Cetaceans of the Mediterranean and Black Seas: State of Knowledge and Conservation Strategies

SECTION 13

Disturbance to Mediterranean Cetaceans Caused by Noise

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Introduction

Sounds underwater. When a sound is emitted by a source, series of compression waves move away from this source and passes through the surrounding media, making the molecules of these media oscillate around their original location by changes of pressure, in the direction of the waves. It is important to note that the way the molecules of a medium will oscillate depends on both natures: that of the sound and that of the medium.

For one given medium, the amplitude of the movement of its molecules is due to the amount of energy of the waves causing fluctuations of pressure, which is called intensity when related to the density of the media, and the "rapidity" of the movement is tied to the frequencies of the waves. In other words, the intensity and the frequency of the sound make the molecules move more or less far away from their original location and vibrate more or less fast respectively, and therefore are the two principal components used as descriptors of the nature of sound. Intensity is measured in decibels (dB), which is a logarithmic scale comparing the intensity of the sound measured to that of a reference sound. It is worth highlighting that this reference value is different for sounds measured in the air and under water, since this difference (roughly, an intensity of x dB in the water will be equivalent to an intensity of x-26 dB in the air) has been cause of confusion in the literature (Chapman and Ellis 1998). In this report, all intensities cited will take into account the water reference value. Otherwise, frequency is measured in hertz (Hz), corresponding to the number of cycles accomplished per second by the waves.

The nature of the medium plays a critical role in the propagation of sound. It has previously been said that intensity of sound is related to the density of the medium. So is the wavelength, which is the product of its frequency and the speed of sound in the medium, the latter being also directly linked to the density of the medium. Given that sound travels five times faster in the water than in the air, this means that a sound will be heard much farther in the water. Moreover, it is well known that the absorption of a sound depends on its frequency, as well as it depends on the characteristics of the media. In seawater, a high frequency sound of 100 kHz looses 36 dB in intensity per km, while the intensity of a medium or low frequency sound (< 1 kHz) does not decrease of more than 0.04 dB per km. In this medium, measures of emission intensity are usually made (or inferred) at a distance of one meter of the source. On another side, water masses are numerous and so are their physical characteristics: temperature, salinity, pressure defining their density, turbidity, and so on. Thus, the direction and the distance at which a sound may propagate are likely to vary according to the water masses it goes through, or refracts, or reflects. The combination of all makes sound propagation calculations very complicated. Nevertheless, some areas in the ocean are known to be quite remarkable acoustically speaking. Notably, particular conditions occur at certain depths (from 1,000 m in the tropics to a few hundred meters closer to the poles) in water masses causing the sound speed to be minimum. These water masses are called deep sound channel because they trap the sound and concentrate it, allowing a greater propagation. On the other hand, some areas at the surface are relatively protected zones from noise, whereas in others sounds converge (Richardson *et al.* 1995, Moscrop and Swift 1999).

Natural and human-made sounds. Even outside the convergence zones, the world ocean is a noisy place. Considering the natural-made sounds only, the ambient noise at surface near 100 Hz may reach 60-80 dB (it is strongly weather-dependant). This natural background noise expand at least over 1 Hz to 100 kHz and has a lot of sources, including earthquakes and sea ice at low frequencies; waves, din of rain on the surface and biological sources such as croaker fishes, pistol shrimps and marine mammals at medium frequencies; finally, molecular agitation prevails at very high frequencies. Nowadays, one has to add the human-made noise, or anthropogenic noise, which has been estimated by Ross in 1976 to rise between the 50's and 1975 the total background level of 10 dB in the northern hemisphere - the same author predicted at this time another 5 dB increase until the end of the century. Anthropogenic noise is due to explosions, seismic activities, military sonar, exploitation of oil and gas industry, vessels traffic, scientific research, fishing activities and recreational craft. It covers also the wide frequency bands mentioned above for natural sources. Because of the strong development of industries, transports, etc..., ambient man-made noise is even louder in the northern hemisphere, and concentrates particularly in coastal areas. Nevertheless, when we consider both ambient, permanent noise and local, temporary noises, the amount of anthropogenic sounds is likely to threat cetaceans worldwide.

Generalities on sounds and cetaceans. The process by which sound waves interact with surrounding media has been briefly reviewed. If one of these media is an animal, oscillations created in its body allow it to hear the sound. In addition, we have seen that sound propagation underwater was much greater than in the air contrary to vision. Thus, it is no surprise that cetaceans have evolved to rely principally upon their acoustic senses, i.e. hearing, communication and echolocation involving most of their vital functions (navigation, detection of preys and predators, social communication involving in its turn reproduction, care of calves, social cohesion within the group...). Therefore, cetaceans as a whole are very sensitive to sound, either in terms of ecological fitness or of received intensity and frequency. When getting slightly more into details, the larger a cetacean is, the lower the frequencies it uses. Ketten (1992, 1998 in SACLANTCEN) stated that four groups of cetaceans can be distinguished with respects to their acoustic abilities:

- the mysticetes producing dominant signals below 1 kHz. It is the case of one common species in the Mediterranean, the fin whale (*Balaenoptera physalus*);
- the largest odontocetes producing dominant signals below 3 kHz: the sperm whale (*Physeter macrocephalus*), the Cuvier's beaked whale (*Ziphius cavirostris*), and the long-finned pilot whale (*Globicephala melas*);
- the mid-sized odontocetes with signals in the range above 40-80 kHz: the bottlenose dolphin (*Tursiops truncatus*) and the Risso's dolphin (*Grampus griseus*);
- the smallest odontocetes with signals in the range above 80 kHz: the striped dolphin (*Stenella coeruleoalba),* the common dolphin (*Delphinus delphis*) and the harbour porpoise (*Phocoena phocoena*) which is common in the Black Sea.

Impact of sound on cetaceans. If oscillations generated by sound in their body make them very well adapted to their environment when received intensity is normally acceptable for them, such vibrations can have disastrous effects when received intensity brake up their ability limits.

In spite of a certain lack of knowledge, due to insufficient research, and to the difficulties in judging noise effects in isolation from other threats, several effects of noise on cetaceans have been reported, ranging from local and short disturbance to death. The most problematic point is that it is not clear to what extent these effects have long-term implications for cetaceans populations. However, current information suggests that anthropogenic noise has the potential to affect cetaceans in a number of ways which reduce fitness at the level of individuals, populations and species. These ways have been compiled by Simmonds and Dolman (1999):

- Physical: non-auditory (damage to body tissue, induction of air bubble growth and tissue bends) and auditory (gross damage to ears, permanent hearing threshold shift, temporary hearing threshold shift);
- Perceptual: masking of communication with conspecifics, masking of other biologically important noises, interference with ability to acoustically interpret environment, adaptive shifting of vocalisations (with efficiency and energetic consequences);
- Behavioural: gross interruption of normal behaviour (i.e. behaviour acutely changed for a period of time), behaviour modified (i.e. behaviour continues but is less effective/efficient), displacement from area (short or long term);
- Chronic/Stress: decreased ability of individual, increased potential for impacts from negative cumulative effects (e.g. chemical pollutants combined with noise-induced stress), sensitisation to noise (or other stresses) - exacerbating other effects, habituation to noise - causing animals to remain close to damaging noise sources;
- Indirect effects : reduced availability of preys (this effect is not moved on in the present report).

Consequently, physiological consequences are various: energetic implications, stress, hearing impairment (auditory damage and masking), non-auditory physical damages, strandings. In addition, noise can also alter feeding, foraging, resting, socialising and breeding behaviours, and the detrimental impact is likely to be particularly severe in cases where cetaceans are temporarily or permanently displaced from areas that are important for feeding or breeding.

Synergetic effects with other pollution sources are also suspected, as for instance in the case of permanent threshold shift due to heavy shipping noise, increasing the probability of collisions with vessels (André *et al.* 1997). It is well known too that long-term stress-mediated effects due to noise include lower resistance to disease (Geraci and St-Aubin 1980). For areas where chemical pollution is heavy, this may cause several pathological effects, ranging from the death of an individual to the reduction of effectiveness of the immunological defences of entire populations. Perry (1998) highlighted that synergetic effects of noise, chemical pollution, shipping disturbance and over-exploitation of natural resources are likely to have the most severe impacts for cetaceans populations in coastal areas.

Evaluation of noise effects. It remains very complicated to determine, characterise and assess effects of noise. Cetacean behaviour varies naturally according to numerous factors, such as the animal's age, sex and state of activity, as well as environmental influences such as the location, season and time of the day. The significance of a particular acoustic signal, and the way an animal responds to it, may vary according to any of these factors. This means that it is very difficult to establish a baseline against which effects of disturbance can be compared (Perry 1998). In addition, it is rarely known if a behavioural change is a response to a specific noise, rather than to a visual or other disturbance (Richardson *et al.* 1995). Moreover, evidence of causal effects of a particular - and, obviously, even more of a permanent - sound on the physiology of the animal has appeared to be a very controversial matter, as it is almost impossible to demonstrate it statistically (for example, see below the discussion on LFAS) because of the lack of data. In 1998, Ketten stressed that "existing data are insufficient to accurately predict any but the grossest acoustic impacts on marine mammals". In the past three years, methods have evolved and several studies were conducted, but this problem currently remains strong. Now, research work aims at determining ranges of threshold intensities received by animals at the most relevant frequencies and what is the kind of effect in function to the distance of the cetacean from the emitting source, all of that depending on the species affected.

Anyway, literature describes disruption of cetacean behaviour and physiological impacts due to noise from recreational boats, shipping, industrial activities, seismic exploration, oceanographic tests, sonar, acoustic deterrents and aircraft. In this paper, anthropogenic sources of sound and their effects on cetaceans will be reviewed by professional human activity, detailing both general and Mediterranean cases according to the current knowledge, and mitigation recommendations will be proposed.

Traffic noise: shipping, pleasure boats and whale watching

Although being gathered under the same broad word “traffic”, these three categories are well different. In this chapter, we will consider them in two paragraphs with respect to their coastal and deep-sea area occurrence, the first paragraph being separated in two parts, according to the main frequency (high or low) of the sounds they emit. These distinctions have been made because of conservation implication meanings, principally referring to the species affected, to the kind of effect and to the probable duration of disturbance.

Neritic areas. Coastal areas are places where man-made ambient noise is the loudest, notably around harbours. In the Sado estuary (Portugal), Dos Santos *et al.* (1995) recorded a minimum level of ambient noise of 122 dB, the maximum reaching 151 dB near the harbour. Noise is mainly due to the intense traffic converging to such places, to be linked to three socio-professional origins: fisheries, concerning boats displacements to or from their fishing grounds and only considered in this chapter as routing small or mid-sized boats (< 50 m long); recreational tourism, related or not to cetaceans observation; and commerce ships (and aircraft), either for passengers or merchandise transport. The first two categories generally have highly seasonal activities and produce high-frequency sounds, whereas the third one is rather permanent and produce low-frequency sounds. This means that they may have very distinct impacts on cetaceans, but the combination of all in the same areas will affect all cetaceans species and populations – transient or resident – living in neritic areas.

Low frequencies. Though large vessels are transient as they indeed pass through coastal zone, both an effect of concentration along regular and predictable lanes and the large audible range of the noise they make induce a potential disturbance on wide time and space scales.

The impact of fast-ferries on bottlenose dolphins was studied by Browning and Harland (1999). Measuring sound emitted by a water-jet propelled catamaran, they found two peaks of intensity, the first caused by machinery over 130 dB (at a distance of 900 m) around 500 Hz, and the second much less intense above 10 kHz, produced by the displacement of water behind the ship. They did not detect any disturbance on bottlenose dolphins, whether by behaviour disruption or by displacement from the area. On the other hand, grey whales (*Eschrichtius robustus*) left calving lagoons while they were subject to human disturbance, including intense shipping and continuous dredging, and came back several years later, only once shipping has ceased, very presumably as a response to noise disturbance (Reeves 1977, Bryant *et al.* 1984). Glockner-Ferrari and Ferrari (1985, in Perry 1998) attributed a consistent decrease in the percentage of humpback whales (*Megaptera novaeangliae*) mothers and calves to high level of boating and aircraft. When investigating the response of belugas vocal behaviour to ferries noise, Lesage *et al.* (1999) concluded that this kind of traffic was unlikely to have serious impacts on communication among belugas (*Delphinapterus leucas*), because much of the noise emitted by these vessels is concentrated at frequencies < 1 kHz, where belugas sensitivity is quite poor. Nevertheless, they observed several changes of vocal behaviour when vessels were close to the animals, such as changes in calling rates, a tendency to emit calls repetitively, an increase of call duration and an upward shift in the frequency range used to vocalise. André *et al.* (1997) reported cell damage in the ears of two sperm whales, consistent with the effects of permanent threshold shift, suggesting that this might have been caused by long-term exposure to noise from continuous shipping activity.

High frequencies. All of the numerous kinds of boats producing high-frequency sounds have quite limited sizes – unable to support a very powerful engine – and quite limited autonomies, thus moving only within a small range (few nautical miles) from the coast. So, all are resident in neritic areas, but again have to be discriminated with respect to the "passing" character they could have for cetaceans. Practically, high-frequency noise has very little propagation abilities, and therefore participates only little to ambient noise, except in the close vicinity of the source. Thus in this case, the distance cetaceans are from the noise source plays a major role. Thereby, whale-watching boats will be distinguished from the rest of the traffic, since, on one hand, their destination are cetaceans themselves and, on the other hand, they spend a long time close to the animals.

Evans *et al.* (1992) experimented the reaction of bottlenose dolphins to various pleasure boats. They measured intensities at a distance of 3 m of the noise source and audible ranges under sea state 3 condition (keep in mind that all range values increase if sea state declines). They found that jet ski (650 cc.) had the lowest intensity (83 dB at low speed and 90 dB at high speed), thanks to its water-jet propulsion system, followed by the inflatable (6 hp outboard engine), the rigid speed boat (90 hp outboard engine) and finally the lobster fishing boat (240 hp inboard engine). In all cases, cavitation (air bubbles that form and collapse near the blades after speed has reached a critical level) is the most significant source of noise above 2 kHz. Jet ski can be heard by a bottlenose dolphin up to 450 m, inflatable about 1 km away, the speed boat from 800 m (low speed) to 1800 m (high speed), and the fishing boat from 1.1 km (low speed) to 3.1 km (high speed). The general reaction of dolphins was to make longer dives and to move away from the source. Conversely, responses of dolphins were greater to jet ski because the noise produced rises above the ambient level only close to the dolphins, creating a more sudden and startling noise which is likely to frighten them more than that of the larger boat. Moreover, they can be more scared when the craft changes direction erratically, especially when it orients directly toward them. These results are confirmed by Lesage *et al.* (1999) studying responses of belugas to a small motorboat, that showed that this species reacts more to small boats moving erratically than to large vessels moving on a predictable path. They also found that, because of their frequencies, sounds emitted by small boats would be expected to interfere with communication among animals.

In the last fifteen years, whale-watching has exponentially increased all over the world, involving in 1995 5.4 million persons (Hoyt 1996).

Literature about possible disturbances and regulation of this activity is now abundant. Some examples give a good idea of what can bring about whale-watching if it is not conducted in a responsible manner : surfacing frequencies of bottlenose dolphins decreased significantly in response to a whale-watching boat attempting to remain close to the dolphins, while they showed little reactions to other boats in the area (Janik and Thompson 1996); examples of unusual aggressive behaviour of short-finned pilot whales (*Globicephala macrorhynchus*) were observed in response to a large number of whale-watching boats (Heimlich-Boran *et al.* 1994); sperm whales avoided whale-watching operators at a distance of 2 km. (Cawthorn 1992).

Oceanic areas. In offshore areas, sounds from small, high-frequency boats are rare events and then can be overlooked. On the contrary, large vessels traffic increases year after year and is by far the greatest anthropogenic contributor to ocean noise in the frequency band below 100 Hz (Clark 1999). Cargo ships, super tankers and ferries produce low-frequency noise, coming mainly from their propellers, reaching very high levels of intensities (around 190 dB at source for super tankers and very large container ships, 160-170 dB at source for ferries, according to Richardson *et al.* 1995).

Investigating the effects on low-frequency (< 1000 Hz) loud sounds (>140 dB estimated received intensity in certain cases) on foraging largest whales (blue whales *Balaenoptera musculus* and fin whales), Croll *et al.* (2001) found no obvious responses of whales to the sounds and suggested that cumulative effects of anthropogenic low-frequency noise over larger temporal and spatial scales may be of more importance than what it was possible to study in this survey. On the other hand, Bauer *et al.* (1993) reported that swimming speed, respiration and social behaviours of humpback whales were affected by vessel traffic, in particular with respect to vessel number, speed and proximity. Using a software model, Erbe and Farmer (2000) estimated that the zone of disturbance of an ice-breaker on belugas was slightly smaller than its audible range (35-78 km., depending on locations). They added that propeller cavitation noise accounted for all long-range effects. Masking of communication was predicted up to a minimal distance of 14 km, and temporary hearing damage can occur if a beluga stays within 1-4 km of the boat for at least 20 min.

The Mediterranean case. The Mediterranean is subjected to a huge traffic. Over 80,000 vessels cross the Straits of Gibraltar each year, concerning 75 % of the international volume (De Stephanis *et al.* 2000). In addition, recreational craft and fisheries are very well developed in the northern regions. In spite of a very important cause of concern as highlighted by Von Bismarck *et al.* (1999), very few data exist on its noise pollution significance. Nevertheless, the considerations described in the general case are likely to apply here, with the possible exception of the masking effect, as habituated animals to an intense traffic noise may react differently in comparison to others inhabiting quieter areas.

Perez *et al.* (2000) investigated the effects of the acoustic pollution produced by a heavy maritime traffic (mostly commercial ships, then fishing fleets and pleasure boats) in the Alboran Sea. They used both acoustic (estimating intensities of ship noise and cetaceans sounds on a scale of 0-5) and visual (recording simultaneously numbers of boats and cetaceans) methods. Visual results demonstrated that cetaceans do not completely avoid passing vessels. However, they found a negative correlation between cetaceans clicks and whistles and ship noise, what can be interpreted either as a response by small cetaceans to shipping noise, or as ship noise masking the analyst's ability to detect cetaceans sounds. In the two cases, they concluded that cetaceans possibilities to explore their environment through sound production (in the first case by a decrease of their calls) and reception (in the second case by masking of sounds to be received) could be greatly reduced.

Industrial noise

Industrial activities generate a great variety of sounds, some of them reaching very high levels of intensity. Periods of sound emission range from several days up to several years according to the activity. Once again data are scarce, except for oil and gas exploitation (exploration made by seismic surveys will be treated in the scientific part), and for acoustic devices used by fisheries which have been very recently implemented and studied.

Oil and gas exploitation. Exploitation of oil and gas requires a huge material investment. Platforms and pipes are constructed, drills are positioned and holes are bored into the seabed rock. All structures are then to be destroyed with TNT. Drilling and dredging rigs put out loud low-frequency sounds over a long-term scale. Even when the rig may be idle, numerous supply ships and transport helicopters are in activity (and may be of more influence on marine life than the rig itself) so that the noise emitted is continuous.

Playback studies have shown that most bowhead whales (*Balaena mysticetus*) avoid drill ship or dredging noise with broad-band (20-1000 Hz) received levels around 115 dB. In case of typical drilling and dredging vessels, such levels occur at 3-11 km (Richardson *et al.* 1990). Higher noise is endured if the only migration route requires close approach to the sound projector (Richardson and Greene 1993, in Perry 1998). It has recently been demonstrated that spatial distribution of bowhead whales was highly correlated to distance from the drilling rig, indicating that the presence of the rig resulted in a significant temporary loss in available habitat (Schick and Durban 2000). Grey whales reacted in a similar way when 3500 individuals responded to playback of an oil platform noise (Malme *et al.* 1983). Avoidance responses began at broad-band received levels of 110 dB, and proportions of animals showing avoidance increased with sound intensities, reaching over 80 % at received levels higher than 130 dB. According to our knowledge, no studies have investigated odontocetes reaction to such kind of noise.

Sonars and Pingers associated with fisheries. Echo-sounders, functioning as directional sonar, are widely used in fish and depth detection on board of many fishing boats. Ed Harland, in a communication to Nick Tregenza (2001), drew attention on them as a source of noise pollution: 'the source levels of the echo-sounders vary between 200 dB and 240 dB, depending on frequency, model and application. Frequencies vary from 30 kHz for the big fishing boats units that double as fish-finders to 200 kHz for the small boat units. Beam width of the units is typically 30 degrees, but varies considerably depending on frequency and application'. The effect on marine mammals has not yet been documented, but in many countries odontocetes are observed very close to fishing boats when they are in activity.

To prevent marine mammals from net entanglement (for protected species particularly) or to keep them away from aquaculture farms, various methods have been employed, and among them one solution has consisted of putting acoustic devices (pingers) on nets and cages. These devices have been designed to emit sounds at the audible frequencies range of pinnipeds and small odontocetes, in order to alarm them of a potential danger (in this case pingers are called Acoustic Deterrent Devices, ADD) or to harm them (thereby called Acoustic Harassment Devices, AHD). ADD tend to have shrill-sounding frequencies (generally 12-17 kHz, but can range up to 160 kHz), with intensity levels at source between 120 and 140 dB, and to be brief (e.g. 300 ms pulses), while AHD are usually set around 10 kHz and produce very loud intensity pulses of about 190 dB at source (Perry 1998, NRDC 1999, Würsig and Gailey 2001). They have been found to be effective in several controlled experiments (Anderson *et al.* 2001) and to show reasonable success in certain areas considering the species for which they have been designed (harbour porpoises *Phocoena phocoena*, Hector's dolphins *Cephalorhynchus hectori*), and thus they are enjoying widespread use (Würsig and Gailey 2001).

Despite their relative success, pingers are very controversial. First of all, habituation of cetaceans is often related. Effectively, once the deterrent effect has been acknowledged by the animals, they generally return and the loud sounds can even condition cetaceans to perceive the acoustic signal as a "dinner bell" (Mate and Harvey 1987). Secondly, non-target species are affected too : the case is recently reported with killer whales (*Orcinus orca*) that may have been displaced from their regular movements avoiding ensonified bays and channels in long term as a result of AHD emissions aiming at deterring harbour seals *Phoca vitulina* (Morton and Symonds, in Würsig and Gailey 2001). Finally, the strongest critic is that pingers add new man-made sounds to ambient noise, and dramatically change the acoustic world of all marine species, not only that of cetaceans. Particularly, the aversive effect provokes not only acoustical reactions such as reducing or stopping echolocation (Tregenza 2001), but has also been proved to make cetaceans abandon "pingered" areas (within 2 miles of a single AHD in the case of harbour porpoises), degrading many miles of quality habitat (Olesiuk *et al.* 1996).

Others. Industrial sources of noise are diverse underwater, but until now they have not been considered as a subject matter of research in itself. Hence, the following examples rather come from opportunistic data or studies made available in the literature.

The most documented of those sources appeared to be blasting. For instance, Ketten *et al.* (1993) found that two humpback whales having died in fishing gear near blasting had damaged ears, whilst two other individuals, similarly killed in gear from areas where there were no industrial activities, showed no signs of ear damage. With respect to the same species, Lien *et al.* (1995) reported an unusually high percentage of ear damage during post-mortem examinations from individuals found dead in a area of intense industrial noise due to blasting, drilling and dredging, this noise reaching 140-150 dB at source between 20 and 400 Hz. On the other hand, an experiment conducted by Madsen and Mohl (2000) on sperm whale encountered no behavioural reaction to the discharge of eight detonators from any of the six individuals studied, with estimated received levels of some 180 dB. Again, Maggi *et al.* (1998) monitored a series of blasting in conjunction to the construction of a pipeline and found no confirmation of injuries of the cetaceans sighted in a radius of 0.66 nautical mile from the blasting point. The disposition and distribution of charges was acutely managed so that low sound pressure levels were recorded at distances of 70 meters from the blasting point.

Finally, two other sources of industrial noise are related: Bryant *et al.* (1984) showed that grey whales abandoned calving lagoons in response to the intense activity associated to a salt-production plant. Harbour infrastructures constructions generate sounds of high intensities at low and mid-frequencies, as documented by Würsig *et al.* (2000) for percussive hammering piling in order to create a wharf.

The Mediterranean case. Oil and gas exploitation is not very developed at this time in the Mediterranean, but this could change completely in the next years. Effectively, a geologist of Total-Fina-Elf, one of the major companies worldwide, recently highlighted the need to invest in the exploration of new fuel reserves, and the United States Geological Service found last year good indices of oil and gas reserves in the western Mediterranean that could be economically profitable (Pujol Gebelli 2001).

Moreover, Azzali (1999) indicated that oil and gas exploration was to be conduct in some areas of the Adriatic Sea in the immediate future. To prevent its possible effects on marine life from remaining controversial, Azzali *et al.* (2000) presented a study assessing pre-impact baselines on marine mammals and small pelagic fishes of the entire Adriatic Sea, with three focus topics: to identify “hot spots” where these animals have been found to congregate, to estimate the potential risk levels in those areas, and to provide a data base to evaluate the short- and long-term effects of the oil activity on marine mammals. For this purpose, they divided the area in 50 blocks of 30x30 nautical miles each, to be classified as of high, medium and low risk. They found that spatial distribution of cetaceans (using acoustic and visual methods) and small pelagic fishes (using acoustic methods) were cross-correlated, and gave the seasonal (winter/summer) variations of cetaceans and fishes distribution on a ten years scale (from 1988 to 1998). As a conclusion, the total number of high level risk blocks was 27, of which 2 are of concern only for small pelagic fishes, 16 for dolphins (bottlenose, striped and common) all-year round, 5 for dolphins in winter, 1 for dolphins in summer and 3 because of the presence of cetaceans species considered rare in the Adriatic.

Considering now the fisheries activities, entanglements of various species are known since a long time in the Mediterranean, as well as damage to the nets by dolphins (generally by bottlenose dolphins), provoking often conflicting interactions between fishermen and cetaceans. Direct kills have been reported, and Tunisian fishermen developed in 1993 a mechanical wave generator to keep dolphins away from the nets (Ben Naceur Lofti 2000). This device gave satisfactory results before habituation of dolphins. Pingers are not yet established in the area and could become frequent in the next future, but their effect are still to be proved, as in the following example around the Balearic Islands.

A recent project has been started by Gazo *et al.* (2001) to assess the effectiveness and practicality of using pingers to keep bottlenose dolphins away from fishing nets and, by the way, to reduce entanglement and damage to the gears. They monitored three experimental sets of nets: the first was equipped with pingers transmitting 8 different frequencies ranging from 20 to 160 kHz – without precisions on the intensity emitted – with an inter-pingers distance of 150 m, the second was equipped with non-operative pingers and the last had no pingers at all. To establish the effectiveness of the devices, fish catches, dolphins sightings and damage to the nets were evaluated. The preliminary results were inconclusive with regards to the effectiveness of the pingers.

No literature has been found on other industrial activities and their effects on cetaceans in the Mediterranean.

Scientific noise

Noise pollution is involved during research surveys in three scientific fields: geology, climate change oceanography and cetology. While the latter produce a great variety of sounds at (normally) moderate intensities, the formers put out very loud low-frequency sounds. The time scales at which operate these noise sources are variable, from the short-term to the long-term (several years).

Controlled Exposure Experiments (CEE) and playbacks on cetaceans. In order to improve the knowledge on cause-effect relationships between sound production (both natural and man-made) and cetaceans behaviour, scientists can use active techniques which consist of emitting specific sounds toward the animals in a controlled context. In the case of anthropogenic noise pollution, these surveys hope to fill in the gaps concerning mostly the lack of data on identification of behavioural responses to specific kinds of sound, the assessment of species auditory thresholds at different impact levels and the estimates of secure distances from noise source ranges. But even if these studies have an objective of animals conservation, they clearly add new anthropogenic noise and some of them have the potential to strongly affect target and non-target individuals.

In very recent series of workshops on CEE where numerous researchers specialised in acoustics were present, some guidelines on "why" and "how" CEE should be conducted have been proposed. Part of them are the following: the main advantage of CEE is its statistical power and the possibilities it allows researchers to control many factors such as age, sex, history of individual, location, time season, etc…and overall to quickly investigate a variety of exposure scenarios; CEE should stop quickly after behavioural response, take into account the sources of variation in response, identify acute behavioural and physiological parameters to be measured, prioritise species and individuals as focal animals for exposure experiments, control for the effects of the observation and playback vessels and measure masking. Anyway, CEE only allow short-term and well-known behaviours to be investigated (Gordon and Thompson 2001). Some critics and questions can be addressed, principally with reference to the current lack of knowledge on many aspects of the biology and ecology of cetacean species: the main assumption is that behavioural responses will occur before physiological damage, which may be a false statement in the case of unknown threshold shifts; moreover, it has been well recognised that no measured response does not necessary imply no impact; non-target species may have lower safe thresholds; can we conduct experiments anywhere (in protected areas for example)? Will all researchers follow these basic guidelines ? An example of this last point is given by the work aiming to determine masked temporary threshold shifts, for which bottlenose dolphins and belugas were exposed to 1 second tones as intense as 190-200 dB (Schlundt *et al.* 2000), which is equivalent to the sounds produced by AHD. Is such study worth, even if it concluded that small levels of temporary threshold shifts may be fully recovered ?

Seismic surveys and Acoustic Thermography. Seismic surveys are used to detect geologic layers composition under seabed, and are therefore largely employed by geologist scientists and petroleum companies for oil and gas exploration. The process produces intense low frequency sounds, often using arrays of airguns and sometimes explosives. The intensity required for these sounds is to enable deep penetration of the earth's surface and show reflection off rock layer (WDCS/CCSA). Duration of studies is usually of several months. Pulses are emitted every few seconds, with an intensity at source depending on the size of the air-gun array (Perry 1998), but generally comprised between 242 and 252 dB for a multiple airgun array and about 226 dB for a single airgun (Würsig and Evans, in press). McCauley (1994) indicates that, dependant on the sound propagation characteristics of the area, intensity only decreases to 180 dB at 1 km and to tensity only decreases to 180 dB at 1 km and to approximately 150 dB within 10 km of source. Goold and Fish (1998) added that seismic power (from a 2120 cubic inches airgun, which is less than typically used by prospecting companies) dominated the entire recorded bandwidth of 200 Hz - 22 kHz at ranges of up to 2 km of the sound source, even if the background level was yet far in excess of ambient noise because of the ship propeller, engine, …

Effects of seismic surveys on cetaceans are well documented and appear to show the second most dramatic responses of all types of noise pollution for any species considered, after the military sonar. Sperm whales were found to be displaced to a distance of 60 km of the sound source by Mate *et al.* (1994) and they stopped vocalising more than 300 km away from relatively weak seismic pulses (Bowles *et al.* 1994). 10 % of grey whales showed avoidance at 164 dB received level, 50 % at 170 dB and 90 % at 180 dB (Malme *et al.* 1983). Ljungblad *et al.* (1988) observed initial behavioural changes of bowhead whales more than 8 km away from the seismic source, at received levels of 142-157 dB. Common dolphins avoided an area of 1-2 km around the sound source – cited before in the Goold and Fish study – (Goold 1996) and these authors estimate the sound to be audible to dolphins at a distance of at least 8 km. Evans *et al.* (1993) found a significant decrease in the population of small cetaceans after seismic exploration, although the possibility of seasonal movements can not be ruled out.

Acoustic thermography of the oceans is widespread. It investigates temperature changes, aiming at giving proves of the greenhouse effect through the increase of temperature. Studies are hence planned on a long-term basis, over several years or decades and over a long range distance scale, the ocean basins. The process involved is very similar to that of seismic studies, although its principle is different. Low-frequency regular pulses are directed toward the open sea instead of the sea floor, using the deep sound channel to cross entire basins. Speed of sound, dependant on temperature, is measured and then monitored over years to assess long-term temperature fluctuations (Munk and Wunsch 1979). In addition, source intensities are considerably lower than those used in seismic pulses, around 200 dB, and most of the sound energy is kept trapped in the channel. Orders of magnitude in both time and space scales are considered the main threat for marine life. Major effects were expected to concern deep-divers such as teutophagous species, since these animals often enter the deep sound channel to feed upon bathyal preys. Effectively, sperm and long-finned pilot whales were found to be completely silent during such operations in areas where they were heard before and 48 hours after the thermographic study (Bowles *et al.* 1994). Aerial surveys showed that humpback and sperm whales were distributed significantly further away from the source, on the contrary to pacific white-sided dolphins (*Lagenorynchus obliquidens*) and grey whales (Calambokidis *et al.* 1998). Hearing thresholds of captive false killer whale (*Pseudorca crassidens*) and Risso's dolphin to such pulses of 1 second duration were measured by Au *et al.* (1997) who found relatively high received levels of about 140 dB.

The Mediterranean case. Very few data exist on playback experiments and CEE in the Mediterranean. On another side, an important program is to be implemented in the Ligurian Sea under the leadership of J. Gordon and P. Tyack, in collaboration with the ICRAM and the Tethys Research Institute. The primary research objective is to determine what characteristics of exposure to specific sounds evoke behavioural responses of marine mammals. Target individuals will be exposed to received levels between 120-160 dB, and will be subject to section-cup tagging. In addition to the eight common species of the Mediterranean, rough-toothed dolphin (*Steno bredanensis*) and *Kogia* spp. have been defined as target species. This project will surely fillin some gaps in our current knowledge, but it is disturbing that the sole permit, to our knowledge, required by the principal investigator to the U.S. National Marine Fisheries Service allow some animals to be taken by harassment (NMFS 2000a).

Seismic activities have already been performed in the Mediterranean by oceanographers and geologists, but no data exist on their effect on cetaceans. On the other hand, as it has been mentioned in the precedent chapter, the western Mediterranean is likely to become the place of seismic activities for oil and gas exploration within the next decade (Pujol Gebelli 2001). Estimates of oil and gas reserves in the seabed rock of the area (between the Balearic to Corsica and Sardinia Islands, and between French and Italian to Algerian coasts) reveal that the probable existence of 1 to 15 oil fields and of 60 to 140 gas deposits. The expected productivity could reach 50 to 2500 millions of oil barrels and 600,000 to 3,600,000 millions of cubic feet of gas. At a median depth of 5 km for oil and 6 km for gas, they would require extremely powerful sounds to be investigated and found.

Military noise

When dealing with this subject, the main obvious basic problematic matters are first to be warned about what will happen and then to obtain data. If the first step is quite accessible on land, as militaries organisations have to prevent civil population from accidents, it remains very difficult at sea and almost all operations are hidden. It is no surprise then that military exercises have occurred for many years, but their effects on marine life are just being tested. As far as cetaceans are concerned, it began with numerous strandings reported just after navies have tested powerful low frequency active sonar (LFAS) employed to detect foreign submarines. This has captured scientific and public attention, and the topic is now well discussed, allowing knowledge to filling important gaps. The following two parts are then distinguished in this chapter:

General exercises. Parsons *et al.* (2000) provided information on several military activities, including sonar, torpedo testing, missile firing ranges and training exercises. Frequency bandwidth and average source intensities are some available data on sonar and differ with the type: search and surveillance sonar ranges 2-57 kHz and has a source intensity of 230 dB, mine and obstacle avoidance sonar ranges 25-200 kHz for 220 dB and weapon mounted sonar ranges 15-200 kHz for 200 dB (LFAS will be detailed below). In addition to sonar, communication system between two submarines has a source level of 180-200 dB within 5-11 kHz. Torpedoes have been documented to be a cause of mortality of a large number of whales during the Falklands conflict (Gardner 1996 in Parsons *et al.* 2000). Military artillery usually produce noise levels in excess of 180 dB, but some missile firing ranges put out broadband frequencies at a source level in excess of 270 dB. Such sound sources could cause auditory damage to cetaceans at distances of several km and disturbance at distances of tens of km. Training exercises often involve the participation of numerous warships, jets, submarines, landing draft, power boats and sonobouys, producing a large amount of noise with various types of sounds. These sounds have the potential to affect all species of cetaceans, although deep-divers such as beaked whales presumably may be the most sensitive to military effects (McLeod 1999). Only one response of cetaceans to general military activities was documented, by Parsons *et al.* (2000) who reported a significant decrease in minke whale (*Balaenoptera acutorostrata*) and harbour porpoises occurrence during training exercises.

Low Frequency Active Sonar. This system has been imagined and set up during the cold war, with the aim to detect at very long ranges of distance (hundreds of nautical miles) foreign silent submarines. To reach such long ranges, low frequency (100-1000 Hz) very loud (up to 235 dB) pure tones are emitted from a string of sound elements suspended 50 m or more below a specially equipped ship (NRDC 1999, NOAA 2000). Sounds of 1 minute or more are usually produced repeatedly (every 10-15 min), and using principles of refraction on different layers (surface, bottom or deep sound channel), can still reach intensities of 140 dB 300 nautical miles away from the source.

Some effects of LFAS on cetaceans remain controversial due to insufficient data, but they have been considered, as a whole, to be of major concern and to range from strong behavioural disruption to death. What raised up attention on this noise source are at least three distinct atypical mass strandings of several species, mostly of beaked whales (especially Cuvier’s), occurring the same day or a few days after navies had tested LFAS (Vonk and Martin-Mantel 1989, Frantzis and Cebrian 1998, MARMAM 2000). These mass strandings were called atypical because animals were not found on shore grouped in one location, but there were rather numerous lone individuals in several points. In one case, animals were alive when stranded but necropsies showed no abnormalities, so that the relationship with the LFAS test could not be proved (see *the Mediterranean case* for details). The demonstration of the relationship has been achieved four years later (on March 2000) when all of 17 individuals but one, belonging to at least 4 species

(Cuvier's and dense beaked whales *Mesoplodon densirostris*, Atlantic spotted dolphin *Stenella attenuata*, minke whale), stranded the same day. Balcomb (2001) showed, by combining both theoretical calculations and necropsies of the animals, that the LFAS, through the resonance phenomenon in airspace of the beaked whales, was responsible of the cetaceans deaths. He explained that when whales dive deep to forage, the pressure makes the air volume pass from their lungs to other body parts, especially in cavities close to the inner ear. Effectively, the air volume contained in the body decreases when pressure increases. The resonance frequency changing with the air volume, it will change with the pressure, and, in the case of the airspace of a Cuvier's beaked whale at a depth of 500 m, it reaches 290 Hz, in the middle of the range of a LFAS emission. When the sonar is active, sound passes through these airspaces, compressing and decompressing the air volume, causing thereby haemorrhages. Balcomb found such lesions in the four whales necropsied, hence corroborating theoretical calculations. He also found the aversive and/or physiological damage impact distances to range from 20 to 100 km from the sound source. With the help of photoidentification work, he added that this species was reasonably common in the area before the tests, but only saw two individuals in the next year, these individuals being new for the region. According to Balcomb, it is likely that no ancient resident survived the test.

Apart from physical damage, some strong behavioural reactions were reported, mainly resulting of playback or CEE experiments, but are still not regarded as sufficient proves by the navies. Male humpback whales were found to modify their sexual displays when exposed to a maximum received level of 150 dB (Miller *et al.* 2000); grey whales deviated from their migration paths, the deviation being greater as sound intensity increases (Tyack and Clark 1998); blue, fin and sperm reacted to LFAS by decreasing and even ceasing calls, as far as 20 km for the latter species (Watkins *et al.* 1993, Clark *et al.* 1998).

The Mediterranean case. No information is available with respect to general exercises, apart from one mention of three missile firing ranges in the Straits of Gibraltar (De Stephanis *et al.* 2000), indicating a possible threat for in this area. In contrast, effect of sonar on cetaceans is now quite well identified, as in the general case. The following study give an example of a behavioural response: while surveying acoustics of cetaceans in the Ligurian Sea, Rendell and Gordon (1999) heard a military sonar, regularly for one month and a half and on some occasions loud enough to stop crew from sleeping, but they never saw it, suggesting a minimal distance of about 15 nautical miles. The sounds were emitted in a regular pattern and repeated every 41 seconds, with main energy around 4 kHz. During this period, the authors encountered and stayed with a pod of long-finned pilot whales, recording their vocalisations. They found that the overall rate of calling was significantly higher during and just after sonar pulses, clearly indicating a short-term response of pilot whales to the sonar. Certain whistle types showed temporal correlation with the sonar, whilst others did not. According to the authors, possible interpretations range from curiosity to fear, and although it was impossible to make a choice between the different possibilities because of the lack of knowledge on pilot whales vocal behaviour, it was clear that the animals appeared not to have habituate to the signals after at least several hours of exposure (possibly more than a month).

Physiological damage of LFAS have been thoroughly discussed as a major source of concern, both by scientists and by military organisms. The 12th May 1996, Frantzis and Cebrian (1998) recorded a very rare event: an atypical mass stranding of 12 Cuvier's beaked whales in the Kyparissiakos Gulf (Greece). Since 1963, strandings of more than 4 individuals of this species have only been reported seven times worldwide, and in the area, the average number of whales stranded was 0.7 per half-year. In one week, the whales stranded alive and died after some time, spreading along 38 km of coast, being separated at a mean distance of 3.5 km. In addition, a dead animal stranded on a beach 57 km away from the closest other strandings. No apparent abnormalities were found from the eight necropsies carried out and the stomach contents indicated recent feeding. The general robust condition of the animals and the absence of scars added to their sudden end excluded the possibilities of pathogenic and chemical factors, as well as a direct cause involving fisheries interaction. No tectonic nor geophysical events were reported, so that the only possible cause remaining was the test in the area of LFAS performed by the NATO from the 11th to the 15th May 1996. The test generated sounds of over 230 dB in frequencies ranging from 250 to 3000 Hz. Behavioural responses already known to high intensities acoustic transmissions (escape reaction, startle effect, ..) are likely to be the mechanism that drove the whales ashore, especially if they were found between the coast and the source when emission began. Taking the past 16.5 previous years into account, the authors calculated that the probability of a mass stranding occurring for other reasons was less than 0.07 %. They therefore concluded that if pure coincidence could not be ruled out, it seemed very improbable that the two events were independent.

The SACLANTCEN-NATO Special Report (1998) of this event indicated that an acoustic link can neither be clearly established nor eliminated as a direct cause. The panel considered that, because of the lack of a comprehensive necropsy and complete tissue analyses, the possibility of a pathological cause can not be eliminated too. The panel hence strongly recommended that appropriate environment assessment procedures be implemented as soon as possible and also noted that the lack of adequate anatomical data on the stranded animals, particularly auditory and other tissue analyses, was a serious obstacle. It finally recommended that proper specimen collection be supported to ensure complete necropsy in the future. In an unclassified document (SACLANTCEN), it is revealed that between 1981 and 1996, 11 trials have been conducted by NATO in the Mediterranean.

As a final word, Balcomb (2001), applying calculations he made for the mass stranding of March 2000 cited in the general case, answered that the panel missed the crucial point of matching resonance in critical airspaces. Then he added that, taking into account the sonar impact at received level well below 180 dB related in the NATO report (this level corresponding to what the panel assumed to be the lower threshold temporary shift for Cuvier' beaked whale) and the calculations made by NATO concerning the propagation loss in intensity for the 1996 test, the received level of the first whale to strand was approximately 150 dB. His conclusion is that aversion and/or physiological damage evidently and repeatedly occurs in beaked whales at received levels of somewhat between 150 and 180 dB of either low frequency or mid-frequency sonar signals in the normal whales habitat. These levels are well below those assessed by Nascetti *et al.* in 1996, without taking into account the resonance phenomenon: they estimated that the danger received level for fin and sperm whale was 210 dB, the safe level being around 170 dB for both species and the non-interference level at 150 dB for sperm whale.

Mitigation

To limit spreading and intensity of noise in the world ocean, measures can be implemented. These measures are of different kinds and involve various responsibilities, but almost all are feasible without putting in danger the professional activity concerned. Richardson and Würsig (1995) spelled out some of them:

- To ensure that, from a purely technical point of view, the equipment be as silent as possible. In the case of a vessel, propeller shrouding that has been used to silence ships of war is an example, as is also acoustic isolation of the generators from the hull and of engine trains from drive shafts and propellers. A simple regular maintenance of blades can greatly reduce cavitation. Lowering of the vessel speed may play an important role in reducing the background noise.
- To organise seasonal and daily timing of the industrial activities the most possible in accordance with migrations and movements of the animals. Staggering out the sound production so that it does not occur throughout the day can also be helpful if cetaceans in the area have been proved not to be attracted by changes in the duty cycle.
- Changes of location can sometimes be efficient measures with only minimum increase in expense of fuel and time.
- Adjustment of operational procedures can help for mitigation, as for example by monitoring the area for cetaceans: if animals are present, the activity has to be delayed. This has been widely used, but if not conducted both acoustically and visually simultaneously by trained observers could reveal meaningless.

Würsig *et al.* (2000) investigated a new technique consisting of creating a curtain of air bubbles into a perforated rubber hose surrounding a pile driver employed to build a wharf. Sounds that were bubble-screened were lowered by about

3-5 dB at distances of 250 to 1000 m, within 100-25600 Hz. Although the technique remain to be comprehensively studied, it shows promise.

Concerning whale-watching and given the weak propagation of high frequency sounds, regulation rules generally adopted are sufficient to preserve cetaceans from noise disturbance: the operators have to maintain a respectable distance from the animals, they should limit erratic movements and apply caution to not change speed and bearing suddenly.

Quieter alternatives for traditional drilling include semi submersible ships with machinery lying well above the surface, special floating rigs known as caissons, artificial islands, or finally platforms mounted directly on the ocean floor (Richardson *et al.* 1995).

In the case of LFAS, it appears that any mitigation measure can be regarded as really efficient. NATO (SACLANTCEN) and NMFS (2000b) mitigation proposition have been strongly rejected by both acousticians and biologist scientists (Balcomb 2001, Blue 2001, Rendell 2001). Considering that the need of a so much powerful sonar is not obvious and is at least not yet a priority, another system, less intrusive, could be developed instead: an example is a passive sonar the Advanced Deployed Systems, program which was ready for testing in 1998 (NRDC 2000).

Conclusions

Noise pollution and its effects vary according to the sound source which depends on the socio-professional activity performed. This report has briefly reviewed what effect is or could be linked to anthropogenic activities. Table IV.E.1 summarises these effects qualitatively, indicating for each activity the type of the effect, the category of species affected, the range of distance from the noise source, the range of time involved and the Mediterranean status concerning this effect.

An important point is the dramatic lack of knowledge on this topic. Perry (1998) urges that there is an immediate need of research on the establishment of audiograms in relation to low-frequency sounds, the assessment of functional significance of communication and distances over which it operates, the establishment of the impact of short and long-term behavioural disruption, including abandonment of important feeding and breeding habitats, energetic implications and the effects of stress, on post-mortem examinations of stranded animals, particularly of inner ear structure and airspace cavities.

Finally, it is worth remembering the fact that cetaceans themselves also mitigate against noise disturbance, as efficiently as they are able to. Changes of behaviour such as adjusting echolocation, deviating migration routes, moving away from their initial habitat show the need they have to face and to adapt adequately to situations humans are responsible of. The issue of sound has only recently been investigated concerning cetaceans. We believe that this is one of the major cause of concern for these animals, if not the major one, with regards to the importance it has for them in their daily life as well as in their adaptive fitness at all levels, from the individual to the species. This is a much less "evident" problem than many others that cetaceans and marine life in general have to face, but we think that waves displacements have always been, and will always be, the major regulator of the ocean.

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Table 13.1 - Summary of the effects of anthropogenic sound sources reported on cetaceans according to the current knowledge, with an evaluation of the Mediterranean case.

Anthropogenic activity		**Type of effect reported**	**Group of species affected**	**Propagation of sounds**	**Duration of emissions**	**Mediterranean status**
Traffic	Large vessels	masking, stress, auditory damage: temporary and permanent threshold shifts, displacement	mysticetes and large odontocetes	medium and long ranges	short-term in itself, long-term as a whole	important concern
	Small boats		all odontocetes	short ranges	short-term except whale-watching and busy areas	
Industry	Oil & gas exploitation	displacement	mysticetes	long ranges	long-term	small current concern, possible important concern in the future
	Sonar & pingers	displacement, temporary and permanent threshold shifts, chronic (habituation)	mid-sized and small odontocetes	short ranges	short-term to long-term	
	Others	gross damage to ears	mysticetes	short and medium ranges	short-term to long-term	
Scientific	CEE	behavioural disruption, temporary threshold shifts	all species	short and medium ranges	short-term	small current concern, possible important concern in the future
	Seismic surveys	displacement, masking, possible physical damage	all species	long ranges	long-term	
Military	General exercises	displacement, possible auditory damage	all species	long ranges	short-term	important concern
	LFAS	physical damage: non-auditory and auditory, behavioural disruption	all species	long ranges	short-term	