SONG OF DEATH

An analysis of the LFAS issue with especial reference on how cetaceans are affected

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Sometimes the ocean is described as the "world of silence"; however this couldn't be more far from the truth.

The way we think of underwater sound is physiologic determined; our eardrums are not adapted to do it and the sound does not amplify as is does in air. An understanding of the auditory processing and the adaptations of cetaceans for underwater sound producing and hearing is important for an analysis and evaluation of which acoustic features are more salient and how cetaceans interact and are affected by it.

Noise levels in the ocean (ambient or background) are the product of different oceanic sources, natural and man-made (anthropogenic). Physical and biological processes are among the typical natural sources. Seismic (tectonic) activity in the earth's crust (volcanoes and earthquakes), wind and waves are examples of physical processes generating noise, while vocalizations of marine mammals and fish are examples of biological processes. Sound can also be classified as continuous (over periods of seconds or more), like vessel traffic or a humpback whale, *Megaptera novaeangliae*, song (which can take up to 30 minutes) and transient such as a pressure wave generated by an explosion or sperm whale, *Physeter macrocephalus*, clicks (Whitehead et al. 2000, Parsons et al. 2003).

Cetaceans and terrestrial mammals share the same basic mechanisms for sound producing; both make sound by passing pressured air past membranes that vibrate. Attending to the different physical properties of the elements (air and water), evolutionary forces had to meet the special needs of animals that dive while vocalizing. When a terrestrial animal vocalizes it usually must open its mouth for the sound is propagated to the surrounding air, and does it while exhaling (and filling their lungs in the next inhalation); however when a cetacean produces sound underwater the vibrations of their soft tissues of the nasal passages (that have almost the same density as seawater) is enough for the sound to be transferred to the surrounding medium, but most cetaceans vocalize while diving when they cannot breathe again for tens of minutes. Take the example of the humpback whale that sing underwater to as long as 30 minutes producing a complex series of low grunts, squeals, chirps, whistles and wails without surfacing to breath and without emitting air bubbles. The observations of such event leads us to infer that if sound producing involves the flow of air in the vocal tract, this air may need to be stored in the upper respiratory tract and be recycled again between vocalizations (Tyack 2000, Carwardine et al. 2002).

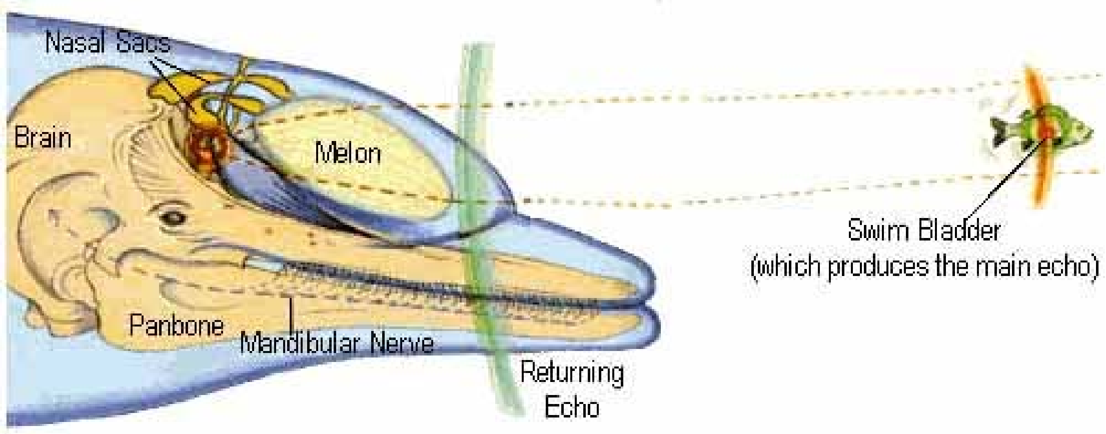
The same basic design of the inner ear is observed in both cetaceans and terrestrial mammals. The sound is received by an amplification chain of three small ear bones that transmit sound to detectors in the inner ear. After running all the oval window the inner ear is the last site which sound achieves before it's converted into neural signals and transmitted to the central nervous system via the auditory nerve. In the inner ear this acoustic energy makes a membrane, named basilar membrane, to vibrate. The movement of the membrane produces a shear force on hair cells, generating acoustic stimulated neural frequencies (Tyack 2000).

The ability of mammals to discriminate different level of frequencies seems to be related with the density of neurons receiving input from sensory cells on the basilar membrane (ganglions), making the membrane more or less sensitive depending on the number of cells per millimetre along the basilar membrane. As might be expected for animals that base their lives so much upon hearing, cetaceans have an unusual high density of these ganglion cells (ranging from an average of 2,000 cells/mm in the spotted dolphins, *Stenella attenuata*, to 2,750 cells/mm in the harbour porpoise, *Phocoena phocoena*) permitting them to detect differences in frequency as little as 0.2% (Tompson and Herman 1975, Ketten 1990; Tyack 2000).

The hearing ranges in cetacean vary according species and can be estimated anatomically by measuring the dimensions of the resonant frequencies of the basilar membrane. Ketten (1994) has analysed inner ears of several cetacean's species and suggests there are 3 basic different patterns. The baleen whales have ears specialized for low frequency hearing allowing them to hear sounds in the range of approximately 20-200 Hz. All of the Odontocetes have inner ears well adapted to high frequencies hearing well still above 100 Hz. However there seems to be 2 basic ear types. Animals such as the bottlenose dolphin, *Turciops truncatus*, being a generalist adaptation for high frequency hearing, in the range of 40-70 Hz, and the platanistid dolphins (including the porpoises) that appeared to be particularly specialized to hear above 100 Hz.

Odontocetes differ from Mysticetes in another side of the highly evolved hearing mechanism known as echolocation. Echolocation can be defined as the ability to produce high frequency clicks and to detect echoes that bounce of distant objects. Odontocetes produce the sound in the soft tissues of the nasal passages, inside the forehead between the skull and the blowhole. The melon (a large, fatty, internal structure), apparently helps to transmit sound forward and out into the water as a narrow beam. Theoretically, when sound is transmitted through different media such as bone, and water, a loss of efficiency would be expected. It's not clear how Odontocetes avoid "transmission loss" for outgoing and returning sound. However some species can echolocate well enough to detect a 2.5 cm metal target about 72 m away, 1.5-3 mm in diameter, from distances up to 3 m and some can discriminate between ball bearings 5 cm in diameter and those of 6.5 cm. Echolocation requires complex identification of different types of sound. The target distance is determined from the length of time it take from a echo to return, but this means that outgoing sound must be distinguished from faint echoes. Usually a dolphin will only emit another click after receiving the echo of the previous one. Also, the sensitive ear must be isolated from the intense noise of the sound-producing region. Complex air-filled sinuses inside the head provide isolation; which probably separate the right and left ears from each other providing a directional hearing. Returning sounds are received at the side of the head and must pass a succession of structures starting on the "panbone" in the jaw, a fat body, a large ear bone (analogically similar to our eardrum), and an amplification chain of three tiny bones before it reaches the inner hear, and passes the sound signals to the brain. What is uncertain is how the brain processes and interprets those signals. This mechanism allows Odontocetes to orientate themselves is low or absent light conditions. High frequency has been occasionally recorded from baleen whales, however they lack the structured form observed in Odontocetes; they also lack the complex nasal passages that in Odontocetes generate the echolocation sounds. It seems that Mysticetes do not use echolocation in a major way. Nevertheless acoustic models have been used to show that bowhead whales use echoes from their calls to detect ice obstacles, and they do it much farther than the limit of underwater visibility (Clarck 1989, Tyack 2000, Carwardine et al. 2002).

Figure 1.0 – Schematic representation of the echolocation model used by Odontocetes.



Odontocetes use sound exactly as humans use sonar, except that we have used sonar for about 50 years while they have been echolocating for millions. Sonar acts in the same way as the echolocation model; it uses emitted sound and its returning echo to detect the presence, distance, and position of objects. Sonar systems usually emit short pulses of sound and are designed to focus as much energy as possible in narrow ranges of direction. Simple sonar systems produce and target sound in just one direction while some more complex ones may emit beams of high energy in several different directions. Over the past 6 years a new sonar type as been developed and tested in the ocean, it is based in very low frequencies and has an unimaginable range of action, it's known as LFAS (Low Frequency Active Sonar). Two sonar systems of this type are currently in process of being introduced; the US (SURTASS LFA) and the UK (SONAR 2087). Both rely on low frequency sound to track and determine military targets. Other countries are introducing or plan to operate similar systems. According to the U.S. Navy's own studies, LFAS generates sounds up to 140 dB re 1µPa even more than 300 miles away from the sonar source. During testing off the California coast, noise from a single LFAS system was detected across the breadth of the North Pacific Ocean (Carwardine et al. 2002, Parsons et al. 2003, Ziegler 2003).

Table 1.0 - The acoustic properties of some active sonar systems (Richardson et al. 1995; Perry 1998; Møhl 2003). Taken from the WDSC Report – Oceans of Noise.

SONAR TYPE	FREQUENCY RANGE (KHZ)	AV. SOURCE LEVEL (dB re 1 uPa/1 a)
53C sonar used during Bahamas stranding	6.8, 8.2	245
Search and surveillance	2-57	230+
56 sonar used during Bahamas stranding	2.6, 3.3	223
Mine & obstacle avoidance	25-200	220+
Weapon mounted sonar	15-200	200+
Low Frequency Active Sonar (LFAS) used by NATO	0.25-3.0?	230+
Surveillance Towed Array Sensor System (SURTASS) Low Frequency Sonar (LFA)	c. 0.1-0.5	215-240
SONAR 2087 (UK Royal Navy Low Frequency Sonar System)	c. 0.1-0.5	200

Although, there is a growing body of information pointing to these new systems as a major source for underwater noise. Furthermore, several scientific studies have voiced concern over the potential impacts of these military activities upon marine life including cetaceans. Despising the fact that some studies had been conducted over the last 15 years related to noise disturbance in cetaceans only now we start so visualize the increasing negative effects that anthropogenic noise has on our oceans. These proposed LAFS systems are a good reason for alarm and some immediate action must be taken to prevent irreversible negative consequences over entire populations of cetaceans. Nowadays there is evidence and little margin for doubts that high intensity active sonar cause lesions in acoustic organs which are severe enough to be lethal. The same sources may also produce behaviours that cause acute lesions that eventually lead the animals to strand and die.

These conclusions have different sources from strandings to observed changes in behaviour. Strandings in alarming frequency occurred at the same time as sonar experiments. Beaked whales seem to be the more affected but are certainly not alone in this. In 1991 24 beaked whales were stranded on the Canary Islands, in 1996 12 beaked whales in Greece, in 2000 14 beaked whales, two humpback whales and one dolphin on the Bahamas (and a whole group of beaked whales simply disappeared), in 2002 13 beaked whales stranded on the Canary Islands. Between 1999 and 2001 3 beaked whales stranded in Madeira probably due to NATO military tests in the area. Researchers reported that the whales demonstrated signs of haemorrhaging in the inner ears and cranial air spaces, consistent with impulsive trauma - i.e. intense, loud sound, which did not come from a nearby explosion (Balcomb and Claridge 2001). Also, sperm whales, *Physeter macrocephalus*, off St. Lucia responded to sonar signals (often at a considerable distance) associated with the U.S. military invasion of Grenada in 1983 by becoming silent (Watkins et al. 1985). These same whales also showed longer-term effects in behaviour by becoming much quieter and much more wary of the research vessel then during other research cruises in the same area. Most recently, more than a dozen of harbour porpoises were found stranded near San Juan Islands soon after the U.S. Navy tested active sonar in the Haro Strait in May. Videotape shows a pod of Orcas in the foreground behaving erratically as the Shoup, a U.S. Navy vessel, emits loud sonar blasts. Recent tests on one of the harbour porpoises revealed injuries consistent with acoustic trauma. Also blue and fin whales demonstrated possible vocal responses, gray whales displayed avoidance of the noise during their migration, and humpback whales temporarily stopped singing and lengthened the duration of their song (Tyack 2000).

These events came to attest the high power of these new systems and their drastic impacts over cetaceans. Ziegler (2003) says that military forces plan to permanently send out very loud low frequency signals in 80 percent of the world’s oceans in the future.

Even after all the research carried out (mainly focused on the hearing organs) a new problem has came to light. The possibility of cetaceans may also suffer from decompression sickness (DCS) also known as the “bends” and observed in human scuba divers. It’s probable that acoustic fields might cause gas filled organs to resonate and be damaged (Crum 1984). The complex sinuses in the heads of cetaceans, and other organs, could be harmed in this way by a received acoustic field of a specific frequency and sufficient intensity. Initial attention on how DCS might occur in the presence of sound was focussed on the growth of bubbles by a process known as rectified diffusion, where an acoustic field pulses bubbles and can effectively pump gas into them, inflating the bubbles, in both saturated and super-saturated tissues (Crum and Mao, 1996 and Houser et al. 2001). Whatever the precise cause and mechanism of bubble growth in cetacean’s body tissues, we currently have no idea at what exposure levels this effect is being induced, and we are not sure that it is being induced at all. Presently is not possible to establish safety limits for exposure, although levels at which physiological damage is known to occur can be alluded too.

Photo 1.0 – Stranded Cuvier's Beaked Whale (*Ziphius caviostris*) in Madeira (2000) probably due to NATO military tests in the area. Courtesy of the Whale Museum.
Photo 1.1 – Stranded Cuvier's Beaked Whale (*Ziphius caviostris)* in Bahamas (2000). Strand cause was pointed to U.S. military tests in the area. Courtesy of The Centre for Whale Research.

Photo 1.0 © Whale Museum (Madeira, Portugal)

Photo 1.1 © The Centre for Whale Research

Simmonds and Dolman (1999) proposed the following role of several possible impacts of noise on cetaceans:

Physical - (Non Auditory) damage to body tissue, induction of the "bends", (Auditory) gross damage to ears, permanent hearing threshold shift, and temporary hearing threshold shift.

Perceptual - masking of communication with conspecifics, masking of other biologically important noises, interference with ability to acoustically interpret environment, and 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), and displacement from area (short or long term).

Chronic/Stress - decreased viability of individual, increased vulnerability to disease, increased potential for impacts from negative cumulative effects (e.g. chemical pollution 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 Effect - reduced availability of prey, increased vulnerability to predation or other hazards, such as collisions with fishing gear, strandings, etc.

The U.S. Navy has been clearly violating the Marine Mammal Protection Act (MMPA), the Endangered Species Act (ESA) and the National Environmental Policy Act (NEPA) because it did not adequately assess or take steps to mitigate the risks posed by the system to marine mammals and fish and even admitted that LFAS were the cause of the mass strand in Bahamas (2000) and did not refused the claim of other stranding occurred because of the military tests. With so many relevant evidences, soon the problem was taken to the court of law and after a victory for cetaceans in 2002 court decision taken by the Magistrate Judge Elizabeth Laporte limiting the use of the U.S. Navy LFAS the area of operation was temporarily reduced to a large part of the Pacific Ocean focused around the remote Mariana Islands - an estimated area of one million square miles. While this is a substantial area of ocean, it's only about 10-15% of the area for which the U.S. regulators originally proposed permits (NMFS, 2002). However new reasons for concern came up in the 7th of November 2003 when the Bush administration won House approval to use sonar wherever the Defence Secretary Donald Rumsfeld sees fit (McClure 2003). This resolution has upset both biologists and activists who say that marine life is more at risk now. Several proposals for the management of research and use of the LAFS have been done as an effort to minimise the drastic consequences of the implementation of these system may have. Some of these recommendations are (After the NRC report 2003, and ECS statement 2003):

• Research on the effects of man-made noise on marine mammals is urgently needed and must be conducted to the highest standards of scientific and public credibility, avoiding all conflicts of interest. Whenever possible, structure research to relate individual observed responses to population-level effects;

• Target efforts to measure ocean noise toward important marine mammal habitats. Until these habitats are fully described, long-term monitoring programs should begin in coastal areas, marine mammal migration paths, foraging areas, and breeding grounds. In areas of cetacean concentration, the use of underwater powerful noise sources should be limited until their short- and long-term effects on marine mammals are understood and can be taken into consideration;

• Conduct research to determine whether subtle changes in marine mammal behaviour might result from the masking of biologically important sounds by anthropogenic sounds;

• Determine whether there are reliable long-term stress indicators and whether they can be used to differentiate between noise-induced stress and other sources of stress in representative marine mammal species;

• Examine the impact of noise on non-mammalian organisms in the marine ecosystem. Fish are important members of the marine habitat and food web, and have been shown to use sound in many ways that are comparable to the ways marine mammals communicate and sense their environment;

• Non-invasive mitigation measures must be developed and implemented.

Is necessary to meet these points in order to protect the oceanic fauna of such threat and preserve it on a sustainable manner. The protocol for the use of the LAFS is inconceivable and has to me changed before it achieves dramatic and irreversible results.

"… As they fell down sideways they splashed the water high up, and the sound reverberated like a distant broadside."

Journal of a Voyage around the world
CHARLES DARWIN (1809-82), English naturalist

Document Statistics:

Pages	5
Words	3,013
Characters (no spaces)	15,832
Characters (with spaces)	18,823
Paragraphs	39
Lines	244

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WebPages:
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Photos/Diagrams:
Cover. © Francisco Gonçalves (2003) - Spotted Dolphins off La Gomera, Canary Islands, Spain.

Figure 1.0 taken from www.inkokomo.com/dolphin/ echolocation.html

Photo 1.0 © Whale Museum (Madeira, Portugal) (2000) – Stranded Cuvier's beaked whale in Madeira

Photo 1.1 © The Centre for Whale Research (2000) - Stranded Cuvier's beaked whale in Bahamas.