Noise-Related Stress and Marine Mammals: An Introduction

Andrew J. Wright and Stan Kuczaj

Marine mammals (especially cetaceans) use sound as their primary sensory input for social communication, foraging, and other vital life-processes. Background noise has the potential to interfere with these functions by masking normal sounds, and at least some noise sources have been linked to behavioral and physiological responses (with lethal and non-lethal consequences). Consequently, it is reasonable to assume that at least some acoustic sources may act as stressors (stimuli leading to a stress response) for marine mammals.

The notion that noise may act as a stressor for free-ranging marine mammals is not a new one. Several reports and reviews in both the noise and the stress literature have mentioned this possibility (e.g., Richardson et al., 1995; Fair & Becker 2000; NRC 2003, 2005; Nowacek et al., 2007). The most common conclusion in this literature is that very little is known regarding marine mammal stress responses to noise. The most common recommendation is that more data be gathered. As a result, managers have been left with little information to guide their decisions.

There are large gaps in our knowledge about the particular physiological effects that chronic, repetitive or even acute noise exposures may have on cetaceans and other marine mammals. Experiments with captive animals alone are unlikely to bridge this gap, given the ethical dilemmas that arise when one considers exposing animals to potentially harmful levels of noise. Nonetheless, we suspect that studies with captive animals will prove valuable in ascertaining the more subtle effects of noise, such as masking and interference with cognitive processing. Given the paucity of data specific to marine mammals, evidence gathered from other animal populations might constitute a baseline on which to ground hypotheses regarding the likelihood of cetaceans to experience similar stress processes.

To initiate such a transfer of information, Dokumentes des Meeres (www.sound-in-the-sea.org), as part of its ongoing project on anthropogenic noise and marine mammals, brought a number of marine mammal scientists together with a diverse range of experts from other fields to discuss the impacts of noise. The objectives of the workshop were twofold:

- to identify the potential and likely consequences of noise-induced stress for individual animals and the populations to which they belong; and
- to determine the likelihood that, and the ways in which, noise exposure may induce stress responses in marine mammals based on what is known about the effects of noise on humans and other animals in addition to the available information for marine mammals.

These discussions are represented in two papers in this issue. The first summarizes what is known about the physiological stress response, the initiation of that response by anthropogenic noise, the importance of context (physiological, psychological and environmental) in the stress response, and the ways that noise itself can change that context (Wright et al., this issue, a). The contents of this paper are broad and it is hoped that the conclusions and findings will be of use to anyone that studies or manages any species that may be subject to disturbance by
anthropogenic activities. The second paper applies to marine mammals the concepts brought together in the first, drawing on what is known about the responses of marine mammals to noise as well as other anthropogenic activities (Wright et al., this issue, b). Important contextual considerations specific to marine mammals are also discussed, and a collection of key findings and research recommendations are offered. Finally, a summary table is provided in the appendix with examples of the various known effects of stressors on an array of animals for easy comparison.

**Definitions**

It became clear very early on in discussions at the workshop that the disparate fields of science often used terminology in slightly, but notably, different ways. A related issue arose from the different measures of sound in air and in water, as well as conversions between the two. The latter issue is considered by Hatch & Wright (this issue), and in more detail in the references therein. However, as the discussions surrounding the terms ‘stress’ and ‘habituation’ could have lasted for the entire duration of the workshop, participants agreed to disagree, but also to adopt a set of working definitions for the purposes of the workshop.

**What is stress?**

Early discussions quickly revealed that participants were using the term ‘stress’ in a number of different ways, as discussed by Romero (2004). These included referring to:

- the threatening\(^1\) stimuli to which an individual is exposed;
- the physiological and behavioral coping responses to those stimuli; and
- the over-stimulation of the coping responses that results in disease.

To allow for a productive dialogue the participants decided to adopt the terminology and definitions provided in Romero (2004) to distinguish between these different meanings. Consequently, we use ‘stressor’ to refer to a threatening stimulus, ‘stress response’ to refer to the various physiological and behavioral coping mechanisms, and ‘chronic stress’ to refer to long-term over-stimulation of coping responses. We also use the term ‘stressed’ (sparingly) to refer to an individual that is already experiencing a stress response that may either be chronic or acute.

The participants adopted these as working definitions while recognizing that the biomedical community itself is debating the various terminology, with the controversial concepts of ‘allostasis’, ‘allostatic load’ and ‘allostatic overload’ being recently proposed by McEwen & Wingfield (2003, summarized briefly below and in more detail by NRC 2005 and Romero 2004). This adoption does not represent agreement by any participant of those definitions, simply recognition that common ground would be required as we moved forward with our discussions.

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\(^1\) Romero (2004) used ‘noxious’ instead of ‘threatening’. However, the term noxious is often used to refer specifically to painful stimuli. Noxious stimuli will certainly provoke a stress response, but many stressors represent psychological or physiological threats in the absence of overt pain.
**Allostasis**

Allostasis is the maintenance of homeostasis within a changing life-cycle and environment. Animals may build up an ‘allostatic load’ when they must work harder and/or consume more to handle a normal life-history task (such as breeding or migration) or deal with some additional drain on their energy budget. When they are no longer able to fully offset the additional demands they enter a state of ‘allostatic overload’, the state in which energy requirements exceed the capacity of the animal to replace that energy from environmental resources (a ‘stressed’ state). Consequently, McEwen & Wingfield (2003) proposed that ‘stress’ only be used to refer to stimuli that require an emergency energetic response (i.e., when stimuli push the animal into a state of allostatic overload).

Allostasis does not easily consider effects without direct (if any) energetic consequences, such as loss of sleep and missed opportunity costs. As a result it is central to an ongoing debate in the biomedical world. Although this was all discussed at the workshop, the participants did not want to enter into the debate, but simply to recognize that it exists.

**What is habituation?**

Habituation has a specific and consistent meaning in the psychological literature: “the gradual weakening of a response to a recurring stimulus” (e.g., Domjan, 2005; Kuczaj & Xiteo, 2002). Similarly, Telch, Valentiner, Ilai, Petruzzi & Hehmsoth (2000) defined physiological habituation as the “reduction of arousal that results in a disassociation between the stimulus and response propositions”. It was noted at the workshop that it is possible for overt responses to weaken without an associated reduction in physiological response. It is thus not surprising that the term “habituation” has been used in a variety of ways by those who study marine mammals, partly due to the fact that this taxonomic discipline brings together scientists with a variety of different backgrounds. Furthermore, the term “habituation” is also often invoked without reference to the literature and seemingly in conflict with the use of the term in the biomedical or psychological literature (see Bejder et al., 2006). Consequently, it has on occasion been used seemingly to demonstrate the end of impact, despite the fact that the psychological literature recognizes that habituation can be a negative consequence in itself. For example, the U.S. Minerals Management Service, Alaska Outer Continental Shelf Region (MMS Alaska OCS Region), noted in their discussion of the likely effects of the planned Oil and Gas Lease Sale 193 in the Chukchi that as “other cetaceans seem to habituate somewhat to continuous or repeated noise exposure when the noise is not associated with a harmful event, this suggests that bowheads will habituate to certain noises that they learn are nonthreatening” (MMS Alaska OCS Region 2007, pp IV-105). A precise definition or source is never offered, however it is noted in the same report that certain birds “become habituated to shipping activity… and spend the summer nesting or living nearby without apparent harm” (MMS Alaska OCS Region 2007, pp IV-196). This latter comment suggests that MMS are equating a habituated animal with one that is unaffected by further exposure to the stressor concerned.
Workshop participants were generally in disagreement with the idea that a behaviorally habituated animal is unaffected by a stressor. However, they also disagreed about which specific definition of habituation should be used. Guidance was provided by Romero (2004), who presented a definition for the related term “acclimation” as to be when an animal no longer responds physiologically in the same robust manner to repeated or chronic stressors, such as repeated handling. In acclimation, the psychological context of the stressor has effectively changed: the stimulus is no longer threatening to the animal and the physiological stress response is reduced. However, it should be noted that there are situations where a reduction in behavioral response can occur without an associated reduced physiological response, as discussed in more detail by Wright et al. (this issue, a).

Psychologists will recognize that Romero’s definition of acclimation is in fact the definition of habituation (albeit focused on the physiological response), and undoubtedly wonder why acclimation was preferred to habituation. Suffice it to say that some workshop participants wished to distinguish themselves from the various perceived misuses of the term “habituation” by others, especially pertaining to the management of marine mammals, and so acclimation was viewed as a less controversial term.

An organism sometimes becomes acclimated to one stimulus but then shows sensitization to a perceivably different stimulus presented at some later time (see Domjan, 2005; Romero, 2004). The acclimation process can alter the animals’ physiology such that responses to novel stressors are enhanced compared to responses of non-acclimated animals. This process is known as “sensitization” or “facilitation” and it occurs frequently, although not always, as a result of acclimation. For example, if rats exposed to repeated handling are then transferred to a novel environment their physiological stress response is higher than in naïve controls (Dallman et al., 1992). In many cases, it is the sensitized response that signals pathological consequences or acclimation to repeated exposure to a stressor (i.e., researchers look for sensitization to a novel stimulus to assess acclimation to a previous, repeated stimulus). It is important to recognize that apparently calm or other non-responsive behavior does not necessarily indicate acclimation (see Beale, this issue). In addition, acclimatizing to a stimulus (e.g., an intense sound source) may reduce the stress response, but not eliminate the potential physiological damage on, for instance, hearing. Examples of this have been seen in human behavior (see Clark & Stansfeld, this issue).

**Working definitions**

In light of the above, participants agreed to use the following terminology and definitions (based mostly from Romero, 2004) for the purpose of the workshop. This does not necessarily reflect the preferred usage for any individual, nor establish a position in any discussion surrounding the concepts.

**Stressor**: a threatening or unpredictable stimulus that causes a stress response.

**Stress response**: the physiological, hormonal and behavioral changes that result from exposure to a stressor.
Chronic stress: a state that an organism enters when repetitive or long-term exposure to a stressor has exceeded an organism’s regulatory capacities.

Context of a stressor: the physical and psychological conditions present when a stressor appears.

Acclimation: after repeated or chronic exposure to a single stressor, an animal no longer perceives the stressor to be threatening and reduces its physiological stress response. The decrease in stress response is specific to that stressor and does not generalize to other stressors as long as the animal is capable of distinguishing between them.

Sensitization:\(^2\): when acclimation to one stressor increases subsequent stress responses to novel stressors.

“Stress hormones”: a generic and non-scientific term for hormones whose concentrations change in response to stressors and are indicative of a stress response. They are divided in two main types: catecholamines (e.g., epinephrine/adrenaline, norepinephrine/norrenaline, etc.) and glucocorticoid-steroid hormones (e.g., cortisol, corticosterone, etc.). Some hormones (e.g., cortisol) have been traditionally used as indicative of stress. However, they may exhaust under repetitive stimuli and may not reflect chronic stress.

Steroid hormones: a class of hormones (including testosterone, estradiol and cortisol) typified by a four-ring structure.

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\(^2\) We use sensitization instead of facilitation as per Romero (2004) as this is the standard term in the psychological literature.
References


