A call for research to assess risk of acoustic impact on beaked whale populations

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***Abstract*--We report the first observation implicating low-frequency seismic exploration in whale strandings. This observation, together with whale multiple strandings linked with naval exercises using mid-frequency sonar, suggests that acoustic-related mortality may pose problems for some deep diving whales. Detecting beaked whales is difficult both because whales are usually submerged and surfacings are inconspicuous . The worldwide increase in use of high-intensity underwater sound raises serious conservation concerns for this suite of species. Because of their rarity and their remote, deep-water distribution population declines are unlikely to be detected. We call for collaborative research to assess the magnitude of the problem and develop acceptable solutions.**

Index terms--Beaked whales, *Ziphius cavirostris*, Cuvier's beaked whale, Gulf of California, high-intensity sound, seismic exploration, whale strandings, mid-frequency sonar, air guns.

A series of multiple whale strandings have been associated with the use of high-intensity sonar during military operations, but now there is reason to suspect that high-intensity sound used for academic research and perhaps maritime oil exploration may also be capable of injuring some types of cetaceans.

On 25 September, 2002, while vacationing in the Gulf of California (Mexico), six of the authors found two freshly dead Cuvier's beaked whales (*Ziphius cavirostris*) showing no signs of external trauma. We subsequently learned that the *R/V Maurice Ewing* (operated by Columbia University, Lamont-Doherty Earth Observatory) was nearby conducting a seismic survey using an airgun array. At 13:00 September 24 the Ewing was firing airguns 22 km from the stranding site. Between 14:00 and 16:00 local fishermen found the live stranded whales and tried to return them to the sea. By 27 September, when one carcass was necropsied, the advanced state of decomposition prevented finding conclusive physical evidence for a link to the seismic research. However, this observation joins a growing body of evidence correlating strandings with high-intensity acoustic activities.

Table 1 compiles multiple strandings (comprising at least two whales) for *Ziphius cavirostris*, a deep-diving whale from the family Ziphiidae (beaked whales). Despite reports of multiple strandings of other species of beaked whales dating back to the 1800s, such records for *Z. cavirostris* began only recently and are increasing in frequency. The Bahamas standings of 2000 [1] provided a direct link between beaked whale stranding and high-intensity acoustic

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transmissions: four of five necropsies revealed auditory structural damage, with the two freshest specimens revealing injuries sustained prior to death with debilitating hemorrhages consistent with loss of navigational abilities that lead to stranding. The most likely source of the acoustic trauma was mid-frequency AN/SQS-53C tactical sonars (235 dB re: microPa@1m concentrated between 2.6 and 3.3 kHz) used by U.S. Navy ships. Military mid-frequency sonar was also linked to the stranding of 15-17 beaked whales in the Canary Islands in 2002 [2]. The seismic research associated with our observations in the Gulf of California produced higher intensity sounds (263 dB re: microPa@1m) than the tactical sonar, although the peak frequencies were lower (100 Hz). Sound intensity levels consistent with those documented to produce harmful effects in the Bahamas incident were estimated to extend to 15km from the *R/V Ewing* airguns assuming simple spherical spreading of energy.

A number of recent court rulings highlight the gravity of this issue. On October 28, 2002 a court order was issued against the National Science Foundation restraining the *R/V Ewing's* operations in Mexico because of the whale strandings observed by the authors. Two days later a similar order was separately issued blocking U.S. Navy deployment of a new low-frequency sonar system (LFA) because of potential harm to marine mammals. On August 26, 2003 a U.S. District Court issued a permanent injunction regarding the use of LFA in coastal areas [3]. The court mandated pre-operation surveys to help protect marine mammals such as beaked whales from the risk of stranding.

We still do not understand the mechanism of injury, the magnitude of the problem, or appropriate mitigation strategies. Necropsies of animals in the 2002 Canary Islands mass stranding (Table 1) noted gas bubbles in the tissue thought to supply the reason for stranding [2], but much is yet to be learned about causality. The magnitude of the problem will depend on whether the mechanism causing mortalities is strictly physiological or whether behavior plays an important role. The population-level impacts will also depend on the structure of populations and the probability that an injured beaked whale will be found on a beach. We do not yet know whether *Z. cavirostris* is especially vulnerable to high-intensity sound, whether this species is simply more likely to strand rather than sink, or whether they are just more abundant than other beaked whales. Even if most dead beaked whales float, we need more data to estimate the likelihood of carcasses reaching a beach or being detected in an aerial survey. Appropriate mitigation strategies must recognize that beaked whales are difficult to see in anything less than perfect conditions. Compared to many other whales, beaked whales are smaller (5-7m), surface less conspicuously, and spend a smaller fraction of their time at the surface. It has been estimated that skilled observers searching with 25X binoculars in calm seas can visually detect only 23% of animals that pass directly under ships and that essentially none can be detected beyond 3 km [4]. At this stage we are overwhelmed with the lack of essential information and with the technical difficulties of obtaining it.

Ours is the first observation implicating low-frequency seismic exploration in whale strandings. The potential risk to beaked whales is greatly increased if both low- and mid-frequencies prove injurious. Oil drilling companies are attempting to access oil deposits at depths up to 3,000 m. Of 78 beaked whale sightings during a 1993 survey off California and Baja California and in the Gulf of California, only one was found in depths where oil extraction is common (<150 m), whereas 67% were between 150 m and 3000 m. Nearly all of the 21 species of beaked whales are naturally rare worldwide. All are difficult to detect. Some species have never been seen alive in the wild and therefore likely have highly restricted distributions [5].

The worldwide increase in uses of high-intensity underwater sound raises serious conservation and management concerns for this suite of species. Evidence presented in Table 1 is sufficient to identify a problem for beaked whales, even if the magnitude of this problem is not yet known. Collaborative research between acousticians and biologists is needed to assess the magnitude of the problem. Such research should include mapping of current and planned high-intensity acoustic activities, mapping of beaked whale densities and identifying areas where no data are available, estimating beaked whale densities and population structures particularly in areas of high acoustic activity, investigating the mechanism of harm to beaked whales from high-intensity acoustics, developing improved beaked whale detection methods, and estimating the probability of detecting lethal effects on beaked whales.

Conservation of rare species is often fraught with uncertainties. Rarity itself is an impediment to conservation because low numbers of sightings result in low statistical power to detect a population decline. Two types of errors are common when statistical power is low: under-protection errors where populations do not receive sufficient conservation action because problems go unrecognized and over-protection errors where actions are taken far beyond the warranted level because problem magnitude cannot be adequately estimated. . Avoiding potential costly over-protection errors can most constructively be averted through a concerted research effort to rapidly increase our knowledge so that constructive steps can be taken.

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Year	Location	Species (numbers)	Correlated activity mentioned
1914	United States (NY)	Zc (2)	
1963	Italy	Zc (15+)	
1965	Puerto Rico	Zc (5)	
1968	Bahamas	Zc (4)	
1974	Corsica	Zc (3), Stenella coeruleoalba (1)	Naval patrol
1974	Lesser Antilles	Zc (4)	Naval explosion
1975	Lesser Antilles	Zc (3)	
1980	Bahamas	Zc (3)	
1981	Bermuda	Zc (4)	
1981	United States (AK)	Zc (2)	
1983	Galapagos	Zc (6)	
1985	Canary Islands	Zc (12+), Me (1)	Naval maneuvers
1986	Canary Islands	Zc (5), Me (1)	
1987	Canary Islands	Zc (group), Me (2)	
1987	Italy	Zc (2)	
1988	Canary Islands	Zc (3), Me (1), Hyperoodon ampullatus (1), Kogia breviceps (2)	Naval maneuvers
1989	Canary Islands	Zc (19+), Me (2), Md (3)	Naval maneuvers
1991	Canary Islands	Zc (2)	Naval maneuvers
1991	Lesser Antilles	Zc (4)	
1993	Taiwan	Zc (2)	
1994	Taiwan	Zc (2)	
1996	Greece	Zc (12)	Navy LFAS trials
1997	Greece	Zc (3)	
1997	Greece	Zc (8)	
1998	Puerto Rico	Zc (5)	
2000	Bahamas	Zc (8), Md (3), Ziphiid sp. (2), Balaenoptera acutorostrata (1), Balaenoptera sp. (2), Stenella frontalis (1)	Naval maneuvers
2000	Galapagos	Zc (3)	Ewings seismic
2000	Madeira	Zc (3)	Naval maneuvers
2001	Salomon Islands	Zc (2)	
2002	Canary Islands	Zc, Me, Md (15-17 whales)	Naval maneuvers
2002	Mexico	Zc (2)	Ewings seismic

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Table 1. Strandings involving at least 2 *Ziphius cavirostris* (Zc) from Smithsonian records plus recent events (the last three rows). "Strandings" refers to individuals that became stranded on beaches and does not imply death (some were redirected out to sea and their fate is unknown). These also represent the only known multiple stranding events for *Mesoplodon europaeus* (Me) and *Mesoplodon densirostris* (Md). The Galapagos 2000 standing occurred when the *R/V Ewing* was operating 500 km distant from the stranding site using the same seismic equipment as in the Gulf of California.