Concerns related to chronic stress in marine mammals

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ABSTRACT

The management of marine mammals traditionally focuses on lethal takes, such as in bycatch, vessel collisions and strandings. However, we are beginning to realise that non-lethal impacts of human disturbance can also have serious conservation implications, indicating that mortality counts only reveal a fraction of the picture. Possibly the most important of non-lethal (at least, not immediately lethal) impacts arises from the prolonged or repeated activation of the stress response. The physiological stress response is a life-saving combination of systems and events that essentially maximises the ability of an animal to kill or avoid being killed. However, “chronic stress” is linked to numerous conditions in humans, including coronary disease, immune suppression, anxiety and depression, cognitive and learning difficulties, and infertility. How does this relate to marine mammals and their conservation? Growing human activity in the marine environment is increasing the frequency with which human disturbance triggers stress responses in cetaceans and other marine mammals and thus also the likelihood of inducing chronic stress. As noise travels further in water than air, marine mammals, like other marine fauna, will be exposed acoustically to human activity at much greater distances than terrestrial animals and may thus be particularly sensitive to chronic stress. Coastal species will be especially vulnerable due to the concentration of human activity in these areas. Whalewatching may also be a particular concern because it specifically targets marine mammals. The possibility that endangered marine mammals might express the various conditions linked with chronic stress in humans has troubling implications for conservation efforts (especially Marine Protected Areas), demands management attention, and may explain, at least in part, why some species have not recovered after protective measures have been put into place.

Keywords: stress, noise, whalewatching, sanctuaries, survivorship, reproduction

INTRODUCTION

Marine mammal management and conservation traditionally focuses on lethal takes, such as in bycatch, vessel collisions and strandings. Thus, the most widely known issue related to underwater sound is that of the plight of beaked whales exposed to military mid-frequency sonar, which are thought to react behaviourally at sound levels well below those thought to cause ‘injury’ (Hildebrand, 2005), in ways that ultimately cause the mortalities and mass strandings that have been highly publicised (Cox *et al*., 2006; Rommel *et al*., 2006; Tyack *et al*., 2006). However, there is increasing concern that non-lethal impacts of human disturbance could also have serious conservation implications, indicating that the mortality counts (which are themselves likely to be substantial underestimates: see Parsons *et al*., 2008) only reveal a fraction of the picture.

Possibly the most important of non-lethal (at least, not immediately lethal) impacts arises from the prolonged or repeated activation of the stress response. The physiological stress response, which is highly conserved across species, is a life-saving combination of systems and events that essentially maximises the ability of an animal to kill or avoid being killed (for detailed reviews and further information see Deak, 2007 and Romero & Butler, 2007.) However, it is important to note that the goal of physiological stress responses is to survive the immediate threat, not necessarily to preserve functioning for distant periods into the future. The principle systems involved are the sympathetic nervous system (SNS) and the hypothalamic-pituitary-adrenal (HPA) axis – both of which are activated immediately upon the *perception* of a threat by the animal. Within seconds, the release of adrenalin & noradrenalin (AKA epinephrine & norepinephrine) by the SNS produces numerous changes, including increases in heart rate, gas exchange and visual acuity, and a redistribution of blood to the brain and muscles and away from the stomach and other non-essential organs. Behavioural changes also result, most famously the "fight or flight" response. Meanwhile, a chain of hormones released through the HPA axis leads to the release of glucocorticoids (GCs) from adrenal cortex (e.g., cortisol, corticosterone, cortisone), usually within 3-5 minutes. These induce similar changes: an increase in blood glucose and suppression of non-essential activities, such as digestion, immune activity, growth, and reproduction, although the reproductive system can, in some reproductive contexts, become resistant to inhibition by GCs. Glucocorticoids can also alter behaviour in context-specific ways, such as inducing hiding or abandonment of an area; reproductive behaviour may also be suppressed. This suite of effects is thought to allow the animal to recover from a stressor by delaying functions that can be postponed until the danger has passed, as well as to prepare the animal for subsequent threats to survival.

However, this response can become maladaptive when initiated too often or for prolonged periods. This state of "chronic stress" is linked to numerous conditions in humans, including coronary disease, immune suppression, anxiety and depression, cognitive and learning difficulties, and infertility (see Clark & Stansfeld, 2007, Romero & Butler, 2007). In addition, *in utero* exposure to GCs via the mother and/or through mothers milk to newborns has been shown to alter the stress response itself in these neurologically-vulnerable young, leading to life-long health and psychological problems (e.g., Kapoor *et al*., 2006).

STRESS RESPONSES IN MARINE MAMMALS

Marine mammals live increasingly in a world influenced by human action. We know that many marine mammals carry high levels of contaminant loads, which can have a range of consequences for them, potentially including a prolonged activation of the stress response (see reviews by Kakuschke & Prange, 2007 and Martineau, 2007). It is also highly likely that changes to habitat and prey abundance and distribution through various mechanisms ranging from both coastal and offshore development to the widespread influences of climate change will be, for certain species, detrimental and may induce stress responses as well (e.g., Stirling & Derocher, 1993).

However, probably the most underestimated mechanism for inducing a (prolonged) stress response in marine mammals is that of human disturbance, of which underwater noise is likely to be an important component (e.g., Miksis-Olds *et al*., 2007). In addition to simply disturbing marine mammals, exposure to noise can have a range of other impacts (e.g., Nowacek *et al*., 2007; Weilgart, 2007) that can trigger stress responses in-and-of themselves. For example, masking – the obscuring of signal of interest to the animal by noise – can interfere with communication (including for mating), navigation and foraging as many marine animals have evolved to supplement or replace the ineffective use of vision underwater with hearing (Bradbury & Vehrencamp, 1998; Berta *et al*., 2006; Jensen *et al*., 2008). Furthermore, noise is a particular concern because it can travel large distances underwater, especially at low frequencies (Urick, 1983), which means the 'acoustic footprint' of human activities can be considerably larger than the area over which they actually occur.

Shipping and Masking

The classic example of an activity with an extensive acoustic footprint is that of shipping. There is increasing evidence that distant shipping, with some contribution from other human activities, has substantially increased low-frequency background noise throughout huge areas of oceans around the world – in some cases doubling in power each decade over the past 50 years (e.g., Zakarauskas *et al*. 1990; Andrew *et al*. 2002; Cato & McCauley 2002; McDonald *et al*. 2006). This increases the likelihood of signal masking and has unquestionably curtailed communication ranges quite dramatically in low-frequency users, such as the baleen whales (see Wright (ed.), 2008) and may also be having psychological impacts, such as causing anxiety (Bateson 2007). Other species may also be masked nearer to shipping lanes where the higher frequency components of the noise remain above ambient, or by smaller craft that produce noise predominantly at higher frequencies (e.g., Jensen *et al*., 2008).

Seismic surveys and avoidance

Another anthropogenic sound that can travel over ocean basins, at least on occasion, is that of airgun arrays, used primarily to detect oil and natural gas deposits under the ocean floor in seismic surveys (Nieukirk, *et al*, 2004). While less likely to mask signals of interest to marine mammals because of their short duration (although it may still occur – see Nieukirk, *et al*, 2004), their huge source levels and high rate of repetition (see Nieukirk, *et al*, 2004; Madsen *et al*., 2006 and references therein) does mean that exposure rates can be quite high. Marine mammals have been documented to exhibit a “startle” reaction in response to seismic surveys at reasonable distances (e.g., sperm whales at 2 km; Stone 2003), which is likely indicative of the initiation of a stress response. There have also been reports of avoidance of such surveys. For example, cetacean diversity off the coast of Brazil dropped from 1994 to 2004 during seismic survey operations, with a conspicuous decrease in 2000-2001 when there were a greater number of seismic surveys (Parente *et al*., 2007). However, it is hard to determine exactly what such avoidance means to the animals concerned. It may represent a number of possible situations, ranging from the possibility that avoidance may have little cost to them (as might be expected if marine mammals slightly divert their migration routes) to an indication that the exposure is too unpleasant to remain in an area of particular importance despite their need to forage or breed there (see summary by Beale, 2007). Similarly, animals that remain in important areas may either be unaffected, or so dependent on the particular habitat, source of prey, or other resource that they remain despite the disturbance and/or acoustic assault, the latter of which may actually be the most stressful of the possibilities (Beale, 2007).

Navy sonar and beaked whale strandings

As mentioned above, beaked whales are thought to react behaviourally to military mid-frequency sonar at relatively low exposure levels in ways that can ultimately cause mortality and stranding (Cox *et al*., 2006; Rommel *et al*., 2006; Tyack *et al*., 2006). This hypothesis appears to be supported by the limited and preliminary, but direct data obtain in recent studies (Moretti *et al*., 2008; Tyack, 2008). This, like the startled sperm whales described above, is likely to indicate a flight reaction, allowing us to deduce that a stress response has occurred, although this response, in and of itself, is not likely to be responsible for the strandings (see Wright *et al*., 2007). Beaked whales might be particularly sensitive to exposure to all sorts of stressors because they are thought to be diving at their physiological limits (Tyack *et al*., 2006). Another possibility is that the effects of pressure on the central nervous systems of diving cetaceans may result in “hyperexcitability” of the nervous system, meaning that the extremely deep-diving beaked whales may exhibit a more intense behavioural response to sonar noise when at depth (Talpalar & Grossman, 2005). A further complication arises when the usual increase in the rate of gas exchange during a stress response is considered, as this presents a problem for an animal holding its breath, which may thus have the potential to become an additional stressor itself by inducing anxiety, hypoxia, or both.

Whalewatching and energy budgets

Concern over the possible effects of whalewatching on marine mammals has increased over recent years, especially as information about the long-term impacts are beginning to become available (see Lusseau & Bejder, 2007). Unlike the other activities discussed above, whalewatching actively targets marine mammals meaning that disturbance can, in some cases, reach quite high levels. Cetaceans may begin to avoid certain areas if the disturbance reaches a certain threshold or if there is little cost (see Lusseau & Bejder 2007). However, those that stay must contend with the consequences of the attention from whalewatching vessels, which can include, but are not limited to, feeding and resting disturbance, and masking (see SC61/WW1 for a review of recent studies). Remaining animals will often display local avoidance, which might be represented by increased travelling time and a decrease in time resting or foraging, as was observed in northern resident killer whales (*Orcinus orca*; Williams *et al*., 2006). Although this change led only to a relatively small (although not necessarily inconsequential) estimated increase in energetic demands of 3%, it also led to an estimated reduction in energetic intake of 18% (Williams *et al*., 2006). These figures represent minimum estimates, as they do not include any costs associated with an active stress response (physiological or psychological). For example, the increase in heart rate observed in kittiwakes (*Rissa tridactyla*) in association with chronic human disturbance carried metabolic costs that led to an estimated increase of 7.5 to 10% in daily energy expenditure for some individuals (e.g., Beale, 2004).

CUMULATIVE EXPOSURES AND THE CONSEQUENCES OF CHRONIC STRESS

The potential for noise exposure alone to lead to chronic stress and the associated array of consequences and conditions has been studied in other species. For example, adverse health consequences related to chronic stress have been reported in humans that live near airports or busy roads (see Clark & Stansfeld, 2007). It should be noted, however, that these latter examples may include a combination of noise-related disturbances as well as toxicant exposure, since jet fuel and automobile exhaust can serve as chemically-based stressors in and of themselves that adversely impact the effects of noise exposure (Fechter *et al*., 2007). In other studies, a modest increase in continuous background noise may have caused a significant reduction in growth and reproduction in brown shrimp (Lagardère, 1982; Régnault & Lagardère, 1983). Similarly, studies in rats have demonstrated that noise can trigger a stress response at levels of exposure below those that induce observable behavioural reactions (Baldwin, 2007). Indeed, exposure to noise in the laboratory is a commonly used method for evoking stress-related changes in behaviour and physiology across taxonomic orders (Masini *et al*., 2008; Saltzman *et al*., in press).

Thus, the above activities, along with a plethora of others, have the potential to induce a state of chronic stress in marine mammals if the exposures are of sufficient intensity, duration and frequency. This eventuality is more likely if the exposed animals are already undergoing stress responses due to one or more of the many other potential threats to cetaceans, such as persistent pollutants, habitat degradation, reduction in food availability, other noise sources, etc. (Reeves & Ragen, 2004). Generally of greatest concern to managers are those effects that detrimentally alter survivability or fecundity, such as the physiological suppression of the immune system and the behavioural and physiological suppression of the reproduction.[1]

MANAGEMENT IMPLICATIONS

But what does all this mean for the management of marine mammal populations? Growing human activity of any kind in the marine environment is increasing the rate at which marine mammals are exposed to disturbance and other stressors and thus also the likelihood of inducing chronic stress. As noise travels further in water than air and stress responses may be triggered at levels below those at which behavioural reactions are induced and/or observed, this may be a particular problem for marine mammals. Furthermore, the potential exists for the various conditions linked with chronic stress in humans to lead to an unobserved decline in abundance without observable fatal impacts.

This has very obvious implications for area-based mitigation efforts, such as Marine Protected Areas (MPAs), which are not usually large enough to provide effective shelter from anthropogenic noise for marine mammals (see Agardy *et al*., 2007 and references therein). Marine human activities are concentrated in coastal regions, which means that chronic stress may be increasingly likely to occur in coastal species. Similarly, extreme breath-holding and pressure-related hyperexcitability might make deeper diving species more susceptible to detrimental consequences once exposed. Many MPAs exist in coastal areas, and their effectiveness at preventing disturbance within their boundaries would be reliant upon the establishment of buffer zones around those boundaries. Management of human activities within the buffer zone would then need to consider the acoustic footprint of those activities, and not just their physical location, to prevent potentially disruptive levels of sound from entering the boundaries of the MPA itself.

Likewise, activities that produce high-levels of sound or sounds with sharp rise times should be highly restricted in areas where deep-diving species, such as beaked whales, are abundant given their particular sensitivities and the potential for adverse impact. This is especially important given the lack of information available on their

[1] The reproductive system can become resistant to such inhibition, such as when the benefits of maintaining the reproductive efforts outweigh the costs of not responding to the stressor in terms of fitness. One example might be when an older mother's potential for future reproductive opportunities is limited and she 'decides' to continue her reproductive efforts despite the presence of a stressor. However, in that case the total number of offspring that female may have produced in her lifetime might still have been reduced in the face of chronic stressor exposures. In any case, the susceptibility of reproduction to inhibition by the stress response is highly context-specific and depends upon age, sex, stage of the breeding cycle, etc (Wingfield & Sapolky, 2003; Romero & Bulter, 2007).

population structures and abundances, which would make observing any population-level impacts near impossible.

The targeted nature of whalewatching presents a particular challenge since such exclusions will be immediately detrimental to the industry. However, they may indeed be necessary for the protection of the animals, as well as scientific inquiry and public awareness, at least in the short-term, until quieter vessels are introduced and/or operational guidelines specifically to reduce acoustic disturbance can be developed and disseminated. In any case, these measures will not eliminate the disturbance cause by the presence of the vessel itself. Land-based operations are highly recommended, but not always viable. Other options include permitting or licensing systems and zones of temporal or spatial exclusion where animals may at least get some respite from vessels.

CONCLUSIONS

Much uncertainty exists on the issue of noise-induced stress responses (and even in our understanding of how sound propagates underwater; e.g., Madsen *et al*., 2006), but the potential for serious and possibly multi-generational impacts in marine mammals merits immediate and appropriate management action. In this regard, the International Maritime Organisation should be commended for recently taking steps to address the contribution of shipping to low-frequency ambient noise because of concerns over the impacts on cetaceans, especially baleen whales. We recommend that other management regimes and organisations consider similar actions with regards to reducing the introduction of human-generated sound from other activities into the ocean whenever possible and suggest that MPA managers consider acoustic buffer zones to limit the potential for chronic stress within their boundaries.

Most studies investigating the impacts of noise on cetaceans (e.g., whalewatching disturbance) tend to investigate behavioural changes (e.g., see SC61/WW1; SC60/WW1; SC59/WW1). Many of these studies give little enlightenment as to the life history impacts of noise on cetaceans. Due to the potential for chronic stress to detrimentally alter critical life history parameters (e.g., disease susceptibility, reproductive rates, mortality rates), we suggest that the IWC highlights the importance of investigating stress responses, chronic stress and their effects in cetaceans. We also suggest that the IWC highlights the need for investigations of the cumulative and synergistic impacts of multiple stressors (e.g., noise, prey depletion, chemical pollution) upon the demographic rates of cetacean stocks and populations.

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