Sonars and Strandings: Are Beaked Whales the Aquatic Acoustic Canary?

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"The basic question is simple: Are sonars or any other anthropogenic sound resulting in significant, population level impacts in the ocean? The answers are far from simple."

Figure 1. *A Cuvier's beaked whale stranded on the beach on Grand Bahama Island, March 2000. (Image courtesy of Nan Hauser, Center for Cetacean Research and Conservation).*

Introduction

On the morning of 15 March, 2000, phones began ringing in Washington, Virginia, and Massachusetts. Emails flew between the USA and the Bahamas. The event behind these communications was a mass stranding of beaked whales (Ziphiidae) in the northern Bahamas extending from Grand Bahama to the tip of Abaco (Evans and England, 2001). Over two days, 17 whales were reported on shore, of which nearly half succumbed to the stress and trauma of stranding. Four years earlier, in 1996, 12 overtly healthy Cuvier's beaked whales (Ziphius cavirostris) beached and died near ship based trials of mid and low frequency sonars in Kyparissiakos Gulf, off the Peloponnesian coast of Greece. It soon became evident that the Bahamian stranding, like the one in Greece, coincided with naval sonar exercises in nearby waters immediately prior to the beachings of these normally elusive, deep diving, deep water whales (Figure 1). Since then, there have been multiple similar events: Madeira (2000), Canary Islands (2002, 2004), Hawai'i (2004), Madagascar (2008), and again Greece (Corfu 2011, Crete 2014), some involving military vessels and sonars; others, industrial and research vessel sonars, fueling demands that scientists solve the question of the relationship between marine mammal strandings and intense sound sources (Frantzis, 1998; Freitas, 2004; Ketten et al., 2004; D'Amico et al., 2009; Fernandez et al., 2012).

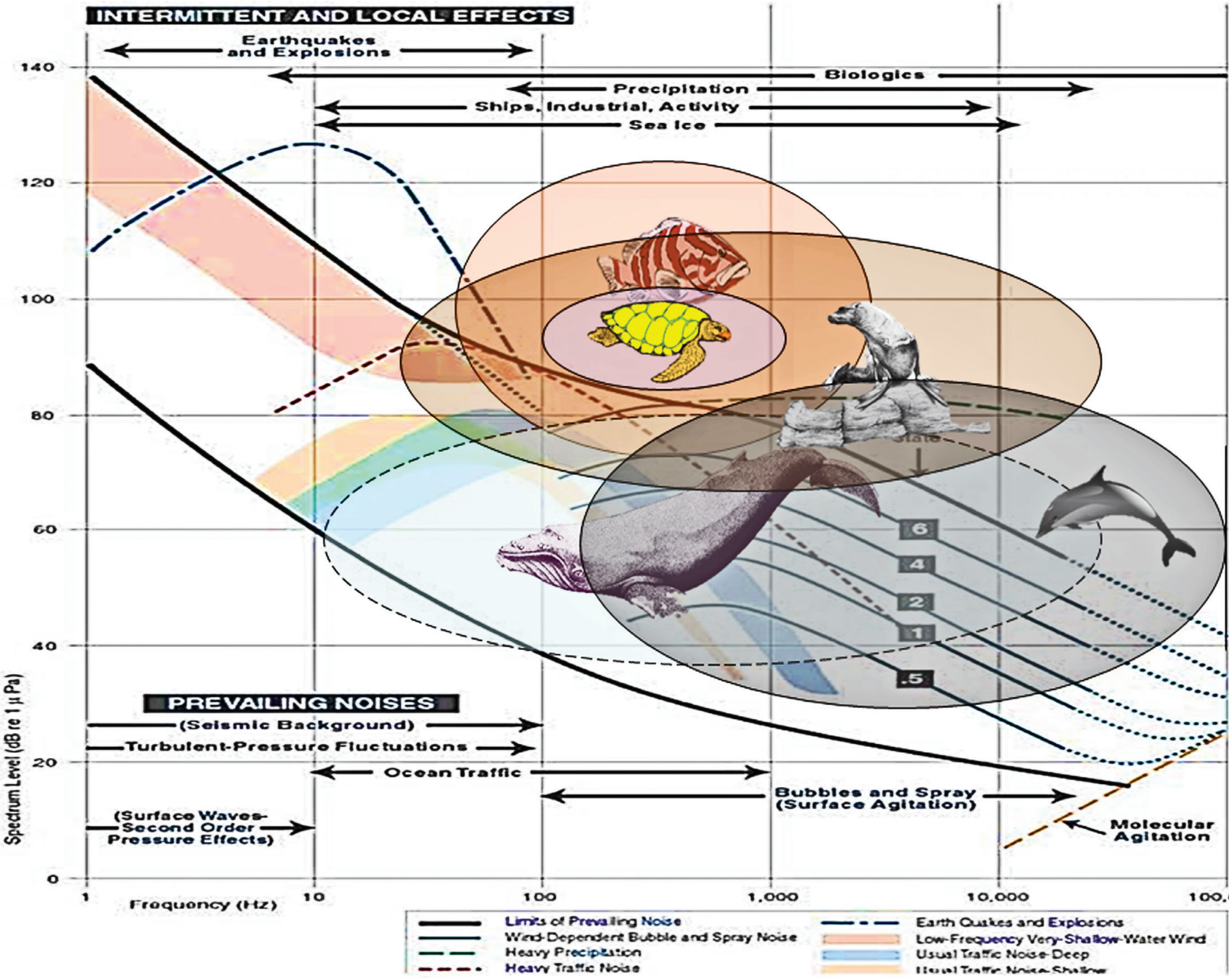


Figure 2. *Wenz curves illustrating the natural ambient and the relative contributions of some human underwater sound sources. The ovals approximate the total hearing range (frequency and sensitivity) of hearing in marine fishes (orange), sea turtles (lavender), seals and sea lions (brown), and toothed whales (gray). Baleen whale hearing (light blue, dotted line) is estimated from vocalizations. The units for the original Wenz curves were dB re 0.0002 dyne/cm^3. They are shown as converted to dB re 1 uPa in NRC (2003). (Adapted from Wenz, 1962; NRC, 2003).*

The events in Greece and the Bahamas were thoroughly investigated and followed by expert panel reviews (D'Amico and Verboom, 1998; Evans and England, 2001; Cox et al., 2006) that cited the simultaneity of the whale beachings and the absence of any apparent typical stranding cause, concluding that military sonar use debilitated the animals and precipitated the strandings.

Were these indeed acoustically driven events with a sole critical factor – the sound of the sonars - or were these strandings a perfect storm of colliding elements – sound, ship movements, bottom topography, sound profiles, species hypersensitive to sonar frequencies – or…what? After more than a decade of research, the problem remains perplexing. Although the primary question is how a group of whales came to die, it is important for the acoustic research community, with facets related to noise impacts, underwater sound propagation, and the design of underwater devices, and answers with repercussions for the future of acoustical research. At present, we do not have all the answers, but there has been progress.

Sonars and Ocean Noise

Among the important issues are what is the acoustic context of these events and what is the evidence for and against sonar as the critical agent.

The natural ambient in which marine mammals evolved is not silent. A quiet ocean is a dead ocean, and our global ocean is still very much alive. Natural sources of ocean noise are abundant and variable. Major geophysical events, such as undersea quakes and volcanic activity, produce intense and sometimes prolonged seismic to low frequency sounds. More constant, broader spectra noise comes from wave action, bubbles and cavitation, hydrothermal vents, substrate and ice movements, and surface events like lightening and storms. Some natural phenomena may increase local ambient levels by as much as 35 dB (Figure 2) (NRC, 2003, 2005).

The largest contributor to natural marine noise however is "life." All marine fauna produce and detect sounds that are critical survival cues. Biotic sounds range from infrasonic to ultrasonic frequencies, with source levels as high as 200 dB re 1 μPa rms, although most species hear and employ frequencies primarily at mid to higher frequencies, exploiting the range beyond lower frequencies common to natural abiotic ambient sources.

Anthropogenic sources increase the ocean's ambient "budget." There is no human activity in the ocean that does not add noise, intentionally or as a by-product. With the advent of machine- powered vessels, noise increased substantially. Modern human contributions to the ocean soundscape include vessel noise, industrial construction and operations, military activities, transport, fisheries, and research, many of which employ seismic, explosive, and impulse sources. Although ship-based military sonars, have, to date, received the greatest attention in the media, most NATO navies halved their fleets over the last two decades (McGrath, 2013). During this time, the global merchant marine fleet increased exponentially. Today, commercial shipping is by far the dominant anthropogenic source in the sea. It is estimated to have increased background noise by 15 dB in the last 50 years and accounts for over 50% of the total ocean noise budget in the northern hemisphere (NRC, 2003).

Seismic sources, such as air gun arrays (peak spectra below 100 Hz), are the mainstay of oil and gas exploration and the next largest source, followed by research and commercial sonar systems employing infra to ultrasonic frequencies. These are used as bottom profilers, scanners, navigational aids, and depth sounders in ocean exploration, transport, fisheries, tourism, and recreation. Commercial system source levels are difficult to determine because specifications are not conventionally provided by manufacturers, but they have been estimated to exceed 230 dB re 1 μPa at 1 m (Hildebrand, 2009).

Sounds we are adding may be soft or intense, intermittent or constant, static or mobile, varying by region, activity, and season. Consequently, our concerns about anthropogenic noise impacts are no longer just for immediate, acute impacts but also cumulative, long-term exposures. In effect, in some ocean areas and particularly along our fragile coasts, we may be creating an environment akin to that of human industrial workplaces. Much of this concern came about because strandings showed us underwater anthropogenic sound could have tragic environmental consequences.

The Case Against Sonar

Echo-ranging devices appeared in the early 20th century and were first used to detect submarines during World War I (D'Amico and Pittenger 2009). Hull mounted sonar systems proliferated during World War II; and by 1960, surface ship active sonars were using longer pings at lower frequencies (100 Hz to 8 kHz) and exploiting bottom bounce and convergence paths to increase detection range. Today, multiple military sonar systems are deployed worldwide, including low (LFA) and mid-frequency (MFA) active military sonars.

Most research on sonar precipitated strandings have focused on beaked whales as the prevalent whale group stranded in association with naval sonar exercises. Prior to 1950, beaked whales, especially Cuvier's beaked whales, did not commonly strand, singly or en masse. However, from 1874, when international stranding records began, to 2004, there were136 beaked whale strandings with 539 beaked whales in total distributed across multiple beaked whale species. Of these, 126 cases involving 486 animals, nearly all Cuvier's beaked whales, occurred after 1950 (D'Amico et al., 2009). The first post-1950 major stranding of Cuvier's beaked whales occurred near the NATO base in La Spezia in 1963, shortly after a new generation of MFA sonars were tested, followed by beaked whale strandings coinciding with NATO LFA sonar trials beginning in 1981 (D'Amico and Verboom, 1998)… then came the repeated incidents listed above.

Although the absolute number of sonar related beaked whale strandings is small, averaging fewer than 10 animals per year, it is not the raw number but rather the fact that the stranding incidence increased coincident with sonar exercises that is damning. Further, while Cuvier's are the dominant species, some are mixed species strandings involving also Blainville's beaked whales (*Mesoplodon densirostris*), and two stranding events have been reported with a non-beaked whale species. Two melon-headed whale (Peponocephala electra) strand-

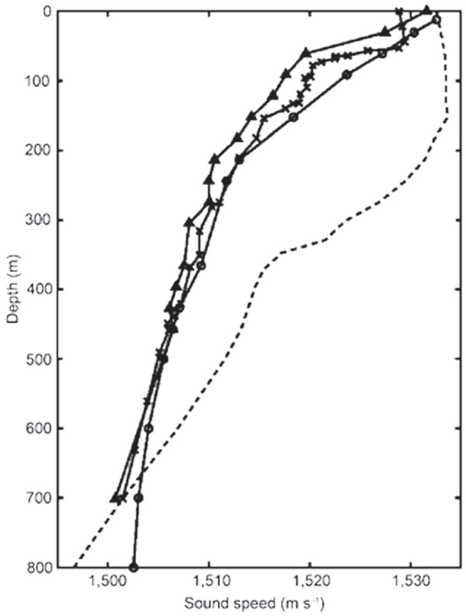


Figure 3. *Sound speed profiles taken from 3 expendable bathythermographs (XBT) in the Canary Islands (circles, triangles and 'x's) and in the Bahamas (dashed line) near the stranding events. Two datasets show a steady decrease with depth but one curve for the Canary Islands and the Bahamian curve suggest a surface duct that would "…trap mid to high frequency sound radiated by acoustic sources within the duct…;" i.e., ship mounted sonars. (reprinted with permission, d'Spain et al., 2006. Journal of Cetacean Research and Management)*

ings occurred while military and commercial sonars were in use in Hawai'i (NOAA 2004) and Madagascar (IWC 2013). Reviews of these events (NOAA, 2004; IWC, 2012) concluded sonar was the probable cause. If so, these events suggest that at least for several species, activities involving repeated, high intensity underwater sound sources, carries a serious, to the point of mortal, risk. This conclusion, in turn, has led to broader claims in the media, on blogs, and in lawsuits that far more animals are being harmed than have been seen and that a cacophony of anthropogenic underwater noise threatens extinction of already threatened or endangered species, many of which rely primarily on hearing for survival.

To understand if these concerns are valid, and to put bounds on the risks, it is important to try to understand exactly what precipitated the strandings by dissecting the events and the bodies. If there is a common cause, key questions become what underlying features are common to the events, what were the sound profiles, what other activities were underway, and what do the bodies tell us. We also need to understand why, considering the breadth and number of sonars in use worldwide, we are not seeing more strandings and why more abundant dolphin and whale species in the same area as the beaked whales were not similarly affected?

Acoustic Profiles

To understand what sound the whales that stranded could have encountered, we need an understanding of not just the received intensity, but also the peak spectra, duration, duty cycle, onset, and directivity, and how those vary with distance and depth, which amounts to a model of sound propagation specific to the source and environment in which it was deployed. Acoustic intensity decreases as sound travels through any medium according to spreading, absorption, and interaction with obstacles. Idealized losses are generally characterized as having spherical or cylindrical spread according to whether the medium is uniform or stratified. In the latter, a "duct" may trap sound, acting like a wave guide, decreasing the loss, for some frequencies, in comparison to the idealized models. The SOFAR channel is a classic example, however, of the wave guide that has been estimated for some of the stranding events differs in that it is in the upper waters (surface duct), which is not uncommon seasonally throughout the ocean (d'Spain et al., 2006).

For any real world situation, modeling the spreading can be difficult. A great deal of effort has gone into spreading models, both for the ideal and regional case as well as explicit models for several of the stranding events (see Fromm and McEachern, 2000, Zimmer, 2004; d'Spain et al., 2006). It is notable that in three major cases, Greece, Bahamas, and Canary Islands (2002), there were several common features: ships with active sources made near shore transects in waters deeper than 1km, traveling at > 5 knots while emitting periodic, high amplitude, transient pulses 15-60s apart with peak energy between 1-10kHz. The models created for all three sites indicate that variable ocean sound speed layering created an acoustic wave guide delimited by bottom refraction with sources positioned within the wave guide. Sound levels would not attenuate as rapidly as normally expected coupled with pulse integrity maintained with little scattering in calm weather (Figure 3); in effect, creating an anomalously high intensity acoustic cage. We have no data on the location of any of the animals prior to beaching, but at least in the Bahamian case, that "cage" was coincident with the preferred dive depths of Cuvier's beaked whales. We must also bear in mind that the "cage" was mobile, moving in repeated sweeps that came ever closer to shore. Thus we have several important elements: an acoustic phenomenon plus a movement pattern. That brings us to bodies on the beach.

Strandings

Our perception and response to strandings varies significantly according to culture and over time. Throughout the Ancient into Middle Ages, whales were largely seen as a food and fuel resource even while they were revered and a subject of curiousity (Aristotle, c 350 BC; Oppianus, c 150 AD). A 1324 law gave all rights to stranded or captured cetaceans in Britain to the Crown (BMNH, 2005) and drawings of crowds around stranded whales, some rather fancifully rendered, were common in Europe from the 15th century onward. Only in the last century did many countries turn away from whaling and initiate conservation efforts, including stranding response teams, for marine mammals.

Approximately 4,000 marine mammals strand along U.S. coasts annually (https://mmhsrp.nmfs.noaa.gov/mmhsrp/html/seahorse_public.htm). It is important to understand that "stranding" is not synonymous with dead. "Stranding" is defined officially (http://www.nmfs.noaa.gov/strandings.htm) as an animal found dead or alive in an "inappropriate" location. In many cases, a stranded animal washes ashore after death or dies on or near shore; however, "stranding" also applies to animals in waters atypical for that species, such as pelagic species coming into a harbor. A "mass stranding" is defined as two or more animals that are not mother-calf or mother-pup pairs, stranding simultaneously or synchronously; i.e., a few animals or several hundred. Timing and proximity are critical. In the beaked whale cases, animals were found strung along a common arc several kilometers apart; in Hawai'i (2004) and Madagascar (2008), melon headed whales, an offshore species, came into a bay and swam up a major estuary.

Animals succumb to disease, age, complications in calving, habitat disruption, food shortages, predators, and naturally occurring injuries and toxins, but of course many die or strand as a result human interactions, particularly from by-catch (caught in fishing operations), entanglements in gear and debris, ship strikes, and even intentional assaults, such as shootings, as well as from cumulative stressors, like chemical pollutants and noise. By-catch once accounted for as many as 100,000 cetaceans annually worldwide (Read, 2006, 2008), but in recent years, through gear improvements, the numbers have decreased to less than 2,000 annually, which is approximately equal to animals taken in commercial and scientific whaling fisheries. Drive fisheries, both today and in the past, have used sound to herd whales and dolphins around the world. Aristotle comments on such fishing methods as "…a loud and alarming resonance...induce the creatures (dolphins) to run in a shoal high and dry…on the beach and so …catch them while stupefied with …noise." Similar drives continue today in the Faroe Islands and Taiji fisheries. Depth and fish finders are also reported to bring whales to the surface (Payne, 1995). It is somewhat ironic that for millennia we exploited anthropogenic sound as a fishing tool and only now are attempting to understand the mechanism behind it in order to protect what was once our prey.

Anatomy of a Stranding: Cause, Mechanism, and Manner of Death

When a stranding occurs, local response personnel determine whether to assist the animal, if live, back into the water or transport to a rehabilitation facility. If it is moribund or dead, they will document its condition and collect the carcass to conduct a necropsy, a systematic examination of the body following an established protocol performed on the beach or in a dissecting facility. The goal of the necropsy is a comprehensive analysis of the animal's condition to obtain data related to its life history and any evidence related to its stranding and death.

As with a formal autopsy, the necropsy attempts to determine the "cause, mechanism, and manner of death." These are exact terms with well-defined clinical significance. Cause of death refers to an underlying physiologic condition, such as trauma or disease, critical to initiating the lethal event. Mechanism of death refers to the proximal physiologic process that the cause set in motion which resulted in death. Manner is a term for the category of the event, such as natural, accidental, or, in human cases, homicide or suicide. As an example, consider the case of an individual who steps off a curb into the path of a car and falls, striking his head on a curb, snapping his neck. The cause of death is a traumatic injury to the brainstem and severing of the spinal cord; the mechanism is neck extension and skull fractures resulting in hemorrhage and crushing and tearing of associated soft tissues; the manner of death is accidental from a collision with a car and resulting fall. Similarly, a diving fatality may have as a mechanism of death drowning, but the cause of death is cardiac arrest while diving, and the manner of death is then natural. These determinations, and the extensive, rigorous exam process behind them, are just as applicable and important for the analysis of strandings as in human cases.

Figure a

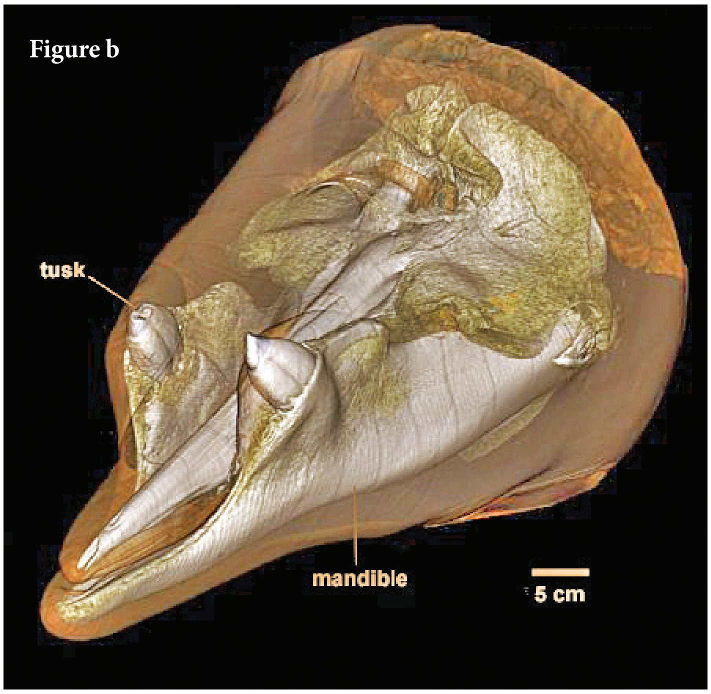


Figure b

Figures 4 (a,b,c,d). *Include live and CT images of adult male Blainville's Beaked Whale (Mesoplodon densirostris). (CT images courtesy of WHOI Imaging Facility. All rights reserved. http://csi.whoi.edu)*

Figure 4a. *Male Blainville's beaked whale swimming near Abaco, Bahamas. (Photo courtesy of Diane Claridge, Bahamas Marine Mammal Research Organisation, all rights reserved.)*

Figure 4b. *The 3D reconstruction from CT scans of the head of a stranded male Blainville's beaked whale shows the skin surface (translucent) and the characteristic male tusks and skull shape. The right tusk has lost its tip from trauma or decay. Two videos accompany this image, one showing a set of CT scans of the head and the second shows the reconstruction of the head built upon the CTs.*
To view videos visit http://acousticstoday.org/?p=2315.

Figures 4c and 4d. *Anterior and posterior views of the internal anatomy of the head of a beaked whale that stranded on Abaco, March 2000. The scans demonstrate the origin, location, and extent of a left subarachnoid hemorrhage (red) that traveled along the internal auditory canal to the left ear region.*

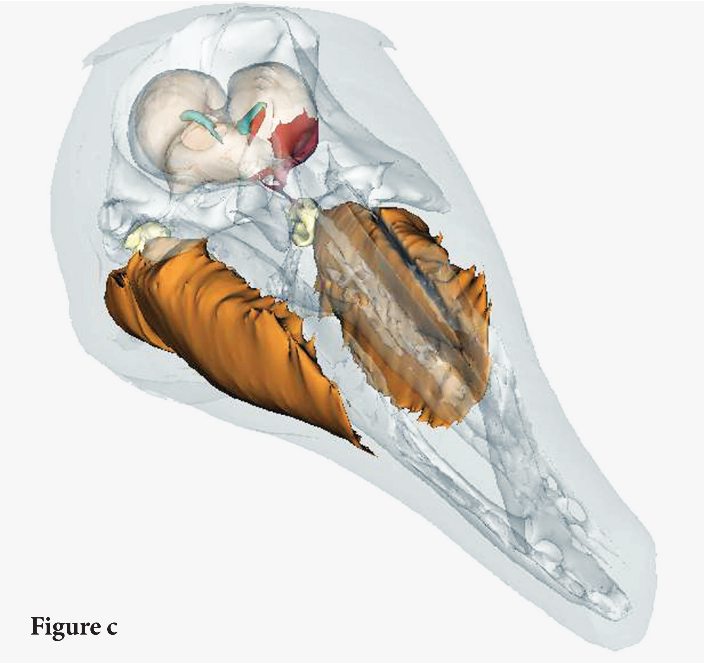


Figure c

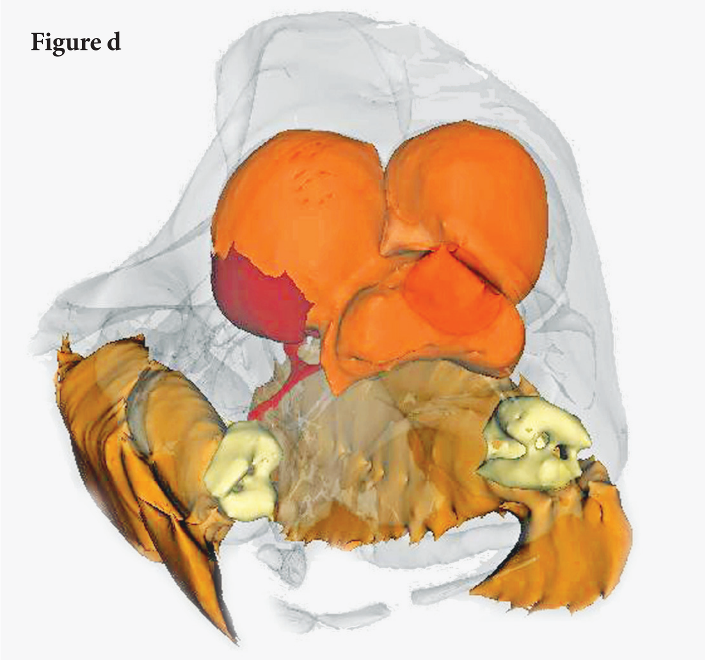


Figure d

Because of practical limitations on examining large animals under field conditions, such as post mortem times and ambient conditions, tissue loss from scavengers and decay, limited resources for analyses, etc., comprehensive findings are not possible for every necropsy. In the last decade, clear cause of death could be assigned in only 30% to 40% of all stranding cases examined worldwide. Even for strandings that qualify as an Unusual Mortality Event (UME) because of the rarity of species or the location and numbers of individuals involved, answers can be difficult. In UMEs, a far more extensive necropsy and series of exams are undertaken. Nevertheless, despite the far more thorough analyses involving multiple specialists, a cause of death has been ascertained for only 53% of UMEs in the past five years.

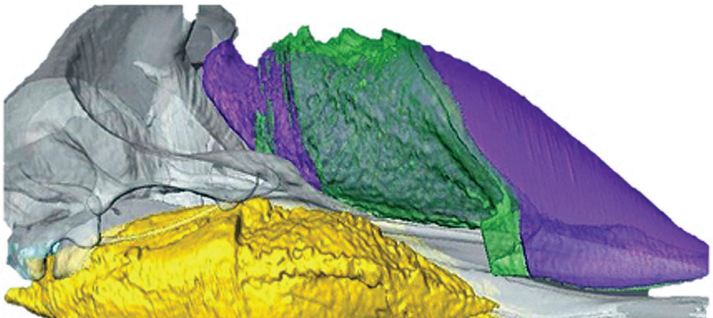


Figure 5a.(left) *Stranded Cuvier's Beaked Whale (Ziphius cavirostris) being prepared for necropsy.*

Figure 5b (above) *3D image of the head showing the skull (white), melon (purple) through which echolocation signals are emitted; surrounding dense collagen band (green); fatty tissues along the mandible that connect to the ear complex (gold).*

Figure 5c (right) 3*D CT scan image of the inner ear of the same animal. The difference in the auditory nerve (an) and the vestibular nerve (vn) diameters in this ear are typical of toothed whale VIIIth nerves. Their auditory nerve has approximately 20 times more nerve fibers than the vestibular nerve. The relatively small diameter of the vestibular canals (ssc = the juncture of the semicircular canals at the ampullae) in comparison to the cochlea and the change in scalae diameters along the cochlear canal are also typical of whale ears (sv = scala vestibule; ow = oval window). A video accompanies these images that examines the head of a stranded female Cuvier's beaked whale (Ziphius cavirostris) showing the surface (translucent) and the skull. Two tusks shown embedded in the lower jaw are typical of females and juvenile males of this species. Only the adult male has erupted, externally visible tusks. As the video image rotates to a ventral view the exceptionally dense ear bones (white) can be seen just inside and slightly posterior to the mandibles (lower jaw bones). To view video visit http://acousticstoday.org/?p=2315.*

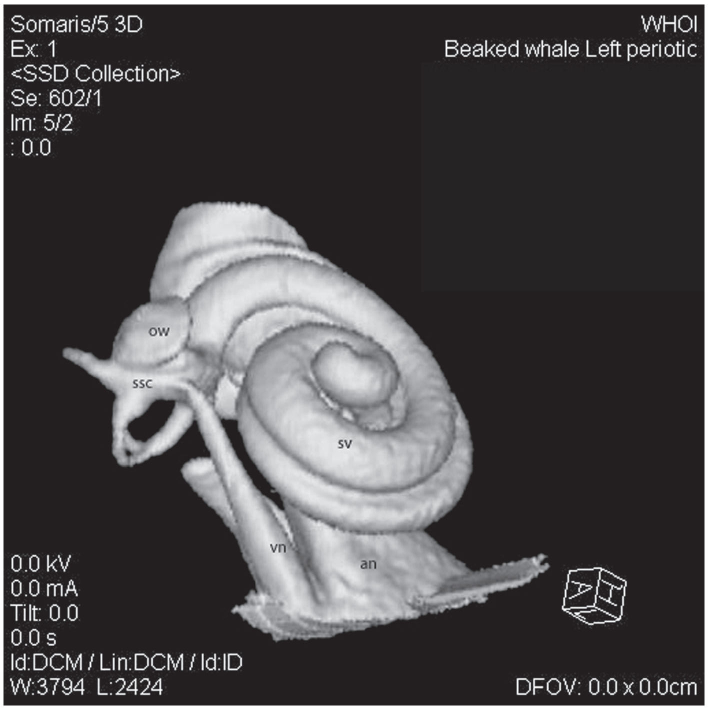
The Findings

It is important to appreciate that the sonar related stranding events are globally distributed and therefore the response and analyses depend upon the regulations and processes of the country with jurisdiction over the stranding event. Thus, there is substantial variability amongst the sonar stranding cases in the available data.

In Greece, in 1998, all 12 beached animals were found dead. It was reported that the bodies appeared to be overtly healthy, well nourished animals, but they were too remote for responders to obtain useful samples from the carcasses (D'Amico and Verboom, 1998). Several later stranding events had similar outcomes. In some cases, the bodies had extensive post mortem autolysis (breakdown of tissues) or the working conditions allowed only the most basic tissue samples; in others, local customs resulted in dismemberment or immolation that destroyed critical anatomy (Freitas, 2004; Ketten, 2005; IWC, 2012).

In the Bahamian cases, necropsies were performed on a few whole carcasses on Grand Bahama Island, but these bodies were not discovered until they had lain on hot sand on secluded beaches, in tropical heat, for 12 or more hours post mortem (Figure 1). Little could be gleaned that was not corrupted by postmortem artifacts. On Abaco, however, the story was quite different. Abaco lies to the south of Grand Bahama and is also the home base of the Bahamas Marine Mammal Research Organisation (BMMRO), which has a respected history of research on beaked whale ecology and behavior. Because BMMRO was alerted as soon as the beaked whales began coming ashore, of the 17 whales reported stranded, 10 were returned to deeper water. Of the remaining seven that died, six were preserved and necropsied.

As in Greece, the animals were in good body condition with no evidence of debilitating infectious disease, toxins, lacerations, fractures, or blunt trauma. The principal anatomical elements of underwater hearing common to high frequency,



echolocating, toothed whales were all there (Figure 4), and as later studies showed, there were no features suggesting they would be particularly sensitive at mid or low frequencies (Ketten, 2005). CT scans of the freshest intact heads from these specimens, however, showed blood deposits within the inner ears and hemorrhaging in the fluid of the subarachnoid spaces surrounding the brain that were confirmed on dissection (Figure 5). Similar hemorrhages in humans or land mammals would not likely have been fatal nor caused permanent hearing loss, but they could be at least temporarily debilitating. The intracochlear blood may have compromised hearing temporarily or caused disorientation. Ultimately, it was determined that these whales died as a result of cardiovascular collapse (mechanism) due to hyperthermia and high endogenous catecholamine release (cause) consistent with the extreme physiological stresses associated with beaching in an accidental stranding (manner) (Evans and England, 2001).

The strandings clearly coincided with a multi-ship exercise using tactical MFA sonars. The critical elements are there of both time and proximity, and there was no evident, alternative common cause for the strandings. The investigation panel concluded that tactical mid-frequency sonars in use aboard U.S. Navy ships during the sonar exercise in Bahamian waters were the force majeure, the most plausible instigating force for the strandings (Evans and England, 2001). The sonars in use have an operational source level of approximately 220 to 230 dB re 1 μPa @ 1m. Multiple sonar units were operating over an extended period of time, ensonifying a complex environment that included a strong surface duct and steep topography. To that, add beaked whales diving in the ensonified undersea canyons with sheer walls and limited exits.

In the Canary Islands, the topography was different but the pattern of events and results were similar. Multiple ships used MFA sonars in a box-like maneuver towards shore, followed by beaked whale strandings along that coast. In addition to similar hemorrhage sites in those bodies, some animals were reported to have widely disseminated intravascular bubbles (Fernandez et al., 2012). Bubbles were also reported in major organs of stranded animals in the United Kingdom in a retrospective study (Jepson et al., 2003). These reports have led to a number of speculations that exposure to sonars results in a rapid surfacing that promulgates decompression sickness (DCS). While these findings are worth noting, it is also important to bear in mind that the consensus of experts in diving fatalities and dive physiology is that "presence of gas in any organ or vessel after a scuba diving death is not conclusive evidence of decompression sickness or air embolism" (Caruso, 2014). It is critical for a diagnosis of DCS to have consistent trauma in lungs, ears, and brain and specifically interarterial and left ventricle high oxygen content, gas emboli, not simply broadly distributed bubbles (Brubakk and Neuman, 2002; Edmonds et al., 2002; Piantadosi and Thalman, 2004; Hooker et al., 2012; Caruso, 2014). Bubbles in post-dive, post-mortem animals are to be expected because normal off-gassing processes by the lungs are halted by death and they may occur also from decomposition. To date, we have no reports documenting the critical symptoms of DCS. Therefore, it is not yet possible to state with certainty that DCS or pathology from altered dives is present in these cases.

Concerning the two melon head whale stranding events investigated by the National Marine Fisheries Service (NMFS) and the International Whaling Commissions (IWC), in Hawai'i, a pod of these normally off-shore animals entered a shallow bay simultaneous with Navy vessels passing through the region. One calf in poor health died during the incident; the others left the bay several days later. In Madagascar, a large pod entered an estuary on the west coast coincident with sonar use during an oil and gas exploration operation. Most of these whales died over the next week, trapped by tidal flows and tangled in the mangroves and mud. The majority of bodies found were in very poor condition, and again, the necropsy findings were inconclusive, but, as in the Bahamian cases, some of the ears from the Madagascar cases were in sufficient condition to establish that there was evidence of longer term hearing loss associated with aging or infections but no evidence of recent, acute auditory or vestibular damage (Ketten, 2005; IWC, 2012).

In both of the melon head cases, as with the beaked whale cases, no typical stranding cause was found, which led the panel to implicate sonar use in the area as a probable cause. It should be noted, however, that in the Hawaiian case, a report was later published that documented a mass stranding of the same species simultaneous with the Hawaiian incident, but 5,000 miles to the West and with no nearby acoustic event, raising the question for the Hawaiian case at least of some unappreciated, underlying, non-acoustic trigger, such as prey movement or lunar cycles (Jefferson et al., 2006).

The Unusual Suspects

At this point, we have no clear causal impact phenomenon for these strandings, but there are a number of possible suspects. Cox et al. (2006) summarized proposed impacts as follows:

> (1) behavioral avoidance responses to sound that leads to stranding;
> (2) maladaptive dive responses (rapid ascent, or remaining at depth or surface longer than normal) leading to tissue damage (bubble formation, hypoxia, hyperthermia, cardiac arrhythmia, hypertensive hemorrhage, or other trauma);
> (3) tissue damage or other direct physiological effects from sound exposure (acoustically mediated bubble formation, vestibular damage, tissue resonance, species disseminated diathetic coagulopathy, which is failure to clot exacerbated by stress).

Later panels eliminated some of these theories, such as resonance effects, as improbable for a variety of reasons. At present, the focus of research is on behavioral responses. The current large-scale Behavioral Response Study (BRS) is pursuing the difficult task of locating and tagging free-ranging beaked whales with data-loggers in order to measure changes in diving and acoustic behavior of whales exposed to test signals. Results to date show that beaked whales have a consistent avoidance response, not simply to sonar signals, but to novel sounds in general. This contrasts sharply with responses of other species, such as pilot whales which were attracted to the same stimuli (Southall et al., 2012). The BRS data also show that avoidance behaviors occur at relatively low sound levels, which suggests an avoidance response is not the result of inner or middle ear injury, consistent with the necropsy findings of no acoustic trauma or acute inner ear pathology in the stranded animals.

Conclusions: Mind the Gap

The basic question is simple: Are sonars or any other anthropogenic sound resulting in significant, population level impacts in the ocean?

There is no question that underwater anthropogenic noise has the potential to do harm, directly or indirectly, to marine animals, just as noise in air can harm humans and other animals (http://www.nidcd.nih.gov/health/hearing/pages/noise.aspx). The susceptibility of beaked whales to sonar-related stranding, set us the task to find out why and how they were impacted. It is not clear that there is a common cause or mechanism for the pathologies documented across the Bahamas, Greece, and Canary Island stranding cases nor to what extent acoustics were involved vs. ship movement or any other element. Questions remain about whether the focus of mitigation to prevent another event should be: (a) sonar exposures of all types; (b) novel sound exposures with parameters like those eliciting behavioral responses; (c) use of sonars and/or novel signals in beaked whale habitats; d) multi-ship and/or multi-sonars exercises near shore; or (e) some or all of the above.

The issue of potential impacts of sounds from sonars is real, and it raises a bigger question of whether we, as scientists, need to work to assure the perception of the risk is accurate and neither underestimates nor exaggerates the actual threat. The acoustic research community has seen the effects of public uncertainty before in reactions to the Heard Island and ATOC experiments (Munk et al., 1994; Potter, 1994). Since then, thinking has shifted from individual to population level effects (Hastings, 2008). The sonar cases raise legitimate concerns. Until a mechanism is determined, we cannot say definitively whether these strandings are limited to the cases we have observed, or if, as has been asserted, they are a shadow image of a far broader problem. At present, we have no direct evidence of a significant, population level impact from sonar or any other sources, but we must be alert to more subtle events than strandings, including changes in behavior, habitat use, and demographics.

In summary, we have several concerns. There is no denying the potential importance of anthropogenic sound impacts in our oceans and the appropriateness of regulating the deployment and use of sound sources. Hearing is considered the most important sensory system for many marine species. Shifting the noise budget of the oceans, as we are doing, can result in a significant hazard to not only marine mammals but other species, including fishes, turtles, and invertebrates (Popper et al., 2014; Hawkins and Popper, 2014). A robust research program on sound impacts is essential to protecting the marine environment and providing a balanced and scientifically informed risk assessment. If we are to continue to conduct essential ocean research, we must face the challenge of public education on the vital role of research for placing valid limits on sound use in our seas.

Acknowledgments

Much of the data included in this article were obtained through the support of NOAA/NMFS, ONR, Navy Environmental Division, LMR, NIH, the Seaver Institute, and the Mellon Foundation. The preparation of this manuscript, parts of which were adapted from a book chapter in press, was supported by support through a Western Australia Premier's Fellowship. Scott Cramer and Julie Arruda provided exceptional technical and imaging assistance for this effort.

Biosketch

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