FASE. 4.2 “Raccolta e l’elaborazione dati sulle fonti di inquinamento acustico e la loro interazione con i cetacei nell’area marino costiera toscana”

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The shipping noise issue

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The shipping noise issue

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Introduction

Marine life is threatened by habitat degradation caused by intense human activities such as fisheries, ship traffic, pollution, and coastal development. In addition to being affected by chemical pollution, cetaceans and other vertebrates are affected by noise pollution (Richardson et al., 1995).
At present, noise represents a ubiquitous form of marine pollution, especially in areas of heavy maritime traffic and developed coasts. Intense underwater noise is generated by airguns, widely used for geophysical explorations for oil and gas industry as well as for academic and administrative purposes, by high power sonar, either military or civil, by ship traffic, by shoreline and offshore construction works, and by a series of other commercial, scientific, military and industrial sources. With the most powerful sources (airguns, sonars, explosions and, in some cases, pile driving) this may lead to direct injure of animals in the nearby of the source. General ship traffic, heavy industries on the coast, windfarms and a variety of different human activities, on the other side, generally don't generate such intense noise, but this different acoustic pollution is constant over time and may affect large areas. It may result very dangerous not to individual animals, but to entire populations. The increased background noise, in fact, affects underwater life as airborne noise does on terrestrial animals, included human beings.
However, considering that sound in water travels 5 times faster than in air, and that the density of the water transmit acoustic energy very efficiently over distances much greater than in air, in particular at low frequencies, the underwater noise effects may extend over very large water volumes. The knowledge that man-made noise can affect marine life, marine mammals in particular, and the need for a regulatory system to mitigate such effects has increased over the past few years, mainly in the context of military sonars and seismic surveys. Increasing concern is now given to all types of noise pollution, in particular shipping noise, and extends to consider other zoological groups such as fishes and invertebrates.

The noise from marine activities has increased dramatically over the last decade. Man-made underwater noise has the capacity to directly cause disturbance to marine mammals, such as seals, whales, dolphins and porpoises, and may also cause secondary effects, for instance by disturbing important food sources such as fish.
The effects of noise can include death or lethal injury, physical injuries that can have longer term consequences for the animal such as deafness, and sub-lethal behavioural effects such as the avoidance of an area. All of these may have significant consequences for individuals or stocks of a species, by directly affecting them, or by inducing avoidance of noisy areas.

With the noise produced by ship traffic we may have two scenarios, one in close proximity of noisy ships and one over large distances where the noise irradiated by a number of ships merges into a relatively constant and diffuse background noise more or less dominated by ship noise.

Marine mammals are acoustic specialists and depend on sound for survival (e.g., communicating, navigating, finding food and mates, detecting predatore and threats). For example, blue and fin whales produce intense infrasonic songs that can be heard over an entire ocean, while humpback songs can be heard over many hundreds of miles. With the advent of modern shipping, ocean noise in the low-frequency range (10-300 Hz) has been doubling approximately every decade, drastically reducing these ranges. Although the long-term impacts on marine mammals from this increased noise are not yet known with certainty, increased noise obscures an animal's ability to hear, and therefore has serious implications for reproduction and survival. This is a global problem.
There is a relationship between commercial shipping and the amount of underwater noise. Given that shipping is increasing and expected to expand into new areas, e.g., the Arctic, noise from shipping will continue to rise.
Unlike chemical pollution, noise does not persist in the environment. Thus, if a source of noise is reduced, the amount of noise energy in the water is immediately lowered. Under these favorable

circumstances, the goal is to reduce the amount of incidental underwater noise from shipping to reduce or eliminate the impacts of noise on marine mammals.

This goal would be accomplished by reducing noise contributions from individual ships and also by applying specific traffic management options.
The engineering tools and methodologies currently available are sufficient to reduce radiated noise from ships, or can be developed with limited effort. Some operational measures can be implemented immediately.
The widespread application of technical and operational noise reduction measures applied on an individual ship basis would lead to a reduction in ambient noise within few years and would result in an overall increase in potential communication/hearing ranges for marine mammals.

It is now clearly recognized that shipping noise is a trans-boundary, international issue that should be addressed by all stakeholders by developing new legislation within a suitable scientific framework.

Ocean noise

The underwater environment has its own acoustic peculiarities (Wenz, 1962) and marine mammals are extraordinarily well adapted to them. In the last century human activities began to contributo significatively to the ocean noise composition and level; this is happening fastly, within a time frame incomparatively shorter than the times taken by evolution to make animals well adapted to the natural background noise.

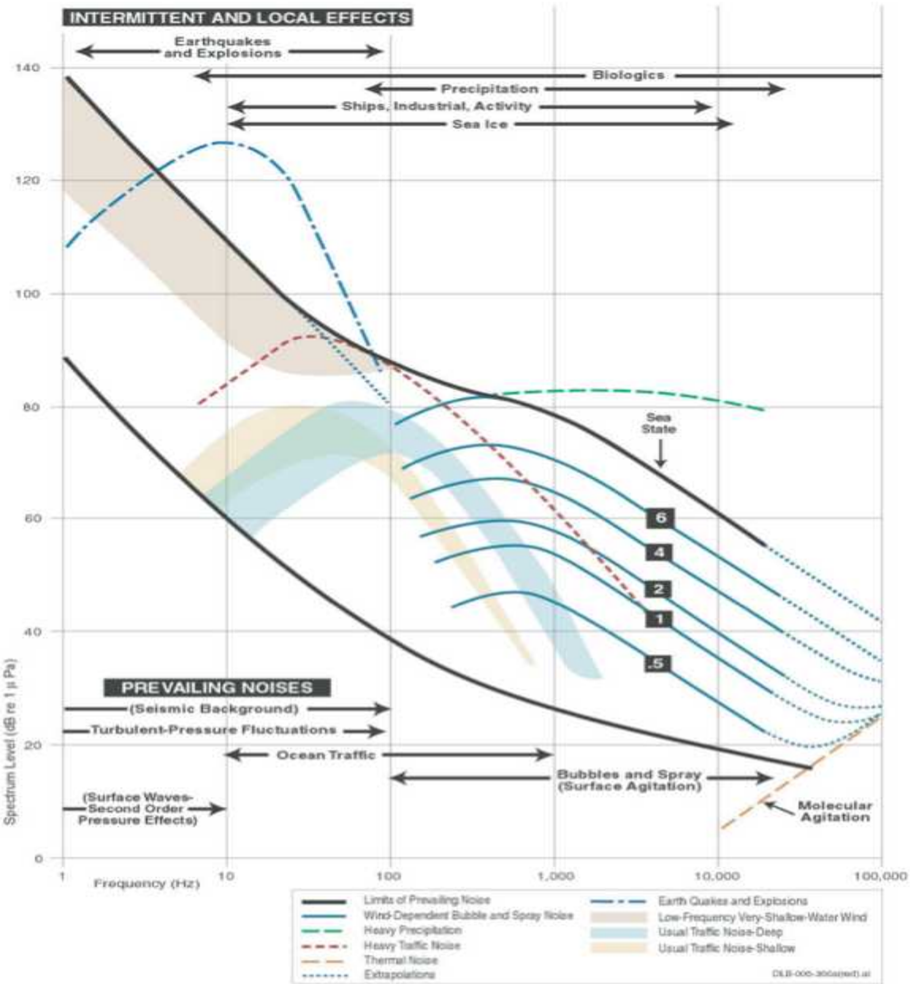


Figure - Wenz curves describing pressure spectral density levels of marine ambient noise from weather, wind, geologic activity, and commercial shipping. (Adapted from Wenz, 1962.)

Anthropogenic noise sources

Many anthropogenic sources produce sounds into water and contribute to increase local and global noise levels.
To summarize, these are the sources and activities to be taken into consideration within the context of the ocean noise issue:

- Long range ship traffic (cargo ships, high speed ferries), “sea highways”
- Local ship traffic (any type of motorboat, whale watching boats)
- Fisheries vessels
- Military sonars (e.g. patrolling, testing, training exercises)
- Civil sonars (e.g. academic, research, testing)
- Airguns and Sparkers, including arrays of them, used for seismic surveys, either academic or industrial
- Explosives, including the blasting of residual war weapons, shipshock tests and other military exercises, decommissioning of offshore structures
- Construction/demolition works on harbours/coast, including pile drivers, jack hammers, etc.
- Offshore construction/demolition works
- Coastal industries that may produce vibrations that propagate through the substrate
- Ports
- Drilling and oil/gas extraction offshore platforms
- Offshore wind farms (including the construction and decommissioning)
- Oceanographic instruments (bottom and sub-bottom profilers, side-scan sonars, current meters, underwater modems, acoustic thermometry experiments, etc.)
- Scientific research on marine mammals (e.g. playback experiments and Controlled Exposure Experiments (CEE))
- Echosounders and other acoustic navigation aids and instruments
- Pingers (used on fishing nets) and Acoustic Harassment Devices (AHD)

Although all these sources should be evaluated and monitored individually for their acoustic emission features in their local context, they also should be evaluated for their contribution to the ocean noise budget and for any synergistic effect.

Marine mammals and sound

The underwater environment has its own acoustic peculiarities (Wenz, 1962) and marine mammals are extraordinarily well adapted to them. In these mammals acoustic communication and perception has acquired a privileged role compared with other senses and other zoological groups. Marine mammals live in a medium which poorly transmits light but through which sound propagates very well, even over long distances, especially when frequencies are low or the sound is channelled by pressure and temperature gradients (Urick, 1983; Richardson et al., 1995). Marine mammals rely heavily on sound to communicate, to coordinate their movements, to navigate, to exploit and investigate the environment, to find prey and to avoid obstacles, predators, and other hazards.
Mysticetes mostly use low frequency sound (15 to 1000 Hz) to communicate over large distances; Odontocetes use mid to high frequency sound to communicate (1 kHz to 25 kHz) and ultrasounds to echolocate (30 to more than 150 kHz). Sound production and hearing are reciprocally adapted, with hearing typically more extended in frequency to allow listening for environmental sounds and other species sounds (e.g. predators).

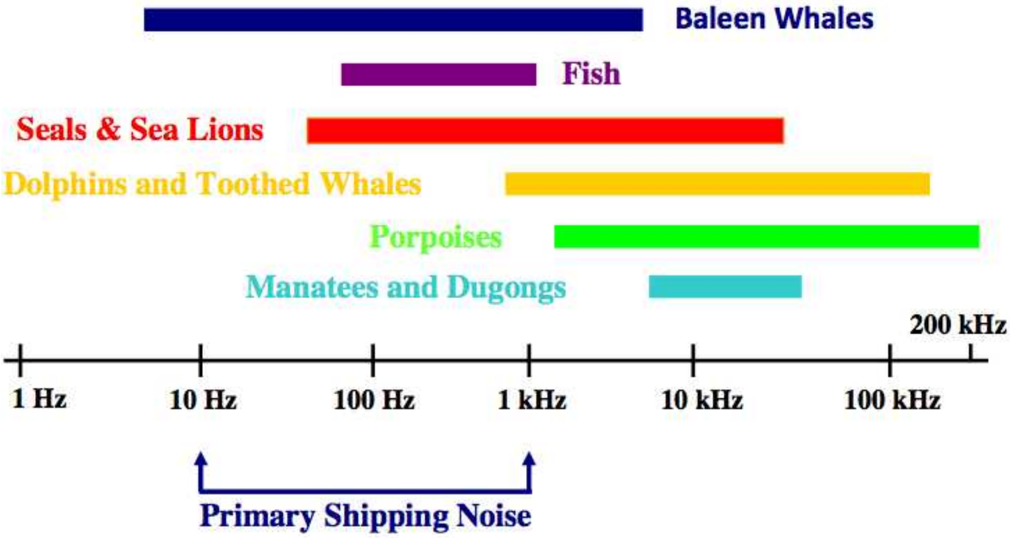


Figure - Frequency ranges used by marine animals vs shipping noise.

Marine mammals hearing

Odontocetes, sea lions and seals have been studied with several techniques to produce audiograms. These techniques include behavioural hearing tests in captivity, responses to sound in the wild, ABR techniques on both captive and free ranging dolphis, anatomy based modelling.

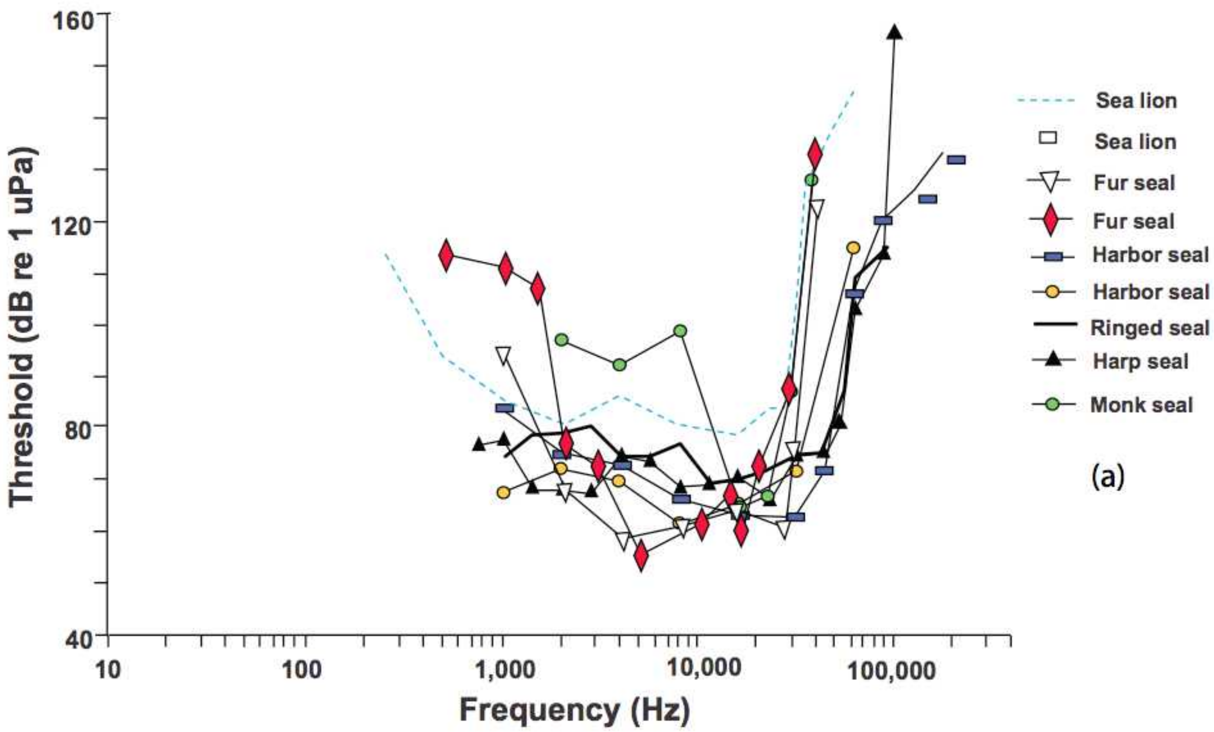


Figure – Hearing curves in seals and sea lions. Bradley & Stern, 2008.

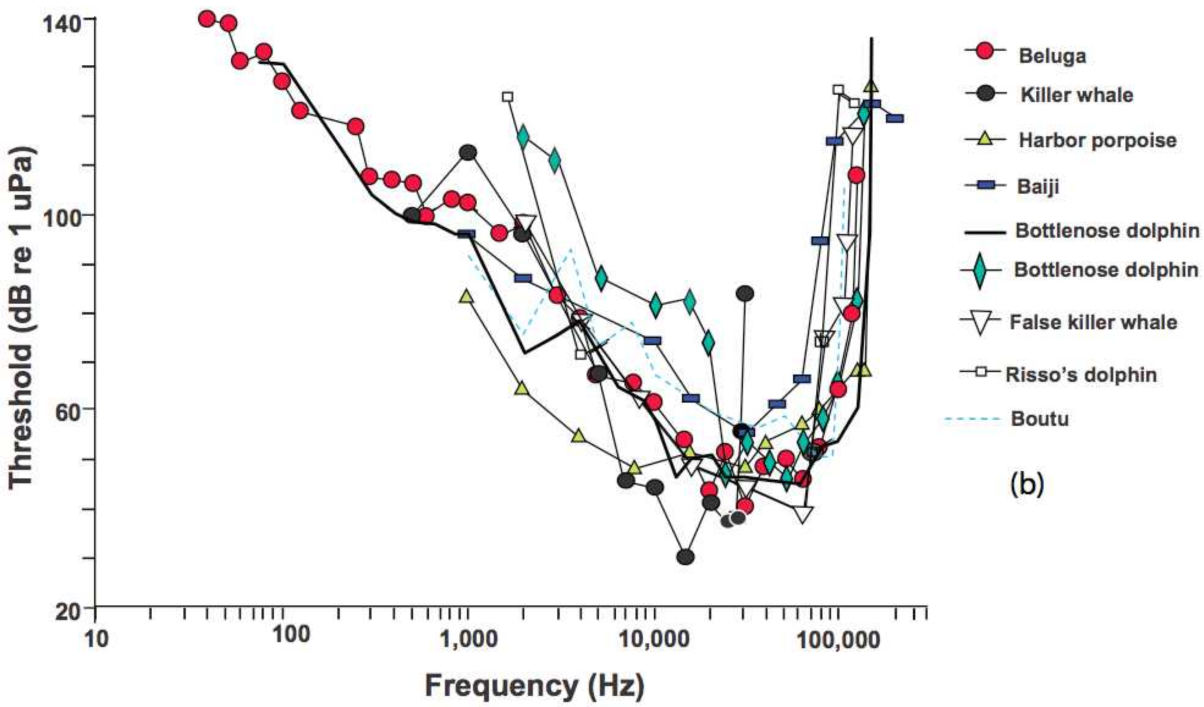


Figure - Hearing curves in Odontocetes.

The hearing characteristics of baleen whales (Mysticetes) are virtually unknown. At present, we do not know how they receive sounds, their frequency range of hearing, or their hearing sensitivity at any frequency (see Au, 2000). This is not in itself surprising as there is a great deal of basic knowledge about mysticetes that remains unknown, including fundamental aspects of their life history, physiology, ecology, and behavior. Much of what is generally known about hearing in the mysticetes has been broadly summarized in scientific reviews including those by Richardson and colleagues (1995), Au and colleagues (2000), Wartzok and Ketten (1999), and in a series of reports by the National Research Council (NRC) of the United States (1994, 2000, 2003b, 2005).

The auditory data that are presently available derive from sound production ranges, responses of free-ranging whales to sound and anatomy-based modeling.

For most species the frequency range of hearing has been estimated equal or larger than the range of sounds emitted for communication, in few species the range has been estimated by models of the hearing apparatus, in particular the size, shape and mass of the basilar membrane (Ketten ….); in both cases sensitivity ans hearing thresholds remain unknown. In few cases, field observations on the distance of whales' reaction to known sound sources allowed to estimate hearing thresholds (Tyack 2009).

Tyack (2009) reports about some early experiments, motivated by concerns about the impact of offshore oil-industry activities, tracked migrating gray whales as they passed a sound source moored in the migration corridor off California. The whales, which were exposed to experimental playback of continuous industrial sounds such as those from ships or drill rigs, avoided sound pressure levels (SPLs) of 120 dB relative to 1 μPa. Aerial observations of bowhead whales migrating past a seismic survey vessel showed that those whales also avoided ex- posures greater than about 120 dB. The air guns used for the seismic surveys were so intense that the whales rarely came within 20 km of a survey vessel.

Noise impacts on marine mammals

Noise can severely interfere with marine life. Noise pollution can cause marine mammals to abandon their habitat (Borsani et al., 2007) and/or alter their behaviour by direct disturbance or by masking their acoustic signals over large areas (Payne & Webb, 1971; Hildebrand, 2005); higher sound levels could directly affect their hearing capabilities by producing either temporary or permanent hearing losses (Simmonds and Lopez-Jurado, 1991; Richardson et al., 1995; NRC, 2000; NRC, 2003; Gordon et al., 2004). All these effects may be critical for the survival of marine mammals. Some high energy sound sources can have immediate impacts and even trigger mortality events, as recently evidenced by several dramatic and well documented atypical mass strandings (mass strandings are defined as 2 or more animals stranded in the same area) of beaked whales (e.g. Greece 1996, Bahamas 2000, Canary Islands 2002. See: D'Amico, 1998; Frantzis, 1998; Evans and England, 2001; NOAA, 2001; Dep't of the Environment, 2002; Evans and Miller, 2004; Fernández, 2005).

In some cases anthropogenic high power sound sources (up to 250 dB re 1 µPa at 1m distance) radiate low- to high-frequency sound and individual animals can be exposed to high levels of sound (> 160 dB re 1 µPa) over relatively short periods of time (acute exposure), e.g. in some military sonar operations. In other cases potential exposure to high noise levels can occur for longer periods, weeks and months, as in the case of seismic surveys or some construction works (i.e. pile driving for construction of ports, bridges) (Borsani et al., 2007).

Seismic surveys and low-frequency naval sonar, other than high levels close to the source, may radiate low-frequency sound over very large areas thereby exposing populations to lower sound levels (< 160 dB re 1 µPa) over relatively long periods of time (chronic exposure). Continuous exposure to low frequency sound is also the effect of distant shipping noise, multiple distant seismic surveys or construction works (Tyack, 2003; Nieukirk et al., 2004; Borsani et al., 2007; Pavan, personal observation).

Regarding received levels, it is generally accepted that levels greater than 120 dB re 1 µPa may produce behavioural changes (Richardson et al., 1995; Moore et al, 2002) and levels greater than 150 dB can lead to effects ranging from severe behavioural disruption to TTS (Temporary Threshold Shift), that means temporary lowering of the hearing sensitivity; levels greater than 170-180 dB are considered able to produce PTS (Permanent Threshold Shift), that means permanent hearing loss, deafness and physical damage, including death in some circumstances. These numbers are debatable, they may vary according to environmental context, behavioural context and to specie, as demonstrated by Cuvier's beaked strandings that occurred after (multiple) exposures at levels believed safe.

According to current US regulations, SPLs above 180 dB pose a risk of injury to whales and dolphins. Despite seals' apparently greater sensitivity to noise exposure, regulations set 190 dB as the threshold for risk of injury to them. US regulations also establish criteria for disrupting behavior. They set the disruption threshold at 160 dB for whales and dolphins. The threshold for porpoises is lower—120 dB— because of evidence that they respond to sounds at lower levels than many other cetacean species. Worth to note that beaked whales beaked whales have been observed to avoid SPLs of 136–140 dB re 1 µPa or greater.

However, the integrated sound exposure level (SEL), a measure that takes into account the duration of the exposure, is a better overall predictor of risk than just the SPL. Brandon Southall and colleagues (2007) established criteria for acoustic injury for whales and dolphins; the criteria set a maximum 0-to-peak pressure level of 230 dB, a maximum SEL of 198 dB for pulsed sounds, and a maximum SEL of 215 dB for nonpulsed sounds. Data from seals suggest that their auditory systems may be affected by lower levels of sound; criteria for them are a maximum 0-to-peak pressure level of 218 dB and maximum SELs of 186 dB for pulsed sounds and 203 dB for nonpulsed sounds.

Note that the US regulations are in terms of SPL, a different measure from the 0-to-peak pressure and SEL used for the criteria suggested by Southall et al..

Although atypical mass strandings represent the most dramatic and known class of incidents related to acute sound exposure, at least for certain marine mammal species (beaked whales) (Frantzis, 1998; Evans and England, 2001; NOAA, 2001; Dep't of the Environment, 2002; Evans and Miller, 2004; Fernández, 2005), it should be remembered that the effects of repeated non lethal exposures and of increased noise levels are generally unknown but may potentially have significant both short and long term effects. Furthermore, the biology of "disturbance" and the effect of noise on the fecundity of marine mammals and their prey species are not well understood.

Levels of impact

Types of expected effects based on the information in a large literature (OSPAR, 2009a), and as early defined by Richardson *et al.* (1995), in simplified, progressively increasing scale:

• Negligible
• Behavioural responses: behavioural reactions;
• Masking: Obscuring of sounds of interest (for example communication or echolocation signals) by interfering sounds, generally at similar frequencies;
• Temporary threshold shift (TTS): a temporary elevation of the hearing threshold due to noise exposure, depends on exposure level, sound type and duration;
• Permanent threshold shift (PTS): a permanent elevation of the hearing threshold due to noise exposure, depends on exposure level, sound type and duration;
• Injury: tissue damages at different levels, includine embolies, due to high level sound exposure;
• Death.

It should be noted here that the assessment is concerned with potential effects based on information on documented responses and modelling exercises. The scale of these potential effects is assessed on a two-fold scale as either being short-range, that is happening only in the immediate vicinity of the source and / or within the area the activity is carried out (for example vicinity of a high power sound source) or long-range, that is occurring beyond that. It should be emphasised that this is a very preliminary and rather subjective measure that needs further amendment. It is to be noted that noise can have potential effects on a wide range of distances, up to several kilometres. Yet, zones of noise influences are so diverse and depending on so many variables, that a further split in spatial scales of effects is difficult to quantify.

Further, among non lethal effects and death we can have a continuum where few reference points can be set.

The discussion and debate over how marine mammals may be affected by human noise in the ocean (see: National Research Council 2000, 2003, 2005, Cox et al. 2006, Southall et al. 2007), has mostly been directed at understanding the physiological impacts from short-term, small-scale (i.e., acute), high intensity exposures. However, there is recognition that long-term, large-scale (i.e., chronic), low intensity exposures might also be affecting individuals and populations, and acoustic masking is often mentioned or implied as a probable mechanism (Payne & Webb, 1971, NRC 2000, 2003, Southall 2005, McDonald et al. 2006, Nowacek et al. 2007, Hatch et al. 2008).

IMO 2008 states that the primary concern regarding potential adverse effects of shipping noise is not related to acute exposures, but rather to the general increase in background ambient noise that may result from concentrations of vessel operation. That is to say, the potential environmental impacts from ship noise are likely related to masking of communication systems. While there is insufficient data to conclude that ambient noise levels are increasing in large areas of the ocean as a function of vessel sounds, two recent studies off California analysing measurements over several decades do indicate changes that, for these particular areas, suggest an increasing trend in background noise of ~ 3 dB/decade in the low-frequency band (Andrew *et al*, 2000; McDonald *et al*, 2006). Because of the logarithmic nature of sound and what is known about hearing systems in mammals, seemingly small changes in background noise levels can result in large reductions of communication range.

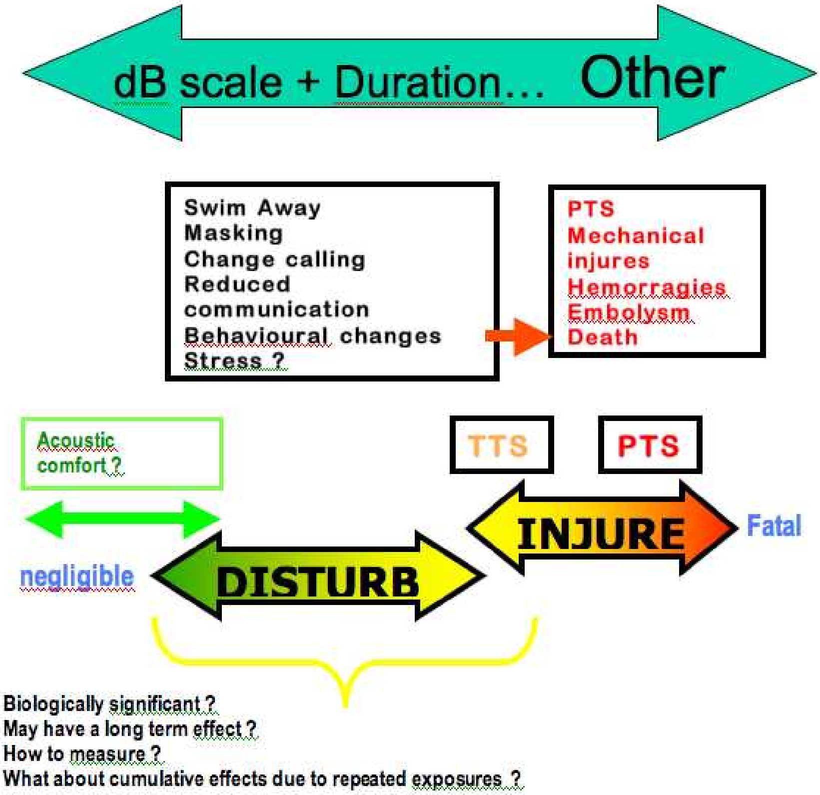


Figure x – The many uncertainties in evaluating the effects of noise exposure.

Direct physical damage

Shock waves, high sound pressures, high changes in pressure levels, mostly produced by explosions, but potentially generated by high power sound sources at very short distance, may produce direct physical damages (e.g. emorrhagies, embolies, etc.).

Permanent treshold shift (PTS)

Estimates of levels that induce permanent threshold shifts in marine mammals cannot be made reliably, at this time. However, it can be estimated that levels higher than 100 dB above the species-specific threshold can prodice PTS.
While auditory trauma, particularly from short or single exposures may impair an individual, it is unlikely to impact most populations. Long-term, constant noise that disrupts a habitat or key behaviour is more likely to involve population level effects. In that sense, the question of individual hearing loss or animal loss from a single, intense exposure is far less relevant to conservation than that from a more subtle, literally quieter but more pervasive source that induces broad species loss or behavioural disruption.
Relatively few species are likely to receive significant impact for lower frequency sources. Cetaceans currently believed to be likely candidates for LF acoustic impact are the mysticetes

Temporary treshold shift (TTS)

Received levels that induce hearing loss, at any one frequency, are highly species dependent and are a complex interaction of exposure time, signal onset and spectral characteristics, as well as received vs. threshold intensity for that species at that frequency.
The best available data suggest that exposure to a narrowband sound for a protracted to short-term

period of time, at a received level ranging typically from 150-190 dB re 1 μPascal, and which is approximately 80-90 dB above the species-specific threshold, will induce temporary threshold shift. Furthermore, from long- and short-term exposure studies on a number of species, the data are converging toward a common slope suggesting that energy flux density is the critical parameter for predicting threshold shift for a given set sound parameters. If so, this suggests that extrapolation from land mammals may be possible once the significant differences amongst different species' ears are determined.

Masking

A special type of noise impact is masking. This happens when the interfering noise is above the hearing threshold so much so that a sound of interest (a communicative signal from another individual, or an echo from a prey, or a sound from a predator) cannot be perceived or recognized. Masking happens when the energy of the noise (i.e., sound intensity over time), as well as its general spectral and temporal characteristics, reduces the ability to perceive sound signals of interest.
The noise that produce masking can extend to levels that may produce temporary or permanent loss of hearing sensitivity, e.g. in the case of a noisy ship passing close to a cetacean.

The notion that noise from anthropogenic sources night be having an impact on marine mammals was first articulated in a paper by Payne and Webb (1971) in which they proposed that the sum of very-low-frequency noise (< 100Hz) from ocean shipping might reduce the range over which some of the great whales are able to communicate.
Payne and Webb were the first to raise the alarm about the effect of sound on marine mammals. They considered the recently discovered low-frequency calls associated with the reproduction of baleen whales and noted that in the preindustrial ocean those calls could have been heard about 280 km away, but the low-frequency propulsion noise of modern commercial ships had so elevated ambient noise in the sea that the detection range for whale calls could be as low as 90 km.

In recent times masking due to ship noise has been recognized as a real threat to marine life; however, besides few studied cases, there are no generalized models to depict the real and potential extent of the problem.
Few models have been created to estimate the spatial extent of masking. One such model for beluga whales (*Delphinapterus leucas*) considered the physical environment as well as both the acoustic behavior and hearing ability of the animal (Erbe & Farmer 2000). Clark et al. (2009) are developing models for measuring the potential for acoustic masking on free-ranging animals, particularly the low-frequency specialists, baleen whales, because this is the group at highest risk from chronic exposure to anthropogenic sounds.

During IWC 61, Clark (SC/61/E10) presented information on and results from a recent model that quantifies acoustic masking of individuals and populations of baleen whales as a result of anthropogenic sound sources. There were four primary messages: (1) The mechanical and analytical tools exist for measuring and quantifying the spatio-spectral- temporal variability in different whale acoustic habitats; (2) These have been merged into an algorithm and implemented in a model that quantifies a relative measure of acoustic masking for individuals and populations, and this model addresses the issue of cumulative impact from multiple sources of masking; (3) Model results indicate that different species experience very different levels of masking as a result of their species-specific bioacoustical adaptations and behaviours; and (4) The results lead to and support the concept of a marine acoustic ecology and the notion that individuals, and thus populations, incur a cost when there are changes to their acoustic habitats, and those costs are of particular concern when the ecological changes occur at rates and levels to which animals are poorly adapted.

During discussion, Clark noted that these acoustic masking levels are not directly damaging to the cetaceans, but do appear to inhibit their ability to communicate with their conspecifics. One foreseen difficulty is how to evaluate the risk from masking effects on whale behaviour. A huge next step would be to determine how to translate this type of model into changes in life history parameters. The author has observed that, off New England, USA, as noise levels increase due to vessel traffic or weather events, right whales in the area stop calling. Although there is evidence that noise is having an effect on the population, it is difficult to translate the impact that chronic high noise environments have on survivorship of the population.

Clark and his group are aimed at developing models that combine the ocean sound propagation and animals' acoustic communication to derive a metric for acoustic masking.
This process is based on the few known species-specific sound characteristics and several assumptions about signal recognition thresholds. The model is exercised with some empirical ship noise data to reveal how the process results in a standardized metric for communication masking. The results for three different species revealed how different species are impacted differently given the same anthropogenic noise activity. Empirical data is actually compared with real data provided by a wide interdisciplinary monitoring and research project being carried out by Clark in the Stellawagen Marine Park, on the east US coast north of Cape Cod.

Independent of species, what emerges by recent advances, is that individuals and therefore populations rely on an "acoustic habitat" for establishing and maintaining normal communications and when their acoustic habitat is degraded, acoustic communication is degraded. This then leads to the concept of an "acoustic ecology" and of an "acoustic landscape" within which the acoustic communication functions and without which the social system can become dysfunctional.
In other words each species has his specific "acoustic niche" within a lager "acoustic habitat"; in analogy with human environments, each species needs his own level of "acoustic comfort" to behave according to his own evolution path.
"acoustic ecology" research leads to the conclusion that there are costs associated with the loss of acoustic habitat (e.g., in the reduction of feeding efficiency, mating success, predator avoidance), and these costs can affect primarily individuals and then populations.
It is likely that for a broad range of marine mammals, acoustic masking is having an increasingly prevalent impact on acoustic information transfer including both communication and other key activities such as navigation and prey/predator detection. In an evolutionary time frame relevant to species adaptations, these impacts are both quite recent and relatively rapid.

Reduction of these impacts could be achieved by reducing the noise irradiated by ships and by managing ship traffic; to protect special areas it could be required the establishement of specific MPAs.

Behavioural disruption and stress

Noise exposure can produce a range of behavioral effects such as changes in diving profiles, reduction in calling activity (Sousa Lima et. Al., 2008), increase in calling activity, moving away from the noise sources, change direction during migration, alteration of migration routes. However, more subtle changes and the induction of stress are difficult to evaluate and to correlate with noise exposure. In captive animals discomfort can be revealed by a specific hormone, the cortisole, that has been evidenced in fishes and other animals exposed to noise.
Whilst there is little direct evidence, it is likely that if the disruptions occur frequently, for extended periods of time, or during biologically important activities such as mating, feeding, birth and mother-young pair bonding, they can affect longevity, growth, and reproduction.
Further, frequent or chronic exposure to low intensity sounds may cause hearing loss, and make animals that rely on hearing to locate and capture prey, and to detect and avoid predators, less able to do so. Also, frequent or chronic exposure to variable intensity sounds may cause stress (Wysocki et al., 2006), which human and terrestrial animal studies indicate can affect growth, reproduction, and disease resistance.

Site avoidance

Noise may induce to abandon areas otherwise beneficial to the animals, or to deviate from known migration routes. If animals are forced to abandon a feeding area this could turn into damage to individuals and to the population. However we have to consider these animals are opportunistic and may tolerate disturbance if it is counterbalanced by an advantage in finding food. In such a case the population may be damaged by the noise exposure.

Indirect impacts on marine mammals

Noise may not always have an immediate impact on cetacean populations but may indirectly effect them through its effects on prey abundance, behaviour and distribution. Cetaceans can be divided into two major groups by their dietary requirements, (1) Piscevores, and (2) Planktivores. Odontocetes fall into the former group and mysticeti into the latter, although it should be noted that their diet may overlap.

Impacts on fishes and other marine organisms

Most interest in anthropogenic noise and its mitigation has focused on marine mammals (mainly cetaceans and pinnipeds) and a few other vertebrates (e.g. sea turtles), however there is increasing concern regarding the impact of such noise on fishes, other vertebrates such as aquatic and diving birds, and marine invertebrates (e.g. crabs, lobsters).
Fish sensitivity to noise has been largely demonstrated (Myrberg, 1990; McCauley et al., 2003; Popper, 2003; Amoser & Ladich, 2003; Amoser & al., 2004; Popper et al., 2004; Wysocki et al. 2006).
Despite increasing interest in the effect of sounds on fishes and its economic implications, this issue has only been addressed on a limited scale.
Fishes use sounds to communicate and to perceive information from the environment; more than 50 families of fish use sound, generally below 2-3 kHz, in a wide variety of behaviours including aggression, protection of territory, defence, and reproduction.
Although much less is known about the effects of anthropogenic sounds on fishes than on terrestrial or marine mammals, there is a small but growing body of literature demonstrating that such sounds can mask communicative sounds (Wahlberg & Westerberg, 2005), generate stress that negatively affects the animals' welfare (Wysocki et al., 2006), induce fishes to abandon noisy areas (Mitson & Knudsen, 2003), destroy the sensory cells in fish ears and that long-term exposure to such sounds can cause temporary, and possibly permanent, loss of hearing (McCauley et al, 2003; Popper, 2003; Smith et al., 2004; Popper & al., 2005) and also damage eggs.
In addition, the gas-filled swim bladder in the abdominal cavity, that may serve as a sound amplifier for both hearing and sound production, is a potential receiver for sound energy even at frequencies not used for communication.
Although it is known that noise can deafen fish and otherwise seriously impact them (McCauley et al., 2003; Popper et al., 2004, 2005), ethical concern is rarely expressed, and little interest has been given to the ecological implications of such effects and few mitigation procedures address fish or spawning aggregations. This issue has only been addressed on a limited scale and will need exploration in the future also taking into consideration the effects on the trophic web, on fisheries activity, and the effects on top predatore, e.g. marine mammals.

Fish in particular are affected by intense sound because of the presence of air filled cavities, e.g. swim bladders. Although marine fish typically have less sensitive hearing than marine mammals they are most sensitive at frequencies between 100 and 500Hz where most shipping, explosive and seismic exploration noise is produced. At these frequencies they are certainly more sensitive than those odontocetes studied so far. Effects of explosive pulses on fish range from serious injury at short ranges to avoidance behaviour, possibly over many km (Turnpenny and Nedwell, ????). Reduced catch rates have been reported for several species of fish in areas of intense seismic

activity. The pathological and behavioural effects of noise on higher marine invertebrates, e.g. squid and octopus, are not known. However, far-field hearing has been demonstrated for cephalopods and all invertebrates have well-developed mechanosensory systems that could potentially detect broadband and low frequency pulses. Squid are known dietary staple for the sperm whale and beaked whales and any effects of noise on deep-sea cephalopods could potentially have negative impacts on deep diving whale populations.
These studies show a variety of effects on potential prey species. If noise causes fish or squid that are the prey of marine mammals to become less accessible, either because they move out of an area or become more difficult to catch, then marine mammals distributions and feeding rates can be affected. In the long term, this could lead to effects at the population level.

The impact of noise on fish can have a negative effect on fisheries and also interfere with scientific surveys aimed at evaluating fish stocks; (Skaret & al., 2005) demonstrate vessel avoidance of spawning herring (*Clupea harengus* L.) studied off the coast of southwestern Norway. According to these and other smilar results it is reccomended that scientific survey vessels should be quiet enough to not disturb fish aggregations and fish schools (Mitson, 1995; Soria et al., 1996; Smitson & Knudsen, 2003).

It should be emphasised that the reaction of fish to sound has only been studied in a limited number of species, and the existing data cover only a few types of noise sources. There are data that suggest that the exposure to such sounds not only can occur in the natural environment but may also occur in locations such as marine aquaria and aquaculture facilities and result from background noises such as those produced by pumps and air bubbler sources (Bart et al, 2001).
Though, great care is needed when extrapolating existing data to other species and sound types and in different environmental and behavioural contexts. Concerning marine invertebrates, few studies are available.

Shipping noise

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

Ship traffic has been increasing in the oceans, and especially in the Northern Hemisphere, in the last decades and very likely will increase exponentially in future. Ship traffic produces diffuse and almost continuous noise that may affect very wide areas. Low-frequency (< 1000 Hz) ambient noise levels generated by ship traffic have increased in the northern hemisphere by two orders of magnitude over the last 60 years (3dB/decade) (Andrew et al., 2002) thereby reducing the potential for long-range communication in mysticetes (masking effect) (Payne & Webb, 1971).
Increases in the number, size, speed, and horsepower of commercial ships led Ross (1976, 1993, and 1974) to say that ocean ambient noise levels at low frequencies (10–150 Hz) had increased 15 dB between 1950 and 1975. At frequencies above about 150 Hz, ocean ambient noise levels are dominated by wind driven surface waves (National Research Council, 2003). At frequencies below 5 Hz, the dominant noise source is mi- croseisms (Webb, 1998).
Deep ocean ambient noise has been predicted to be increasing over the past few decades due to anthropogenic sources (National Research Council, 2003).

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.

The propulsion noise of ships accounts for more than 90% of the acoustic energy that humans put into the sea (Green et al., 1994). Commercial shipping is estimated to have elevated the average ambient noise levels in the 20-200 Hz band by about 10 dB in the past century. Payne and Webb (1971) point out that this is the dominant frequency band used by baleen whales for communication. Ubiquitous and continuous noise may have chronic effects, degrading the quality of marine habitats; even subtle effects, such as avoidance and signal masking, may have long-term population consequences if exposure is continuous. In addition, some problems such as collisions between whales and vessels may involve acoustic risk factors. In this case, the question is not whether there are adverse reactions to noise itself, but why whales may sometimes not react to the noise of an oncoming vessel and get out of the way (Tyack, 2003).

Ship noise is fundamentally generated from three elements: the engine, propeller and associated machinery and the flow of water over the hull. Ship propellers can also provoke cavitation, 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 impulsive sound. Cavitation accounts for up to 80-85% of all noise made by maritime shipping traffic.

Ship noise can have different features, resulting from the combination of multiple radiating sources. Noise can be burst/pulsed type, such as that produced by propeller’s cavitation, or continuous broadband with tonal components, at low frequency (<100Hz), generated by engines, at higher frequencies (<1000 Hz) generated by rotating gears and by mechanical resonances, or even higher tonals (1-2 kHz) like those emitted by turbine engines and hydro-jets (e.g. fast ferries). Other sources can be pumps and auxiliary engines, generators, compressors or other machinery. Sound levels and frequency characteristics caused by propulsion are roughly related with ship size and speed, but there is significant variability among ships of the same class and no accurate prediction models are available (Heitmeyer et al., 2004). Large traditional ships may have dominant tones with source spectrum levels near 180 dB re 1 μPa/Hz^2 at 1 m, with broader band tonal components near 200 dB (Richardson et al., 1995). Large ships may create louder and lower in frequency sounds, with greater potential for long range propagation, because of their greater power, slower turning engines and propellers, and larger surfaces able to efficiently transmit vibrations to water.

Special case of Fast Ferries - An important type of shipping in the Mediterranean Sea and in particular in the Ligurian Sea (Pelagos Sanctuary) involves fast ferries. These ferries have different propulsion systems compared to traditional vessels, and have different sources of noise. Fast ferries produce broader band noise than traditional vessels; they produce high level hydrodynamic noise, up to 10 kHz and more, and engine noise often with narrow peaks at high frequencies (1-2 kHz); in some cases they are quieter than large cargo ships and they move so fast that they may pose an increased risk of vessel collision rather than of noise impacts.

Recreational boating - Small tourist recreational boats, with the potential of moving almost everywhere with very few restrictions, may be an additional cause of disturbance to marine life either in pelagic waters where they can impact on marine mammals or in shallow waters where the noise may affect local fish populations. In shallow waters the impacts may extend beyond acoustic effects on animals with physical alteration of benthic habitats and communities. Yachts and motorsailing boats with inboard engines may produce multiple noises like large ships, normally at lower levels but higher frequencies. On the contrary, inflatables and boats with outboard engines and small propellers may produce very loud broadband noise, in particular if pushed at high speed. Although the in-air noise emissions are regulated by EEC Recreational Craft Directive 2003/44/EC, no limits are set for underwater noise emission.

Severe restrictions to tourist navigation should be applied to safeguard marine animals. In areas where marine mammals are present, in fish breeding grounds, and in particular in MPAs and SACs, underwater noise emission of any vessel should be regulated and monitored.

Whale watching boats - Whale watching is an activity that is increasing every year and that may have an impact on marine mammals' individuals, populations, and stocks. Rules and permits are already in force in many countries, but the noise issue is seldom taken into consideration. Noise irradiated by engines and propellers is an important component of the disturbance to animals (Erbe, 2002). Beyond complying with national rules and restrictions in approaching marine mammals, whale watching operators should also comply with noise emission limits to minimize their disturbance.

Impact of ship noise

Whilst there is little evidence to suggest that ship noise has an immediate acute effect (e.g. death of animals), the repeated disturbance and the effects of increased noise levels are generally unknown but may potentially have significant long term impact at the population/stock level. However, shipping noise in high traffic areas can be higher and more widespread than those levels that caused Cuvier' beaked whales strandings.

Low intensity sounds can cause masking and behavioural disruptions; whilst there is little direct evidence, it is likely that if the disruptions occur frequently, for extended periods of time, or during biologically important activities such as mating, feeding, birth and mother-young pair bonding, they can affect longevity, growth, and reproduction. Noise may induce to abandon areas otherwise beneficial to the animals, or to deviate from known migration routes.

Further, frequent or chronic exposure to low intensity sounds may cause hearing loss, and make animals that rely on hearing to locate and capture prey, and to detect and avoid predators, less able to do so. Also, frequent or chronic exposure to variable intensity sounds may cause stress (Wysocki et al., 2006), which human and terrestrial animal studies indicate can affect growth, reproduction, and disease resistance.

Masking appears to be the most relevant issue for animals that rely on low frequencies to communicate. Baleen whales do rely on low frequency sound to communicate over long distances; if whales do not have mechanisms to compensate for the increased noise, the noise may significantly reduce the range over which they can communicate and investigate the environment. It is also to be considered that commercial whaling has decimated populations of many baleen whale species. This may lead to increased ranges between whales compared to the environment in which their communication evolved.

Masking is an issue for fishes too, as they use low frequency sound to communicate, but generally over shorter distances, with lower level sounds than whales.

The consequences of masking could be dramatic, in particular if we consider long range communication. In a simple 20*log(range) transmission loss scenario - an ideal type situation where sound energy spreads spherically – any 6 dB increase of the background noise level reduces the communication distance (the range at which a signal can be heard above the background) by a factor of two and the area in which the signal can be heard by a factor of four. But when the propagation approaches the cylindrical spreading and the transmission loss is close to 10*log(range), the same 6 dB noise increase reduces the communication range by a factor of 4 and the area by factor of 16. In such a case, a 20 dB increase in the background noise reduces the communication range by a factor of 100, e.g. a dramatic reduction from 100km to 1 km.

The combination of increased range between signaling and receiving whales in populations that are already reduced by other impacts, and the reduction in effective range of communication caused by shipping noise, could adversely impact endangered whales if it interferes with communication used for reproduction and social behaviours. Furthermore, the negative effect of masking could be further enhanced if whales have lowered hearing sensitivity caused by long exposure to noise.

The Mediterranean Sea case

The Mediterranean Sea in general and the Ligurian Sea in particular, are heavily impacted by many different sources of manmade noise; nevertheless, few scientific papers regarding noise and little basic information regarding the main noise sources are available to set up noise management

strategies.
The most important sources of anthropogenic noise in the Mediterranean are: maritime traffic, seismic surveys, military sonar, drilling operations, coastal construction works and underwater explosions originating from military exercises.
Considering its small area (0.8% of the world's oceans) the Mediterranean Sea suffers probably the heaviest maritime traffic than any other sea in the world. According to Notarbartolo et al. (in Agardy et al., 2007), about 220.000 vessels greater than 100 tonnes cross the Mediterranean each year. The region's maritime traffic volume was estimated ten years ago as the 30% of the world's total merchant shipping and 20% of oil shipping. Although most of the traffic is along an east-west axis, the lanes web in some areas, including important habitats for marine mammals, is very complex. The total number of large cargos that are crossing the Mediterranean Sea at any moment is > 2000, indicating that silent areas may no more exist in the basin. See Dobler (2002) for a more detailed analysis of maritime traffic in the Mediterranean Sea.
The high ship traffic levels in the Mediterranean Sea results in high background noise levels (Fig. 2) that are likely to make it harder for whales to communicate between each other and also to receive acoustic cues, for example to detect approaching vessels or other hazards.

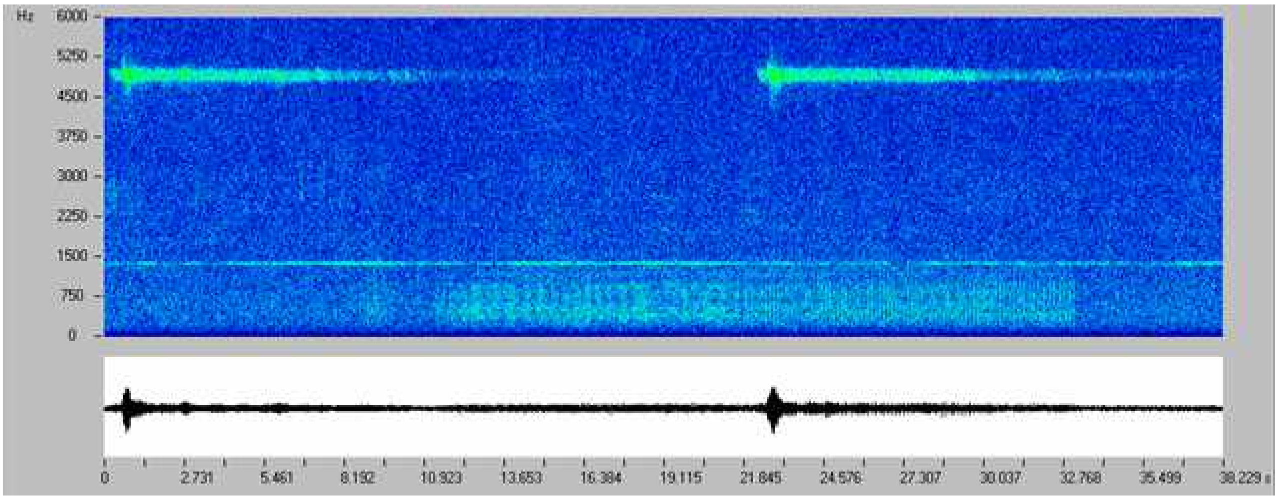


Figure x - *Spectrogram indicating noises from three different manmade sources recorded in the Ligurian Sea. Impulse noises (below 1 kHz) from a jack hammer used for construction in Monaco Harbour (about 40 nm of distance), a fast ferry passing by (the line at 1.4 kHz), and a sonar operating from an unknown location (5 kHz). (CIBRA).*

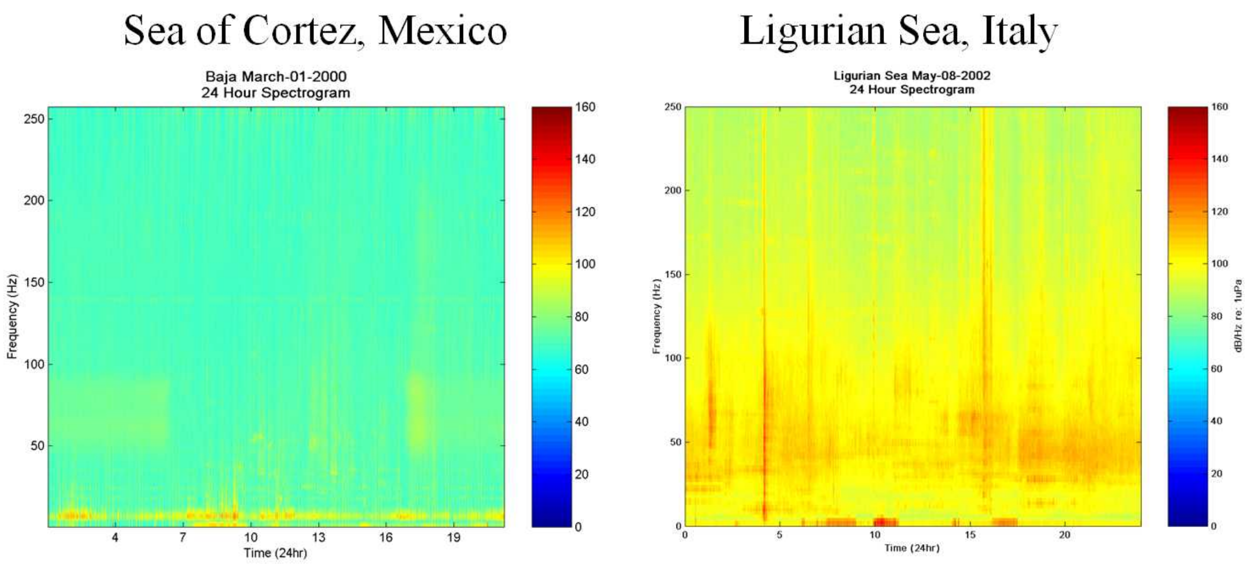


Figure x - *24h noise map of the Ligurian Sea compared with the Sea of Cortez (Mexico): the noise level in the 0-250 Hz band is up to 40dB higher in the Ligurian Sea. Courtesy of C.Clark (Cornell University, US).*

The short and long term impacts are difficult to evaluate, but we can think that, despite controversial facts, the noise issue appears to be related with the collision issues. Collisions could be linked to a number of factors: (a) high density maritime traffic, (b) increased masking ambient noise, (c) possible hearing impairment due to long-term exposure to unnaturally high noise levels, (d) impossibility to avoid the collision area due to high density shipping noise all around.

Other ship-related impacts

According to the IUCN report on maritime trafic and biodiversity (Abdulla, 2008) the high volume of shipping in some areas (e.g. the Mediterranean Sea and other high traffic areas) results in high background noise levels that do not allow for silent areas or refugia and are likely to make it difficult for cetaceans to communicate with each other or to receive acoustic cues, for example to detect approaching vessels or other hazards. There appears to be a link between noise and collisions, where collisions may be related to high-density maritime traffic, increased masking ambient noise, possible hearing impairment in cetaceans, and cetaceans' inability to avoid the collision area because of the high density of shipping noise all around.
Other impacts taken into consideration in the report:
- ship-generated oil discharges and exhaust emissions
- collisione, physical impacts and antifouling TBT paint
- transport of alien species

Reducing risk to marine mammals

We now know that anthropogenic sound in the ocean is a serious threat, although we do not have sufficient information at this time to understand the full extent of the problem. One of the biggest challenges faced in regulating the effects of noise is our ignorance of the characteristics and levels of sound exposures that may pose risks to marine mammals, and fishes too, in particular in the long term and when multiple exposures act together.
Given the current state of our knowledge it is therefore required to take a precautionary approach in the regulation of noise and expand efforts to protect and preserve marine mammals by instituting and using effective mitigation measures, such as geographic exclusion zones, to keep marine mammals at a distance from noise sources that have the potential to harm or kill them.
Because the occurrence and use of sources of potentially harmful anthropogenic noise are likely to increase in the coming years and new sound sources are continuously being introduced, the question of how to mitigate the harmful effects of these noise sources is pressing. Acoustic Risk Mitigation procedures have been developed or are being developed by navies, administrations, and commercial companies. Generally these are concerned with avoiding exposing animals to sound pressures that can cause direct damage of their hearing system, or produce other types of physical damage that may lead to impairment of vital functions or to death, or that could disrupt their behaviour so that their survival could be threatened.
Marine mammals are difficult animals to study in the wild and relatively little effort has been directed towards understanding this problem. Consequently large data gaps exist in relation to both marine mammal populations and the effects of noise, which combined result in substantial uncertainty in the effects of noise on marine mammal populations, especially in the long term.
Fundamental research on marine mammal acoustics, on their habitats and habits, as well as on their prey, is thus needed to address this very complex subject, and to issue appropriate protection politics and mitigation measures. Very similar considerations are due about fishes.
In this context, a monitoring of ships' underwater noise is required to model noise diffusion and the impact on the underwater environment. Ship noise impacts can be reduced by lowering the noise emitted by engines and propellers, and by modifying ship tracks to avoid sensitive areas such as breeding grounds, feeding grounds and migratory corridors.

In spite of significant advances in ship-induced noise research, there remain significant limitations on the ability to predict either current levels of the ambient noise or future trends in those levels that might result from changes in the world's shipping fleet. This is due to both deficiencies in the environmental and shipping databases that constitute the inputs to the noise models and to limitations in the noise models themselves.
Fundamental research on underwater acoustics, on marine animals, on their habitats and habits, and on the biology of disturbance, is thus needed to address this very complex issue.

Acoustic impacts on marine environment need to be addressed through a comprehensive and transparent management and regulatory system (McCarthy, 2004). This should address chronic and acute anthropogenic noise, long-term and short-term effects, cumulative and synergistic effects, and impacts on individuals and populations.
A regulatory system should be implemented to develop a strategy based on prevention and on the precautionary principle. The implementation of a regulatory system requires a series of steps and synergistic actions to promote education, awareness and research. Much effort should be devoted to developing a legal framework where underwater noise is recognized and regulated as a real threat.
In this context, the creation of Special Areas of Conservation (SAC) and Marine Protected Areas (MPA) that take noise pollution into account should ensure protection of areas of critical and productive habitats, and particularly of vulnerable and endangered species.
The designation of SACs and MPAs can be used to protect marine mammals and their habitats from environmental stressors including the cumulative and synergistic effects of noise. In these areas, noise levels should not be allowed to exceed ambient levels of more than a given value, including the contributions from sources that are located outside of the MPA but whose noise propagates into MPA boundaries. This would require additional research to establish baseline noise data and evaluate thresholds for noise levels that can be considered acceptable; i.e. can be tolerated without any significant negative effect.
In other words, other than defining which impacts should be avoided or mitigated, we also need to define a model of "acoustic comfort" we should guarantee to animals, at least in wide enough protected areas. This is a novel concept that has been accepted by IUCN (2009). It means we should define the (near to) zero impact noise level the habitat should have for each type of marine life.

Hatch et al. (2008) recommended '*the use of passive acoustic monitoring data to aid regional managers and maritime transport stakeholders in the development of proposals to the [International Maritime Organization], national regulatory agencies, and/or regional/local conventions to reroute and/or consolidate shipping traffic to minimize exposure of sensitive species to noise and risk of ship strike'*. They also recommended '*buffers for marine protected areas...with dimensions determined by the sensitivity of local species and local noise conditions)*'. The concept of voluntary 'quiet zones' should be tested or implemented where appropriate. Finally, the authors recommended '*that future research explore the potential for using data from quasi- permanent, continuously recording passive acoustic monitoring systems to evaluate differences in ship noise profiles under different 'quieting' treatments*'.

Legislative framework

Worldwide regulation

In the past few years, there has been increasing international recognition of the potential impact of shipping generated noise on marine life.

The UN Convention on Migratory Species (CMS) and its daughter agreements, recognise underwater noise, including noise from shipping, as a form of pollution that needs to be addressed

(CMS 2008).

The International Union for Nature Coservation (IUCN) clearly recognize the negative effects of large scale underwater noise pollution and the need for regulating shipping and reccomends actions to reduce it (see chapter on reccomendations).

UNCLOS is a treaty governing the global marine environment, and it has been partially adopted into common law. It already provides a solid basis for treating harmful, human-generated noise as a form of pollution that must be reduced and controlled. The agreement defines the term "pollution" as "the introduction by man, directly or indi- rectly, of substances or energy into the marine environment..., which results or is likely to result in such deleterious effects as harm to living resources..." (Art. 1(1) (4)).
According to UNCLOS, underwater noise should be expressly classified as a pollutant (where not already so defined) by all Nations and managed accordingly.

IMO (International Maritime Organization) members should initiate an amendment to MARPOL (the International Convention for the Prevention of Pollution from Ships) to include "energy" in its definition of pollution, consistent with Article 1(1)(4) of the U.N. Convention on the Law of the Sea (UNCLOS).

Based on a proposal by the USA, the International Maritime Organization (IMO) added "Noise from commercial shipping and its adverse impact on marine life" as a high priority item to the work program of its Marine Environment Protection Committee (MEPC) in October 2008 and established a correspondence group to work on the development of non- mandatory technical guidelines for ship-quieting technologies as well as potential navigation and operational practices (IMO, 2008b).
The target completion date for this work should be either MEPC 61 (October 2010) or MEPC 62 (July 2011). Issues that have arisen in the course of discussions include the need for a better understanding of noise output from large commercial vessels, the need to target noise reduction measures towards vessels that contribute most to overall noise impacts on cetaceans, and the relationship between vessel noise and ship strikes. See IMO Shipping noise and marine mammals 84-INF4 2008.
The IMO, as the only organisation competent to regulate international shipping, should consider possible options to reduce the impact of ship-source noise on marine life, such as building new rules upon the IMO's Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas (PSSAs), (Para 2.2 of Resolution A. 982(24)), which identify shipping noise as a marine pollutant. This could be done by appropriately using existing navigational measures (e.g. planning traffic lanes) or developing new ship quieting requirements (Agardy et al., 2007).

For an overview of how underwater sound is regulated worldwide, see also McCarthy, 2004.

US
In the US it is mandatory to comply with the Marine Mammal Protection Act (MMPA) and with the Endangered Species Act (ESA) for any action with a potential direct impact on marine life, in particular on marine mammals; for this reason the implementation of mitigation measures is designed to balance scientific, industrial and military needs with the protection of marine resources also taking into consideration the precautionary principle. The permit system is managed by NMFS and by other US Agencies, depending of the type of permit. Concerning the underwater sound, this permit system addresses the cases of exposure to high power sound sources with the potential of producing effects ranging from behavioural disruption to lethal.

Europe
The European Union Habitat Directive states that it is not permissible to deliberately disturb in the wild, any creature which is enlisted in Annex IV (a), where all Cetaceans (and several other marine mammals) are listed. In addition to species protection, the Habitats Directive also makes provision

for the site-based protection of a range of marine mammal species (listed in Annex II), including bottlenose dolphins and harbour porpoises and all species of seal. To achieve this, Special Areas of Conservation (SAC), as well as Marine Protected Areas (MPA) should be proposed and designated as key tools for marine mammals' protection.
However, the Directive does not cite noise explicitly (Pavan, 2007). With few exceptions related with high power acoustic sources (explosions, sonars, seismic surveys) that may have a direct immediate impact on marine mammals, underwater noise is largely unregulated (McCarthy, 2004).

The EEC (European Economic Community) Recreational Craft Directive 2003/44/EC requires the compliance with specific sound emissions levels in air, but there is no mention of noise emitted underwater. New directives are required to force naval industries to take into account the noise emitted underwater as well.
An example is given by the ICES recommendation about the noise generated by research vessels that can introduce a bias into fish abundance estimates (Mitson, 1995; Mitson & Knudsen, 2003).

Regional agreements existing in the Mediterranean region, such as ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area) and the SPA protocol (Specially Protected Areas Protocol of the Barcelona Convention for the protection of the Mediterranean Sea) should extend their competence over noise and be an effective means of identifying and designating noise-related issues. Also they should act as interfaces among the interested parties.
ACCOBAMS Resolution 3.10, based on the document prepared by Pavan (2006) presses all the parties to take noise into great consideration and to consider underwater noise levels a quality parameter in assessments of habitats, zoning and managing marine areas of special interest. Also, this parameter should be considered a priority for the protection of critical habitats and where noise might affect essential behaviour (e.g. feeding, reproduction, nursing) of marine mammals.
See ACCOBAMS Recommendations and Resolutions (2004-2007).

Given the lack of specific laws, it is important to act in a precautionary way and give these animals, together with marine turtles and other zoological groups, protection against noise.
To create the basis for a suitable regulatory system, it is necessary to promote an interdisciplinary and international approach to create a suitable legislative framework where underwater noise is considered a real threat to marine life.

The EU Marine Strategy framework

Recent initiatives such as the EU Marine Strategy Framework Directive (2008/56/EC) and international conventions, such as the UN Convention on Migratory Species (CMS) and its daughter agreements, recognise underwater noise, including noise from shipping, as a form of pollution that needs to be addressed (EU, 2008; CMS 2008, ACCOBAMS 2007 and ASCOBANS 2006).

The EU Directive specifically mentions the problem of noise pollution and provides a legal framework for addressing this issue.
The Directive represents the first international legal instrument to explicitly include man-made underwater noise within the definition of pollution (Article 3 (8)), which needs to be phased out in order to achieve the good environmental status (GES) of European marine waters by 2020 (Article 1).
The Directive identifies 11 "environmental descriptors", the 11th is the anthropogenic noise ("the introduction of energy, including underwater noise, at levels that do not adversely affect the marine environment") to achieve the GES (Annex I (11)) and sets out clear obligations for member states to address this form of pollution.

A working group has been established to develop the protocols and metrics for these descriptors. With this Directive the underwater noise is now an issue of great relevance and all memver states have to face with it as they are obliged to provide an evaluation of the "good status" of their seas based on those descriptors.

However, we still observe a lack in the legislative framework and the implementation of the EU Directive is still a question mark.

In the absence of specific laws, and given that underwater noise is a transboundary pollutant, in the Mediterranean waters the EU Habitat Directive is probably the best framework for developing a permit system that complies with the opinions expressed by international organizations (ACCOBAMS Recommendation 2.7 and ACCOBAMS Resolution 2.16, the recommendations of the 56° and 58° IWC meetings (held in 2004 and in 2006), and the European Parliament Motion B6-0089/04).

In this context, the creation of Special Areas of Conservation (SACs) and Marine Protected Areas (MPAs) that take noise pollution into account should ensure protection of areas of critical and productive habitats, and particularly of vulnerable and endangered species.
The designation of SACs and MPAs can be used to protect marine mammals and their habitats from environmental stressors including the cumulative and synergistic effects of noise. In these areas, noise levels should not be allowed to exceed ambient levels of more than a given value, including the contributions from sources that are located outside of the MPA but whose noise propagates into MPA boundaries. This would require additional research to establish baseline noise data and evaluate thresholds for noise levels that can be considered acceptable; i.e. can be tolerated without any significant negative effect.

Italy
As specific national laws are lacking, in Italy the legal reference framework is the Habitats Directive. The Office of Protected Marine Resources (Ministry of the Environment) is in charge for authorizing high impact activities, e.g. seismic surveys, and for providing basic mitigation guidelines to minimize impact on marine fauna. But no office in charge of controls exists, and the effectiveness of the whole regulatory system is unclear.
In support of a stronger implementation of mitigation procedures, a recent law (L. 8 febbraio 2006, n. 61) allows extending Italian jurisdiction beyond the national waters, creating special Ecological Protection Zones.

Guidelines & Reccomendations

In the last twenty years GOs and NGOs have developed a huge series of reccomendations and guidelines, initially addressed at reducing the impacts of seismic surveys and military sonar exercises, and then embracing a wider range of activities, such as whale-watching, touristic boats, marine windfarms, construction works, shipping noise, etc. For a comprehensive review of guidelines see ACCOBAMS Guidelines 2006; Castellote 2006. All these recommendations and guidelines clearly influenced the development of the EU Marine Strategy.

During their last meeting (October 2007), the ACCOBAMS Contracting Parties have adopted Resolution 3.10 (Annex 1) on the appropriate tools for assessing the impacts of underwater noise on cetaceans in order to establish mitigation measures to reduce these impacts and a Set of Guidelines which will guide Governments in the application of such measures.
A Working Group composed by France, Italy, Spain and paired with the Ospar Convention, the WDCS and the NRDC, is currently developing the Guidelines which will be presented to ACCOBAMS Contracting Parties by the end of 2010 for adoption. These guidelines, based on previous guidelines developed for the ACCOBAMS Secretariat (…….), will address several types of underwater noise including shipping noise.

The issue of underwater noise has been largely discussed in recent IWC meetings (mainly since the 2004 meeting in Sorrento, Italy) and now the interest towards shipping noise is raising. This issue is the core topic to be discussed in the section of the "Environmental concerns" in the next meeting (IWC 62, 2010). The following topics should be addressed:

- the general issue of potential chronic effects of anthropogenic noise on marine mammals and their acoustic habitats;
- the acoustic masking from low-frequency (<1,000 Hz) shipping noise on marine mammals;
- the issue of potential influences of noise masking from an ecological perspective;
- the potential chronic effects of anthropogenic noise on marine mammals and their acoustic habitats.

IUCN recognizes the importance of the underwater noise issue and the need of a new approach. Noise trends should be studied and related to biological factors such as species abundance, distribution and movements. A 'noise budget' model should be developed, in which synergistic and cumulative effects are considered. The concept of 'acoustic comfort' should be defined and models should be developed to define noise ranges that can be tolerated without negative effects.
Predictive noise maps should be prepared in order to evaluate the impact of new noise sources and the effect of mitigation measures. Risk assessments should be carried out, examining the effects of noise on marine fauna and identifying mitigation measures for noise pollution in partnership with the industry sectors involved.

IUCN (Report 062, 2009) proposes specific pilot actions:

- Systems for monitoring underwater noise trends and seasonality should be put in place in the Mediterranean.
- Noise trends should be studied and related to biological factors such as species abundance, distribution and movements.
- A 'noise budget' model should be developed, in which synergistic and cumulative effects are considered.
- The concept of 'acoustic comfort' should be defined and models should be developed to define noise ranges that can be tolerated without negative effects.
- Predictive noise maps should be prepared in order to evaluate the impact of new noise sources and the effect of mitigation measures.
- Risk assessments should be carried out, examining the effects of noise on marine fauna and identifying mitigation measures for noise pollution in partnership with the industry sectors involved.

OSPAR takes into consideration all threats on the marine environment. OSPAR published a report (OSPAR 2009, PN 436) on the impact of noise considering many different noise sources. Specific publications refer to the shipping noise (OSPAR 2009b, PN 440, in press) and to the impact of small touristic vessels (OSPAR 2008. PN 369).

Tourism (OSPAR, 2008)
The tourism industry can create underwater noise in the form of recreational boating, cruise travelling and whale watching. There are no regulations explicitly to mitigate against underwater noise disturbance due to whale watching, but some guidelines are in place that will also have an effect on underwater noise emissions during this activity. Under the auspices of the Convention for Migratory Species, two regional marine agreements specific to cetaceans have been concluded: the 1992 Agreement for Small Cetaceans of the Baltic and North Seas (ASCOBANS, which has been amended to include the Seas around Ireland, Portugal and Spain), and the 1996 Agreement on the Conservation of Cetaceans of the Black and Mediterranean Seas and Contiguous waters (ACCOBAMS). At the first meeting of ACCOBAMS parties, a resolution providing a detailed code of conduct for whale-watching was passed. The consequences in practice of the "soft law" provided by such resolutions can only be gauged over time. The guidelines for whale watching agreed by the

ACCOBAMS parties are unusual in that they are provided as an exemplary regime for states in the agreement area to follow. Some countries have developed specific legislation at this regard, for example Spain has approved Royal Decree 1727/2007, of 21st December, establishing protective measures for cetaceans. This basic tool has been enacted on the basis of the obligations assumed with the Convention on Biological Diversity (CBD). In Ireland, the Department of Communications, Energy and Natural Resources issued Marine Notice No. 15 of 2005 providing clear guidelines to all vessel operators (including recreational and charter craft) on correct procedures when encountering whales and dolphins in Irish coastal waters.

Shipping (OSPAR, 2009)
There is a reasonably long and successful history of quieting both surface and sub-surface military vessels to reduce their acoustic signature and thus vulnerability to detection by enemy passive acoustics. Additionally, commercial applications of ship quieting technology, are rapidly advancing in such areas as acoustic research vessel design, ferries, and environmentally-sensitive cruise ships. There are some commonalities in both of these quieting contexts, based purely on the physics of sound and constraints of vessel design, and many of the associated technologies focus on aspects of the propeller or other components of the propulsion systems. Reducing the overall noise level on board might also be beneficial to the ship's crew and passengers, while the reduction of structural vibrations might be beneficial to the integrity and lifetime of the vessel. Additionally, there may also be tangible benefits in terms of efficiency and reduced fuel consumption associated with reduced propeller cavitation, to the extent that may be achieved, it will also reduce the overall radiated noise signature. Efforts at reducing noise are most effective when incorporated into the design of ships, though retrofitting of vessels may also be successful to varying degrees, though generally at much greater cost. Minimizing propeller cavitation across the range of operating conditions is likely to remain the primary focus in efforts to quiet large vessels, given the fact that other noise sources (for example machinery) will likely be overwhelmed by cavitation noise until considerable quieting treatments were applied. Efforts to reduce structure-borne noise may be facilitated by advances in electrical propulsion systems which, provided that measures have been taken to reduce interference frequencies in the power supply, can enable the main engine room to be positioned away from the propeller shaft to a location where it can be acoustically isolated from transmitting underwater sound more easily. Additionally, operational measures (for example routing and speed restrictions) could have positive outcomes in terms of ambient noise reduction in some areas. However, these must be carefully considered in the light of potential related impacts arising from modifying traffic schemes (for example possibly increasing noise in specific areas and possible impacts on the likelihood of vessel strikes). The relative costs and environmental benefits of either technological or operational mitigation measures related to vessel noise output are not well-known. However, the United States has recently submitted a proposal to the Marine Environment Protection Committee of the International Maritime Organization to explicitly consider this international matter and consider a global strategy to address it (IMO 2008, 2009)

Ship noise contributes to the background ocean noise

The primary concern regarding potential adverse impacts of shipping noise on marine mammals is not related to acute exposures (e.g. like those produced by sonars or airguns), but rather to the increase in ambient noise (IMO, 2008a) at local and global level that may result from concentrations of vessel operation. Because of the logarithmic nature of sound and what is known about hearing systems in mammals, seemingly small changes in background noise levels can result in large reductions of communication range.
While there is insufficient data to definitively conclude that ambient noise levels are increasing in large areas of the ocean as a function of vessel sounds, two recent studies off California analysing measurements over several decades do indicate changes that, for these particular areas, suggest an increasing trend in background noise of ~ 3 dB/decade in the low-frequency band (Andrew *et al*,

2000; McDonald *et al*, 2006).
Studies have suggested that there has been a 10-12dB increase in offshore marine ambient noise in the 10-50Hz range during the last 40 years, attributed primarily to increased commercial shipping (McDonald et al. 2006).
According to MacDonalds & al. (2006), due to the complexity of propagation modes, shipping noise does not directly correspond to the distribution of ships. Ship or wave generated noise from the sea surface will contribute to ambient noise levels across the entire ocean basin if it is introduced into the deep sound channel. One pathway for shipping noise to enter the deep sound channel is at locations where the sound channel intersects bathymetric features such as the continental slope. By a process commonly referred to as down-slope conversion, noise propagating down the continental slope (including the noise generated by sources on the shoreline or seismic surveys on shalllow continental platforms) can readily enter the deep sound channel. Therefore, shipping lanes that traverse the continental slope will be sites for efficient conversion of noise into the deep sound channel.
Another route for noise to enter the deep sound channel occurs at high latitudes, where the sound channel shoals to intersect the sea surface (Bannister, 1986). In such a case, noise produced at the sea surface by shipping or other sources enters the deep sound channel and propagates efficiently to distant sites. Great circle vessel routes (the shortest distance) put most of the shipping traffic at high latitudes in the North Pacific, passing near the Aleutian Islands. The high latitude North Pacific is a major shipping route carrying the substantial vessel traffic between ports along the west coast of North America and Asia. Shipping noise that enters the deep sound channel at high latitudes can propagate to lower latitude sites, and become a component of the ambient noise.

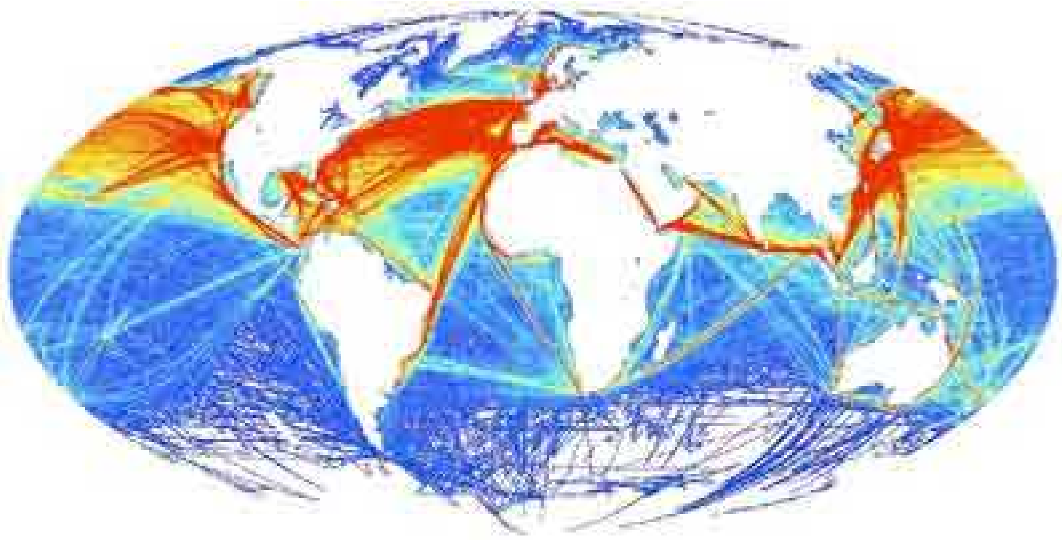


Figure – World wide map of ship traffic given by AIS.

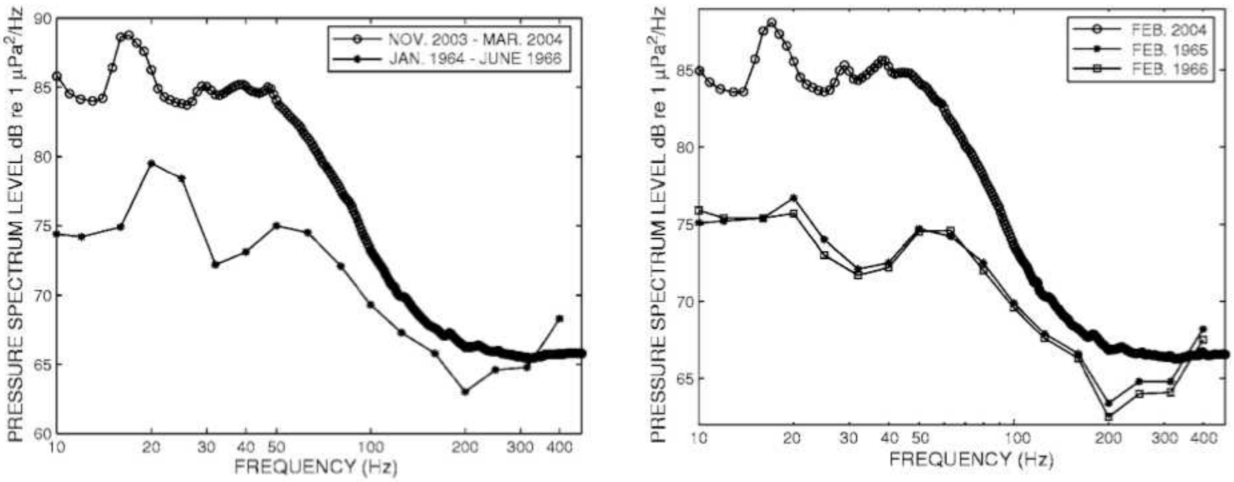


Figure – Noise levels at San Nicolas (California) measured in years 2004-2005 compared with measures made in years (1964-1966). From MacDonald et al. 2006.

A study conducted near Point Sur (California) shows an increase in ambient noise over the 33-year period. In the frequency range 20–80 Hz, this increase is approximately 10 dB (Andrews et al., 2002). The primary explanation is an increase in commercial shipping; increases in whale stocks can account for at best only a minor portion of this increase. The cause of the increase beyond 100 Hz up to 400 Hz and beyond (which is as large as 9 dB) is less obvious; this is generally the regime dominated by the ocean surface wind contribution, but no large changes in average surface wind speeds have been noted. There is no satisfactory explanation for why the increase should have a minimum near 100 Hz.

We are aware of only a few published reports of trends in ambient sound level over long periods, all by Ross. He presented data that indicated sound levels had increased by 15 dB between 1950 and 1975 because of shipping. He further predicted that shipping noise levels would increase by only about 5 dB over the balance of the century, projecting that the pace of shipbuilding would slow and that improvements to propulsion power plants would be incremental at best.

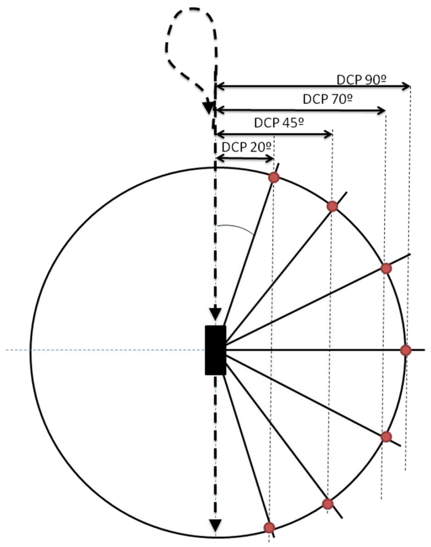
Ship noise reduction

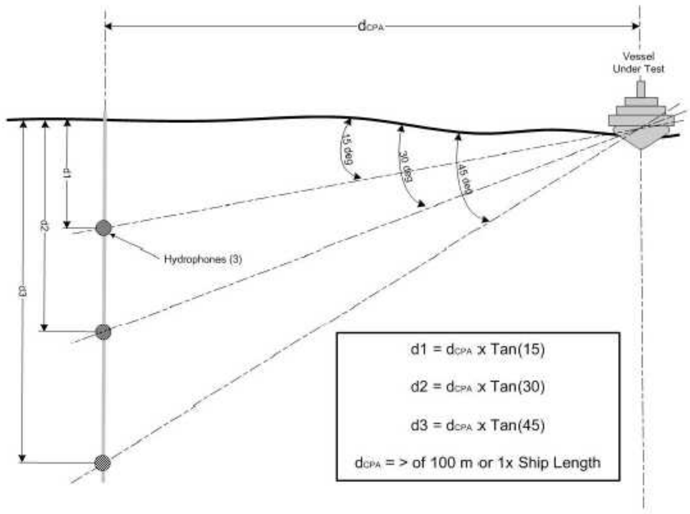
As already stated, noise from ships should be evaluated both at close range for its direct possibile effects on local marine life and at long-range for the contribute to background noise at low frequencies. It is still difficult to say how much the radiated noise should be reduced to get visibile effects. However, noise reduction should be evaluated in order to reduce both local and long range effects (see Quieting technologies).

Measuring ship noise

Measuring the source characteristics is the first required step to build a noise diffusion model. It is important to have a measure of the 3D noise field generated by a passing ship to modelize the local effects and also the long range propagation. At present no definitive nor satisfactory standards are available. The current American standard for ship measurement (ANSI-ASA S12.64-2009) is the main reference in the field. Although the ANSI-ASA standard is a good approach to the ship noise measurement problem, it contains some gaps that could lead to misunderstandings and wrong characterization of the noise sources.
The effects of the bottom depth, bottom composition, distance to shore, local sound speed profile that depends temperature profils and the presence of currents have all an effect on the 3D propagation of noise and could represent a serious problem in in performing acoustic measures.
Local propagation conditions must be taken into consideration when measuring a ship radiated

noise, to correctly refer to 1m distance a measure taken tens or hundreds of meters away.
These problems and the complex radiating structure of the ship (Wales & Heitmeyer, 2002; Gloza 2008) could make difficult the creation of a reliable 3D propagation model. To possibly reduce all these uncertainties a huge set of measures should be taken and integrated. Measures should be takem at different angles to possibly approximate the noise diffusion on both the horizontal plane (the standard proposes 7 measures at different angles) and the vertical plane (the standard proposes 3 hydrophones at different depths to to get measures at 15°, 30°, and 45° on the vertical plane).





The use of only three hydrophones appears quite inadequate as the emissions under the ship are not measured. It could be recommended to use additional deep hydrophones deployed close to the ship track to measure the noise projectd in a narrow cone below the ship, or repeat the passages closer to 3 hydrophone vertical array, or use bottom recorders whenever possible.
At present most of the information about ship noise emissions derive from few measurements points.

Scrimger & Heitmeyer (1991) present a set of 50 source spectra obtained from merchant ships of opportunity near Genova, Italy. The source spectra were calculated from radiated-noise spectra with a transmission-loss model and then aggregated according to the ship classes to produce three main ship categories.

Wales & Heitmeyer (2002) present an evaluation of the classical model (Ross, 1976) for determining an ensemble of the broadband source spectra of the sound generated by individual ships and proposes an alternate model to overcome the deficiencies in the classical model.

Gloza (2008) presents an analysis of the transmission of low frequency sounds from ships into the water environment.

Propagation and far –field measures

The combined contribution of individual vessels to overall ambient noise is complex and depends on propagation conditions along the route of the vessel, particularly with respect to surface ducting and water depth.

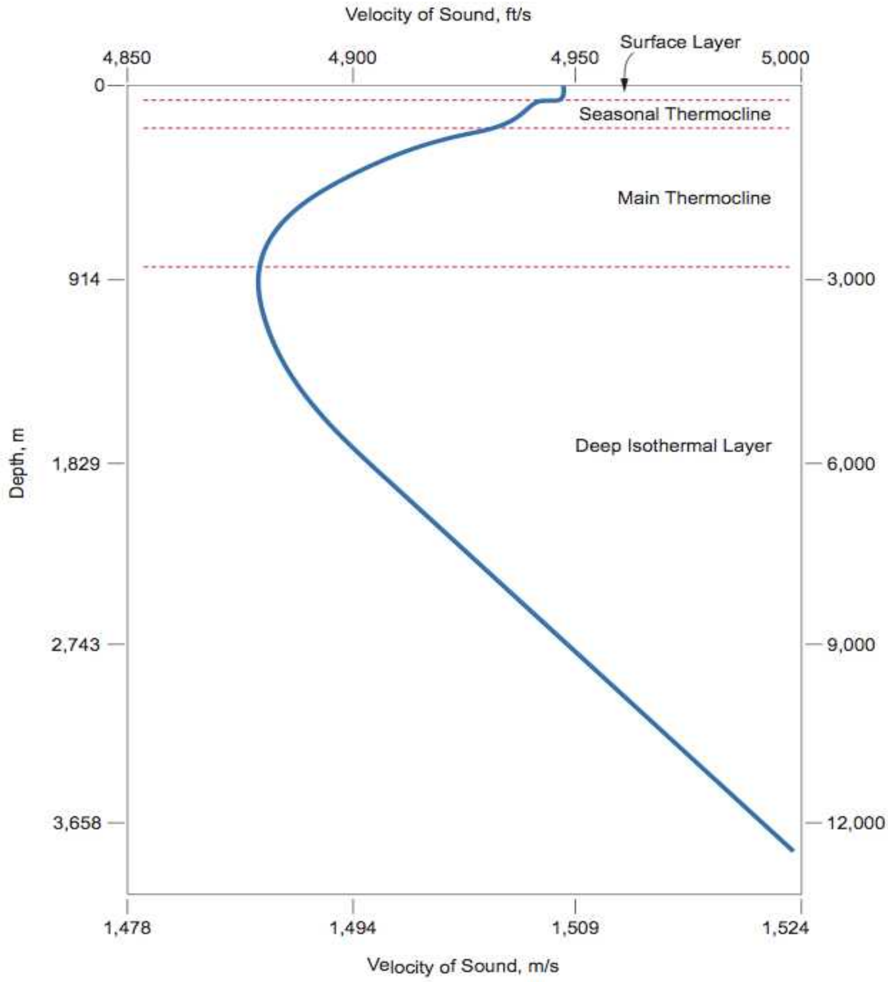


Figure – Model of sound speed profile.

The studies of sound propagation in varying local conditions have been given considerable attention for a long time, and a number of papers have been published on the subject. A thorough treatment is given in Urick (1983).

Two basic models area available to assess propagation loss in marine environment: spherical spreading and cylindrical spreading.
Attenuation at a given distance can assessed as

RL=SL-20Log(R) for spherical spreading (e.g. in deep waters)
RL=SL-10Log(R) for cylindrical spreading (e.g. in shallow waters)

Where RL is received level at distance R from a source with SL emission level.
These formulae are valid for low frequency sound, say, below 1kHz, while higher frequencies are attenuated more.
However, propagation mdes are much more complex then the two basic models. In the sea a phenomenon called sound channels frequently occurs. Changes in sound propagation velocity due to temperature and pressure, will form these sound channels at varying depths and with varying thickness. Both these factors will influence how signals are transmitted through sound channels.
Sound channels act like ducts that tend to focus the sound energy, and attenuation in these ducts can be significantly less that normal spherical spreading. Through this mechanism sound can travel over considerable distances.

In many cases an acceptable approximation is RL=SL-15Log(R) (Hatch, 2008); for high frequency sounds, above 1kHz, additional attenuation by absorpton should be also taken into consideration.

Reducing the contribution of shipping to ambient noise levels at an ocean basin level will require addressing the ships that make the greatest contribution. NRC (2003) recommended calculation of the relative contribution made by individual sound sources to overall noise levels to establish a 'noise budget' within an area. Hatch et al. (2008) present such calculations for the contribution of shipping noise to the Stellwagen Bank National Marine Sanctuary. They calculated the relative contribution of different vessel types in terms of total acoustic power based on source levels and total time spent within the area.

Although contribution to total acoustic power is a good measure, it does require considerable data.

One simple approximate measure of the likely relative contribution of an individual ship is its 'acoustic footprint' – or the area of ocean ensonified to a particular noise level (Leaper et al., 2009). This area increases exponentially with source level according to

A=10^(2*(SL-T)/L)

Where A is the area of the acoustic footprint, T is the noise threshold used to define the footprint and the loss in dB with distance r is expressed as Llogr. For cylindrical spreading, L will be 10 and for spherical spreading L will be 20. Empirical measurements have suggested that L=15 is a good approximation in many areas (Hatch et al., 2008). A commonly used value for T is 120dB re 1µPa. Hatch et al. (2008) present estimates of the distances at which the received level from vessels where source levels had been measured was expected to be below120dB re 1µPa. These distances ranged from 380m for a research vessel up to 26km for an oil tanker.

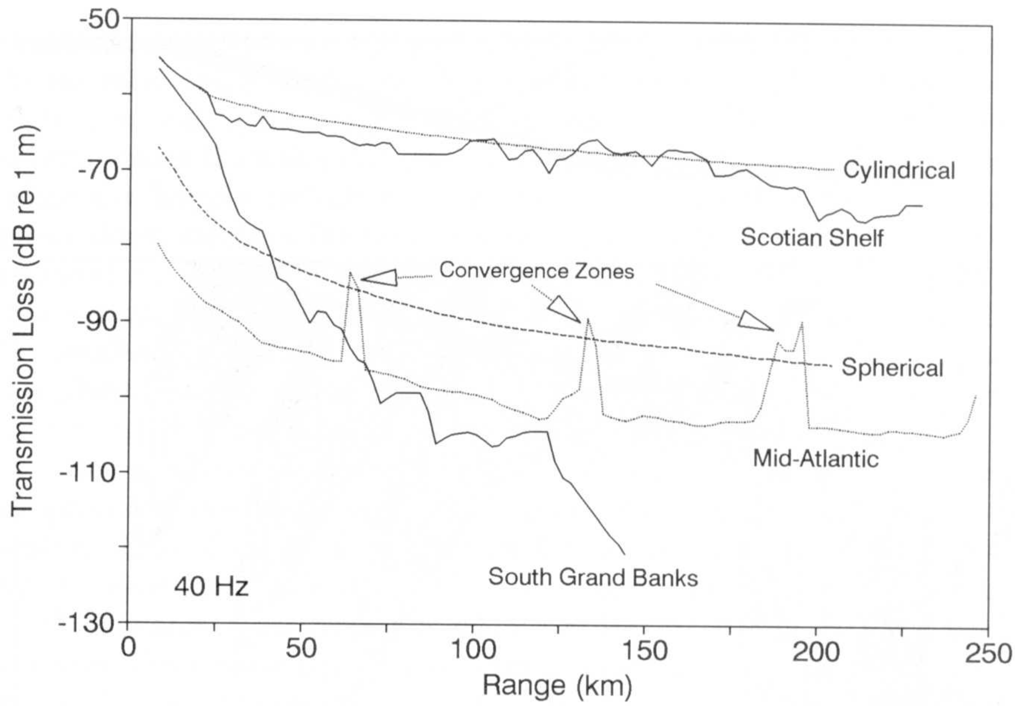


Figure – Propagation loss versus range for a 40 Hz sound traeling in deep and shallow waters at different locations. Dotted lines are theoretical predictions. Richardson et al., 1995.

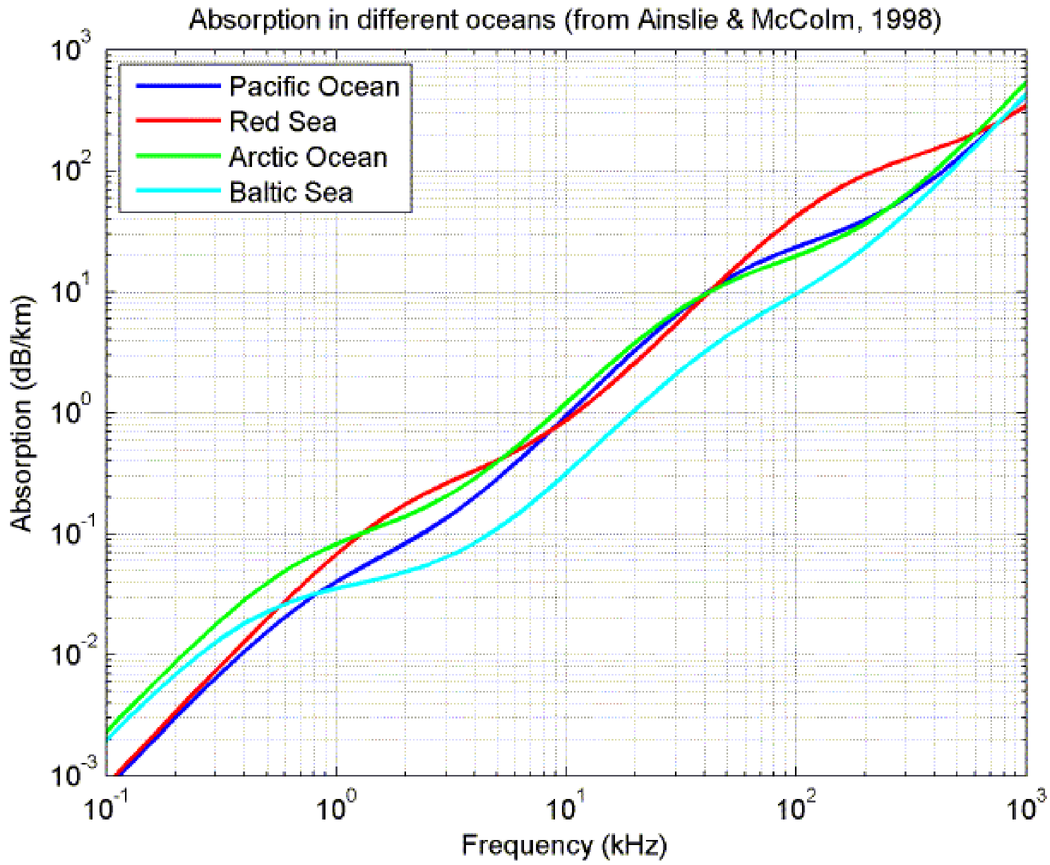


Figure – Sound absorption vs frequency in different oceans.

As a contribution to the work of the IMO on these issues, IFAW funded a study to look at possible ways of reducing underwater noise pollution from large commercial vessels (Renilson, 2009). The report identified many data gaps in the understanding of shipping noise. In particular, there is a lack of standard methods for conducting and analysing full scale noise measurements from commercial vessels. The ISO Technical Committee on Ships and Marine Technology is also currently developing measurement methods and formats for reporting data on underwater noise from vessels (Piersall, 2009). There is also a general lack of data on noise output from large commercial vessels across a range of operating conditions, for example when fully laden or in ballast.

The research on ship noise can join bioacoustic research on marine mammals sounds and communication systems.
Acoustic systems designed to monitor baleen whale vocalisations generally cover the frequency ranges that are of most concern in terms of shipping noise. Long term deployments of acoustic recording devices may also provide opportunities to study the contribution of shipping to background noise (e.g. Andrew et al., 2002; McDonald et al. 2006) but also to relate noise measurements to transits by individual vessels (e.g. Hatch et al., 2008). Many of the technologies developed for studying whale acoustics could also be effectively applied to monitoring noise output from individual vessels, particularly when combined with tracking individual vessels using Automatic Identification Systems (AIS). There is considerable potential to address some of the data gaps identified in understanding the factors related to hydro-acoustic noise from ships by using data collected during studies of marine mammals. Studies using towed hydrophones to monitor marine mammal vocalisations may also provide information on individual vessels and how noise levels change with speed and operating conditions (e.g. Leaper and Scheidat, 1998).

Regulating Shipping Noise

Reduction of shipping noise is a world-wide problem strictly connected to the general problem of the impact of underwater noise on marine life (Richardson et al., 1995; Gisiner, 1998; NRC, 2000 &

2003; Tyack, 2003; McCarthy, 2004; Merril, 2004; Popper & al., 2004; Southall, 2005; Vos & Reeves, 2005; Weilgart, 2006; Nowacek & al., 2007, and many others).

The ship noise issue developed in recent years. In 2004, the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and a number of other government, industry, and academic partners convened the first formal meeting ("Shipping Noise and Marine Mammals: A Forum for Science, Management, and Technology") to consider the effects of sounds from large vessels on marine life (see: www.nmfs.noaa.gov/pr/acoustics/).
The final report (NOAA, 2004) made several recommendations, including increasing awareness within the shipping industry concerning marine noise issues, creating alliances across various stakeholder groups, and engaging the industry and other maritime industries in the development of creative and practical solutions to minimize vessel noise.
This meeting was followed by a second NOAA-sponsored and internationally attended symposium held in May 2007, "Potential Application of Vessel-Quieting Technology on Large Commercial Vessels" to further explore the problem, in particular to examine the economical and practical issues in the extensive application of vessel-quieting technologies of those noise reduction solutions already applied to military and research vessels (Smitson, 1995; Smitson & Knudsen, 2003; NOAA, 2007).
In April, 2008, Okeanos - Stiftung für das Meer (Foundation for the Sea), a non-profit organization created to protect the ocean and marine life, convened a workshop in Hamburg, Germany, focused on shipping noise and marine mammals. This workshop concentrated on engaging members of the international maritime transport industry, particularly ship builders and architects.

At its 2008 meeting, the IWC Scientific Committee endorsed as a target a reduction in the contribution of shipping to ambient noise levels in the 10-300Hz range by 3dB in 10 years and by 10dB in 30 years relative to current levels. This target was proposed at an International Workshop on Shipping Noise and Marine Mammals held in Hamburg in April 2008 (Anon, 2008) and achieving it will require changes within the shipping industry, particularly because shipping tonnage is predicted to increase.

To preserve the quality of the underwater environment, it is required to introduce specific underwater noise emission limits for new ships and boats as already occurs for land motor vehicles. As emitted noise and vibration often means a loss of energy and mechanical problems, it could be possible to establish cooperation with naval industries to start a cooperation for the design of quieter and more energy efficient ships that in the long range will be more economical and more environmentally compliant.

To address the problem of increased ambient noise due to shipping, governments and stakeholders should promote the introduction of ship-quieting technologies, such as those reviewed in the NOAA symposium.
Priority actions to reduce the impact of shipping noise should include:

Reduce radiated noise

a) reduce noise radiated by existing ships and boats by encouraging good maintenance of engines and propellers,
b) adopt quieting technologies in the design of new ships and boats,
c) encourage speed restrictions and alternative routes to avoid sensitive habitats, including marine mammals' key habitats and marine protected areas; define appropriate buffer zones around them; consider the impact of long-range sound propagation.

Improve research

d) develop models of the generated sound field in relation to oceanographic features (depth/temperature profile, sound channels, water depth, seafloor characteristics)

e) use models to produce predictive maps of noise, to simulate impacts and mitigation measures
f) consider cumulative impacts over time and effects modelling; include consideration of seasonal and historical impacts from other activities (shipping, military, industrial, other seismic) on marine mammals' population,
g) determine safe and harmful exposure levels for any zoological group (e.g. mysticetes, odontocetes, pinnipeds, marine turtles, fishes, invertebrates) and critical species (e.g. beaked whales).

Managing impacts

Although we know that anthropogenic sound in the ocean is a serious threat, we do not have sufficient information at this time to understand the full extent of the problem. One of the biggest challenges faced in regulating the effects of noise is our ignorance of the characteristics and levels of sound exposures that may pose risks to marine mammals. Given the current state of our knowledge we must therefore take a precautionary approach in the regulation of noise.

Acoustic impacts on the marine environment need to be addressed through a comprehensive and transparent management and regulatory system. This should address chronic and acute anthropogenic noise, long-term and short-term effects, cumulative and synergistic effects, and impacts on individuals and populations.

However, it emerges that a stronger scientific framework is needed to develop any mitigation action and legislative approach. In particular, a model to correctly evaluate ship noise masking effects and impact extent at both individual and population is required.

The Clark approach (Clark et al., 2009) expands on some previous syntheses and recent research (*e.g.*, Clark & Ellison 2004; Southall et al. 2007; Hatch et al. 2008). It merges these ideas to introduce the concept of a dynamic spatio-spectral-temporal acoustic habitat and uses this perspective to introduce analytical representations by which to study acoustic masking. Clark formalized a protocol that integrates a form of the sonar equation (Urick 1983) with biological knowledge to quantify the affects of masking noise from a single source on the area over which an animal's acoustic communication signal might be recognized by a conspecific. This procedure for a single animal is then expanded to a population of calling animals to quantify the spatio-spectral-temporal distribution and variability of masking and to predict the affect that masking might have on the ability of a population of calling animals to communicate throughout their habitat region. Finally, by expanding the algorithm to include multiple noise sources, Clark proposes a method for quantifying the cumulative effects of varying numbers and types of anthropogenic sources affecting a specific "acoustic habitat".

Results of these model can help in identifying the impact extent in space and time, in identfying cumulative impacts, and, on the other side, should also help in identifying the "excess noise" of a ship and thus to estimate the amount of noise reduction required to reduce the impact and make the ship environmentally compliant.

Reduction of the noise impact of individual ships can be accomplished in several ways (good maintainance and/or modification of existing ships, better design of new ones), however, at a larger scale, global ship traffic management options are also available (Agardy et al., 2009; Hatch et al., 2009). Reducing the impact of shipping, however, should not be limited to noise (Panigada et al., 2008).

Quieting technologies

The noise irradiated by ships has been already recognized an issue for military ships and research vessels. Quieting technologies have been implemented to make warships and submarines silent enough to reduce the risk of detection, and also on research ships to reduce the interference on acoustic tests and scientific research (Mitson, 1995; Mitson & Knudsen, 2003).

The introduction of quieting technologies in the management of the existing fleets and in the design of new ships is now driven primarily by the recognition of the noise impact on marine life.
Main constraints are the costs associated with the research, development and implementation of quieting technologies as well as the cost for the research required to set the standards.
Controlled reduction of global shipping noise should be achieved by implementation of noise limits or guidelines for individual ships, which will likely benefit the health and wellbeing of the crews aboard the vessels as well as marine mammals and other marine animals. Any noise criteria under these limits or guidelines would need to be defined with consideration of existing technology. To achieve noise reduc- tion, the criteria should be incorporated into ship building standards and integrated into the design and building process of a ship. Verification of achieving the noise standard and minimization of economic impact on ship construction and operation should be included in the implementation process.

Quieting technologies are discussed in several workshops (NOAA 2004, 2007; OKEANOS, 2008) and papers (Leaper et al., 2009).
IMO Report MEPC 59/19 (2009) is the report of the IMO Correspondence Group on the issue of "Noise from commercial shipping and its adverse impact on marine life", which was added to the Committee's agenda by MEPC 58 as a high priority item (see IMO 2008a, 2008b, 2009).

Targets to reduce the contribution from shipping noise to ambient noise have also been endorsed by the IWC Scientific Committee. At frequencies below 300Hz, the underwater noise signature from large vessels will be dominated by propeller cavitation and the noisiest vessels are likely to be those that suffer excessive cavitation. Based on the distribution of source levels across merchant fleets reported in SC/61/E19, the noisiest 10% of vessels may contribute between around 48% and 88% of the total sea area ensonified by shipping noise to a given level, depending on assumptions about propagation conditions. Thus noise reduction targets could most easily be achieved by targeting measures at a relatively small percentage of the noisiest vessels. These measures may also result in efficiency savings which could pay back initial costs within 1 or 2 years.
Reductions in overall ambient noise achieved through quieting the noisiest vessels may also assist whales in avoiding collisions with quieter vessels and contribute to a reduction in ship strike mortality. Many data gaps remain and this hinders the understanding of factors that contribute to the variation in noise output from different vessels. There is a clear need for systematic studies of vessel noise. The equipment and deployment of recording devices for studies of whale vocalisations, combined with individual vessel tracking, may provide opportunities to obtain data on noise signatures from ships.
At its 2008 meeting, the IWC Scientific Committee endorsed as a target a reduction in the contribution of shipping to ambient noise levels in the 10-300Hz range by 3dB in 10 years and by 10dB in 30 years relative to current levels. This target was proposed at an International Workshop on Shipping Noise and Marine Mammals held in Hamburg in April 2008 (Anon, 2008) and achieving it will require changes within the shipping industry, particularly because shipping tonnage is predicted to increase.

Nevertheless, international workshops, including the two symposia hosted by NOAA (Southall, 2005; Southall & Scholik-Schlomer, 2008) have suggested that substantial reductions (5-20dB) in noise emissions could be achieved for most types of vessel at relatively little cost without major technical innovation.

It is still difficult to say how much the radiated noise should be reduced to get visibile effects.

However, noise reduction should be also evaluated in order to reduce both local and long range low frequency effects.
A reduction of 20 dB in the low frequency range, below 100 Hz, may have a beneficial effect at long range only if applied to a good proportion of ships. The same reduction, on a broader band extending, say, to 1000 Hz, may have a beneficial local effect in particular where whale density is high.
However, because each zoological group and species has a unique hearing curve that differs from others in range, sensitivity, and peak hearing, it is not possible to provide a single number or decibel level for all species for all signals.

Ship traffic management

The management of ship traffic at a global scale is required to reduce the multiple impacts on the environment (Panigada et al., 2008; Agardy et al., 2007).

Until new classes of quiet ship will cross our seas, alternative measures should be adopted to reduce noise exposure at least in critical areas.

The International Maritime Organization (IMO) should adjust routes, merge existing routes and/or create new routing measures or speed restrictions to minimize exposure of marine mammals sensitive to noise and preserve critical habitats from commercial shipping and other large ocean-going vessel traffic. This approach has been applied in the U.S. EEZ (Exclusive Economic Zone) (shifting of traffic lanes in Massachusetts Bay relative to distribution of endangered western North Atlantic baleen whale populations), the Canadian EEZ (mainly shifting of traffic routes relative to the North Atlantic right whale (*Eubalaena glacialis*) population in the Bay of Fundy) and within the Straits of Gibraltar and neighbouring Spanish Alboran Sea (shifting of traffic routes and speed restrictions relative to sperm whale (*Physeter macrocephalus*) population west of the Strait) (Agardy et al. 2007).

In areas with high traffic and sensitive marine mammal populations, regulatory authorities, marine mammals scientists, shipping industry representatives and NGOs should initiate dialogues in order to identify possible measures, suggesting re-routings and/or consolidations that would balance the needs of species protection (from noise and collisions, other than from chemical pollution and overfishing) and commerce needs.

This would require the undertaking of further research into the appropriate placement of shipping routes, the evaluation of generated noise fields, and the implementation of basin-wide monitoring networks to control noise levels and in particular in critical habitats and where quieting measures are being applied. The Pelagos Sanctuary, in the Central Mediterranan Sea, could be a laboratory where experiment new rules to balance human activities and nature conservation; however, the noise issue is scarcely considered there.

Geographical and temporal restrictions to ship traffic can be permanent, to avoid affecting MPAs or stable key marine mammals habitats, or seasonal to avoid affecting MPAs or key marine mammals habitats during sensitive/critical periods of the life cycle (breeding, feeding, nursing, etc.).
In this context it is of primary importance the identification of low-risk areas where shipping line can be routed without affecting marine mammals in the short range.

IUCN Report (Abdulla, 2008) Highlights Noise Impact of Shipping in Mediterranean and calls for MPAs to provide "Acoustic Comfort" . The report provides a comprehensive look at Mediterranean shipping and includes a long section in the early pages on noise impacts. Due to the concentration of shipping in the Mediterranean, ambient noise is 40dB higher than in relatively shipping-free seas such as the Sea of Cortez. Among the recommendations made in regards to noise are that "Much effort should be devoted to developing a legal framework within which underwater noise is recognized and regulated as a threat," and the advocacy of MPAs that are designed to provide acoustic protection to critical and productive habitats, where "noise levels should not be allowed to exceed ambient by more than a given value, including noise from sources located outside the MPA." In addition, the report stresses the importance of moving rapidly to develop regional hydrophone networks with which to monitor noise and develop current "noise budgets," as well as the need for expanded research with Auditory Brainstem Response techniques to examine hearing sensitivity and changes due to noise exposure, and analysis of stress hormones in response to noise. The authors of the report forge important new ground as they summarize: *"In addition to defining which impacts should be avoided or mitigated, we also need to draw up a model of 'acoustic comfort' that we should guarantee to animals, at least over sufficiently extensive protected areas. This is a novel concept. It means we should define the (near to) zero-impact noise level that a habitat should have for each type of marine life."*

Marine protected areas

The creation of Special Areas of Conservation (SACs) and Marine Protected Areas (MPAs) that take noise pollution into account should ensure protection of areas of critical and productive habitats, and particularly of vulnerable and endangered species.
The designation of SACs and MPAs can be used to protect marine mammals and their habitats from environmental stressors including the cumulative and synergistic effects of noise (Weilgart, 2006; Agardy et al., 2008). In these areas, noise levels should not be allowed to exceed ambient levels of more than a given value, including the contributions from sources that are located outside of the MPA but whose noise propagates into MPA boundaries. This would require additional research to establish baseline noise data and evaluate thresholds for noise levels that can be considered acceptable; i.e. can be tolerated without any significant negative effect.

Main organizations/agreements/conventions

Many governmental and non governmental institutions face with the problems of sea management and conservation. Here the GOs and NGOs that take noise into high consideration (see also in References):

ACCOBAMS - Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area

Since 2002 (Pavan, 2002) the impact of anthropogenic noise is among the ACCOBAMS priorities. In 2007 the ACCOBAMS Contracting Parties have adopted Resolution 3.10 on the appropriate tools for assessing the impacts of underwater noise on cetaceans in order to establish mitigation measures to reduce these impacts and a Set of Guidelines which will guide Governments in the application of such measures.

ASCOBANS - Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas

The impact of anthropogenic noise is among the ASCOBANS priorities. Recently ASCOBANS adopted ACCOBAMS Guidelines as a reference for the development of its own guidelines and recommendations.

ICES - International Council for Exploration of the Seas

ICES produced many documents on the impact of sonars on cetaceans.

IFAW – International Fund for Animal Welfare

IFAW commissioned to Renilson Marine Consulting Pty Ltd the report “REDUCING UNDERWATER NOISE POLLUTION FROM LARGE COMMERCIAL VESSELS” March 2009

IMO – International Maritime Organization

IMO includes a Marine Environment Protection Committee (MEPC) that in 2008 established a correspondence group to work on the development of non- mandatory technical guidelines for ship-quieting technologies as well as potential navigation and operational practices (IMO, 2008b).

IUCN – International Union for the Conservation of Nature

IUCN is concerned with the protection of Nature and produces lists of endangered species.

See Panigada et al., 2008, IUCN 2009

IWC – International Whaling Commission

The scientific committe of IWC meets every year to discuss the most relevant topics about marine mammals conservation and management. The issue of noise has been largely discussed in recent meetings (mainly since the 2004 meeting) and now the interest towards shipping noise is raising. This issue is the core topic to be discussed in the section of the “Environmental concerns” in the next meeting (IWC 62, 2010).

JNCC – Joint Nature Conservation Council

Produced guidelines mainly aimed at reducing the impact of seismic surveys and sonar trials.

NATO

Developed guidelines about sonar exposure for human divers and marine mammals.

OKEANOS

Organized the INTERNATIONAL WORKSHOP ON SHIPPING NOISE AND MARINE MAMMALS (Anon, 2008) and produced several documents.

OSPAR

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. OSPAR is concerned with all impacts on the marine environment, includine shipping noise from both large ships and small recreational boats. See Refs.

UNCLOS - United Nations Convention on the Law of the Sea

UNCLOS is a treaty governing the global marine environment, and it has been partially adopted into common law. It already provides a solid basis for treating harmful, human-generated noise as a form of pollution that must be reduced and controlled. The agreement defines the term "pollution" as "the introduction by man, directly or indi- rectly, of substances or energy into the marine environment..., which results or is likely to result in such deleterious effects as harm to living resources..." (Art. 1(1) (4)).

WDCS – Whales and Dolphions Conservation Society

WDCS published many reports on the noise issue (among them see Simmonds et al., 2004) and cooperates with other organizations (e.g. ACCOBAMS and ASCOBANS).

THE NORTH AMERICAN OCEAN NOISE COALITION (NAONC)

THE EUROPEAN COALITION FOR SILENT OCEANS (ECSO)

THE LATIN AMERICAN OCEAN NOISE COALITION

Conferences/Workshops

THE EFFECTS OF NOISE ON THE AQUATIC ENVIRONMENT
(Nyborg, Denmark from 13th – 17th August, 2007)

INTERNATIONAL WORKSHOP ON SHIPPING NOISE AND MARINE MAMMALS
Held By Okeanos - Foundation for the Sea Hamburg, Germany, 21st-24th April 2008

A GLOBAL SCIENTIFIC WORKSHOP ON SPATIO-TEMPORAL MANAGEMENT OF NOISE.
Scientific Workshop, Puerto Calero, Lanzarote, June 4–6, 2007.

NOAA International Conferences:

SHIPPING NOISE AND MARINE MAMMALS: A FORUM FOR SCIENCE, MANAGEMENT, AND TECHNOLOGY. NOAA International Symposium, Arlington, Virginia, USA, May 18–19, 2004.

POTENTIAL APPLICATION OF VESSEL-QUIETING TECHNOLOGY ON LARGE COMMERCIAL VESSELS. NOAA International Symposium, 1-2 May, 2007, Silver Spring, MD, USA.

References – Cited literature & suggested readings

Abdulla A., London O. (editors), 2008. Maritime traffic effects on biodiversity in the Mediterranean Sea: Review of impacts, priority areas and mitigation measures. Malaga, Spain: IUCN Centre for Mediterranean Cooperation, Report 2008-042. 184 pp.

ACCOBAMS, 2004. Recommendation 2.7 "Man-made noise".

ACCOBAMS, 2004. Resolution 2.16 "Assessment and impact assessment of anthropogenic noise". Online at http://www.accobams.org/2006.php/parties/documents/2

ACCOBAMS, 2006. Recommendation SC4.3 "Anthropogenic noise". Online at http://www.accobams.org/2006.php/meetings/recommendations/4

ACCOBAMS, 2007. Resolution 3.10 "Guidelines to address the impact of anthropogenic noise on marine mammals in the ACCOBAMS area". Online at http://www.accobams.org/2006.php/parties/documents/5

Agardy T., Aguilar N., Cañadas A., Engel M., Frantzis A., Hatch L., Hoyt E., Kaschner K., LaBrecque E., Martin V., Notarbartolo di Sciara G., Pavan G., Servidio A., Smith B., Wang J., Weilgart L., Wintle B. and Wright A., 2007. A Global Scientific Workshop on Spatio-Temporal Management of Noise. Report of the Scientific Workshop. 51+vii pages.

Aguilar Soto, N., Johnson, M., Madsen, P., Tyack, P.L., Bocconcelli, A., Borsani, J.F. 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? Marine Mammal Science, 22(3):690-699.

Amoser S., Ladich F., 2003. Diversity in noise-induced temporary hearing loss in otophysine fishes, *Journal of the Acoustical Society of America* 113, pp. 2170–2179.

Amoser S., Wysocki L.E., Ladich F., 2004. Noise emission during the first powerboat race in an Alpine lake and potential impact on fish communities, *Journal of the Acoustical Society of America* 116, pp. 3789–3797.

Andrew, R.K. et al. 2002. Ocean ambient sound: Comparing the 1960s with the 1990s for a receiver off the California coast. Acoustics Research Letters Online, 3(2):65-70.

Anon 2008. International Workshop on Shipping Noise and Marine Mammals. Okeanos – foundation for the sea. Hamburg, Germany. 21-24 April 2008. http://www.okeanos-stiftung.org/okeanos/download.php?id=14

ASCOBANS, 2006. Resolution No. 4 "Adverse Effects of Sound, Vessels and other Forms of Disturbance on Small Cetaceans" adopted by the 5th Meeting of Parties.

Banner A. , Hyatt M., 1973. Effects of noise on eggs and larvae of two estuarine fishes, *Transactions of the American Fisheries Society* **1**, pp. 134–136

Bart, A. N., Clark J., Young J., And Zohar Y. 2001. Underwater ambient noise measurements in aquaculture systems: a survey. Aquacultural Engineer, 25:99-110.

Bradley D.L., Stern R., 2008. Underwater sound and the marine mammal acoustic environment. A guide to fundamental principles. US MMC: 1-77.

Castellote, M. (2007). General Review of Protocols and Guidelines for Minimizing Acoustic

Disturbance to Marine Mammals from Seismic Surveys. *Journal of International Wildlife Law & Policy*, *10*(3), 273-288.

Clark C.W., Alter L., Gedamke J., Parsone C., Pavan G., Rose N., Rosenbaum H., Simmonds M., Suydam R., Young J., 2009. Steering Group to develop an E-Agenda Work Plan on Anthropogenic Sound for SC/62 (2010) . IWC 61.

Clark C.W., Ellison W.T., Southall B.L., Hatch L., Van Parijs S., Frankel A., Ponirakis D., 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. Mar Ecol Prog Ser, Vol. 395: 201–222.

Clark CW, Ellison WT (2004) Potential use of low-frequency sounds by baleen whales for probing the environment: evidence from models and empirical measurements. In: Thomas JA, Moss CF, Vater M (eds) Advances in the study of echolocation in bats and dolphins. University of Chicago Press, p 564-589

Clark CW, Gillespie D, Nowacek DP, Parks SE (2006) Listening to their world: Acoustics for monitoring and protecting right whales in an urbanized ocean. In: Kraus S, Rolland R (eds) The urban whale. Harvard University Press, Cambridge, p 333-357

Cox TM, Ragen TJ, Read AJ, Vos E, Baird RW, Balcomb K, Barlow J, Caldwell J, Cranford T, Crum L, D'Amico A, D'Spain G, Fernández A, Finneran J, Gentry R, Gerth W, Gulland F, Hildebrand J, Houserp D, Hullar T, Jepson PD, Ketten D, Macleod CD, Miller P, Moore S, Mountain DC, Palka D, Ponganis P, Rommel S, Rowles T, Taylor B, Tyack P, Wartzok D, Gisiner R, Mead J, Benner L (2006) Understanding the impacts of anthropogenic sound on beaked whales. J Cet Res Manage 7:177-187-

Crain C.M., Kroeker, K. and..Halpern, B.S. (2008) Interactive and cumulative effects of multiple human stressors in marine systems. Ecology Letters 11

Croll DA, Clark CW, Acevedo A, Tershy B, Floress S, Gedamke J, Urban J (2002) Only male fin whales sing loud songs. Nature 417:809.

Curtis K.M., Howe B.M., and Mercer J.M., 1999. Low-frequency ambient sound in the North Pacific: Long time series observations. J. Acoust. Soc. Am. 106, 3189-3200.

Dobler, J. P. 2002. Analysis of shipping patterns in the Mediterranean and Black seas. CIESM. Alien marine organism introduced by ships in the Mediterranean and Black seas. CIESM Workshop Monographs, 20:19-28.

E.U. 2008. The European Union Marine Strategy Framework Directive (adopted in June 2008). Available on http://ec.europa.eu/environment/water/marine/index_en.htm

Erbe C, Farmer DM (2000) A software model to estimate zones of impact on marine mammals around anthropogenic noise. J Acoust Soc Am 108:1327-1331

Erbe, C. 2002. Underwater noise of whale watching boats and potential effect on killer whales (*Orcinus orca*), based on an acoustic impact model. Marine Mammal Science, 18 (2):394-418.

European Habitat Directive 92/43/EEC.

European Parliament, 2004. Naval sonars European Parliament resolution on the environmental effects of high intensity active naval sonars. P6_TA(2004)0047 B6-0089/2004

Evans P.G.H. 2003. SHIPPING AS A POSSIBLE SOURCE OF DISTURBANCE TO CETACEANS IN THE ASCOBANS REGION. Report to ASCOBANS. MOP4/Doc. 17(S).

Evans, D.L., England, G.R. 2001. Joint Interim Report: Bahamas Marine Mammal Stranding Event of 15-16 March 2000. Unpublished Report. U. S. Department of Commerce and U. S. Navy, 61 pp. Online at http://www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf.

Frankel AS, Ellison WT, Buchanan J (2002) Application of the Acoustic Integration Model (AIM) to predict and minimize environmental impacts. IEEE Oceans 2002:1438-1443

Frank V., 2009. Underwater Noise from Commercial Shipping: a look at the Arctic.

Gisiner, R. (Ed.), 1998. Proceedings of the workshop on the effects of anthropogenic noise in the marine environment. 10-12 February 1998, Office of Naval Research, 141 pp.

Gloza I., 2008. Transmission of low frequency sounds from ships into water environment. Acoustics 08.

Gordon, J.C.D., Gillespie, D., Potter, J., Frantzis, A., Simmonds, M., Swift, R., Thompson, D. 2004. A review of the effects of Seismic Survey on Marine Mammals. Marine Technology Society Journal, 37(4):14-34.

Green, D.M., DeFerrari, H.A., McFadden, D., Pearse, J.S., Popper, A.N., Richardson, W.J., Ridgway, S.H., Tyack, P.L. 1994. Low-frequency sound and marine mammals: current knowledge and research needs. (NRC report) Washington, D.C.: National Academy Press.

Hatch L.T., Fristrup K.M., 2009. No barrier at the boundaries: implementing regional frameworks for noise management in protected natural areas. Mar Ecol Prog Ser, Vol. 395: 223–244.

Hatch, L, Clark, C, Merrick, R, Van Parijs, S, Ponirakis, D, Schwehr, K, Thompson, M, and Wiley, D, 2008, Characterising the relative contributions of large vessels to total ocean noise fields: a case study using the Gerry E Studds Stellwagen bank national marine sanctuary. Environmental Management 42:735-752

Heitmeyer, R.M., Wales, S.C., Pflug, L.A. 2004. Shipping Noise Predictions: Capabilities and Limitations. MTS Journal, 37(4):54-65.

1Hildebrand, J. 2005. Impacts of anthropogenic sound. *In* Marine mammal research: conservation beyond crisis. *Edited by* J.E. Reynolds, III, W.F. Perrin, R.R. Reeves, S. Montgomery, and T.J. Ragen. Johns Hopkins University Press, Baltimore, Maryland. pp. 101-124.

IFAW, 2008. Ocean Noise: Turn it down. A report on ocean noise pollution published by IFAW, June 2008

IMO 2008a. Minimizing the introduction of incidental noise from commercial shipping operations into the marine environment to reduce potential adverse impacts on marine life. Paper MEPC 58/19 submitted by the United States to 58th session of IMO Marine Environment Protection Committee. October 2008.

IMO 2008b. Report of the 58th session of IMO Marine Environment Protection Committee. October 2008.

IMO 2009. Noise From Commercial Shipping and its Adverse Impacts on Marine Life, Report from the Correspondence Group (MEPC59/19), April 09. Available at http://www.sjofartsverket.se/pages/19596/59- 19.pdf

IUCN, 2009. Towards a better Governance of the Mediterranean. Report of the IUCN's Group of Experts 2007-2008. Report prepared by Carole Martinez (IUCN-France) with the support and participation of Mondher Bel-Hadjali, Habib Slim, Nilufer Oral (IUCN/CEL) and François Simard (IUCN)

IUCN, 2009. Risks from maritime traffic to biodiversity in the Mediterranean Sea. Identification of issues and possible responses. IUCN Report 062.

IWC, 2004. Report of the Scientific Committee. IWC 56 Summary Report & Annexe K.

IWC, 2006. Report of the Standing Working Group on Environmental Concerns. Proc. 58th IWC. Annex K:1-73.

Jensen F.H., Bejder L., Wahlberg M., Aguilar Soto N., Johnson M., Madsen P.T., 2009. Vessel noise effects on delphinid communication. Mar Ecol Prog Ser, Vol. 395: 161–175.

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 Engineer, 28 (1):3-12.

Kastelein RA, de Hann D, Verboom WC (2007) The influence of signal parameters on the sound source localization ability of a harbor porpoise (*Phocoena phocoena*). J Acoust Soc Am 122:1238-1248

Leaper R., Renilson M., Frank V., Papastavrou V., 2009. Possibile steps towards reducing impacts of shipping noise. IWC - SC/61/E19

Leaper, R. and Scheidat, M. 1998. An acoustic survey for cetaceans in the Southern Ocean Sanctuary conducted from the German Government research vessel Polarstern. Rep. int. Whal. Commn. 48:431-437.

Lesage V.C., Barette C., Kingsley M.C.S., Sjare B., 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence river estuary, Canada, *Marine Mammal Science* 15, pp. 65–84.

Mark Simmonds, Sarah Dolman and Lindy Weilgart (2004) Oceans of Noise A WDCS Science Report 168 Pages published by WDCS and available on their website

McCarthy, E. 2004. International Regulation Of Underwater Sound: Establishing Rules And Standards To Address Ocean Noise Pollution. Kluwer Academic Publ.:287pp.

McCauley, R., Fewtrell, J., Popper, A.N. 2003. High Intensity Anthropogenic Sound Damages Fish Ears. Journal of the Acoustical Society of America, 113(1):638-642.

McDonald M.A., Hildebrand J.A., Wiggins S.M., 2006. Increase in deep ocean ambient noise in the Northeast Pacific west of San Nicola Island, California. J.Acoust.Soc.Am., 120 (2): 711-718.

Merril, J. (Ed.). 2004. Human-generated Ocean Sound and the Effects on Marine Life. Marine Technology Society Journal, 37(4):4-5.

Mitson R.B., Knudsen H.P., 2003. Causes and effects of underwater noise on fish abundance estimation, *Aquatic Living Resources* 16, pp. 255–263.

Mitson, R.B. 1995. Underwater noise of research vessels: review and recommendations. ICES Cooperative Research Report, 209.

Myrberg A.A., 1990. The effects of man-made noise on the behavior of marine animals, *Environment International* 16, pp. 575–586.

National Research Council (2000) Marine mammals and low-frequency sound: Progress since 1994. National Academies Press, Washington, DC

National Research Council (2003) Ocean noise and marine mammals. National Academies Press, Washington, DC: 192pp.

National Research Council (2005) Marine mammal populations and ocean noise : Determining when noise causes biologically significant effects. National Academies Press, Washington, DC

NATO Standardization Agreement (STANAG), "Standards for use when measuring and reporting radiated noise characteristics of surface ships, submarines, helicopters, etc. in relation to sonar detection and torpedo risk, May 29, 1995.

NOAA. 2001. Joint Interim Report Bahamas Marine Mammal Stranding Event of 15-16 March 2000. NOAA Ocean Acoustics Program, 1-66. Online at http://www.nmfs.noaa.gov/pr/acoustics/

NOAA. 2004. Symposium "Shipping Noise and Marine Mammals: A Forum for Science, Management, and Technology" Final Report. Online at http://www.nmfs.noaa.gov/pr/acoustics and http://www.shippingnoiseandmarinemammals.com

NOAA. 2007. Symposium "Potential Application of Vessel-Quieting Technology on Large Commercial Vessels". NOAA Ocean Acoustics Program. Online at http://www.nmfs.noaa.gov/pr/acoustics/

Nowacek, D., M. P. Johnson and P. L. Tyack. 2004b. 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.

Nowacek, D.P., Thorne, L.H., Johnston, D.W., Tyack, P.L. 2007. Responses of cetaceans to anthropogenic noise. Mammal Review, 37(2):81-115.

NRC (National Research Council). 2000. Marine Mammals and Low-Frequency Sound. Washington, DC: National Academy Press. 146 pp.

NRC (National Research Council). 2003. Ocean Noise and Marine Mammals. Washington, DC: National Academy Press. 192 pp.

OSPAR Commission, 2008. Assessment of impacts of tourism and recreational activities. Publication number 369/2008.

OSPAR Commission, 2009. Assessment of the environmental impact of underwater noise. Publication Number: 436/2009

OSPAR Commission, 2009b. Assessment of impacts of shipping. Publication number 440. (in press)

Panigada S., Pavan G., Borg J.A., Galil B.S., Vallini C. 2008. Biodiversity impacts of ship movement, noise, grounding and anchoring. Pp. 9-56 in Abdulla A., Linden O. (Eds). *Maritime traffic effects on biodiversity in the Mediterranean Sea: Review of impacts, priority areas and mitigation measures*. IUCN Centre for Mediterranean Cooperation, Malaga, Spain.

Parks SE, Clark CW, Tyack PL (2007) Short- and long-term changes in right whale calling behavior: The potential effects of noise on acoustic communication. J Acoust Soc Am 122:3725-3731

Pavan G., 2002. Effects of underwater noise on marine mammals. Les effets des bruits sous-marins sur les mammifères marins. Bulletin ACCOBAMS, 4 (February 2002): 11-14.

Pavan G., 2007. Acoustic Risk Mitigation in the Mediterranean Sea. Proc. Underwater Defence Technology (UDT 2007). Published on CDROM.

Pavan G., 2007. The Noise Issue. A challenge for the survival of marine mammals. In: Agardy T. et al. 2007. A Global Scientific Workshop on Spatio-Temporal Management of Noise. Report of the Scientific Workshop: 32-33.

Panigada S., Pavan G., Borg J.A., Galil B.S., Vallini C. 2008. Biodiversity impacts of ship movement, noise, grounding and anchoring. Pp. 9-56 in Abdulla A., Linden O. (Eds). *Maritime traffic effects on biodiversity in the Mediterranean Sea: Review of impacts, priority areas and mitigation measures*. IUCN Centre for Mediterranean Cooperation, Malaga, Spain.

Pavan, G. 2006. Guidelines to address the issue of the impact of anthropogenic noise on marine mammals in the ACCOBAMS area. Report prepared for the 4th ACCOBAMS Scientific Committee. ACCOBAMS SC4 Doc 18.

Pavan, G. 2007. Acoustic Risk Mitigation in the Mediterranean Sea. Proceedings Underwater Defence Technology (UDT 2007). Published on CDROM.

Payne, R., Webb, D. 1971. Orientation by means of long range acoustic signalling in baleen whales.

Ann. N.Y. Acad. Sci., 188:110-141

Piersall, C.H. 2009. When silence means survival –Protecting the marine ecosystem from underwater irradiated noise. ISO Focus January 2009: 38-39

Popper A.N., 2003. Effects of anthropogenic sounds on fishes, *Fisheries Research* **28** (2003), pp. 24–31

Popper A.N., Fewtrell J., Smith M.E., McCauley R.D., 2004. Anthropogenic sound: effects on the behavior and physiology of fishes, *Journal of Marine Science and Technology* **37**, pp. 35–40.

Popper, A.N. 2003. Effects of anthropogenic sound on fishes. Fisheries, 28:24-31.

Popper, A.N., Fewtrell, J., Smith, M.E., McCauley, R.D. 2004. Anthropogenic Sound: Effects on the Behavior and Physiology of Fishes. In Merril J. (Ed.) 2004:35-40.

Porter M, Reiss EL (1985). A Numerical method for bottom interacting ocean acoustic normal modes. J Acoust Soc Am 77:1760-1767

Renilson, M. 2009. Reducing underwater noise pollution from large commercial vessels. Report to IFAW. 44 pages. ISBN: 978-1-906920-02-9. Available from www.ifaw.org/oceannoise/reports

Riccobene, G., Casentino, L., Musumeci, M., Pavan, G., Speziale, F. 2004. Acoustic detection of UHE neutrinos: a station for measurement of the deep sea acoustic noise. Nuclear Instruments and Methods in Physics Research A, 518:220–222.

Riccobene, G., Cosentino, G., Musumeci, M., Pavan, G., Speziale, F., NEMO Collaboration. 2007. Acoustic background measurements with NEMO-ONDE. INFN LNS Reports 2006:144-147.

Richardson, W.J., Greene, C.R.Jr., Malme, C.I., Thomson, D.H. 1995. Marine Mammals and Noise. Academic Press, 576pp.

Ross D., 1976. *Mechanics of Underwater Noise* (Pergamon Press, New York, 1976).

Ross D., 1982. “Role of propagation in ambient noise," in *Underwater ambient noise: Proceedings of a conference held at SACLANTCEN on 11-14 May 1982*, edited by R. Wagstaff and O.Z. Bluy (SACLANT ASW Research Center, La Spezia, Italy, 1982).

Ross D., 1993. “On ocean underwater ambient noise," Acoust. Bull. 18, 5-8 (1993).

Scholik, A.R., Yan, H.Y. 2002. Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas.* Environmental Biology of Fishes, 63: 203–209.

Scrimger P., Heitmeyer R. M., 1991. Acoustic source-level measurements for a variety of merchant ships. J. Acoust. Soc. Am. 89 (2): 691-699

Simmonds M., Dolman S., Weilgart L., 2004. Oceans of Noise. WDCS Science Report: 1-168.

Skaret, G; Axelsen, B E; Nøttestad, L; Fernö, A; Johannessen, A, 2005. The behaviour of spawning herring in relation to a survey vessel. ICES Journal of Marine Science, 62 (6): 1061-1064.

Smith M.E., Kane A.S., Popper A.N., 2004. Noise-induced stress response and hearing loss in goldfish (*Carassius auratus*), *The Journal of Experimental Biology* 207 (2004), pp. 427–435.

Soria, M; Frion, P; Gerlotto, F, 1996. Analysis of vessel influence on spatial behaviour of fish schools using a multi-beam sonar and consequences for biomass estimates by echo-sounder. ICES Journal of Marine Science, 53 (2): 453-458.

Soto, N.A.; Johnson, M.P.; Madsen, P.T.; Tyack, P.L.; Bocconcelli, A.; Borsani, J. F, 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? Marine Mammal Science, 22 (3): 690-699.

Sousa-Lima, R.S. and Clark, C.W. 2008. Modeling the effect of boat traffic on the fluctuation of humpback whale singing activity in the Abrolhos National Marine Park, Brazil. *Canadian Acoustics* 36: 174-181)

Southall B.L. 2005. Shipping noise and marine mammals: a forum for science, management, and technology. Final Report of the National Oceanic and Atmospheric Administration (NOAA) International Symposium. U.S. NOAA Fisheries, Arlington, Virginia, May 18–19, 2004. Available at: http://www.nmfs.noaa.gov/pr/pdfs/acoustics/shipping_noise.pdf

Southall BL (2005) Final report of the 2004 international symposium "Shipping noise and marine mammals: A forum for science, technology, and management." National Oceanic and Atmospheric Administration, Washington, DC

Southall BL, Bowles AE, Ellison WT, Finneran JJ, Gentry RL, Greene CR, Jr., Kastak D, Ketten DR, Miller JH, Nachtigall PE, Richardson WJ, Thomas JA, Tyack PL (2007) Marine mammal noise exposure criteria: Initial scientific recommendations Aquat Mamm 33:411-521

Southall, B.L. 2005. Shipping Noise and Marine Mammals: A Forum for Science, Management, and Technology. Final Report of the NOAA International Symposium. Arlington, Virginia, US, 18-19 May 2004.

Southall, BL and A. Scholik-Schlomer. 2008. Final report of the NOAA International Conference: "Potential Application of Vessel-Quieting Technology on Large Commercial Vessels," 1-2 May, 2007, Silver Spring, MD, U.S.A.

Southall, Bowles, Ellison, Finneran, Gentry, Green Jr, Kastak, Ketten, James Miller, Nachtigall, Richardson, Thomas, Tyack. (2007) Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Special Issue of the journal Aquatic Mammals Volume 33, Number 4, pp 411-522.

Spreng M., 2000. Possible health effects of noise induced cortisol increase, *Noise and Health* **7**, pp. 59–63.

Tyack, P.L. 2003. Research Program to Evaluate Effects of Manmade Noise on Marine Mammals in the Ligurian Sea. ACCOBAMS Document CS2/Inf. 13

Tyack, P.L., 2009. Human generated sound and marine mammals. Physics Today, November: 39-44.

UN Convention on Migratory Species (CMS), Resolution 9.19 "Adverse Anthropogenic Ocean Noise Impacts on Cetaceans and other Biota", 2008.

Urick RJ, 1983. Principles of underwater sound,. McGraw-Hill Book Company, New York

Vasconcellos J.M. and Latorre R.G., 2001. Recreational boat noise level evaluation, *Ocean Engineering* **28**, pp. 1309–1324.

Vos, E., Reeves, R.R. 2005. Report of an international workshop : Policy on Sound and Marine Mammals, 28-30 September 2004, London, England. Marine Mammals Commission, Bethesda, Maryland: 129pp. Online at: http://www.mmc.gov/sound

Wahlberg, M., Westerberg, H. 2005. Hearing in fish and their reactions to sounds from offshore wind farms. Marine Ecology Progress Series, 288:295 – 309.

Wales S.C., Heitmeyer R.M., 2002. An ensemble source spectra model for merchant ship-radiated J. Acoust. Soc. Am. 107 (1):1211-1231.

Watkins WA, Tyack P, Moore KE, 1987. The 20-Hz signals of finback whales (*Balaenoptera physalus*). J Acoust Soc Am 82:1901-191

Weilgart, L.S. 2006 Managing Noise through Marine Protected Areas around Global Hot Spots. IWC document SC/58/E25.

Weilgart, L.S. 2007. The impacts of anthropogenic noise on cetaceans and implications for management. Can. J. Sool. 85 (11): 1091-1116.

Weir, C.R. and Dolman, S.J. (2007). Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. Journal of International Wildlife Law and Policy, 10: 1-27.

Wenz, G. M. 1962. Acoustic ambient noise in the ocean: Spectra and sources. Journal of the Acoustical Society of America 34, 1936-1956.

Wysocki L.E., Dittami J.P., Ladich F., 2006. Ship noise and cortisol secretion in European freshwater fishes, Biological Conservation, Volume 128, Issue 4: 501-508