached 5 minutes after exposure with a recovery rate of some 1.5 dB on duplicating the time. TTS occurred in frequencies of 8 to 16 kHz, with a maximum of 16 kHz.	Nachtigall *et al.* 2004
	Monitor and study TTS in the hearing of a harbor porpoise at 7.5 kHz.	After 30 minutes of exposure the animal displayed a TTS of 12 to 18 dB when the stimulus was 96 dB above the animal's hearing threshold at that frequency.	Au *et al.* 1999
Harbor porpoise	Calculate the TTS in harbor porpoise.	It was calculated that the harbor porpoise can suffer severe distress and TTS in 1 km from an AHD using fishing nets. Injuries and auditory lesions could occur within 7 meters distance from this device. This is most worrying since these devices can be set and activated at full power, manually or by a sensor network.	Taylor *et al.* 1997
	Calculate theoretical TTS zones depending on frequency in relation to pile driver noises used in wind farms, of 1.5 MW (wideband SL peak=228 dB0-P re µPa ref 1m/206 dB re µPa^{2}s ref 1m).	These theoretical TTS zones at 1 km from the hearing range are less than 80 km.	Thomsen *et al.* 2006
Porpoises	Calculate theoretical	An auditory zone was determined in	Madsen *et*

and harbor seals	hearing range zones in relation to wind farm pile driving in an exercise similar to the previous.	relation to the pile driver zone of less than 100 km and possibly up to 1000 km for porpoises and harbor seals.	*al.* 2006a
Killer whale	Model the wideband sounds produced by a whale watching zodiac with motors of 150 hp with received levels of 120 dB_{RMS} re 1 µPa at 1 m. in order to calculate potential auditory damage zones.	The zones with audible levels, of masking, with behavioral changes, TTS (5 dB after 30 to 50 min. exposure) and PTS (2 to 5 dB, 8 hours/day, 5 days/week during 50 years) were 1600, 1400, 200, 450 and 1000 m. respectively.	Erbe 2002

6.3. Behavioral effects

The behavioral change responses to noise are complex and still not fully known[87]. It may be that they are conditioned by certain factors such as auditory sensitivity, behavioral state, habit or desensitization, age, sex, presence of young, proximity to exposure and distance from the coast[88].

Short term reactions to man-made sounds on cetaceans include sudden dives, fleeing from sound sources, vocal behavioral change, shorter surfacing intervals with increased respiration, attempts to protect the young, increased swim speed and abandonment of the polluted area[89]. In general, cetaceans are more susceptible to a specific noise when it is new or when its intensity is increased[90]. The reaction thresholds also tend to be smaller for continuous than for short-term[91], and less for moving or erratic signals than for static ones[92]. The most commonly seen effect of noise on cetaceans, and probably the most difficult to evaluate, long term, is "alteration"[93].

Little is known with respect to the long term effects on behavioral changes in individuals or populations. Nevertheless, it is possible to confirm that the disruption of feeding activity, reproduction, migration or caring for the young induced by noise, can precipitate a reduction in successful reproduction, chance of survival in the young and a reduction in food intake. These detrimental impacts will be more severe in cases where cetaceans have been displaced (permanently or temporarily) from important breeding and feeding zones.

There is an ample volume of scientific literature[94] that describes behavioral change in cetaceans due to recreational boat noise, industrial maritime traffic activities, seismic surveys, oceanographic tests, sonar, acoustic hardware, airplanes and explosions.

In addition, there are numerous documented cases of cetaceans abandoning areas that have been subjected to high levels of noise. The displacement of bottlenose dolphin[95], harbor porpoise[96], beluga[97] and sperm whale[98] populations associated with seismic surveys and maritime traffic have all been well documented. Humpback

[87] Richardson *et al.* 1995b
[88] Richardson and Würsig 1997; Ketten and Finneran 2004; Richardson and Tyack 2004
[89] See table 6
[90] Edds and Macfarlane 1987
[91] Richardson 1997
[92] Watkins 1986; Edds and Macfarlane 1987
[93] Disturbance
[94] See table 6
[95] Evans *et al.* 1993
[96] Evan *et al.* 1994
[97] Finley *et al.* 1990
[98] Mate *et al.* 1994

whales[99], blue whales[100] , grey whales[101] and Bowhead whales[102] have all abandoned areas in reaction to shipping activity, aircraft and industrial activities including dredging. The direct consequence of group displacement of cetacean populations is unknown. Regardless, it is conceivable that this displacement from coastal area breeding grounds and nursery areas[103] will have a deleterious impact on survival and growth of the population group.

Depending on the acoustic sensitivities of the species studied, they will react in a distinct way to acoustic sources of different characteristics:

- Low frequency cetaceans[104]. At present, there are studies on a moderate number of species and experimental conditions. From these studies we can cite the case of Bowhead whales, which, during migration, began to show signs of "alteration" in behavior as a result of compressed air guns used in a seismic survey at received levels 120 dB re 1µPa[105]. Other species studied (including Bowhead whales that were not migrating) began to show signs at received levels around 140 to 160 dB re 1 µPa[106] or higher[107] for sound sources of the same nature. When these species were exposed to sources of industrial sonar, topographic or research[108] origin, the results indicated that there was no response (or a very limited one) in received levels of 90 dB to 120 dB re 1µPa, increasing the probability of evasion and other behavioral effects at levels 122-160 dB re 1µPa. As we can see, these facts also indicate a considerable variability in received levels associated with the behavioral responses. Other variables such as the proximity to the source, its novelty or the operational characteristics, seem to have less influence on the type and strength of the response[109].

- Mid frequency cetaceans[110]. Responses of cetaceans sensitive to medium frequencies have been documented against emission sources such as ships[111], acoustic hardware[112], industrial activities[113], mid frequency active sonar[114] and seismic survey[115]. These studies have not attained clear conclusions on the coincidence on received levels and behavioral responses. For example, cases have shown severe behavioral responses to exposure of between 90 and 120 dB re 1µPa in some individuals while others did not demonstrate these responses, not even at received levels of 120 to 150 dB re 1µPa. It seems that these response

[99] Glockner-Ferrari and Ferrari 1985; Green 1991
[100] Macfarlane 1981 in Gordon and Moscrop 1996
[101] Bryant *et al*. 1984; Reeves 1997, in Richardson *et al.* 1995b
[102] Richardson *et al.* 1997
[103] Reeves 1997; Glockner-Ferrari and Ferrari 1985; Green 1991
[104] See table 2
[105] Richardson *et al.* 1995
[106] Malme *et al.* 1993, 1994, 1995, 1996, 1998 ; Richardson *et al.* 1986 ; Richardson and Malme 1993 ; Richardson 1998 ; Ljungblad *et al.* 1988 ; Todd *et al.* 1996 ; McCauley *et al.* 1998, 1999, 2000 ; Brownell 2004 ; Gordon *et al.* 2004
[107] Miller *et al.* 2005
[108] Baker *et al.* 1982; Malme *et al.* 1983, 1984, 1986; Richardson *et al.* 1990 ; McCauley *et al.* 1996 ; Biassoni *et al.* 2000 ; Croll *et al.* 2001 ; Palka and Hammond 2001 ; Nowacek *et al.* 2004
[109] Southall *et al.* 2007
[110] See table 2
[111] LGL and Greeneridge 1986; Gordon *et al.* 1992; Palka and Hammond 2001, Buckstaff 2004, Morisaka *et al.* 2005
[112] Watkins and Schevill 1975; Morton and Symonds 2002; Monteiro-Neto *et al.* 2004
[113] Awbrey and Stewart 1983; Richardson *et al.* 1990
[114] NRL 2004a, 2004b; NMFS 2005
[115] Madsen and Møhl 2000; Madsen *et al.* 2002

variations can be explained by differences between species and individuals more than by received levels[116]. Notable reaction differences between animals in the wild and those in captivity have been detected; the latter normally exceed 170 dB re 1µPa before inducing a behavioral response. Some sperm whales exposed to artificial sources of 190 dB re 1µPa ignored them following an initial reaction to flee, this was most likely due to the need to remain in acoustic contact with the rest of their group[117].

- High frequency cetaceans[118]. Research studies have been carried out on the reaction of cetaceans that possess greater sensitivity to higher frequencies from various acoustic hardware devices in both natural[119] settings and in captivity[120]. One of the conclusions that was arrived at refers, for example, to the fact that harbor porpoises are most sensitive to a wide range of man-made sounds and very low exposure levels (90 to 120 dB re 1µPa), at least in initial exposures. All recorded exposures that exceeded 140 dB re 1µPa induced evasive behavior in wild porpoises. The inuring to sound exposure was observed in some studies but not in all of them. It is possible that very strong initial reactions to relatively low levels might diminish in some conditions of repeated exposure, and with experience the subject[121] becomes "accustomed" to them.

---

[116] Southall *et al.* 2007
[117] André, M., Terrada, M., Watanabe, Y. Sperm whale behavioral response after the playback of artificial sounds. Rep. International Whale Commission, Volume 47, pages 499 to 504, 1997
[118] See table 2
[119] Culik *et al.* 2001; Olesiuk *et al.* 2002; Johnston 2002
[120] Kastelein *et al.* 1997, 2000, 2005, 2006
[121] Southall *et al.* 2007

Table 6. Summary of relevant articles on behavioral change due to man-made noise carried out on cetaceans[122].

Species	Experiment objectives	Results and conclusions	Source
Various cetacean species	Evidence of alteration due to ships.	Moving among cetaceans on a research vessel in total silence without alterations, concluding that the majority of reactions to vessels are a result of noise emissions, more than the vessel's physical presence.	Schevill 1968
Blue whale	Evidence of alteration due to ships.	Erratic and rapid approaches of boats near blue whales provoked flee reactions, separation of pairs, shorter respiration rhythms and displacement.	Macfarlane 1981 (in Gordon and Moscrop, 1996)
	Evidence of alteration from seismic surveys. The acoustic tracking of a blue whale during the execution of a seismic operation involving compressed air guns producing pulses at 215 dB re µPa at 1m (band: 10 to 60 kHz).	The blue whale began its song sequence when the boat in question was at a distance of 15 km and it approached the boat until 10 km (where a reception level of 143 dB re µPa was estimated). After a moment of silence, the whale began a new series of songs and moved diagonally away.	McDonald *et al.* 1995
Blue whale and fin whale	Evidence of alteration due to ships.	Short term flee reactions in blue whales and fin whales in response to shipping in the Saint Lawrence estuary particularly if boats moved quickly or erratically.	Edds y Mcfarlane 1987
Blue whale, fin whale and grey whale	Evidence of alteration by sonar. A series of playback experiments were carried out to evaluate the impact of SURTASS LFA at SPL levels not greater than 160 dB re 1 µPa.	No obvious responses were observed during feeding. However, a decrease in a number of whales which produced long-sequence sound patterns was noted. Deviation's in migratory trajectory was observed during playback.	Clarke *et al.* 1998
Basking or glacial Northern Right whale	Evidence of alteration from acoustic hardware devices. The warning signal device used emitted pure tones of 1000 Hz and modulated amplitude tones and descending sweeps.	Estimated received levels were from 148 dB re 1 µPa/sgrt (Hz). 5 or 6 individuals swam upwards and maintained a depth of some 5m below the surface.	Nowacek *et al.* 2001
Grey whale	Evidence of alteration by ships	Grey whales in San Diego bay responded to noise by abandoning nursery areas, only returning after shipping decreased.	Reeves 1977 (in Richardson *et al.* 1995b)
	Evidence of alteration by ships	Grey whales abandoned lake 'Guerrero Negro' over a period of various years whilst the bay was subjected to human	Bryant *et al.* 1984 (in Gordon and Moscrop 1996)

[122] Unless specified dB as it appears will refer to dB re 1µPa at 1 m. SURTASS, sonar sweeping surveillance sensors of the US Navy; LFA, low frequency sonar; SPL, Source Pressure Level; ATOC (Acoustic Thermometry of Ocean Climate); ADD (Acoustic Deterrent Device); AHD (Acoustic Harassment Device); p-p (peak-to-peak). Information from Perry *et al.* 1998 and Nowacek 2007

		activities (intense shipping traffic and dredging). Once this diminished the whales returned.	
	Evidence of alteration by industrial activities	Oil exploration playback noises were broadcasted underwater as 3500 grey whales were passing. Evasive responses began around the received wideband level of 110 dB re 1 μPa and the responses increased in measure to the increasing levels. More than 80% of the whales showed evasive responses at received levels of over 130 dB re 1 μPa.	Malme *et al.* 1983; 1984 (in Richardson *et al.* 1995b)
	Evidence of alteration by seismic survey. Air gun arrays with 65.54 L compressed air.	10% of the grey whales showed evasive behavior in received wideband levels of 164 dB re 1 μPa, 50% at 170 dB re 1 μPa and 90% at 180 dB re 1 μPa. The whales moved from a wavier shallow zone to an area of sound protection between rocks.	Malme *et al.* 1983; 1984 (in Richardson *et al.* 1995b)
	Evidence of alteration by aircraft. Grey whales reaction to helicopter playback noises was observed (excluding low frequency components).	Three simulated passes per minute provoked evasive responses in 50% of the whales in received wideband levels of 120 dB re 1 μPa.	Malme *et al.* 1984 (in Richardson *et al.* 1997)
Bowhead whale	Evidence of alteration by ships	The whales swam quickly to flee the ships located at 0.8-3.4 km distance, with less surface and diving time spent. The whales were dispersed with an average distance between animals that increased from 7.5-37 individuals; this effect lasted for less than an hour.	Richardson *et al.* 1985
	Evidence of alteration from industrial activities. Comparison of Bowhead whale distribution and industrial activity in the Beaufort sea, Canada.	It is thought that since 1980, a decrease in numbers of Bowhead whales has occurred in the Beaufort Sea, due to the accumulation of industrial activity which began in 1976. The effects on the changing distribution of Zooplankton and other environmental factors are not known.	Richardson *et al.* 1987
	Evidence of alteration from industrial activities.	Playback studies found that the majority of whales avoided drill ships or wideband dredging noises (20-1000Hz) with received levels of 115 dB re 1 μPa, levels that can be found from between 3-11 Km from said machinery. This shows a threshold response of 110 dB re 1 μPa in the 1/3 octave band where the industrial noise is most prominent. The whales could endure higher intensity	Richardson *et al.* 1990

		sounds if their only migratory route, obliges a nearby approach to the emission's source (Richardson and Greene 1993).	
	Evidence of alteration from seismic surveys.	The whales swam rapidly, fleeing from a ship engaged in seismic surveys at a distant 24 km.	Koski y Johnson 1987 (in Richardson *et al*. 1995b)
	Evidence of alteration from seismic surveys.	A change in behavior began at more than 8 km from the source, with received levels of 142-157 dB re 1 µPa.	Ljungblad *et al.* 1988
	Evidence of alteration from seismic surveys.	Subtle changes were noted in surfacing behavior, breathing and diving cycles in response to boats carrying out seismic surveys, indicating, that the absence of conspicuous responses did not prove an animal had not been affected.	Richardson *et al.* 1985
	Evidence of alteration by seismic surveys.	Whales behaving normally were observed at 6 km from the ships when estimated received levels were at 158 dB re 1µPa.	Richardson *et al.* 1986
	Evidence of alteration by airplanes.	Flee responses in whales when an aircraft approached and flew in circles around or below 305 m. above see level.	Richardson *et al.* 1985
	Evidence of alteration by airplanes.	Whales reacted less to passing aircraft when they were actively occupied in feeding, during social activities and when resting.	Richardson *et al.* 1995a
	Evidence of alteration by airplanes.	Received levels were 114 dB_{RMS} re 1 µPa at 1 m. to 3 m. depth and of 120 dB at 18 m. depth. Short and abrupt dives, moving away from the sound source were observed.	Patenaude *et al.* 2002
Belugas	Evidence of alteration by ships. Belugas in the Saint Lawrence estuary were monitored during and after exposure to motor boat and ferry noise.	Reaction to the approaching boats included a reduction in the diversity and rates of vocalization and the repetition of specific vocalizations in the first km. In the first 300 m., the belugas changed the peak frequency of their signals from 3.5 kHz to 5.2-8.8 kHz.	Lesage *et al.* 1993
	Evidence of alteration by ships.	Reactions of elusion to the playback of ship noise at levels which were believed to be hardly perceptible. It was concluded that the belugas seemed to be more influenced by the habitat and by activity at the moment of alteration than by the intensity of the sound.	Stewart *et al.* 1982
	Evidence of alteration by	Altered behaviors were shown	Lawson 2005

	ships.	in swim speed and direction, changes in immersion patterns, breeding and surfacing time and/or changes in vocal behaviour.	
	Evidence of alteration by simulated distant underwater explosions.	A perturbation threshold was established at 220 dBp-p re 1 μPa. No TTS was predicted >6 dB above 221 dBp-p re 1 μPa.	Finneran *et al.* 2000
Belugas and narwhal	Evidence of alteration by ships. Reactions of belugas and narwhals to icebreakers in the Canadian Arctic.	The belugas reacted with a flee response and the narwhals remained motionless, a typical response characteristic when faced with Killer whales. The belugas avoided the ships that came within 45 to 60 km., and appeared to be conscious of a ship at 85 km. distance. The results show that belugas were aware of boat sounds far further than predictions based on threshold levels calculated in captive animals, placing in doubt the relevance of these audiograms in natural situations. Reactions began when wideband noise levels from boats (20-100 Hz) were 94 dB re 1 μPa. The belugas moved up to 80 km. from their original position in response to the ship and remained absent for 1-2 days. The effects on the narwhal appeared to be temporary, recommencing their normal activities when the wideband received levels were 120 dB re 1 μPa.	Finneran *et al.* 2000
Sperm whales	Evidence of alteration by ships.	The responses observed in sperm whales faced with ships included reduced surface times, shorter respiration intervals and a reduction in the frequency of "tail" showing dives.	Gordon *et al.* 1992
	Evidence of alteration by whale watching ships.	Sperm whales in New Zealand avoided whale watching ships, keeping at a distance of 2 km.	Cawthorn 1992
	Evidence of alteration by seismic surveys.	Warning investigations showed that the sperm whales displaced at a distance of 60 km. from the area in the Gulf of Mexico where seismic surveys took place.	Mate *et al.* 1994
	Evidence of alteration by seismic surveys.	Sperm whales ceased vocalizations in response to relatively weak seismic pulses coming from a ship at hundreds of km's distance.	Bowles *et al.* 1994
	Evidence of alteration by seismic surveys.	Studies in the northern Gulf of Mexico point to seismic survey having a negative impact, from a communication and	Rankin and Evans 1998

		sense of direction point of view, in sperm whales, but, no effects on the distribution of toothed whales was observed.	
	Evidence of alteration by seismic surveys emitting at 210-260 Hz.	It is estimated that levels animals can receive before exhibiting acoustic or behavioral responses, are from146 dBp-p re 1 μPa.	Madsen *et al.* 2002
	Evidence of alteration by seismic survey in the Gulf of Mexico.	Sperm whales in this area have been exposed to seismic survey sounds for many years (Wilson *et al.* 2006). By means of visual surveillance and satellite tracking, the animals were not witnessed to have shown changes in behavior or that these changes were undetectable from this range.	Gordon et al. 2006; Winsor and Mate 2006
	Evidence of alteration by seismic survey in experiments of controlled exposure with specialized recorders or DTAG – digital acoustic recording tag's (Johnson and Tyack, 2003) attached to the animals.	The animals didn't demonstrate any evasive behavior in a 1-13 km range from the source with received levels of 152-162 dBp-p re 1 μPa (135-147 dB_{RMS} re 1 μPa, 115-135 re 1 $\mu Pa^2 s$). While most of them continued with their dive patterns, less of these included the typical tail showing and with less numbers of "buzzes".	Miller *et al.* 2006
	Evidence of alteration by sonar.	The sperm whales reacted to military sonar at a distance of 20 km or more from the source. Sonar of 6-28 kHz frequency caused them to stop vocalizing and adopt at times, an elusive behavior from the source.	Watkins *et al.* 1985; 1993
	Evidence of alteration by acoustic devices.	A plan to 'chase' sperm whales away from Canary Island ferry routes using playbacks of a variety of sounds found that the sperm whales reacted strongly to a 10 kHz pulse, notably when they were surfacing for air after a long dive.	André *et al.* 1997
	Evidence of alteration by explosions.	The received levels were from < 179 dB_{RMS} re 1 μPa at 1 m. No behavioral or acoustic effects were noticed.	Madsen and Møhl 2000
	Exposure and acoustic behavior of 8 tagged sperm whales, before, during and after 5 controlled explosions with air guns, separated by 1-2 hours.	None of the 8 sperm whales changed behavior (7 feeding, 1 resting) following the initial 'ramp up' at a distance of 7-13 km, or during the exposures (1-13 km). The animal closest to the source was resting during the experiment, but began to feed soon after the sound tests stopped, possible indicating a delay in the search for food occurred during the exposure.	Miller *et al.* 2009

		The sperm whales did not exhibit any flee response to avoid the source. There was a 6% reduction in "pitch" signals made and a 19% decrease in the rate of "buzzes" during feeding, but the latter didn't turn out to be significant.	
Sperm and pilot whales	Evidence of alteration from acoustic thermometry. The Heard Island viability study transmitted sound during one hour, every three hours, with source levels of 209-220 dB re 1µPa ref 1m at a depth of 175 m (the estimated depth of the deep sound canal near Heard Island). The central frequency was 57 kHz with a wideband maximum of 30 Hz.	Sperm and pilot whale signals were heard 23% of 1181 minutes of acoustic monitoring before transmission, but were absent in 1939 minutes of monitoring during the transmission. The sperm whale clicks were finally heard 36 hours after the last transmission. The size of the warning samples was too small to be able to estimate changes in the cetaceans' densities.	Bowles *et al.* 1994
Short fin pilot whale	Evidence of alteration by whale watching ships.	Dive times significantly longer in response to a large number of whale watching ships in the Canary Islands. Respiration patterns finally normalized although examples of unusually aggressive behavior were noted during observations.	Heimlich-Boran *et al.* 1994
	Evidence of alteration by ramp up used as a mitigation strategy in possible air gun sound impact. A group of 15 pilot whales were monitored before, during and after a seismic ramp up procedure of 30 minutes in a 2-D seismic survey in Gabon.	No behavioral changes were observed during the initial ramp up period. Nevertheless, 10 minutes after the start (air gun pistol volume of 940cu³) the nearest subgroup fled suddenly from the source. Subsequent behavior included milling, tail slapping and a 180° change of direction away from the seismic ship.	Weir 2008
Common dolphin	Evidence of alteration by seismic surveys with air gun at 80-100 m depth which emitted at ; a) 250 Hz, b) 2 kHz, c) 10 kHz, d) 20 kHz. The dolphins were monitored before, during and after seismic surveys in the Irish Sea.	Evasive reaction of the dolphins in monitored area. The received levels were 170 (a), 140 (b), 115 (c) and 227 (d) dB re 1µPa/sgrt (Hz). The animals at 5 km from the source exhibited a greater number of vocalizations by hour after and during the surveys. Compressed air guns of 34,711 were deployed the smallest of which were arrays normally used by exploration companies.	Gould 1996
Long fin common dolphins	Evidence of alteration by seismic exploration with air gun emitted at: a) 200 Hz, b) 20 kHz.	Received levels were from 140 (a) and 90 (b) dB re 1 µPa/sgrt (Hz). The signal was estimated to be clearly audible for dolphins at a range of 8 km. The animals 750 m from the source showed a lower	Gould and Fish 1998

		proportion (4%) of acoustic contact during emissions than when air guns were not in use.	
Bottlenose dolphin	Evidence of alteration by ships. The sound effects of motor boats and the playback of their sound were monitored in dolphins in Cardigan Bay.	Responses of less surface and longer dive times and evasive movements to ships in 150/200 m. It has been suggested that the boats moving fastest but in greater silence, caused more upset to the dolphins than larger and slower vessels which emit sound of higher intensity. As the noise emanating from high speed boats is greater than ambient levels for only a short time before its maximum approach, it would provoke a response due to the fact that the animals would have been frightened.	Evans *et al.* 1992
	Evidence of alteration by recreational craft which emitted levels of noise of 113-138 dB_{RMS} re 1 µPa at 1 m.	There were a high proportion of whistles from the dolphins during and after the exposure.	Buckstaff 2004
	Evidence of alteration by whale watching boats.	Reduction in time spent on surface in response to a whale watching ship that intended to remain close by the group. Dolphins showed little response to other boats in the area.	Janik and Thompson 1996
	Evidence of alteration by seismic survey. Small groups of cetaceans in the Irish Sea were monitored before, during and after seismic survey.	Despite the majority of test samples being too small for statistical analysis, a significant diminution of dolphin numbers in the area during the exploration was clear, suggesting that a proportion of the population had moved out of the area during this period. It is not known if these movements were due to seismic activity or down to seasonal movements.	Evans *et al.* 1993
	Evidence of alteration by acoustic devices. The ADD used emitted pulses of 10 kHz every 4 s at 132 dB re 1 µPa at 1m.	The received levels were 120 dB_{RMS} re 1 µPa at approximately 100 m. No differences were seen between the maximum approach distance to the source when the device was activated or not.	Cox *et al.* 2004
	Evidence of alteration by distant simulated underwater explosions.	An alteration threshold was established between 196 and 209 dBp-p re 1 µPa. No TTS >6 dB was forecast above 221 dBp-p re 1 µPa.	Finneran *et al.* 2000
Hectors dolphin	Evidence of alteration by acoustic devices. The ADD used emitted pulses of 10 kHz every 4 s at 132dB re 1 µPa at 1 m.	The maximum estimated level in the closest approach to the source (552 m) was 86 dB_{RMS} re 1 µPa. An evasive response to the sound source was witnessed.	Stone *et al.* 1997

	Evidence of alteration by aircraft. Helicopter flew overhead and produced tones of between 10 and 500 Hz and was at 450 m altitude.	The received levels were of 120 dB_{RMS} re 1 µPa at 3 m depth and 112 dB at 18 m depth. Short, abrupt dives along with distancing themselves from the source were witnessed.	Stone et al. 1997
Indo-Pacific dolphin	Evidence of alteration by tourist boats in Zanzibar.	The 5 mother-calf pairs studied did not exhibit swim pattern changes where they were few boats in the area but showed a very significant number of erratic movements when they were scuba divers in the water. The proportion of "tail out" dives increased with the escalation of human (tourist) activity.	Stensland and Berggren 2007
False killer whale and Risso's dolphin	Evidence of alteration by ATOC. Auditory thresholds in one grey pilot whale and one false killer whale in captivity were measured with ATOC signal pulses of 1 s.	Both species had a relatively high threshold to sound (139-142 dB re 1 µPa), indicating that these animals would have to dive to around 400 m depth, directly under the source, to detect this sound.	Au *et al.* 1997
Harbor porpoise	Evidence of alteration by ships.	The porpoises' response was to avoid the research vessels.	Polacek and Thorpe 1990
	Evidence of alteration by ships.	The porpoises of the South-East Shetland Islands evaded ships of all sizes, at times leaving the area. It was discovered that the porpoises had a greater chance to avoid the infrequent passing of ships, than ships which tended to regularly navigate these waters, such as the daily ferry.	Evans *et al.* 1994
	Evidence of alteration by industrial activity, specifically pile driving during the construction of a Danish offshore wind farm.	The porpoises exhibited a flee response of up to 10-20 km from the source and ceased vocalizations.	Tougaard *et al.* 2003, 2005
	Evidence of alteration by 3 types of wind turbine generators in Denmark and Sweden (Middlegrunden, Vindeby and Bockstigen-Valar). Turbine noise was measured only above the ambient noise in frequencies less than 500 Hz.	The total SPL was in the 109-127 dB_{RMS} re 1 µPa range, at a distance between 14 to 20 m from the cement foundations. The maximum levels of 1/3 octave were in the range of 106-126 dB_{RMS} re 1 µPa. The audibility was low for the porpoises reaching 20-70 m away from the base. It appears improbable that the porpoises would react to the noise in behavior unless they were very close to the cement foundations.	Tougaard *et al.* 2009
	Evidence of alteration by seismic survey.	The porpoises showed evasive behavior towards the source above received levels of 145 and 155 dB_{RMS} re 1 µPa up to 70 km distance.	Bain and Williams 2006
	Evidence of alteration by	The animal exhibited constant	Lucke *et al.*

	compressed air gun.	reactions of aversive behavior in received SPL above 174 dBp-p re 1 µPa or SEL of 145 dB re 1 µPa²s.	2009
	Evidence of alteration by acoustic devices. 4 experiments were carried out with different ADD's: 1) clicks, tones and sweeps of 17.5 to 140 kHz; 2) tones of 2.5 kHz and 110-131 dB; 3) 110 kHz, 158 dB; 4) 325 kHz, 179 dB.	Received levels were ≤107 dB_{RMS} re 1 µPa at 1 m. An evasive reaction to the sound source was observed growing in proportion to the levels as they increased.	Kastelein *et al.* 1997
	Evidence of alteration by acoustic devices. 3 experiments with different ADD's were carried out: 1) pulses of 10 kHz every 4s at 132 dB; 2) pulses of 10 kHz with a random reduction, 132 dB; 3) sweeps between 2 and 3.5 kHz, 100 dB.	Received levels ≤124 dB_{RMS} re 1µPa at 3.5 kHz in the 1/3 octave. In all cases an evasive behavioral response to the sound source was observed with an increase in respiration rates.	Kastelein *et al.* 2000
	Evidence of alteration by acoustic devices. 3 experiments were carried out with different ADD's: 1) 16 tones (constant wide pulses) between 9 and 15 kHz, 145 dB; 2) as above 1), but with a random wide pulses; 3) 0.1s ascending sweeps at 0.2s descending sweeps between 20-80 kHz and 96-118 dB re1 µPa at 1m.	Received levels were ≤138 dB_{RMS} re 1 µPa at 1 m at 33 kHz in the first experiment and of ≤140 dB_{RMS} re1 µPa at 1 m at 12 kHz in the second and of ≤90 dB_{RMS} re 1 µPa at 1 m at 6 kHz in the third. In all cases an evasive behavioral response to the source was observed with an increase in respiration rates.	Kastelein *et al.* 2001
	Evidence of alteration by acoustic devices. The ADD used emitted sweeps between 20 and 169 kHz and at 145 dB re1 µPa at 1 m.	The maximum estimated level in the closest approach to the source (130 m) was 102 dB_{RMS} re1µPa. Evasive behavior to the sound was observed.	Culik *et al.* 2001
	Evidence of alteration by acoustic devices. The ADD used emitted tones of 115 dB re1 µPa at 1 m at 2.5 kHz.	The maximum estimated level in the closest approach to the source (130 m) was 72 dB_{RMS} re1 µPa at 1 m. Evasive behavior to the sound was observed.	Koschinski and Culik 1997
	Evidence of alteration by acoustic devices. The ADD used emitted pulses of 10 kHz every 4 s at 132 dB re1 µPa at 1 m.	The received levels were of 118-122 dB re 1µPa $_{RMS}$ at 1m. The exclusion distance was reduced in 50% after four days.	Cox *et al.* 2001
	Evidence of alteration by acoustic devices.	Initially the porpoises reacted vigorously to the sonar pingers by diminishing vocalizations, surface times and heartbeat, entering below normal bradicardial rate. In the following test sessions the animals appeared to get used to the noise.	Teilmann *et al.* 2006
	Evidence of alteration by	It was estimated that the	Johnston and

	acoustic devices. The ADH used emitted at levels of 180-200 dB re1 µPa at 1 m.	animals received levels of 122 dB_{RMS} re1 µPa at the maximum range of influence. A possible habitat exclusion was concluded in a high percentage of locations where ADH's were used.	Woodley 1998
	Evidence of alteration by acoustic devices. The ADH used emitted at levels of 180-200 dB re1 µPa at 1 m.	The porpoises avoided the sound source. No animals were seen in the first 200 m. Levels were estimated to be ≤134 dB_{RMS} re1 µPa at 200 m from the source exclusion zone.	Olesiuk *et al.* 2002
	Evidence of alteration by acoustic devices. The ADH used emitted at levels of 180 dB re1 µPa at 1 m.	The porpoises avoided the sound source; approaching a maximum distance of 645 m. Levels were estimated to be of 125 dB_{RMS} re1 µPa at 991 m from the source.	Johnston 2002
	Evidence of alteration by acoustic devices. The ADH used emitted levels of 180-200 dB re1 µPa at 1 m.	Authors concluded that the ADH could exclude non- target species from important habitats. They estimated levels greater than 130 dB_{RMS} re1 µPa at 1 km from the source of 200 dB re1 µPa at 1m.	Taylor *et al.* 1997
Harbor porpoise and striped dolphin	Evidence of alteration by acoustic devices. The ADD used emitted 16 tones (with wide pulses and constant intervals) between 9 and 15 kHz and 145 dB re1 µPa at 1 m.	Received levels were ≤138 dB_{RMS} re1 µPa at 1 m at 33 kHz. The porpoises showed evasive behavior towards the source; however the dolphins showed no reaction.	Kastelein *et al.* 2006
Harbor porpoise and harbor seal	Evidence of alteration by acoustic devices. The ADH used emitted at levels of 172 dB re1 µPa at 1m.	The seals that were approximately 45 m from the source, received levels of 158-164 dB_{RMS} re1 µPa, avoided the sound source.	Jacobs and Terhune 2002
Killer whale	Evidence of alteration by whale watching ships, which were at more than 100 m from the Killer whales and produced sounds at 100 Hz.	The Killer whales were noted to have engaged in movements in which the trajectory was less direct and less predictable.	Williams *et al.* 2002
Minke whale, fin whale, humpback and right whale	Evidence of alteration by whale watching ships.	The baleen whales gave variable responses to the boats off Cape Cod depending on species and these responses changed in that time. In general the white fin whales, humpbacks and fin whales seemed to get used to the boats, while the right whale's behavior showed no changes.	Watkins 1986
Fin whale	Evidence of alteration by whale watching ships.	Golf of Maine fin whales showed a significant reduction in dive times and a reduction in a number of breathtaking while at the surface here whale watching ships (boats) were present.	Stone *et al.* 1992
Humpbacks	Evidence of alteration by	Swimming speed, respiration	Bauer *et al.*

	ships.	and social behavior of the humpbacks were affected by maritime traffic, in particular to the speed, proximity and numbers of boats. One case study showed how a calf that had been frightened by a large ship, placed itself in harm's way in response to the noise of a smaller motor boat, that had not provoked any previous response.	1993
	Evidence of alteration by ships. The response of humpbacks' feeding in the presence of boats was studied.	At 2-4 km from the boats responses included shorter dives, greater gaps between breaths and increased swimming speed. At less than 2 km distance responses showed longer diving, shorter interval between breaths and slower swim speed (i.e. the humpbacks evaded the ships by staying submerged).	Baker *et al.* 1982; 1983 (in Richardson *et al.* 1995b)
	Evidence of alteration by ships. The same group of humpbacks was studied in their breeding grounds off Hawaii.	A drop in the number of mother-calf pairs in shallow waters when faced with increased ship and aircraft activity.	Glockner-Ferrari and Ferrari 1985
	Evidence of alteration by ships.	Motorboats towing Para gliders displaced humpbacks in coastal Hawaiian waters, including mother-calf pods.	Green 1991
	Evidence of alteration by commercial (C) and experimental (E) seismic surveys.	The received levels were 258 (C) and 227 (E) dBp-p re1 µPa. Evasion responses were observed at 160-170 dBp-p re1 µPa for both arrays C and E.	McCauley *et al.* 2000
	Evidence of alteration by sonar.	The Hawaiian humpbacks displayed an evasive response to sonar pulse playbacks of 3.3 kHz and to sonar sweeps of 3.1-3.6 kHz. The reaction came from the similarity between the sonar signals and sounds that the humpbacks associated with threats or warnings.	Maybaum 1993
	Evidence of alteration by sonar. A series of playback experiences were carried out to simulate and evaluate the impact of SURTASS LFA with "transducers" at a depth of 60-180 m, emitting at 130-160 Hz (low frequency component) and at 260-320 Hz (high frequency component).	The received levels were 130-150 dB_{RMS} re1 µPa at 1 m. A significantly longer whale song was heard during exposure to sounds than either before or after their emission.	Miller *et al.* 2000
	Evidence of alteration by sonar. A series of playback experiences were carried out to simulate and evaluate the impact of	The received levels were 130-150 dB_{RMS} re1 µPa at 1 m. Songs were longer during the pings and these effects lasted for at least 2 hours after the pings.	Fristrup *et al.* 2003

	SURTASS LFA with "transducers" at a depth of 60-180 m, emitting at 130-160 Hz (low frequency component) and at 260-320 Hz (high frequency component).		
	Evidence of alteration by detonations at 1.8 km distance, 400 Hz.	The received levels were 140-153 dB_{RMS} re1 µPa at 1 m. No changes in respiration rates were detected, reactions on the surface or differences in the rates of "re-spotting".	Todd *et al.* 1996
	Evidence of alteration by ATOC, that emitted a central frequency of 75 Hz.	The humpbacks found at a depth of 10-80 m and at 100-200 m from the source exhibited longer dives and distanced themselves further from the source between dives. The humpbacks which were at 8-12 km from the source showed an increase in dive time and in distances between dives with the estimated received level. Both situations were estimated to have received levels of ≤130 dB_{RMS} re1 µPa ref 1 m.	Frankel and Clark 1998
Humpbacks and sperm whales	Evidence of alteration by ATOC.	Aerial census carried out over the central Californian Pacific showed that humpbacks and sperm whales were distributed significantly far from an ATOC source during an acoustic emission.	Calambokidis *et al.* 1998
	Evidence of alteration by ATOC	Studies employing low frequency ATOC playback sounds have provoked some responses in humpbacks and sperm whales.	Gordon *et al.* 1998a

6.4. Non-auditory alterations or injuries

In necropsies performed on beaked whales that had atypically stranded in the Bahamas[123] and the Canary Islands[124], they were found to have had suffered multiple hemorrhages, particularly in the kidneys, lungs, eyes, oral cavities, peribular tissues and in the inner ear cranial cavities, tissue surrounding inter-cranial membranes and along the length of the acoustic fatty tissue (mandibles and peribular sinuses).

Nevertheless, some atypical cases of beaked whale strandings occurred due to exposure to sound levels inferior to those considered to cause TTS[125] or the formation of bubbles. Acoustic field models of beaked whale strandings (Bahamas Islands 2000) showed that the affected individuals were probably exposed to levels inferior to 150-160 dB_{RMS} for 50-150 s, however the received levels were certainly far less most of the time[126]. These levels are far lower to those that are suspected to be the cause of hearing loss in small toothed whales, or to those that are used by some regulatory authorities as acceptable or safe for use in management guidelines[127].

There is still no data on the characteristics of the exposures which may cause PTS in cetaceans. Acoustic trauma indicators are to this day excluded in standard postmortem protocols[128] and are often difficult to detect implying that the analysis can disregard important indications on the effect and impact of noise. As a consequence, until inner ear structures are routinely analyzed, an alternative option to estimate conditions that may cause PTS would be to combine available TTS data with data on the increase of TTS from acoustic exposure in land mammals.

6.4.1. Bubble formation. Traumatic injuries caused by accidents

High level shockwave sounds can induce damage to tissue membranes, particularly in the interfaces between tissue membranes of different densities[129]. The acoustic resonance can also provoke amplification of pressure in mammalian air cavities as a response to sounds. As marine mammals possess airspaces in their lungs and gastrointestinal tracts, it is possible that these organs are particularly vulnerable to damage caused by shockwaves[130].

Obviously, marine mammals situated near large explosions have a high probability of suffering fatal injury to tissues and organs. In some areas, this must be quite common, and likely to have significant long term effects on cetacean populations[131].

Although it has been already accepted that animals will move away from sources before sound would reach high enough levels deemed to cause damage, the fact is that this is not always the case. As studies have shown with two cetaceans that were killed when faced with strong industrial noises, no behavioral changes had been noticed beforehand[132].

Table 7 shows the results of studies completed to date on the evidence of physiological effects on the cetaceans due to their interaction with acoustic sources.

---

[123] NOAA and US Navy 2001; Ketten *et al.* 2004
[124] Fernandez 2004; Fernandez *et al.* 2005a,b, Fernandez 2006b
[125] Finneran *et al.* 2002
[126] Hildebrand *et al.* 2004; Hildebrand 2005; Balcomb 2006
[127] E.g. CCC 2002; NMFS 2000
[128] IWC 2004, 2006b
[129] Turnpenny and Nedwell 1999
[130] Richardson *et al.* 1995
[131] Baird *et al.* 1994
[132] Lien *et al.* 1993

Studies carried out as much *in vivo* as in theory, relating to tissue damage in land based mammals, upholds that the damage threshold is situated in the order of 180-190 dB re1 µPa[133]. Further research on damage as a consequence of explosions indicates that the mechanical impact from a short pressure pulse (positive acoustic impulse) is linked to organ damage[134]. For example, pressure peaks of 222 dB re1 µPa have resulted in the perforation and hemorrhaging of rat intestines[135]. Pressure peaks of 237 dB re1 µPa are known to cause pulmonary contusions, hemorrhages, barotraumas and gaseous embolisms in sheep's arteries with fatal results[136]. With regard to cetaceans, the cause of death in 2 humpbacks was attributed to an explosion of almost 5000 kg and, upon examination, the ears revealed significant trauma from the blast[137].

Furthermore, when it comes to cetaceans that make deep dives, neuronal irritation, strandings induced by sonar and related pathology[138], have all been taken into account.

Deep diving Marine mammals do not appear to have the need for decompression after having been exposed to such immense pressures, though we are still not aware of the protective mechanisms they employ to make this possible[139].

It has been demonstrated[140] that 750 Hz sounds could provoke bubbles in bodily fluids (*in vivo* cavitation). Research into the possibility that low frequencies modify their diffusion concluded that bubbles produced continue to grow until they reached their resonant frequency, i.e. a lower frequency will give a greater amplitude resonance. For example, a 250 Hz signal will result in the growth of a theoretical bubble up to 1cm. Such large sized bubbles increase the risk of arterial blockages in average sized (diameter) arteries.

Even though theoretical models[141] show that the growth of bubbles in a range of frequencies from 250-1000 Hz requires over saturation and a high level of sound pressure before large diameters are reached, they will attain capillary diameters (10 µm) in a matter of minutes with sound pressure levels above 190 dB re 1 µPa SPL.

The postmortems of animals stranded after exposure to low frequency sonar in the Canary Islands in 2002[142], in 2004[143] and in Almeria in 2006[144] showed syndromes in line with a fat and gas embolism[145] with symptoms that manifested a certain analogy with sicknesses associated with decompression in human beings (DSC Syndrome), although there is no scientific consensus on this subject[146]. This pathological mechanism could cause the death of an animal in a short period of time, for example, in a subsequent severe cardiovascular failure.

[133] Cudahy *et al.* 1999, Cudahy and Elison 2002
[134] Green and Moore 1995
[135] Bauman *et al.* 1997
[136] Fletcher *et al.* 1976
[137] Ketten *et al.* 1993
[138] Talpalar and Grossman 2005
[139] In the case of humans, sound created bubbles could cause a problem as humans do require decompression.
[140] Ter Haar *et al.* 1981
[141] Crum and Mao 1993, 1996
[142] Martín 2002; Martín *et al.* 2004
[143] Espinosa del los Monteros et al 2005; Fernández 2006b
[144] Dalton 2006; Fernández 2006 a, b
[145] Jepson *et al.* 2003; Fernández 2004; Fernández e tal 2005 a, b; Fernández 2006b
[146] Piantadosi and Thalmann 2004

6.4.2 Stress

In this context, the term stress is used to describe physiological changes that transpire in immune (and neuroendocrine) systems following exposure to sound. Stress indicators in marine mammals have been recorded but physiological responses to stress are still not completely known. For example, dolphins undergo changes in heartbeat rhythm in response to sound exposure[147]. A beluga showed a higher hormonal stress level (norepinephrine, epinephrine and dopamine) with an increase in exposure level[148]. Prolonged stress brought about by noise may weaken resistance to illnesses and endocrine imbalances that could affect an animal's ability to reproduce[149].

Stressed mammals normally produce an increased level of the hormone corticotrophin (ACTH) which activates the secretion of adrenal hormones, such as corticosteroids (e.g. cortisol) and catecholamine (e.g. adrenaline) from the adrenal cortex, and in time, the chronic activation of the adrenal cortex can trigger detrimental physiological effects[150]. Elevated levels of cortisol, for example, result in a reduction of the white blood cells essential to a functioning immune system and thus resistance to infections[151].

Cetaceans reveal stress symptoms much in the same way as other mammals and can be extremely sensitive to over stimulation of the adrenal cortex[152]. It is therefore highly feasible that cetaceans living in areas of high density maritime traffic or coastal areas and affected by relentless high intensity noise are continually at risk from stress related to that noise.

Certain behaviors of cetaceans show us that they may be undergoing some kind of stress. For example, in Hawaii, unusual behavior in pilot whales was witnessed[153] seemingly in response to the presence of a large number of whale watching boats. Although the continued presence of cetaceans in areas of high boat/ship density and other noise creating activity could mean that some whales can grow used to anthropogenic noise, it has also been observed that the whales might remain in these areas despite their upset, for the lack of any alternative that fulfills their vital needs. This of course will provoke stress[154].

6.4.3 Reproduction

Very few studies into the effect of noise on reproduction have been carried out, and the ones that have been effectuated in humans have focused mainly in the area of vibration, understood as movement of a mechanical system. Physiological examples of mechanical systems are the brain and organs such as the lungs, heart and skin. The combination of noise and vibration appears to have had an important effect on reproduction in rats when compared to the effect of noise alone[155]. It has also been shown that men exposed to elevated occupational vibrations[156] have higher oligosperm, azosperm and sperm deformation. Other research suggests that women who remain in areas of high levels of noise and vibration suffer increased menstrual irregularities, miscarriages and stillbirths[157].

---

[147] Miksis *et al.* 2001
[148] Romano *et al.* 2004
[149] Geraci and St. Aubin 1980
[150] Seyle 1973
[151] Gwazdauksas *et al.* 1980
[152] Thomson and Geraci 1986
[153] Heimlich-Boran *et al.* 1994
[154] Brodie 1981, in Richardson *et al*. 1995b
[155] Shenaeva 1990
[156] Penkov *et al.* 1996
[157] Seidel and Heide 1986; Seidel 1993

Table 7. Documented evidence of stress and other physiological effects induced by human activities on cetaceans

Species	Experiment objectives	Results and conclusions	Source
Belugas (captive)	Study stress produced in cetaceans by anthropogenic activities. 4 captive belugas were subjected to recorded 'drill platform' sounds (source levels of 153 dB re 1 µPa ref 1m).	Blood levels of catecholamine (adrenaline and noradrenalin) were not higher after the experiment or were any significant changes in behavior noticed. It was put forward that the captive cetaceans may become used to the noise (low frequency) created by water jets (blasters) and advised caution when applying these results to belugas in the wild in the absence of any long term study.	Thomas *et al.* 1990
Irrawaddy River dolphin	Find Evidence of physiological effects on cetaceans by man-made activities.	Incidental mortality, use of explosives by fishermen and capture was attributed to the loss of dolphin numbers in this northeastern part of Cambodia.	Baird *et al.* 1994
Bottlenose dolphin	Study stress in cetaceans provoked by man-made activities.	When the dolphins were chased and captured they showed an elevated level of cortisol associated with the loss of leucocytes. The animals which already showed high levels of cortisol due to their handling did not exhibit further cortisol increases in response to injections of ACTH, suggesting that the adrenal cortex was already stimulated to the maximum. Two of the dolphins administered with ACTH died.	Thomson and Geraci 1986
	Find Evidence of physiological effects produced on cetaceans by man-made activities	Marine mammals or humans very close to low frequency noises with a SPL above 210 dB re 1µPa at 500 Hz, experienced a significant increase of bubbles in capillaries and other small blood vessels. The authors suggested that low intensity noise could induce the growth of bubbles in bodily fluids already saturated with gas.	Crum and Mao 1996
	Study evidence of physiological effects produced on cetaceans by man-made activities	Some cetaceans make repeated dives to great depths which could produce excessive nitrogen pressure in muscle tissues. It is theoretically possible that intense sounds cause pathologies associated with the development of bubbles or 'aeroembolisms' in cetaceans.	Ridgway and Howard 1982; Ridgway 1997
Harbor porpoise	Study evidence of physiological effects produced in cetaceans	The harbor porpoise may suffer tissue damage in the first 7 m from an AHD	Taylor *et al.* 1997
Beaked whales	Necropsies carried out on stranded beaked whales in 2002 and Almeria in 2006 after Naval maneuvers where mid frequency sonar had been in operation.	The stranded animals showed a syndrome of embolisms (fat and gas) that manifested a certain analogy with sicknesses related to decompression in humans.	Jepson et al., 2003; Degollada et al., 2003 ; Fernández, 2004; Fernández et al 2004, 2005 a and b; Fernández 2006b

7.1 Definition

The nature and possibility of mitigation of many environmental impacts can be considered within the scope of the tool known as "Risk Framework ". This concept was developed for its application to health risks in human beings, and with time has come to be an important tool in conservation risks to wild fauna. The Risk Framework helps to rationalize the effort in applied scientific research, focusing it on the most sensitive aspects that need to be addressed in the terms of environmental impacts. The following Risk Framework applied to the effect of anthropogenic noise on marine mammals is an adaptation of generic frameworks used for other types of pollution and risks[158].

The Risk Framework is applied in a 5 stage analytical process[159], which we will detail below and that is enunciated as follows: a sound originates from a source, e.g. sonar transducer, air gun array (compressed air) for seismic studies, moves through the water and is converted into an "exposure" (sound received by marine mammals). The exposure creates an impact in exposed animals (a type and quantity of noise received by animals which can be expressed in many ways) and the magnitude (strength), duration and other impact characteristics determine the extent in which the animal is affected. The model is made up of the following analytical steps:

1. Risk identification: implies the identification of sound sources and the suspected circumstances where they may present danger, the quantification of the concentrations found in the environment, a description of the specific effects of the noise source, and an assessment of the conditions under which the effect can be expressed in exposed marine mammals to be able to determine the cause of injury. Information from this first step can be extracted from environment monitoring data and other kinds of experimental work, as is presented in this work. This step is common to quantitative and qualitative risk assessments.

2. Response Assessment: implies the evaluation of the conditions under which the effects of sound can manifest themselves in exposed animals with special emphasis on the quantitative relationship between impact and response. This step can include an assessment of the variations of the response, for example; sensitivity differences of individual species, auditory effects, behavioral effects, non-auditory physiological effects, trophic eco-system effects, population effects, susceptibility in relation to age, sex, reproductive status and time of year.

3. Exposure Assessment: implies the characteristics of the population that can be exposed to a danger (including the number and distribution of cetaceans), identification of the routes along which exposure can take place, estimating the characteristics (magnitude, duration and schedule) of the levels that marine mammals might have received as a result of exposure and the overlap between cetacean signals and sounds, assuaged by the species' auditory sensitivity.

4. Risk characterization: implies the integration of information taken from the first 3 steps with the objective of developing a qualitative or quantitative

[158] NRC 1994
[159] Boyd *et al.* 2008

estimate of the probability that some of the hazards associated with the sound source may have affected the exposed marine mammals. This is the step where risk assessment results are posted. The characterization of the risk should also include a description of the uncertainties associated with risk valuation.

5. Risk management: includes the design and application of mitigation measures to reduce, eliminate or rectify the estimated risk of the previous step. Above identifying priority risks, the scientific community can contribute to the management of these risks, sharing and assessing information on the effectiveness of mitigation techniques and strategies that could be used to reduce risks. The efforts applied to risk management would depend on whether the danger of injury is biologically significant, if it exceeds the levels established by law (regulation levels), or if it is generating a rejection in social perception.

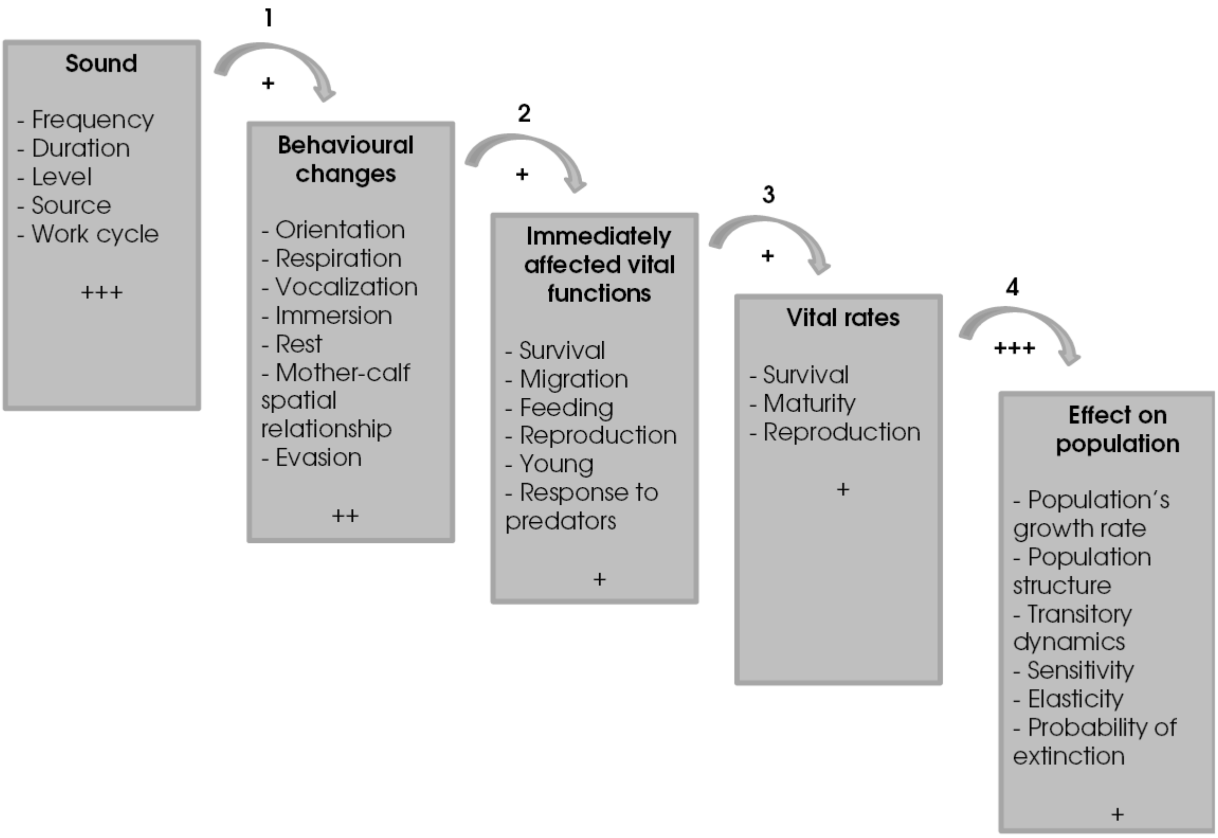
Not all risk assessment needs necessarily embrace the 5 steps described above. Risk assessment could sometimes consist of, in "simple" cases or in well known and well documented situations, in the simple valuation of the potential risk that the anthropogenic noise can represent for marine mammals. Applying the risk framework to the effects of man-made noise in marine mammals will also assist in defining the necessary priority issues for investigation, helping to reduce the scientific uncertainty that still exists. Table 8 and Fig. 2, show in abridged form, the grade of existing scientific uncertainty with regard to different elements of the 5 steps of the risk framework described.

Table 8. Summary of the steps and elements in the Risk Framework of the impact on anthropogenic sound on marine mammals, with graded expressions to the level of scientific uncertainty existing for each[160]

Risk Framework	Research	Sub-issues	Grade of uncertainty
Step 1: Risk Assessment	Sound sources in the marine environment	Characteristic of natural sound sources (biological, non-biological and man-made)	Moderate
		Abundance and distribution of sound sources	High
	Sound fields in marine environment	Ambient sound fields	High
		Individual sound field sources	Moderate
		Auditory sound detection	Moderate
		Non-auditory sound sensitivity	Moderate
Steps 2 and 3: Assessment of the exposure and response in function if level (short and long term)	Marine mammals as acoustic receptors	Alteration and abundance of marine mammals (including vertical dose)	High
		Auditory sound detection	Moderate
		Non-auditory sound sensitivity	Moderate
		Distribution and abundance of sound sources	High
	Effects of sounds on individuals	Physiological effects (e.g. TTS, PTS, stress)	Auditory effects: moderate Stress effects: high
		Masking (including potentially chronic effects)	High
		Behavioral effects	High
		Effects on vital functions (feeding, reproductive condition)	High
		Mobility	High
		Issues related to mass strandings of beaked whales e.g. nitrogen bubbles, tissue resonance and hypotheses on multi-focal hemorrhaging	High
		Effects of sound on feeding owing to availability of prey	High
	Population effects	Changes in fertility rates (vitality, fertility, survival)	High
	Accumulated synergetic effects	Effects of multiple exposure to sound	High
		Effects of sound combined with stress	High
Step 4: Risk characterization	Risk impact	Overlapping of exposure and effects	High
Step 5: Risk management	Methods of preventing or reducing risk	Mitigation tools and decisions to trigger management action	High

[160] There is some overlap between the principal research issues in risk assessment. For example, the distribution and abundance of man-made noise sources is as relevant for the identification of any danger, as it is an evaluation of the response-dose. Boyd *et al.* 2008

Figure 2. Consequences at population level of acoustic alterations. The number of symbols + shows the relative level of understanding (Boyd *et al.* 2008)



7.2. Physical impact criteria

As we have seen, man-made noise can cover a wide selection of frequencies and sound levels, and the form in which a particular species reacts to the sound will depend on the range of frequencies it can hear, from sound level to its spectral level. Hearing sensitivity varies as much as the range of frequencies that can be perceived from one species to another.

In humans, sound is ultrasonic (i.e. above the human auditory range) above the 20 kHz mark. However, for many fish, sounds above 1 kHz are already ultrasounds. For marine mammals, the greater part of energy from an air gun can be infrasonic, since many of these species can not perceive sounds below 1 kHz. These considerations show the importance of bearing in mind the auditory capacity to evaluate the effect of underwater noise in marine mammals. The concern with environmental effects that may come from noise produced by human activities has motivated some authors[161] to develop and propose the concept of "dBht (*species*)" (or dB auditory threshold of the species) as an official metric to assess the effects of noise.

[161] Nedwell and Turnpenny 1998

The dBht (*species*) establishes a sound measurement that reflects the auditory differences between species, passing sound through a filter which reproduces the auditory capacity of that species. A combination of coefficients is used to define the behavior of the filter in a manner which corresponds to the way the sharpness of the species' hearing varies with frequency. The sound level is measured after the filter; on this scale, the level is different for each species (this is the reason why the name of the species is specified), and it corresponds with the probable level of sound perception of the species in question.

The scale is identifiable to a dB scale where the auditory threshold of the species is used as a unit of reference. This formulation is identical in concept to the dB (A), scale used for the qualification of behavioral effect of noise in humans. In effect, the dB (A) could be thought of as the "dBht (homo sapiens)". One of the main benefits of this scale is its simplicity; one unique number, the dBht (*species*), can be used to describe the effect of noise in any particular species.

It is foreseen that the eventual use of the dBht (*species*) will be to provide "species sonometers", which will allow carrying out simple noise measurements in biologically significant units for those users who are not experts in underwater acoustics.

At present, and as we have also seen, there are many acoustic measurements[162] that could be employed to measure the impact of sound on animals. Nevertheless, when using these measurements, it is impossible to predict without error which impact could be capable of causing significant injury or alteration in behavior for each species. This is due to various reasons: inter-specific differences of species, the fact that sound exposures contain a great variety of temporal patterns and pressure characteristics, and to the lack of audiograms for all considered species. In particular, the sound pressure level RMS is inadequate as an autonomous and unique measurement when evaluating acoustic risks in a transient sound/noise in marine mammals[163]. Impulse sounds give a maximum peak of higher sound pressure level, but with little energy content. As physical injury and hearing disability can be caused by sounds characterized by an elevated pressure peak and by the flow of energy, it is important that any safe or secure sound exposure limit mention both measurements; the maximum energy flow and the pressure peak received. This criteria, that we can call "double criteria" (energy and pressure peak)[164], would better reflect the potential of short pulses of elevated pressure to cause physical damage, as well as, those of high energy transient sounds with lower pressure peaks to cause physiological impacts[165].

The "double criteria" approach has also been proposed for alterations to behavior for single pulses[166].

On the other hand, the pressure criteria for physical impacts can also be defined by those SPL peaks (sound pressure levels) above which there will be a tissue injury, independent from the exposure duration. Thus, any simple exposure above this pressure peak will be considered a potential cause of tissue damage, independent of the complete exposure's SPL or SEL.

---

162 RMS, or SPL peak, SEI, kurtosis
163 Madsen 2005
164 As has been suggested by "the noise exposure criteria group" of the USA (Ketten and Finneran 2004/Noise Exposure Criteria Group)
165 Madsen 2005
166 Richardson and Tyack 2004; see section 6.3.

Finally, for different exposures that contain intense transient pressure peaks, the sound exposure level (SEL) is the measurement (or one of the appropriate measurements), to estimate the emergence of TTS and to predict its development in humans[167]. This use of SEL is based on the assumption that equivalent energy sounds will generally have similar effects on the auditory systems of exposed human subjects, even if they differ in SPL, duration and/or temporal exposure patterns[168].

TTS and PTS

As we have come to show in this Document, there are no universally accepted sound exposure thresholds which adequately reflect the complex physical and environmental relationships and the biological parameters. In some recommended texts or even in national legislations[169], values of 120, 140, 160, 180 or 190 dB (for example SPL or RMS) have been used as a critical acoustic pressure threshold for specific exposures to noise and signals. But these threshold values are very controversial, since in the case of some species, such as beaked whales, atypical strandings have happened after exposure to sound pressure levels of far lower intensity[170].

Remembering that "PTS" or "Permanent Threshold Shift" means "Permanent change in auditory threshold" and that "TTS" or "Temporary Threshold Shift" means "Temporary change in auditory threshold", one must take for granted that a PTS will appear if the auditory threshold is increased ≥40 dB (measured from the first occurrence of a TTS)[171].

Until now, TTS measurements in marine mammals have been of a small magnitude (generally inferior to 10 dB). The occurrence of TTS has been defined as a temporal elevation of the auditory threshold in 6 dB[172] although smaller auditory threshold changes have been proved statistically significant[173]. There is solid evidence that signals of 80 dB above the auditory threshold are generally capable of causing PTS[174].

Recently[175], Southall et al. revised all the possible impacts on marine mammals. They followed the guidelines of the Marine Mammal Protection Act[176] (USA) with particular reference to level A (Physical damage) and B (Harassment, see section 6.3.), and they proposed a series of dual criteria for level A impacts for 3 source categories (single pulse, multiple pulse and no pulse sources) and for 5 groups of marine organisms within the cetacean category of "low frequency", "mid frequency", and toothed whales "high frequency" (see Tables 9 and 10).

---

[167] ISO 1990
[168] Kryter 1970; Nielsen *et al.* 1986; Yost 1994; NIOSH 1998
[169] HESS 1999; USDoN of 2001, The Californian Coastal Commission 2002; NMFS 2003; NMFS/NOAA 2005, IUCN 2006
[170] Low as in the RL model >150-160 dBRMS re 1 μPa; Hildebrand *et al.* 2004; Hildebrand 2005.
[171] Southall *et al.* 2007 used available TTS data on marine mammals and extrapolated, following the principle of precaution, the protocols on the occurrence of PTS based on land mammal data.
[172] Schlundt *et al.* 2000
[173] Kastak *et al.* 1999; Finneran *et al.* 2005
[174] At least in human and animal experiments, when exposed for a longer period of time. (Gisiner *et al.* 1998)
[175] 2007
[176] US MMPA

Despite the dual criteria recommended for level A not yet having been used in environmental advocacy and norms, Table 9 shows level A criteria that are consistent with those energy criteria applicable to baleen and toothed whales. The summary of data in this study indicates the following thresholds (SEL) corresponding to changes in behavior, TTS and PTS:

- Changes in behavior (Level B): 183 dB re 1 μPa^2 s
- TTS: 195 dB re 1 μPa^2 s
- PTS (Level A): 215 dB re 1 μPa^2 s

Table 9. Physical injury criteria proposed for cetaceans exposed to "discreet" acoustic events (simple or multiple exposures in a 24 hours period)[177,178]

	Sound types		
Cetacean group	**Single pulses**	**Multiple pulses**	**No pulses**
Low frequency			
Sound pressure level	230 dB*	230 dB*	230 dB*
Sound exposure level	198 dB**	198 dB**	215 dB**
Mid frequency			
Sound pressure level	230 dB*	230 dB*	230 dB*
Sound exposure level	198 dB**	198 dB**	215 dB**
High frequency			
Sound pressure level	230 dB*	230 dB*	230 dB*
Sound exposure level	198 dB**	198 dB**	215 dB**

* dB re 1 μPa at 1 m; ** dB re1 $\mu Pa^2 s$

Table 10. Sound types, acoustic characteristics and selected examples of anthropogenic sound sources[179]

Sound type	Acoustic characteristics	Examples
Single pulse	Individual acoustic event;	Individual explosions, sonic booms, airguns, pile driving, single pings of certain sonar, deepwater sounders and pingers
Multiple pulse	Multiple discreet acoustic events	Series of explosions, airgun sequences, pile driving, some sonar activity (IMAPS), some deepwater sounding signals
No pulse	Individual acoustic events or multiple stationary events	Ship and aircraft passage, drilling, sundry types of construction or other industrial operations, some sonar (mid frequency tactical LFA), acoustic dissuasive and deterrent devices, acoustic thermometry system (ATOC), some deepwater sounding signals

[177] For the interpretation of this Table, please refer to Tables 10 and 2.
[178] Southall *et al.* 2007
[179] The types of sound measured are based on characteristics measured at the source. In certain conditions the sounds classified as pulses in the source can lack these characteristics in distant receptors (Southall *et al.* 2007).

7.3. Criteria for behavioral change

The perturbation criteria of behavior for sound pulses have been typically met at 160 dB re 1 µPa, principally based on previous observations of baleen whales (mysticetes) reacting to airgun pulses[180]. Nevertheless, this relationship has yet to be met for toothed whales and other marine organisms. Despite having been in effect in various regulations and recommendations[181] for more than a decade, these criteria remain controversial and cannot be thought of as accepted, nor have they been purposefully implemented.

It is also important to note the observations of short or less profound reactions, or without sustained/deep responses, or reproduction, survival and growth cycles without biological relevance . The biological relevance of the behavioral response to the exposure to noise will depend in part on the length of time it persists (see Table 11). There are many mammals which carry out vital functions (such as feeding, rest, navigation and socializing) in their daily 24 hour cycle. Repeated or sustained disruptions of these functions have a higher probability to have provable effects on their vital signs than a sporadic or brief perturbation.

Table 11. The scale of severity observed in the behavioral responses of wild and captive marine mammals exposed to various types of anthropogenic sound[182]

Response score*	Corresponding behavior (individuals in wild)**	Corresponding behavior (individuals in captivity)**
0	No response	No response
1	Short orientation response (visual orientation/research)	No response
2	Moderate or multiple orientation behaviors Brief cessation/minor modification of vocal behavior Brief or minor change in respiration rate	No negative response observed: may have appreciated sounds as some new object
3	Prolonged orientation behavior Individual warning behavior Small changes in swimming speed, direction and/or diving but fleeing from sound source Moderate change in respiration rate Cessation/lesser modification of vocal behavior (< duration of source operation)	Small changes in response to trained behavior (e.g. delay in returning to initial position, intervals between longer tests)
4	Moderate changes in swimming speed, direction and/or in diving profile but no fleeing from sound sources Small or brief change in group distribution Cessation/moderate modification of vocal behavior (direction≈ source operation time span)	Moderate changes in response to trained behaviors (e.g. reticence to return to initial position, intervals between longer tests)
5	Consistent or prolonged changes in swimming speed, direction and/or diving profile but no fleeing from the sound source Moderate change in group distribution Change in distance between animals and/or size of group (aggregate or separate) Prolonged cessation/modification of vocal behavior (duration > duration of source operation time)	Severe and substantial changes in response to trained behaviors (e.g. splitting from position during test/experiment sessions

[180] Malme *et al.* 1983, 1984; Richardson *et al.* 1986
[181] Principally in the USA
[182] Southall *et al* 2007

6	Moderate or less evasion of individuals and/or groups to sound source Brief or small separation of mother from dependent young Aggressive behavior related to the exposure to sound (e.g. tail/flipper slapping, opening and closing of mouth (making noise), abrupt changes in movement, formation of bubble clouds Cessation/modification of vocal behavior Visibly startled/frightened response Brief cessation in reproductive behavior	Refusal to commence trained tasks
7	Considerable or prolonged aggressive behavior Moderate separation between mothers and dependant young Clear anti-predator response Severe sustained evasion to sound source Moderate reduction in reproductive behavior	Evasion from experimental situation or seeking of refuge (≤ duration of the experiment) Menacing behavior or of attack towards the sound source
8	Obvious aversion and/or progressive sensitization Prolonged or severe separation between mothers and dependant young with disruption of acoustic regrouping mechanisms Long term evasion from the area (> operation of the source) Prolonged cessation of reproductive behavior	Total evasion from acoustic exposition area and refusal to carry out trained behaviors for over 24 hours
9	General panic, fleeing, stampede, attacking of congeners, or strandings Evasive behavior related to the presence of predators	Total evasion from acoustic exposition area and refusal to carry out trained behaviors for more than 24 hours

*The scores in severity of the behavioral responses are not necessarily equivalent in conditions of liberty and captivity
**Any response results in a corresponding score (i.e. one must observe all the members of a group and their behavioral responses). If multiple responses are given, the highest scoring will be the one selected for use in the analysis.

8. Mitigation solutions and management

As already mentioned in this Document, anthropogenic sound sources must be divided into two categories: those derived from human activity which do not pretend to extract information from the noise produced, and those which intentionally create noise in the environment for exploration or the compiling of data.

In the first case, it is possible to compel the promoters of activities that generate noise to adopt the necessary measures to reduce said levels. In the second case (subsection 3.2.1), until less polluting alternative acoustic technologies are developed, it is not feasible to block the development of these technologies because of the economic, energy and strategic interests that they stand for, although one can recommend the adoption of all of the preventative measures which exist to mitigate the negative effects associated with the introduction of high intensity sounds into the environment. In both cases, promoters must be required to adopt adequate follow-up and monitoring programs, which permit, in the medium term, the improvement of existing information and improved research.

All cases recommend the identification, in areas of interest, of bioindicator species and ascertain, based on the auditory sensitivities published in scientific literature, the levels dBht (species) of those species faced with the introduction of anthropogenic noise sources (see section 6.2).

8.1. Reduction in the levels of anthropogenic noise sources

This section does not attempt to give an exhaustive list of noise reduction methods, but rather offers examples whose application may presume a partial yet significant solution when it comes to impact of underwater noise.

Construction of quieter oceangoing vessels and the adaptation of existing ones. It is possible to apply a design to the propellers that reduces cavitation, which is the source of most of the noise generated by ships. There are techniques to isolate and absorb sound, such as the isolation based on elastic support's that can reduce radiated mechanical energy[183].

Adequate maintenance of ships. It is important to bear in mind that ship noise can be lessened through good engine maintenance practices, which will not only reduce mechanical noise but save fuel and increase efficiency. Engine repairs will be fewer and the ship's passage will be quieter and more comfortable for crew (and/or passengers)[184].

"Skysail" deployment. The use of what are called Skysails[185] can result in the saving of up to 35% in fuel costs and cut noise levels accordingly as there is less engine demand. The skysails are attached to the bow of the ship and harness the wind in assisting the ship's propulsion.

Route modification. On occasions, and in cases of necessity to reduce acoustic pollution in critical areas, maritime traffic could alter its routes and put a safe distance between itself and cetacean habitats of biological importance (see Annex V). Another beneficial outcome will be a reduction in the risk of mammal-ship collisions.

---

[183] Southall 2005
[184] As above.
[185] http://skysails.info/index.php?L=1

Navigation speed moderation. The simple act of cutting the speed in predetermined areas where ships navigate will lessen the probability of collisions with cetaceans and at the same time reduce noise emissions. It has been documented[186] that most dangerous or fatal lesions caused by collisions with cetaceans happen when ships navigate at 14 knots (~26km/h) or more. This measure could be combined with the modification of routes in specific moments or spaces in Marine Protected Areas (MPA's).

Bubble screens. Air bubbles in water attenuate underwater sound because they change the impedance (acoustic resistance) in the medium of propagation and act as an acoustic mirror. A significant reduction of sound can be obtained without a great quantity of bubbles. Bubble screens can be effective not only in high and medium frequencies but also in low frequencies[187]. For example, they can be used to minimize the effects of underwater explosions in nearby structures[188] and have been successfully experimented with to reduce the sound made during a pile driver operation[189]. They have also been deployed[190] to attenuate high frequency sounds (10-20 kHz) up to 30dB. Bubble screens can be very efficient in reducing narrow band noise adjusting its resonant frequency (i.e. its size to the frequency of interest) and can in fact be frequency adjusted. Other researchers mentioned bubble curtain tests to reduce the horizontal propagation of airgun noise and ship propeller noises. Bubble system emitters around propellers are effective and practical in reducing cavitation noise[191]. Nevertheless, bubble curtains are not effective in lessening sounds of very low frequency, such as those produced by large propellers[192].

8.2. Mitigation of the effects derived from the use of acoustic signals

Charting and vigilance of safe areas. Geographic and seasonal restrictions. The most effective measures of mitigating the ensonification of species and habitats, particularly sensitive are geographic and seasonal restrictions. Human activities that produce acoustic signals (section 3.2.1) can be programmed to avoid areas and/or moments when/where the most sensitive species of marine mammals or other taxonomic groups are normally engaged in crucial activities such as mating, nursing, feeding or migrating. In some specific cases, and on the margin of these activities, the mere presence of these species in these areas should warrant the implementation of mitigation measures, for example, in the case of beaked whale habitats and the planned use of mid frequency military sonar.

Such measures have already been implemented in Spain around the Cabo de Gata coastline in Almeria. The Environment Ministry and Industry Ministry have set apart a 20 mile safe area limit for cetaceans around Cabo de Gata. This defined limit has been published in International Nautical Charts[193]. These measures have also been carried out in other states and fields of application[194]. The IUCN recommends that member states use their national and international legislation to establish noise restrictions, at

[186] Laist *et al.* 2001
[187] Gisiner *et al.* 1998
[188] Green *et al.* 1985
[189] Greene described a test demonstrating a curtain of bubbles around a pile driving operation in Hong Kong port which resulted in an important attenuation of the noise, including low frequency components.
[190] Erbe in Victoria, B.C., Canada
[191] Urick 1983
[192] Gisiner *et al.* 1998
[193] Tejedor *et al.* 2007
[194] Australia (Environment Australia 2001), Brazil 2004, UK, ASCOBANS 2003, ACCOBAMS 2004, and in the report of the Scientific Committee of the International Whaling Commission (IWC 2004)

least in Marine Protected Areas, that in turn will be included in their Management Plans[195].

Exclusion or security zones: security zones must be defined in relation to their sound source position whether or not this is found to be stationary or in motion. The operators of these activities should be obliged to review the exclusion zone (visually or acoustically) and to control, anticipate, rethink or delay the activities which produce sound[196] or to cease them completely[197] if marine mammals or other sensitive species enter into the area. The zone radius should be set relative to the sound source levels and to sound propagation conditions, which could fluctuate between 500 m and many km[198].

Ramp up. "Ramp up" is the process involving the gradual increase of sound pressure level produced by a sound source. "Ramp up" has been used as a mitigation measure in military and seismic activities and is based on the notion that animals will avoid sounds which cause them discomfort. In this way, the marine organisms are given the opportunity to abandon the area before sound pressure levels reach damaging levels. In the USA, Australia and the UK, "ramp up" has already been recommended for use with airguns, each time a seismic array is deployed[199]. The effectiveness, however, of the "ramp up" process needs further research as low pressure sound levels often attract curious animals rather than dissuading them[200]. Furthermore, complex multipath sound transmission can create convergence zones with higher levels at greater distances from the source[201]; in this case an animal intending to avoid the high sound emissions might swim directly towards it.

Mitigation measures should consider the cumulative effect of sound sources operating simultaneously in the zone and the status of particularly sensitive populations.

---

[195] IUCN 2004
[196] MMS 2004, New Zealand, JNCC of 2003, Environment Australia 2001
[197] Environment Australia 2001
[198] Environment Australia 2001, IUCN 2006, JNCC 2003, MMS 2004
[199] MMS 2004, Environment Australia 2001, JNCC 2003
[200] IWC 2006 b; McCauley and Hughes 2006
[201] Madsen *et al.* 2005

8.3. Monitoring and follow-up of activities generating underwater acoustic pollution

Monitoring and follow-up of activities with environmental impact are a generally accepted necessity and a legal obligation for any type of plan or project in the field of underwater acoustic pollution. It is therefore of truly vital importance, since the lack of research that has been mentioned in this Document (and summarized in the Epilogue), could be alleviated through monitoring systems established in the corresponding Environmental Impact Declarations, or in the management guidelines of Marine Protected Areas.

The two basic recommended avenues for monitoring and follow-up would be the following:

- Vigilance in security and exclusion zones: (understood here as "security and exclusion zone" – see section 8.2) any marine protected area or other area which by virtue of its management system or environmental impact declaration have excluded the possibility to carry out any form of activity that might generate acoustic pollution undersea. The International Whaling Commission (IWC) Scientific Committee asks that (a) continued acoustic vigilance in critical habitats of sufficient temporal and spatial scales, in relation to pre- and post-seismic activity is performed, (b) independent supervision of critical habitats (from platforms or ships) is done in order to assess displacement from critical habitats and/or the possible behavior alteration of cetaceans in critical habitats, and (c) efforts are redoubled to address and analyze strandings that might coincide with this activity[202]. In order to control exclusion zones in real time a variety of systems can be used, including onboard visual observations, aerial vigilance, and acoustic vigilance[203]. The latter, acoustic vigilance could be indispensable in some cases since it has been pointed out[204] that the possibility to control some species in other ways is very limited, even in small radii. For example, the probability of making visual contact with beaked whales is 1-2% at the most, due to their prolonged dives[205], for this species the only available option open for its monitoring is therefore the use of PAM (passive acoustic monitoring) in real time. It is important to note that all these methods of control have their advantages but can also suffer limitations and that their combined use can compensate for any shortfall. The vigilance of the security and exclusion zones must be unwavering and permanent.

- Follow-up reports (in the scope of management plans or vigilance program measures). The elaboration of follow-up reports can help to improve the lack of knowledge on behavioral reactions and other consequences related to sound exposure. These reports need not be final or permanent but rather linked to the activity or project being considered.

With regard to main monitoring and follow-up instruments, we can refer ourselves to:

- Acoustic cartography and modeling. The modeling of populations can be used in managing endangered species and in predicting impacts and benefits of possible management options[206]. However, caution must be taken when analyzing and using results taken from the models, notably when data is limited. Even the simplest of models will generally require more data (and more

[202] IWC 2004
[203] PAM, Passive Acoustic Monitoring, André *et al.* 2008, André 2009
[204] Barlow y Gisiner 2006
[205] US-MMC 2004
[206] Mas *et al.* 2008

research) than what is available at the moment to have complete confidence in the model's predictions. In particular, population models tend to suffer from lack of data in demographic rates, spatial distribution, dispersion, management response, habitat correlations and the magnitude of seasonal variations. Although physiological and behavioral responses of cetaceans faced with man-made noise have been identified, assessment of acoustic impacts on populations demands a greater effort due to the difficulties associated with the clear identification of the connection between individual behavioral responses and physiological impacts. It is essential to observe and gauge parameter changes of cetaceans' populations, taking into account the long time intervals in which populations changes are manifested in species with long life spans as the ones we are dealing with[207].

- Passive acoustic monitoring (PAM). As we have seen, marine mammals use acoustic signals intensively in order to communicate, navigate, and detect prey and predators. As with birds, many species and sub-groups can be identified by the specific signals they emit. Recording these signals enable us to reveal the presence of species in zones of interest. As sound propagates extremely efficiently in water, the range of detection can be far reaching, over 100 km in favorable conditions for low frequency signals[208]. This far surpasses the possibility of visual detection. For this it is necessary to turn to a new methodology called PAM (passive acoustic monitoring) in which a great deal of research[209] effort has been spent[210] (since 2003 dedicated biennial international workshops have been set up to treat this issue)[211].

  The locating of cetaceans' sound sources in their habitat began in the early 70's[212]. This technique was quickly put to use in the tracking of baleen whales over great distances[213]. Advances in electronics, Information Technology and numerical analysis today grant that this technique (PAM) can be applied with more cost-effective and accessible technologies, using diverse systems such as, cabled observatories, observatories connected via radio, drift buoys and arrays of autonomous recorders[214]. The objective of such passive acoustic monitoring systems is to chart a continuous map of the presence and distribution of cetaceans [215] to assess their density[216] on occasion in real time[217]. PAM´s capacity to efficiently perform these tasks depends on the elaborate characteristics of the acoustic signals it sets out to detect, on the environment, on the material used, its display and configuration.

  PAM´s performance can differ significantly from one case to the next. Success will depend on its capacity to isolate desired signals from other acoustic events and ambient[218] in which they can be incorporated, especially for distant sources and of low signal/noise (SNR). The level of the source, the attenuation of

---

[207] Wintle 2007
[208] For example, Stafford *et al.* 1998, Simard *et al.* 2006 a and b, 2008 a and b
[209] Mellinger *et al.* 2007
[210] Delory *et al.* 2007, Mellinger *et al.* 2007
[211] Desharnais *et al.* 2004, Adam 2006, Moretti *et al.* 2008
[212] Watkins and Schevill 1972
[213] Cummings and Holliday 1985, Clarke *et al.* 1986
[214] Simard *et al.* 2008b
[215] Greene *et al.* 2004, Simard *et al.* 2004, Sirovic *et al.* 2007, Stafford *et al.* 2007
[216] Ko *et al*. 1986, McDonald and Fox 1999, Clarke and Ellison 2000
[217] Thiemann and Porter 2004, André *et al.* 2009ª, 2009b, 2009c, van der Schaar *et al.* 2009, Zaugg *et al.* 2009 a and b
[218] André *et al.* 2009, Zaugg *et al.* 2009 a and b

signal due to propagation, and ambient ocean noise will define the detection ranges[219].

Acoustic signals of cetaceans vary considerably in time and frequencies, from the infrasonic components of baleen whales to the ultrasonic sonar "clicks" signals of toothed whales which also vary in amplitude between species and within the vocal repertoire of same species[220]. The ocean also boasts a considerable noise level and variability in time and space, in response to the fluctuations of natural sound sources, such as wind, ice, rain or the biological sounds sent out by diverse organisms, besides anthropogenic sources[221]. The characteristics of the speed of sound in the water column can focus sounds coming from distant sources in acoustic channels. The 3-D spatial layout of the sources and hydrophones, and their depth in relation with the acoustic channel are indeed of great interest for the development of PAM. PAM's optimum configuration can be studied by simulator models[222]. Localization can be favored by the knowledge of precise arrival times[223]. "Arrival times" are also affected by some low[224] SNR (Signal to Noise Ratio) and by the multi-trajectory propagation conditions where direct, reflected and refracted signals superimpose. The precision of the "arrival times" can be finalized with the correct synchronization of the antennae[225].

The Epilogue of this work includes the list of research activities that are urgently required to cover the wide gaps in the existing scientific knowledge. Even though a good deal of these activities should be the subject of scientific research agendas, other key areas could be looked at, even partially, if in the follow-up and mitigation programs set out in the Environmental Impact Assessment framework, or in Marine Protected Area management plans, they will have taken into account some concrete activities which the promoters and/or managers will be in condition to embrace.

These activities will be as follows:

- Examine stranded individuals in order to detect the acoustic sensitivities of the different cetacean species through electrophysiological study of the stranded individuals (auditory evoked potential)
- Postmortem study of the acoustic pathways to determine the possible injuries, related to artificial sound source exposure
- Comparative postmortem study of the presence of injury in "non-auditory" organs.

[219] See Sirovic *et al.* 2007, Stafford *et al.* 2007, Simard *et al.* 2008b
[220] Mellinger *et al.* 2007
[221] NRT 2003
[222] Simard *et al.* 2008b, Gervaise and André 2009
[223] Spiesberger and Wahlberg 2002, Spiesberger 2004, 2005, Houegnigan *et al.* 2009
[224] Clark and Ellison 2000, Buaka Muanke and Niezrecki 2007
[225] Thode *et al.* 2006, Sirovic *et al.* 2007, Gervaise and André 2009

9. Anthropogenic noise measurements

As we have shown, even though the acceptance that man-made noise has a capacity to produce effects in marine mammals[226], the current problem facing the scientific community in attempting to weigh and establish measurements which classify the types of sounds that produce said effects, is that there are no standardized measurements for noise, nor any protocols to fulfill them.

This section will attempt to depict what measures are thought to be indispensable for the characterization of noise sources in the marine environment and the reasons why these measures should not be bound in one unique value.

Sound pressure levels. The magnitude of sound pressure levels in water are normally described as sound pressure in a decibel scale (dB) relative to a pressure reference RMS of 1µPa (dB re 1µPa). Decibels are not an intuitive magnitude and the different references which are used for air, water and the distinct characteristics of the two mediums, have wrought much confusion in the interpretations of the measurements[227]. It is clear that if a decibel sound pressure magnitude does not include any pressure reference to which it has been calculated it will not be valid, but it is equally important to specify how the magnitude was quantified. As we have seen throughout this work, in bioacoustics and sub-aquatic noise studies, "peak-to-peak", peak measurements, envelope peak, peak–RMS and RMS measures are often used. For a single impulse sound (as generated by pile driving or some cetacean clicks) the dB values can vary by 10 dB or more between these distinct measurements, rendering any comparisons useless[228]. For this reason, often enough, the measurements taken for impulse sounds are inconsistent, incomparable with other values and are of course, therefore exempt from the scrupulous demands of standardization.

All cases recommend the identification, in areas of interest, of bioindicator species and ascertain their auditory sensitivity, published in scientific literature, when faced with the introduction of anthropogenic noise sources (see section 6.2).

Even though RMS has been used to establish a safe level for marine mammals[229] and is normally used in estimating the impact of sound in the sea, these methodologies have been and continue to be rejected as a unique measurement within the scientific community for their lack of coherence[230].

Level of equivalent sound (Leq). The level of equivalent sound is established by splitting the sound pressure measurements to assess the impact of continuous sound sources (although variable in time). It is understood as the level of a continuous and constant source that in a determined period of time, will contain the same energy as the studied source variant in time.
This measurement does not take into account the particular events in time but rather gathers all of them into one single value.

Sound exposure level (SEL): Is understood as the equivalent level of sound (Leq) normalized in one second and allows the comparing of noise events of different durations.

[226] Richardson 1995
[227] Chapman and Ellis 1998
[228] Madsen 2005
[229] Nedwell *et al.* 2003
[230] Madsen 2005

Power spectral density. Until now, at no time has the frequency distribution of energy produced by acoustic sources been spoken of. Nevertheless, to determine the impact this activity may have on marine fauna, it is fundamental to obtain these types of measurements. We know that the most potentially damaging impacts on marine mammals occur as a consequence of signal masking that these produce or by the temporal or permanent displacement of its auditory threshold. Said effects are produced whenever there is overlapping between the noise spectrum and signals of interest or the frequencies that each species may perceive. For this it is important to specify i) the range of frequencies on which each level has been measured, and ii) the frequency filters used.

The levels of spectral density (dB re 1µPa²/Hz) represent the sound pressure average for each band of 1 Hz. Levels are often measured in octave bands (1 octave indicates a factor of 2 between superior and inferior frequency of the band[231]), but in both land and sea mammals, 1/3 octave bands are generally used (could be understood as the sum of the sound power of all the 1Hz bands included in the band being studied). The reasoning behind this measurement is that the effect of bandwidth for mammals seems to approach the 1/3 octave[232]. Weighing up the measurements through 1/3 octaves could be valid in some cases although one can always extract the results of power spectral densities with greater resolution. In the case of studying noise emission from any source, it is important to highlight the multi-tonal nature of any sources with which the use of high resolution frequencies become fundamental.

If the analyzed signals are continuous sounds or noise, RMS quantification can be used and in that case the distribution of noise is not taken into account. For impulse sounds, peak measurements are employed in combination with other measures such as the energy flux density that takes into account a time window depending on the energy distribution over time.

Energy flux density is formally defined as the energy traversing in a time interval over a small area perpendicular to the area of the energy flow, divided by that time interval and by that area. The energy flux density in acoustics (dB re 1 µPa² s) is a measure suitable for impulse sounds that can be approximated by 10 log to the time integral of the squared pressure over the duration of the pulse under certain assumptions[233]

For everything exposed and due to the multiple natures of noise sources there is not just one acoustic measure that will give an indication of a possible impact due to a noise source. It should be a combination of different measures, depending on the type of noise analyzed, which would allow a proper discussion on these effects. The specific measurements to take for each source are currently a matter for discussion in international forums[234] and it is not the aim of this document to constitute a reference in standard measurements but to point out the possible problems associated with inappropriate measurement protocols.

---

231 ANSI/ASA SI. 11-2004 and ANSI SI. 6-1984 Standards (see also ISO 266: 1997)
232 Richardson et al. 1995b
233 Madsen, 2005
234 TNO draft report on Measuring Underwater Sound; ANSI/ASA S12.64-2009 Quantities and Procedures for Description and Measurement of Underwater Sound from Ships; Marine Strategy Framework Directive, Task Group 11 - indicator of marine energy and noise

Before addressing activities that can cause noise pollution in the sea, within the framework of its authorization system (Environmental Impact Assessment), or by mean of its introduction in management systems of Marine Protected Areas, it is important to carry forth the following activities:

- Noise pollution measurements that the activity might provoke, like Sound Pressure Levels, Equivalent Sound Level (Leq), Sound Exposure Level (SEL), Energy Flux Density and Power Spectral Density (see section 9).

- Comparison of results obtained from the measurements with tolerance thresholds of the different species present in the area, according to currently available scientific data (Tables 3, 5, 6, 7 and 11).

- Description of the need to adopt some of the reduction measurements of the sound source (see section 8.1).

- Description of the need to adopt some of the mitigation measurements from the produced impact (see section 8.2).

Once the activity is authorized (in its case with its reduction or mitigation measurements), the following must be adopted and implemented:

- Monitoring systems by means of sound propagation modeling and acoustic cartography.

- Monitoring by means of PAM (see section 8.3).

Special attention will be paid to the necessity of addressing the following within the monitoring framework of the activity:

- The electrophysiological examination of stranded individuals in order to reveal the different acoustic sensitivities of different species (Auditory Evoked Potentials, AEP).

- The postmortem study of acoustic reception channels to establish possible injuries related to artificial sound source exposure.

- Comparative postmortem study of injuries in non-auditory organs.

Epilogue; Research needs

The research recommendations (see Table 12) represent a collective vision of the concentrated efforts that will be required in the coming decades.

Summarized below are highlighted areas of the scientific priorities in urgent need of development:

- The study of the acoustic sensitivities of cetacean species through electrophysiological research in stranded individuals (Auditory Evoked Potentials).
- Postmortem studies into the acoustic reception channels to determine the injuries that are possibly linked to exposure to artificial sound sources.
- Comparative postmortem study on the presence of injuries and lesions in "non-acoustic" organs.
- Development of passive acoustic monitoring techniques for the locating and following, in real time, of individuals and populations in areas of interest.
- Study of populations: patterns of distribution and behavior in areas of interest.
- Acoustic charting of areas of interest.
- Develop the concept of dB hearing threshold (species), for the definition of tolerance limits.
- Develop a standard protocol for the measurement of acoustic levels.

Table 12. Research recommendations for various necessary areas in order to improve future criteria for sound exposure in marine mammals (adapted and completed from Southall et al. 2007; Weilgart 2007).

Research Issue	General description	Necessary critical information
Acoustic measurements and relevant sound sources	Detailed measurements on source levels, frequency content and sound field radii around intense/chronic sound sources	Exhaustive and calibrated measurements of the properties of man-made acoustic sources, including propagation depending on frequency and the received characteristics in different environments.
Measurement of ambient noise	Systematic measurement of sub-aquatic marine environment noise necessary to quantify how human activity affects them in the acoustic medium. Real time monitoring for decision making in the event of negative impact.	Exhaustive and calibrated measurements of ambient noise, including spectral, temporal and directional aspects in different ocean environments.
Risk assessment studies	Work on the assessment of risk in accumulated effects and synergies from noise and other exposures to individuals and populations.	Research on the effects of noise in ecological and dynamic processes in populations together with accumulated and synergetic effects from noise and other environmental stress elements. In order to obtain in-depth information of impacts on populations, long term systematic observations are necessary in known cetacean populations. Individuals need to be studied under different noise conditions using ongoing activities which produce noise to avoid adding further noise to the environment.
"Absolute" auditory measurements	Audiometric data in order to determine the functional wideband, differences between species and individuals, dynamic auditory ranges, detection of thresholds for realistic biological stimuli. Auditory Evoked Potentials.	Behavioral measurements and electrophysiological controls of the auditory sensitivity vs. frequency for more individuals and species, particularly for high priority species such as beaked and baleen whales. Detection thresholds for complex biological signals.

Analysis of the auditory scenario	Measurements to determine the sophisticated perceptive capacities and processes of marine mammals that allow them to detect and find sounds in complex environments.	Measures of segregating currents, spatial perception, localization and multidimensional detection of sources (in individuals habituating in noisy areas compared with individuals control, frequency discrimination, temporal resolution and feedback mechanisms between sound pressure and the auditory system.
Behavioral responses of marine mammals exposed to sounds	Various methods of measurement of behavioral reactions are needed for many sources of sound including all the acoustically relevant contextual variables and responses.	Observational experiments and exposures constructed for consideration, not only on the received level but also the source range, movement, SNR (signal to noise ratio) and detailed information on receptors, including the point of departure behavior (before sound exposure) and the response during the test.
Effects of sound exposure on the hearing of marine mammals: masking, PTS and TTS	A continued and analytical effort is needed on the effects of sound exposure on the hearing of marine mammals as with the understanding of their basic acoustic capacities.	Auditory thresholds of masking for single stimulus in more species and individuals, as with complex biological signals and realistic masking sources. Consider directional effects: data compared in the first appearance of TTS and growth in a greater number of species and individuals for anthropogenic pulsed and non pulsed sources; recuperative functions after one and between repeated exposures. Direct rigorous and complete analysis of stranded animals, to be conveniently used in constraints. Stranding networks must be expanded globally, standardizing postmortem protocols, with ongoing and continuous updating and sharing of information and techniques as they advance to detect acoustic lesions. (E.g. the analysis of ear pathologies).
Effects on non-auditory systems in marine mammals after exposure to sound	Physiological measurements are needed for sharp/chronic sound exposure conditions to investigate the effects on non-auditory systems.	Measurements from various starting points and conditions of exposure, including saturation levels of nitrogen, bubble nuclei, the formation of hemorrhages, embolisms/or lesions, stress level hormones and cardiovascular responses to sharp/chronic sound exposure.
Extremely sensitive species: beaked whales	Information on this relatively unknown group to asses their susceptibility to certain anthropogenic sound sources.	Various studies, including measurements and models related with 1) auditory sensitivity, 2) diving and vocalization parameters, 3) tissue properties, 4) formation of gas/fat embolisms and its importance, 5) analysis of the ear structures in stranded animals, 6) advanced detection capacity for the locating and following of beaked whales, 7) behavioral reactions to various acoustic sources, man-made and natural.
Definition of exclusion zones	More research is needed for the determination of safe areas and their vigilance (acoustic and visual monitoring), such as geographic and seasonal restrictions on developing acoustic activity.	To avoid sound exposure in a great number of cetaceans and other marine organisms, studies must be carried out in the following areas to: - identify “hot spots” and “cold spots” or ocean deserts for marine life where it will be more adequate for the performance of activities which produce high sound levels. - define safe zones around sites where anthropogenic noise generating activities are being carried out.

Annex I – Glossary of terms

Shallow Water; effective for this work, < 200 meters

Deep Water; effective for this work, > 200 meters

Seismic Array; a seismic array is a small extended net with sensors situated in predetermined positions. The control of an array is simpler than that of a seismic net since the sensors are spread over a smaller area. It is possible to locate earthquakes (epicenters) with an array. Data sent by the sensors is gathered and processed by software in an instant as soon as the shockwaves have been recorded. There is no need to search for the propagation of the seismic waves in detection stations, since the moment the shockwave has crossed the arrays sensors, it has been already precisely located.

Cavitation; phenomenon by which bubbles form where the pressure has fallen below the fluid's vapor pressure. The collapse of the vapor bubbles that follows, produces shock waves (noise) which in turn produces a noise with the capacity to damage mechanical structures, for which it is generally considered undesirable with particular regard to ship's propellers.

Decibel; "unit" that expresses the logarithmic dependence relative to a certain value of reference. Any physical magnitude or any gain or loss can be expressed in dB. In the case of physical magnitude, the value of reference must be explicitly expressed after the dB symbol.

Duration; the length of sound measured in seconds. Duration is important as it affects other sound measurements, particularly "root mean square" and/or RMS. Sound duration can be difficult to estimate due to reverberation.

Temporary Threshold Shift (TTS); this constitutes a temporal elevation in the auditory threshold caused by exposure to a sound with full recovery expected after a period of time.

Echolocation; an object can be found by means of echolocation which is the emission of a pulse and the subsequent reception of the resulting echo. The elapsed time between the emission and the echo's reception allows for the calculation of the distance between the emitting source and the object.

Doppler Effect; named after the Austrian Christian Doppler, consists in the variation of the wavelength of any type of wave, emitted or received by an object in movement.

Masking; occurs when a noise reduces, partially or fully the audibility of a signal.

Frequency; is the number of oscillations a harmonic wave produces in one second. Its unit measure is Hz. Any periodic wave can be decomposed in fundamental frequency component and its multiples.

Hertz (Hz); a Hertz is the unit measurement of frequency. It represents one cycle per second, "cycle" meaning the repetition of an event. In case of pure tones, the cycle is the period of the signal. In another periodic signal, the cycle is the period of its fundamental components.

Peak Sound Pressure (Pmax); is the maximum absolute value of a sound pressure measured in a fixed interval of time and expressed in Pascal units (Pa).

Sound Exposure Level (SEL); in order to compare sounds of various kinds and duration, SEL is defined as the pressure level of a constant wave which, if maintained for 1 second, will generate the same acoustic energy to the receiver as the sound being studied. It basically deals with a Leq normalized in one second.

Threshold; is the minimum level in which a sound can be perceived.

Source Level; or level of sound emission measured at 1 meter from the source.

Sound Pressure Level (Lp); is defined as 20 times the logarithmic relationship of the efficient sound pressure with respect to a pressure reference p0, value of 1 μ Pa in the case of water.

Leq; is defined as the pressure level of a constant wave, which if maintained during the same duration as the signal being studied, will generate the same acoustic energy. It is a comparative measurement between different sounds of the same duration.

Received Level (RL); is the level of the sound emission measured in the receiver.

Non-impulsive sound; basically a stationary sound of a relatively long duration (opposite to a short-term sound to a pulse).

Pascal (Pa); is the unit of pressure of the System International (SI). It is defined as the pressure exerted of 1 Newton on a surface of 1 square meter. This unit was named in honor of Blaise Pascal, eminent mathematician, physicist and French philosopher. (Pressure is named for the magnitude that measures the force exerted over a unit of surface).

Peak-to-peak; is the algebraic difference between the maximum positive and the maximum negative of a signal.

Pingers; are emitters of acoustic signals highly bothersome to cetaceans, which are deployed as acoustic dissuasive devices (ADD) to frighten away cetaceans from specific areas.

Pulse; basically a transient (short duration) type of sound (opposite to a non impulsive sound).

Ramp-up; Process consisting of a gradual increase of sound pressure level produced by a source.

Annex II. List of abbreviations

- ACDP; Acoustic Doppler Current Profiler
- ACM; Acoustic Current Meter
- AEP; Auditory Evoked Potentials
- ADD; Acoustic Deterrent Device
- AHD; Acoustic Harassment Device
- ATOC; Acoustic Thermometry of Ocean Climate
- CMS; Convention of Migratory Species
- dB; Decibel
- Hz; Hertz
- IWC; International Whaling Commission
- LFA; Low Frequency Active (SURTASS)
- OSHA; Occupational Safety and Health Administration
- Pa; Pascal
- PAM; Passive Acoustic Monitoring
- Pmax; Maximum Sound Pressure
- PTS; Permanent Threshold Shift – Permanent hearing loss after auditory threshold change
- RAFOS; Ranging and Fixing of Sound - drift devices periodically emitting from ocean depths in a high density tone or a continuous signal with duration of 80 seconds or more.
- RL; Received Level
- SEL; Sound Exposure Level
- SPL; Sound Pressure Level
- TTS; Temporal Threshold Shift - temporary impairment of hearing

ANEXO III. Bibliography

- ACCOBAMS 2004: Second Meeting of Parties, Res. 2.16, "Assessment and Impact Assessment of Man Made Noise."
- Adam, O. 2006. (ed). Proceedings of the 2005 workshop on detection and localisation of marine mammals using passive acoustics. Applied Acoust. 67(10-11).
- André, M., Kamminga, C. and Ketten, D. 1997a. Are Low Frequency Sounds A Marine Hearing Hazard: A Case Study in the Canary Islands Proc. I.O.A. 19 (9):77-84.
- André, M., Terada, M., y Watanabe, Y. (1997). Sperm whale (Physeter macrocephalus) behavioural response after the playback of artificial sounds. Report of the International Whaling Commission, 47, 499-504.
- André, M., Supin, A., Delory, E., Kamminga, C., Degollada, E., Alonso, J.M. Evidence of deafness in a striped dolphin, Stenella coeruleoalba. Aquatic Mammals, Vol. 29, issue 1, p.3-8, 2003
- André, M., Delory, E., Degollada, E., Alonso, J.M., del Río, J., van der Schaar, M., Castell, J.V., Morell, M. Identifying Cetacean Hearing Impairment at Stranding Sites. Aquatic Mammals Special Issue, vol 33, issue 1, p.100-109, 2007
- André, M., y Nachtigall, P. E. (2007). Electrophysiological measurements of hearing in marine mammals. Aquatic Mammals, 33, 1-5.
- André, M., van der Schaar, M., Zaugg, S., Houegnigan, L., Mas, A., Morell, M., Solé, M., Sánchez, A. And Castell, J.V. 2009a. From deep-sea observatories passive acoustic monitoring to RT mitigation of noise impact. 4th International Workshop on Detection, Classification and Localization of Marine Mammals using Passive Acoustics. Pavia, Italy, 2009.
- André, M. Listening to the Deep-Ocean Environment in a changing climate. 2009b. 23rd Conference of the ECS, Istanbul, Turkey.
- André, M., van der Schaar, M., Mas, A., Romà, A., Castell, J.V., Morell, M., Solé, M., Rolin, J.F., Pearson, R. 2009c Real-time acoustic monitoring of the deep-ocean environment. Bioacoustics, The International Journal of Animal Sound and its Recording 17, 231-291
- André, M., Vallez, S., Gervaise, C., Sánchez, A., van der Schaar, M., Mas, A., Morell, M. Monitoring the ocean noise interactions 22nd Annual Conference of the European Cetacean Society, Egmond and Zee, The Netherlands, p.78, Mar 2008
- André, M., 2009. The sperm whale sonar: Monitoring and use in mitigation of anthropogenic noise effects in the marine environment NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 602(1):262-267..
- ASCOBANS 2003: Fourth Meeting of Parties, Res. 5, "Effects of Noise and of Vessels".
- Au, W. W. L. and P. W. B. Moore (1984). Receiving beam pattern and directivity indices of the Atlantic bottlenose dolphin. J Acoustic Soc Am 75: 255-262
- Au, W.W.L., Carder, D.A., Penner, R.H. and Scronce, B.L. 1985. Demonstration of adaptation in beluga whale echolocation signals. J. Acoust. Soc. Am. 77:726-730.
- Au, W.W.L. (ed.) 1993. The Sonar of Dolphins. Published by Springer - Verlag, New York Inc. 275pp.
- Au, W.W.L. and Nachtigall, P.E. 1993. The effects of noise on dolphin echolocation. J. Acoust. Soc. Am. 94(5).
- Au, W. W. L., Nachtigall, P. E., y Pawloski, J. L. (1997). Acoustic effects of the ATOC signal (75 Hz, 195 dB) on dolphins and whales. Journal of the Acoustical Society of America, 101, (5) 2973-2977.
- Au, W.W.L., Nachtigall, P.E. and Pawlowski, J.L. (1999). Temporary threshold shift in hearing induced by an octave band of continuous noise in the bottlenose dolphin. *J. Acoust. Soc. Am*. 106, 2251.
- Au, W.W.L. y Green, M. (2000) Acoustic interaction of humpback whales and whale-watching boats. Marine Environmental Research, 49, 469–481.

- Au, W.W.L., Benoit-Bird, K.J., Kastelein, R.A., 2007. Modelling the detection range of fish by echolocating bottlenose dolphins and harbor porpoises. Journal of the Acoustical Society of America 121, 3954-3962.
- Awbrey, F. T., y Stewart, B. S. (1983). Behavioral responses of wild beluga whales (Delphinapterus leucas) to noise from oil drilling. Journal of the Acoustical Society of America, 74, S54.
- Baker, C. S., Herman, L. M., Bays, B. G., y Stifel, W. F. (1982). The impact of vessel traffic on the behavior of humpback whales in southeast Alaska. Honolulu: Research from Kewalo Basin Marine Mammal Laboratory for U.S. National Marine Fisheries Service, Seattle, WA. 78 pp.
- Bain, D.E. & Williams, R. 2006: Long-range effects of airgun noise on marine mammals: Responses as a function of received sound level and distance. – IWC-SC/58E35.
- Baird, I.G., Mounsouphom, B. and Stacey, P. 1994. Preliminary Surveys of Irrawaddy Dolphins (Orcaella brevirostris) in Lao PDR and Northeastern Cambodia. Rep. IWC. 44:367-369. Bauer, G.B., Mobley, J.R. and Herman, L.M. 1993. Responses of wintering humpback whales to vessel traffic. J. Acoust. Soc. Am. 94 (5).
- Balcomb, K.C III 2006: Statement for the Report of the Advisory Committee on Acoustic Impacts on Marine Mammals to the Marine Mammal Commission, pp. A-1 – A-3. http://mmc.gov/sound/committee/pdf/soundFACAreport.pdf
- Barlow, J. & Gisiner, R. 2006: Mitigating, monitoring and assessing the effects of anthropogenic sound on beaked whales. Journal of Cetacean Research and Management 7(3): in press.
- Bauman, R. A., N. Elsayed, J. M. Petras and J. Widholm (1997). Exposure to sublethal blast overpressure reduces the food intake and exercise performance of rats. Toxicology 121(1): 65-79.
- Biassoni, N., Miller, P. J., y Tyack, P. L. (2000). Preliminary results of the effects of SURTASS-LFA sonar on singing humpback whales (Technical Report #2000-06). Woods Hole, MA: Woods Hole Oceanographic Institute. 23 pp.
- BODC/British Oceanographic Data Centre 2006: Monitoring the Atlantic Inflow toward the Arctic (MAIA). http://www.bodc.ac.uk/projects/european/maia/
- Bohne, B.; J. Thomas, E. Yohe and S. Stone. 1985. Examination of potential hearing damage in Weddell seals (Leptonychotes weddelli) in McMurdo Sound, Antarctica. Antarct. J., 20:174-176.
- Bordino, P., Kraus, S., Albareda, D., Fazio, A., Palmerio, A., Mendez, M. y Botta, S. (2002) Reducing incidental mortality of Franciscana dolphin Pontoporia blainvillei with acoustic warning devices attached to fishing nets. Marine Mammal Science, 18, 833–842.
- Boyd, I., R. Brownell, D. Cato, Chris Clark, D.P. Costa, P. Evans, J. Gedamke, R. Gentry, R. Gisiner, J. Gordon, P. Jepson, P. Miller, L. Rendell, M. Tasker, P. Tyack, E. Vos, H. Whitehead, D. Wartzok, W. Zimmer. 2008. The effects of anthropogenic sound on marine mammals: A draft research strategy. European Science Foundation Marine Board Position Paper 13. 24 pp.
- Bowles, A. E., M. Smultea, B. Wursig, 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(4): 2469-2484.
- Buaka Muanke, P., and Niezrecki, C. 2007. Manatee position estimation by passive acoustic localization. J. Acoust. Soc. Am. 121: 2049-2059. Canada 2008 Species at risk registry. http://www.registrelep.gc.ca/default_e.cfm
- Britt, J. R., Eubanks, R. J., y Lumsden, M. G. (1991). Underwater shock wave reflection and refraction in deep and shallow water. In A user's manual for the REFMS code (Version 4.0) (Volume 1). St. Joseph, LA: Science Applications International Corporation.
- Brownell, R.L. jr. 2004: Oil development threats to western grey whales off Sakhalin Island. – IWC SC/56/BRG39.

- Brownell, R.L. jr. 2005: Overview of recent stranding database. – ECS Workshop: Research priorities to reduce risk to beaked whales from military sonar. La Rochelle, 3 April 2005.
- Brownell, R.L. jr., Mead, G.G.; Van Helden, A.L.; Yamada, T.K. & Frantzis, A. 2005: Worldwide mass strandings of beaked whales: Retrospective review and causes. – Presentation/Abstract 19th Annual Conference of the European Cetacean Society, La Rochelle, 2-7 April 2005.
- Bryant, P. J., C. M. Lafferty and S. K. Lafferty 1984. Reoccupation of Laguna Guerrero Negro, Baja California, Mexico, by gray whales. Pp 375-386 in The Gray Whale Eschrichtius robustus. M. L. Jones (ed.), Academic Press, Orlando, Fl.
- Buckstaff, K. C. (2004). Effects of watercraft noise on the acoustic behavior of bottlenose dolphins, Tursiops truncatus, in Sarasota Bay, Florida. Marine Mammal Science, 20, 709-725.
- Calambokidis, J., Chandler, T.E., Costa, D.P., Clark, C.W. and Whitehead, H. 1998. Effects of the ATOC Sound Source on the Distribution of Marine Mammals Observed from Aerial Surveys off Central
- Cawthorn, M.W. 1992. New Zealand. Progress Report on Cetacean Research, April 1990 to April 1991. Rep. IWC. 42:357-360.
- Caldwell, J. & Dragoset, W. 2000: "A brief overview of seismic airgun-arrays". The Leading Edge 19(8): 898-902.
- CCC/California Coastal Commission 2002: Consistency Determination No. CD-14-02, USGS, 2002 Southern California seismic survey.
- CDoT/California Department of Transport 2001b: San Francisco – Oakland Bay Bridge East Span Seismic Safety Project – Pile Installation Demonstration Project, August 2001, "Marine Mammal Impact Assessment". – PIDP EA 012081, Caltrans Contract 04A0148, Task Order 205.10.90 PIDP 04-ALA-80-0.0/0.5.
- Chapman, D. M. F., and Ellis, D. D. 1998. ''The elusive decibel: Thoughts on sonar's and marine mammals,'' Can. Acoust. 26, 29–31.
- Clark, C.W.; W.T. Ellison and K. Beeman. 1986. Acoustic tracking of migrating bowhead whales. p. 341-346 In: *Oceans '86 Conf. Record*, Vol. 1. IEEE, Piscataway, NJ.
- Clark, C.W., Tyack, P., Ellison, W.T. 1998. Quicklook, Low-Frequency Sound Scientific Research Program. Phase I: Responses of Blue and Fin Whales to SURTASS LFA, Southern California Bight, 5 September – 21 October, 1997. Report dated February 27, 1998. 5pp.
- Clark, C.W., and Ellison, W.T. 2000. Calibration and comparison of the acoustic location methods used during the spring migration of the bowhead whale, Balaena mysticetus, off Pt. Barrow, Alaska, 1984-1993. J. Acoust. Soc. Am. 197: 3509-3517.
- Cox, T.M., Read, A.J., Solow, A. y Tregenza, N. (2001) Will Harbour porpoises (Phocoena phocoena) habituate to pingers? Journal of Cetacean Research and Management, 3, 81–86.
- Cox, T.M., Read, A.J., Swanner, D., Urian, K. y Waples, D. (2004) Behavioral responses of bottlenose dolphins, Tursiops truncatus, to gillnets and acoustic alarms. Biological Conservation, 115, 203–212.
- Crane, N.L. and Lashkari, K. 1996. Sound production of grey whales Eschrichtius robustus, along their migration route: A new approach to signal analysis. J. Acoust. Soc. Am. 100 (3):1878-1886.
- Croll, D. A., Clark, C. W., Calambokidis, J., Ellison, W. T., y Tershy, B. R. (2001). Effects of anthropogenic low frequency noise on the foraging ecology of Balaenoptera whales. Animal Conservation, 4, 13-27.
- Crum, L.A. and Y. Mao. 1993. Calculations of the thresholds for growth and the growth rate of bubbles in mammalian tissues from exposure to low frequency sound. Report No. C-193, US Naval Submarine Medical Research Laboratory, Naval Submarine Base New London, Groton, CT, Dec 31, 1993.
- Crum, L.A. y Mao, Y. (1996) acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. Journal of the Acoustical Society of America, 99, 2898–2907.

- Cudahy, E., E. Hanson and D. Fothergill 1999. Summary Report on the Bio effects of Low Frequency Water Bourne Sound. Naval Submarine Medical Research Laboratory, Groton, CT 29 pp.
- Cudahy, E. and W.T. Ellison. 2002. A review of the potential for in vivo tissue damage by exposure to underwater sound, report for the Department of the Navy. Department of the Navy, Washington, D.C
- Culik, B.M., Koschinski, S., Tregenza, N. y Ellis, G.M. (2001) Reactions of harbor porpoises Phocoena phocoena and herring Clupea harengus to acoustic alarms. Marine Ecology-Progress Series, 211, 255– 260.
- Cummings, W.C., and Holliday, D.V. 1985. Passive acoustic location of bowhead whales in a population census off Point Barrow, Alaska. J. Acoust. Soc. Am. 78: 1163-1169.
- Dahlheim, M.E. 1993. Responses of grey whales, Eschrichtius robustus, to noise. J. Acoust. Soc. Am. 94 (5).
- Dalton, R. 2006: More whale strandings are linked to sonar. – Nature 440 [News]: 594.
- D'Amico, A. (ed.) 1998: Summary Record, NATO-SACLANTCEN Bioacoustics Panel, La Spezia, Italy, 15 June 1998. – NATO-SACLANTCEN M-133 with Annex A-CCC, Unclassified.
- David, J.A. 2006: Likely sensitivity of bottlenose dolphins to pile-driving noise. – Water and Environment Journal 20: 48–54.
- Degollada, E.; Arbello, M.; André, M.; Blanco, A. & Fernández, A. 2003: Preliminary ear analysis report of the 2002 Canary Islands beaked whale mass stranding. – European Cetacean Society (ECS) 17th Annual Conference, Gran Canaria, 9-13 March 2003.
- Delory, E., André, M., Navarro Mesa, J.-L. and van der Schaar, M. 2007. On the possibility of detecting surfacing sperm whales at risk of collision using others' foraging clicks. J. Mar. Biol. Ass. UK 87: 47–58.
- Desharnais, F. 2004. (ed). Proceedings of the 2003 workshop on detection and localisation of marine mammals using passive acoustics. Can. Acoustics 32(2).
- DeRuiter, S.L.; Tyack, P.; Lin, Y.-T.; Newhall, A.E.; Lynch, J. & Miller, P.J.O. 2006: Modeling acoustic propagation of airgun array pulses recorded on tagged sperm whales. – IWC-SC/58/ForInformation1.
- Dragoset, W. 1990: "Airgun array specs: A tutorial". Geophysics 24-32.
- Edds, P.L. and Macfarlane, J.A.F. 1987. Occurrence and general behavior of balaenopterid cetaceans summering in the St Lawrence Estuary, Canada. Can. J. Zool. 65:1363-1376.
- Engås, A., Løkkeborg, S., Ona, E., and Soldal, A.V. 1993. Effects of seismic shooting on catch and catch availability of cod and haddock. Fisken Havet No. 9.
- Environment Australia 2001: Guidelines on the application of the Environment Protection and Biodiversity Conservation Act to interactions between offshore seismic operations and larger cetaceans, ISBN 064254784X (Oct. 2001).
- Erbe, C. 1997. The masking of beluga whale (Delphinapterus leucas) vocalizations by icebreaker noise. Ph.D. Thesis, University of British Columbia, Canada. 215 pp. Ross, D. 1987. Mechanics of Underwater Noise. Peninsula Publishing Co, Los Altos, CA.
- Erbe, C. and D. M. Farmer (1998). Masked hearing thresholds of a beluga whale (Delphinapterus leucas) in icebreaker noise. Deep-Sea Research Part II-Topical Studies in Oceanography 45(7): 1373-1388.
- Erbe, C., A. R. King, M. Yedlin and D. M. Farmer (1999). Computer models for masked hearing experiments with beluga whales (Delphinapterus leucas). J Acoust Soc Am 105(5): 2967-2978.
- Erbe, C. (2000). Detection of whale calls in noise: performance comparison between a beluga whale, human listeners, and a neural network. J Acoust Soc Am 108(1): 297-303.

- Erbe, C. y Farmer, D.M. (2000) Zones of impact around icebreakers affecting beluga whales in the Beaufort Sea. Journal of the Acoustical Society of America, 108, 1332–1340.
- Erbe, C. (2002) Underwater noise of whale-watching boats and potential effects on killer whales (Orcinus orca), based on an acoustic impact model. Marine Mammal Science, 18, 394–418.
- Espinosa De Los Monteros, A.; Arbelo, M.; Castro, P.; Martín, V.; Gallardo, T. & Fernández, A. 2005: New beaked whale mass stranding in Canard Islands associated with naval military exercises (Majestic Eagle). Presentation/Abstract – 19th Annual Conference of the European Cetacean Society, La Rochelle, 2nd-7th April 2005.
- Evans, P.G.H., Canwell, P.J. and Lewis, E.J. 1992. An experimental study of the effects of pleasure craft noise upon bottlenose dolphins in Cardigan Bay, West Wales. European Research on Cetaceans 6: (Ed) P.
- Evans, P.G.H., Lewis, E.J. and Fisher, P. 1993. A Study of the Possible Effects of Seismic Testing Upon Cetaceans in the Irish Sea. Sea Watch Foundation, Oxford, December 1993.
- Evans, P.G.H., Carson, Q., Fisher, P., Jordan, W., Limer, R. and Rees, I. 1994. A Study of the Reactions of Harbour Porpoises to Various Boats in the Coastal Waters of S.E. Shetland. European Cetacean Society Newsletter No 21. Spring / summer 1994.
- Evans, D. L. and G. R. England (2001). Joint Interim Report Bahamas Marine Mammal Stranding Event of 14-16 March 2000. Washington, D.C., US Department of Commerce and US Navy, 61 pp. Available at: www.nmfs.noaa.gov/prof_res/overview/Interim_Bahamas_Report.pdf.
- Fernández, A. 2004: Pathological findings in stranded beaked whales during the naval military manoeuvres near the Canary Islands. – pp. 37-40 in: Evans, P.G.H. & Miller, L.A. (eds.): European Cetacean Society 17th Annual Conference. Proceedings of the workshop on Active Sonar and Cetaceans. Las Palmas, 8.03.2003. – ECS Newsletter No. 42 - Special Issue Feb. 2004.
- Fernández, A.; Arbelo, M.; Deaville, R.; Patterson, I.A.P.; Castro, P.; Baker, J.R.; Degollada, E.; Ross, H.M;, Herráez, P.; Pocknell, A.M.; Rodríguez, F.; Howie, F.E.; Espinosa, A.; Reid, R.J.; Jaber, J.R.; Martin, V.; Cunninghan, A.A. & Jepson, P.D. 2004: Beaked Whales, Sonar and Decompression Sickness. – Nature 10: 1038.
- Fernández, A.; Mendez, M. ; Sierra, E. ; Godinho, A. ; Herráez, P. ; Espinosa de los Monteros, A.; Rodríguez, F.; & Arbelo, M. 2005 a: New gas and fat embolic pathology in beaked whales stranded in the Canary Islands. Presentation/Abstract – European Cetacean Society's 19th Annual Conference, La Rochelle, 2nd-7th April 2005.
- Fernández, A.; Edwards, J. F. ; Rodríguez, F.; Espinosa de los Monteros, A.; Herráez, P.; Castro, P.; Jaber, J. R.; Martín, V. & Arbelo, M. 2005 b: Gas and fat embolic syndrome involving a mass stranding of Beaked Whales (Family Ziphiidae) exposed to anthropogenic sonar signals. – Veterinary Pathology, 42:446-457.
- Fernández, A. 2006 a: Varamiento y Muerte de Zifios (*Z. cavirostris*) en las Costas de Almeria (Andalucía), España (26-27 de Enero de 2006)/ Beaked whale (*Z. cavirostris*) mass stranding on Almería´s coasts in Southern Spain"(26th – 27th January, 2006). - Universidad de Las Palmas de Gran Canaria, Nota de Prensa: Informe patológico zifios Almería/Press release: Preliminary pathological study.
- Fernández, A. 2006 b: Pathology of stranded beaked whales associated 'temporally and spatially' with naval exercises. – in: Report of the IWC Scientific Committee 2006 (IWC/58/Rep1), para 12.3.7, pp. 52 and Report of the Standing Working Group on Environmental Concerns ("E") of the IWC Scientific Committee, Annex K, para 8.5.1, pp. 27-30.
http://www.iwcoffice.org/_documents/sci_com/SCRepFiles2006/SCREPNEW-GPD.pdf.
http://www.iwcoffice.org/_documents/sci_com/SCRepFiles2006/Annex%20K[FINAL]sq.pdf
- Finley, K.J., Miller, G.W., Davis, R.A. and Greene, C.R. 1990. Reactions of belugas Delphinapterus leucas, and narwhals, Monodon monoceros, to ice-breaking ships in the Canadian high arctic. Canadian Bulletin of Fisheries and Aquatic Sciences, 224, 97-117.

- Finneran, J.J., Schlundt, C.E., Carder, D.A., Clark, J.A., Young, J.A., Gaspin, J.B. y Ridgway, S.H. (2000) Auditory and behavioral responses of bottlenose dolphins (Tursiops truncatus) and a beluga whale (Delphinapterus leucas) to impulsive sounds resembling distant signatures of underwater explosions. Journal of the Acoustical Society of America, 108, 417–431.
- Finneran, J. J., C. E. Schlundt, R. Dear, D. A. Carder and S. H. Ridgway (2002). Temporary shift in masked hearing thresholds in odontoceti after exposure to single underwater impulses from a seismic water gun. J Acoust Soc Am 111(6): 2929-2940.
- Finneran, J. J., Carder, D. A., Schlundt, C. E., y Ridgway, S. H. (2005). Temporary threshold shift (TTS) in bottlenose dolphins (Tursiops truncatus) exposed to mid-frequency tones. Journal of the Acoustical Society of America, 118, 2696-2705.
- Finneran, J. J., Schlundt, C. E., Branstetter, B., y Dear, R. L. (2007). Assessing temporary threshold shift in a bottlenose dolphin (Tursiops truncatus) using multiple simultaneous auditory evoked potentials. Journal of the Acoustical Society of America, 122, 1249-1264.
- Fletcher, H. F. (1940). Auditory patterns. Review of Modern Physics, 12, 47-65.
- Fletcher, E. R., J. T. Yelverton and D. R. Richmond 1976. The thoracic-abdominal system's response to underwater blast. Final Technical Report for ONR contract N00014-75-C-1079, Arlington, VA. pp.
- Foote, A. D., Osborne, R. W., y Hoelzel, A. R. (2004). Whale-call response to masking boat noise. Nature, 428, 910.
- Frankel, A.S. and Clark, C.W. 1998. Effects of Scaled ATOC playbacks on the Behavior of Humpback Whales in Hawaii. The World Marine Mammal Science Conference 20-24 January 1998. Abstracts p46.
- Frantzis, A. 1998: Does acoustic testing strand whales? Nature, 392:29.
- Frantzis A. & Cebrian, D. 1999: A rare, atypical mass stranding of Cuvier's beaked whales. Cause and implications for the species biology. – In: European Research on Cetaceans - 12. Proc. 12th Ann. Conf. ECS, Monaco, 20-24 January 1998, pp. 332-335.
- Frantzis, A. 2004. The first mass stranding that was associated with the use of active sonar (Kyparissiakos Gulf, Greece, 1996). Pp. 14-20 in: Evans, P.G.H. & Miller, L.A. (eds.) 2004: European Cetacean Society 17th Annual Conference: Proceedings of the Workshop on Active Sonar and Cetaceans. Las Palmas, Gran Canaria, 8th March 2003, European Cetacean Society Newsletter, No. 42. Special Issue.
- Fristrup, K. M., Hatch, L. T., y Clark, C. W. (2003). Variation in humpback whale (Megaptera novaeangliae) song length in relation to low-frequency sound broadcasts. Journal of the Acoustical Society of America, 113, 3411-3424.
- Gascard, J-C. & Rouault, C. 2004: Arctic-Sub arctic Ocean Flux Array for European Climate: North (ASOF-N) – Annual Report 2004, WP 1 Status report of float deployment. http://www.awi-bremerhaven.de/Research/IntCoop/Oce/ASOF/results-reports/deliv-2004/D_1_2.pdf#search=%22RAFOS%20site%3Aawi-bremerhaven.de%22
- Gausland, I. 2003: Seismic Surveys Impact on Fish and Fisheries. – Report for Norwegian Oil Industry Association (OLF).
- Geiger, A. & Jeffries, S. J. 1986: Evaluation of seal harassment techniques to protect gillnetted salmon. – Final Report to U.S. Marine Mammal Commission, Contract Rpt. #83-ABC-00133. 27 pp.
- Geraci, J.R. and St. Aubin, D. 1980. Offshore petroleum resource development and marine mammals: a review and research recommendations. Mar. Fish. Rev. 42 (11):1-2.
- Gervaise, C. And André, M. 2008. Théorie de l'estimation appliquée à l'étude de performance d'un système anti-collision entre navires et cachalots / Optimal designo f a whale anti-collision system. Journal de Traitement du Signal. Caractérisation du milieu marin. Vol25(1-2):13-28
- Glockner-Ferrari, D.A. and Ferrari, M.J. 1985. Individual identification, behavior, reproduction, and distribution of humpback whales, Megaptera novaeangliae, in Hawaii. MMC-83/06. U.S. Mar. Mamm. Comm., Washington, DC.
- Goold, J.C. 1996. Acoustic assessment of populations of common dolphin Delphinus delphis in conjunction with seismic surveying. J. Mar biol. Ass. 76:811-820.

- Goold, J.C. and Fish, P.J. 1998. Broadband spectra of seismic survey air-gun emissions, with reference to dolphin auditory thresholds. Journal of the Acoustical Society of America, 103, 2177-2184.
- Goold, J.C. & Coates, R.F.W. 2006: Near Source, High Frequency Air-Gun Signatures. – IWC-SC/58/E30.
- Gordon, J., Leaper, R., Hartley, F. G., y Chappell, O. (1992). Effects of whale-watching vessels on the surface and underwater acoustic behaviour of sperm whales off Kaikoura, New Zealand. In Science and research series (p. 64). Wellington: New Zealand Department of Conservation, Wellington, N.Z.
- Gordon, J. and Moscrop, A. 1996. Underwater Noise Pollution and its Significance for Whales and Dolphins, In: Mark Simmonds and JD Hutchinson (eds) The Conservation of Whales and Dolphins.
- Gordon, J., Gillespie, D., Rendall, L.E. and Leaper, R. 1998a. Playback of low power ATOC-like sound to sperm whales. The World Marine Mammal Science Conference 20-24 January 1998. Abstracts, p55.
- Gordon, J.C.D.; Gillespie, D.; Potter, J.; Frantzis, A.; Simmonds, M.P. & Swift, R. 1998b: The Effects of Seismic Surveys on Marine Mammals. – in: Tasker, M.L. & Weir, C. (eds.): Proceedings of the Seismic and Marine Mammals Workshop London, 23-25 June 1998. http://smub.st-and.ac.uk/seismic/pdfs/6.pdf
- Gordon, J., Gillespie, D., Potter, J., Frantzis, A., Simmonds, M., Swift, R. & Thompson, D. 2004: The effects of seismic surveys on marine mammals. Marine Technology Society Journal, 37, 16-34. Hildebrand, J. 2004:"Overview of Human-Made Sound Sources in the Marine Environment." Presentation to the joint MMC and JNCC Workshop, London 28 September 2004. Scripps Institution of Oceanography, University of California San Diego, LA Jolla, CA. http://mmc.gov/sound/internationalwrkshp/pdf/hildebrand.pdf
- Gordon, J.; Antunes, R.; Jaqet, N. & Würsig, B. 2006: An investigation of sperm whale headings and surface behaviour before, during and after seismic line changes in the Gulf of Mexico. 10pp. – IWC SC/58/E45.
- Gray, L. M. and D. S. Greeley (1980). Source level model for propeller blade rate radiation for the world's merchant fleet. J Acoust Soc Am 67(2): 516-522.
- Green, M. L. 1991. The Impact of Parasail Boats on the Hawaiian Humpback Whale. Paper presented at the annual meeting of the Animal Behavior Society, June 1991, Wilmington, NC. Gwazdauskas, F.C., Paape, M.J., Perry, D.A. and McGilliard, M.L. 1980. Plasma glucocorticoid and circulating blood leukocyte responses in cattle after sequential intramuscular injections of ACTH. Am. J. Vet. Res. 41:1052-1056.
- Greene, G.D.; F.R. Engelhardt and R.J. Paterson (eds.). 1985. Proceedings of the workshop on effects of explosives use in the marine environment, Halifax, N.S., Jan. 1985. Tech. Rep. 5. Can. Oil & Gas Lands Admin. Environ. Prot. Branch, Ottawa, Ont. 398
- Greene, C. R. J. and S. E. Moore 1995. Man-made Noise. Pp 101-158 in Marine Mammals and Noise. D. H. Thomson (ed.), Academic Press, San Diego.
- Greene, C.R., McLennan, M.W., Norman, RG, et al. 2004. Directional frequency and recording (DIFAR) sensors in seafloor recorders to locate calling bowhead whales during their fall migration. J. Acoust. Soc. Am., 116, 799–813.
- Guerra, A.; González, A. F. & Rocha, F. 2004: A review of records of giant squid in the north-eastern Atlantic and severe injuries in Architeuthis dux stranded after acoustic exploration. – paper CC: 29, ICES-Annual Science Conference, Vigo.
- Heimlich-Boran, J.R., Heimlich-Boran, S.L., Montero, R. and Martin, V. 1994. An Overview of Whale- Watching in the Canary Islands. European Cetacean Society Newsletter No. 21. Spring / summer 1994.
- HESS/High Energy Seismic Survey Team 1999: High Energy Seismic Survey review process and interim operational guidelines for marine surveys offshore Southern California. Report from the High Energy Seismic Survey Team for the California State Lands Commission and the US Minerals Management Service Pacific Outer Continental Shelf Region, California. 98 pp.
- Hildebrand, J. 2004: Impacts of anthropogenic sound on cetaceans. Paper SC/56/E13 presented to the IWC Scientific Committee, June 2004.

- Hildebrand, J.; Balcomb, K. & Gisiner, R. 2004: Modelling the Bahamas beaked whale stranding of March 2000. – Presentation given at the third plenary meeting of the Marine Mammal Commission Advisory Committee on Acoustic Impacts on Marine Mammals, San Francisco, 29 July 2004. http://www.mmc.gov/sound/plenary3/pdf/hildebrand-balcomb.pdf
- Hildebrand, J. A. 2005: Impacts of Anthropogenic Sound. – In: Reynolds, J.E. et al. (eds.): Marine Mammal Research: Conservation beyond Crisis. The Johns Hopkins University Press, Baltimore, Maryland. pp 101-124.
- Hohn, A.A., D.S. Rotstein, C.A. Harms & B.L. Southall 2006: Report on marine mammal unusual mortality event UMESE0501Sp: Multi-species mass stranding of pilot whales (*Globicephala macrorhynchus*), minke whale (*Balaenoptera acutorostrata*), and dwarf sperm whales (*Kogia sima*) in North Carolina on 15-16 January 2005. NOAA Technical Memorandum NMFS-SEFSC-537, 222 p. http://www.sefsc.noaa.gov/PDFdocs/Report_on_UMESE0501Sp.pdf
- Houegnigan, L., Zaugg, S., van der Schaar, M. and André, M. 2009. A real time three-dimensional localization and tracking algorithm for acoustic events in noisy marine environments. 4th international Workshop on Detection, Classification and Localization of Marine Mammals using Passive Acoustics. Pavia, Italy, 2009.
- IfM-Geomar 2005: http://www.ifm-geomar.de/index.php?id=rafos&L=1 http://www.ifm.uni-kiel.de/fb/fb1/po2/research/sfb460/sfba3_ze/floatpage/results.html
- Institute of Shipping Economics and Logistics (ISL). 1989. Shipping Statistics Yearbook 1989, ISL, and Bremen, West Germany.
- International Standardization Organization (ISO). (1990). *Acoustics – Determination of occupational noise exposure and estimation of noise-induced hearing impairment* (ISO 1990-01-15). Geneva, Switzerland.
- IUCN World Conservation Union 2004: Resolution 3.068, "Undersea noise pollution"(Nov. 2004).
- IUCN-World Conservation Union 2006: Report of the interim independent scientists group (IISG) on mitigation measures to protect Western grey whales during Sakhalin II construction operations in 2006. Workshop convened by the IUCN, Vancouver, British Columbia, 3–5 April 2006.
- IWC/International Whaling Commission 2004: Report of the Scientific Committee, at § 12.2.5, pp. 37-39 and Annex K – Report of the Standing Working Group on Environmental Concerns, pp. 267-275 and pp. 282-289. – Journal of Cetacean Research and Management Vol. 7 Suppl. April 2005, ISSN 1561-0713.
- IWC/International Whaling Commission 2006 a: Overview of the global seismic industry: today and future trends. Report of the Scientific Committee – Report of the Standing Working Group on Environmental Concerns, Annex K § 6.1.3 p. 3. http://www.iwcoffice.org/_documents/sci_com/SCRepFiles2006/Annex%20K[FINAL]sq.pdf
- IWC/International Whaling Commission 2006 b: Report of the IWC Scientific Committee 2006 (IWC/58/Rep1), § 12.1: Seismic surveys and cetaceans, pp 49-52 and § 12.3.7: other issues "Pathology of stranded beaked whales associated 'temporally and spatially' with naval exercises", pp. 52 and Report of the Standing Working Group on Environmental Concerns ("E") of the IWC Scientific Committee: Annex K, § 6 (report seismic-workshop) pp. 1-16, plus Annex K, § 8.5.1 "Pathology of stranded beaked whales associated 'temporally and spatially' with naval exercises" pp. 27-29. http://www.iwcoffice.org/_documents/sci_com/SCRepFiles2006/SCREPNEW-GPD.pdf ; http://www.iwcoffice.org/_documents/sci_com/SCRepFiles2006/Annex%20K[FINAL]sq.pdf
- Jacobs, S. R., y Terhune, J. M. (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.
- Janik, V.M. and Thompson, P.M. 1996. Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. Marine Mammal Science. 12 (4):597-602.
- JCNB/NAMMCO 2005: Appendix 5. Narwhal Status Report. – p 46 in: Final Report Joint meeting of the NAMMCO Scientific Committee Working Group on the Population

Status of Narwhal and Beluga in the North Atlantic and the Canada/Greenland Joint Commission on Conservation and Management of Narwhal and Beluga Scientific Working Group, 13-16 October 2005, Nuuk, Greenland.

- Jefferson, T. A. & Curry, B. E. 1994: A global review of porpoise (Cetacea: Phocoenidae) mortality in gillnets. – Biological Conservation 67: 167-183.
- Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, F. Rodríguez, F.E. Howiell, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, & A. Fernández 2003: Gas-bubble lesions in stranded cetaceans. – Nature 425: 575-576.
- JNCC-Joint Nature Conservation Committee 2003: JNCC Report No. 323, C.J. Stone, The Effects of Seismic Activity on Marine Mammals in UK Waters, 1998-2000 (2003).
- Johnson, C.S., McManus, M.W. and Skaar, D. 1989. Masked tonal hearing thresholds in the beluga whale. J. Acoust. Soc. Am 85:2651-2654.
- Johnson, M. P. & Tyack, P.L. 2003: A digital acoustic recording tag for measuring the response of wild marine mammals to sound. – IEEE Journal of Oceanic Engineering, 28, 3-12.
- Johnston, R. C., Reed, D. H., and Desler, J. F. (1988), Special Report of the SEG Technical Standards Committee. SEG standards for specifying marine seismic energy sources, *Geophysics*, 53, 566 - 575.
- Johnston, D. W. (2002). The effect of acoustic harassment devices on harbor porpoises (Phocoena phocoena) in the Bay of Fundy, Canada. Biological Conservation, 108, 113-118.
- Johnston, D. W., y Woodley, T. H. (1998). A survey of acoustic harassment device (AHD) use in the Bay of Fundy, NB, Canada. Aquatic Mammals, 24, 51-61.
- Kastak, D., y Schusterman, R. J. (1999). In-air and underwater hearing sensitivity of a northern elephant seal (Mirounga angustirostris). Canadian Journal of Zoology, 77, 1751-1758.
- Kastelein, R. A., de Haan, D., Goodson, A. D., Staal, C., y Vaughan, N. (1997). The effects of various sounds on harbor porpoise. In A. J. Read, P. R. Wiepkema, y P. E. Nachtigall (Eds.), The biology of the harbor porpoise (pp. 367-383). Woerden, the Netherlands: De Spil Publishers.
- Kastelein, R. A., Rippe, H. T., Vaughan, N., Schooneman, N. M., Verboom, W. C., y de Haan, D. (2000). The effects of acoustic alarms on the behavior of harbor porpoises in a floating pen. Marine Mammal Science, 16, 46-64.
- Kastelein, R. A., Rippe, H. T., Vaughan, N., Staal, C., y Schooneman, N. M. (2001). The influence of three acoustic alarms on the behavior of harbor porpoises (Phocoena phocoena) in a floating pen. Marine Environmental Research, 52, 351-371.
- Kastelein, R.A., Verboom, W.C., Muijsers, M., Jennings, N.V. y van der Heul, S. (2005) the influence of acoustic emissions for underwater data transmission on the behaviour of harbour porpoises (Phocoena phocoena) in a floating pen. Marine Environmental Research, 59, 287–307.
- Kastelein, R. A., Jennings, N. V., Verboom, W. C., de Haan, D., y Schooneman, N. M. (2006). Differences in the response of a striped dolphin (Stenella coeruleoalba) and a harbor porpoise (Phocoena phocoena) to an acoustic alarm. Marine Environmental Research, 61, 363-378.
- Kastelein, R.A., y P.J. Wensveen. 2008. Effect of two levels of masking noise on the hearing threshold of a harbor porpoise (*Phocoena phocoena*) for a 4.0 kHz signal. Aquatic Mammals 34(4):420-425.
- Ketten, D.R., Lien, J. and Todd, S. 1993. Blast injury in humpback whale ears: Evidence and implications. J. Acoust. Soc. Am. 94(30): 1849-1850.
- Ketten, D.R. 1998: Marine Mammal Auditory Systems: A Summary of Audiometric and Anatomical Data and its Implications for Underwater Acoustic Impacts. – NOAA-NMFS-SWFSC Technical Memorandum 256.
- Ketten, D.R. 2004: Marine Mammal Auditory Systems: A Summary of Audiometric and Anatomical Data and Implications for Underwater Acoustic Impacts. – pp. 79-92 in:

AWI & DGP (eds.): Proceedings of the Conference on Impact of Acoustics on Marine Organisms, 17-19 June 2002, Berlin. – Polarforschung, 72 (2/3).

- Ketten, D.R. & Finneran, J. 2004: Noise Exposure Criteria: "Injury (PTS) Criteria". – in: Presentation at the Second Plenary Meeting of the Advisory Committee on Acoustic Impacts on Marine Mammals, "Noise Exposure Criteria" Noise Exposure Criteria Group, U.S.-Marine Mammal Commission – Sound Program - Second Plenary Meeting, Session III, 28-30 April 2004 Arlington, VA. http://mmc.gov/sound/plenary2/pdf/gentryetal.pdf
- Ketten, D.R.; Rowles, T.; Cramer, S.; O'Malley, J.; Arruda, J. & Evans, P.G.H. 2004: Cranial trauma in beaked whales. pp 21-27 in: Evans, P.G.H. & Miller, L.A. (eds.) 2004: European Cetacean Society 17th Annual Conference: Proceedings of the Workshop on Active Sonar and Cetaceans. Las Palmas, Gran Canaria, 8th March 2003, European Cetacean Society Newsletter, No. 42. Special Issue.
- Ko, D., Zeh, J.E., Clark, C.W., et al. 1986. Utilization of acoustic location data in determining a minimum number of spring migrating bowhead whales unaccounted for by the ice-based visual census. Rep. Int. Whaling Comm. 36: 325-338.
- Koschinski, S., y Culik, B. (1997). Deterring harbor porpoises (Phocoena phocoena) from gillnets: Observed reactions to passive reflectors and pingers. Report of the International Whaling Commission, 47, 659-668.
- Koski, W. R., y Johnson, S. R. (1987). Behavioral studies and aerial photogrammetry. In Responses of bowhead whales to an offshore drilling operation in the Alaskan Beaufort Sea, autumn 1986 (Section 4). Report from LGL Ltd., King City, ON, and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Western Exploration and Production Inc., Anchorage, AK. 371 pp.
- Kraus, S., Read, A., Anderson, E., Baldwin, K., Solow, A., Spradlin, T., et al. (1997). A field test of the use of acoustic alarms to reduce incidental mortality of harbor porpoise in gill nets. Nature, 388, 525.
- Kryter, K. D. (1970). *Effects of noise on man.* New York: Academic Press. 633 pp.
- Kryter, K. D. (1994). The handbook of hearing and the effects of noise. New York: Academic Press. 673 pp.
- Lankhorst, M.; Nielsen, M. & Zenk, W. 2004: Rafos Float Trajectories from the Labrador Sea Water Level in the Iceland Basin 1997-2003. http://www.ifm-geomar.de/index.php?id=999&L=1
- Lawson, J. 2005: Overview: Beluga whale and noise. – JWG-2005-18. p 24 in: Final Report – Joint meeting of the NAMMCO Scientific Committee Working Group on the Population Status of Narwhal and Beluga in the North Atlantic and the Canada/Greenland Joint Commission on Conservation and Management of Narwhal and Beluga Scientific Working Group, 13-16 October 2005, Nuuk, Greenland.
- Lesage, V., Barrette, C. and Kingsley, M.C.S. 1993. The Effect of Noise from an Outboard Motor and a Ferry on the Vocal Activity of Beluga (Delphinapterus leucas) in the St. Lawrence Estuary, Canada. p70 In: Abstr. 10th Bienn. Conf. Biol. Mar. Mamm., Galveston, TX, Nov. 1993. 130pp.
- Lesage, V., C. Barrette, M. C. S. Kingsley and B. Sjare (1999). The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River Estuary. Marine Mammal Science 15: 65-84.
- LGL Ltd. y Greeneridge Sciences. (1986). Reactions of beluga whales and narwhals to ship traffic and icebreaking along ice edges in the eastern Canadian High Arctic: 1982-1984. In Environmental studies (No. 37).
- Lien, J., Todd, S., Stevick, P., Marques, F. and Ketten, D. 1993. The reaction of humpback whales to explosives: Orientation, movements and behaviour. J. Acoust. Soc. Am. 94:1849.
- Ljungblad, D. K., Würsig, B., Swartz, S. L., y Keene, J. M. (1988). Observations on the behavioral responses of bowhead whales (Balaena mysticetus) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic, 41, 183-194.
- Lloyd's Register of Ships. Lloyd's of London, 1989.
- Lucke, K., Siebert, U., Lepper, P. A., Blanchet, M. A. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (Phocoena phocoena) after exposure to seismic airgun stimuli. 125(6):4060-4070.

- Madsen, P. T., y Møhl, B. (2000). Sperm whales (Physeter catodon L. 1758) do not react to sounds from detonators. Journal of the Acoustical Society of America, 107, 668-671.
- Madsen, P. T., Møhl, B., Nielsen, B. K., y Wahlberg, M. (2002). Male sperm whale behavior during exposures to distant seismic survey pulses. Aquatic Mammals, 28, 231-240.
- Madsen, P. T. 2005, Marine Mammals and Noise: Problems with Root Mean Square Sound Pressure Levels for Transients. The Journal of the Acoustical Society of America, 06/00, , vol. 117, no. 6, pp. 3952-3957.
- Madsen, P. T., M. Johnson, N. Aguilar de Soto, W.M.X. Zimmer and P.L. Tyack, Biosonar performance of foraging beaked whales (*Mesoplodon densirostris*), *Journal of Experimental Biology* 208 (2005), pp. 181–194
- Madsen, P.T.; Wahlberg, M.; Tougaard, J.; Lucke, K.; Tyack, P. 2006 a: Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Mar. Ecol. Prog. Ser., Vol. 309: 279–295.
- Madsen, P.T., Johnson, M.P., Miller, P.J.O., Aguilar Soto, N., Lynch, J. y Tyack, P. (2006b) Quantitative measures of air-gun pulses recorded on sperm whales (Physeter macrocephalus) using acoustic tags during controlled exposure experiments. Journal of the Acoustical Society of America, 120, 2366–2379.
- Malme, C. I., Miles, P. R., Clark, C. W., Tyack, P., y Bird, J. E. (1983). Investigations of the potential effects of underwater noise from petroleum industry activities on migrating grey whale behavior (BBN Report No. 5366; NTIS PB86-174174). Report from Bolt Beranek and Newman Inc. for U.S. Minerals Management Service, Anchorage, AK.
- Malme, C. I., Miles, P. R., Clark, C. W., Tyack, P., y Bird, J. E. (1984). Investigations of the potential effects of underwater noise from petroleum industry activities on migrating grey whale behavior. Phase II: January 1984 migration (BBN Report No. 5586; NTIS PB86-218377). Report from Bolt Beranek and Newman Inc. for U.S. Minerals Management Service, Anchorage, AK.
- Malme, C.I., P.R. Miles, C.W. Clarke, P. Tyack & J.E. Bird 1985: Investigations of the potential effects of underwater noise from petroleum industry activities on feeding humpback whale behavior. BBN Report 5851. OCS Study MMS 85-0019. Report by BBN Laboratories Inc., Cambridge, MA, for the U.S. Department of the Interior, Minerals Management Service, Anchorage, AK. NTIS PB86-218385.
- Malme, C. I., Würsig, B., Bird, J. E., y Tyack, P. L. (1986). Behavioral responses of grey whales to industrial noise: Feeding observations and predictive modeling (BBN Report No. 6265, OCS Study MMS 88-0048; NTIS PB88-249008). NOAA Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators, 56, 393-600.
- Malme, C.I., B. Würsig, J.E. Bird, & P. Tyack. 1988. Observations of feeding grey whale responses to controlled industrial noise exposure, pp. 55-73. In: W.M. Sackinger et al. (eds.), Port and ocean engineering under arctic conditions, vol II. Geophys. Inst., Univ. Alaska, Fairbanks. 111 pp.
- Martín, V.M. 2002: Resumen del informe sobre los Varamientos en Masa Atípicos de Zifios en Canarias en Septiembre de 2002 durante la Celebración de Ejercicios Navales. – Sociedad para el estudio de los Cetáceos en el Archipiélago Canaria, SECAC por la Dirección General de Política Ambiental del Gobierno de Canarias.
- Martín, V.; Servidio, A. & García, S. 2004: Mass strandings of beaked whales in the Canary Islands. Pp. 33-36 in: Evans, P.G.H. & Miller, L.A. (eds.) 2004: European Cetacean Society 17th Annual Conference: Proceedings of the Workshop on Active Sonar and Cetaceans. Las Palmas, Gran Canaria, 8th March 2003, European Cetacean Society Newsletter, No. 42. Special Issue.
- Mas, A., van der Schaar, M., Morell, M., Alonso, J.-M., LLarena, M., Solé, M. and André, M. 2008 Acoustic Map of the oceans: a tool for management. Proc. of the 22nd Conf. of the European Cetacean Society, The Netherlands, March
- Mate, B. & Harvey, J. (eds.) 1987: Acoustical deterrents in marine mammals conflicts with fisheries. – Oregon State Grant Publication ORESU-W-86-001. Sea Grant Communications, Oregon State University, Corvalis, Oregon.

- Mate, B.R., Stafford, K.M. and Ljungblad, D.K. 1994. Change in sperm whale (Physeter macrocephalus) distribution correlated to seismic surveys in the Gulf of Mexico. J. Acoust. Soc. Am. 96:3268-3269.
- Maybaum, H. L. (1993). Responses of humpback whales to sonar sounds. J Acoustic Soc Am 94: 1848-1849.
- McCauley, R. D., Cato, D. H., y Jeffery, A. F. (1996). A study of the impacts of vessel noise on humpback whales in Hervey Bay. Queensland, Australia: Report for the Queensland Department of Environment and Heritage, Maryborough Office, from the Department of Marine Biology, James Cook University, Townsville. 137 pp.
- McCauley, R. D., Jenner, M-N., Jenner, C., McCabe, K. A., y Murdoch, J. (1998). The response of humpback whales (Megaptera novaeangliae) to offshore seismic survey noise: Preliminary results of observations about a working seismic vessel and experimental exposures. Australian Petroleum Production and Exploration Association Journal, 38, 692-707.
- McCauley, R.D. et al. 1999: "Marine Mammal Seismic Surveys: Analysis and Propagation of Air-Gun Signals; and Effects of Air-Gun Exposure on Humpback Whales, Sea Turtles, Fishes and Squid," Curtin University, Centre for Marine Science and Technology (August 1999).
- McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M.N., Penrose, J.D., Prince, R.I.T., Adhitya, A., Murdoch, J. y McCabe, K. (2000) Marine Seismic Surveys – A Study of Environmental Implications. Australian Petroleum Production and Exploration Association Journal, 40, 692–708.
- McCauley, R.D. & Hughes, J.R. 2006: Marine seismic mitigation measures – perspectives in 2006. – IWC SC/58/E44, 10pp.
- McDonald, M.A., Hildebrand, J.A. and Webb, S.C. 1995. Blue and fin whales observed on a seafloor array in the Northeast Pacific. J. Acoust. Soc. Am. 98 (2, Pt 1): 712-721.
- McDonald, M.A., and C.G. Fox. 1999. Passive acoustic methods applied to fin whale population density estimation. J. Acoust. Soc. Am. 15: 2643-2651.
- Miksis, J.L., Grund, M.D., Nowacek, D.P., Solow, A.R., Connor, R.C. y Tyack, P.L. (2001) Cardiac responses to acoustic playback experiments in the captive bottlenose dolphin (Tursiops truncatus). Journal of Comparative Psychology, 115, 227–232.
- Miller, P. J., N. Biassoni, A. Samuels and P. L. Tyack (2000). Whale songs lengthen in response to sonar. Nature 405(6789): 903.
- Miller, G. W., Moulton, V. D., Davis, R. A., Holst, M., Millman, P., MacGillivray, A., et al. (2005). Monitoring seismic effects on marine mammals – south-eastern Beaufort Sea, 2001-2002. In S. L. Armsworthy, P. J. Cranford, y K. Lee (Eds.), Offshore oil and gas environmental effects monitoring: Approaches and technologies (pp. 511-542). Columbus, OH: Battelle Press.
- Miller, P.J.O.; Johnson, M; Madsen, P.T.; Quero, M.E.; Biassoni, N. & Tyack, P. 2006: At-sea experiments indicate that airguns affect the foraging behaviour of sperm whales in the Gulf of Mexico. 34pp. – IWC-SC/58/ForInfo2.
- Miller, PJO; Johnson, MP; Madsen, PT; Biassoni, N; Quero, M; Tyack, PL. 2009. Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. *Deep Sea Research Part I*. 56 (7): 1168-1181. 10.1016/j.dsr.2009.02.008
- MMS-United States Minerals Management Service 2004: Minerals Management Service NTL No. 2004-G01, "Notice to Lessees and Operators of Federal Oil, Gas, and Sulphur Leases In the Outer Continental Shelf, Gulf of Mexico OCS Region."
- Molinelli, E. et al. 1990. The HITS Update Process to HITS III, Planning Systems Inc., Report 446433 (February 1990). HITS (Historical Temporal Shipping) are a model of commercial shipping lanes and densities based on Lloyd's of London port data. It was introduced for noise prediction models in 1978, and has been updated periodically since. It is the Navy's standard ship model for fleet noise predictions.
- Monteiro-Neto, C., Ávila, F. J. C., Alves-Jr., T. T., Araújo, D. S., Campos, A. A., Martins, A. M. A., et al. (2004). Behavioral responses of Sotalia fluviatilis (Cetacea,

Delphinidae) to acoustic pingers, Fortaleza, Brazil. Marine Mammal Science, 20, 141-151.

- Mooney, T. A., Nachtigall, P. E., Vlachos, S. 2009. Sonar-induced temporary hearing loss in dolphins. Biol Lett;5 565-567
- Morisaka, T., Shinohara, M., Nakahara, F., y Akamatsu, T. (2005). Effects of ambient noise on the whistles of Indo-Pacific bottlenose dolphin populations. Journal of Mammalogy, 86, 541-546.
- Morton, A. B., y Symonds, H. K. (2002). Displacement of Orcinus orca (Linnaeus) by high amplitude sound in British Columbia, Canada. ICES Journal of Marine Science, 59, 71-80.
- Munk, W. and Wunsch, C. 1979. Ocean acoustic tomography: A scheme for large-scale monitoring. Deep Sea Res. 26:123.
- Nachtigall, P. E., Pawloski, J. L., y Au, W. W. L. (2003). Temporary threshold shifts and recovery following noise exposure in the Atlantic bottlenose dolphin (Tursiops truncatus). Journal of the Acoustical Society of America, 113, 3425-3429.
- Nachtigall, P. E., Supin, A. Ya., Pawloski, J. L., y Au, W. W. L. (2004). Temporary threshold shifts after noise exposure in the bottlenose dolphin (Tursiops truncatus) measured using auditory evoked potentials. Marine Mammal Science, 20, 673-687.
- National Research Council (NRC). 1994. *Science and Judgment in Risk Assessment.* Committee on Risk Assessment of Hazardous Air Pollutants. NATIONAL ACADEMY PRESS, Washington, D.C. 652 pp
- National Institute for Occupational Safety and Health (NIOSH). (1998). *Criteria for a recommended standard: Occupational noise exposure* (Publication #98- 126). Washington, DC: U.S. Department of Health and Human Services, NIOSH.
- NMFS/ National Marine Fisheries Service 2003: Taking marine mammal's incidental to conducting oil and gas exploration activities in the Gulf of Mexico. – U.S. Federal Register 68, 9991–9996.
- NMFS/NOAA, U.S. National Marine Fisheries Service/National Oceanic and Atmospheric Administration 2005: Endangered Fish and Wildlife; Notice of Intent to Prepare an Environmental Impact Statement. – Federal Register Vol. 70, No. 7 January 11, 2005, pp. 1871-1875.
- National Marine Fisheries Service (NMFS). (2005). Assessment of acoustic exposures on marine mammals in conjunction with USS Shoup active sonar transmissions in Haro Strait, Washington, 5 May 2003 (NMFS Office of Protected Resources report).
- Nielsen, D. W., Bauman, M. J., & Brandt, D. K. (1986). Changes in auditory threshold during and after long duration noise exposure: Species differences. In R. J. Salvi, D. Henderson, R. P. Hamernik, & V. Colletti (Eds.), *Basic and applied aspects of noise-induced hearing loss* (pp. 281-293). New York: Plenum Press.
- Naval Research Laboratory (NRL). (2004a). Acoustic modeling results of the Haro Strait for 5 May 2003 (Naval Research Laboratory Report). Arlington, VA: Office of Naval Research.
- Naval Research Laboratory (NRL). (2004b). EEEL analysis of Shoup transmissions in the Haro Strait on 5 May 2003 (Naval Research Laboratory briefing of 2 September 2004).
- Nedwell J R, Turnpenny A W H (1998) 'The use of a generic frequency weighting scale in estimating environmental effect'. Proceedings of the Workshop on Seismic and Marine Mammals, 23-25th June 1998, London, UK.

- Nedwell, J., Langworthy, J. and Howell, D. 2003. Assessment of Sub-Sea Acoustic Noise and Vibration from Offshore Wind Turbines and its Impact on Marine Wildlife; Initial Measurements of Underwater Noise during Construction of Offshore Windfarms, and Comparison with Background Noise. The Crown States Office, 2003
- Nedwell, J. & Howell, D. 2004: A review of offshore windfarm related underwater noise sources. Report No. 544 R 0308, Subacoustech Ltd. http://www.thecrownestate.co.uk/35_literature_review.pdf

- Nieukirk, S. L., K. M. Stafford, D. K. Mellinger, R. P. Dziak and C. G. Fox (2004). Low frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. Journal of the Acoustical Society of America. 115(4): 1832-1843.
- NOAA & U.S. Navy 2001: Joint interim report Bahamas marine mammals stranding event of 15-16 March 2000. – U.S. Department of Commerce, NOAA, NMFS, US-Navy. http://www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf
- NODC/National Oceanographic Data Center 1996: The North Atlantic Float Program. Extracts from the Plans for the Atlantic Climate Change Experiment (ACCE)-US WOCE Report 1996.
http://www.nodc.noaa.gov/woce_V2/disk01/floats/exper_na.htm
- Nowacek, S. M., R. S. Wells and A. R. Solow (2001). Short-term effects of boat traffic on bottlenose dolphins, Tursiops truncatus, in Sarasota Bay, Florida. Marine Mammal Science 17(4): 673-688.
- Nowacek, D., Johnson, M.P. y Tyack, P.L. (2004) North Atlantic right whales (Eubalaena glacialis) ignore ships but respond to alerting stimuli. Proceedings of the Royal Society of London. Series B, Biological Sciences, 271, 227–231.
- Olesiuk, P. F., Nichol, L. M., Sowden, M. J., y Ford, J. K. B. (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.
- Palka, D., y Hammond, P. S. (2001). Accounting for responsive movement in line transects estimates of abundance. Canadian Journal of Fisheries and Aquatic Sciences, 58, 777-787.
- Parkes, G. & Hatton, L. 1986: The Marine Seismic Source. – Kluwer Academic Publishers, 128 pp. NOAA & US-Navy 2001: Joint interim report Bahamas marine mammals stranding event of 15-16 March 2000. – U.S. Department of Commerce, NOAA, NMFS, US-Navy.
http://www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf
- Patenaude, N.J., Richardson, W.J., Smultea, M.A., Koski, W.R., Miller, G.W., Wuersig, B. y Greene, C.R. Jr. (2002) Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. Marine Mammal Science, 18, 309–355.
- Penkov, A.; R. Stanislavov and D. Tzvetkov. 1996. Male reproductive function in workers exposed to vibration. Cent. Eur. J. Public Health. Sep 4(3), p185-188, 1996.
- Perry, C. 1998. A review of the Impact of Anthropogenic Noise on Cetaceans. Report for the environmental Investigation Agency, London, UK. SC/50/E9
- Piantadosi, C.A. & Thalmann, E.D. 2004: Pathology: whales, sonar and decompression sickness. Nature (London) 428(6984): 1 following 716; Discussion 2 p. following 716.
- Polacheck, T. and Thorpe, L. 1990. The Swimming Direction of Harbor Porpoise in Relationship to a Survey Vessel. Rep. IWC. 40:463-470.
- Rankin, S. and Evans, W.E. 1998. Effect of Low Frequency Seismic Exploration Signals on the Cetaceans of the Gulf of Mexico. The World Marine Mammal Science Conference 20-24 January 1998. Abstracts p110.
- Reeves R.R. 1977. The problem of grey whale (*Eschrichtius robustus*) harassment at the breeding lagoons and during migration. MMC-76/06. U.S. Mar. Mamm. Commn. 60 p. NTIS PB-272506.
- Revello, T.E. and R.S. Klingbeil. 1990. Acoustic Source Levels of Commercial Vessels for Use in Sonar System Modeling and Analysis, Naval Underwater Systems Center, New London Laboratory, New London, CT (1 August 1990). (Distribution limited to U.S.Government Agencies and their contractors only.)
- Richardson, W.J., Fraker, M.A., Würsig, B., Wells, R.S. 1985. Behaviour of Bowhead Whales Balaena mysticetus Summering in the Beaufort Sea: Reactions to Industrial Activities. Biological Conservation 32:195- 230.
- Richardson, W. J., Würsig, B., y Greene, C. R., Jr. (1986). Reactions of bowhead whales, Balaena mysticetus, to seismic exploration in the Canadian Beaufort Sea. Journal of the Acoustical Society of America, 79, 1117- 1128.

- Richardson, W.J., Davis, R.A., Evans, C.R., Ljungblad, D.K. and Norton, P. 1987. Summer distribution of Bowhead Whales, Balaena mysticetus, Relative to Industry Activities in the Canadian Beaufort Sea, 1980-84. Arctic 40 (2):93-104.
- Richardson, W. J., Greene, C. R., Jr., Koski, W. R., Malme, C. I., Miller, G. W., Smultea, M. A., et al. (1990). Acoustic effects of oil production activities on bowhead and white whales visible during spring migration near Pt. Barrow, Alaska—1989 phase (OCS Study MMS 90- 0017; NTIS PB91-105486). LGL Ltd. report for U.S. Minerals Management Service, Herndon, VA. 284 pp.
- Richardson, W.J. and Greene, C.R. Jr. 1993. Variability in behavioural reaction thresholds of bowhead whales to man-made underwater sounds. J. Acoust. Soc. Am. 94 (5).
- Richardson, W.J., & C.I. Malme 1993: Man made noise and behavioral responses, pp. 631-700. In: The Bowhead Whale. – Spec. Publ. 2. Society for Marine Mammology, Lawrence, KS. 787 pp.
- Richardson, W. J. , 1995 Marine Mammals and Noise. San Diego: Academic Press. ISBN 0125884400.
- Richardson, W.J., Finley, K.J., Miller, G.W., Davis, R.A., Koski, W.R. 1995a. Feeding, social and migration behaviour of bowhead whales, Balaena Mysticetus, in Baffin Bay vs the Beaufort Sea - regions with different amounts of human activity. Marine Mammal Science 11 (1):1-45.
- Richardson, W.J., Greene Jr. C.R., Malme, C.I., Thomson, D.H. 1995b. Marine Mammals and Noise. Academic Press, San Diego, CA. 576pp.
- Richardson, W.J. 1997. Marine mammals and man-made noise: Current issues. p. 39-50 In: Underwater bio-sonar and bioacoustics symposium, Loughborough Univ., Dec. 1997.
- Richardson, W.J. & Würsig, B. 1997: Influences of man-made noise and other human actions on cetacean behaviour. – Mar. Fresh. Behav. Physiol. 29: 183-209
- Richardson, W.J. 1998: Reactions of Bowhead whales and Ringed seals to an open water seismic program in the Alaskan Beaufort Sea. In: Workshop Documentation, Seismic and Marine Mammals Workshop, 23-25 June, London.
- Richardson, W. J., Miller, G. W., y Greene, C. R., Jr. (1999). Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. Journal of the Acoustical Society of America, 106, 2281.
- Richardson, W.J. & Tyack, P. 2004: Noise Exposure Criteria: "Behavioral Criteria". – in: Presentation at the Second Plenary Meeting of the Advisory Committee on Acoustic Impacts on Marine Mammals, "Noise Exposure Criteria" Noise Exposure Criteria Group, U.S.-Marine Mammal Commission – Sound Program - Second Plenary Meeting, Session III, 28-30 April 2004 Arlington, VA. http://mmc.gov/sound/plenary2/pdf/gentryetal.pdf
- Ridgway, S.H. and Howard, R. 1982. Dolphins and the bends. Science 216:651.
- Ridgway, S.H. 1997. Who are the Whales? Bioacoustics. 8:3-20.
- Ridgway, S.H. and Carder, D.A. 1997. Hearing deficits measured in some Tursiops truncatus, and discovery of a deaf/mute dolphin., J. Acoust. Soc. Am 101 (1):590-594.
- Ridgway, S., Carder, D., Schlundt, C., Kamolnick, T., Elsberry, W. 1997. Temporary shift in delphinoid masked hearing thresholds. J. Acoust. Soc. Am. 102 (5, Pt 2):3102.
- Rodkin, R.B. & Reyff, J.A. 2004: Underwater sound pressures from marine pile driving. – J. Acoust. Soc. Am., Vol 116(4 Pt. 2): 2648 (abstract).
- Romano, T.A., Keogh, M.J., Kelly, C., Feng, P., Berk, L., Schlundt, C.E., Carder, D.A. y Finneran, J.J. (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.
- Ross, D. 1987. Mechanics of Underwater Noise. Peninsula Publishing, Los Altos, CA. Scrimger, P. and R.M. Heitmeyer. 1991. Acoustic source-level measurements for a variety of merchant ships. J. Acoust. Soc. Am., 89:691-699.
- Ross, D. (1993). On ocean underwater ambient noise. Acoustics Bulletin January/February: 5-8.

- Rossby, T., D. Dorson and J. Fontaine (1986). The RAFOS system. J. Atmos. Oceanic Tech 3: 672-679.
- Scheifele, P.M. 1997. Impact of low-frequency anthropogenic noise on the auditory system of the beluga (Delphinapterus leucas) in the Saint Lawrence river estuary. Report from National Undersea Research Center.
- Schevill, W.E. 1968. Quiet Power Whaleboat. J. Acoust. Soc. Am. 44(4):1157-1158.
- Schlundt, C.E., Finneran, J.J., Carder, D.A. y Ridgway, S.H. (2000) Temporary shift in masked hearing thresholds of bottlenose dolphins, Tursiops truncatus, and white whales, Delphinapterus leucas, after exposure to intense tones. Journal of the Acoustical Society of America, 107, 3496–3508.
- Schlundt, C. E., Dear, R. L., Carder, D. A., y Finneran, J. J. (2006). Growth and recovery of temporary threshold shifts in a dolphin exposed to mid-frequency tones with durations up to 128 s. Journal of the Acoustical Society of America, 120, 3227.
- Scrimger, P.; R.M. Heitmeyer and P. Boulon. 1990. A Computer Model of Merchant Shipping in the Mediterranean Sea, SACLANTCEN Report SR-164, NATO SACLANT Undersea Research Centre, La Spezia, Italy (June 1990).
- Seidel, H. 1993. Selected health risks caused by long-term, whole-body vibration. Am. J. Ind. Med., Apr 23(4):589-604. Effects of Anthropogenic Noise in the Marine Environment 74
- Seidel, H. and R. Heide. 1986. Long-term effects of whole-body vibration: A critical survey of the literature. Int. Arch. Occup. Environ. Health. 58(1) p1-26, 1986.
- Seyle, H. 1973. The evolution of the stress concept. American Scientist 61:692-699.
- Shenaeva, T.A. 1990. Vliianie vibratsii i shuma na generativnuiu funktsiiu v eksperimente. Gig. Tr. Prof. Zabol., (9) p16-21.
- Simard, Y., Bahoura, M., Roy, N. 2004. Acoustic detection and localization of whales in the Bay of Fundy and St. Lawrence Estuary critical habitats. Canadian Acoustics 32(2): 107-116
- Simard, Y., Roy, N, and Gervaise, C. 2006a. Shipping noise and whales: World tallest ocean liner vs largest animal on earth. MTS/IEEE OCEANS'06, Boston. IEEE, Piscataway, NJ, USA. DOI : 10.1109/OCEANS.2006.307053 p. 1-6.
- Simard,Y., M. Bahoura, C.W. Park, J. Rouat, M. Sirois, X. Mouy, D. Seebaruth, N. Roy, and R. Lepage. 2006b. Development and experimentation of a satellite buoy network for real-time acoustic localization of whales in the St. Lawrence. MTS/IEEE OCEANS'06, Boston. IEEE, Piscataway, NJ, USA. DOI: 10.1109/OCEANS.2006.307052 p. 1-6.
- Simard, Y., and Roy, N. 2008a.Detection and localization of blue and fin whales from large-aperture autonomous hydrophone arrays: a case study from the St. Lawrence estuary. Can. Acoust. 36(1): 104-110.
- Simard, Y., and Roy, N., and Gervaise, C. 2008b. Passive acoustic detection and localization of whales: effects of shipping noise in Saguenay–St.Lawrence Marine Park. J. Acoust. Soc. Am. 123: 4109-4117.
- Skalski, J. R., W. H. Pearson, & C. I. Malme 1992: Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes ssp.*). – Canadian Journal of Fisheries and Aquatic Sciences 49:1357-1365 (1992).
- Sodal, A. 1999: Measured underwater acoustic wave propagation from a seismic source. In: Proceedings of the Airgun Environmental Workshop, London, July 6, 1999.
- Southall, B.L. 2005. National Marine Fisheries Service (NMFS). *Report of the "Shipping Noise and Marine Mammals: A Forum for Science, Management, and Technology" Symposium*. 18-19 May 2004, Arlington, VA.
- Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene Jr., C. R., Kastak, D., Ketten, D. R., Miller, J. H., Nachtigall, P. E., Richardson, W. J., Thomas, J. A., and Tyack, P. L. (2007). Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33(4), 411-522.
- Spiesberger, J.L. 2004. Geometry of locating sounds from differences in travel

time: Isodiachrons. J. Acoust. Soc. Am. 116: 3168–3177.

- Spiesberger, J.L. 2005. Probability distributions for locations of calling animals, receivers, sound speeds, winds, and data from travel time differences. J. Acoust. Soc. Am. 118: 1790-1800.
- Spiesberger, J.L., and Whalberg, M. 2002. Probability density functions for hyperbolic and isodiachronic locations. J. Acoust. Soc. Am. 11: 3046–3052.
- Stafford, K.M., C.G. Fox, and D.S. Clark. 1998. Long-range detection and localization of blue whale calls in the northeast Pacific using military hydrophone arrays. *Journal of the Acoustical Society of America* 104:3,616–3,625.
- Stafford, K.M., Mellinger, D.K, Moore, S.E. and Fox, C.G. 2007. Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999–2002. J. Acoust. Soc. Am. 122: 3378-3390.
- Stensland, E. y Berggren, P. 2007. Behavioral changes in female Indo-Pacific bottlenose dolphins in response to boat-based tourism. Marine Ecology Progress Series, 332:225-234.
- Stewart, B.S., Evans, W.E. and Awbrey, F.T. 1982. Effects of man-made waterborne noise on behavior of beluga whales (Delphinapterus leucas) in Bristol Bay, Alaska. Hubbs/Sea World Research Institute Report 82-145.
- Stone, G.S., Katona, S.L., Mainwaring, A., Allen, J.M. and Corbett, H.D. 1992. Respiration and surfacing rates of fin whales (Balaenoptera physalus) observed from a lighthouse tower. Rep Int. Whal. Commn. 42:739.
- Stone, G., Kraus, S., Hutt, A., Martin, S., Yoshinaga, A. y Joy, L. (1997) Reducing by-catch: can acoustic pingers keep Hector’s dolphins out of fishing nets? Marine Technology Society Journal, 31, 3–7.
- Talpalar, A.E. & Grossman, Y. 2005: Sonar versus whales: noise may disrupt neural activity in deep-diving cetaceans. – Undersea and Hyperbaric Medicine 32(2): 135-9.
- Taylor, V. J., Johnston, D. W., y Verboom, W. C. (1997). Acoustic harassment device (AHD) use in the aquaculture industry and implications for marine mammals. Proceedings of the Institute of Acoustics, 19(9), 267- 275.
- Teilmann, J.; Tougaard, J.; Miller, L.A.; Kirketerp, T.; Hansen, K. & Brando, S. 2006: Reactions of Captive Harbour Porpoises (*Phocoena phocoena*) to Pinger-like Sounds. Marine Mammal Science 22(2): 240-260.
- Tejedor, A.; Sagarminaga, R.; De Stephanis, R. & Cañadas, A. 2007: “Management of MPA’s. Options and Challenges for the Maritime Transport Sector. Spanish Case studies” in: presentation at the European Cetacean Society Congress 2007.
- ter Haar, G. R. and S. Daniels. “Evidence for ultrasonically induced cavitation *in vivo*,” *Phys. Med. Biol.*, vol. *26*, pp. 1145-1149, 1981.
- Thode, A., Gerstoft, P., Burgess, W., et al. 2006. A portable matched-field processing system using Passive acoustic time synchronization. IEEE J.Ocean. Eng. 31: 696-710.
- Thomas, J.A., Kastelein, R.A. and Awbrey, F.T. 1990. Behavior and Blood Catecholamines of Captive Belugas During Playbacks of Noise From an Oil Drilling Platform. Zoo Biol. 9:393-402.
- Thomson, C.A. and Geraci, J.R. 1986. Cortisol, Aldosterone, and Leucocytes in the Stress Response of Bottlenose Dolphins, Tursiops truncatus. Canadian Journal of Fisheries and Aquatic Sciences 43:1010- 1016.
- Todd, S., Stevick, P., Lien, J., Marques, F., y Ketten, D. (1996). Behavioral effects of exposure to underwater explosions in humpback whales (Megaptera novaeangliae). Canadian Journal of Zoology, 74, 1661-1672.
- Tolstoy, M.; Diebold, J.B.; Webb, S.C.; Bohnenstiehl, D.R.; Chapp, E.; Holmes, R.C. & Rawson, M. 2004: Broadband calibration of R//V Ewing seismic sources. – Geophysical Research Letters, Vol. 31, 4 pp.
- Tougaard, J.; Carstensen, J.; Henriksen, O.H.; Skov, H. & Teilmann, J. 2003: Short-term effects of the construction of wind turbines on harbour porpoises at Horns Reef. Technical report to Techwise A/S. Technical report to TechWise A/S. HME/362-02662, Hedeselskabet, Roskilde, DK.

- http://www.hornsrev.dk/Miljoeforhold/miljoerapporter/Hornsreef%20porpoises%202002.pdf
- Tougaard, J.; Carstensen, J.; Teilmann, J. & Bech, N.I. 2005: Effects of the Nysted Offshore Wind Farm on harbour porpoises - Annual status report for the T-POD monitoring program. Report Request. Commissioned by ENERGI E2 A/S. National Environmental Research Institute. - Technical report to Energi E2 A/S: 51 pp.
- Tougaard, J., Henriksen, O. D., Miller, L. E. 2009. Underwater noise from three types of offshore wind turbines: Estimation of impact zones for harbor porpoises and harbor seals. Journal of the Acoustical Society of America, 125(6):3766-3773.
- Turnpenny, A.W.H. and Nedwell, J.R. 1994. The Effects on Marine Fish, Mammals and Birds of Underwater Sound Generated by Seismic Surveys. Fawley aquatic research laboratories Ltd. October 1994.
- Urick, R.J. 1983. Principles of underwater sound for engineers 3rd ed. 423p. (Reprinted 1996, Peninsula Publ., Los Altos, CA). McGraw-Hill, New York.
- U.S.DoN/Department of the Navy (2001): Selection of 180 dB as the Upper Reference Point in the Risk Continuum for SURTASS LFA Sonar Signals. http://www.surtass-lfa-eis.com/docs/180dBCriteria.pdf
- US-MMC 2004: Beaked Whale Technical Workshop Summary. April 13-16, 2004, Baltimore, Maryland. http://mmc.gov/sound/beakedwhalewrkshp/pdf/bwhale_wrkshpsummary.pdf
- van der Schaar, M., Zaugg, S., Riccobene, G., Sánchez, T., Pubill, O. and André, M. 2009. System Architecture for real-time monitoring of noise pollution.. 23rd Conference of the ECS, Istanbul, Turkey.
- Versluis, M., B. Schmitz, A von der Heydt, and D. Lohse (2000). "How Snapping Shrimp Snap: Through Cavitating Bubbles". Science 289: 2114–2117
- Ward, W. D. (1997). Effects of high-intensity sound. In M. J. Crocker (Ed.), Encyclopaedia of acoustics, Volume III (pp. 1497-1507). New York: John Wiley y Sons.
- Watkins, W. A., y Schevill, W. E. (1972). Sound source location by arrival-times on a non-rigid three-dimensional hydrophone array. Deep-sea Research 19:691-706.
- Watkins, W. A., y Schevill, W. E. (1975). Sperm whales (Physeter catodon) react to pingers. Deep Sea Research I, 22, 123-129.
- Watkins, W.A., Moore, K.E. and Tyack, P. 1985. Sperm whale acoustic behaviours in the Southeast Caribbean. Cetology 19:1-15.
- Watkins, W.A. 1986. Whale reactions to human activities in Cape Cod Waters. Mar. Mamm. Sci. 2:251- 262.
- Watkins, W.A., Daher, M.A., Fristrup, K.M., Howald, T.J. and Notarbartolo, di Sciara, G. 1993. Sperm whales tagged with transponders and tracked underwater by sonar. Mar. Mamm. Sci. 9 (1):55-67.
- WDCS/Simmonds, M.; Dolman, S. & Weilgart, L. (eds.) 2003: Oceans of Noise – A WDCS Science report. 164 pp. http://www.wdcs.org/dan/publishing.nsf/c525f7df6cbf01ef802569d600573108/792dcdcba3d9c51180256f3500499bfe/$FILE/OceansofNoise.pdf
- Weilgart, L. S. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. Can. H. Zool. 85: 1091-1116.
- Weir, C.R. 2008. Short-finned pilot whales (*Globicephala macrorhynchus*) respond to an airgun ramp-up procedure off Gabon. Aquatic Mammals 34(3):349-354.
- WHOI/Woods Hole Oceanographic Institution 2004: NSF Sponsored Workshop "Arctic Observing Based on Ice-Tethered Platforms", WHOI, June 28 to 30 2004. Appendix 1: Plans for Arctic Observing Systems, A1.4. Arctic Acoustic Thermometry and Tomography, Appendix 4: A vision for interaction of autonomous and Lagrangian platforms with Ice-Based Observatories. http://www.whoi.edu/science/PO/arcticgroup/projects/ipworkshop_report.html#top
- Wilson, J.; Rotterman, L. & Epperson, D. 2006: Minerals Management Service overview of seismic survey mitigation and monitoring on the US outer continental shelf. 13pp. – IWC SC/58/E8.

- Williams, R., Bain, E., Trites, A. y Ford, J. (2002) Behavioural responses of killer whales to a 'leapfrogging' vessel. Journal of Cetacean Research and Management, 4, 305–310.
- Winsor, M.H. & Mate, B.R. 2006: Seismic survey activity and the proximity of satellite-tagged sperm whales. 8pp. – IWC SC/58/E16.
- Yost, W. A. (1994). *Fundamentals of hearing* (3rd ed.). New York: Academic Press. 326 pp.
- Yost, W. A. (2000). Fundamentals of hearing: An introduction (4th ed.). New York: Academic Press. 349 pp.
- Zaugg, S., van der Schaar, M., Riccobene, G. and André, M. 2009a. Real-time detection and classification of natural, biological and anthropogenic sources form underwater antennas. 23rd Conference of the ECS, Istanbul, Turkey.
- Zaugg, S., van der Schaar, M., Houegnigan, L., André, M. 2009b. Real time classification of sperm whale clicks and shipping impulses from a deep sea antenna.
- Zimmer, W.M.X. 2003: Sonar systems and stranding of beaked whales. - Document AC10/Doc. 44 (S) presented to ASCOBANS 10th Advisory Committee Meeting, Bonn, Germany, 9 - 11 April 2003.

Annex IV. Areas particularly sensitive on the Spanish coast for the presence of cetaceans

1. Internationally Protected Mediterranean Marine Zone

Name	Hectares	Classification	Characteristics
Alboran Island Seabeds (Almeria)	26,457	Natural Park	Endemic relevant marine species and threats.
Cabo de Gata-Nijar (Almeria)	49,547	Natural Park	Coastal area including a marine strip with 22 habitats of community interest.
Almerian Seabeds	6,313	National Monument and LIC*	Ocean Posidonia (Sea grass beds)
Cliffs de Maro-Cerro Gordo (Granada)	1,815	Natural Park	Endemic relevant marine species and threats, habitats of community interest.
Mar Menor and surroundings (Murcia)	26,000	Natural Park Natural Reserve Protected countryside	Protected coastal lake and associated marine coastal strip of high interest, with endangered species.
Columbretes Islands (Castellon)	12,306	Natural Reserve Marine Reserve	Small islands and seabed with important presence of protected species
Cape Creus (Catalonia)	13,886	Natural Park	Protected species
Cabrera Archipelago (Balearic Islands)	10,021	National Park (marine and terrestrial park)	Endangered species of flora and fauna, maritime and terrestrial.
Medes Islands (Catalonia)	511	Marine Reserve	Small islands and seabed of high interest for the protection of flora and fauna.

2. Marine Reserves

Name	Designation
Tabarca Island	Ministerial Order, 4/04/1986
Columbretes Islands	Ministerial Order, 15/06/1988
Isla Graciosa and Northern Lanzarote small islands	Ministerial Order, 19/04/1990
Cape Palos Islands Hormigas	Ministerial Order, 19/05/1995
Cabo de Gata-Nijar	Ministerial Order, 22/06/1995
Punta de la Restinga-Mar de las Calmas (Isla de El Hierro)	Ministerial Order, 24/01/1996
Alboran Island	Ministerial Order, 31/07/1997 (modified for Ministerial Order 08/09/1998)
Masia Blanca, Tarragona	Ministerial Order, 21/12/1999

3. Natura 2000 Zones LIC's Proposed for the Autonomous Communities in Marine Areas

Autonomous Community	Number and LIC Code	Proposed Species
Andalusia	Although these have been designated LIC's and Maritime-Terrestrial Public Domains (some of vital importance for cetaceans such as Alboran Island – ES6110015 or Straits of Gibraltar – ES6120012, in no case has any file, official or designated quoted cetaceans).	
Ceuta and Melilla	ES6310002 Yellow zone maritime terrestrial of Monte Hacho (Ceuta) ES 6310001 Yellow zone maritime terrestrial Los cliffs of Aguadu (Melilla)	*Turisops truncatus* (Bottlenose dolphin)
Asturias	Despite the designated areas (Cape Busto-Luanco and Ria de Ribadesella - Ria de Tinamayor for Tursiops truncatus) appearing in the webpage of the Principality, there are no areas designated for cetaceans to be found in any official designation files.	
Balearic Islands	ES5310035 North Menorcan marine area	*Turisops truncatus* (Bottlenose dolphin)
	ES5310036 South Citadella marine area	
	ES0000083 Cabrera Archipelago	
	ES5310005 Pollenca and Alcudia Bays	
	ES5310025 Cape Barbaria	
	ES0000081 Cape Enderrocat-Cape Blanc	
	ES5310030 Levante Coast	
	ES0000233 D'Addaia to Albufera	
	ES0000078 Es Vedra-Vedranell	
	ES5310023 West Ibiza Islands	
	ES0000242 Santa Eulalia, Rodona and es Cana Islands	
	ES5310024 La Mola	
	ES0000221 Sa Dragonera	
	ES0000234 Ses Salines Ibiza and Formentera	
	ES0000002 Tagomago	
Canary Islands	ES7010016 Marine Area La Isleta	*Turisops truncatus*
	ES7010037 Confital Bay	
	ES7010016 1. Mogan Marine Strip	
	ES7010035 Sotavendo de Jandia Beach	
	ES7010022 Sebadales de Corralejo	
	ES7010020 Sebadales de la Graciosa	
	ES7010056	

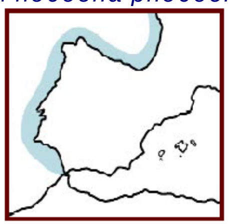
	Sebadales de Playa del Ingles (English Beach)	
	ES7020122 Fuencaliente Strip	
	ES7020123 Santiago-Valley Gran Rey	
	ES7020017 Teno-Rasca Marine Strip	
	ES7020057 Las Calmas Sea	
Catalonia	ES5140001 Cape Saint Creus	*Turisops truncatus*
	ES5140007 Tarragona Litoral	
	ES5210007 Cape Creus	
	ES5120016 Medes Islands-El Montrgi	
Galicia	ES0000001 Cies Islands	*Turisops truncatus*
	ES1140004 Ons O Grove Complex	In the designated file, *Turisops truncatus and* Phocoena. But, in the webpage of the autonomous government: phocoena *Delphinus delphis Globicepala melas.*
	ES1110006 Humedo de Corrubedo Complex	In the designated file, *Turisops truncatus* and *Phocoena phocoena*. But, in the webpage of the autonomous government: *Delphinus delphis*
	ES1110005 Costa da Morte (Morte Coast)	In the designated file only *Turisops truncatus* but in the webpage *Delphinus delphis* and Globicephala melas are mentioned.
	ES1140010 Costa de la Vela	*Turisops truncatus* and *Phoncoena phocoena.*
Murcia	There are LIC's designated in the zone of Public Maritime-Terrestrial Domain but cetacean's do not appear in any of its files.	
Valencia	ES5213024 Tabarca	*Turisops truncatus*
	ES0000061 Columbretes Islands	

Annex V. Cetaceans present in Spanish Waters

Note; The table below lists the cetacean species present in Spanish Waters compiled from legal catalogues on endangered species, or "Red Books" of Endangered Species. Nevertheless, the cetacean species listed in the table are not the only ones present in Spanish Waters. To these the following should be added: Atlantic Spotted Dolphin, (*Stenella frontalis)* Tropical Spotted Dolphin, *(Stenella attenuata)* Rugged Toothed Dolphin, *(Steno bredanensis)* Fraser's Dolphin, *(Lagenodelfis hosei)* Melon Head Dolphin, *(Peponocephala electra)* False Killer Whale, *(Pseudorca crassidens)* Pygmy Killer Whale, *(Feresa attenuata)* Sowerby's Beaked Whale, *(Mesoplodon bidens)* Blainville's Beaked Whale, *(Mesoplodon densirostris)* True Beaked Whale, *(Mesoplodon mirus)* Baird's Beaked Whale, *(Hyperoodon ampullatus)* Tropical Fin Whale, *(Balaenopetra edeni)* Northern Fin Whale, *(Balaenoptera borealis)* Blue Whale, *(Balaenoptera musculus).*

Species (4)	Red Books (1)			Legal Norms (3)				
	World	Andalusia	Balearic Islands	EU (2)	Status	Andalusia	Balearic Islands	Canary Islands
Common Dolphin *Delphinus delphis* 	Endangered	Critical threat of extinction	Endangered	Annex IV	Vulnerable (Mediterranean population) Special interest, Atlantic population	Vulnerable (Mediterranean population) Special interest, Atlantic population	Vulnerable	Special interest
Bottlenose Dolphin *Tursiops truncatus* 	Insufficient data	Under threat of extinction	Vulnerable	Annex II and Annex IV	Vulnerable	Vulnerable	Vulnerable	Vulnerable

Striped Dolphin *Stenella coeruleoalba* 	Almost threatened with extinction	Under threat of extinction	Almost threatened with extinction	Annex IV	Special interest	Special interest	Special interest	Special interest
Long Finned Pilot Whale *Globicephala melas* 	Not threatened	Insufficient data	Lesser concern	Annex IV	Special interest	Special interest	Special interest	Special interest
Risso's Dolphin *Grampus griseus* 	Insufficient data	Insufficient data	Lesser concern	Annex IV	Special interest	Special interest	Special interest	Vulnerable

Short Finned Pilot Whale *Globicephala macrorhynchus* 				Annex IV	Vulnerable (the population of the Canary Islands) Special interest (Atlantic, peninsula and Mediterranean)	Special interest		Vulnerable
Killer Whale *Orcinus orca* 	Almost threatened with extinction	Insufficient data		Annex IV	Special interest	Special interest		Special interest
Harbor Porpoise *Phocoena phocoena* 	Vulnerable to extinction	Danger of extinction		Annex II and Annex IV	Vulnerable	Vulnerable		

Sperm Whale *Physeter macrocephalus* 	Vulnerable to extinction	Vulnerable to extinction	Vulnerable	Annex IV	Vulnerable	Vulnerable	Vulnerable	Vulnerable
Pygmy Sperm Whale *Kogia breviceps* 				Annex IV	Special interest	Special interest		Special interest
Fin Whale *Balaenoptera physalus* 	Danger of extinction	Almost threatened with extinction	Almost threatened with extinction	Annex IV	Vulnerable	Vulnerable	Vulnerable	Danger of extinction

Minke Whale *Balaenoptera acutorostrata* 	Almost threatened with extinction	Almost threatened with extinction		Annex IV	Vulnerable	Vulnerable		Vulnerable
Sei Whale *Balaenoptera borealis* 	Danger of extinction	Insufficient data		Annex IV	Vulnerable	Vulnerable		Danger of extinction
Blue Whale *Balaenoptera musculus* 				Annex IV	Vulnerable	Vulnerable		Danger of extinction

Humpback Whale *Megaptera novaeangliae* 	Vulnerable to extinction	Insufficient data		Annex IV	Sensitive to change of habitat (all population, less those of the Canary Islands) Special interest	Sensitive to change of habitat		Special interest
Northern Right Whale *Eubalaena glacialis* 	Danger of extinction	Critical danger of extinction		Annex IV	Danger of extinction	Danger of extinction		Danger of extinction
Beaked and Cuvier's Beaked Whale *Ziphius cavirostris* 	Insufficient data	Insufficient data	Insufficient data	Annex IV		Special interest		

Legend:
(1). Red Books. Cetaceans not included in the national Red Book of vertebrates
(2). Annex II, from the Habitats Directive, signifies there have been areas designated for these species and special conservation zones, (Article 4). Annex IV signifies "strict protection" (Article 12 Habitats Directive), i.e. , capture prohibited, sacrifice, alteration, - especially during reproduction periods, nursing of young, hibernation y migration - , and damage or o destruction of breeding, rest and Reproduction grounds.
(3)Catalonia is not included as "all cetacean species" found there qualify as "protected species", not even Galicia, where in its Catalogue only recognizes Bottlenose dolphins (Tursiops truncatus), in the category "Vulnerable". The remaining CCAA coasts do not Have Catalogues, or do not recognize Cetaceans in them.
(4) Maps in the distribution of this Table are only indicative. The Community of the Canary Islands ought to be included in them, for in corresponding column, some classified species appear.