Deafening Silence: The Impact of Naval Sonar Activity on Cetaceans

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The ban on commercial whaling by most countries in the 1970's paved the way for the co-existence of humans and cetaceans i.e. modern whales and dolphins. Despite this advance, cetaceans still find themselves unintentionally in conflict with humans through the presence of anthropogenic acoustic noise in the oceans, particularly through the use of naval sonar. The use of naval sonar has been associated with both behavioural changes, such as modified dive behaviour, and physiological changes, such as Gas and Fat Embolic Syndrome, across many cetacean species. As a result of such changes, the lethal mass strandings of several cetacean species has occurred globally. High levels of public support and scientific data have prompted recent changes to naval sonar usage including complete moratoriums and limited activity in areas frequented by cetaceans. This contemporary issue and our response, demonstrates a greater understanding of the impacts human activities have on other species.

Introduction

The attitude of Humans towards other animals is constantly changing and nowhere is this clearer than with our attitude toward cetaceans. Humans and cetaceans have shared a long and often exploitative history, with cetaceans being harvested for various body products for thousands of years (Zelko, 2012). The expansion of the whaling industry throughout the 20th century ultimately resulted in the depletion of many whale populations, by up to 99% (Freedman, 1995). Thankfully, due to work by the International Whaling Commission and other organisations, the harvesting of many cetaceans has been prohibited by most countries since 1975, allowing cetacean populations to recover (Clark and Lamberson, 1982). In fact, cetaceans are now worth more alive than dead with the global whale-watching industry currently generating $2.1 billion in revenue annually (O'Connor *et al.,* 2009).

Despite this enhanced legal protection, many cetaceans still find themselves subject to injury and stress caused unintentionally by humans. One of the main ways this occurs is through the presence of anthropogenic acoustic noise within their environments, particularly through the use of active naval sonar, which ultimately impacts upon their reproduction and survival (Sivle *et al.,* 2012).

Cetaceans are particularly well adapted to the low-light environment of the ocean, utilising acoustic signals for many basic functions, including feeding, communication, and reproduction. This is termed biosonar or echolocation (Surlykke *et al.,* 2014). As a result, they possess a heightened sensitivity to acoustic signals. The frequency that toothed whales (Infraorder Odontoceti) use ranges from 40 Hz to 325 kHz, while the frequency that baleen whales (Infraorder Mysticeti) use ranges from 10 Hz to 31 kHz respectively (Richardson *et al.,* 1998). As a comparison, humans are most sensitive to frequencies between 2,000 Hz and 5,000 Hz only. The broader frequency spectrums of cetaceans makes them more susceptible and sensitive to anthropogenic sounds produced as part of naval sonar activity.

Naval sonar employs both mid frequency active sonar (MFS) of 1kHz-10kHz, and to a lesser extent low frequency active sonar (LFS) of 100Hz-500Hz in order to determine the size, distance, and speed of objects within the sea through the principles of sound propagation and reflection (Friedman, 1997), similar to the way cetaceans use to find food. The use of sonar is often vital to the correct functioning of naval units (Friedman, 1997).

Almost all of the sound produced by naval sonar activity is inaudible to humans, however the use of sonar has been shown to elicit behavioural and physiological changes in cetaceans, particularly the toothed whales, impacting their overall fitness (Parsons *et al.,* 2008, Mooney *et al.,* 2009). Naval sonar activity has been associated spatially and temporally with the lethal mass strandings of several toothed whale species also (Filadelfo *et al.,* 2009). Here, I review the current known impacts of naval sonar activity on cetaceans.

Impacts: Behavioural

The impacts of naval sonar use on cetaceans vary according to species, age, location, time of year etc. However a general avoidance of the sonar by rapid movement away from the source is a common characteristic across many species (Miller et. al., 2012). This can be seen in Beaked Whales (Family *Ziphiidae*), where Tyack et al. (2011) reported a cessation of deep diving, which is associated with foraging, and echolocating in the presence of MFS and avoidance of the source with a prolonged ascent.

Such activity has also been shown to significantly influence the diving behaviour of Killer Whales (*Orcinus orca*), with an abrupt change from deep dives to shallow diving at sonar onset (Sivle *et al.*, 2012). This can impact the fitness of the individuals and the population as a whole, as deep diving has been shown to be associated with feeding (Sivle *et al.*, 2012). Other, more severe behaviour alterations have also been observed in Killer Whales, such as the temporary separation of a calf from its pod, cessation of feeding/resting, and the continuation of avoidance movements after the sonar had stopped being emitted (Miller et. al., 2012). However a study by Kuningas et al. (2013) demonstrated that the level of reaction to sonar by Killer Whales can be influenced by multiple factors, concluding that the availability of prey was the main factor dictating the movements of the Killer Whales.

Contrastingly, Long-Finned Pilot Whales (*Globicephala melas*) have been observed as increasing their vocalisations and huddling together in response to MFS, as opposed to the typical avoidance behaviours mentioned above (Rendell and Gordon, 1999).

Although the majority of studies carried out have been on toothed whales, baleen whales have shown behavioural modifications in response to naval sonar activity also. Grey Whales (*Eschrichtius robustus*) have shown an avoidance of sonar and travel displacement during seasonal migrations (Tyack, 1990). Humpback Whales (*Megaptera novaeangliae*) have also shown a cessation of 'singing' when exposed to prolonged sonar activity (Tyack, 1999). A study by Goldbogen et al. (2013) showed behavioural responses of Blue Whales (*Balaenoptera musculus*) to naval sonar ranging from cessation of deep feeding to an increased swimming speed and directed travel away from the sound source. This disruption of feeding and displacement from potentially high-quality feeding grounds could have important and previously undocumented impacts on the foraging ecology, individual fitness and overall population health of baleen whales (Goldbogen *et al.*, 2013). These behavioural alterations caused by naval sonar activity can also have more important physiological effects on cetaceans.

Impacts: Physiological

Physiologically, the use of prolonged sonar has been shown to induce temporary hearing loss in species such as the Bottlenose Dolphin (*Tursiops truncatus*) in addition to mild behavioural alterations and disorientation (Mooney *et al.*, 2009). The loss of hearing and subsequent loss of echolocational abilities in cetaceans likely impairs the orientational abilities and maintenance of ordinary dive behaviour in cetaceans (Talpalar and Grossman, 2005).

However of greater concern is that the modified diving behaviour as a result of naval sonar activity has been suggested as the cause of Gas and Fat Embolic Syndrome in cetaceans (Fernandez *et al.*, 2005). Gas and Fat Embolic Syndrome is the formation of gas bubble-associated lesions and fat embolism within the vessels and tissues of vital organs. These form due to the modified diving behaviour caused by naval sonar, resulting in nitrogen supersaturation above a level normally tolerable in tissues. This is similar to the decompression sickness or 'bends' seen in humans, a condition resulting when decompression occurs too quickly, causing nitrogen bubbles to form in the tissues of the body. It had previously been thought that cetaceans did not suffer from such conditions (Fernandez *et al.*, 2005). This particular syndrome is induced by behavioural alterations associated with exposure to MFS and particularly affects deep-diving Beaked Whales, such as Cuvier's Beaked Whales (*Ziphius cavirostris*) and Blainville's Beaked Whales (*Mesoplodon densirostris*). The reason behind the heightened sensitivity of deep diving species to sonar is believed to be due to the fact that under high pressures at depth, sonar activity may stimulate more sensory fibres than at the surface water pressures, due to increased dendritic conduction and excitability as part of the adaptation of the CNS to high pressures (Talpalar and Grossman, 2005).

This is supported by the stranding and death of fourteen Beaked Whales in the Canary Islands in September 2002, close to the site of an international naval exercise. Strandings commenced approximately four hours after the onset of MFS. In this case no inflammatory or neoplastic processes were recorded, and no pathogens were identified. However the whales showed severe congestion and haemorrhage in areas such as the acoustic jaw fat, ears, brain, and kidneys due to gas-bubble associated lesions (Fernandez *et al.,* 2005). The mass stranding of cetaceans, and particularly Beaked Whales, in response to naval sonar activity is now believed to involve Gas and Fat Embolic Syndrome (Fernandez *et al.*, 2004)

The Result: Mass Strandings

Naval sonar activity has been associated both spatially and temporally with the lethal mass strandings of several whale species, particularly toothed whales. Historically, mass strandings of Beaked Whales having been reported in the scientific literature since 1874. During the period 1874-2004, 136 Beaked Whale mass strandings were recorded, and of these, 126 occurred between 1950 and 2004, after the introduction and application of contemporary, high-powered sonar (D'Amico *et al.*, 2009). However due to a lack of historical records, only 12 (9.5%) can be proven to coincide spatially and temporally with MFS naval activity.

Perhaps the most important mass stranding event to coincide with naval sonar activity occurred on March 15th 2000 in the Northern Bahamas. This event consisted of the stranding of 17 cetaceans, mainly Beaked Whales, within a 36 hour period following US naval activity in the area. Of these, seven died and were shown to have inner ear and brain damage. In a joint report by the National Ocean and Atmospheric Administration (NOAA) and the United States Navy it was agreed that naval sonar activity operating in the area was the most likely cause of the acoustic trauma and mass stranding (NOAA *et al.,* 2001).

The modern consensus regarding mass strandings and naval sonar activity is that sonar causes behavioural alterations in cetaceans, such as rapid ascent from depths while diving, which can in turn cause disorientation and physiological changes. These alterations are believed to be the principle cause of mass strandings (NOAA *et al.,* 2001, Cox *et al.,* 2006). In this way it is the combination of many factors operating together which ultimately cause the lethal mass strandings that have recently become popularised by the media.

The input of numerous factors influencing mass strandings is shown by the fact that the susceptibility of cetaceans, and particularly Beaked Whales, to naval sonar is not uniform. A study by Filadelfo et al. (2009) showed that naval sonar activity is not causing the mass stranding of Beaked Whales everywhere, but that certain populations are more susceptible due to particular bathymetric (ocean floor topography) conditions that are problematic. This finding was supported by the fact that strandings have been significantly correlated with naval sonar activity in areas such as the Mediterranean and Caribbean Seas where there is steep ocean bathymetry directly adjacent to the coastline, but not off the coasts of Japan or California where bathymetric conditions show broader shelves adjacent to the coastline (Filadelfo *et al.,* 2009).

It is also important to note that mass strandings are not exclusively as a result of naval sonar activity. Seasonal patterns of stranding have been observed for Beaked Whales (MacLeod *et al.,* 2004) and climatic factors such as weather and animals simply 'taking the wrong way' have also been suggested as likely causes of mass strandings (Mazzariol *et al.,* 2011). A worrying study by Madsen et al. (2006) has also suggested that acoustic disturbance due to the presence of wind turbines in the marine environment can alter the behaviour of cetaceans in a similar way to naval sonar, and this has been put forward as a possible cause for the deaths and strandings of 30 Sperm Whales (*Physeter macrocephalus*) in the UK and Western Europe between January and February 2016.

The mass stranding events that have occurred are atypical and further research is required in order to understand the exact cause and mechanism behind them and to limit any future events. However if it were not for the occurrence of such events, the discovery of important physiological responses of cetaceans to sonar such as Gas and Fat Embolic Syndrome (Fernandez *et al.*, 2005) would probably have been greatly delayed. The stranding of Beaked Whales particularly has also provided us with huge insights into the ecology and feeding patterns of these elusive species. The inspection of the stomach contents of stranded individuals allows us to infer information about their lifestyles and feeding patterns by the presence of freshly ingested food in their stomachs. The 2002 stranding of Beaked Whales in the Canary Islands allowed Santos et al. (2007) to show differential prey and thus feeding styles between Beaked Whale species. This rare ecological insight demonstrates the information we can garner and the learning opportunities available from these unfortunate lethal incidents.

The Future: A Quieter Ocean?

The solution to this problem seems simple, reduce or discontinue MFS usage. A complete moratorium on naval exercises in the waters off the Canary Islands employed by the Spanish government in 2004 has resulted in a complete cessation of mass strandings. This area had previously been considered a 'hotspot' for cetacean strandings (Fernandez *et al.,* 2013). However such extreme measures are not the global norm.

Current mitigation methods used during naval exercises focus on preventing auditory damage (Parsons *et al.,* 2008). This is achieved through the timing and location of naval exercises, the gradual increasing of sonar intensity over time, termed 'soft-start', and through monitoring the presence of animals in order to maintain an exclusion zone surrounding the sites (Dolman *et al.,* 2009). However behavioural changes, which are associated with mass strandings, often occur at lower sonar levels than auditory damage and can be just as damaging (Parsons *et al.,* 2008).

Although alternatives to the use of active sonar have been suggested, their effectiveness in contemporary situations is much more limited. The use of passive sonar (the detection of acoustic signals produced by an external source) rather than active sonar (producing your own signal and analysing its reflection) has been employed for many years (Horwitz, 2015), and unlike active sonar, passive sonar has no impact on cetaceans. In fact, passive sonar has even been used to study the movements of deep-diving cetaceans, such as Sperm Whales (Zimmer *et al.,* 2003). However the use of silent machinery in modern submarine vehicles greatly limits the future prospects of passive sonar (Horwitz, 2015).

A complete ban on naval sonar activity is unlikely to be the most viable solution currently, due to the extensive use of active sonar by naval units globally. Perhaps the way forward is simply a more responsible use of naval sonar in areas where the impacts it may have are greater due to natural ocean bathymetry conditions and species occurrence. In order to move forward, a balance between naval security and cetacean conservation must be made.

Conclusion

Due to the wealth of evidence available, there is now a generally accepted link between naval sonar activity and cetacean behaviour, physiology and strandings. This has resulted in an array of legal cases and formal statements of concern by international bodies and organisations seeking to limit the use of naval sonar to environmentally acceptable levels (Parsons *et al.,* 2011). This has been largely supported by the public, with a study by Parsons et al. (2011) showing that 51.3% of people surveyed believing that naval sonar impacted cetaceans and 75.8% believing that sonar use should be moderated if it impacts cetaceans. Increased public awareness combined with growing scientific data have prompted recent changes to the use of MFS. This is shown by the recent agreement of the U.S. Navy to limit its use of sonar in the waters off California and Hawaii, areas considered cetacean 'hotspots'.

Such advancements in the conservation of cetaceans provide a solid grounding for future conservation efforts for many species, not just cetaceans, and demonstrate a realisation of the unintentional impacts that human activities have on the natural world. However as we enter the Anthropocene, a period where many species will face the risk of extinction, it is important to reiterate that commercial whaling still operates in countries such as Japan and Iceland and that true cetacean conservation and protection has yet to be achieved. However if it is to be achieved an understanding of all the threats cetaceans face is required.

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