# NOISE AS AN INDICATOR OF QUALITY OF LIFE: ADVANCES IN MEASUREMENT OF NOISE AND NOISE EFFECTS ON HUMANS AND ANIMALS IN THE ENVIRONMENT

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A jointly-sponsored session on "Advances in Measurement of Noise and Noise Effects on Humans and Animals in the Environment" took place for the first time at the meeting of the Acoustical Society of America in New Orleans (November 2007). It was organized by Ann Bowles representing Animal Bioacoustics and Brigitte Schulte-Fortkamp representing Noise. Recent studies on both humans and animals were presented in two half-day sessions, followed by panel discussions on selecting efficient metrics with which to discuss notions of soundscape versus acoustic topology versus acoustic environment, and "meta-acoustic" influences on response to noise. The outcome of the session is summarized in this article in "snap-shot" form, with a short overview of the papers presented, proposed concepts, and main topics discussed during the panels. The corresponding abstracts can be found in the *Journal of the Acoustical Society of America*, Volume 122, Number 5, Part 2, November 2007, 154th Meeting: Acoustical Society of America, p. 9-11 and 33-35.

*"Results of a special session on recent advances in the study of noise and noise effects on humans and animals to foster the dialog about methodologies and theoretical principles common to both."*

The purpose of the session was to bring together work from the Noise and Animal Bioacoustics Technical Committees reflecting the development of methodologies as well as new research in both fields. The organizers were most interested in highlighting commonalities between human and non-human animal studies (common problems, theories, and solutions). The invited and contributed presentations focused on models, prediction, and measurements taken from both field and laboratory studies.

Brigitte Schulte-Fortkamp presented an overview paper on evaluation of effects of environmental noise on humans. She introduced a different approach for making measurements in defined environments, pointing out the need for qualitative approaches that are appropriate to explain human reactions to noise brought about by factors other than physical acoustic characteristics. This approach is central to soundscape research.[1,2]

Danielle Dubois discussed how semantics may help understanding of both animal behavior and human cognition. She showed that contemporary cognitive models of information processing that purport to be universal cannot account for the ways that "ordinary" humans perceive and react to environmental noise in the complex "real" world. In everyday life, humans process multimodal incoming stimulations in a holistic manner. For example, humans reconceive noise as meaningful events, relating soundscape to human

*Fig. 1. Soundwalk.*

*Fig. 2. Ranking, writing comments, and psychoacoustic evaluation.*

*Fig. 3. Measuring people's minds; talking to the new experts.*

activities over areas and in time. Sounds are processed differently by people in diverse cultures and different meanings and evaluations can be given to the "same" acoustical event depending on living situations.

The question whether there is any significant influence on animals through environmental noise was brought up with respect to psychoacoustic measurements by Klaus Genuit and Andre Fiebig. In contrast to Schulte-Fortkamp and Dubois, who prioritized the meaning of noise, they highlighted relevance, determination, and interpretation of psychoacoustics and other hearing related parameters "in the context of environmental noise, with respect to hearing sensation of humans." The question of whether animals undergo similar psychoacoustic processes was debated at the end of their talk. Finding techniques to make these measurements represents an important challenge of animal research.

David C. Waddington and his coworkers described a practical application of these ideas, describing the assessment of residential low frequency noise complaints. They collected field measurements of both noise and citizen complaints and described results that included a considerable "top down" influence of subject attitudes on generation of noise complaints, uncorrelated with the acoustic characteristics of the noise.

Overview papers on animals showed the importance of improving technological as well as theoretical approaches to studying the effects of noise on wildlife. Due to differences in the psychoacoustic capabilities and ecology of the many species of concern, a wide range of approaches and metrics have been applied over the past twenty years to determine effects on animals, making studies somewhat difficult to compare and progress slow (Robert Kull). Issues and outcomes of experimental studies of noise impact on wildlife suggested that much of this research has been overly focused on short-term, high-amplitude exposures. More sophisticated models of effect need to be developed, with emphasis on mechanisms of injury, which are rarely documented in animals, and long-term, cumulative impact of exposure to multiple sources (A. Bowles and coworkers).

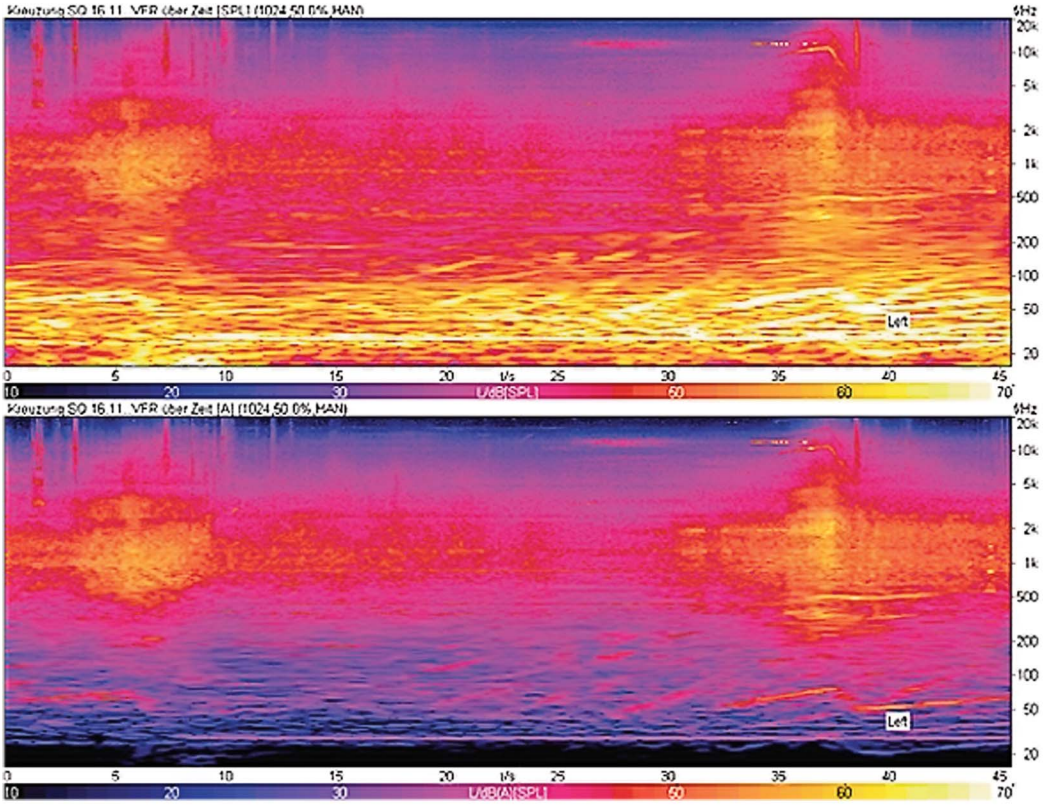


*Fig. 4. Psychoacoustic analysis.*

Delaney and his coworkers gave an example of an approach that may make such research possible. They reported on a study collecting continuous measurements of noise exposure to gopher tortoises using "on-board" monitoring devices. The goal of this study was to benefit the recovery and management of the gopher tortoise population under varying conditions, including exposure to military training operations.

Don Hunsaker and his coworkers reported on the effects of helicopter noise on the reproductive success of the coastal California gnatcatcher based on a 5-year field study of noise exposure with relation to reproductive success. Because the study was one of the first to collect an adequate sample of breeding attempts based on *a priori* analysis, it was possible to show that the "factors best predicting reproductive success were measures of suitable nesting habitat, not noise levels." A. Bowles reported that preliminary analysis was showing a similar outcome from a 6-year study of breeding Mexican spotted owls exposed to low-flying military jet overflights. In that case, changes in flight routes by German Air Force cooperators made it possible to demonstrate experimentally that habitat was a more parsimonious explanation for patterns of breeding success than exposure to aircraft.

In a study more comparable to research done on human speech interference, Susanna Blackwell and her coworkers examined the effects of sounds from an artificial oil production island on bowhead whale calling behavior over a three year period. Their analysis showed that an increase in transient sounds from noise, for example, boats, resulted in significantly shorter calls. They also showed that that call detection rates were dependent on the direction that the whales swam, suggesting that other perceptual features might be important, just as Schulte-Fortkamp and Dubois had described for humans.

Kathleen J. Vigness Raposa's group described an effort to model the acoustic characteristics of exposures and marine wildlife responses using a system called the Marine Wildlife Behavior Database (MWBD). Their system is designed to assist environmental planners in estimating impacts of proposed new projects. The MWBD includes specific standards for measuring and characterizing behavior in a manner that allows movements or other behaviors to be integrated into models of noise propagation.

Metrics to characterize human responses to noise are still a subject of active investigation, even after over 40 years of research. Ambivalence about noise and noise effects in human soundscapes forces us to think about whether noise has only negative implications, such as annoyance, or whether features such as sound quality and previous experience are important. Assessments that include multiple noise sources and sensory qualities will be needed for effective and efficient evaluation.[3] Richard Horonjeff introduced a hierarchical method for single-observer, continuous sound source logging that has been applied in a number of national parks over the last 15 years. His method allows the relative importance of exposures to human observers to be evaluated, something that is still a challenge in studies of animals whose behaviors are more difficult to translate into a perceptual continuum such as annoyance.

**Table 1.** Noise disturbances affecting the percentage of the population in Germany, according to the source and level of noise.

| Level and Source | Extreme, high | Extreme, high, medium | Extreme, high, medium, low |
|---|---|---|---|
| Road | 10 | 30 | 60 |
| Neigborhood | 6 | 17 | 43 |
| Air traffic | 4 | 12 | 32 |
| Trade, Industry | 2 | 7 | 19 |
| Rail | 3 | 8 | 20 |
| | | | |

Source: Federal Environment Agency, Germany 2004

From a comparative point of view, it is important to realize that nearly all of the effort to develop efficient metrics has concentrated on only one of about 58,000 vertebrate species, all of which are thought to be capable of hearing (over 5,400 mammal, 10,000 bird, 8,200 reptile, 6,200 amphibian, and 28,000 fish species [Integrated Taxonomic Information System, http://www.itis.gov/]). Lacking species-targeted alternatives, much of the work on animals has been conducted using metrics designed for humans, but a number of session authors emphasized the risks of this approach. Mardi Hastings and her coworkers gave an excellent example by reviewing exposure metrics for evaluation of effects of sound on fish hearing. They described several studies indicating that the equal energy hypothesis does not apply when evaluating auditory effects of noise on fish.

West and his coworkers described the other side of the problem, the identification of outcome measures for animals. They reviewed the literature on potential noise impact on birds. They described that 'takes' (significant effects on individuals) "can be physiological, behavioral, or ecological, but must be verifiably correlated with significant changes in species viability." This aspect of the National Environmental Policy Act law underscores the greatest differences in studies of humans and animals—while mechanisms of injury to animals may eventually prove to be similar to those identified in humans, the measurement of outcomes is different because impact on humans is assessed based on individual effects, while it is based on population-level effects in wildlife, such as effects on reproductive success.

Sheyna Wisdom referred to the role of science in assessing noise impacts on wildlife under the National Environmental Policy Act. Principles of adaptive management (management that changes with new information on impacts or population trends) are used by wildlife managers to implement policies. However, development of management methods is extremely challenging in the face of large data gaps. Managers must both protect wildlife and yet enable humans to function without unnecessary constraint.

Commonalities in impact research on humans and wildlife were clearer when research was conducted in areas where both humans and animals were impacted by noise. Kurt Fristrup gave examples of applying noise metrics in park lands managed by the U.S. National Park Service which is responsible for the experience of both humans and wildlife.

He pointed out that, while hearing is a ubiquitous sense among vertebrates, there is a great need for models of effect that capture the idiosyncrasies of species auditory capabilities, a range of possible mechanisms of injury, and variable real-world noise environments.

Plotkin and his coworkers described key components of an adaptive management system for exposure to sonic booms that has been designed to ensure preservation of a highly valued ecosystem in Labrador, Canada. They described efforts to monitor, predict and manage military aircraft training activities at Goose Bay, a sensitive ecosystem under airspace that has been host to military flying operations since World War II. Since 1995, a local organization funded by a consortium of stakeholders, the Institute for Environmental Monitoring and Research, has conducted effects research and negotiated mitigation of the effects of low altitude flight operations, serving to protect the welfare of aboriginal people as well as the survival of wildlife species.

David Dall'Osto and Peter H. Dahl presented a pilot study to characterize environmental noise underwater in Puget Sound by describing different components of the noise budget, including injection of noise from airplane flyovers, and correlation between pressures above and below water. Their work emphasized that noise in real-world environments comes from many different sources, sometimes including the target species themselves, and may involve characterization of transmission through a variety of media.

Panel discussions focused on commonalities between studies of noise effects on humans and animals. The search for metrics relating acoustic environment to outcome measures was certainly a common concern. Commonalities were also easily understood in hearing loss. However, some panelists and authors saw a gap concerning cognitive, behavioral or social responses to noise.

Human actions are rarely interpreted as adaptive, nor are animal responses posited to be intelligent and flexible. However, the panelists considered that both perspectives are likely to be important in developing general models of effect. Recent reviews of the disturbance literature for animals have begun to characterize animal responses to disturbance as strategies, behaviors that are chosen based on context that minimize risk and cost and maximize benefits.[4] Even though effects on humans and animals are assessed very differently from a legal point of view, there was a consensus that noise could be conceptualized as an environmental challenge to be met with adaptive responses in both cases. In humans, adaptive responses are constrained by economic or social needs, whereas animals are driven to maximize survival and reproduction. However, whether human or animal, non-auditory impact is mediated by processes in the brain—perception, evaluation of risk, and response. A small first order list of predictors was agreed on during the panel discussion:

1. Acoustic features such as signal to noise ratio and absolute level, particularly those that differ greatly from background or expected noise;
2. Control and predictability;
3. Association with perceived threat (e.g., predatory or social challenge);
4. Interference with function, such as sleep interference, masking of biologically-significant signals like speech, or competition for attention

During the discussion, there was agreement that effects on attention were particularly under-appreciated. In this view, attention should be modeled as a limiting resource that can be used up by noise. In the case of wild animals, it may distract attention from important activities such as vigilance against predators or socializing. In the case of humans, it may interfere with activities that require attention, such as learning.

The concept of "soundscapes" as differentiated from physical acoustic characteristics of the environment, variously called the acoustic environment or acoustic topology, came up repeatedly during the discussion. In the sense that the term soundscape describes sounds that vary predictably over an area, the two did not seem to differ greatly. However, soundscape was also linked to human conceptual and emotional perceptions of their acoustic environment. There was an extensive discussion about the value of treating acoustic measurements of the environment as objective, given that the best information available now suggests that mental processes of both humans and animals are closely tied to effect. However, there did seem to be value in recognizing that the human-based concept of soundscape can be examined by conversing with humans, whereas animal perceptions must always be measured by indirect experimentation.

Based on this discussion, panelists noted that there was a continuum of noise exposure from completely natural to highly urban environments. They noted an urgent need to develop quantitative measures at both individual and aggregate levels in both humans and animals.

At the 156th Meeting of the Acoustical Society of America in Miami

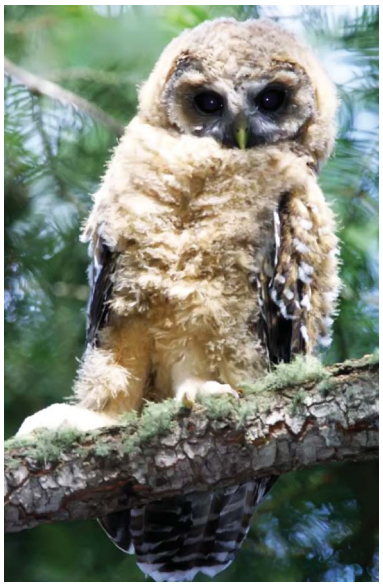

*Fig. 5. Alerting response of Mexican spotted owl chick to disturbance. Responses of owls were documented during low-altitude training overflights by Tornado aircraft flown by the German Air Force in the Gila National Forest, New Mexico (photo by A. Bowles).*

*Fig. 6. In experimental trials, even domestic poultry evaluate disturbances cognitively before selecting a response. In this photograph, naïve turkey poults move to a location where they can see a low flying military jet and monitor its movements (photo by A. Bowles).*

(Nov-ember 2008), the search for models common to humans and non-human animals will continue in the Workshop: *Advances in measurement and noise and noise effects on humans and non-human animals in the environment*, to be organized by Brigitte Schulte-Fortkamp and Ann Bowles.


## Acknowledgements

We would like to thank all presenters in the session and of course the audience contributing to the important and exciting discussion on recent and further collaboration on noise metrics, measurements on humans and animals. AT


## References for further reading:


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4. J. A. Gill, K. Norris, and W. J. Sutherland, "Why behavioural responses may not reflect the population consequences of human disturbance," Biological Conservation **97**, 265-268 (2001).


*Photo courtesy of Sea World San Diego.*

Ann E. Bowles is a Senior Research Scientist at the Hubbs-SeaWorld Research Institute (HSWRI). She specializes in Animal Bioacoustics, particularly the study of animal communication and effects of human-made noise. Under contract to agencies such as CalTrans, U.S. Air Force, U.S. Army, NASA, U.S. Fish and Wildlife Service, U.S. Forest Service, and National Marine Fisheries Service, as well as private organizations, she has spent 29 years studying the effects of noise and disturbance on a wide range of taxa. Her work has emphasized a general understanding of behavioral and physiological effects of noise on animals, with the ultimate goal of developing predictive models of effect. Dr. Bowles worked to bring ASA's Animal Bioacoustics Technical Committee to full committee status (1990-1996) and is now a fellow of the Society and participant in the ASA Committee on Standards. She was a panelist for the NOAA Ocean Acoustics Program, which has developed the first set of science-based recommendations of noise exposure standards for marine mammals.

Brigitte Schulte-Fortkamp is a Professor at the Technical University Berlin, Germany. For over 20 years her research activities have been concerned with assessing transportation noise related to annoyance and quality of life from an interdisciplinary point of view. She is particularly interested in evaluation of soundscapes by means of psychoacoustics, acoustic ecology and person-environment-fit approaches. Her research concentrates not only on the impact of noise on sensitive groups such as noise sensitivity in people, but also with comfort related issues concerning defined acoustical environments. She is a fellow of the Acoustical Society of America, JASA Associate Editor for Noise, and Chair of the Technical Committee on Noise.