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Impacts of Navy Sonar on Whales and Dolphins: Now beyond a Smoking Gun?

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The risks military sonar poses to cetaceans received international attention with a highly-publicized mass stranding of Cuvier's beaked whales (*Ziphius cavirostris*), Blainville's beaked whales (*Mesoplodon densirostris*), and northern minke whales (*Balaenoptera acutorostrata*) in the Bahamas in 2000. This was the first time that the US Government determined a stranding to be the result of mid-frequency active sonar use. Subsequently attention has been drawn to other mass strandings coincident with naval exercises, including events preceding the 2000 mass stranding. The list of species for which mass strandings have been linked to naval exercises has also increased to include other beaked whales, dwarf and pygmy sperm whales (*Kogia* spp.), pilot whales (*Globicephala* spp.), several dolphin species (*Stenella* sp. and *Delphinus delphis*), and harbor porpoises (*Phocoena phocoena*). In particular, there have been several mass strandings in the northern Indian Ocean coincident with naval exercises—including one of the largest (200–250 dolphins)—which have received little attention. Changes in beaked whale behavior, including evasive maneuvering, have been recorded at received levels below <100 dB re 1 μPa (rms) and mass stranding may occur at received levels potentially as low as 150–170 dB re 1 μPa. There is strong scientific evidence to suggest that a wide range of whale, dolphin and porpoise species can also be impacted by sound produced during military activities, with significant effects occurring at received levels lower than previously predicted. Although there are many stranding events that have occurred coincident with the presence of naval vessels or exercises, it is important to emphasize that even the absence of strandings in a region does not equate to an absence of deaths, i.e., absence of evidence does not mean evidence of absence. Strandings may be undetected, or be unlikely to be observed because of a lack of search effort or due to coastal topography or characteristics. There may also be "hidden" impacts of sonar and exercises not readily observable (e.g., stress responses). Due to the level of uncertainty related to this issue, ongoing baseline monitoring for cetaceans in exercise areas is important and managers should take a precautionary approach to mitigating impacts and protecting species.

Keywords: cetacean, beaked whales, mass strandings, sonar, underwater noise, conservation, naval exercises

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INTRODUCTION

The risks sonar poses to cetaceans received international attention with a highly-publicized mass stranding of Cuvier's beaked whales (*Ziphius cavirostris*), Blainville's beaked whales (*Mesoplodon densirostris*), and northern minke whales (*Balaenoptera acutorostrata*), in the Bahamas, in 2000 (Balcomb and Claridge, 2001). This was the first time that the US Government determined a stranding to be the result of mid-frequency active sonar use[1] (Anonymous, 2001), although the link between naval exercises and beaked whale strandings had first been documented in the 1970s (Van Bree and Kristensen, 1974). Following the Bahamas strandings, concerns started to be expressed about the threats posed to cetacean populations by active sonar and scientists started to point to evidence of more sonar-related strandings in various parts of the world (Parsons et al., 2008a; Dolman et al., 2011) This concern led to several court cases in the US and legal injunctions against military exercises using sonar (Zirbel et al., 2011a); sonar-related resolutions from international treaty organizations; and statements of concern by professional organizations (see Parsons et al., 2008a; Dolman et al., 2011; Simmonds et al., 2014).

Although there was mounting scientific evidence that sonar could cause impacts on cetaceans, the issue of military sonar was—as Parsons et al. (2008a) put it—a "smoking gun" in relation to its possible link to cetacean strandings, injuries and mortalities. The largely precautionary approach, by legal bodies and organizations, to protect cetaceans from a possible and on-going threat, appears to be supported by the general public. A survey restricted to the Washington DC area found that 51% of respondents believed that naval sonar impacted marine mammals and, moreover, three-quarters (75.2%) thought that the Navy should not be exempt from environmental regulations during peacetime. They also believed that "sonar use should be moderated if it impacts cetaceans" (75.8%; p. 49) and there was bipartisan support for such protection (Zirbel et al., 2011b).

This paper provides an update on the latest scientific data on the effects of sonar on cetaceans, showing that the impacts of military sonar on a variety of cetacean species are now more than a "smoking gun," that all navies need to fully assess the likely true extent of these impacts, and immediately implement best practice, including effective monitoring and mitigation measures.

BEAKED WHALE STRANDINGS

Beaked whale mass strandings are relatively unusual events and draw attention when they occur (see Parsons et al., 2008a; for a previous summary).

An analysis of "atypical" mass strandings[2] of beaked whales found enough evidence for a statistically significant correlation between 12 of these events (out of 126 beaked whale mass standings since 1950) and naval exercises in the Caribbean and Mediterranean (D'Amico et al., 2009; Filadelfo et al., 2009a). A further 27 beaked whale mass stranding events occurred either adjacent to naval facilities or at the same time as nearby naval vessels could have been using active sonar (D'Amico et al., 2009; Filadelfo et al., 2009a). It should be noted that due to a lack of availability of data on naval sonar use, it is entirely possible more of these beaked whale mass strandings may have been linked to naval sonar use, or exercises.

Subsequently, in 2014, five Cuvier's beaked whales stranded on the coast of Crete during the *Noble Dina 2014* joint exercise with the Israeli, Greek and US Navies (Dolman, 2014). In early 2015, during the hunt for a Russian submarine off the coast of western Scotland and Ireland, a further eight Cuvier's beaked whales ("atypically") stranded on the coast of Ireland (Sibylline, 2015). Also in 2015, three beaked whales stranded simultaneously but in different locations along the southern coast of Guam. It was confirmed that a joint US-Japanese naval exercise, incorporating sonar use and anti-submarine activities, was being conducted in nearby waters when the strandings occurred (23–27 March 2015; Kuam News, 2015).

There have also been mass strandings where anthropogenic underwater noise has been suspected to be a factor; however, there was not enough information to make a link. For example, in 2008 there was a high level of cetacean strandings reported (56 animals over a 7-month period)—including Cuvier's and Sowerby's beaked whales (*Mesoplodon bidens*) and long-finned pilot whales (*Globicephala melas*)—off the coast of Ireland and Scotland (Dolman et al., 2010). However, a full investigation was not conducted due to the carcasses' advanced state of decomposition. In the winter of 2014-15 (Amos, 2015; Siggins, 2015), there was a recurrent increase in Cuvier's beaked whale strandings in this region ($n = 15$), which appeared to have occurred at the same time as a high level of anti-submarine activity, although active sonar use in this region was denied by the Royal Navy (Farmer, 2015).

THE RECEIVED LEVELS OF SONAR AND BEAKED WHALES IMPACTS

In 2007, a US government-convened panel published guidelines for the level of noise at which injury occurs to cetaceans (Southall et al., 2007). They considered impulsive sound at levels of 230 dB re:1 μPa peak pressure was an uppermost "safe" exposure limit for marine mammals, including beaked whales. The 2007 limit has since been adopted by many noise producers and managers as an absolute level at which injury impacts to cetaceans occur [(for example, a European Union advisory group used these criteria

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[1] Mid-frequency active sonar has a frequency range of 1kHz-10kHz. One of the systems most frequently used and/or associated with stranding events is the AN/SQS 53C system (3.5kHz with most energy in the 2.5kHz-4.5Hz range) with a source level of 235 dB rms re 1 μPa @ 1m. Low frequency active sonar has a frequency range of 100-500Hz and is utilized at approximately the same source level as mid-frequency sonar.

[2] These "atypical" mass strandings are when multiple animals come ashore, but the strandings may occur over sizeable geographic area over a short time frame (Frantzis, 1998). D'Amico et al. (2009) use a definition of two or more animals stranding within a six day period over a 40 nautical mile (74km) stretch of coastline.

for their advice on harmful sound levels in EU waters (Tasker et al., 2010; Genesis, 2011)]. The approach used by Southall et al. (2007) has been criticized on methodological and statistical grounds, such as inconsistency of weighting functions and problems with pseudo replication that downplay the sensitivity of animals to sound (Tougaard et al., 2015; Wright, 2015). For example, the proposed levels were developed using limited available evidence, where levels at which temporary (TTS) and permanent threshold shift (PTS) and other responses occur in a small number of captive cetaceans from a limited number of species [i.e., common bottlenose dolphins (*Tursiops truncatus*) and beluga whales (*Delphinapterus leucas*)], particularly animals kept in the US Navy's marine mammal research facilities. Critics have noted that trained, captive cetaceans, often in noisy facilities and exposed to high sound level experiments many times, may not respond in the same way as naïve, wild animals (Parsons et al., 2008a; Wright et al., 2009). Scientists studying US captive cetacean responses to sound have also highlighted that using these animals to directly predict the behavior of wild animals can lead to biased and/or inaccurate predictions. Such studies are "likely not directly transferrable to conspecifics in the wild. The dolphins have years of experience under stimulus control, which is a necessary condition for the performance of trained behaviors, and they live within an environment with significant boating activity. These factors likely impact the threshold of responsiveness to sound exposure, potentially in the direction of habituation or increased tolerance to noise" (Houser et al., 2013, p. 130). In fact, the original panel that published the 230 dB re:1 μPa peak pressure safe level noted that cetacean strandings, and thus injury and probable death, could occur at much lower levels due to behavioral changes occurring at much lower sound levels than their criterion (Southall et al., 2007). NOAA Fisheries has since introduced updated guidance (National Marine Fisheries Service, 2016) which, for example, notes that the 230 dB re:1 μPa peak pressure is an impulsive (one off) exposure level that could cause PTS in species, such as beaked whales (224 dB re:1 μPa peak pressure for TTS). The updated guidance notes that a cumulative sound exposure level (over 24 h) of 185 dB re 1 μPa^2s could likewise cause PTS or 170 dB re 1 μPa^2s for TTS (National Marine Fisheries Service, 2016). However, this guidance is written in an extremely technical format and is far from accessible to non-specialists.

That behavioral impacts occur at lower sources levels than noted above, is an important caveat is frequently overlooked by noise managers when developing mitigation measures to active sonar. Following the 2000 Bahamas mass stranding it was estimated that these whales were exposed to sound levels no higher than "160–170 dB re1 μPa @ 1 m for 10–30 s" (p. 286 in Hildebrand, 2005a); or even 150–160 dB re 1 μPa for 50–150 s (Hildebrand, 2005b), a level clearly much lower than the (now widely-used) noise impact guideline level of 230 dB re: 1 μPa (Southall et al., 2007), which would result in a much larger impact radius around the active sonar source.

Subsequent at-sea studies investigated the specific responses of tagged Blainville's beaked whales to military sonar ($n = 6$). Tyack et al. (2011) found that one animal stopped feeding above 138 SPL dB (or a cumulative sound exposure level (SEL) of 142 dB re 1 μPa^2-s), while a second experiencing a received level of 146 re 1 μPa swam 10s of km away (an average of 54 ± 10 km) from the center of the testing range and remained out of the area for 2–3 days (McCarthy et al., 2011; Tyack et al., 2011). The calls of beaked whales in the area also decreased during sonar exposure and did not recover to pre-exposure levels for up to 108 h after exposure, although calls were produced even at estimated exposure levels of 157 dB re 1 μPa (rms) (McCarthy et al., 2011).

In a more recent study on tagged Cuvier's beaked whales ($n = 2$), the animals began to respond at received levels of 89 dB re 1 μPa (rms) by ceasing to beat their tail flukes (DeRuiter et al., 2013). One animal stopped echolocating, ceased foraging, and swam rapidly away from the source at a received level of 98 dB re 1 μPa (rms). The avoidance response lasted for 1.6 h. The other whale demonstrated similar responses, and displayed an abnormal diving pattern for 7.6 h after exposure to sonar. One of the whales was incidentally exposed to sonar levels similar to those that produced a response (78–106 dB re 1 μPa rms) from a naval vessel that was using sonar 118 km away, according to the ships' log (DeRuiter et al., 2013). The researchers stated that "current US management practices assume that significant behavioral disruption almost never occurs at exposure levels this low" (DeRuiter et al., 2013). In fact, significant impacts to beaked whales could occur at levels lower, and from sound sources at greater distances from animals, than previously thought, arguably making current US mitigation guidelines for mid-frequency active sonar ineffective at preventing wide-scale impacts to whales.

Miller et al. (2015) determined that Northern bottlenose whales (*Hyperoodon ampullatus*) showed a "high sensitivity… to acoustic disturbance, with consequent risk from marine industrialization and naval activity" (p. 1). At a received sound pressure level (SPL) of 98 dB re 1 μPa, a tagged whale turned to approach the sound source, but at a received SPL of 107 dB re 1 μPa, the whale began moving in an unusually straight course and then made a near 180° turn away from the source, and performed the longest and deepest dive (94 min, 2339 m) recorded for this species (Miller et al., 2015). Animal movement parameters differed significantly from baseline for more than 7 h until the tag fell off 33–36 km away (Miller et al., 2015). No clicks were emitted during the response period, indicating cessation of normal echolocation-based foraging. A sharp decline in both acoustic and visual detections of conspecifics after exposure suggests other whales in the area responded similarly (Miller et al., 2015). Sivle et al. (2015) also noted avoidance behavior by bottlenose whales to a 1–2 kHz sonar signal, starting at a sound pressure level of 130 dB re 1 μPa. They noted "severe" responses to the sonar exposure (as ranked by experts grading the responses), including cessation of feeding and long-term avoidance (Sivle et al., 2015).

Reponses to (simulated) sonar signals (3.5–4 kHz) were also noted for Baird's beaked whale (*Berardius bairdii*) by Stimpert et al. (2014). The researchers noted that "within 3 min of exposure onset, the tagged whale increased swim speed and body movement, and continued to show unusual dive behavior for each of its next three dives," with reactions by the whale occurring at a received level of approximately 127 dB re 1 μPa.

A number of studies suggest population-level impacts in beaked whales from repeated exposures to naval activities (Dolman and Jasny, 2015). A Blainville's beaked whale population on the Navy's AUTEC naval range, in The Bahamas, had lower abundance and recruitment success (calf to female ratio) than another off-range Bahamas population, based on a 15-year field study (Claridge, 2013). Further, adult females showed high residency at the navy range, putting them at risk, especially when pregnant and lactating (Claridge, 2013). In California, naval activities were proposed as one of two plausible hypotheses, along with ecosystem change, to explain a precipitous decline in beaked whale populations in the California Current ecosystem (Moore and Barlow, 2013).

The studies above document behavioral changes in beaked whales at relatively low levels of mid-frequency sonar exposure that can be expected to occur at distances many hundreds of miles from the sonar source. It should be noted, however, that the degree of responses by animals, and the received level of sound at which these responses occur, might be affected by the context in which the sound is received. For example, a mother and calf might be more "skittish" than a solitary male; an animal that urgently needs to feed may show less of a behavioral change than one that is relatively well-fed; a young animal that is more vulnerable to predation might react more quickly to an intense noise than a larger adult; a habituated animal might respond at higher received levels than a naive animal; or a chronically stressed animal might responded differently to a non-stressed animal (see section Absence of Evidence Does Not Mean Evidence of Absence–the Need For Precaution Below; Beale and Monaghan, 2004; Beale, 2007; Wright et al., 2007; Guerra et al., 2014; Forney et al., 2017).

Even if the changes in beaked whale behavior resulting from sonar use do not lead to stranding events, they could still lead to sub-lethal impacts and significantly impact the health of individuals, and potentially populations, by affecting biologically important behaviors, such as preventing normal feeding or separating family members. The degree to which this happens is currently an important question for cetacean conservation, in all species (e.g., Parsons et al., 2015). For example, even minor reductions in feeding behavior as the result of human disturbance were estimated to have dramatic effects on the energy budget of cetaceans, which could translate into substantive negative impacts on cetacean fitness and health (Christiansen et al., 2013).

To quantify this energetic impact, Williams et al. (2017) tried to estimate the energetic cost of beaked whales evading sonar. Using the energetic costs of bottlenose dolphin fluke strokes (3.31 ± 0.20 J kg^{-1} stroke^{-1}), the cost of high speed evasion responses in cetaceans, including observed escape responses of beaked whales to naval sonar (increased fluking rates and longer bursts of powered swimming), was estimated. Williams et al. (2017) reported a theoretical 30.5% increase in beaked whale metabolic rate, with an elevated rate being maintained for more than 90 min after the exposure to noise. Even increasing the amplitude of vocalizations—so that calls may be heard in a noisy environment—may have an energetic cost (Holt et al., 2015). However, the impact of these energetic costs on cetacean health, both short- and long-term, needs to be evaluated.

There are several modeling efforts underway to estimate the health and population-level impacts of behavioral disturbances upon cetacean populations, with beaked whales being a particular cause for concern. The most notable are the PCOD and PCAD models (see King et al., 2015 and Harwood et al., 2016 for details). One particularly enlightening study, on gray whales (*Eschrichtius robustus*), predicted that an energy loss of 4% because of disturbance events during the year of pregnancy would result in reproductive failure (Villegas-Amtmann, et al., 2015). Moreover, a 30–35% energy immediately before pregnancy would mean that a female would lack sufficient energy to become pregnant (Villegas-Amtmann, et al., 2015). Death would occur at a 40–42% energy loss (Villegas-Amtmann, et al., 2015). This equates to a loss of only 10 days of feeding opportunities due to disturbance theoretically leading to an unsuccessful pregnancy or loss of a whale calf (Villegas-Amtmann, et al., 2015).

OTHER CETACEAN SPECIES AFFECTED BY ACTIVE SONAR

A young male beluga whale was exposed to mid-frequency sound frequencies [19–27 kHz;140–160 dB (no reference level given)] and exhibited significantly increased heart rate, with the rate increasing with the intensity of the sound level (Lyamin et al., 2011). Heart rate increased no matter how many times the whale was exposed to the sound and the animal showed no signs of habituation. The respiration rate of the animal also increased significantly at the beginning of exposures. Such "severe tachycardia" is the heart's reaction to a stressor. This started at very low noise levels (i.e., 140 dB), suggesting a relatively severe physiological stress response to anthropogenic noise exposure in this whale. One would expect similar, substantive, yet not readily observable and effectively "hidden" stress responses to occur in other cetacean species with similar physiologies (such as beaked whales). Although short-term (acute) stress responses are essential for the survival of animals, allowing them to undergo "fight or flight" responses, continued (chronic) activation of substantive stress responses can be physiologically detrimental to animals (Wright et al., 2011).

Tagged blue whales (*Balaenoptera musculus*) in the Southern California Bight displayed behavioral responses to experimental mid-frequency active sonar. Although the sound levels produced in the experiments were orders of magnitude below most military systems, the blue whales responded by stopping feeding, increasing swimming speed and traveling away from the sound source, with displacement occurring at a received level of 140 dB re 1 μPa, with other responses, such as cessation of feeding, occurring at lower source levels (Goldbogen et al., 2013). Baleen whales thus alter biologically important activities in the presence of sonar sounds. Moreover, the researchers expressed their concerns that "frequent exposures to mid-frequency anthropogenic sounds may pose significant risks to the recovery rates of endangered blue whales" because they ceased feeding and were displaced (p. 6 in Goldbogen et al., 2013).

Northern minke whales (*Balaenoptera acutorostrata*) had been noted previously (Parsons et al., 2008a) to strand during military sonar-related beaked whale mass stranding events (e.g., in 2000 in the Bahamas and in 2005 in North Carolina; Anonymous, 2001; Balcomb and Claridge, 2001; Hohn et al., 2006). Moreover, it has been noted that during naval exercises in Scotland, minke whale sighting rates significantly decreased (Parsons et al., 2000). It was subsequently proposed that minke whales hear well within the range of mid-frequency active sonars, and thus they are likely to be at risk from them over wide ranges, although this species is often overlooked in exercise planning (Tubelli et al., 2012). Subsequently, Sivle et al. (2015) found that minke whales exhibited "high speed avoidance" (p. 469) when exposed to 1–2 kHz sonar signals, with avoidance starting at sound pressure levels of 130 and 146 dB re 1 μPa,

Minke and blue whales may not be the only baleen whales that are vulnerable. Between 1982 and 2007, of 180 gray whale (*Eschrichtius robustus*) standings that occurred in California, 22% coincided in time and location with military exercises (Filadelfo et al., 2009b). Although the monthly pattern of whale strandings in relation to military exercises was statistically insignificant, nonetheless a substantial proportion of gray whale strandings did occur coincident with naval exercise periods and the situation warrants precautionary management and further investigation into whether this species may also be vulnerable to military noise (Filadelfo et al., 2009b). Indeed, a study noted that migrating gray whales moved around a stationary sound source emitting low frequency active sonar sounds (0.1–0.5 kHz), based on land-based observations (Buck and Tyack, 2000; Croll et al., 2001; Tyack, 2009), with avoidance occurring at a received level of approximately 140 dB re 1 μPa (Buck and Tyack, 2000). Minor movement to avoid a loud sound source may not seem like a major impact at first glance, but as mentioned above, Villegas-Amtmann, et al. (2015) estimated that just 10 days of lost foraging opportunities due to disturbance could lead to an unsuccessful pregnancy/loss of a calf in gray whales (Villegas-Amtmann, et al., 2015).

Humpback whales (*Megaptera novaeangliae*) changed their singing behavior, lengthening their songs—with some ceasing altogether—when exposed to low frequency active sonar (Miller et al., 2000). As humpback whale song plays a significant role in their mating behavior (Parsons et al., 2008b), this may have biological significance. Sivle et al. (2015) noted humpback whales responded to 1–2 kHz active sonar, although the responses were less severe, at received levels higher than did minke and bottlenose whales. However, Sivle et al. (2016) found that the first exposure of 12 humpback whales to military low-frequency sonar (1.3–2.0 kHz with SPLs at the source up to 160–180 dB re 1 μPa) led to a statistically significant, 68% reduction in lunge feeding rates. Moreover, during a second exposure, the feeding rate was 66% below normal, pre-exposure levels. Such a significant reduction in feeding might have an impact on the energy budget of these whales.

The following species, other than beaked whales, have stranded coincident with naval exercises: dwarf sperm whales (*Kogia sima*); pygmy sperm whales (*K. breviceps*); short-finned pilot whales (*Globicephala macrorhynchus*); long-finned pilot whales (*G. melas*); pygmy killer whales (*Feresa attenuata*); and several dolphin species (*Stenella attenuata* and *S. coeruleoalba*) (Kaufman, 2004, 2005; Department of the Environment and Heritage, 2005; Hohn et al., 2006; Wang and Yang, 2006; Parsons et al., 2008a). Some of these standings occurred even though naval vessels were 90 nautical miles away from the stranding area (Kaufman, 2005)—a distance which is now known to be within the range that sonar exercises could potentially cause cetacean behavioral changes (DeRuiter et al., 2013). It should be noted that the strandings of long-finned pilot whales were usually associated with high frequency sonar (50–200 kHz) usage, as opposed to mid-frequency active sonar (the latter is often considered to be the sound source of most concern) (Department of the Environment and Heritage, 2005). Another species that could be added (although not stranding as such), is the melon-headed whale (*Peponocephala electra*). This species has entered unusually shallow waters in response to sonar exposure—a so-called "milling event" (Southall et al., 2006).

Even sperm whales (*Physeter microcephalus*) have been documented responding to sonar. Isojunno et al. (2016) and Curé et al. (2016) reported avoidance behavior, interruption of foraging and/or resting behavior, and an increase in social sound production in response to 1–2 kHz active sonar. Sperm whales stopped foraging at cumulative received sound exposure levels (SEL) of 135–145 dB re 1 μPa (Curé et al., 2016). They also displayed avoidance and social call changes in response to 6–7 kHz sonar, although the responses were less pronounced (Curé et al., 2016; Isojunno et al., 2016).

In recent years, more dolphin species have been found during mass stranding events coincident with naval exercises. In June 2008, a mass stranding of common dolphins (*Delphinus delphis*) was associated with a naval exercise in Falmouth Bay, UK and at least 26 of these animals died. The researchers who evaluated the standing event determined "naval activity to be the most probable cause of the Falmouth Bay [mass stranding event]" (Jepson et al., 2013). One of the largest dolphin stranding events to date, however, occurred 6–7 March 2009 on Gaddani Beach on the Balochistan coast of Pakistan, 50 km northwest of Karachi, when a mass stranding of 200–250 pan-tropical spotted dolphins (*Stenella attenuata*) occurred on the second day of a multi-national naval exercise, AMAN 09 (5–14 March 2009, involving 20+ warships from the US, UK, France and Australia) (Kiani et al., 2011). This event was the largest (atypical) mass stranding recorded of this species by an order of magnitude. It seems highly likely that this unusual mass mortality was also caused by naval exercises.

A common dolphin mass stranding (*Delphinis capensis*; $n = 11$) occurred on the Iranian coast on 22 January 2011 (Mohsenian et al., 2014). Although this paper's authors stated that they had been told that no Iranian naval activity had occurred prior to the mass stranding (Mohsenian et al., 2014), a large multi-national naval exercise involving the Indian, French and US navies in the Arabian Sea had commenced on 11 January 2011 (Anonymous, 2011). These mass strandings of dolphins in the northern part of the Indian Ocean have received little to no attention by government agencies in Europe and the US.

Other delphinids may also be vulnerable to active sonar. For example, killer whales (*Orcinus orca*) exposed to mid-frequency active sonar in Norway responded at received levels much lower than currently addressed by US Navy mitigation measures (Miller et al., 2014). In fact, Harris et al. (2015) found that killer whales were more likely to respond to sonar at lower received levels than sperm whales or long-finned pilot whales.

Recent research has also highlighted the susceptibility of porpoises to naval activities. In one incident, 85 harbor porpoises (*Phocoena phocoena*) stranded along approximately 100 km of Danish coastline from 7 to 15 April 2005 (Wright et al., 2013). Bycatch was established as the cause of death for most of the individuals, and military vessels from various countries were confirmed in the area from 7 April, *en route* to the largest naval exercise in Danish waters to date (Wright et al., 2013). Although sonar usage could not be confirmed, it is likely that ships were testing sonar equipment prior to the main exercise. Thus, naval activity cannot be ruled out as a possible contributing factor (Wright et al., 2013).

In fact, recent acoustic exposure experiments suggest that harbor and finless porpoises (*Neophocaena phocaenoides*) may be more sensitive to anthropogenic sound than previously thought. Previous predictions had extrapolated their sensitivity to sound based on results from common bottlenose dolphins (*Tursiops truncatus*), but experimental results show this appears to have underestimated the sound levels at which impacts (behavioral and TTS) to harbor porpoises might occur (Tougaard et al., 2015). For porpoises, Tougaard et al. (2015) found that impacts strongly depend on the frequency of the sound, with avoidance reactions occurring just 40–50 dB above the hearing threshold for a particular frequency, with TTS occurring at about 100 dB above the hearing threshold.

There is a substantive and growing body of corroborating evidence to suggest that a wide range of whale, dolphin and porpoise species can be impacted by sound produced during military activities. The risk active sonar poses is not limited to beaked whales only. In fact, there may be more individuals of non-beaked whale species that have stranded coincident with military exercises than beaked whales. In addition, the level of sound at which impacts can occur is generally lower than previously believed. Thus, there is an urgent need for nations to require more strategic and wide-spread active sonar management. A more concerted effort to monitor for cetacean strandings, including delphinids, and to plan mitigation measures for all naval exercises—especially in the Indian Ocean—is warranted.

ABSENCE OF EVIDENCE DOES NOT MEAN EVIDENCE OF ABSENCE–THE NEED FOR PRECAUTION

Although there are many stranding events that have occurred coincident with the presence of naval vessels or exercises, it is important to emphasize that even when strandings do not occur coincident with naval exercises, this does not mean there have been no deaths or other negative impacts.

It is highly likely that injury or mortality at sea caused by noise will not be observed, as explained previously (Fernández et al., 2005; Parsons et al., 2008a). In some locations, even if animals do strand, it is unlikely carcasses will be observed or recovered, either because they wash away before they are seen or the location is too remote for them to be observed at all.

To illustrate this: there have been 11 cetacean mass stranding events in the Hawaiian Islands in a 22-year period, of which six have coincided with military exercises (Faerber and Baird, 2010). However, despite the occurrence of beaked whales in these waters, none of these mass strandings have involved beaked whales. Through 2006, only nine single beaked whale strandings were recorded on Hawaii's coasts (Faerber and Baird, 2010). Due to this paucity of records of beaked whale strandings, the US Navy has stated that there are no impacts on vulnerable beaked whales in this location from military activities (Faerber and Baird, 2010). However, an analysis of topography and coastal characteristics indicates that a variety of factors—a lack of beaked whale habitat close to shore, a prevalence of steep cliffs, lower human densities on the coast—decreases the likelihood of strandings occurring and/or being detected in Hawaii compared to elsewhere (e.g., Canary Islands) (Faerber and Baird, 2010). Faerber and Baird (2010, p. 610) stated that "it is inappropriate to conclude there has been no impact on beaked whales from anthropogenic activity in the Hawaiian Islands." This conclusion could be extrapolated to any location where coastal features make strandings unlikely, or unobservable, or locations where there is a lack of public awareness about the need to report stranded cetaceans so necropsies can be done, or a lack of search effort for cetacean carcasses, at sea or beached, during active sonar exercises. Moreover, most cetaceans sink upon death (Allison et al., 1991), which means discovery of any cetacean killed during exercises in deep waters is unlikely. Indeed, most of the world's coastlines can be considered regions of low reporting for cetacean mortalities.

Decomposition is also relevant, as time is a critical factor to collecting pathology evidence. For example, Morell et al. (2015) has developed a novel technique that requires carefully examining the microscopic hair cells inside the ear of the whale and appears able to pinpoint damage as well as the frequency of the damage, which is critical for identifying the sound source. Ears need to be removed within just a few hours of death to be analyzed.

Other impacts include biologically important behavioral changes, over scales that far exceed current management measures, which are difficult to accurately predict or to take into account. Moreover, absence of behavioral changes, such as moving from feeding habitat, is not necessarily an indicator of no impact. For example, in Australia two sites occupied by dolphins were investigated–an area where dolphin-watching occurred and an area undisturbed by dolphin-watching 17 km away. At the site where there was no dolphin-watching, dolphin behavior changed more significantly than at the site where dolphin-watching (and therefore noise disturbance) occurred (Bejder et al., 2006). This would normally lead to the conclusion that boat traffic had little impact on animals at the site where dolphin-watching occurred, i.e., they were habituated, but the study also looked at changes in dolphin abundance at the two sites over 10 years. The researchers found that in the area where dolphin-watching occurred, there was a significant decline in dolphin numbers (14%) linked to an increase in dolphin-watching activity (Bejder et al., 2006). The researchers concluded that the most sensitive animals moved away from the area, but this effect would have been hidden without more detailed examination. As a result of this study, the Australian government implemented restrictions on dolphin-watching boats (to one), and thus reduced disturbance in the area.

Therefore, even if there are cetaceans still visible in an area while military exercises are being, or have been, conducted, managers should not conclude that there has been no effect on cetaceans in the area. The animals being observed could possibly be less sensitive animals that have remained in an area, and more sensitive animals (such as pregnant females) may have been displaced. Even with detailed observations on the movement of individual animals in the population, one cannot say categorically there has been not been a significant impact of a sound-producing activity.

Moreover, a lack of visible behavioral response by an animal might be an indication that an animal is extremely stressed already. A stressed, starving or sick animal may not display any observable response if they do not have the energy or capability to react behaviorally; for example, if the disturbance location is the only viable feeding area, the animal may not leave (Beale and Monaghan, 2004; Beale, 2007; Wright et al., 2007; Forney et al., 2017). In short, absence of a behavioral response to noise does not necessarily translate to absence of a significant or life-threatening impact. Sonar management should account for this and a "precautionary" approach should be taken, with efforts undertaken to minimize noise exposure even though there might not be immediately obvious impacts upon cetacean behavior.

Finally, there are "hidden" responses by animals that may not be readily visible. As noted above, animals may undergo a substantial stress response at relatively low levels of noise exposure, and chronic stress could well lead to major physiological and health impacts (Wright et al., 2009). The level and impacts of stress in populations of animals that face chronic sound exposure (such as those within sonar testing ranges or in regular military exercise areas) need to be studied urgently. There are many non-invasive methods of studying stress hormone levels in cetaceans that are now viable (Hunt et al., 2013) and this could be done relatively easily on potentially impacted populations.

UNCERTAINTY IN MARINE SCIENCE

In Australia, over 10 years of data were required to determine that there was a disturbance impact on a dolphin population (Bejder et al., 2006). In the Bahamas, it took 15 years to gather enough data to note a decline in beaked whale abundance on a military testing range (Claridge, 2013).

A lack of longitudinal data and studies gathering baseline data before the onset of sound-producing events are common problems with cetacean research. In addition, there are logistical difficulties in collecting data and observing the behavior of animals that may spend significant amounts of time underwater. This is particularly true for deep-diving beaked whales, where the likelihood of detecting a whale at the surface in normal conditions may only be one in a hundred, according to Barlow and Gisiner (2006). All militaries need to commit to long-term surveillance monitoring, as well as impact monitoring.

For numerous reasons, collecting data in the marine environment is logistically much more difficult, and more expensive, than in the terrestrial environment (Norse and Crowder, 2005). For example, for 60 years no one noticed the extinction of a limpet species (*Lottia alveus)*, even though the area it inhabited was studded with marine laboratories and stations (Carlton et al., 1991). Perrin's beaked whale (*Mesoplodon perrini;* Dalebout, 2002) was only discovered recently, and confirmed sightings of a living individual have yet to be made in the wild, despite the species inhabiting the waters off California, one of the most surveyed regions in the US and the world, with probably one of the greatest densities of marine mammal biologists in the country.

Because of the high degree of variability and uncertainty in cetacean data, the ability to detect trends is very limited (Gerrodette, 1987; Taylor and Gerrodette, 1993; Taylor et al., 2007), even for well-studied species and populations. It can take a decade or more to detect a decline in the best studied dolphin populations (Wilson et al., 1999; Thompson et al., 2000). Scientific uncertainty is a major problem for assessing cetacean conservation status (Parsons et al., 2015). However, lack of data and effort for beaked whales, coupled with difficulties in studying them, makes discerning their conservation status particularly difficult (Parsons, 2016). The percentage of precipitous declines that would *not* be detected was 90% for beaked whales (where a precipitous decline is a 50% decrease in abundance in 15 years, at which point a stock could be legally classified as "depleted" under the U.S. Marine Mammal Protection Act) (Taylor et al., 2007). Even where declines in marine mammal populations have been identified, the ultimate cause of declines can sometimes be difficult to determine due to a wide range of subtle contributing factors (Merrick et al., 1987; Alverson, 1992; Marmontel et al., 1996). The difficulty with monitoring the effects of anthropogenic impacts on cetaceans and the huge level of uncertainty involved have been noted as key issues that need to be addressed via scientific research, in order to better conserve, manage and protect cetaceans (Agardy et al., 2007; Dolman, 2007; Dolman and Jasny, 2015; Parsons et al., 2015; Parsons, 2016).

The importance of not delaying conservation action when a concern exists, but scientific data and analysis have not incontrovertibly established the threat exists, i.e., "the precautionary principle," has been enshrined in a number of international laws (Hey, 1991), including the 1992 Convention on Biological Diversity (Principle 15 of the so-called "Rio Summit"). Because of this level of uncertainty and difficulty in establishing beyond a reasonable doubt trends and threats in cetacean populations, it has been argued that in order to effectively conserve and manage populations one must be precautionary, as otherwise catastrophic declines in cetacean populations could occur before science catches up with the problem (Mayer and Simmonds, 1996; Parsons et al., 2010, 2015; Parsons, 2016). It may be a long time before technology and methods are easily available to answer the many still unanswered questions about the exact nature and degree of the impacts of sound on cetaceans, especially when we know that many of the mitigation measures in place for protecting cetaceans against the impacts of sound are untested "best guesses" or, indeed, are known to be ineffectual (Parsons et al., 2009). Therefore, it is essential that as precautionary and conservative an approach to management is taken as possible with respect to the effects of military sonar on cetaceans. Although there is now a better idea of the scale and range of species that are affected, and the means by which strandings might occur and possibly the levels of sound that are most harmful, there are still many unknowns. Management of cetaceans needs to be precautionary because of these large number of unknowns, and at present this is mostly not the case. As Simmonds et al. (2014) and Erbe et al. (forthcoming) note, the science about the impacts of underwater noise on marine mammals is advancing, but management is lagging behind.

Many militaries have committed to investigate and mitigate their activities to protect marine mammals. However, there is an additional need for militaries to commit to conducting adequate baseline monitoring in areas where exercises routinely occur, to understand and to plan better to avoid deaths and, more importantly, to avoid behavioral impacts at appropriate ranges, and to mitigate accordingly. There is also a need for governments to develop criteria for assessing—and to commit to independently and thoroughly investigate—all atypical mass strandings in future.

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