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The Threat of Underwater Noise on Whales: Management in Light of Scientific Limitations

by Linda Weilgart[1] and Hal Whitehead[1]

There is no longer any question that noise can significantly impact individual marine mammals, even to the point of killing them (BALCOMB & CLARIDGE 2001, NATIONAL MARINE FISHERIES SERVICE & UNITED STATES NAVY 2001). The difficult question before us now is: does noise affect the health of populations and of ecosystems? This is an important issue that seems often forgotten in our efforts to gather more data on individual reactions. So, noise can affect anatomy (hearing loss), physiology (it can theoretically trigger "the bends"; HOUSER et al. 2001), behaviour (change in dive pattern), and psychology (stress, avoidance of areas which were previously loud). If we are concerned about animal welfare, then all these could have impacts on the welfare of an animal. If we are concerned about populations, then all these factors could affect the population of a focal species, but in addition, they could affect the populations of other species. If the focal species changes its behaviour relative to predators or prey, then that impacts other species as well. If we are concerned about ecosystems, then these impacts on the populations of several species could affect ecosystem function. These first effects fall under the area of population biology, and the second ones are in the area of community ecology. And yet, only the anatomy, physiology, and behaviour - mainly behaviour - of individuals exposed to noise have been studied up to this point. If one considers the picture portrayed above, one can see how many interrelationships and links are already present, and then remember that this only represents one focal species. If one considers more species, the picture gets vastly more complex.

The problems we are facing, then, in trying to study the effects of noise on whales in the open ocean are: there are too many potential links in the ecosystem, marine population biology is very hard to study and is very imprecise (for most whale and dolphin species we can only estimate population sizes within 40 %, so populations could be 40 % larger or smaller than we have estimated; WHITEHEAD et al. 2000), marine community ecology is especially hard to study as few relationships between species have been clearly established (how does one species' population size affect another's?), the spatial scales are huge in the ocean, the natural variation in marine ecosystems is huge, the maximum rates of increase of some species are very low (ca. 1 % per year for Sperm Whales; WHITEHEAD (in press) so we are looking for very small, but potentially profound, effects; and the logistics of Department of Biology, Dalhousie University, Halifax, Nova Scotia, Canada studying animals in the open ocean are very difficult. Added to these problems are the difficulties in studying the effects of noise, in particular: hearing damage is hard to assess, especially in the great whales (few audiograms exist); those characteristics of noise which make it disturbing are hard to define, even for humans, there is great variability in sensitivity to noise between individuals, between species, between age classes (mother-calf pairs tend to be most sensitive), between sexes (males sometimes approach noise sources, perhaps because they perceive noise as aggressive or a threat display), and reactions or sensitivity to noise can depend greatly on the activity the whales are engaged in (RICHARDSON et al. 1995). Resting animals often avoid noise, whereas foraging animals often ignore noise, i.e. they may be "putting up with" noise because the food is there (RICHARDSON et al. 1995). And finally, it is difficult to determine which effects of noise on cetaceans really are biologically significant, i.e. will they significantly impact the population?

This is why, to date, it is practically impossible to predict what the impacts of a certain type of noise will be, and which types of noise will be dangerous to which animals under which circumstances. A major obstacle is the fact that the short-term effects of noise are not necessarily linked to the long-term impacts. For instance, if there are changes in dive pattern this does not mean that such a short-term effect would impact the population over the long-term. Conversely, even if there are no observable changes in short-term behaviour, there could still be severe impacts on the population. Humpback Whales off Newfoundland exposed to explosions showed little behavioural reaction to the noise (no decreased residency, no change in overall movements, no change in general behaviour; TODD et al. 1996). However, it soon became evident that these Humpback Whales had a higher incidence than elsewhere in Newfoundland of becoming entangled in fishing gear and dying. The whales may have become hearing impaired and thus, did not detect the presence of the nets as well (TODD et al. 1996). Were it not for the unique situation of a) Humpbacks becoming entangled in fishing gear and b) the knowledge of what "normal" entanglement rates are, this likely harmful effect of the explosions would have gone unnoticed, as do undoubtedly hundreds of other such effects. Caribou exposed to low-level jet fighter overflights exhibited a startle reflex, causing them to run for a few seconds. This effect seemed mild and short-term. However, analysis showed that the more exposure a female caribou had to jet overflights, the less likely her calf was to survive (HARRINGTON & VEITCH 1992). Here, a mild, short-term reaction was shown to have serious consequences for the population.

So, short-term effects are not easily linked to long-term impacts. Yet, it is the long-term changes in populations or population measures (like birth, death, and growth rates) that are the most important. These are the effects we should be concerned about, as they are measures of the well-being of a

[1] Department of Biology, Dalhousie University, Halifax, Nova Scotia, Canada

population. Unfortunately, these very effects are undetectable for most cetaceans.

We have tried to come up with a very incomplete list of the sorts of effects on free-ranging cetaceans that we can detect and the ones we cannot detect, unless they are very dramatic. These detectable effects are only short-term ones on individuals, rather than on populations. Detectable effects include: respiration rate, swim speed, vocalizations, dive times, dive depth, residence times, distribution, movement relative to sound source, heart rate. Non-detectable effects (unless dramatic) include: birth rate (miscarriage rate, pregnancy rate, birth defects, mating rate, rate of finding mates, lactation rate, changes in mating dynamics), death rate (injury, disease, morbidity; vulnerability to hazards like shipping, fishing nets, predators), growth rate, change in echolocation ability as in ability to process echoes, change in group bonds and coordination, change in mother-calf bonds or maternal behaviour; annoyance, pain, panic, confusion, anxiety, etc.; change in memory, learning ability, cognitive functions; change in navigational ability; stress; change in aggressiveness; changes in immune response; changes in metabolic rate; deafness and hearing impairment; effects on contractile forces of muscles; hyperthermia; effects on vibrotactile system; vestibular/central nervous system effects; change in susceptibility to the "bends"; change in predator-prey interactions; change in ecosystem balance; cumulative noise effects. Some of these responses we have taken from a table entitled "Possible Effects of Exposure to Low Frequency Acoustics" published under "Exposure Guidelines for Navy Divers" (DEPARTMENT OF THE NAVY 2001).

Another problem is that it is easy to misinterpret the few effects we can observe. For instance, if more whales are seen at the surface during noise exposure trials, it could mean that they are attracted to the noise or that they are trying to avoid it, since sound levels can be much reduced at the surface (RICHARDSON et al. 1995).

One aspect of noise that can make it so potentially destructive is the huge spatial scale over which loud sounds can be heard. Seismic activity off Nova Scotia is prominent in the acoustic background off the Bahamas, and along the mid-Atlantic Ridge, several thousands of kilometres away (NATIONAL MARINE FISHERIES SERVICE & UNITED STATES NAVY 2001, CLARK 2002). Seismic noise can still reach levels of 110 dB re 1 μPa at a distance of 1,000 km (BOWLES et al. 1994). Low Frequency Active Sonar (LFA), a new type of sonar developed by the U.S. Navy to detect newer, quieter enemy submarines, only drops to a level of 120 dB at a distance of around 500 km from the source (J. Potter, pers. comm.). Several marine species, not just whales, try to avoid sound at an average received level of 120 dB, so this could mean that marine life over an area of 800,000 km^2 are impacted during every broadcast of LFA sonar. LFA sonar was in use off the coast of Greece in 1996 as 12 Beaked Whales stranded and died. The correlation in time and space between the ship's movements and the strandings was very strong, so LFA sonar is suspected of causing this stranding (FRANTZIS 1998). In March of 2000, this tragedy was repeated off the Bahamas Islands (BALCOMB & CLARIDGE 2001, NATIONAL MARINE FISHERIES SERVICE & UNITED STATES NAVY 2001). 17 whales of at least four species, but mostly Beaked Whales, stranded and at least seven died. Necropsies showed hemorrhages around the ears and brain, and these injuries were consistent with an intense, acoustic event as opposed to a nearby explosion. In this case, the U.S. Navy admitted that its tactical mid-range sonar was the most plausible source of the stranding (NATIONAL MARINE FISHERIES SERVICE & UNITED STATES NAVY 2001). And while we have heard much of the anatomical injuries, there has been comparatively little talk of the most devastating aspect of this incident, namely that the local population of Cuvier's Beaked Whales was probably destroyed, or at the very least, seriously displaced. None of the known animals that had been studied over the past nine years has been re-sighted since the stranding event (BALCOMB & CLARIDGE 2001). Here, we have a very clear population-level effect, one that no one predicted.

And how common are these multi-species strandings? Between 1838 and 1974, there were no multi-species strandings in which at least one beaked whale species was involved. But from 1974 to 2001, a total of seven multi-species strandings were documented involving at least one beaked whale species. In all seven of these cases, naval maneuvers were conducted nearby (BALCOMB & CLARIDGE 2001).

So there is no longer any question that sound can be deadly to cetaceans in ways no one predicted. And while the naval sonars may have very different characteristics from the scientific acoustic sources used in the Antarctic, there are also sufficient and overlapping similarities in intensity, frequency, duration, etc. It remains to be proven which characteristics of noise make it dangerous. Until such time as this is definitively determined, prudence and precaution demand that we treat all loud, far-ranging noise sources as potentially dangerous as well. Moreover, Antarctica presents special problems as many marine mammal species are dependent on this fragile, unique ecosystem for their survival. Beaked Whales, which may be particularly sensitive to noise, number among its inhabitants. As the deep sound channel is at or near the surface in polar waters, transmission loss in surface waters, which are frequented by more marine mammals, will be less, and thus, the effects of noise could be more far-ranging and severe (RICHARDSON et al. 1995).

Because of all the problems mentioned earlier, it is our belief that the question: "What is the effect of undersea noise on cetaceans?" will remain, for all intents and purposes, unanswerable. The question: "How can we make undersea noise less harmful?" is answerable, though. Here, we don't need to have a perfect understanding of all the fundamental processes (physiological, behavioural, etc.) which are involved in the effects of noise on cetaceans. Instead, we can look at the range of possible outcomes of our actions and make rational decisions on how to reduce bad outcomes. This falls under the category of science relating to risk reduction in the face of uncertainty (LUDWIG et al. 1993).

We propose the following process to consider noisy projects that may provide benefits yet pose large-scale environmental risks:

(1) Justify project. Strong justification for the need and benefit could be required for any project that is potentially devastating to the environment. It would be helpful if proponents made a convincing case that there are no adequate, more be-

nign alternatives. Only if the project can be well justified, might one proceed to the next steps.

(2) One could design the project to minimize harm. This could be done by:
a) avoiding marine life either spatially or temporally. In the case of seismic work in the Antarctic, it may be difficult to spatially avoid concentrations of marine mammals but perhaps one could find a season where fewer marine mammals are present.
b) reducing the impact of the noise would be beneficial, for instance by making it quieter.
c) avoiding duplication by sharing results of tests when-ever possible.
d) avoiding the use of mid-range frequencies like 1-10 kHz, preferably using extremely low frequencies (1-2 Hz or below) or high frequencies (over 200 kHz).
e) turning sounds off when animals are detected, visually or acoustically. It should be recognized that this sort of mitigation is better than nothing, but won't really prevent the exposure of a large proportion of cetaceans to noise, as there will always be cetaceans that aren't visible or audible, especially over larger ranges.
f) avoiding new sources of noise.

After designing a project to minimize harm, it would be useful if proponents would:

3) Provide funds to an independent agency to sponsor non-aligned research on the effects of sounds on marine life. It is best if marine mammal scientists don't have close ties to their paymasters, the noise polluters. The perception of bias is as damaging to the science and credibility of the scientists as true bias (WHITEHEAD & WEILGART 1995). An independent committee which has power could establish priorities for the research, commission it, and recommend regulations.

At present, the U.S. Navy provides the majority of funds for marine mammal research in the world (Vice Admiral Dennis V. McGinn, Testimony to US House of Representatives, Committee on Resources, 11 October 2001), which, given that the U.S. Navy is one of the worst acoustic polluters, is a conflict-of-interest situation.

We have focused on some of the limitations of studies of short-term, individual, reactions to noise. Probably the most useful are studies correlating changes in the acoustic environment with occurrences such as strandings, as was done with naval activities and strandings. Long-term studies relating long-term effects on population size with changes in noise levels would help improve our understanding of the effects of noise on whale populations over the long term.

In conclusion, underwater noise is dangerous but the most important consequences cannot now be determined; levels should be reduced, distanced from marine life and new noise sources avoided; major polluters should not directly fund the research; and finally, in deciding whether environmentally-risky projects should proceed, the more prudent course of action follows the Precautionary Principle, where measures are taken to prevent harm even in the absence of conclusive scientific evidence.

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