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A Brief Review of Known Effects of Noise on Marine Mammals

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Marine mammals, especially cetaceans, are highly vocal and dependent on sound for almost all aspects of their lives, e.g. food-finding, reproduction, communication, detection of predators/hazards, and navigation. They are thus likely sensitive to anthropogenic noise. Sound has a large potential area of impact, sometimes covering millions of square kilometers of ocean with levels high enough to cause possible disturbance in marine mammals. There can be great variation in the reaction of marine mammals to noise, depending on such factors as species, individual, age, sex, prior experience with noise, and behavioral state. Species with similar hearing capabilities can respond differently to the same noise. Observed effects of noise on marine mammals include: changes in vocalizations, respiration, swim speed, diving, and foraging behavior; displacement, avoidance, shifts in migration path, stress, hearing damage, and strandings. Responses of marine mammals to noise can often be subtle and barely detectable, and there are many documented cases of apparent tolerance of noise. However, marine mammals showing no obvious avoidance or changes in activities may still suffer important, even lethal, consequences. Acoustically-induced strandings may displace a local beaked whale (*Ziphiidae*) population (for an extended period if not permanently) or even possibly eliminate most of its members. As beaked whales seem to be found in small, possibly genetically isolated, resident populations, even a transient and localized acoustic impact could have prolonged population consequences. Observed reactions to noise in marine mammals could theoretically result in impacts such as decreased foraging efficiency, higher energetic demands, less group cohesion, higher predation, decreased reproduction, and thus seriously impact the population. Alternatively, they may be harmless. However, noise is thought to contribute to at least some species' declines or lack of recovery (Southern resident killer whales (*Orcinus orca*), western gray whales (*Eschrichtius robustus*) off Sakhalin).

As sound travels much better than light in the oceans, many marine animals, including marine mammals, use hearing as their primary sense. Cetaceans, in particular, are heavily dependent on sound for food-finding, communication, reproduction, detection of predators, and navigation. They are therefore likely sensitive to the introduction of anthropogenic noise into their environment. Unfortunately, because sound travels further than light in water, sounds have a large potential area of impact. Low frequency sounds, such as naval Low Frequency Active (LFA) sonar and distant shipping, travel especially well and may sometimes be heard over millions of square kilometers of ocean with levels high enough to cause possible disturbance in marine mammals. Seismic surveys can raise the background noise levels by 20 dB over 300,000 sq. km. continuously for days (IWC, 2005). Human use of the sea is growing and thus increasing the amount of noise that we introduce into the oceans (see Hatch & Wright, this issue).

Several reviews have examined the various known effects of noise on marine mammals (e.g., Richardson, Greene, Malme, & Thomson, 1995; Hildebrand, 2005; Nowacek, Thorne, Johnston, & Tyack, 2007; MMC, 2007). Such efforts will not be repeated here. Instead, the intent is to provide an overview

of the various effects that noise is known to have on marine mammals for those new to the subject. Consequently, this is not an exhaustive review. However, the examples do represent a variety of impacts including: changes in vocalizations, respiration, swim speed, diving, and foraging behavior; displacement, avoidance, shifts in migration path, stress, hearing damage, and strandings.

Especially in species as difficult to observe as cetaceans, we are limited in our ability to detect impacts. Thus, failure to find a response to noise may be more due to measuring the wrong variables or an inability to measure the right ones, rather than a true lack of response. Populations may be threatened by noise through, for instance, increased stress levels or masking, yet these effects would be difficult to detect in cetaceans, since only a handful of the ca. 84 species have population estimates that are more precise than $\pm 40\%$ (Whitehead, Reeves, & Tyack, 2000). The vast majority (72-90%) of serious population declines in cetaceans would not be detected under the current population monitoring effort (Taylor, Martinez, Gerrodette, Barlow, & Hrovat, 2007). Even when responses to noise are found, the biological significance to cetacean populations is hard to discern. Usually, only short-term responses to noise are studied, for practical reasons. However, short-term effects are hard to interpret. They may be an indication of serious population consequences or they may be insignificant. Conversely, long-term population impacts may occur without dramatic or even observable short-term reactions, as has been demonstrated in bottlenose dolphins, *Tursiops* spp. (Bejder, 2005) and caribou, *Rangifer tarandus* (Harrington & Veitch, 1992). Thus, long-term studies are more useful in relating disturbance reactions to population impacts (Bejder, 2005).

Changes in Vocalizations

Increases in vocalizations may represent an attempt by the animal to overcome 'masking,' when a sound is obscured or interfered with, by background noise. Masking can both reduce the range over which signals can be heard and reduce the signal's quality of information. The following observations may or may not be attempts to compensate for masking. Beluga whales (*Delphinapterus leucas*) used specific calls more often and shifted frequencies upward when boats were near (Lesage, Barrette, Kingsley, & Sjare, 1999). St. Lawrence River belugas were also shown to increase the level of their vocalizations as a response to increases in the levels of shipping noise, an indication of a Lombard vocal response (Scheifele et al., 2005). In response to high levels of boat traffic, killer whales increased the durations of their calls (Foote, Osborne, & Hoelzel, 2004). Humpback whales (*Megaptera novaeangliae*) lengthened their mating songs during exposure to LFA sonar (Miller et al., 2000). Pilot whales (*Globicephala melas*) produced more whistles in response to military mid-frequency sonar (Rendell & Gordon, 1999), as did bottlenose dolphins (*Tursiops truncatus*) in response to boat approaches (Buckstaff, 2004).

Marine mammals have also been observed to decrease their vocalizations in response to noise, sometimes ceasing to call entirely for periods of weeks or months. This can have implications for breeding, feeding, or social cohesion,

depending on the calls affected. Decreases in “creaks,” thought to be prey capture attempts, have been observed in a Cuvier’s beaked whale (*Ziphius cavirostris*) in response to ship noise (Soto et al., 2006), and in sperm whales (*Physeter macrocephalus*) in response to seismic surveys (IWC, 2007). Sperm whales have also been observed falling silent when exposed to pingers (Watkins & Schevill 1975), mid-frequency military sonar signals (Watkins, Moore, & Tyack, 1985), seismic surveys, and low frequency ATOC-like¹ sounds (Bowles, Smultea, Würsig, DeMaster, & Palka, 1994). The ATOC-like sounds and perhaps seismic surveys had similar effects on pilot whales (Bowles et al., 1994), though the power to detect effects in this study was low.

Fin whales (*Balaenoptera physalus*) reduced their calling rates in response to boat noise (Watkins, 1986). About 250 male fin whales stopped singing for weeks-months over 10-20,000 sq. nm. in the presence of a seismic survey, resuming singing within hours-days after the survey ended (IWC, 2007). It is likely that there were breeding consequences of this behavior, as these fin whale calls are thought to function in mating (Croll et al., 2002).

Changes in Diving and Foraging Behavior

Marine mammals have been observed to change their surface behavior (e.g. swim speed, respiration rate, etc.) in the presence of seismic noise, with largely unknown consequences. However, if foraging dives are affected by noise, it is quite likely that there will be associated reductions in foraging efficiency. In addition to other responses, sperm whales undertook no foraging dives when approached closely by a seismic survey vessel emitting airgun noise, and reduced the number of fluke strokes and effort at more distant exposures (IWC, 2007). Similarly, in response to the nearby passage of a noisy ship, a Cuvier’s beaked whale was seen to dive for shorter periods, with less time spent echolocating, in addition to a lower production of creaks as was mentioned above (Soto et al., 2006). It was suggested that the combined effects resulted in a 50% reduction in foraging efficiency (Soto et al., 2006).

Northern elephant seals (*Mirounga angustirostris*) increased descent rates and decreased ascent rates similar to an escape response, when exposed to the low-frequency noise of ATOC (Costa et al., 2003). Western gray whales reacted to seismic surveys by swimming faster and straighter over a larger area with faster respiration rates (IWC, 2007). In addition to a tendency for avoidance and less feeding across all cetaceans during seismic surveys, mysticetes generally spent more time at the surface while smaller odontocetes tended to swim faster (Stone & Tasker, 2006). More subtle responses to seismic surveys were also seen at quite large distances. For example, one study found that bowheads (*Balaena mysticetus*) displayed no avoidance or a change in calling or general activities, but were

¹ Acoustic Thermometry of Ocean Climate was an oceanographic project which broadcasted loud sounds across whole ocean basins. It continues to operate under the name NPAL, or North Pacific Acoustic Laboratory.

undertaking shorter dives with a slower respiration rate at distances up to 50-70 km away (Richardson, Würsig, & Greene, 1986; Richardson et al., 1995).

Avoidance and Displacement

Displacement from critical feeding and breeding grounds has been documented in a number of marine mammal species exposed to noise. Possibly the most striking example is the displacement of gray whales from breeding lagoons in response to industrial noise (for over 5 years: Jones, Swartz, & Dahlheim, 1994) or dredging and shipping (displaced for 10 years: Bryant, Lafferty, & Lafferty, 1984). The critically endangered population of western gray whales off Sakhalin Island was also displaced from one of their primary feeding areas by seismic survey activity (IWC, 2005; 2007).

Beluga whales appeared to actively avoid icebreakers at distances of 35-50 km, remaining away for 1-2 days (Finley, Miller, Davis, & Greene, 1990; Cosens & Dueck, 1993). Killer whales were displaced from an area for 6 years by acoustic harassment devices, or AHDs (Morton & Symonds, 2002). Humpback whales avoided seismic surveys, with resting females staying 7-12 km away, although males were occasionally attracted to the sounds (McCauley et al., 2000). In addition, sighting rates of many cetaceans in UK and adjacent waters were significantly lower, and their distance to the seismic noise source (large volume airgun array) significantly higher, during periods when the source was on in comparison to those when it was not (Stone & Tasker, 2006).

Slight, but obvious, shifts in migration paths have also been noted in several species when a noise source was placed in their migration route. For example gray whales adjusted their migration path to avoid an LFA sonar source placed inshore, but not offshore (Tyack & Clark, 1988). In addition, both gray and bowhead whales have been observed detouring around continuous industrial noise (Malme, Miles, Clark, Tyack, & Bird, 1983, 1984; Richardson et al., 1985, Richardson, Würsig, & Greene, 1990).

Strandings and Fatalities

Much attention has been focused recently on acoustically-induced strandings, primarily with respect to beaked whales and military mid-frequency sonar (e.g., Fernandez et al., 2005, Cox et al., 2006). The Bahamas March 2000 mass stranding was one of the best studied of such strandings, and occurred together with naval exercises involving mid-frequency sonar. Several species of whale were found dead with injuries to their acoustic organs. The government acknowledged the fact that "...tactical mid-range frequency sonars aboard U.S. Navy ships...were the most plausible source of this acoustic or impulse trauma." (NOAA & U.S. Navy, 2001). This stranding was the only stranding for which baseline beaked whale survey data were available. Thus, it could be determined that there were no sightings of Cuvier's beaked whales for a 20 month period (May 2000 - February 2002) following the stranding, despite increased field effort in 2000 and 2001 (Claridge, 2006). Sighting rates since February 2002 appeared to be

back to those found from 1997-1999 (Claridge, 2006). The at least temporary and possibly permanent disappearance of pre-stranding known individuals seems to indicate that the affected local population of Cuvier's beaked whales was isolated from a larger population, implying that a population-level effect may have resulted from the brief transit of five naval vessels using sonar (Balcomb & Claridge, 2001; IWC, 2005). It is unknown how many whales from the local population of the species were killed during the naval exercise, but at minimum they were displaced from their former habitat. Beaked whales appear to be found in small, possibly genetically isolated, local populations that are resident year-round (Wimmer & Whitehead, 2004; Balcomb & Claridge, 2001). Such population characteristics make beaked whales particularly vulnerable to disturbance and population impacts.

Other cetacean species may also be involved in acoustically-induced strandings (see ICES, 2005), and the possibility that noise can lead to strandings and/or death in marine mammals exists beyond naval sonar. For instance, seismic noise has been implicated in a stranding of beaked whales (Hildebrand, 2005).

Hearing Damage

Noise has the potential to induce temporary hearing loss (either across the frequencies or more specific to a smaller frequency band), also known as temporary threshold shift (TTS), if it is loud or long enough in duration. In general, the higher the sound level and/or longer the duration, the more likely TTS is to occur. If exposure is prolonged or repeated or even as a result of one very loud noise event, the hearing damage can become permanent, also known as a permanent threshold shift (PTS). Experiments with captive bottlenose and beluga have, however, shown that both tonal (e.g., Schlundt, Finneran, Carder, & Ridgway, 2000) and very short duration impulsive (Finneran et al., 2002) sounds are capable of causing TTS, although the sound levels required for the impulsive sounds to do so were much higher than the 1 second tonal signals. Combining her research results along with other cited studies, Cook (2006) generally found that captive animals showed more hearing loss than similar-aged free-ranging dolphins. TTS and PTS are thought to have very similar effects on marine mammals as masking: reduction in foraging efficiency, reproductive potential, social cohesion, and ability to detect predators.

Hearing damage can kill indirectly, as in the case of humpback whales found fatally entangled in fishing gear at the same time and place as underwater explosions were occurring (Todd et al., 1996). Humpback whales in the area displayed no avoidance or behavioral reactions to the explosions, yet an unusual pattern of fatal entanglement occurred, suggesting hearing damage (if whales use sound to passively detect nets) or some other compromise to their navigation or sensory systems. Based on a good baseline of typical whale entrapment rates and patterns, it was found that entrapment rates both at the time and in the nearby area of blasting were dramatically and significantly higher, even though there were fewer fishing nets in the area (Todd, Stevick, Lien, Marques, & Ketten, 1996). Additionally, re-entrapments of the same animals occurred, something that had not happened for the previous 15 years. It is important to note that, based on the

whales' behavior, one would have incorrectly concluded that the explosions did not impact the animals, were it not for the special case of higher and unusual entanglement rates or patterns.

Noise and Stress

Although several reviews have entertained the possibility that noise induces a physiological stress response in marine mammals, there have been few studies. Romano et al. (2004) exposed a captive beluga whale and bottlenose dolphin to sounds from a seismic water gun and (for the bottlenose dolphin) 1-s, 3-kHz pure tones. They looked for various hormones in the blood, including cortisol, before and after exposure and saw changes (especially with the seismic sound) that were considered detrimental. These changes increased with increasing sound levels, and were significant. Thomas, Kastelein, & Awbrey (1990), however, did not find elevated stress hormone levels in the blood after playbacks of oil drilling platform noise to captive belugas, though their measures were less sensitive than those used in Romano et al. (2004). Miksis et al. (2001) found that heart rate in a captive bottlenose dolphin increased in response to threat sounds produced by other dolphins.

Context and Consequence

There can be great variation in the reaction of marine mammals to noise, depending on such factors as species, individual, age, sex, prior experience with noise, and behavioral state. Species with similar hearing capabilities can respond differently to the same noise (IWC, 2007). There are many documented cases of apparent tolerance of marine mammals to noise, which also demonstrate much variability. For example, bowhead whales tolerated an increase in 40 dB in seismic survey noise when feeding in summer than during the fall migration, where broadband received levels of airgun pulses corresponding to avoidance were 120–130 dB re 1 μ Pa (rms over pulse duration) and above (Richardson et al., 1995, Richardson, Miller, & Greene, 1999). Other examples of apparent tolerance can be found in sperm whales with seismic surveys in Norway (Madsen, Møhl, Nielsen, & Wahlberg, 2002), blue (*Balaenoptera musculus*) and fin whales with LFA sonar (Croll et al., 2001) and sea lions (*Zalophus californianus*) to AHDs (NMFS, 1996). It is not known what the consequences of this apparent tolerance are: it may represent acclimation or habituation of some kind, but may also represent an unrelenting need, e.g. for feeding or reproduction, to remain in a particular location despite exposure to noise, that could result in increased impacts from masking, hearing loss, and other potential effects, such as stress.

The observed reactions to noise in marine mammals could theoretically result in impacts such as decreased foraging efficiency, higher energetic demands, less group cohesion, higher predation, decreased reproduction, and other effects, thus seriously impacting the population as well as the individual. Alternatively, they may be harmless. However, noise is thought to contribute to at least some

species' declines or lack of recovery (Southern resident killer whales, Sakhalin gray whales; NMFS, 2002; IWC, 2007).

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