The Complexity of Noise Impact Assessments: From Birdsong to Fish Behavior

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Anthropogenic noise is on the rise. Sounds generated by human activities make the world more noisy in terms of sound levels as well as through expansion in time and space. The artificial noise penetrates all media (air, water, soil, vegetation) where it changes habitat acoustics for animals that are able to hear and for which hearing sounds may play a critical role in survival and reproduction (Slabbekoorn 2010). Awareness is also on the rise. Policy makers, industrial parties, and scientists are all increasingly aware of the potentially detrimental impact of noise pollution (Barber et al. 2009; Popper and Hastings 2009; Slabbekoorn and Ripmeester 2008; Southall et al. 2007). Dramatic physical consequences for animals in close proximity to sounds of loud intensities often draw the most attention. However, it becomes clear that more moderate noise levels, which are often widespread and long term, can also negatively affect many animals (Slabbekoorn et al. 2010). The increase in both anthropogenic noise levels and the awareness of the potential impact of high- and low-intensity sounds on animals leads to a need for adequate impact assessment methods.

The development of noise impact assessment methods is difficult, and there are many reasons why any future standardized procedure will likely be complex. First, any impact will depend on the transmission properties of the medium and the species-specific sensitivity to sound. Attenuation rates in water and air are very different and vary with locality and weather conditions, whereas species-specific hearing ranges vary considerably and sometimes do not even overlap. Furthermore, being aware of an anthropogenic sound does not necessarily mean being affected by it (Knudsen et al. 1992), and, similarly, behavioral changes associated with sound exposure can indicate, but are no proof of, negative consequences. There are many impact factors that can occur at the same time, that are not mutually exclusive, and that are often interrelated but not necessarily leading to additive effects (Table 1, Fig. 1).

The six main impact factors of anthropogenic noise include 1) physical damage, such as temporary or permanent hearing loss; 2) physiological stress, e.g., reflected by a rise in heart beat or cortisol level; 3) auditory masking, meaning a reduced detectability or recognizability of environmental or echolocation sounds or communicative signals; 4) spatial deterrence, by which animals move away from potentially favored feeding or breeding areas; 5) behavioral interruption, which can involve a breakdown of typical signal-response chains or interruption of activities such as schooling or spawning; and 6) signal modification, which refers to any temporal or spectral alteration of communicative signals. These impact factors do not stand alone and are interrelated in a complex network

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Table. 1 An overview of all pairwise relationships among the six main impact factors of anthropogenic noise on animals

	Physical Damage	Physiological Stress	Auditory Masking	Spatial Deterrence	Behavioral Interruption	Signal Modification
Physical damage		+	+	+	+	+
Physiological stress	+		+	+	+	+
Auditory masking	n	n		+	+	+
Spatial deterrence	–	–	–		+	n
Behavioral interruption	n	n	n	+		n
Signal modification	n	+	–	n	+	

The impact factors are represented as cause in the first column and as consequence in the first row. One impact factor affects the other positively (+; making it worse) or negatively (–; leading to some release) or has no logical effect (n; neutral)

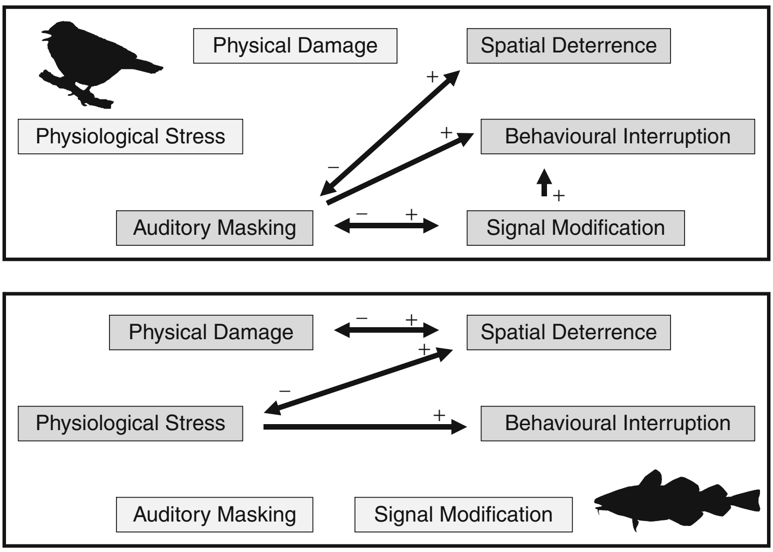

Fig. 1 Complexity of noise impact assessments and the parts that have received the most attention in studies in birds and fish. Relationships between two impact factors can be positively (+) or negatively (–) correlated, in which case one factor may be detrimental in itself but may reduce the impact of another at the same time

in which all pairwise combinations may influence each other in the sense that one is likely to make the other worse or likely to reduce the impact of the other (Table 1).

For example, any physical damage or physiological stress is likely to further increase the direct impact of anthropogenic noise on all other factors, whereas spatial deterrence may be detrimental for various reasons, but it could also lead to lower and shorter exposure levels that can release the negative impact through physical damage, physiological stress, or auditory masking. Auditory masking is in turn likely to contribute to the probability of behavioral interruption, spatial deterrence, and signal modification, of which the latter two yield two other examples of negative feedback loops through masking release (Brumm and Slabbekoorn 2005). Not all possible impact factors are always relevant and not all relationships are always critical to explore, but it is important to realize the full complexity of a proper noise impact assessment on individual fitness. Short-term consequences in one or two factors can only provide limited insight, whereas incorporation of the possible relationships among factors elucidates that some factors are inherent properties of noise exposure that animals just have to undergo while other factors may not need to be fully detrimental and can concern more or less adaptive response patterns.

Physiological and behavioral responses are often based on mechanisms evolved in the context of more natural noise patterns that could signal an increase or decrease in the probability of danger. Such responses can still benefit the animal in the context of artificial noise depending on species-specific response patterns and the impact factor. The impact of a predator escape response for animals nearby pile-driving sounds depends, e.g., on whether they flee or freeze. The impact of a habituation response can reduce spatial deterrence but at the same time leave auditory masking unaffected.

The impact factors are represented as cause in the first column and as consequence in the first row. One impact factor affects the other positively (+; making it worse) or negatively (−; leading to some release) or has no logical effect (n; neutral).

Studies on noise impact assessments in birds and fishes can provide a complementary picture because they have been biased to different factors (Fig. 1). On the one hand, many studies in birds have explored auditory masking and the consequences for spatial deterrence of breeding birds away from otherwise suitable habitat alongside noisy highways or industrial sites with noisy compressors (e.g., Francis et al. 2009). Also, the noise-dependent consequences for signal perception and signal production have been well studied in birds, which may both cause behavioral interruption in terms of a drop in response-eliciting capacity (Slabbekoorn and Ripmeester 2008). On the other hand, many studies in fish have explored the physical damage in hearing loss and physiological changes in cortisol secretion after sound exposure. Furthermore, understandably in the context of fisheries, several studies have addressed the spatial deterrence of fish, e.g., away from areas of seismic shooting or behavioral interruption of schooling behavior caused by vessel noise (Popper and Hastings 2009; Slabbekoorn et al. 2010). The impact factors that are not highlighted reflect relative data gaps (but see Ryals et al. 1999 for physical damage in birds; Codarin et al. 2009 and Hawkins and Chapman 1975 for auditory masking in fish).

In conclusion, conceptual similarities and complementary findings could mean a fruitful scientific integration when insights from bird and fish studies are combined in future research efforts to get a better understanding of the complexity of noise impact assessments.

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