Sources of background noise and their influence on vertebrate acoustic communication

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Abstract
Many animals rely on long-range communication for species recognition, mate selection and territorial defense, but background noise from the environment can constrain their communication. Background noise from both biotic and abiotic sources is ubiquitous. In general, acoustic noise from abiotic sources, including anthropogenic noise, has energy mostly below 1 kHz. Arthropods tend to produce sounds in the 4–10 kHz range, while birds, amphibians and mammals generally have vocalizations with frequencies between 1 and 5 kHz. There are several ways that signalers could improve the efficiency of their acoustic signals to counteract the constraints of background noise. Signalers could make long-term and short-term signal adjustments to increase the detectability and discriminability of their signals. As predicted by signal detection theory adjustments can include increases in contrast between signals and noise, such as the intensity of the signal, the structure of the signal and an increase in signal redundancy. Our study reviews the sources of acoustic background noise, adjustments made by signalers to increase signal efficacy, and the influence of acoustic background noise on the evolution of acoustic communication in terrestrial vertebrate species.

Keywords
ambient noise, acoustic communication.

1. Introduction
Animals rely on long-range communication for species recognition, mate selection, and territorial defense, but background noise from the environment can constrain their communication (Bradbury & Vehrencamp, 1998; Brumm & Slabbekoorn, 2005). A receiver often must detect a signal or discriminate
between signals in the presence of irrelevant but similar energy in the environment (Brenowitz, 1982; Ryan & Brenowitz, 1985; Wiley, 1994, 2006; Bradbury & Vehrencamp, 1998; Wollerman, 1999). The maximum distance at which a receiver can separate a signal from noise limits the possibility of communication to a particular area around the signal. The area in which a signal can be detected and discriminated by the receiver is the active space of the signal (Marten & Marler, 1977; Brenowitz, 1982; Klump, 1996).

Many of the factors that determine the active space of a signal have been well studied, especially for avian and anuran taxa. There have been comprehensive reviews of the physical influences on acoustic signal transmission, including attenuation with increasing distance from the signaler (Morton, 1975; Richards & Wiley, 1980; Wiley & Richards, 1982; Naguib & Wiley, 2001). It is clear that when a signal’s amplitude is reduced to a level equal to the sensory threshold of the receiver, the maximum transmission distance has been reached (Klump, 1996). However, the physical environment, amplitude of a signal, and sensory thresholds are not the only factors that influence the distance at which a signal can be detected. Background noise is another major determinant of the active space of a signal (see Figure 1).

Background noise affects the active space of a signal because it influences both the detection and discrimination of a signal by intended receivers (Wiley & Richards, 1982; Wiley, 1994, 2006). Detectability is a measure of a receiver’s ability to separate a signal from background noise, whereas discriminability is the ability to separate two or more signals. Background noise is any energy in the environment that is irrelevant to the communication between a signaler and a particular receiver. Sources of acoustic background noise include conspecific individuals, heterospecific species, as well as physical features in the environment, such as wind and water, and the anthropogenic noise resulting from human activity (Lohr et al., 2003). The intensity and nature of background noise have important consequences for signal discrimination. For example, background noise that is loud, near the receiver, and similar to the signal creates greater problems than noise that is quiet, distant and dissimilar (Bradbury & Vehrencamp, 1998).

Signal detection theory (SDT) provides a framework to best understand the problems that receivers face in terms of signal detection and discrimination in the presence of irrelevant background noise. SDT has clear predictions about communication that can help elucidate the strategies used by signalers and receivers to improve signal detection and discrimination