



Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Review

Navy sonar and cetaceans: Just how much does the gun need to smoke before we act?

E.C.M. Parsons^{a,b,*}, Sarah J. Dolman^{c,d}, Andrew J. Wright^e, Naomi A. Rose^f, W.C.G. Burns^g^a Department of Environmental Science and Policy, George Mason University, 4400 University Drive, Fairfax, VA 22030, USA^b University Marine Biological Station Millport (University of London), Cumbrae KA28 0EG, UK^c Whale and Dolphin Conservation Society, Brookfield House, 38 St. Paul Street, Chippenham, Wiltshire SN15 1LJ, UK^d School of Biological Sciences, Zoology Building, Tillydrone Avenue, University of Aberdeen, Aberdeen AB24 2TZ, Scotland, UK^e Leviathan Sciences, 3414 17th Street N, Number 3, Arlington, VA 22207, USA^f Humane Society International, 2100 L Street, NW, Washington, DC, USA^g Santa Clara University School of Law, 500 El Camino Real, Santa Clara, CA 95053, USA

ARTICLE INFO

Keywords:

Cetacean
Beaked whales
Sonar
Underwater noise
Conservation

ABSTRACT

Cetacean mass stranding events associated with naval mid-frequency sonar use have raised considerable conservation concerns. These strandings have mostly involved beaked whales, with common pathologies, including "bubble lesions" similar to decompression sickness symptoms and acoustic traumas. However, other cetacean species have also stranded coincident with naval exercises. Possible mechanisms for the strandings include a behavioral response that causes deep divers to alter their diving behavior, which then results in decompression sickness-like impacts. Current mitigation measures during military exercises are focused on preventing auditory damage (hearing loss), but there are significant flaws with this approach. Behavioral responses, which occur at lower sound levels than those that cause hearing loss, may be more critical. Thus, mitigation measures should be revised. A growing number of international bodies recognize this issue and have urged increasing scrutiny of sound-producing activities, but many national jurisdictions have resisted calls for increased protection.

© 2008 Elsevier Ltd. All rights reserved.

1. Introduction

In March 2000, at least 16 whales of three species stranded on beaches and in mangroves in the northern Bahamas, within a short period of time but spread out over several kilometers and islands. US Navy vessels were transiting through the area at the same time. Researchers studying beaked whales in the Bahamas suggested that this unusual stranding event resulted from the use of high-intensity active sonar by these vessels (Balcomb and Claridge, 2001). A US government investigation (Anonymous, 2001) later concluded that the use of mid-frequency active sonar¹ by Navy ships was the most likely cause of the strandings and of the injuries sustained by the animals. The effects of active sonar on marine mammals have subsequently become a major welfare and conservation issue (Marine Mammal Commission, 2007; Weilgart, 2007).

The Bahamas incident was not the first mass stranding of cetaceans that had been linked to naval activities (Frantzis, 1998, 2004; Frantzis and Cebrian, 1999; Simmonds and Lopez-Jurado, 1991; Van Bree and Kristensen, 1974). However, it was certainly the most publicized and the first with sufficient post-event evidence gathered to build a strong scientific case for causation, mainly because of the ongoing long-term study of cetaceans in the area. Crucially, one of the biologists on site was a former member of the US Navy who, as a result of his knowledge of underwater acoustics and the particular nature of the injuries sustained by the whales, made the link between the strandings, the presence of naval vessels and the possible effects of sonar use on cetaceans (Balcomb and Claridge, 2001).

2. Military exercise-related beaked whale mass strandings and events

As a result of the international publicity surrounding the Bahamas situation, scientists have examined previous patterns of mass strandings and military activities around the world. A considerable number of beaked whale mass stranding events have occurred concurrently with naval activities in several countries, although the use of mid-frequency sonar during these exercises cannot be

* Corresponding author. Address: Department of Environmental Science and Policy, George Mason University, 4400 University Drive, Fairfax, VA 22030, USA. Tel.: +1 240 626 4512.

E-mail address: ecm-parsons@earthlink.net (E.C.M. Parsons).

¹ The sonar system involved was AN/SQS-53C a US Navy tactical mid-frequency sonar, producing 'pings' primarily in the 2.6–3.3 kHz frequency range at a source level of approximately 235 dB re 1 μPa.

confirmed in all cases (Brownell et al., 2004; Espinosa et al., 2005; Fernández et al., 2005b; Fernández, 2006; Freitas, 2004; Hildebrand, 2005a; ICES, 2005; Martin et al., 2004; Podesta et al., 2006; Taylor et al., 2004; Van Bree and Kristensen, 1974). Many of these events have taken the form of an “atypical” mass stranding (including the stranding in the Bahamas in 2000), which involves more than two animals, stranding approximately simultaneously but not in the same location (Brownell et al., 2004; Frantzis, 1998; International Whaling Commission, 2005a). Such events appear to be reliable indicators of localized intense noise pollution.

Worth specific note are at least eight mass strandings of beaked whales that have been associated with military exercises around the Canary Islands (Fernández et al., 2005b; ICES, 2005; Taylor et al., 2004). The most recent of these, in July 2004, involved four Cuvier's beaked whales, *Ziphius cavirostris*, and coincided with the naval exercise “Majestic Eagle”, which was conducted 100 km to the north of the islands in the week prior to the beaked whale carcasses being discovered (Espinosa et al., 2005; Fernández et al., 2005b). Fernández et al. (2005b) considered it highly probable that these animals died at sea, rather than stranding live and then dying onshore. This increases the concern that additional animals to those found beached may be affected during similar events and may die in open water, but are not being discovered and examined (Fernández et al., 2005b).

The possibility of this “hidden” mortality is not surprising. While it is widely accepted that carcass detection rates can be quite low in wild populations of terrestrial animals, and thus the discovery of a single body should always be considered indicative of a wider problem (pp. 14–15, Wobeser, 1994), this same logic has not been applied by managers to the issue at hand. This is troubling, as carcass detection rates are likely to be lower still in the marine environment where human observers, especially on isolated stretches of coastline and at sea, are present more rarely than in many terrestrial environments and dead animals can quickly be scavenged upon, carried away by strong currents, or sink beneath the surface (Allison et al., 1991).

Japan appears to be another hot spot for strandings. US government scientists presented a paper at the 2004 meeting of the International Whaling Commission (IWC) that analyzed mass strandings of Cuvier's beaked whale and Baird's beaked whale, *Berardius bairdii*, in Japan from the late 1950s until 2004 (Brownell et al., 2004). The paper reported that there were 11 mass strandings (a total of 51 animals) involving these species, all of which occurred in Suruga Bay or Sagami Bay on the central Pacific coast of Honshu. Both of these bays are adjacent to the command base for operations of the US Navy's Pacific 7th Fleet (Brownell et al., 2004).

Nearby, in Taiwan, several cetacean strandings occurred from 24 February to 10 March 2004, including that of a ginkgo-toothed beaked whale, *Mesoplodon ginkgodens*. These strandings coincided with a joint US/Philippine military exercise, to the south of the island (Wang and Yang, 2004, 2006). Researchers conducted a necropsy of the intact head and partially cleaned post cranial skeleton of the beaked whale and revealed unusual injuries to structures that are associated with, or related to, acoustics and diving. Wang and Yang (2006) considered that “the freshness of the carcass, its discovery location and the coincidence of the event with nearby large-scale military exercises are suggestive that the energy source may have originated from these exercises” (p. 289). However, the Scientific Committee of the International Whaling Commission (IWC) was more emphatic, stating that the cranial lesions and trauma “suggest that this beaked whale died from acoustic or blast trauma that may have been caused by exposure to naval activities south of Taiwan” (p. 273, International Whaling Commission, 2005b).

More recently, an “atypical” mass stranding of Cuvier's beaked whales occurred off Almería on the Spanish coast in January

2006 (Fernández, 2006), which was coincident with a NATO naval exercise. A number of Cuvier's beaked whales have stranded on several of the western isles off Scotland through February and March 2008, dying at sea and washing ashore in a decomposed state (Dolman et al., 2008), further supporting concerns raised by Fernández et al. (2005b) of deaths at sea. Researchers are currently investigating potential naval activities in the vicinity.

3. Military exercise-related mass strandings of other species

Most attention has been focused on the beaked whale strandings concurrent with naval activities. However, while they do make up the majority of the casualties, several other species have stranded coincident with naval exercises (ICES, 2005; Nowacek et al., 2007; Weilgart, 2007). For example, a northern minke whale, *Balaenoptera acutorostrata*, was found in the 2000 Bahamas incident (Balcomb and Claridge, 2001).

In addition to beaked whales, short-finned pilot whales, *Globicephala macrorhynchus*, also stranded in the 2004 Taiwan incident (Wang and Yang, 2004). Similar strandings in coastal areas of southwest Taiwan occurred in February 2005, with two mass stranding events of live pygmy killer whales, *Feresa attenuata*, as well as a milling event² involving this species, with a group entering a shallow coastal harbor (Wang and Yang, 2006). A necropsy of one of the pygmy killer whales revealed hemorrhaging in the cranial tissues of the animal. Moreover, between 19 July and 13 August 2005, there were 22 further stranding events throughout Taiwan, involving several species³ and a total of 25 animals, primarily along the northern coast of Taiwan (Wang and Yang, 2006). This spate of strandings is, to date, the greatest rate of cetacean strandings recorded for the country (Wang and Yang, 2006). During July, a naval exercise was being conducted by the Chinese military in the East China Sea, and in August, a joint Japanese/US Navy exercise took place, albeit at a considerable distance from Taiwan, off the coast of Okinawa and Guam (Wang and Yang, 2006). Tissues from six cetaceans from these stranding events were examined, and five were found with small bubble-like lesions (Wang and Yang, 2006), similar to those found in other military-related strandings (see below; Fernández et al., 2004, 2005b; Jepson et al., 2003).

Thirty-four short-finned pilot whales, one minke whale and two pygmy sperm whales, *Kogia breviceps*, stranded in the Outer Banks, North Carolina, between 15 and 16 January 2005 (Kaufman, 2005a). Coincident with the stranding, one US Navy vessel was known to have used sonar for seven minutes about 90 nautical miles southeast of the stranding area (Kaufman, 2005a). The government reported that the stranding had a number of features in common with other “atypical” sonar-related strandings, e.g., the wide distribution of animals, involving multiple offshore species, all stranding alive, and without evidence of common infectious or other disease process (Hohn et al., 2006).

Similarly, on 25 and 27 October 2005, mass stranding events occurred in Tasmania, Australia, involving approximately 145 long-finned pilot whales, *G. melas*. On investigation, it was found that the animals stranded during three separate periods, the first occurring six hours before the arrival of two Royal Australia naval vessels (Department of the Environment and Heritage, 2005). However, the second event began just over an hour after the vessels began using high frequency (50–200 kHz) sonar in the vicinity

² A “milling event” is when a group of cetaceans enters shallow water and begins to circle continually or move about haphazardly in a tightly packed group, with an occasional member breaking away and swimming toward the beach. See section below.

³ These species included dwarf sperm whales, *Kogia sima*, striped dolphins, *Stenella coeruleoalba*, Blainville's beaked whales, *Mesoplodon densirostris*, and Longman's beaked whales, *Indopacetus pacificus*.

of the stranding, and a behavioral reaction to the sonar facilitating the second and third stranding events could not be ruled out (Department of the Environment and Heritage, 2005). While these Tasmanian strandings are more tenuously linked to military activities than the various beaked whale “atypical” mass strandings mentioned above, they should not be overlooked, as it is quite possible that the military activities, acting cumulatively and/or synergistically with other factors responsible for the first period of strandings, exacerbated the situation (see discussion of cumulative effects in Deak, 2007; Weilgart, 2007; Wright et al., 2007b).

4. Non-stranding related effects and events

There have been effects other than stranding reported for cetaceans in proximity to military exercises or when exposed to active sonar. These include, but are not limited to: significant decreases in northern minke whale sightings rates in western Scotland during periods of naval exercises (Parsons et al., 2000); changes in vocalizations of long-finned pilot whales during a military exercise involving active sonar in the Ligurian Sea Cetacean Sanctuary (Rendell and Gordon, 1999); alterations in singing behavior of male humpback whales, *Megaptera novaeangliae*, when exposed to low frequency sonar sounds (Miller et al., 2000); and temporary silence in sperm whales, *Physeter macrocephalus* (Watkins et al., 1985). The long-term implications of such behavioral changes are unknown.

In one particularly noteworthy case, on 5 May 2003, researchers noted abnormal behavior in killer whales, *Orcinus orca*, harbor porpoises, *Phocoena phocoena*, and a minke whale in Haro Strait, in Washington State (Vancouver Aquarium Marine Science Centre, 2003). Simultaneously, the researchers heard an extremely loud screeching sound while recording whale calls, which was later revealed to come from the mid-frequency SQS-53C sonar on a US Navy destroyer transiting the area.

Another unusual milling event occurred at 7:30am on 3 July 2004, when 200 melon-headed whales, *Peponocephala electra*, normally deep-water animals, were found in shallow water in Hanalei Bay, Hawaii (Kaufman, 2004; Southall et al., 2006). Coincident with this event, the US and other Rim-of-the-Pacific (RIMPAC) navies were conducting a biennial active sonar tracking exercise approximately 20 miles northwest of Kauai. Initially the US Navy denied that there was a link between the milling event and its activities, contending that it had not used sonar in the area until after the event had occurred. However, Navy officials later admitted that vessels involved in the exercise had used sonar just prior to the event, specifically between 6:45 and 7:10am (Kaufman, 2004). Sonar had also been used the night before, several hours before the animals were discovered in the bay. The government report concluded that the sonar use was a “plausible, if not likely” cause of the milling event, citing the “close spatiotemporal correlation” and “the absence of any other compelling causative explanation,” among other evidence (Southall et al., 2006). Subsequently, a stranded calf was found. Upon necropsy, no obvious acoustic-related trauma could be found in this calf, with its death possibly being due to separation from its mother (Southall et al., 2006), for which the milling event could have been a contributing factor.

5. Possible mechanisms

Why do these strandings occur? At first it was suggested that the stranding of beaked whales in the Bahamas was the result of the sonar frequencies causing reverberation of the air spaces (i.e., resonance) within the skull of the stranded whales (Balcomb and Claridge, 2001). However, the discovery of bubble-like lesions and fat emboli in the tissues of cetaceans coincident with naval exercises suggested something different (Fernández et al., 2005a,b;

Fernández, 2006; Jepson et al., 2003). These lesions were first found in various UK odontocetes and then subsequently in beaked whales that had stranded in the Canary Islands and mainland Spain and were similar to those caused by decompression sickness, or the bends, particularly in the beaked whales (Jepson et al., 2003).

Decompression sickness is an affliction of human divers and it was generally assumed that cetaceans possessed physiological adaptations to avoid this problem. However, it has recently been proposed that this may not be the case, at least for some deep diving species, such as sperm whales (Moore and Early, 2004). Specifically, it has been suggested that beaked whales have super-saturated levels of dissolved nitrogen in their blood, but avoid the formation of tiny nitrogen bubbles that block blood vessels and cause the bends because they normally spend so little time at the surface exposed to low ambient pressures (Rommel et al., 2006). It has been further suggested that either sonar pulses cause nitrogen to come out of solution through changing pressures (Houser et al., 2001; Crum et al., 2005), or the noise of the sonar causes an aversive behavioral reaction in the animals, forcing them rapidly to the surface, where they may remain for extended periods in shallow water. In this scenario, they start to rapidly depressurize, and the bends-like lesions occur (Fernández et al., 2004; Rommel et al., 2006).

The latter hypothesis has been criticized, primarily on the grounds that the bends causes different types of lesions in humans, but not bubbles in the liver as observed in the Jepson et al. (2003) study (Piantadosi and Thalmann, 2004). In particular, critics have noted that, for decompression sickness in humans, “chronic lesions are found only in the long bones and central nervous system” (p. 1, Piantadosi and Thalmann, 2004, emphasis added). However, the veterinarians, pathologists and whale biologists who investigated the Canary Islands beaked whales stated that they did not investigate bone tissue and only examined the central nervous system in two animals, so they could not say whether there were such lesions in these tissues or not. Rather they report finding “acute, systemic and widely disseminated lesions consistent with, but not diagnostic of [decompression sickness]” (p. 1, Fernández et al., 2004) and stated that large numbers of gas bubbles in liver vessels, and other lesions observed, have indeed been reported as a symptom of the bends in humans (e.g., Francis and Mitchell, 2003).

In addition, a paper has reported lesions in sperm whale bones consistent with the chronic pathology found in the bones of human divers suffering from decompression sickness, adding more support to the noise-induced/provoked bends hypothesis (Moore and Early, 2004). Although decompression sickness-like lesions were reported from bones of animals that died as long as 111 years ago (i.e., long before the invention of military sonar), the authors of the study noted that bone damage caused in recent years could be due to cetaceans being driven to the surface rapidly by underwater noise (Moore and Early, 2004). A commentator on this study also noted that although sonar was not around a century ago, commercial whaling certainly was (Mitchell, 2005) and forced surfacing of whales was a technique used by these operations (Ohsumi, 1980). Such methods could theoretically cause rapid depressurization and the onset of the bends as effectively as being forced to the surface by sonar-related noise. At the very least, Moore and Early (2004) suggest that deep-diving cetaceans may not be immune to decompression sickness, as was previously assumed they must be.

The aversive behavioral reaction hypothesis has become the most widely accepted mechanism proposed to explain gas emboli and bends-like lesions (Cox et al., 2006), although recently it has been suggested that damage could stem from a response that involves repeated dives shallower than the depth of lung collapse, rather than a rapid ascent (Tyack et al., 2006). Tagging studies have reinforced the idea that “decompression problems are more likely

to result from an abnormal behavioral response to sonar” (p. 4238, Tyack et al., 2006).

6. Current exposure standards and their basis

Evaluations of the potential impacts of noise on cetaceans have generally used the likelihood of temporary or permanent hearing loss (referred to as Temporary or Permanent Threshold Shift – TTS or PTS) as an index of potential harm (e.g., National Research Council, 2003) due to early thought that these were the main physiological impacts that could be expected (e.g., Ketten, 1995). This has led to exposure guidelines in the United States, United Kingdom, and elsewhere that considered sound exposure levels of up to 180 dB (re 1 μPa @ 1 m) to be safe for cetaceans; for example, in UK oil and gas seismic exploration guidelines (JNCC, 2004). The US government convened a *Noise Criteria Panel*, a body of experts to consider “safe” exposure levels for marine mammals (Southall et al., 2007). Despite limitations and caveats with its methodology, the Panel nevertheless has recommended raising the injury-free exposure criterion for cetaceans to 230 dB re 1 μPa peak pressure, although they do note that a lower criterion for some sounds is likely to be needed for beaked whales (Southall et al., 2007).

There has been much discussion over the wisdom of using amplitude alone to determine “safe” exposure, or whether energy, intensity and exposure duration are preferable (e.g., Madsen, 2005). In an effort to address this concern, Southall et al. (2007) have in fact developed dual exposure criteria, using peak pressure and total energy, which incorporates exposure duration. The latter still results in a recommended increase in the “safe” exposure criterion, to 215 dB re 1 $\mu\text{Pa}^2 \text{ s}^{-1}$, weighted for the hearing of marine mammals. These “safe” limits of sound exposure for cetaceans are primarily based upon extrapolations of responses (typically onset of TTS) of a few species of marine mammals, observed in a captive, experimental environment (see below). This methodology is widespread; for example, it was the method used in a UK government impact assessment for its then-new SONAR 2087 low frequency system (QinetiQ, 2002). However, the applicability of such captive studies to cetaceans in the wild is frequently debated (e.g., Finneran and Schlundt, 2007; Houser and Finneran, 2006; Nowacek et al., 2007; Weilgart, 2007), with studies to date generally demonstrating a wide divergence between predicted sensitivities to sound and those actually observed.

For example, studies on the hearing abilities of captive beluga whales, *Delphinapterus leucas*, estimated that the whales could detect shipping traffic at 20 km, but observations of wild animals showed vessel detection at distances of more than 80 km and active avoidance at distances up to three times farther away than the captive studies suggested (Findley et al., 1990). Another study documented short-beaked common dolphins, *Delphinus delphis*, fleeing noises produced by oil-related seismic surveys, despite the received levels of sound being orders of magnitude (48 dB) quieter than levels at which captive animal studies predicted there would be an effect (Gould and Fish, 1998, 1999). It is possible that the high levels of background noise in captive facilities lead to hearing impairment (Finneran et al., 2005; Popov et al., 2007) and even deafness (Ridgway and Carder, 1997), either of which could potentially also result from years of exposure to sound during controlled experiments. In addition, the small pools used in many of these tests may influence results, with reverberation of sound and patterns of interference effectively exposing test animals to different intensities of sound than are actually being produced from the sound source (Finneran and Schlundt, 2007). Additionally, the administration of antibiotics to one captive cetacean has been implicated in hearing damage, a situation that

would bias the results of studies on some captive animals (Finneran et al., 2005).

Using the behavioral reactions by trained, captive animals to predict the responses of wild animals may therefore be flawed. The motivations of these two groups of animals are also markedly different: wild animals are trying to forage and evade predators in order to survive, while captive animals are merely expecting a reward (fish or praise). Furthermore, exposure to only 15 min of relatively low level white noise per day in laboratory rats has been shown to produce a variety of non-lethal effects consistent with a chronic stress response, which could alter the way the animals respond to experimental conditions (Baldwin, 2007). Although inter-specific extrapolation of data should be viewed with extreme caution, the conservation of the stress response over a range of taxa could be used to extrapolate these results to captive cetaceans (Wright et al., 2007a,b) and so this issue at least warrants attention. Context of exposure is another major complicating factor (see discussion in Wright et al., 2007a,b, and references therein), with animals often reacting more strongly to novel or unusual sounds in comparison to those with which they are more familiar and to which they are possibly habituated (Hernandez et al., 2007).

Many problems inherent with acoustic-related behavioral response studies have, however, been largely removed by recent use of auditory evoked potentials (AEP) to estimate marine mammal hearing abilities. With this method, the electrical impulses in an animal’s brainstem when exposed to noise are directly measured via suction cup sensors attached to the skin’s surface, removing the subjective element of interpreting behavioral responses (Nachtigall et al., 2007). Studies have found that behavioral responses can deviate from AEP data on hearing sensitivities by 20 dB or more, although a recent paper noted that for certain frequencies the AEP method produced results that did not differ greatly from behavioral response data (Schlundt et al., 2007). Nevertheless, results from work using this technique have demonstrated that dolphin hearing abilities vary greatly, with sensitivity decreasing as animals age, more so in males than females (Houser and Finneran, 2006; Popov et al., 2007). Two animals tested showed signs of profound deafness (Houser and Finneran, 2006). In addition, Nachtigall et al. (2005) tested the hearing sensitivities of a stranded infant Risso’s dolphin, *Grampus griseus*, with AEP and discovered that the young animal had a greater sensitivity to sound than a previously tested adult individual, leading them to conclude that current assumptions on Risso’s dolphin acoustics “probably underestimate the best hearing sensitivity for this species” (p. 4187, Nachtigall et al., 2005). This conclusion is probably valid for any hearing data gathered from only males or older dolphins, from animals that have been treated with antibiotics, or in studies sampling small numbers of individuals.

Additional concern regarding any recommendation to raise noise exposure limits (e.g., Southall et al., 2007) arises from suggestions by some researchers and environmental advocates that the current noise exposure threshold of 180 dB (re 1 μPa @ 1 m) is already unsafe for cetaceans. For example, data presented to the Scientific Committee at the 2004 meeting of the International Whaling Commission suggest that the sound exposure level for the beaked whales involved in the 2000 Bahamas incident was actually much lower than previously thought, i.e., “[t]he modelled sound exposure levels do not exceed 160–170 dB re 1 μPa @ 1 m for 10–30 s” (p. 286, Hildebrand, 2005b). It was considered that “[t]hese levels are not sufficient enough to produce even temporary threshold shift...for captive bottlenose dolphins or beluga whales” (p. 286, Hildebrand, 2005b).

While in many cases of sonar-related strandings it is not possible to calculate the exact exposure level, as the location of the animals during first exposure is not known, some cetacean strandings coincident with the use of military sonar have almost certainly

occurred at levels of sound exposure lower than would cause physical damage to cetacean auditory systems (Hildebrand, 2005b). Although exposure at a high enough received level could theoretically cause lethal trauma, it is likely that in many sonar exposure cases it is behavioral change, rather than physiological impacts, that is the problem. As noted earlier, perhaps the sounds elicit abnormal diving behavior, which may then bring about decompression sickness-like effects, such as reported by Jepson et al. (2003), which in turn could lead to pathological changes that injure, disable or kill cetaceans (Cox et al., 2006; Hildebrand, 2005b; International Whaling Commission, 2006a). Such impacts may not happen instantaneously but could occur over periods of days or weeks (Jepson et al., 2003).

Ideally a new way of calculating safe sound exposure levels for cetaceans is required. Kastelein et al. (2006) suggests an “acoustic discomfort threshold,” which they defined as “the boundary between areas that the animals generally occupy during the transmission of the sounds and the areas that they generally do not enter during transmission. The [sound pressure level in decibels] at this boundary is the discomfort threshold” (p. 21). Such a behavioral threshold is a possible way forward, although as noted above, using data based on captive animals may not result in an accurate model for behavior of animals in the wild.⁴ Establishing reliable behavioral thresholds is also unlikely to be an easy task, as demonstrated by the complexity of and the number of caveats in the attempt by Southall et al. (2007).

Finally, it should be emphasized that not all strandings necessarily involve behavioral mechanisms. Also, and more importantly, biologically significant effects on cetacean populations do not just arise from strandings. For example, Williams et al. (2006) described elevated energetic costs resulting from disturbance that could be biologically significant. In addition, there is potential for significant impacts arising from the interplay of the various consequences of masking (i.e., the “drowning out” of biologically important sounds), including loss of opportunities for foraging or reproduction, anxiety or stress, and non-detection of predators (Bateson, 2007; Weilgart, 2007; Wright et al., 2007a,b).

Indeed population level effects are more likely to be sub-lethal (e.g., repeated and widespread reduction in foraging or reproductive success, widespread impaired immune function, or large-scale displacement), which could lead to morbidity and/or indirect mortality (Marine Mammal Commission, 2007; Weilgart, 2007). To date, studies looking at impacts of anthropogenic sound on cetaceans tend to be of individual or group responses. How (or if) these responses translate into population level effects is not a minor question (e.g., Weilgart, 2007) and has been at the center of much debate (Marine Mammal Commission, 2007). It is extremely difficult to demonstrate under what circumstances changes in individual or even group behavior lead to changes in significant population parameters, such as foraging efficiency, reproductive success, or infant mortality (National Research Council, 2005). Indeed, as noted by the National Research Council, “sound may represent only a second-order effect on the conservation of marine mammal populations; on the other hand, what we have observed so far may be only the first early warnings or ‘tip of the iceberg’ with respect to sound and marine mammals” (p. 15, National Research Council, 2005). Sound exposure standards based on population level effects will be a challenge to develop and will require novel ways of thinking (e.g., the conceptual model connecting behavioral changes to ‘life functions’; National Research Council, 2005). However, in the meantime, safe exposure levels will need to be extrapolated from studies looking at measurable (i.e., individ-

ual) responses, which, as noted above, involves its own set of difficulties and challenges.

7. International recognition of the problem

The number of cetacean stranding incidents coincident with military activities and the documented bends-like lesions provide substantial evidence that military sonars are a cause of mortality in beaked whales, and possibly in a range of other cetacean species. To use a term often associated with the situation, strandings coincident with military exercises are “a smoking gun.”

The occurrence of beaked whale mass strandings concurrent with sonar exercises is high enough that it is unlikely to be coincidence, as was noted in 2001 by Hal Whitehead in a letter to the US National Marine Fisheries Service (the responsible authority for cetacean conservation and management in the United States). In this letter, dated 1 May 2001, he noted:

“The International Whaling Commission’s Standing Working Group on Environmental Concerns reported that 8/49 beaked whale strandings occurred with ‘military activities’. We do not know the rate of occurrence of ‘military activities’ but, by assuming rates, it is possible to calculate the probability of these numbers of coincidences (or more) between strandings and military activities, under the null hypothesis that they are unrelated. In fact for the probability that 8/49 (or more) beaked whale strandings occurred with military activities to be greater than $p=0.05$ (the usually accepted level for rejection of a null hypothesis), military activity would have to occur more than 8.4% of the time, and for the probability that 6/6 multiple beaked whale strandings occurred with military activities to be greater than $p=0.05$, military activity would have to occur more than 60.7% of the time. The actual rate of military activities in any area is probably nearer 0.1%. Thus the number of strandings of beaked whales with military activities is very unlikely to be a coincidence. Military activities are strongly implicated in these events.” (Cited in Parsons et al., 2003, p. 40)

International bodies are beginning to take notice. For example, in 2004 after the Scientific Committee of the International Whaling Commission had discussed the cetacean and noise issue, over 200 of the world’s leading whale biologists approved the statement: “. . .there is now compelling evidence implicating military sonar as a direct impact on beaked whales in particular” (p. 37, International Whaling Commission, 2005a).

Anthropogenic noise, including military sonar, has been discussed by the World Conservation Union (IUCN); the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) and the Agreement on the Conservation of Cetaceans of the Black and Mediterranean Seas (ACCOBAMS) (agreements established under the Convention on the Conservation of Migratory Species of Wild Animals); the European Parliament; and even the United Nations. In fact, the Preamble to ASCOBANS identifies “disturbance” as a factor that “may adversely affect these populations” and the agreement’s management plan calls on the Parties to work towards, *inter alia*, the prevention of significant disturbances, “especially of an acoustic nature” (ASCOBANS, 1992).

In the face of available information, various resolutions have been passed at the meetings of these bodies calling for member governments or parties to: (1) consider the impacts of ocean noise on marine living resources, either in general (UN General Assembly – Resolution on Oceans and the Law of the Sea [A/RES/60/30] at paragraph 84), or specifically in the designation of marine protected areas and in decisions on listing, such as the construction of the IUCN’s Red List (IUCN, 2004); (2) introduce guidelines and/or codes of conduct for operations of sound-producing activities

⁴ However, there are also ethical issues surrounding some methods of acoustics research in free-ranging cetaceans that are beyond the scope of this paper.

(ACCOBAMS, 2004; ASCOBANS, 2000; 2003; 2006); (3) employ a precautionary approach and implement conservation measures regardless of full scientific certainty (ASCOBANS, 2000; IUCN, 2004⁵); and (4) work towards, if not immediately implement, limitations on high-intensity sound sources, at least in habitats known to support species of particular concern and until their effects on marine mammals are better understood (ACCOBAMS, 2004; IUCN, 2004).

As noted above, the ASCOBANS Parties adopted a resolution on disturbance urging a precautionary approach in the year 2000. In the context of acoustic disturbance associated with military activities, the resolution invited the Parties and other Range States of small cetaceans in the region “to work with military authorities to introduce codes of conduct and similar measures – such as environmental impact assessments and standing orders – to reduce disturbance of small cetaceans” and to report at a future meeting of the agreement’s Advisory Committee on approaches to reduce disturbances to cetaceans associated with military activities (ASCOBANS, 2000). At the Fourth Meeting of the Parties, this commitment was reaffirmed, and the Parties and Range States were invited to develop effective mitigation measures while consulting with military authorities and to report to the Advisory Committee by 2005 on approaches to reduce or eliminate adverse effects of military activities on small cetaceans in the Agreement area (ASCOBANS, 2003). At the Meeting of the Parties in 2005, there was again an invitation for Parties and Range States to work with military authorities to develop effective measures to reduce acoustic disturbances, emphasizing environmental impact assessments and standing orders (ASCOBANS, 2006). Of course, most striking is the fact that the Parties have had to introduce almost identical resolutions over the span of three Meetings of the Parties in the face of the continuing failure of the Parties to address the issue at the national or regional level.

ACCOBAMS Parties produced a similar resolution that urged all to “avoid the use of man made noise in habitat of vulnerable species and areas where marine mammals or endangered species may be concentrated” and for noise producing activities to only proceed with “special caution” in areas where there may be beaked whales (ACCOBAMS, 2004). The resolution also charged the ACCOBAMS Scientific Committee to develop “a common set of guidelines on conducting activities known to produce underwater sound with the potential to cause adverse effects on cetaceans”, including military sonar, and called for “extreme caution” when conducting noise producing activities in the Mediterranean and Black Seas (ACCOBAMS, 2004). The Scientific Committee produced these guidelines, which were considered at the Third Meeting of the Parties in October 2007. They included recommendations to avoid key marine habitats; to use passive acoustic monitoring to improve detection capabilities; and to employ extra mitigation measures in deep water areas suitable for beaked whales (ACCOBAMS, 2007a). As a result of this document a resolution was passed (Res. 3.10) urging member nations to reduce underwater noise and to “develop quieter and environmentally safer” noise producing technologies (ACCOBAMS, 2007b).

Perhaps most importantly, on 28 October 2004 the European Parliament passed a resolution that is probably one of the strongest statements by an international body yet on the issue of military sonar and its impact on cetaceans. This resolution called on the European Commission and the Member States to:

“adopt a moratorium on the deployment of high-intensity active naval sonars until a global assessment of their cumulative environmental impact on marine mammals, fish and other

marine life has been completed”; and “immediately restrict the use of high-intensity active naval sonars in waters falling under their jurisdiction”; as well as to “set up a Multinational Task Force to develop international agreements regulating noise levels in the world’s oceans, with a view to regulating and limiting the adverse impact of anthropogenic sonars on marine mammals and fish.” (European Commission, 2004)

Despite these strong statements, there has been little substantive action taken subsequently by any nation. However, in November 2004, the Spanish government enacted a ban on military sonar use in the coastal waters of the Canary Islands in response to concerns over the large number of strandings associated with military exercises in this region.⁶ Spain is the only country to introduce such a ban to date.

Indeed, the greatest user of military sonars in the world, the US Navy, appears to be in denial about the situation and dismissive of the concerns of other nations. Indeed, some senior members of the US government are actively working to make conservation of cetaceans, with respect to underwater sound if not in general, more difficult. Despite the head of the US Environmental Protection Agency testifying before the US Senate that “I do not believe that there is a training mission anywhere in the country that is being held up or not taking place because of environmental protection regulation” (Anonymous, 2003), the US government introduced various exceptions to environmental regulations in the November 2003 *Department of Defense Authorization Bill* (H.R.1588; enacted as Public Law No: 108-136), claiming that environmental regulations were hindering military effectiveness (Kaufman, 2003). The US Marine Mammal Protection Act (MMPA) (Public Law 108-136; Sec. 319) was amended, allowing the US military to weaken and/or circumvent processes that previously regulated its activities resulting in “take” (harassment, injury or death) of marine mammals, regardless of whether these activities take place during peacetime or not (Sec. 319 (b)). The changes to the MMPA included removing previous restrictions for confining takes of marine mammals to “small numbers” and to a “specified geographic region” (Sec. 319 (c)(3)).

The US Navy has also resisted the idea of international regulation for military sonars, as was evident in a policy statement memorandum produced largely in response to the European Union resolution noted above (Kaufman, 2005b). The memorandum states that “[t]he US strongly opposes any international regulatory framework addressing military use of active sonar because of the potential to restrict individual states to balance the relevant security and environmental interests” (Kaufman, 2005b). The Navy presumably fears that the resolution could lead to restriction on the use of sonar by NATO and the United States when operating in European waters.

This attitude is exemplified in the legal wrangling over the so-called “SOCAL” exercises in California. The California Coastal Commission (the state agency overseeing development and environmental issues within California’s coastal zone) called for the US Navy to adopt additional mitigation measures for a suite of 14 sonar-utilizing exercises off southern California. Many of these measures had been used previously by the Navy during exercises in the Pacific (Fletcher, 2008). However, the Navy rejected all of the state’s additional mitigation measures with the exception of a reporting requirement, claiming that the measures it was currently utilizing were sufficient to protect cetaceans. This led

⁵ It should be noted that the US representatives did not vote for this resolution, and recused the United States from discussions and deliberations on the topic.

⁶ Act of Publication to the Official Journal of the Convention of Collaboration between the Ministry of Defence and the Government of the Canary Islands relating to the measures that need to be taken in order to avoid mass beaked whale strandings such as those that occurred in the Islands of Fuerteventura and Lanzarote in September 2004.

to a lawsuit, during which the court concluded that the Navy's current measures were "woefully inadequate and ineffectual" (p. 17, Cooper, 2007).

The court imposed several additional mitigation measures, among which were establishing a 12 nautical mile sonar exclusion zone along the California coastline, excluding sonar from an area between the Channel Islands, and mandating a shutdown of sonar operations if marine mammals are spotted within 2 km of the sonar source (Cooper, 2008a). One provision called for increased monitoring by experienced, trained observers because, as the judge noted (Cooper, 2008a), the use of specialist marine mammal observers results in greater mitigation.⁷

In response to this ruling, the White House issued documents exempting the US Navy from the National Environmental Policy Act (NEPA) and certain sections of the Coastal Zone Management Act (CZMA), the key environmental laws under which the case was brought. However, the judge ruled that the executive waiver of NEPA was invalid and the exemption from the CZMA potentially unconstitutional, and while it declined to rule on the CZMA issue under the doctrine of constitutional avoidance, asserted that the Navy remained bound by NEPA (Cooper, 2008b). The federal court of appeals affirmed this decision (Fletcher, 2008). Moreover, it dismissed the Navy's protests that the additional mitigation measures would not allow effective training, stating, "To the contrary, there is significant evidence of the Navy's ability to successfully train and certify its strike groups under the conditions imposed by the district court" (p. 103, Fletcher, 2008). However, this does not end the issue, and the Navy has recently petitioned for the case to proceed to the US Supreme Court.

Thus, despite claims of being a "steward of the marine environment" found in many of its public relations materials (e.g., Byus, 2006), the US Navy is actively opposing increased controls on mid-frequency sonar, as well as dismantling and attempting to avoid laws designed to protect both marine mammals and the environment. But the United States is not the only culprit, as other governments have been slow to acknowledge the issue, or reluctant to take action that curtails their current activities, despite increasing evidence and concerns about mid-frequency sonar expressed by scientists and politicians.

The main argument opposing the taking of appropriate action can be summarized as "national security concerns". For example, navies often suggest that lack of field training will compromise national security, as simulations are not sufficient. However, they do not take into account the security risks posed by the exercises. One key message of the *Millennium Ecosystem Assessment (2005)* report on biodiversity was as follows:

"Biodiversity benefits people through more than just its contribution to material welfare and livelihoods. Biodiversity contributes to security, resiliency, social relations, health, and freedom of choices and actions" (p. vi).

The report goes on to make the following points:

"Many of the costs of changes in biodiversity have historically not been factored into decision making. Many costs associated with changes in biodiversity may be slow to become apparent, may be apparent only at some distance from where biodiversity was changed, or may involve thresholds or changes in stability that are difficult to measure" (p.5).

In fact, recent studies have correlated adverse environmental changes and impacted ecosystems with historic periods of warfare;

⁷ However, scientific studies have shown that the likelihood of detecting vulnerable species such as beaked whales in the near vicinity of sonar-using naval vessels is extremely low (e.g., Barlow and Gisiner, 2006).

therefore, disturbed ecosystems may actually decrease security (Zhang et al., 2007).

In accordance with Wobeser (1994), it must be assumed that military exercises involving sonar are not just affecting a small number of beaked whales, but are likely to be having wider effects on the ecosystem and quite possibly causing loss of biodiversity (at least locally, as appears to be the case in the Bahamas). Accordingly, the stability and security risks associated with such sonar exercises must be carefully balanced against the security risks of a simulated, reduced and/or relocated training schedule. It seems illogical for a country to fight so hard to protect its society, health, and freedom from its enemies while damaging the ecosystems necessary to sustain the very same things.

8. Conclusions

Investigating the true extent of sonar-related strandings and mortality is difficult. Information is lacking about the activities; position in the water column and location of the animals; the number and level of sound exposures; and other environmental variables. Often there is uncertainty surrounding naval maneuvers. In 2004, the International Whaling Commission noted the urgent need for data on the pathology of strandings, the extent of military activities, and possible high-intensity noise-emitting natural phenomenon that might cause strandings (International Whaling Commission, 2005b) and urged the provision of data that could allow an analysis of the impacts of sonar and other activities that produce high-intensity sound. It has reiterated these requests every year subsequently (International Whaling Commission, 2006b, 2007, in press). Without such data, our understanding of these phenomena will be limited. Consequently, with so much unknown and so much uncertainty, fully qualified results may be years, or even decades, away.

However, it should be emphasized that absence of evidence is not evidence of absence. Given absence of evidence, the precautionary concepts that are imbedded in environmental agreements, laws and regulations around the world (including the United States) should be implemented as soon as possible. Currently environmental impact assessment methods largely rely on assessment of physical damage to cetaceans to predict the potential impact of noise producing activities such as military sonar. At the very least these methods should be abandoned or substantially modified, in the face of mounting data and expert opinion that such assumptions are erroneous and that behavioral responses at much lower sound levels have the potential to produce a range of detrimental effects (e.g., Lusseau et al., 2006; Williams et al., 2006; Wright et al., 2007b), including those that may result in injury or death, and given the likelihood that population level impacts can arise from non-lethal exposures.

Also the introduction of new types of military sonar, such as low frequency systems (SURTASS LFA in the United States and SONAR 2087⁸ in the United Kingdom), should proceed with caution. The low frequency sounds produced by these systems will travel much farther than the mid-frequency sonar sounds currently causing concern. Moreover, the potential effects of masking may be more complicated than previously thought (Bateson, 2007; Wright et al., 2007a,b). At the very least the NATO nation should work with scientists and conservationists to conduct a thorough and open assess-

⁸ For the Royal Navy's SONAR 2087 low frequency system (which has a source level at least 10 dB quieter than the US SURTASS LFA system), the environmental impact assessment predicts that cetacean auditory damage (PTS) could occur up to 6.6 km from the source (QinetiQ, 2002), with TTS at up to 71 km (QinetiQ, 2002) and behavioural impacts occurring presumably at a still greater range. Yet the much louder US system only monitors for impacts within a 1 km radius; therefore, many impacts are unlikely to be detected using this monitoring system.

ment of the potential impacts of these sonar systems, both on paper and in the field, postponing the mass deployment of these systems until such an assessment is done to the satisfaction of the marine science and policy community at large. Given that on-board and localized mitigation measures are unlikely to be effective at the lower received levels discussed in this paper, important cetacean habitats should be avoided by naval vessels during training and exercises involving either mid- or low-frequency sonar systems.

This paper reviews some of the cases where military sonar has been associated with cetacean strandings. Furthermore, the probability of these associations occurring by chance is prohibitively low, while the likelihood of undiscovered casualties is very high. There will undoubtedly be other events in the future, which must continue to be documented, in as much detail as possible. However, we contend that there is already enough evidence to know that the current efforts to protect cetaceans from the consequences of exposure to sonar and undoubtedly other intense anthropogenic sound are inadequate and that additional protection measures are therefore required.

We thus assert that the issue of cetacean strandings and mortalities arising from military exercises and sonar use has progressed well beyond the point of finding a smoking gun. Despite this, some senior government officials, particularly in the United States, are deliberately obstructing progress in mitigation and making the protection of cetaceans and their environment from sonar more difficult through deliberate and calculated measures, such as legislative changes. The question is no longer: can we find the smoking gun? It is: how can the governments of the world find the political will to act?

Acknowledgments

The authors would like to thank Robert Brownell and an anonymous reviewer for helpful comments on the manuscript. Michael Jasny provided invaluable assistance on the discussion of the SO-CAL court proceedings.

References

- ACCOBAMS, 2007a. Doc. 20, Guidelines to address the issue of the impact of anthropogenic noise on marine mammals in the ACCOBAMS area, 22–25 October 2007, Dubrovnik, Croatia.
- ACCOBAMS, 2007b. Resolution 3.10. Guidelines to address the issue of the impact of anthropogenic noise on marine mammals in the ACCOBAMS area. 3rd Meeting of the ACCOBAMS Contracting Parties, 22–25 October 2007, Dubrovnik, Croatia. Available from: <<http://www.accobams.org/file.php/1253/Res%203.10.pdf>>.
- ACCOBAMS, 2004. Resolution 2.16. Assessment and impact assessment of man-made noise. 2nd Meeting of the ACCOBAMS Contracting Parties, 9–12 November 2004, Palma de Mallorca, Spain. Available from: <[http://www.accobams.mc/Accob/Wacco.nsf/0/491fb7e7d4267c0cc1256f7e004b4ec8/\\$FILE/E%20Res%202.16.pdf](http://www.accobams.mc/Accob/Wacco.nsf/0/491fb7e7d4267c0cc1256f7e004b4ec8/$FILE/E%20Res%202.16.pdf)>.
- Allison, P.A., Smith, C.R., Kukert, H., Deming, J.W., Bennett, B.A., 1991. Deep-water taphonomy of vertebrate carcasses: a whale skeleton in the Bathyal Santa Catalina Basin. *Paleobiology* 17, 78–89.
- Anonymous, 2001. Joint Interim Report Bahamas Marine Mammal Stranding Event of 14–16 March 2000, Washington, DC, National Oceanic and Atmospheric Administration. Available from: <http://www.nmfs.noaa.gov/prot_res/PR2/Health_and_Stranding_Response_Program/Interim_Bahamas_Report.pdf>.
- Anonymous, 2003. Excerpts regarding DOD exemptions from environmental laws from the Senate EPW hearing, 26 February 2003, on the President's 2004 budget for the Environmental Protection Agency. Christine Todd Whitman testifying. Available from: <http://www.house.gov/commerce_democrats/DODexemptions/excerpts.pdf>.
- ASCOBANS, 1992. Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas. Available from: <<http://www.ascobans.org/index0101.html>>.
- ASCOBANS, 2000. Resolution No. 4. Disturbance. 3rd Session of the Meeting of the Parties, Bristol, UK, 26–28 July 2000. Available from: <http://www.service-board.de/ascobans_neu/files/2000-2.pdf>.
- ASCOBANS, 2003. Resolution No. 5. Effect of noise and of vessels. 4th Meeting of the Parties, 19–22 August 2003, Esbjerg, Denmark. Available from: <http://www.service-board.de/ascobans_neu/files/finalres5.pdf>.
- ASCOBANS, 2006. Resolution No. 4. Adverse effects of sound, vessels and other forms of disturbance on small cetaceans, 5th Meeting of the Parties, 18–20 September and 12 December 2006. Available from: <http://www.service-board.de/ascobans_neu/files/mop5-final-4.pdf>.
- Balcomb, K.C., Claridge, D.E., 2001. A mass stranding of cetaceans caused by naval sonar in the Bahamas. *Bahamas Journal of Science* 8, 1–12.
- Baldwin, A.L., 2007. Effects of noise on rodent physiology. *International Journal of Comparative Psychology* 20 (2–3), in press.
- Barlow, J., Gisiner, R., 2006. Mitigating, monitoring and assessing the effects of anthropogenic sound on beaked whales. *Journal of Cetacean Research and Management* 7, 239–249.
- Bateson, M., 2007. Environmental noise and decision making: possible implications of increases in anthropogenic noise for information processing in marine mammals. *International Journal of Comparative Psychology* 20 (2–3), in press.
- Brownell Jr., R.L., Yamada, T., Mead, J.G., van Helden, A.L., 2004. Mass Strandings of Cuvier's Beaked Whales in Japan: US Naval Acoustic Link? Paper presented to the Scientific Committee at the 56th Meeting of the International Whaling Commission, 29 June–10 July 2004, Sorrento, Italy, SC56/E37.
- Byus, F., 2006. Oceanographer of the Navy RADM Fred Byus's Speech at Marine Technology Society Annual Meeting, Delivered 28 September 2006. Available from: <http://www.navy.mil/pao/oct_nov_2006/currentevents.html>.
- Cooper, F.M., 2007. NRDC et al. vs. D.C. Winter et al. District Court Judge Florence Marie Cooper, order denying defendant's motion to dismiss or stay, 6 August 2007.
- Cooper, F.M., 2008a. NRDC et al. vs. D.C. Winter et al. District Court Judge Florence Marie Cooper, order issuing preliminary injunction, 3 January 2008. Available from: <http://docs.nrdc.org/water/wat_08010301A.pdf>.
- Cooper, F.M., 2008b. NRDC et al. vs. D.C. Winter et al. District Court Judge Florence Marie Cooper, order denying defendants' ex parte application to vacate preliminary injunction, 4 February 2008. Available from: <http://docs.nrdc.org/water/wat_08020401A.pdf>.
- Cox, T.M., Ragen, T.J., Read, A.J., Vos, E., Baird, R.W., Balcomb, K., Barlow, J., Caldwell, J., Cranford, T., Crum, L., D'Amico, A., D'Spain, G., Fernandez, A., Finneran, J., Gentry, R., Gerth, W., Gulland, F., Hildebrand, J., Houser, D., Hullar, T., Jepson, P.D., Ketten, D., MacLeod, C.D., Miller, P., Moore, S., Mountain, D.C., Palka, D., Pongonis, P., Rommel, S., Rowles, T., Taylor, B., Tyack, P., Wartzok, D., Gisiner, R., Mead, J., Benner, L., 2006. Understanding the impacts of acoustic sound on beaked whales. *Journal of Cetacean Research and Management* 7, 177–187.
- Crum, L., Bailey, M.R., Guan, J., Hilmo, P.R., Kargl, S.G., Matula, T.J., 2005. Monitoring bubble growth in supersaturated blood and tissue ex vivo and the relevance to marine mammal bioeffects. *Acoustics Research Letters Online* 6, 214–220.
- Deak, T., 2007. From classic aspects of the stress response to neuroinflammation and sickness: implications for individuals and offspring of diverse species. *International Journal of Comparative Psychology* 20 (2–3), in press.
- Department of the Environment and Heritage, 2005. Marion Bay whale stranding. Department of the Environment and Water Resources, Australian Government. Available from: <<http://www.environment.gov.au/coasts/publications/marion-bay-strandings-2005.html>>.
- Dolman, S.J., Reid, R.J., Barley, J.P., Deaville, R., Jepson, P.D., O'Connell, M., Berrow, S., Penrose, R.S., Pinn, E., Stevick, P.T., Calderan, S., Robinson, K.P., Doyle, T.K., Brownell Jr., R.L., Simmonds, M.P., 2008. A preliminary note on the unprecedented strandings of 45 deep-diving odontocetes along the UK and Irish coast between January and April 2008, SC/60/E5. A Paper Presented to the International Whaling Commission Scientific Committee, Santiago, Chile.
- Espinosa, A., Arbelo, M., Castro, P., Martín, V., Gallardo, T., Fernández, A., 2005. New beaked whale mass stranding in Canary Islands associated with naval military exercises (Majestic Eagle 2004). In: 19th Annual Conference of the European Cetacean Society and Associated Workshops, 2–7 April 2005, La Rochelle, France, European Cetacean Society, La Rochelle, p. 95.
- European Commission, 2004. European Parliament resolution on the environmental effects of high-intensity active naval sonars [B6-0089/2004]. Available from: <<http://www.animalwelfare.com/whales/news/EU%2020Sonar%2020Resolution%202010-2004.pdf>>.
- Fernández, A., 2006. Beaked whale (*Ziphius cavirostris*) mass stranding on Almería's coasts in southern Spain, 26–27 January 2006. Report of the University of Las Palmas de Gran Canaria, Canary Islands.
- Fernández, A., Arbelo, M., Deaville, R., Patterson, I.A.P., Castro, P., Baker, J.R., Degollada, E., Ross, H.M., Herráez, P., Pocknell, A.M., Rodríguez, E., Howie, F.E., Espinosa, A., Reid, R.J., Jaber, J.R., Martín, V., Cunningham, A.A., Jepson, P.D., 2004. Pathology: whales, sonar and decompression sickness. *Nature* 428, 1–2.
- Fernández, A., Edwards, J.F., Rodríguez, F., Espinosa de los Morteros, A., Herráez, P., Castro, P., Jaber, J.R., Martín, V., Arbelo, M., 2005a. "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (Family Ziphiidae) exposed to anthropogenic sonar signals. *Veterinary Pathology* 42, 446–457.
- Fernández, A., Mendez, M., Sierra, E., Godhino, A., Herráez, P., Espinosa, A., Rodríguez, F., Arbelo, M., 2005b. New gas and fat embolic pathology in beaked whales stranded in the Canary Islands. In: 19th Annual Conference of the European Cetacean Society and Associated Workshops, 2–7 April 2005, La Rochelle, France, European Cetacean Society, La Rochelle, p. 95.
- Findley, K.J., Miller, G.W., Davis, R.A., Greene, C.R., 1990. Reactions of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, to ice-breaking ships in the Canadian high Arctic. *Canadian Journal of Fisheries and Aquatic Sciences* 224, 97–117.
- Finneran, J.J., Carder, D.A., Dear, R., Belting, T., McBain, J., Dalton, L., Ridgway, S.H., 2005. Pure tone audiograms and possible aminoglycoside-induced hearing loss in belugas (*Delphinapterus leucas*). *Journal of the Acoustical Society of America* 117, 3936–3943.

- Finneran, J.J., Schlundt, C.E., 2007. Underwater sound pressure variation and bottlenose dolphin (*Tursiops truncatus*) hearing thresholds in a small pool. *Journal of the Acoustical Society of America* 122, 606–614.
- Fletcher, B., 2008. NRDC et al. vs. D.C. Winter et al. Circuit Judge B. Fletcher, opinion, 27 February 2008, Pasadena, California. Available from: <http://docs.nrdc.org/water/wat_08022901A.pdf>.
- Francis, T.J.R., Mitchell, S.J., 2003. In: Brubakk, A.O., Neuman, T.S. (Eds.), *Bennett and Elliot's Physiology and Medicine of Diving*. Saunders, Philadelphia, pp. 530–556.
- Frantzis, A., 1998. Does acoustic testing strand whales? *Nature* 392, 29.
- Frantzis, A., 2004. The first mass stranding that was associated with the use of active sonar (Kyparissiakos Gulf, Greece, 1996). *ECS Newsletter* 42 (Special Issue), 14–20.
- Frantzis, A., Cebrian, D., 1999. A rare mass stranding of Cuvier's beaked whales: cause and implications for the species biology. *European Research on Cetaceans* 12, 332–335.
- Freitas, L., 2004. The stranding of three Cuvier's beaked whales *Ziphius cavirostris* in Madeira archipelago – May 2000. *ECS Newsletter* 42 (Special Issue), 28–32.
- Gould, J.C., Fish, P.J., 1998. Broadband spectra of seismic survey air-gun emissions, with reference to dolphin auditory thresholds. *Journal of the Acoustical Society of America* 103, 2177–2184.
- Gould, J.C., Fish, P.J., 1999. Response to "comments on 'broadband spectra of seismic survey air-gun emissions with reference to dolphin auditory threshold'". *Journal of the Acoustical Society of America* 105, 2049–2050.
- Hernandez, E.N., Kuczaj, S., Houser, D.S., Finneran, J.J., 2007. Middle- and long-latency auditory evoked potentials in bottlenose dolphins (*Tursiops truncatus*) resulting from frequent od.all stimuli. *Aquatic Mammals* 33, 34–42.
- Hildebrand, J.A., 2005a. Impacts of anthropogenic sound. In: Reynolds, J.E., Perrin, W.F., Reeves, R.R., Montgomery, S., Ragen, T.J. (Eds.), *Marine Mammal Research: Conservation Beyond Crisis*. The Johns Hopkins University Press, Baltimore, Maryland, pp. 101–124.
- Hildebrand, J.A., 2005b. Introduction to acoustics. *Journal of Cetacean Research and Management* 7 (Suppl.), 284–286.
- Hohn, A.A., Rotstein, D.S., Harms, C.A., Southall, B.L., 2006. Report on marine mammal unusual mortality event UMESE05015p: multi species stranding of short-finned pilot whales (*Globicephala macrorhynchus*) minke whale (*Balaenoptera acutorostrata*) and dwarf sperm whales (*Kogia sima*) in North Carolina, 15–16 January 2005. NOAA Technical Memorandum NMFS – SEFSC 537. National Oceanic and Atmospheric Administration, Washington, DC.
- Houser, D.S., Howard, R., Ridgway, S., 2001. Can diving-induced tissue nitrogen supersaturation increase the chance of acoustically driven bubble growth in marine mammals? *Journal of Theoretical Biology* 213, 183–195.
- Houser, D.S., Finneran, J.J., 2006. Variation in the hearing sensitivity of a dolphin population determined through the use of evoked potential audiometry. *Journal of the Acoustical Society of America* 120, 4090–4099.
- ICES (International Council for the Exploration of the Sea), 2005. Ad-hoc Group on the Impact of Sonar on Cetaceans. International Council for the Exploration of the Sea, Copenhagen, Denmark.
- International Whaling Commission, 2005a. Report of the scientific committee. *Journal of Cetacean Research and Management* 7 (Suppl.), 1–62.
- International Whaling Commission, 2005b. Report of the standing working group on environmental concerns. *Journal of Cetacean Research and Management* 7 (Suppl.), 267–305.
- International Whaling Commission, 2006a. Report of the IWC scientific committee workshop on habitat degradation. *Journal of Cetacean Research and Management* 8 (Suppl.), 313–335.
- International Whaling Commission, 2006b. Report of the standing working group on environmental concerns. *Journal of Cetacean Research and Management* 8 (Suppl.), 185–220.
- International Whaling Commission, 2007. Report of the standing working group on environmental concerns. *Journal of Cetacean Research and Management* 9 (Suppl.), 227–296.
- International Whaling Commission, in press. Report of the standing working group on environmental concerns. *Journal of Cetacean Research and Management*, 10 (Suppl.).
- IUCN (World Conservation Union), 2004. CGR3, RES053-REV1, Undersea noise pollution. 3rd IUCN congress, 17–25 November 2004, Bangkok, Thailand.
- Jepson, P.D., Arbelo, M., Deaville, R., Patterson, I.A.P., Castro, P., Baker, J.R., Degollada, E., Ross, H.M., Herráez, P., Pocknell, A.M., Rodríguez, F., Howiell, F.E., Espinosa, A., Reid, R.J., Jaber, J.R., Martin, V., Cunningham, A.A., Fernández, A., 2003. Gas-bubble lesions in stranded cetaceans: was sonar responsible for a spate of whale deaths after an Atlantic military exercise? *Nature* 425, 575–576.
- JNCC (Joint Nature Conservation Committee), 2004. Guidelines for minimizing acoustic disturbance to marine mammals from seismic surveys. Available from: <http://www.jncc.gov.uk/pdf/Seismic_survey_guidelines_200404.pdf>.
- Kastelein, R.A., van der Heul, S., Verboom, W.C., Triesscheijn, R.J.V., Jennings, N.V., 2006. The influence of underwater data transmission sounds on the displacement behaviour of captive harbour seals (*Phoca vitulina*). *Marine Environmental Research* 61, 19–39.
- Kaufman, M., 2003. Activists plan fight for marine mammals. Exempt from some rules to protect animals, navy might seek to alter sonar limits. *Washington Post*, 16 November, A11.
- Kaufman, M., 2004. Sonar used before whales hit shore. *Washington Post*, 31 August, A3.
- Kaufman, M., 2005a. Whale stranding in N.C. followed Navy sonar use. *Washington Post*, 28 January, A3.
- Kaufman, M., 2005b. US set to oppose efforts to restrict use of sonar. *Washington Post*, 28 February, A5.
- Ketten, D.R., 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. In: Kastelein, R., Thomas, J.A., Nachtigall, P.E. (Eds.), *Sensory Systems of Marine Mammals*. De Spil Publishing, Woerden, Netherlands, pp. 391–407.
- Lusseau, D., Slooten, E., Currey, R.J., 2006. Unsustainable dolphin watching activities in Fiordland, New Zealand. *Tourism in Marine Environments* 3, 173–178.
- Madsen, P.T., 2005. Marine mammals and noise: problems with root mean square sound pressure levels. *Journal of the Acoustical Society of America* 117, 3952–3957.
- Marine Mammal Commission, 2007. *Marine Mammals and Noise: A Sound Approach to Research and Management*. Report to Congress from the Marine Mammal Commission, March.
- Martin, V., Servidio, A., Garcia, S., 2004. Mass strandings of beaked whales in the Canary Islands. *ECS Newsletter* 42 (Special Issue), 33–36.
- Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington, DC.
- Miller, P.J.O., Biassoni, N., Samuels, A., Tyack, P., 2000. Whale songs lengthen in response to sonar. *Nature* 405, 903.
- Mitchell, E.D., 2005. What causes lesions in sperm whale bones? *Science* 308, 631.
- Moore, M.J., Early, G.A., 2004. Cumulative sperm whale bone damage and the bends. *Science* 306, 2215.
- Nachtigall, P.E., Mooney, T.A., Taylor, K.A., Yuen, M.M.L., 2007. Hearing and auditory evoked potential methods applied to odontocete cetaceans. *Aquatic Mammals* 33, 6–13.
- Nachtigall, P.E., Yuen, M.M.L., Mooney, T.A., Taylor, K.A., 2005. Hearing measurements from a stranded infant Risso's dolphin, *Grampus griseus*. *Journal of Experimental Biology* 208, 4181–4188.
- National Research Council, 2003. Effects of noise on marine mammals. In: *Ocean Noise and Marine Mammals*. National Academies Press, Washington, DC, pp. 83–108.
- National Research Council, 2005. *Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects*. National Academies Press, Washington, DC.
- Nowacek, D.P., Thorne, L.H., Johnston, D.W., Tyack, P.L., 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review* 37, 81–115.
- Ohsumi, S., 1980. Criticism on Japanese fishing effort for sperm whales in the North Pacific. *Report of the International Whaling Commission* 2 (Special Issue), 19–30.
- Parsons, E.C.M., Birks, I., Evans, P.G.H., Gordon, J.G., Shrimpton, J.H., Pooley, S., 2000. The possible impacts of military activity on cetaceans in West Scotland. *European Research on Cetaceans* 14, 185–190.
- Parsons, E.C.M., Swift, R., Dolman, S., 2003. Sources of noise. In: Simmonds, M., Dolman, S., Weilgart, L. (Eds.), *Oceans of Noise*. Whale and Dolphin Conservation Society, Chippenham, pp. 22–44.
- Piantadosi, C.A., Thalmann, E.D., 2004. Pathology: whales, sonar and decompression sickness. *Nature* 428, 1.
- Podesta, M., D'Amico, A., Pavan, G., Drougas, A., Komnenou, A., Portunat, N., 2006. A review of Cuvier's beaked whale strandings in the Mediterranean Sea. *Journal of Cetacean Research and Management* 7, 251–261.
- Popov, V.V., Supin, A.Y., Pletenko, M.G., Tarakanov, M.B., Klishin, V.O., Bulgakova, T.N., Rosanova, E.I., 2007. Audiogram variability in normal bottlenose dolphins (*Tursiops truncatus*). *Aquatic Mammals* 33, 24–33.
- QinetiQ, 2002. Environmental Impact Assessment (EIA) in support of the procurement of Sonar 2087 (S2087 Global EIA – version 1.0). Dorchester, UK, QinetiQ.
- Rendell, L.E., Gordon, J.C.D., 1999. Vocal response of long-finned pilot whales (*Globicephala melas*) to military sonar in the Ligurian Sea. *Marine Mammal Science* 15, 198–204.
- Ridgway, S.H., Carder, D.A., 1997. Hearing deficits measured in some *Tursiops truncatus*, and discovery of a deaf/mute dolphin. *Journal of the Acoustical Society of America* 101, 590–594.
- Rommel, S.A., Costidid, A.M., Fernandez, A., Jepson, P.D., Pabst, D.A., McLellan, W.W., Houser, D.S., Cranford, T.W., Van Helden, A.L., Allen, D.M., Barros, N.B., 2006. Elements of beaked whale anatomy and diving physiology and some hypothetical causes of sonar-related stranding. *Journal of Cetacean Research and Management* 7, 189–209.
- Schlundt, C.E., Dear, R.L., Green, L., Houser, D.S., Finneran, J.J., 2007. Simultaneously measured behavioral and electrophysiological hearing thresholds in a bottlenose dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America* 122, 615–622.
- Simmonds, M., Lopez-Jurado, L.F., 1991. Whales and the military. *Nature* 337, 448.
- Southall, B.L., Braun, R., Gulland, F.M.D., Heard, A.D., Baird, R.W., Wilkin, S.M., Rowles, T.K., 2006. Hawaiian melon-headed whale (*Peponocephala electra*) mass stranding event of 3–4 July 2004, NOAA Technical Memorandum NMFS-OPR-31. Office of Protected Resources Silver Spring, NOAA, Maryland. Available from: <<http://www.nmfs.gov/pr/health/mmmue/event2004jul.htm>>.
- Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene Jr., C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., Tyack, P.L., 2007. Marine mammal noise exposure criteria: initial scientific recommendations. *Aquatic Mammals* 33, 411–521.
- Taylor, B., Barlow, J., Pitman, R., Ballance, L., Klinger, T., DeMaster, D., Hildebrand, J., Urban, J., Palacios, D., Mead, J.G., 2004. A call for research to assess risk of acoustic impact on beaked whale populations. Paper presented to the Scientific

- Committee at the 56th Meeting of the International Whaling Commission, 29 June–10 July 2004, Sorrento, Italy, SC46/E36.
- Tyack, P.L., Johnson, M., Aguilar Soto, N., Sturlese, A., Madsen, P.T., 2006. Extreme diving of beaked whales. *Journal of Experimental Biology* 209, 4238–4253.
- Van Bree, P.J.H., Kristensen, I., 1974. On the intriguing stranding of four Cuvier's beaked whales, *Ziphius cavirostris* G. Cuvier, 1823, on the Lesser Antillean island of Bonaire. *Bijdragen tot de Dierkunde* 44 (2), 235–238.
- Vancouver Aquarium Marine Science Centre, 2003. BC: sonar incident still under investigation. Available from: <<http://www.vanaqua.org/aquanew/fullnews.php?id=103>>.
- Wang, J.Y., Yang, S.-C. 2004. Unusual cetacean stranding events in Chinese waters in early 2004 and the gross examination of a ginkgo-toothed beaked whale, *Mesoplodon ginkgodens*. Paper presented to the Scientific Committee at the 56th Meeting of the International Whaling Commission, 29 June–10 July 2004, Sorrento, Italy, SC56/E38.
- Wang, J.Y., Yang, S.-C., 2006. Unusual cetacean stranding events of Taiwan in 2004 and 2005. *Journal of Cetacean Research and Management* 8, 283–292.
- Watkins, W.A., Moore, K.E., Tyack, P., 1985. Investigations of sperm whale acoustic behaviors in the southeast Caribbean. *Cetology* 49, 1–15.
- Weilgart, L.S., 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology* 85, 1091–1116.
- Williams, R., Lusseau, D., Hammond, P.S., 2006. Potential energetic cost to killer whales of disturbance by vessels and the role of a marine protected area. *Biological Conservation* 133, 301–311.
- Wobeser, G., 1994. *Investigation and Management of Disease in Wild Animals*. Plenum Press, New York.
- Wright, A.J., Aguilar Soto, N., Baldwin, A.L., Bateson, M., Beale, C., Clark, C., Deak, T., Edwards, E.F., Fernández, A., Godinho, A., Hatch, L., Kakuschke, A., Lusseau, D., Martineau, D., Romero, L.M., Weilgart, L., Wintle, B., Notarbartolo di Sciarra, G., Martin, V., 2007a. Anthropogenic noise as a stressor in animals: a multidisciplinary perspective. *International Journal of Comparative Psychology* 20 (2–3), in press.
- Wright, A.J., Aguilar Soto, N., Baldwin, A.L., Bateson, M., Beale, C., Clark, C., Deak, T., Edwards, E.F., Fernández, A., Godinho, A., Hatch, L., Kakuschke, A., Lusseau, D., Martineau, D., Romero, L.M., Weilgart, L., Wintle, B., Notarbartolo di Sciarra, G., Martin, V., 2007b. Do marine mammals experience stress related to anthropogenic noise? *International Journal of Comparative Psychology* 20 (2–3), in press.
- Zhang, D.D., Brecke, P., Lee, H.F., He, Y.-Q., Zhang, J., 2007. Global climate change, war, and population decline in recent human history. *Proceedings of the National Academy of Science* 104, 19214–19219.