UNDERSTANDING THE MASKING EFFECTS OF NOISE ON COMMUNICATION IN NATURAL ENVIRONMENTS

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1. INTRODUCTION

Anthropogenic noises can cause a variety of adverse effects on birds and other wildlife. These effects include stress and physiological changes, auditory system damage from acoustic overexposure, and masking of communication and other important biological sounds. A precise understanding of these effects is of interest to many groups including biologists, environmentalists, and government regulators, as well as city planners and roadway and construction engineers. However, for a number of reasons, it is difficult to reach a clear consensus on the causal relationships between noise levels and these adverse effects. One reason is that there are surprisingly few studies in animals that can definitively identify anthropogenic noise alone as the principal source of stress or physiological effects. A second reason is that, while all humans have similar auditory capabilities and sensitivities, the same is not true for all animals. Still another issue is separating the various effects of noise. There are well documented adverse consequences of elevated noise on humans including hearing loss, masking, stress, physiological and sleep disturbances, and changes in feelings of well-being, and it would not be too surprising to find a similar range of effects in animals.

There are four overlapping classes of anthropogenic noise effects on animals (i.e. PTS, TTS, Masking, and Other Effects) with particular spatial relationships. Using birds, I will suggest a framework for conceptualizing the separate and integrated effects of anthropogenic noise, particularly those of masking. This is useful because independent of other effects, masking of communication signals and other important biological sounds (e.g., sounds of an approaching predator) can potentially have significant adverse consequences for species' behavior and population viability. Most vocal species rely on acoustic communication for species and individual recognition, mate selection, territorial defense, parent-offspring communication and detection of predators/prey. Understanding how and to what extent masking can affect communication between individuals is an important first step toward determining the level of impact to them, and to the species.

1.1 Masking Effects on Different Aspects of Hearing.

Common sense and our own experience tell us that acoustic communication can be severely constrained if background noise is of a sufficient level. Such noise decreases signal-to-noise-ratios and therefore limits the acoustic space (the combination of sound frequencies and levels that are audible) of a sound. Noises can be continuous or intermittent, broadband or narrowband, and predictable or unpredictable in time or space. These noise characteristics determine the strategies that birds might employ to minimize the effect of noise on acoustic communication. Background noise makes it harder for an animal (or human) to detect sounds that may be biologically relevant, to discriminate among these sounds, to recognize these sounds, and to communicate easily. Studies on the effect of noise on hearing in birds and humans show that signal discrimination requires a higher signal-to-noise ratio than detection; recognition requires a higher signal-to-noise ratio than discrimination; and comfortable communication requires an even higher signal-to-noise ratio. We can use this information to estimate the effect of anthropogenic noise on acoustic communication in birds.

1.2. Masking and the Spectrum of Noise

The simplest kind of masking experiment is to measure the sound detection thresholds for pure tones in the presence of a broadband noise. These signal-to-noise ratios in masking (i.e., critical ratios) are now available for 14 different species of birds so we have a fairly good idea of how the average bird hears in noise. Most laboratory studies estimating the effects of noise on signal detection use continuous noises with precisely defined bandwidths, intensities, and spectral shapes. Traffic noise on heavily traveled roads can approximate these features (e.g., relatively continuous, relatively constant spectrum and intensity). This provides the opportunity to move from laboratory results based on continuous noises to predictions of behaviors in the field (e.g., communication distance) that might be affected by anthropogenic noises such as highway noise. From masking studies in birds, humans, and other animals, it is known that the noise in the frequency region of a signal is the most important acoustic feature in masking the signal--- not noise outside that frequency band. Highway noise, for instance, has more energy below 1 kHz than above, and bird vocalizations generally contain more energy above 1 kHz than below. Thus, the masking effects of highway noise on bird vocalizations are less than would be expected from noise of the same level in the same frequency range of bird vocalizations.

1.3. Modeling the Effect of Traffic Noise

To evaluate the effect of masking noise on bird communication, we developed a model that integrates the spectrum and level of the masking noise, the bird's hearing in quiet and noise, the spectrum and level of a signaling bird's vocalizations, and the acoustic characteristics of the environment. The model assumes that the spectrum and amplitude level of the noise and the signaler's vocalization are both known at the location of the receiver. These values can either be measured directly or they can be estimated by applying signal attenuation algorithms to both the noise source and the signals of the sender. The algorithms adjust the spectra and level of the noise and of the signal transmitted over distance and through different habitats (e.g. meadows, forests) between the communicating birds. The challenge for the receiver is to hear the signal in the presence of noise. This is dependent on the species-specific auditory capabilities of the receiver such as how well it hears in noise (i.e., its critical ratio) and the signal-to-noise ratio at the receiver's location. Using a human parallel, the model also incorporates the notion that different auditory behaviors (e.g., communicating comfortably versus just being able to detect that something was said) require different signal-to-noise ratios.

2. RESULTS

Imagine a specific case illustrated for a background noise level at the listening bird of 60 dB(A) – a level typical of traffic noise measured roughly 300 meters from a busy 6 lane highway. The example assumes the calling bird is vocalizing at a peak sound pressure level of 100 dB through an open area and the vocalization is affected by excess attenuation, beyond the loss due to spherical spreading, of 5dB/100 meters. In such a noise, a comfortable level of communication between two birds requires a distance between them of less than 60 meters. Recognition of a bird vocalization by the receiver can still occur at greater inter-bird distances up to about 220 meters. Discrimination between two vocalizations is possible at inter-bird distances up to 270 meters. And finally, simple detection of another bird's vocalization can occur at distances up to 345 meters in this noise.

The distance values above as computed for a 60 dB SPL level of traffic noise can be used to construct a receiver-centric map of distances corresponding to the four different types of auditory communication behaviors. In such a plot, communication distance between the sender (along the periphery of the circle) and receiver (at the center) is represented as the radius "r" for a set of concentric circles defining the boundaries of each of the four levels of communication described above. While any increase in ambient noise level from anthropogenic sources can potentially affect acoustic communication, which auditory behaviors are affected depend on the noise level. The inner (smallest) circle represents the case where the sender is close to the receiver. This represents a signal-to-noise that is sufficiently large that the sender and receiver can communicate comfortably (i.e. about 15 dB above the critical ratio). As the sender moves away from the receiver, the signal level and therefore signal-to-noise ratio, at the receiver drops. At some distance, the receiver can no longer communicate comfortably but can recognize a sender's different vocalizations. If the sender moves even further away, the receiver can still discriminate between two vocalizations but cannot reliably recognize them. Finally, at the outer perimeter, the signal level at the receiver results in such a low signal-to-noise ratio that the receiver can just detect that some kind of a sound has occurred. The distance over which masking from anthropogenic noise sources occurs can be quite large. This schematic provides a way of estimating and quantifying the risk to acoustic communication in birds at different distances from a noise source.

3. DISCUSSION

This approach of considering communication from the standpoint of the receiver may provide a useful metric for evaluating the actual noise impact on individuals, or collectively on populations, in areas subject to anthropogenic noise exceeding ambient levels. For instance, in determining risk to a species, the communication distances derived from this model might be considered in relation to other aspects of biology such as territory size.

REFERENCES

H. Brumm and H. Slabbekoorn. (2005). Acoustic communication in noise. Adv. Study Behav., 35: pp. 151-209

R.J. Dooling, B. Lohr, and M.L. Dent.(2000). Hearing in birds and reptiles. In R.J. Dooling, A.N. Popper, and R.R. Fay, eds., Comparative Hearing: Birds and Reptiles. pp. 308-359. Springer-Verlag, New York,

B. Lohr, T.F. Wright, and R.J. Dooling. (2003). Detection and discrimination of natural calls in masking noise by birds: estimating the active space signal. Anim. Behav., 65: pp. 763-777