We’re too busy singing: acoustic analysis with apes

Fiona French*
Stephen Good*
Karim Mokaddem*
f.french@londonmet.ac.uk
s.good@londonmet.ac.uk
k.mokaddem@londonmet.ac.uk
London Metropolitan University
London, UK

Naomi Frost*
Katherine Finch*
naomi.frost@twycrosszoo.org
katherine.finch@twycrosszoo.org
Twycross Zoo
Leicestershire, UK

Bonobo (Pan paniscus) eating lettuce. Photograph credit: Twycross Zoo.

Abstract

This project focuses on novel methods for investigating auditory perception and associated environmental enrichment of great apes in managed scenarios. Research outputs can inform animal husbandry and the design of human and animal infrastructures in both managed and wild environments. This is a report from the start of the project, explaining the motivation for the research and demonstrating the utility of soundscape analysis for identifying anthropogenic noise that potentially impacts on great ape welfare, natural behaviours and communication strategies. At this early

---

[*] All authors contributed equally to this research.

Unpublished working draft. Not for distribution.

Conference acronym ’XX, June 03–05, 2018, Woodstock, NY

ACM ISBN 978-1-4503-XXXX-X/18/06
https://doi.org/XXXXXXX.XXXXXXX

stage, technology is being used to passively monitor acoustic signals in the environment and subsequently support the analysis of recordings, using visualisation and machine learning techniques to reveal patterns and identify sound sources. Initial findings demonstrate that the fundamental frequency of gorilla low growls fall in the range of 150 to 200 Hz, with subharmonics as low as 30 Hz, just on the edge of human hearing. Ultimately, we are planning a deeper investigation of auditory perception, by developing interactive devices that offer agency to non-humans and enable us to find out more about the hearing capabilities of different species.

CCS Concepts

• **Applied computing** → **Imaging**; • **Human-centered computing** → *Visualization design and evaluation methods*;

Keywords

environmental acoustics, acoustic monitoring, great ape, gorilla, perception, environmental enrichment, animal-computer interaction

ACM Reference Format:
Fiona French, Stephen Good, Karim Mokaddem, Naomi Frost, and Katherine Finch. 2018. We're too busy singing: acoustic analysis with apes. In *Proceedings of Make sure to enter the correct conference title from your rights confirmation emai (Conference acronym 'XX)*. ACM, New York, NY, USA, 7 pages. https://doi.org/XXXXXXX.XXXXXXX

1 Introduction

Human communication strategy evolved so that we can acutely hear the sounds we can produce, enabling sophisticated appreciation of human vocal signals. We can discern speakers and their mood without seeing the person, and our human music uses the harmonics present in the human voice. Other species also evolved to be able to communicate with their conspecifics, and since their vocal utterances often vary in pitch, timbre and volume from human utterances, their perception of sound is very often completely different from ours.

This project explores some of these differences in the context of zoo-housed species in the UK, where we can monitor the acoustic environment around animal enclosures and also capture auditory communication between different members of the same species. By analysing the signals produced by non-human animals, we can infer what they are able to perceive.

Humans do not hear wavelengths outside the human range of auditory perception (very low frequency or high frequency sounds), yet we may produce such sounds unwittingly, with machinery and other technology. Analysing the acoustic environment in the zoo provides data about this type of noise, information that can be very helpful for animal husbandry and management. For example, we can find out if a human-made signal falls within an animal's usual vocal range, suggesting that it might impact on communication strategies or desire to perform natural behaviours, such as mating. In addition, by simultaneously capturing acoustic and contextual data, it is possible to study the effect of anthropogenic noise on animal behaviour.

Our colleagues at Twycross Zoo are keen to mitigate the effects of anthropogenic noise, by masking human sounds, redesigning spaces so that animals have more access to zones of limited anthropogenic disturbance and potentially so they can be offered acoustic enrichment opportunities. Focusing initially on great apes, the project involves monitoring noise levels in the environment around the apes' housing areas. This involves capturing the soundscape at different times of day, and also collecting data on the vocalisations made by different species. Environmental recordings will include species-specific calls that can be filtered and enhanced to gain awareness of the animals' auditory capabilities – production and perception.

Knowledge on how zoo-housed species perceive sound is scarce, so this project provides the opportunity to investigate the perceptive capabilities of a variety of taxa. Our research could influence habitat design by zoos, mitigation efforts for scheduled events and contribute to scientific knowledge concerning the umwelt of different species, specifically their subjective soundscape.

2 Background

There seems to be agreement amongst animal researchers [Kriengwatana et al. 2022, Snowdon & Teie 2009] that communication between conspecifics can express intentions, needs, affiliation and emotions, as well as conveying information relating to environmental conditions, personal health and status. Communication contributes to group dynamics, for example by alerting others to danger, acknowledging hierarchies, resolving disputes, strengthening social bonds and sharing important knowledge. The ability to learn or improvise has enabled a variety of musical features to be expressed in some animals, such as the development of local dialects in songbirds [Hyland Bruno et al. 2021], rhythmic entrainment in parrots [Cate et al., 2016] and sealions [Cook et al., 2013], cultural transmission of whale songs [Tyarks 2022, Shabangu et al. 2022], mimicry in birds [Tanaka, 2023], and bats [Ancilotto et al, 2022], and the acquisition of novel acoustic signals in dolphins [Kohlsdorf et al., 2013, King & Janik 2013, Herzing 2016]. As a result of this, many cognitive scientists treat vocal learning as a critical component of musicality [Doolittle & Gingras 2015].

In all types of signalling behaviour, there are receivers (such as listeners) as well as senders (such as speakers). In different species, the perceptual modalities for receiving and interpreting signals have evolved simultaneously with the physical characteristics that produce those signals.

There exists a relationship between frequency and volume, based on our species-specific hearing sensitivity [Fletcher, 1933]. Frequencies at either end of the human range of hearing are perceived to be quieter, which has resulted in audio amplifiers (designed for human ears) being able to compensate for the reduction in volume by boosting bass and treble so that midrange frequencies don't dominate the acoustic signal. Meanwhile, some types of digital audio file formats, such as MP (Moving Pictures Expert Group Audio), use algorithms to compress data. The compression technique is lossy, meaning that it clips audio frequencies outside human hearing range, so that the recording can never have as much acoustic detail as the original analogue signal. Moreover, even if the digital file is RAW, meaning that there has been no data compression, audio output is limited by the size of the speakers being used. Infrasound, for example, requires huge speakers to generate very low frequency waves.

Clark and Dunn, in their guide to acoustic research with animals [2022], point to some future directions for investigation, including further consideration of decibel levels in relation to the perceptive abilities of different species. They suggest that this could be given more attention when performing acoustic monitoring procedures in zoos and animal shelters, stating: ‘*A major challenge in bioacoustics is to measure sound in a meaningful way—to reflect what animals can hear, rather than what humans can hear.*‘ The authors recommend setting up microphones as close as possible to ‘point of ear’, and establishing soundscape indices for evaluating the acoustic properties of managed environments, so as to reliably compare them with the soundscapes encountered in a natural setting.

Collecting and analysing soundscapes (acoustic data from all the sound producers in the environment) is known as acoustic monitoring. It can offer information about the variety, health and characteristics of different species, as well as provide data on noise levels from other sources. Objective soundscapes include environmental sounds from other animals (biophonic), from natural sources (geophonic), and made by humans (anthrophonic) [Bradfer-Lawrence, 2023]. According to David Dunn [2020], soundscapes offer a complex and holistic perspective on the environment. They point out that music is both a deeply mysterious phenomenon and a fundamental agent in the world, often neglected by humans because of our visually dominant representations of data and thought. Dunn emphasises that it is the listener who ascribes meaning, not the producer, suggesting that music has the potential to help humans understand the ‘profound physical interconnectedness that is our true environment’.

Ecological research into soundscapes has revealed some stark facts about the effects of anthropogenic noise in the environment, beyond the scope of this project but clearly identified as having a negative impact in the sea [Jensen et al., 2009; Erbe, 2002; Parks & Clark, 2007], on land [Shannon et al., 2016; Osbrink et al., 2012; Ortega, 2012; Teff-Seker et al., 2022], and in managed scenarios such as zoos [Queiroz & Young, 2018]. Essentially, research shows that to improve the welfare of other species, humans need to reduce their acoustic impact by avoiding, dampening or masking anthropogenic noise.

However, there is also the possibility of introducing more natural-sounding sonification to acoustically barren environments. Existing successful projects include the regeneration of coral reefs by providing acoustic enrichment (the sound of a healthy, populated reef) to attract fish [Gordon et al., 2019] and encouraging amphibians to use special tunnels beneath human transport lanes by playing a mixed chorus of their usual calls along the new route [Testud et al., 2022]. These studies relied on the principle of conspecific attraction, whereby vocalisations indicate members of the same species and therefore the likelihood of a safe habitat. By contrast, Kiffner et al. [2007] were able to accurately estimate population numbers of hyenas and lions, luring them to a specific location by using the recording of a buffalo calf distress call, thus appealing to a predatory urge. Putman & Blumstein [2019] provide an overview of research into acoustic playback for wildlife management.

Animal acoustics is a newly developing field of research, so any information will be of interest to other institutions and to the scientific community.

3 Method

Twycross Zoo houses all four species of great ape, including Western Lowland Gorillas (*Gorilla gorilla gorilla*). All great apes are vocal, using acoustic signals to express themselves and communicate with conspecifics. The western lowland gorilla troop, consisting of 3 females and 2 males, includes a geriatric female, who is a prolific singer. Members of her troop all have individual songs (Fig. 1).

Figure 1: Biddy, a female singing gorilla, Twycross Zoo. Photograph credit: Phil Grain.

3.1 Aims

(1) To investigate environmental acoustics around great ape enclosures, identifying patterns and sources of sounds.
(2) To monitor auditory signaling strategies between great ape conspecifics and identify specific features of vocalisations .
(3) To provide archive recordings of some of the exciting acoustic signals made by target species.

3.2 Procedure

An early test was carried out in July 2024, using the following equipment:

- Rode M5 small diaphragm XY stereo condenser microphone (pair) [https://rode.com/en/microphones/studio-condenser/m5];
- A Rode NTG2 full range super cardoid directional shotgun microphone [https://rode.com/en/microphones/shotgun/ntg2];
- Zoom F6 32-bit float 6 channel field recorder [https://zoomcorp.com/ video-recorders/field-recorders/f6/];
- Audiomoth full-spectrum acoustic logger (pair) [https://www.opena
- Tripod stand for recorder and ambient stereo microphones;
- Pistol grips for shotgun microphones;
- XLR and TRS cables.

The microphones were secured outside the gorilla enclosure, aimed at an internal housing area (Fig. 2). They recorded into a Zoom F6, set at 48kHz, 32bit float. Each mic was covered with wind protection and isolated from any vibrations from the floor using tripods and shock mounts to ensure the most accurate recording possible. A recording was taken between 1-3pm. One Audiomoth was secured inside the building, on a wall accessible only to staff (Fig. 3). This recorded continuously from 12:00 – 16:00 and was replaced by another Audiomoth, set to record continuously until the batteries ran out. During this period, zoo staff took a 1-hour lunch break and the research team (unknown to the gorillas) left the area.

4 Early Results

In two hours of recordings, a total of 16 vocalisations were recorded, comprising nine growls, three barks, three coughs and one howl.

The fundamental frequency of low growls fell in the range of 150 to 200 Hz, with subharmonics as low as 30 Hz, just on the edge of human hearing.

The barking appeared to contain more upper harmonics than the lower growls, with a fundamental frequency around 200 to 300 Hz. The most dominant harmonic range of these barks fell between 46 to 800 Hz, with frequencies as high as 15 to 20 kHz captured. The high frequencies were accentuated by the resonance of the tiled enclosure, in open spaces they would likely not be as present.

A spectogram of the recording 'Twycross_Gorilla_240724_15.wav' is shown in iZotope RX 10 (Fig. 4), demonstrating a low growl, with the highest consistent amplitude indicated in yellow and sitting around 125 Hz. This rumble continued for around 1 to 2 seconds.

A screenshot showing volume over frequency range of the same recording demonstrates that the inhale portion of the vocalisation is loudest at around 46 Hz (Fig. 5).

In Figure 6, a recording of 'Twycross_Gorilla_240724_16.wav' is shown in iZotope RX, demonstrating the range of the barking vocalisations. The brightest yellows indicate where frequencies have the highest amplitude and so are the main range of the vocalisation.

Figure 2: Zoom F6 and Rode microphone setup.

It was also noticed in the recordings that there was a continuous low frequency hum in the vicinity of the enclosure, likely caused by ventilation or refrigeration units in the area. This was resonating at around 120 to 150 Hz, which was noted as being in the main range of the vocalisations captured. It is not possible to give a dBA value (A-weighted decibel measuring sound pressure levels) using the sound recordings alone and so a dBA reading will need to be captured to ascertain its level. Figure 7, taken from Fabfilter Pro Q3, demonstrates the presence of a continuous hum around 120 to 150 Hz. This could be isolated and removed in the frequency equaliser (EQ), demonstrating it was a mechanical noise.

These early results indicate that low level environmental noise emanates constantly, producing a similar frequency to the gorillas' rumbles (growls). However, this part of the enclosure is supposed to be a 'quiet zone' for the animals, where they can rest undisturbed. It may be that gorillas can perceive this noise much more acutely than humans, suggesting that a thorough soundscape analysis could support husbandry and have a positive effect on gorilla wellbeing.

5 Moving Forward

Since we are at the start of this exciting project, the team welcomes advice, suggestions and questions from members of the Animal-Computer Interaction (ACI) community. At this stage, we are particularly interested in discussing soundscape indices for zoo settings, so they can be incorporated into the methodology for future data collection and analysis.

Figure 3: Audiomoth taped to wall.

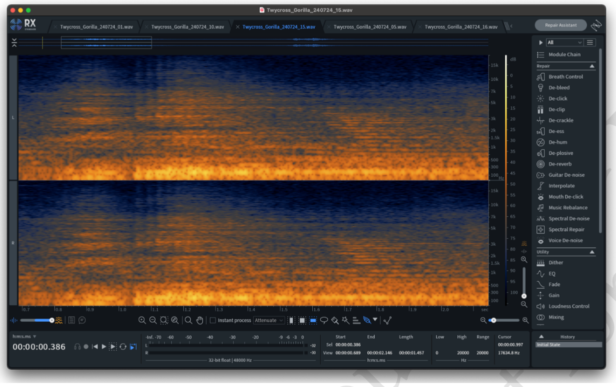

Figure 4: Screenshot of iZotope RX spectogram showing gorilla growl.

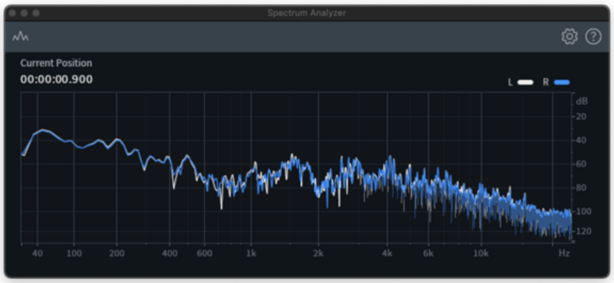

Figure 5: Screenshot from iZotope RX frequency spectrum of gorilla growl.

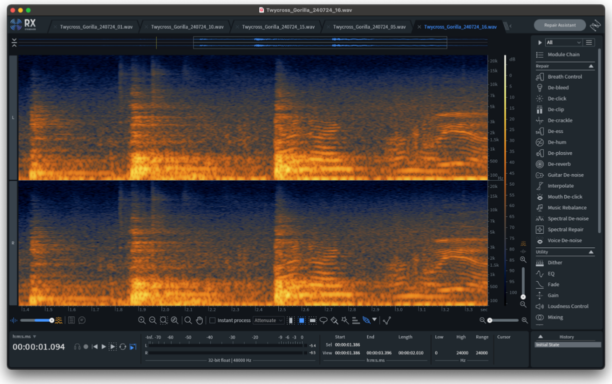

Figure 6: Screenshot from iZotope RX showing spectograms of gorilla barks.

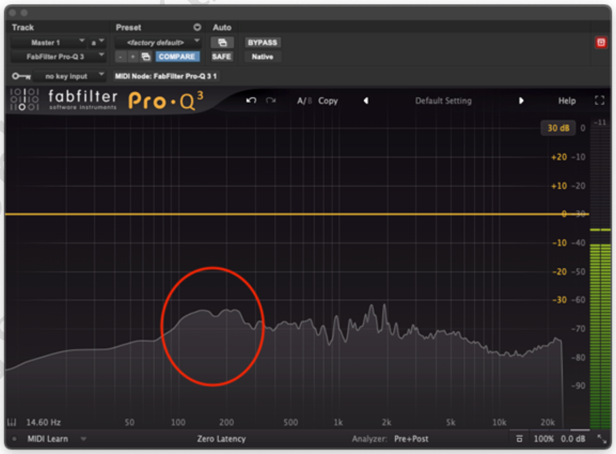

Figure 7: Screenshot from Fabfilter Pro-Q 3 demonstrating background noise level.

As part of a project at UCL, Kang et al. [2023] and Mitchel et al. [2020] are undertaking research into a new way of measuring soundscape indices, emphasising the value of collecting contextual and personal information from people as well as acoustic and environmental data from the sound environment. Their study is focused on human experience of soundscapes, but it illustrates the point that each listener has a unique experience. While these researchers can deploy questionnaires to gather information from their subjects, in a zoo setting, animal experts would need to interpret individual ape behaviour to collect a more nuanced response to the auditory environment. The soundscape indices suggested by Mitchell et al. include a range of indices for measuring soundscapes aimed at human users, namely: (i) location details (e.g., GPS, architecture), (ii) environmental conditions (e.g., weather, number of people), (iii) sound source identification (e.g., traffic, human-made, natural), (iv) perceived affective quality (e.g., pleasant, chaotic, calm) and (v) perceived loudness, as well as (vi) detailed recording data that identifies equipment used to record each parameter.

Bradfer-Lawrence et al. [2023] provide guidance on using acoustic indices in ecoacoustics and also point to the most commonly used indices, namely: (i) acoustic complexity, (ii) acoustic diversity, (iii) acoustic evenness, (iv) activity, (v) background noise, (vi) bioacoustics data, (vii) spectral, temporal and acoustic entropy, (viii) events per second and (ix) median of amplitude envelope.

Recording and analysing environmental noise and animal acoustic signaling is a passive and non-invasive way to undertake research into species-specific hearing sensitivities. Although we can deduce which frequencies are perceivable by each species through considering the range of frequencies in their vocal communications, and similarly measure the decibels to estimate appropriate volume levels, it would be useful to have reliable scales showing equal-loudness contours for all animals.

For a deeper investigation of auditory perception, there is an opportunity to use technology to develop interactive devices that provide information about non-human hearing capabilities through allowing animals to have agency and enact their choices or to freely demonstrate their hearing limitations. Such devices could be repurposed for different species, by modifying the interfaces and adjusting the auditory outputs. Outputs from such research could inform husbandry, such that enclosures could be designed to reduce the impact of unwanted noise (for example). Moreover, if we understand more about the animals in our care, this knowledge can also be applied to wild members of the same species. As an example, vocalization banking of different classes of animal (gender, age) could be used in in-situ population monitoring. Additionally, we suggest that awareness of non-human others can inform design across many disciplines, as humans could use relevant information about the local ecology to adjust how they (and their associated infrastructure) manifest in the environmental soundscape.

6 Acknowledgments

Thank you to staff at Twycross Zoo, in particular: Jennifer Bridges, Annelise Brady and Heather Hill, for continuing support and providing access to animal enclosures.

7 References

Kriengwatana, B. P., Mott, R., & ten Cate, C. (2022). Music for animal welfare: A critical review & conceptual framework. Applied Animal Behaviour Science, 251, 105641. DOI: 10.1016/j.applanim.2022.105641

Snowdon, C. T. (2021). Animal signals, music and emotional well-being. Animals, 11(9), 2670. https://doi.org/10.3390/ani11092670

Hyland Bruno, Julia, Erich D. Jarvis, Mark Liberman, and Ofer Tchernichovski. "Birdsong learning and culture: analogies with human spoken language." Annual review of linguistics 7 (2021): 449-472.

Cate, C.T.; Spierings, M.; Hubert, J.; Honing, H. Can birds perceive rhythmic patterns? A review and experiments on a songbird and a parrot species. Front. Psychol. 2016 ,7, 730

Cook, P., Rouse, A., Wilson, M., & Reichmuth, C. (2013). A California sea lion (Zalophus californianus) can keep the beat: motor entrainment to rhythmic auditory stimuli in a non vocal mimic. Journal of Comparative Psychology, 127(4), 412. - DOI: 10.1037/a0032345

Tyarks, S. C., Aniceto, A. S., Ahonen, H., Pedersen, G., & Lindstrøm, U. (2022). Changes in humpback whale song structure and complexity reveal a rapid evolution on a feeding ground in Northern Norway. Frontiers in Marine Science, 9, 862794. - https://doi.org/10.3389/fmars.2022.862794

Shabangu, F. W., Yemane, D., Best, G., & Estabrook, B. J. (2022). Acoustic detectability of whales amidst underwater noise off the west coast of South Africa. Marine Pollution Bulletin, 184, 114122.

Tanaka, Masashi. "Vocal Imitation, A Specialized Brain Function That Facilitates Cultural Transmission in Songbirds." In Acoustic Communication in Animals: From Insect Wingbeats to Human Music (Bioacoustics Series Vol. 1), pp. 81-94. Singapore: Springer Nature Singapore, 2023.

Ancillotto, L., Pafundi, D., Cappa, F., Chaverri, G., Gamba, M., Cervo, R., & Russo, D. (2022). Bats mimic hymenopteran insect sounds to deter predators. Current Biology, 32(9), R408-R409. - DOI:https://doi.org/10.1016/j.cub.2022.03.052

Kohlsdorf, D., Gilliland, S., Presti, P., Starner, T., & Herzing, D. (2013, September). An underwater wearable computer for two way human-dolphin communication experimentation. In Proceedings of the 2013 International Symposium on Wearable Computers (pp. 147-148). - https://doi.org/10.1145/2493988.2494346

King, S. L., & Janik, V. M. (2013). Bottlenose dolphins can use learned vocal labels to address each other. Proceedings of the National Academy of Sciences, 110(32), 13216-13221. - https://doi.org/10.1073/pnas.130

Herzing, Denise. (2016). Interfaces and Keyboards For Human-Dolphin Communication: What Have We Learned?. Animal Behavior and Cognition. 3. 243-254. 10.12966/abc.04.11.2016.

Doolittle, E., & Gingras, B. (2015). Zoomusicology. Current Biology, 25(19), R819-R820. DOI:https://doi.org/10.1016/j.cub.2015.06.039

Fletcher, H. and Munson, W.A. "Loudness, its definition, measurement and calculation", Journal of the Acoustical Society of America 5, 82–108 (1933)

Clark, F. E., & Dunn, J. C. (2022). From soundwave to soundscape: A guide to acoustic research in captive animal environments. Frontiers in Veterinary Science, 9, 889117. https://doi.org/10.3389/fvets.2022.889117

Bradfer-Lawrence, T., Desjonqueres, C., Eldridge, A., Johnston, A., & Metcalf, O. (2023). Using acoustic indices in ecology: Guidance on study design, analyses and interpretation. Methods in Ecology and Evolution, 14(9), 2192-2204. https://doi.org/10.1111/2041-210X.14194

Dunn, David. Cybernetics, Sound Art and the Sacred. Frog Peak Music, 2020.

Jensen FH, Bejder L, Wahlberg M, Aguilar Soto N, Johnson M, Madsen PT, (2009) Vessel noise effects on delphinid communication. Mar Ecol Prog Ser 395:161-175. https://doi.org/10.3354/meps08204

Erbe, C. (2002), UNDERWATER NOISE OF WHALE-WATCHING BOATS AND POTENTIAL EFFECTS ON KILLER WHALES (ORCINUS ORCA), BASED ON AN ACOUSTIC IMPACT MODEL. Marine Mammal Science, 18: 394-418. doi:10.1111/j.1748-7692.2002.tb01045.x

Parks, Susan E and Clark CW. 2007. Short- and long-term changes in right whale calling behavior: The potential effects of noise on acoustic communication. The Journal of the Acoustical Society of America 122, 3725 (2007); https://doi.org/10.1121/1.2799904

Shannon, G. , McKenna, M. F., Angeloni, L. M., Crooks, K. R., Fristrup, K. M., Brown, E. , Warner, K. A., Nelson, M. D., White, C. , Briggs, J., McFarland, S. and Wittemyer, G. (2016), A synthesis of two decades of research documenting the effects of noise on wildlife. Biol Rev, 91: 982-1005. doi:10.1111/brv.12207

Osbrink, Alison, Megan A. Meatte, Alan Tran, Katri K. Herranen, Lilliann Meek, May Murakami-Smith, Jacelyn Ito, Carrie Nunnenkamp, and Christopher N. Templeton. "Traffic noise inhibits cognitive performance in a songbird." Proceedings of the Royal Society B 288, no. 1944 (2021): 20202851.- https://doi.org/10.1098/rspb.2020.2851

Ortega 2012 - Ortega, Catherine P. "Chapter 2: Effects of noise pollution on birds: A brief review of our knowledge." Ornithological monographs 74, no. 1 (2012): 6-22.

Teff-Seker, Y., Berger-Tal, O., Lehnardt, Y., & Teschner, N. (2022). Noise pollution from wind turbines and its effects on wildlife: A cross-national analysis of current policies and planning regulations. Renewable and Sustainable Energy Reviews, 168, 112801. - https://doi.org/10.1016/j.rser.2022.112801

Queiroz, M., & Young, R. (2018). The Different Physical and Behavioural Characteristics of Zoo Mammals That Influence Their Response to Visitors. Animals, 8(8), 139. doi:10.3390/ani8080139

Gordon et al., 2019 - https://www.nature.com/articles/s41467-019-13186-2 - Gordon, Timothy AC, Andrew N. Radford, Isla K. Davidson, Kasey Barnes, Kieran McCloskey, Sophie L. Nedelec, Mark G. Meekan, Mark I. McCormick, and Stephen D. Simpson. "Acoustic enrichment can enhance fish community development on degraded coral reef habitat." Nature communications 10, no. 1 (2019): 5414.

Testud, Guillaume, Clément Fauconnier, Dorothée Labarraque, Thierry Lengagne, Quentin Le Petitcorps, Damien Picard, and Claude Miaud. "Acoustic enrichment in wildlife passages under railways improves their use by amphibians." Global Ecology and Conservation 24 (2020): e01252. - https://www.frontiersin.org/articles/10.3389/fevo.2022.958655/fu

Kiffner, C., Waltert, M., Meyer, B., & Mühlenberg, M. (2008). Response of lions (Panthera leo LINNAEUS 1758) and spotted hyaenas (Crocuta crocuta ERXLEBEN 1777) to sound playbacks. African Journal of Ecology, 46(2). https://doi.org/10.1111/j.1365-2028.2007.00813.x

Putman, B.J., Blumstein, D.T. What is the effectiveness of using conspecific or heterospecific acoustic playbacks for the attraction of animals for wildlife management? A systematic review protocol. Environ Evid 8, 6 (2019). https://doi.org/10.1186/s13750-019-0149-3

Kang, J., Aletta, F., Oberman, T., Mitchell, A., & Erfanian, M. (2023, September). Subjective evaluation of environmental sounds in context-towards Soundscape Indices (SSID). In Proceedings of Forum Acusticum. European Acoustics Association Forum Acusticum. https://www.doi.org/10.61782/fa.2023.0096

Mitchell, A., Oberman, T., Aletta, F., Erfanian, M., Kachlicka, M., Lionello, M., & Kang, J. (2020). The soundscape indices (SSID) protocol: a method for urban soundscape surveys—questionnaires with acoustical and contextual information. Applied Sciences, 10(7), 2397. DOI:10.3390/app10072397

Received 20 February 2007; revised 12 March 2009; accepted 5 June 2009