An Updated Note on the Vulnerability of Cetaceans to Acoustic Disturbance

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ABSTRACT

This short review of negative impacts of intense marine noise pollution provides an update to an earlier submission to the IWC Scientific Committee (Simmonds and Dolman, 2000) and provides a summary of some important recent developments.

KEYWORDS: Noise, conservation, strandings

INTRODUCTION

For some time, there has been a growing awareness and concern about intense marine noise pollution amongst the general public, governments and researchers. Whilst many questions remain, our understanding of some potential impacts has greatly improved in recent years. This note is a short review providing an update of Simmonds and Dolman (2000). A fuller review of marine noise pollution and its significance for cetaceans is provided in Simmonds *et al*. (2006).

CETACEAN VULNERABILITY

The issue of marine noise pollution has gained increasing international recognition in recent years. This has been due in part to a series of high profile stranding and non-stranding events that have led to heightened international concern. There remains much to be discovered but, for the present, we are aware that noise pollution has the potential to cause a number of negative consequences for marine mammals and these are outlined below in Table 1 (which is based on Simmonds and Dolman, 2000 as updated by Jasny *et al.* 2005).

Physical damage

Non-Auditory
It has become apparent that the consequences of intense noise pollution can be severe. Yet, despite the increasing number of atypical cetacean strandings[1] that have been associated with military sonar, the mechanism of injury remains unknown (Cox *et al.,* 2006). While this may remain the case for some time, there is emerging evidence regarding the nature of the damage and the sound levels that induce it. It is increasingly apparent that tissue damage and live strandings may be induced at received sound levels that are lower than had previously been anticipated and, in particular, at levels lower than those which induce auditory damage.

The available evidence suggests that deep-diving cetacean species may be especially susceptible. In particular, further evidence of decompression-type sickness in beaked whales has been identified (Arbelo *et al.,* 2005; Espinosa *et al.,* 2005; Fernández *et al*., 2005). These authors document an atypical beaked whale mass stranding in the Canary Islands that coincided with an international naval exercise known as 'Majestic Eagle'. This was conducted more than 100 km north of the Canary Islands in July 2004. Although the whale bodies retrieved were too decomposed to allow gas embolisms to be detected, systematic fat embolisms, rarely reported in stranded cetaceans, were found in these animals.

[1] An atypical cetacean strandings is a stranding event involving more than two whales (including one or more species) that strand approximately simultaneously but not in the same location (Frantzis, 1998).

These were also characteristic of the stranded beaked whales associated with an earlier exercise, 'Neo-Tapon', in 2002. More evidence has since come to light with the same symptoms being identified in a recent stranding of four Cuvier's beaked whales on the Spanish mainland near Almería during January 2006 (Fernández, 2006). The Almería event was an 'atypical' stranding – a term that is becoming increasingly familiar, and appears to be a reliable indicator of localised intense noise pollution.

The probability that the animals associated with the 'Majestic Eagle' exercise died at sea is extremely high (Fernández *et al*., 2005). In the Neo-Tapon-related strandings, pathological observations suggested that the animals were severely injured before beaching and that gas and fat emboli were related to the injury and not secondary to the stranding event (Fernández *et al*., 2005). These events increase concern that other animals affected during similar events are also being injured and dying at sea but are not being discovered and examined.

Table 1. Potential Impacts of Noise Pollution

Physiological
Non Auditory
- Damage to body tissue (e.g. internal haemorrhaging, rupture of lung tissue)
- Embolism (and other symptoms consistent with decompression sickness, or the "bends")

Auditory
- Gross damage to ears
- Permanent hearing threshold shift
- Temporary hearing threshold shift

Stress-related
- Compromised viability of individuals
- Suppression of immune system and vulnerability to disease
- Decrease in reproductive rate
- Behavioural
- Stranding
- Interruption of normal behaviours such as feeding, breeding and calving
- Loss in efficiency (e.g. feeding dives are less productive, mating calls are less effective)
- Antagonism towards other animals
- Displacement from area (short or long term)

Perceptual
- Masking of communication with conspecifics
- Masking of other biologically important sounds, such as calls of predators
- Interference with ability to acoustically interpret the environment
- Interference with food finding

Chronic
- Cumulative and synergistic effects
- Sensitisation to noise, exacerbating other effects
- Habituation to noise, causing animals to remain close to damaging levels of noise

Indirect Effects
- Degradation of habitat quality and availability
- Reduced availability of prey

While incidences involving military sonar arguably provide the most conclusive evidence of noise impacts to date, it remains to be determined which characteristics of noise are the most significant (Weilgart and Whitehead, 2004).

A number of mechanisms whereby noise pollution leads to bubble activation in cetaceans, causing injury, and potentially death, have been proposed. The first suggests that noise triggers a behavioural response resulting in tissue damage from either: (i) too rapid an ascent from a deep dive; or (ii) spending more time at the surface than is natural, possibly to escape higher sound levels below the surface (Potter, 2004; Houser *et al.,* 2001).

One line of potentially related evidence comes from a recent study of north Atlantic right whales, *Eubalaena glacialis*, which showed that they responded negatively to auditory-alerting stimuli, dramatically altering their dive patterns (Nowacek *et al.,* 2004). Five of the six animals exposed to the alert signal significantly altered their regular behaviour and did so in an identical fashion. Received sound levels were as low as 133dB re 1μPa. The energetic consequences associated with these responses include losing foraging time and expending energy during the rapid ascent and subsurface swimming that was precipitated. It is possible that other species, perhaps particularly beaked whales, might respond in a similar manner.

At least some deep-diving beaked whales have a dive profile not previously observed in other marine mammals and they may therefore chronically accumulate nitrogen in a manner not dissimilar to human 'saturation divers' (Baird *et al.,* 2004; Cox *et al.,* 2006).

The alternative mechanism for bubble activation may be through the direct ensonification of the individual. Ongoing discussions have led to theoretical modelling and experiments that suggest that even modest acoustic intensities can trigger bubble formation under supersaturated conditions. Bubble nucleation occurred in *ex vivo* bovine blood, liver and kidneys when supersaturated tissues were sonicated (Crum *et al.,* 2005). Crum also reported that the sound source caused previously stabilized, pre-existing microscopic bubbles to be activated. Further investigations into the mechanism of bubble formation are now underway (for example Cox *et al.,* 2006; SMRU, 2004).

Tyack *et al.* (2006) propose that, unlike most marine mammals but similarly to some penguins, sea lions and fur seals, beaked whales are reliant on aerobic-anaerobic metabolism during deep foraging dives and may need to equilibrate during surfacing intervals. These authors examine three periods of concern with regard to potential induction of decompression-type sickness (DCS): (i) the occasional protracted periods that the animals spend near the surface, (ii) the sequence of shallow dives between deep foraging dives, and (iii) the slow ascent from each dive. They conclude that prolonged dives between 30 – 80 metres would be most likely to lead to DCS for beaked whales. This depth range is shallower than lung collapse depth, where the animal is most likely to experience the highest influxes of nitrogen.

Whilst each of these ideas currently remains theoretical, intense sound exposures have clearly produced some fatal results. Although the extent of such losses is currently unknown, that animals seem likely to be dying at sea may have negative population implications, as well as raising welfare concerns.

Auditory impacts
Physical auditory impacts remain important. Hearing sensitivity can be reduced by exposure to noise of sufficiently high intensity and/or duration. A temporary shift in sensitivity can be generated, with recovery after minutes or hours, but a permanent shift can also result if exposure is repeated, prolonged or the noise source is very intense. At this time, there is little understanding of which noise levels may induce such consequences for marine mammals, where only a handful of a few species of captive odontocetes have been studied (see, for example, Finneran *et al.,* 2001 and 2005; Romano *et al.,* 2004). Extrapolations have been made from human hearing to aid consideration of the situation for cetaceans.

Stress-related
Noise has also been accepted as a potential source of stress (Fair and Becker, 2000), where acoustic influences may seriously disrupt communication, navigational ability and social patterns. There is little information on the effect of noise on the long term well-being or reproductive success of these animals (Fair and Becker, 2000), but responses leading to decreased reproduction, immunosuppression, endocrine disruption, and/or adverse behavioural changes have been observed in every vertebrate animal that has been examined (e.g. Holberton *et al*., 1996; Jessop *et al.*, 2003; Lankford *et al.,* 2005; Reneerkens *et al*., 2002). Monitoring changes or failure of these indicators is a challenging task in cetaceans. Given the unique and diverse physiology of marine mammals and the complex pattern of responses in a number of different systems, successful study requires commitment to a multi-disciplinary research approach (Fair and Becker, 2000).

Perceptual
Introduced noise can reduce an animal's ability to detect the sounds of predators, food or others, including signals between animals that are of biological significance (see Richardson *et al.,* 1995). Animals may respond to masking in any number of ways, including displacement or modifying their calls. Scheifele *et al.* (2005) report on the Lombard vocal response in St. Lawrence beluga whales, *Delphinapterus leucas*. The Lombard effect is an unconscious reaction of increased vocalisation level in response to a noisy environment. Whilst exhibiting a Lombard response provides a mechanism for

animals to cope with varying levels of noise, the response is also indicative of the animal attempting to cope with noise levels that are potentially rising towards a point where masking will occur (Scheifele *et al.,* 2005). Further, given the routinely elevated noise levels, a significant impact on the ability of these animals to communicate effectively with potential impact on their energetics seems likely.

Foote *et al.* (2004) report on the extended call duration of killer whales, *Orcinus orca*, in the presence of increased whale watch boat traffic. The authors suggest that the response seems to be initiated to counteract anthropogenic noise once it reaches a critical level. Ashe and Williams (2006) test the responses of adult male killer whales to approach by a few (1-3) vessels versus many (>3) vessels. Responses of killer whales to different numbers of vessels differed significantly. These data highlight the subtlety in response, that had the data been pooled these significant responses would have been masked, leading to a false suggestion that boat presence had no effect. Ashe and Williams (2006) conclude the interpretation of biological significance of null findings from impact assessments is problematic and highlight the need for consideration of statistical power, experimental design and appropriateness of response variables.

Baleen whales may be particularly vulnerable to masking as they use low frequency sound and communicate over great distances (Simmonds *et al*., 2006). It may be relevant that Clark and Fristrup (1997) report that the use of SOSUS array hydrophones was abandoned for long periods in the summer months because levels of background noise were so high, due to oil-related seismic surveying.

Chronic

Not only may behavioural responses be variable and their significance difficult to interpret, but habituation is also possible when the stimulus is no longer novel and no adverse consequences have been associated with it.

The opposite – sensitisation – may also occur. For example, if an animal has been exposed to a painful level of noise from a particular source, it may assiduously avoid the source, even at much greater distances than induce pain or discomfort. Some responses may cause animals to be displaced in the short or longer term. For example, whilst certain acoustic devices have actually been developed to 'alert' cetaceans to fishing nets with some success (e.g. Kraus *et al.,* 1995), one consequence has been to exclude them from certain areas. For example, orcas in the Broughton Archipelago, British Columbia, Canada were displaced from areas of critical habitat for a number of years following the introduction of Acoustic Harassment Devices (AHDs) (Morton and Symonds, 2002).

There may be public misunderstanding about the significance of such displacements. The ocean cannot be considered to be an homogenous single habitat and different marine animal species will have specific habitat requirements, including water depth, temperature and water quality. Habitats are generally not well characterised for cetaceans but some species are known to have relatively limited home ranges. For example, on the Scotian Shelf, off Nova Scotia, northern bottlenose whales, *Hyperoodon ampullatus,* are restricted to the prominent canyon called The Gulley, a relatively small area on the edge of the continental shelf (Gowans and Whitehead, 1995). In fact, a number of cetacean species have been found to have different, if overlapping, distributions in this area.

It should be noted that even where there is no measurable behavioural response, it cannot be assumed that no biological consequences are resulting from exposure to loud noises. Gordon *et al.* (1998), for example, found no measurable response from sperm whales to ATOC-like sounds based on blow rate patterns, whereas studies conducted using D-tags in the noisy Gulf of Mexico showed that airgun operations might affect the foraging behaviour of sperm whales, and possibly reduce their foraging rate, even at moderate received levels (Miller *et al*., 2006) and despite the persistence of seismic noise for many years.

It has also been generally assumed that marine mammals will respond to loud noises by moving away. However, this response requires them to be able to both localise the source and also recognise it as a threat. Further, and of significant concern, Madsen *et al.* (2006) report that the received level of first pulse arrivals can be just as high at 12 km as at a range of 2 km from the seismic array. Indeed, secondary arrivals can have higher received levels at 5 – 12.6 km than they do at ranges closer to the source.

A cetacean's ability to localise sounds may be compromised by: (i) Several sources operating at the same time (for example as is sometimes the case during seismic surveying); (ii) Sources only operating intermittently; and (iii) Sound convergence zones away from the source including (iv) concentration of sound in the deep sound channel (Urick, 1983).

Long-term displacement from a habitat has not been studied extensively, but the short-term responses reported suggest that repeated noise exposure might have cumulative negative effects (Richardson *et al.*, 1991).

Indirect Effects
Noise may also indirectly impact cetaceans through effects on prey abundance, behaviour and distributions. Fish, in particular, can be expected to be particularly vulnerable to intense sound because of the presence in most of a large gas-filled swim-bladder. McCauley *et al.* (2003) reported regionally severe damage in pink snapper with no evidence of repair or replacement of damaged sensory cells up to 58 days after exposure, demonstrating that exposure to seismic can cause significant damage to the ears of fishes.

Should prey animals become less available in an area (either because they have moved away or become more difficult to catch) marine predator feeding rates and distributions may be affected.

PARTICULAR VULNERABILITIES OF SOME SPECIES

As noted earlier, there is evidence that deep-diving cetaceans – primarily beaked and sperm whales - may be particularly vulnerable. Not only is deep-diving likely to take these animals into zones where noise may be concentrated – for example the noises from seismic exploration are focused towards the sea bed – but their special physiology may limit their options for response. For example, a deep-diving mammal leaves the surface with supplies of oxygen in its organs and blood intended to sustain the dive. It may not have the capacity, particularly towards the end of its dives, to swim away from an intense noise source.

However it is also important to also consider some other species that have been included in mortality events in response to intense noise pollution. Whilst Cuvier's beaked whales make up 81% of the total number of stranded animals associated with noise events, other beaked whales, including *Mesoplodon europaeus*, *M. densirostris* and *Hyperoodon ampullatus* account for 14% and other cetaceans, including *Stenella coeruleoalba, Kogia breviceps, Balaenoptera* sp., make up the rest (Hildebrand, 2005).

Further, 'blackfish' (a number of species of typically deep water and deep-diving cetacean species that live in well structured family groups) also appear to be vulnerable to the impacts of intense noise pollution. This has been well supported with the following evidence coming to light in the last year: A multi-species stranding of 33 short-finned pilot whales, *Globicephala macrorhynchus,* a minke whale, *Balaenoptera acuturostrata,* and two dwarf sperm whales, *Kogia sima,* occurred in North Carolina, United States, in January 2005. The unusual conditions surrounding this event prompted the Federal government to identify it as an Unusual Mortality Event. Naval activity using tactical mid-frequency sonar transmissions were spatially and temporally associated with the stranding – which also had a number of other features in common with other sonar-related strandings (e.g. the 'atypical' distribution of strandings involving multiple offshore species, all stranding alive, and without evidence of common infectious or other disease process) (Hohn *et al.*, 2006).

There have been 'non-stranding events' of pods of blackfish where they have exhibited strange behaviour in the vicinity of naval activities. This occurred with a pod of orcas in the Haro Strait in May 2003. In addition, attention has been drawn to the use of sound to herd blackfish in whaling operations (Brownell *et al.*, 2005).

Another non-stranding event occurred in Hawaii, in July 2004 and involved 150 – 200 melon-headed whales, *Peponocephala electra,* including at least one calf. The event was spatially and temporally correlated with the Rim of the Pacific exercises (RIMPAC) involving the US and other Rim-of-the-Pacific Navies. The group was gathered in Hanalei Bay for over 28 hours, until the use of sonar was halted and the whales were then returned to deeper waters by human assistance. The government report stated that evidence that the active sonar use during the exercise caused the unusual behaviour in the pod, and the subsequent death of the calf (which stranded), was overwhelming (Southall *et al.*, 2006).

In this event, the stranding network, local community, government agency and the Navy all responded quickly, were able to stop sonar transmissions and collect a detailed chronology of events. However, the blackfish species have stranded individually and in large numbers for millennia, making initial assessment of such events potentially quite difficult.

CONCLUSIONS AND RECOMMENDATIONS

As documented here, the evidence of impacts of noise pollution continues to increase. Action to protect cetaceans from the intense impacts of noise pollution should not be delayed because of the necessity for further investigative research; but ongoing research should be maintained in parallel with management efforts, to further investigate (i) basic distribution and abundance of vulnerable populations, (ii) mechanisms that lead to injury and death in cetaceans resulting from intense sound exposure and also (iii) the longer-term impacts, that may have negative population consequences, that require on-going funding commitments.

Valuable data can be obtained from strandings and non-strandings. Information collected from dead stranded animals can provide us with data that can often prove the first indication of a wider impact. We can also learn a considerable amount from historic strandings data and efforts should be made to collate such information from all available sources.

Whilst it is important to acknowledge that some mortalities associated with sound may not follow typical patterns, there appear to be some common elements involved in some strandings that may assist in diagnosing them as acoustically-induced. For example, such strandings often involve animals that come ashore within a short time frame of one another, but not necessarily in immediate proximity to each other. Often the animals strand alive. They may involve more than one species and, in some cases, sound-producing vessels have been observed in the vicinity of the stranding.

Whilst necropsy investigations in acoustic events are at an early stage of development, introduction of an international protocol will greatly aid the collation of standardised data to improve knowledge. An acoustic stranding protocol (Geraci and Lounsbury, 2005) that has been developed by experienced veterinarians and pathologists would seem to be an appropriate starting point (Annex 1).

Significant efforts should be focused at making precautionary management decisions that will allow vulnerable populations the respite from intense noise pollution that they may need. Effective Marine Protected Areas may have a significant role to play in this regard. These should be precautionary and dynamic. Adaptive management is important as our knowledge base is rapidly expanding.

Ongoing focused research is required and information that can be collected from stranding events is key to further our understanding of impacts, and their extent, around the world. We therefore make the following recommendations:

1. Action be taken now to implement wide management measures, such as MPAs, for protection of cetaceans from intense noise pollution
2. To aid our understanding of the issue it is important that fresh samples be collected in mortality events. An example of a recent protocol is included in the Annex and such a protocol should be introduced internationally to the greatest extent possible
3. Where such events happen every effort should be made to fully document the event and to make the information publicly available as readily as possible, and
4. That the IWC scientific committee continues its involvement in the noise pollution issue

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Investigating Suspected Acoustic-Related Cetacean Strandings

Cetacean strandings associated with intense sound generated by human activities (e.g., military sonar or air guns used for oil and gas exploration) are controversial and require comprehensive investigation. Examination of beaked whales and other cetaceans that have stranded following presumed exposure to high intensity low frequency (LF) and mid-frequency (MF) naval sonar revealed multiple areas of hemorrhage, primarily in or around the inner ears, brain, acoustic jaw fat, and kidneys, as well as vascular lesions suggestive of decompression sickness ('the bends'). Detailed protocols for sample and data collection for such events have yet to be established. The general guidelines below provide a basic framework for further development.

Initial evidence

Investigate acoustic trauma as a cause or contributor to strandings in the following circumstances

● Mass or multi species strandings of beaked whales over a period of a few days

● Multi-species cetacean strandings, in the absence of other apparent causes of unusual mortality (e.g., toxic algal bloom or offshore fisheries)

● Any cetacean stranding that coincides with local activities involving military sonar, air gun activitiy, or other sources of intense underwater sound

● Any mass or multi species stranding in which animals share pathology findings suggestive of acoustic trauma (*below*)

Necropsy and sample collection

Arrange for immediate expert pathologist consultation and examination (if available)

Conduct a comprehensive necropsy to evaluate other potential causes of stranding or death (e.g., disease, starvation, ship strike) and include sample collection and examination for evidence of lesions associated with noise exposure as described below.

Brain and spinal cord

After examining the soft tissues around the head, the brain and the spinal cord can be examined.

● Ideally, the rbain and spinal cord should be examined and sampled without risk of introducing gas (as artefact) into the CNS circulation. Although attempts can be made to tie-off blood vessels around the cranium, the specific cardiovascular adaptations of marine mammals make the prevention of entry of gas into the CNS vasculature problematic. Alternatively, and prior to removing the head, a window in the skull can be carefully opened and, after excising the dura matter, the blood vessels of the brain surface examined for **hemorrhages**, potential **gas emboli** and other lesions. Any suspected bubbles/lesions should be **described and photographed**.

● The head can then be removed at the atlanto-occipital joint and a sample of cervical spinal cord collected and fixed in 10% formalin.

● Collect and preserve the brain in formalin for histopathology. Once the brain has been removed and preserved, the ears can be collected and placed in formalin (*see below*) and the rest of the head examined.

Investigating Suspected Acoustic-Related Cetacean Strandings - Continued

Earbones

Logistics and anatomical expertise permitting, remove and preserve the earbones for shipment to a qualified laboratory for further examination.

● Position the skull on its dorsal surface.

● Remove the lower jaw and soft tissues to expose the tympanic area. Assess the mandibular fat for hemorrhage.

● Using a chisel, screwdriver and saw, as necessary, remove the tymanoperiotic complex (the tympanc bones and the periotic bones with the attached flanges), severing sift tissue attachments (nerves and vessels).

● In fresh specimens, inject formalin through the round window with a 22- to 25- gauge needle to better preserve the inner ear.

● Place tissues in 10% neutral buffered (NB) formalin for one week before shipping; change the formalin after one week and at least twice during the first month if shipping is delayed. Prior to shipping, wrap the tissues in gauze soaked with 10% NB formalin, place in a bag or container, tape to prevent leakage, and pack with cushioning to prevent damage.

If an expert is not available to remove the ears, remove and freeze the entire head (after the brain has been removed) for later computerized tomography (CT) analysis, ear extraction and examination. Do not allow the head to thaw before shipping. In the laboratory, thaw the head in fixative to minimise deterioration.

Other tissues in the head

● Remove the eyes. Assess the retrobulbar periorbital fat for bleeding.

Other organs

● Incise the larynx and assess the mucosa for evidence of hemorrhage.

● In fresh carcasses, examine the vasculature of intestines, intestinal mesentery, liver and kidneys for intravascul gas bubbles and hemorrhage, and photograph any suspected abnormalities.

Fix tissues in histopathology in 10% NB buffered formalin at a ration of 1 part tissue to 10 parts formalin.

Supplementary data

Supplementary data provide essential circumstancial evidence. Document the following in as much detail as possible (e.g., photographs, GPS, aerial surveys):

● Potentially related strandings (species, numbers, locations; collect skin samples from all animals for genetic analysis and to confirm species and relatedness)

● Spatial and temporal pattern of live and dead strandings

● Pre-stranding and stranding behaviour

● Presence of floating carcasses and/or live animals in the area

● Natural (e.g., seaquakes) or human activities (e.g., seismic surveys or naval activities) in the area

● Historical pattern of strandings in the region.