THE MARINE SOUNDSCAPE AND THE EFFECTS OF NOISE ON AQUATIC MAMMALS

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1. INTRODUCTION

The marine soundscape is made up of natural ambient sounds (e.g. wind and waves), biological sounds (e.g. animal calls) and anthropogenic sounds (e.g. ship noise). Acoustic ecology studies the relationships—mediated through sound—between organisms and their environment. As ocean water conducts light very poorly yet sound very well, marine mammals rely heavily on acoustics for communication and navigation. Since the onset of the industrial revolution, man-made noise in the ocean has steadily increased. The effects of noise on marine animals can be short-term or long-term, transient or chronic, negligible to biologically significant, where the survival of a population is at risk. This article gives an overview of the components constituting the marine soundscape, of the use of sound by marine mammals and of the effects of noise. The acoustic ecology of animals other than mammals and the effects of noise on animals other than mammals are less understood.

2. THE MARINE SOUNDSCAPE

Natural ambient sound in the ocean is largely related to wind, waves and weather. The actual sources are bubbles generated near the surface. Wenz (1962) published spectra (power versus frequency) typical for various wind and sea state conditions, and other ambient contributors. Rain can dominate locally and temporarily. In the polar regions, generally, ice movement and fracturing dominate.

Anthropogenic contributions to ambient noise include shipping, petroleum and mineral exploration and production, construction, sonar etc. Of these, shipping has become so widespread that it adds to the background din where individual sources cannot be distinguished.

Biological contributors to ambient sound vary with location and time of year. Marine mammals are highly vocal underwater. Fish, in particular in tropical regions, produce night-time choruses creating a distinct peak in the ambient spectrum. Snapping shrimp dominate ambient noise in tropical waters at high frequencies.

The spectral contribution of the different sources to the ambient spectrum depend not only on the spectral output of the sources, but also on the distribution and density of the sources, and on the sound propagation environment (as set by sound speed, bathymetry, seafloor geoacoustics and ocean dynamics), and the receiver depth (Dahl et al. 2007).

3. SOUNDS MADE BY MARINE MAMMALS

Odontocetes (toothed whales and dolphins) produce tonal whistles (with some exceptions), burst-pulse sounds and echolocation clicks. Geographic differences as well as dialects of populations sharing the same geographic region exist. Whistles and burst-pulse sounds serve social functions, while echolocation aids navigation and hunting.

Mysticetes (baleen whales) produce frequency-modulated calls, as well as pulses and clicks, though mostly at a lower frequency than odontocetes. Echolocation has not been proven in mysticetes. Humpback, bowhead, blue and fin whales produce song of complex call patterns lasting over long durations.

Pinnipeds (seals and sea lions) produce tonal sounds as well as pulses and clicks in air and under water. All marine mammals further produce sounds by slapping body parts together or onto the water surface (Richardson et al. 1995).

4. THE EFFECTS OF NOISE ON MARINE MAMMALS

Noise can affect marine mammals in many ways. The effects of noise and the ranges over which they happen depend on the acoustic characteristics of the source (e.g., noise level, duration, duty cycle, rise time, spectrum), the medium (hydro- and geoacoustic parameters of the environment, bathymetry), and the receiver (e.g., age, size, behavioural state, auditory capabilities).

4.1 Audibility

At low levels, noise might be merely detectable. Noise levels decrease with range due to propagation losses. Audibility is limited by the noise dropping either below the animal audiogram or below ambient noise levels. Audiograms, hearing thresholds as a function of frequency, have been measured for only few individuals from about 20 marine mammal species. Indirect information stems from observed responses to sound, from anatomical studies and from the assumption that animals are sensitive to the frequencies of their own vocalizations (Richardson et al. 1995).

4.2 Behavioural Reactions

Southall et al. (2007) reviewed the literature on observed behavioural responses of marine mammals to noise. Such responses include changes in swim direction and speed, dive and surface duration, respiration rate, changes in acoustic and contextual behaviour etc. Whether an animal reacts to a sound it hears depends on a number of factors including prior exposure (habituation versus sensitization), behavioural state, age, gender and health. To quantify behavioural responses, studies should be multivariate, considering the full range of metrics appropriate for the sound source and the full range of behavioural and contextual variables.

4.3 Masking

Noise can interfere with marine mammal social signals and echolocation, and the sounds of predators, prey and the environment (e.g. surf). Masking depends on the spectral and temporal characteristics of signal and noise. At a low signal-to-noise ratio (SNR), components of a signal might barely be audible. A higher SNR is needed for signal recognition and discrimination and an even higher SNR for comfortable communication. The potential for masking is reduced by good frequency and temporal discrimination, as well as directional hearing abilities of the animal. Masking can be further reduced in some species if the noise is amplitude modulated over a number of frequency bands (comodulation masking release), if the noise has gaps or the signal is repetitive (multiple looks model), and by antimasking strategies such as deliberate increases in call level and repetition, or frequency shifting (Erbe 2008). Models for the masking of complex calls by anthropogenic noise were developed by Erbe (2000; Erbe et al. 1999) based on behavioural experiments (Erbe and Farmer 1998).

4.4 Auditory Threshold Shift

A threshold shift is a loss of hearing sensitivity, which can be recoverable thus temporary (TTS) or permanent (PTS). TTS, but not PTS, has been measured experimentally in a few species of odontocetes and pinnipeds. A review of these studies led to initial noise-exposure criteria aimed at preventing PTS (Southall et al. 2007).

4.5 Non-auditory Physiological Effects

Systems other than the auditory system, which are potentially affected by noise include the vestibular, reproductive, and nervous systems. Noise might cause concussive effects, physical damage to tissues and organs (in particular gas filled), and cavitation (bubble formation), but data for marine mammals do not exist.

Stress is a physiological response intended to help an organism survive in the face of imminent danger; however, chronic stress can negatively affect health in the long run (Wright et al. 2009). The onset of stress might correspond to fairly low noise levels that induce a behavioural disturbance or masking. Stress might be a direct result of noise, e.g., if an unknown noise is detected, or an indirect result of noise causing, e.g., masking.

5. DISCUSSION

The different effects of noise are often connected, e.g. a TTS affects the audibility of a signal and thus alters the typical behavioural response to that signal. While research has historically focused on single animals, single noise sources and single effects, an integration of effects and a better understanding of the more complex soundscape is required. It is quite feasible to model cumulative sound exposure over multiple sources, long durations and large areas (Erbe & King 2009), but the manner in which exposures get accumulated by the animals and the effects of cumulative exposure remain unknown. Furthermore, the interaction of acoustic and non-acoustic environmental stressors needs to be investigated. Regulation would ideally not focus on a single operation limited in space and time but instead consider cumulative impacts experienced by animals over time and space.

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