Marine Mammals - Vulnerable to Gas Embolisms: The Role of Time/Depth Recorder Instruments and Naval Sonar

For many years, scientists thought it was impossible for marine mammals to suffer from similar conditions to those that sometimes afflict human scuba divers, namely the bends also known as decompression sickness (DCS).[11] To begin to understand the forces at work with embolisms occurring in marine mammals, it is helpful to comprehend how DCS occurs in a human.

Also known as caisson disease or nitrogen narcosis, DCS is a result of a person breathing regular air (79% nitrogen) under pressure.[11] An example of this would be a scuba diver who breathes air under pressure as a result of being at depth. As the diver descends, more nitrogen is absorbed in to the blood than that which is absorbed at the surface. The longer a scuba diver stays underwater, the more nitrogen that accumulates. Under pressure, all gases are absorbed in to the blood; when the pressure is removed, the gases are released from the bloodstream. If a scuba diver ascends slowly, the nitrogen is gradually released and the diver can safely exhale the gas. If the diver rises too fast, the gases are released more rapidly than the diver can exhale. As a result, gas bubbles form as the external pressure is reduced upon ascent. Without time to disperse, the bubbles may burst or lodge in the brain, the central nervous tissues, the joints, or remain in the blood disrupting vital neural pathways in the brain and spinal cord causing severe pain with the potential for hemorrhaging, paralysis, or even death.[11, 14, 15]

Fortunately for the human scuba diver, there is a cure. Decompression chambers allow the person the opportunity to re-pressurize the body without having to be exposed to the further risk of being submerged at depth. Treatment at these facilities allows the gas bubbles to slowly dissipate as in a slow and safe ascent. Even with supervised care at a decompression center, however, the person might suffer some permanent problems and if he or she goes untreated, the outcome can prove fatal.[14, 15]

Historically, it has not been thought that whales suffer from conditions like the bends, primarily because whales do not breathe air at depth so they avoid the buildup of excess nitrogen. Instead, they get their air at the surface and hold their breath in much the same way a human free diver might, who is traditionally also thought not to be susceptible to the bends. However, there have been cases of DCS induced in human free divers undertaking repetitive breath hold diving exercises.[9] If it is possible for a human to exhibit DCS when not exposed to breathing air under pressure; one might deduce that it may also be possible for a marine mammal. One of the other main arguments for a whale's immunity to excessive nitrogen absorption is that at only 100 meters, bottlenose dolphins have been shown to actually collapse their lungs and whales have been shown to collapse their entire rib cage. In the study involving the bottlenose dolphin, once below 100 meters, the…"air in the respiratory system was excluded from the respiratory surface of the lungs and no exchange of gases occurred between the blood and the air. This prevented the blood from absorbing an excess of nitrogen, which is what leads to the bends."[11]

Nevertheless, recent postmortem examinations known as necropsies of stranded animals following the use of naval sonar have shown that marine mammals have formed gas bubbles in their tissues and organs causing them to hemorrhage and in some cases rupture. Such findings are consistent with exposure to an acute change in pressure or acoustical episode.[5, 7, 9] Gas bubble lesions are more common in deep diving marine mammals than in their shallow diving relatives.[17] Suspiciously similar to what occurs with human scuba divers when surfacing too rapidly, scientists are now skeptical that marine mammals are immune to rapid changes of pressure. Some gas exchange evidently can occur under unusual circumstances. There may be a number of factors that contribute to this condition. Speculation includes that marine mammals might attempt to flee the ear-piercing sounds produced by the broadcast of naval sonar (that have been shown to cause the ears to hemorrhage in beaked whales) at depth for quieter areas in the shallows. [14, 17] It is possible this "…modified diving behavior caused nitrogen super-saturation above a threshold value normally tolerated by the tissues (as occurs in decompression sickness)…."[7] While these mechanisms are not yet fully understood, bolting for the surface too rapidly is likely responsible for the formation of the gas bubbles that ultimately prove deadly to the marine mammal.

Understandably, the Navy was resistant to accept any responsibility for the stranding of marine mammals subsequent to sonar tests. Many reasons no doubt contributed to that lack of acknowledgement, one of the most obvious being that naval sonars theoretically should not affect shallow water areas to the same extent they might affect deeper water areas. Sound travels very differently under water than it does through the air, not only much faster but it is affected by any numbers of factors, including thermo clines, currents, and even underwater topographies, will affect the velocity and the potential volume of sound.[17] Many of the animals implicated in strandings following naval sonar exercises have involved midsized whales, thought incapable of achieving the impressive depths of some of their larger relatives such as the giant sperm whale.

Spawned by the concern of deceased marine mammals showing up stranded subsequent to naval sonar exercises, a concerted effort began in 2000 to measure the diving capability of some of the species involved in these mass strandings, namely beaked whales. Dr. Robin Baird, a Canadian biologist, and his research team began attaching time/depth recording (TDR) instruments in an effort to assess diving profiles. TDR technology was adapted from seal studies on the West Coast of the U.S. Manufactured by Wildlife Computers out of Washington state these minimally invasive tools allow researchers to record everything the whale does once it leaves the surface. Each TDR tag is equipped with a velocity meter, a depth gauge, a VHF radio transmitter and antenna that allow researchers to track the animal once the tag is attached. TDR tags do not cause harm to the mammal yet allow researchers to learn, in a most benign manner, how marine mammals use their environment.

TDR tags essentially record everything the animal does while it is out of view documenting not only how deep the animal ultimately dives, how long it stays down, but every depth interval at which it may stop or pause along the way, the surface interval times between dives and the ascent and descent rates. The tag may remain on for varying intervals of time depending on the placement. The suction cupped tags are attached via a pole spear, essentially an extension rod allowing researchers to gently tap the tag on to the back of the animal. If the animal is beyond reach, researchers may use a cross bow to shoot the suction cup tag at the side of the animal. Ideally placing it behind the dorsal fin enables researchers to detect the tag’s VHF signal when the whale surfaces. The suction cup does not actually penetrate the skin of the animal. It would be akin to a person being slapped without expecting it; although beaked whales are relatively small, they weigh in excess of one to three tons. Each tag is attached to a float so that when the tag eventually releases it grip on the skin of the whale, the tag will float to the surface and the antenna will begin emitting a constant beacon that researchers can hone in on using their multi-directional antennae and receiver to retrieve the float from the surface of the water. Once secured, the tag is taken back to the lab, the data is down loaded out of two ports on the top of the tag and the result is a clear graphic illustration of the whale’s diving profile. This information can then be used by scientists to better understand how marine mammals are utilizing their environment. With such comprehension and the scientific data to support their hypothesis and/or conclusion, it is then possible to take steps to help protect the environment whales inhabit, in this instance from noise which may potentially prove fatal.

The assumption that a relatively small animal is not capable of making an extraordinarily deep dive is reasonable and an opinion that is still widely held. However, when these TDR instrument packages were attached to beaked whales in studies conducted off of the Big Island of Hawaii, an entirely different story materialized. Surprisingly these animals, at only 15 to 20 feet in length and weighing approximately 2,000 -6,000 pounds in contrast to the giant sperm whale at nearly 50 feet and weighing 20 - 50 tons, are diving to phenomenal depths of nearly 4,500 feet below the surface and staying under water for extremely long intervals of time, up to 90 minutes on a single dive.[2, 3, 4, 14, 17] These deep diving whales obviously have a lot more going for them physiologically than lung capacity alone, including the mammalian dive reflex and an array of other adaptations that have evolved over millions of years living in a liquid environment.[14, 15]

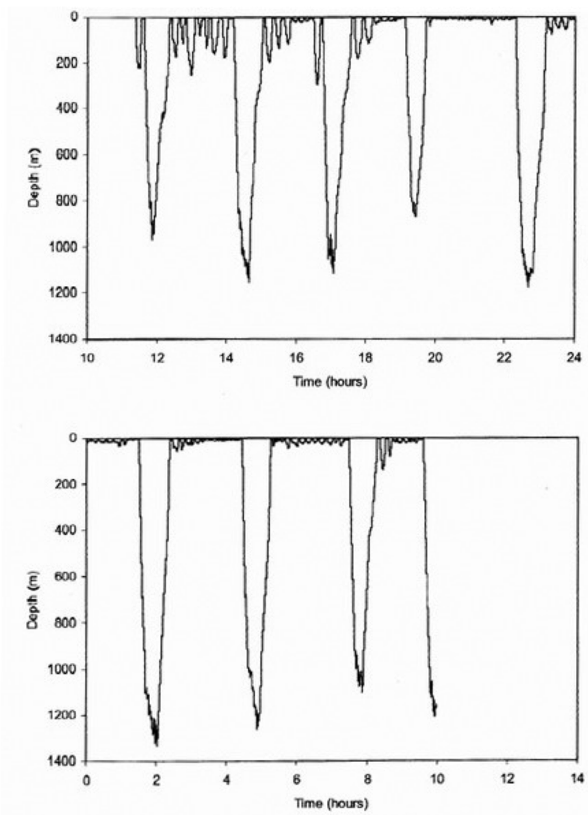
While there may be other factors which contribute to the formation of gas bubbles in marine mammals, it is now well documented that it does occur. The recent strandings including one multi-species incident off of the Bahamas in March of 2000 involving 17 whales, another off of the Canary Islands in 2002 that involved 14 beaked whales, and another event in July of 2004 off of the island of Kauai in Hawaii involving 150 – 200 melon headed whales all followed naval sonar exercises. While some may deem this as coincidence, the picture that is emerging appears quite different and while the mechanisms at work are not completely comprehended at this time, confirming that these smaller whales are capable of diving to extraordinary depths was pivotal in establishing a plausible connection between the naval sonar and the subsequent stranding of marine mammals. The TDR data also shows that in a normal environment, whales ascend slower than they descend.[6] Whether they regulate the speed of ascent consciously or unconsciously is unknown, but a slow ascent prevents embolisms from occurring. Just as in a human diver, an unusually rapid ascent can be a precursor for the development of embolisms.

Other alterations to a whale's normal diving pattern that might precede excess gas bubble formation and its subsequent agony and potentially lethal outcome include repetitive dive breath holding, diving prematurely before having the opportunity to eliminate excess gas, or even staying at depth for too long.[4, 9] It is possible that these changes in diving behavior can be influenced by seismic testing and/or naval sonar testing exercises. The pain induced by the hemorrhage of an ear could have any number of effects on diving behavior. Additionally, sound is very important to the survival of marine mammals as they utilize sound to find food and hunt for prey, to protect themselves from predators, and to communicate with each other. Thus, even if such an injury does not result in immediate stranding or death, it is likely it would ultimately prove to have serious and potentially terminal implications due to the subsequent effects of probable deterioration or even loss of function. So while the connection is still not completely realized, it remains well established with the coinciding incidents of strandings following naval sonar exercises and the results from necropsies that trauma is often induced as a result of such exposure and may result in the animal's demise.[4, 5] TDR tag data from affected species supports the deep diving model of animals that would most likely be implicated in these strandings.

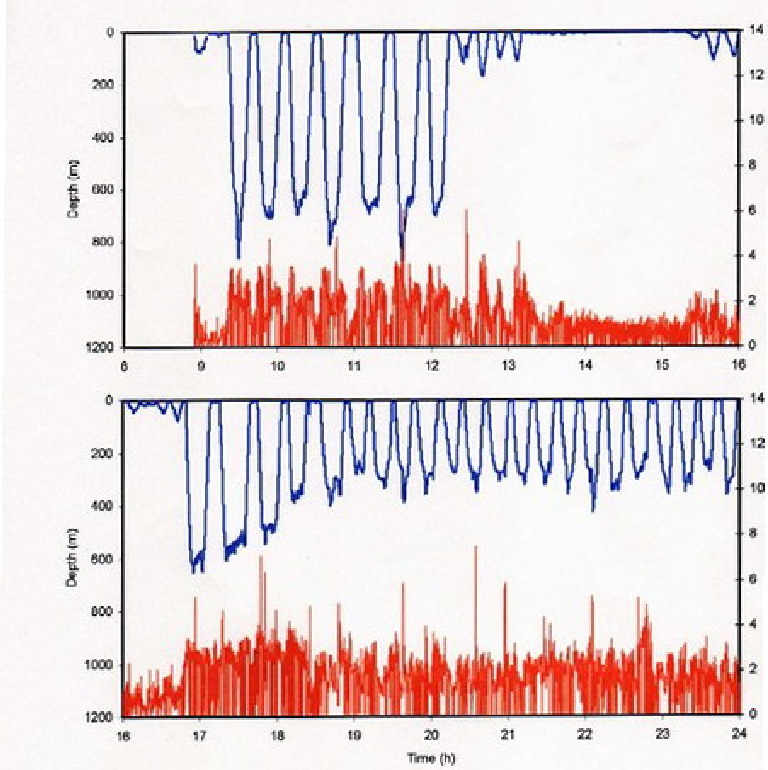
In the 2005 court case between the Natural Resources Defense Council (NRDC) and the U.S. Navy, the Navy did officially accept responsibility for the stranding of some marine mammals, an unprecedented historical event. It was a hopeful indication that the Navy might take more precautions in the future role of naval sonar and its influence in military strategy. While tighter restrictions have been imposed as a result of the court case, naval sonar is continuing to be used for submarine detection potentially putting marine mammals at risk of further stranding and death. National security is clearly crucial, however it is quite conceivable that other technology could be developed that would not directly or indirectly endanger marine mammals. With growing public awareness and education through efforts of organizations like the NRDC, perhaps the public will have a stronger interest in voicing its concern over current naval practices. Meanwhile, more investigative research on the mechanisms at work needs to be continued at every opportunity so that researchers can more effectively influence policy and mobilize change. Currently, issues of national security are being balanced against the welfare of marine mammals; as it presently stands, it is a very lopsided pendulum indeed.

Figure 1. Time Depth Recorder (TDR) tag
Photo courtesy of Dr. Robin Baird

Figure 2. TDR tag attached to a short finned pilot whale.
Photo courtesy of Dr. Robin Baird



Dive data from a *Mesoplodon densirostris*, Hawaii, September 2004.



Depth and swim speed data from an adult male short-finned pilot whale off Kona, Hawaii.

Figure 3. Dive data graphs generated by TDR tags.
Courtesy of Dr. Robin Baird

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Figure 4. Beaked whales frequently implicated in strandings following naval sonar exercises.
Left photo of Blainville’s beaked whale. Right photo of Cuvier’s beaked whale.
Photos courtesy of Dan McSweeney