How does the zoo soundscape affect the zoo experience for animals and visitors?

Marina Bonde de Queiroz

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Supervised by Prof. William J. Davies and Prof. Robert J. Young

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Abstract

This project aims to evaluate the zoo soundscape from the animals and visitors perspective. A complete acoustic environment study in zoological parks should involve these two different, but equally important, characters. This thesis presents the results of the influence of the sound components of the zoo environment in the welfare and behaviour of mammals and in the visitors' experience.

Firstly, a critical literature review was made concerning the impact of noise on wildlife. Several papers were evaluated regarding some topics such as the target species, the sound source studied, and the methodology applied. The aim was to assess the reliability of the articles and to propose a guideline for future studies in this area. The results of the literature review have shown that only seven per cent of the published papers used suitable equipment and acoustic metrics to investigate the sound effect on wildlife and confirmed the importance of a complete and well-described methodology for studies replicability.

The influence of sound on zoo mammals was explored by direct recordings of animal behaviour and sound measurements, and by the collection of faecal samples for glucocorticoid metabolites analysis in two zoos, Chester Zoo and Twycross Zoo. The results show that animals express some behavioural and hormonal responses to different environmental sound amplitudes. Therefore, zoos could use these findings for a better animal management and enclosures planning.

The zoo soundscape perception by the public was investigated by the application of questionnaires with the soundwalk methodology around Chester Zoo. The objective of this part of the study is to understand how the zoo visitors perceive the environmental sound around the zoo and how different aspects of an area can influence the individual perception of the sound. The results show, among other important variables, that technological sounds can have a negative on the visitors' perception and evaluation of the soundscape. For this reason, zoos should be more careful about the environmental sound of places with predominant technological sounds.

In conclusion, for the animals, sound levels and the visitors can be a source of stress that causes variations in the expression of behaviour and in physiological stress levels. For the visitors, the influence of sound is caused mostly by the noise sources and less by the sound levels.

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Glossary

Acoustics-related terms (Howard and Angus (2009) and IEC (2018))

Acoustic masking: is caused by a noise intense enough to render inaudible or unintelligible another sound that is also present.

Audiogram: a graph showing hearing perception as a function of frequency, measured with an audiometer.

Background noise: is the sound level at a given location and time, measured in the absence of intermittent noises, any other extraneous or alleged noise nuisance sources (i.e. baseline noise level).

Decibels: a logarithmic unit used to describe the ratio between the measured sound level and the reference level, widely used in acoustics, electronics, and communications.

Equivalent sound levels: is the sound level in decibels equivalent to the total sound energy measured over a stated period of time.

Frequency weightings: is a way to correlate the measured sound pressure levels with the subjective human response.

Infrasound: acoustic oscillation whose frequency is below the low-frequency limit of audible sound (about 16 Hz).

Integration period: is the time histories measured and recorded in the sound level meters.

Octave frequency bands: range of frequencies whose upper-frequency limit is twice that of its lower frequency limit. Sound pressure level is often measured in octave bands.

Peak sound level: is the greatest instantaneous value of a standard-frequency-weighted sound pressure level, within a stated time interval.

Sound pressure level: uses a logarithmic scale to represent the sound pressure of a sound relative to a reference pressure. The reference sound pressure is typically the threshold of human hearing.

Soundscape: is the component of the acoustic environment that can be perceived by humans.

Soundwalk: the acoustic method used to investigate individual's perception of the soundscape in which the participants follow a defined route and evaluate the sonic environment.

Statistical noise levels (L_n): is the level exceeded by the chosen percentage of the time (widely used in 10%, 90% and 95%).

Ultrasound: acoustic oscillation whose frequency is above the high-frequency limit of human audible sound (about 16 kHz).

Biological-related terms (Mills (2010))

Animal welfare: how an animal is coping with the conditions in which it lives or its quality of life.

Abnormal behaviour: is defined as an untypical behavioural reaction to a particular combination of motivational factors and stimuli. It is often considered to be an indicator of poor animal welfare.

Cortisone enzyme immunoassay: is a kit designed to quantitatively measure cortisone present in extracted dried faecal samples, urine, saliva, plasma, etc. This is often used to assess physiological stress levels.

Ethogram: a catalogue or table of all the different kinds of behaviour or activity with their description observed in an animal.

Focal sampling: is a sampling method in which all of the actions of one animal are recorded for a specified time period.

Foraging behaviour: is the act of searching for food resources.

Metabolite: is a substance produced during or taking part in metabolic processes.

Phylogenetics: is the study of the evolutionary history and relationships among individuals or groups of organisms.

Scan sampling: is a sampling method in which the behaviours of all the individuals in a group of animals are recorded at predetermined time intervals.

Vocalization: refers to any sound an animal may make to communicate information to other individuals.

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Section 1. General introduction

Environmental noise can affect human well-being adversely and this effect has been extensively investigated (see Basner and McGuire (2018), Clark and Paunovic (2018), Guski et al. (2017), Marquis-Favre et al. (2005a), Marquis-Favre et al. (2005b), Nieuwenhuijsen et al. (2017), Sliwinska-Kowalska and Zaborowski (2017), and van Kempen et al. (2018), for review). Thus, human studies can provide baseline information about this effect in other mammals, especially as the mammalian auditory system morphology is broadly similar across species (Fay, 1994), despite species having different sensitivities to different sound frequencies, due to differences in the scale and forms of the middle and external ear structures (Fay, 1994). However, even in humans, it is difficult to measure the impact caused by noise because tolerance levels differ between populations. Singh and Davar (2004) state that noise may result in the loss of hearing, stress, high blood pressure, loss of sleep, distraction, and a reduction in the quality of life. In the same study, the authors concluded that noise could interfere with interpersonal communication.

Several studies have investigated what is the relationship between the quantitative measurement and the human perception of the sound (Axelsson et al., 2010, Chau et al., 2010, Nilsson and Berglund, 2006, Park and Siebein, 2015, Raimbault, 2006, Vianna et al., 2015). Research made in various ambient (e.g. urban, city parks, green areas, rural, countryside) explored the effects of noise on people and some subjective scales and concepts of the acoustic environments. Moreover, one common conclusion in these aforementioned studies is the relevance of the acoustic comfort or annoyance knowledge in the fields of noise pollution or soundscape planning.

The perception of the sound can be influenced by the individual sensitivity to noise, by the different environment, and by the activity undertaken. A study has shown that in a countryside area, people who go for family activities or barbeques are less annoyed by nonnatural (aircraft and road noise) sounds than people that go to the same place for hiking or scenery appreciation (Chau et al., 2010). The same study revealed that visitors can express dislike and annoyance for human-caused noise, such as conversation, for example.

This concept of sound effect and human annoyance to noise can be applied to a zoo environment, where people go for diverse activities and could be impacted in any way by the acoustic environment of the place. For instance, if an animal enclosure causes echoes or reverberation of the sound, this could make people speak louder and, consequently, it can result in a negative effect on the visitors' perception of the venue. Furthermore, if the inside area of the same enclosure (the animal area) is also reverberant, this may have a reflection of the animals and cause an impact on their well-being.

In humans, the study of the effects of noise on health and how the noise can cause different levels of annoyance is possible to perform (Floud et al., 2013, Jarup et al., 2008, Nivison and Endresen, 1993, Sorensen et al., 2011, Sorensen et al., 2014). In wild animals, there is still the possibility of using behavioural and physiological aspects to investigate the noise effect on health (Blickley et al., 2012, Derose-Wilson et al., 2015, Hayward and Hayward, 2009). However, the wild animals' annoyance to noise could be much more difficult to measure, because this would require an individual assessment. In humans, the stressful effects caused by noise may be reduced if people feel that they can control or escape from the noise (Payne et al., 2009). In most zoo environments, such control is possible for visitors, who can easily leave an uncomfortable area, but this control is not possible for the animals. This reinforces some findings supporting that the opportunity to escape from aversive stimulus would be beneficial for animals (Fernandez et al., 2009, Kuhar, 2008).

Zoos have been trying to make animal enclosures visibly more natural from the visitor's perspective, but it is hard to create a realistic environment from the animals' perspective, and some influences such as sound are difficult to control. In nature, animals live with environmental sound in forests and savannahs; however, there are few cases where the natural sound is compared with the noise in zoos (Morgan and Tromborg, 2007). The mean sound pressure levels (SPL) during open days at the zoo can be more than 60 dB(A) (Quadros et al., 2014), while in the wild, Atlantic Forest, for example, it is normally around 38 dB(A) (Santos, 2012).

Presently, around ten per cent of the world's human population visits zoos every year, and, consequently, many zoo animals are exposed to large numbers of visitors (Gusset and Dick, 2011). This number of visitors in zoos has led to a variety of studies, many of them related to the impact of visitors presence on animal welfare--the zoo visitor effect (Davey, 2006b, Davey, 2007, Hosey, 2000). Modern zoos have important goals such as conservation, public education, research, and entertainment (Fernandez et al., 2009) and the UK visitors perceive zoos in this manner (Reade and Waran, 1996). Despite this, in the same study, people said that the major reason for a visit to a zoo is for their entertainment.

1.1. General methodology

This research is divided into three main topics: an evaluation of the literature regarding the methods applied when the impact of sound pollution on wildlife was investigated (Section 2); the zoo animals' perspective of the environmental sound and how they can be influenced by it (Section 3 and 4); and the zoo visitors' perspective about the soundscape of this venue (Section 5). All the research reported here was approved by the Chester Zoo and Twycross Zoo's Ethics Committee and by the University of Salford Science and Technology Ethics Panel (ethics application ST1617-46).

The extensive systematic literature review was made with the intent to discuss the importance of a complete and well-described methodology and to investigate how the acoustic knowledge has been applied in studies involving biological topics. The outcomes from this critical review are found in the next section (Section 2).

The investigation of the mammals' response to noise (behavioural and physiological) was made by the observation of five different species in two different zoos in the UK, Chester Zoo (aye-aye - *Daubentonia madagascariensis*, black rhinos - *Diceros bicornis*, okapi - *Okapia johnstoni*, and two-toed sloths - *Choloepus didactylus*) and Twycross Zoo (Bornean orang-utans - *Pongo pygmaeus*). The choice of the species was based on species that the zoos are more concerned about their welfare and mammal enclosures that receive larger audiences, which would help in analysing different characteristics of the sound produced. The data collection applied to each zoo and the results will be described in more details in the sections regarding this subject (Sections 3 and 4).

The zoo visitors' perception of the acoustic environment was made by the soundwalks methodology in Chester Zoo. The participants, zoo members and volunteers recruited with the help of the Chester Zoo staff, answered questionnaires that helped to get an on-site response about the zoo soundscape. Details about the participants' recruitment, the soundwalks practice, and the results can be found in Section 5.

The three main topics of the present study, mentioned above, are being developed with the aim to contribute to zoos around the world and their role in animal conservation. There are some factors that are crucial for the zoos: the number of visitors and the duration of their visit (Fernandez et al., 2009). Active and healthy animals (Johnston, 1998, Moss and Esson, 2010) and enclosures that simulate a natural environment (Davey, 2006a, Johnston, 1998) increase the number of visitors and the duration of a visit. Large crowds and longer visits are important because they increase the profits from sales of food and souvenirs, for example, which can be invested in a better quality of life for the zoo animals.

Section 2. Evaluating the impact of noise on wildlife: a methodological literature review

Sound pollution is recognised as a critical environmental problem, alongside water and air pollution, and in urban areas, it is considered a serious threat to human quality of life (Rossing, 2007, WHO, 1999). The effect of noise on animals has been studied for more than fifty years, when several papers were published covering a variety of subjects concerning the different sources of sound pollution, especially anthropogenic noise (Chen and Koprowski, 2015, Delaney et al., 2011, Grubb et al., 2013, Quadros et al., 2014, Shannon et al., 2014). Anthropogenic noise has greater acoustic energy at low frequencies (Katti and Warren, 2004), which permits this kind of noise to propagate for longer distances since low-frequency waves attenuate more gradually by distance than sound at higher frequencies (Kinsler et al., 2000).

For a long time, research on the impacts of sound was only in relation to human health (Azrin, 1958, Fausti et al., 1981, Jerison, 1959, Nowak et al., 2016, Smith, 1989, Szalma and Hancock, 2011). Thereafter, following the worldwide concern about environment conservation, this topic has now been more commonly shared with non-human animals (Andersen et al., 1989, Brewer, 1974, Conomy et al., 1998, Crino et al., 2013, Lengagne, 2008). Most of the studies about the impact of sound on animals has had laboratory animals as their subjects (Heffner and Heffner, 2007, Lauer et al., 2009, Liu et al., 2016, Longenecker et al., 2014, Milligan et al., 1993, Sales et al., 1999, Turner et al., 2005, Turner et al., 2012, Voipio, 1997); however, the impact of noise on wildlife, as a research topic, has recently become more popular with scientists (Chen and Koprowski, 2015, Derose-Wilson et al., 2015, Ditmer et al., 2015, Duarte et al., 2015, Hillman et al., 2015, LaZerte et al., 2015).

The influence of sound on wildlife is largely assessed by how it modifies animal behaviour because the expression of abnormal behaviour or changes in frequencies of normal behaviours can be an indicator of stress (Barnett and Hemsworth, 1990). For vocal animals, such as birds, calling behaviour plays an essential role in their survival (Hollen and Radford, 2009). These animals are constantly affected by acoustic interference (masking) when the background noise reduces the active space of the signal they produce (Marten and Marler, 1977). Despite the majority of the studies evaluating animals' responses to noise by behavioural analysis, physiological responses can also show stress-related outcomes (Barnett and Hemsworth, 1990) and should be applied more in studies related to stress. Exposure to a brief but loud noise event can result in an acute stress response, increasing the secretion of glucocorticoids (a hormone associated with stress); in contrast, long-term exposure to a chronic noise stressor can result in reduced glucocorticoid levels (Romero, 2004, Wikelski and Cooke, 2006).

All of these responses that animals can make to noise may be triggered by different sound sources, such as traffic, machines, conversation, guns, compressors, chainsaws, aircraft, environmental sound (rain, wind, and other animal vocalisations), and others (Chen and Koprowski, 2015, Cote et al., 2013, Duarte et al., 2015, LaZerte et al., 2015). These different kinds of sounds, each one with different acoustic characteristics, require different acoustic evaluations (see examples in Pater et al. (2009) and Delaney et al. (1999)). However, these specific measurements have not always been done using appropriate methods, and this will be discussed further below.

An overview of what is found in the present literature about the impact of noise on wildlife is presented. It includes a selection of studies on vertebrates, though some vertebrates were not included due to differences in sound perception and emission, which demand a different kind of evaluation (they are elephants which involve infrasound – sounds between 1 Hz and 20 Hz – and vibration, bats which involve ultrasound – sounds over 20 kHz –, and fish which involve underwater sound signals). It was searched Web of Science™ using the keywords “noise, noise pollution, noise exposure, ambient noise, aircraft noise, anthropogenic noise, environmental noise, traffic noise, urban noise, acoustic adaptation, acoustic communication, acoustic interference, acoustic stress, aircraft disturbance, human disturbance” combined with the following keywords “animal behav*, animal communication, animal welfare, wildlife, zoo*, captive animal”. The initial search found 1421 articles, which were filtered by reading the abstracts to confirm that they fell within the subject of this review. The discussion will refer to 121 articles (Appendix 1), from 1974 to 2015, which were evaluated according to sources of noise and the procedures used to measure the noise effect on wildlife (e.g. kind of equipment used, the acoustic metric described, how the animals were evaluated, and others). The aim is to assess the methodologies described in these studies and to propose a practical guideline for future research in this multidisciplinary area.

2.1. Publications overview

Acoustic interference on wildlife can be caused by diverse sources of sound. Until 1999, the most studied source of noise (84% of papers) was that produced by aircraft, such as helicopters or aeroplanes, even though many other sources of noise can affect animals. After the year 2000, the concern about noise impact in wildlife changed to the investigation of anthropogenic and, specifically, traffic noise (64% of papers). Traffic noise was considered as a separate category from other sources of anthropogenic noise because of the significant number of papers that have evaluated this specific kind of disturbance. As anthropogenic noise, it was considered sounds generated by machines, conversations, guns, explosions, oil and natural gas drilling and compressors, chainsaws, and mining. Environmental noise, such as background noise in nature, and some experiments using white noise are also found in the literature, even though they are not the most studied source of noise (17% of papers).

The methodologies applied in the papers reviewed here differ significantly between them, which makes comparison difficult to perform. Some studies did not use any equipment to measure or record the sound (19% of papers). These studies have evaluated noise in a subjective manner, considering only the presence or absence of noise, or the proximity to the noise source. The evaluation of animal response to noise without quantifying the noise appropriately restricts the usability of the results (Pater et al., 2009) because the perception of noise varies and it depends on the receptor. The use of noise meters or sound level meters (SLM) is an easy way to work around this lack of information about the amplitude of the sound. Many authors have used this methodology (62% of papers) and have applied the objective measurement of sound; however, to improve the reliability of the acoustic data, this equipment needs to be calibrated before and after use, and only 15% of the cited studies have mentioned the calibration of the devices. Calibration is important to ensure that the measurements are consistent and accurate against a consistent noise source. Failure in doing the calibration can cause bias in the results leading to an error of a few decibels. When purchasing a sound level meter, the kit normally includes a portable calibrator that is adequate for daily calibration. Nevertheless, all equipment, including the calibrator, need to be checked regularly (every two years) (IEC 61672-3, 2013, Talbot-Smith, 1999). The sound level meters can be classified as class 1 or class 2. Class 1 sound level meters present a lower tolerance for errors and provide frequency-weightings A, C, and Z, that will be described below (IEC 61672-1, 2013). For these higher specifications, class 1 sound level meters are indicated for environmental field use. Sound pressure levels can also be extracted from sound recordings using computers and specific software, but this method was used only by 15% of the examined studies. When this method is used, the computer system should be acoustically calibrated.

When recording or measuring noise, the frequency range of the microphone needs to be checked to make sure that it specifications will reach the requirements of the study. For example, a microphone suitable for the human hearing range (20-20000 Hz) might not record the lower frequencies of an elephant vocalisation (normally around 14-35 Hz; Payne et al. (1986); Poole et al. (1988)), and this could cause an underestimation of the effect of noise on its callings. Equally important, to help increase the accuracy of the field measurements, a windshield should be used over the microphones to avoid an interference of wind noise in the lower frequencies of the measurement (Lin et al., 2014).

Although field studies often do not mention equipment calibration, studies using the playback of sound to animals were more aware of calibration. Eighty-four per cent of these playback studies mentioned calibration of the sound before the animals were exposed to it. This calibration in playback experiments is important, as it is known that the animals can express a response to the reproduction of sound (Hanna et al., 2014, Meillere et al., 2015, Shannon et al., 2014): if the sound is played at a high amplitude, the animal can respond due to the intensity of the recording and not due to a specific frequency or specific type of noise, or the opposite situation can happen if the sound amplitude is too low. There is another point that the researchers should take into account when developing this kind of experiments; the response to the playback can happen due to the sudden increase of sound pressure levels, when the sound source is turned on, and may not express a direct response to the kind of noise or loudness of the noise. A study made with humans has shown that people tend to respond to an *in-situ* soundscape differently from a soundscape reproduction (Sudarsono et al., 2016). It has been discussed that soundscape reproduction by speakers (2D ambisonic system), possibly, causes a different perception of the sound between the reproduction experience and the *in-situ* experience.

2.2. Acoustic metrics applied

Regarding the acoustic metrics used by the researchers, it is possible to notice a lack of consistency: 31% of them have only presented the results in decibels, not specifying which kind of metric was used, 30% have used sound pressure levels (SPL), and 23% have used equivalent sound level (L_{eq}). The absence of description when mentioning the acoustic metrics applied during the study can cause an impediment if a researcher wants to replicate the experiment. L_{eq} is a metric frequently used as a noise index because it calculates the average equivalent sound level experienced over a period of time (Howard and Angus, 2009). It is based on the mean acoustic energy over time of a varying sound, and it gives a convenient single-figure average of a noisy environment, which may be varying over a wide range of amplitudes at a variable rate. L_{eq} has been shown to be a suitable basis for predicting human response to noise both at high levels (e.g. hearing loss; Howard and Angus (2009)) and more moderate exposure (e.g. annoyance; Miedema and Vos (2004)). There is no evidence that it is the best predictor for non-human animals. Nevertheless, it is possible to use this metric for mammals, assuming that their hearing systems are similar among the group, and it is probably better to use it than SPL or an unspecified decibel metric. It is important to state that L_{eq} is not a simple mean of the SPL over a period of time, but rather the average of the underlying sound energy. Obtaining L_{eq} needs either an integrating sound level meter to measure it directly or a calculation by an equation as found in Howard and Angus (2009) and Pater et al. (2009), for example. L_{eq} is a good measure of the total acoustic environment but it does not discriminate between components of the sound field. If it is suspected that the observed response to the sound depends on either the background sound or conversely on the highest amplitudes, then percentile levels can be used. L_{10} is the SPL exceeded 10% of the monitoring time and is often used as a more stable and representative measure than the maximum or peak SPL for high amplitudes measurements. L_{90} is the SPL exceeded 90% of the monitoring time and is often used to represent the background underlying or ambient SPL. None of the evaluated papers has used this last metric when analysing the effect of environmental noise. If transient noise sound levels caused by specific events, such as an aircraft flyover, are important, these can be assessed with the sound exposure level (SEL). SEL can be defined as the constant sound pressure levels that have the same amount of energy in one second as the original noise event (Pater et al., 2009). One SEL should be measured for each event when using this metric. Although this acoustic metric is ideal for analysis of transient noise events, only 21% of the evaluated papers have used it to express the disturbance caused by aircraft.

Another type of acoustic metric that represents an important modifying role in acoustic measurements is the frequency response filter. This filter is generally used to simulate the response of the ear system to acoustic signals. The human ear does not respond to different sound amplitude at different frequencies in the same manner: it is frequency selective. Hearing sensitivity varies as the frequency varies; it is not flat, and it is dependent on the sound pressure levels. During sound measurements, a way to compensate these differences in the sensibility to sounds is the use of correct frequency weighting filters (Howard and Angus, 2009). In the reviewed literature, 49% of the studies have used A-weighted filter, 20% have used flat, linear, unweighted, or z-weighted filters, 14% have used C-weighted filter, 4% have used a species-specific frequency curve, and 22% have not described the filter used. As was pointed out previously, methodologies should always be adequately described, and the mention of the frequency filter used during the noise measurements is an essential requirement. A-weighting is a standard filter used in acoustics that approximates human hearing and it was introduced as an attempt to assess noise in the same way that the human ear perceives it (IEC 61672-1, 2013, Talbot-Smith, 1999). The A-weighting is commonly appropriate for low-amplitude sounds (Howard and Angus, 2009), so its use, depending on the circumstances, may lead to an underestimation of the annoyance caused by low-frequency dominant noise (Persson and Bjorkman, 1988). In some cases, this is the most appropriate weighting filter when investigating the effect of low-level sounds on mammals since the hearing structures among mammals are similar (Krausman et al., 2004). According to the selected literature, authors often used A-weighting filter in studies with birds (Table 1), which is not proven an effective measurement for this group of animals, as they have a hearing structure different from humans. The C-weighted frequency filter is used to estimate the human hearing response to loud and transient noise and for peak sound level analysis (IEC 61672-1, 2013), also it could be appropriately used in the analysis of military training noises or aircraft noise. This filter is more suitable for higher sound pressure levels sounds, and it is more sensitive to the lower frequencies of the noise (Howard and Angus, 2009). The papers published that have used this “C” curve filter mostly did experiments using white noise (Appendix 1), which does not seem to be justified for this kind of noise source. The impediments of using these human-derived metrics to analyse non-human response will be discussed throughout the next sub-sections.

When reporting the sound data, it is important to state the time of exposure to noise that was used in the data collection. The most common ones are the day equivalent level (L_{day}) when measurements are made over 12 hours from 7 am to 9 pm using A-weighted equivalent sound levels, and day-evening-night equivalent level (L_{den}) when A-weighted equivalent sound level measurements are made over a 24 hours period. Specific periods of measurements should also be reported. For example, if the measurements are made during a period of one hour using A-weighted equivalent sound levels, the sound data should be reported as $L_{Aeq,1hour}$.

2.3. Animal groups studied

Almost all papers published regarding the impact of noise on wildlife were focused on a specific animal group. The majority of these studies were made with birds; possibly, for the reason that these animals frequently express vocal related behaviours, and, because of that, they could be more likely to suffer from acoustic interferences, such as acoustic masking that is considered a major disturbance factor (Brumm, 2004, Nemeth and Brumm, 2009, Rheindt, 2003). The second most studied animal group was mammals, followed by amphibians. There were no studies found in the literature with reptiles, and fish were not included in this literature review because of the specificities on the underwater acoustic topics, as previously mentioned in the introduction.

The aforementioned animal groups have been well evaluated by the analysis of behavioural and physiological responses (Appendix 1). Behavioural responses were investigated by changes in vocalisation, behaviour, group structure, reproductive success, use of habit, and population size (some of the newest studies on these topics: Payne et al. (2012), Cote et al. (2013), Chen and Koprowski (2015), Derose-Wilson et al. (2015), and LaZerte et al. (2015)). Physiological responses were assessed by metabolite tests and measurements involving body condition, body temperature, and cardiac response (some of the newest studies on these topics: Derose-Wilson et al. (2015), Potvin and MacDougall-Shackleton (2015), and Ware et al. (2015)). The outcomes of these studies have shown that animals are often affected by noise (78% of the studies came to this conclusion), showing variations in common behaviours, vocalization frequencies, body condition, reproductive success, among others (some of the newest studies: Chen and Koprowski (2015), Derose-Wilson et al. (2015), Ditmer et al. (2015), LaZerte et al. (2015), and Leonard et al. (2015)).

For humans, annoyance is the adverse attitude, which is formed against sounds that distract attention from or interfere with activities such as speech, communication, recreation, relaxation, and sleep. The annoyance caused by noise depends on acoustical aspects of the sound but also depends on non-acoustical aspects, including biological, psychological, and sociological factors (Crocker, 2007, Fidell, 2007). Individual noise sensitivity can explain variations in noise-annoyance reactions towards a given sound source, as much as noise exposure measures (Ellermeier et al., 2001). Non-human animals are able to express individual differences between their behaviours depending on the context – the animal personality (Dingemanse et al., 2010). This suggests that individual animals may perceive noise and the annoyance caused by it in different manners, depending on their personality. A study made with great tits (*Parus major*) found that animals with different personalities do not express the same behaviours in the presence of noise (Naguib et al., 2013). Some individuals can be severely impacted by sound pollution while others can be slightly affected or be able to habituate to it. These variations should be taken into consideration when evaluating animals' response to noise.

2.4. Are the acoustic metrics used with the animal groups appropriate to evaluate them?

As discussed previously, A-weighted and C-weighted frequency filters represent the human hearing response to acoustic signals. Consequently, the use of these metrics is not indicated in studies with non-human animals. Mammals have a hearing system similar across the group, especially in the middle ear area, which reflects in a similar threshold at low sound pressure levels (Fay, 1994). However, the frequency hearing range has a great variation among the group (Fay, 1994). In fact, several mammal species are capable of hearing frequencies above that perceived by humans, such as mice, rats, hamsters, rabbits, guinea pigs, dogs, cats, pigs, and Japanese macaques (Heffner and Heffner, 2007). Thus, the use of the frequency filters cited before could restrict the assessment of animal responses to sound when studying these species. For example, in case of using A-weighting filter when studying the effect of noise on a low-frequency sensitivity species, it can cause an underestimation of animal response to this frequency range because this filter is less sensitive to low-frequency signals. Furthermore, when studying animals that are sensitive to high frequencies, as an illustration, a mistake can also happen as the A-weighting filter was defined for a maximum frequency of 20 kHz, which is equivalent to the upper limit of the human frequency hearing and cannot express the actual response to higher frequencies.

Although there are limitations in the use of the frequency filters as previously mentioned, these metrics are being widely applied in amphibian, bird, and mammal studies (Table 1). It is unlikely that these filters work with these animal groups since their hearing systems are different from humans. Birds, for example, have a different frequency perception. The frequency range within avian species is narrower than in mammals (Beason, 2004, Sturkie, 1986), which suggests a mistake in using the same acoustic metrics when studying both groups. Using this method could cause the results to contain some frequencies, which are not perceived by birds and are perceived by humans, and could, therefore, cause misinterpretation of the data. There are no studies with amphibians that have analysed the frequency range heard by this group; however, if the frequency range of their vocalisation (between 0.5-9 kHz) is considered (Hanna et al., 2014, Parris et al., 2009, Sun and Narins, 2005), which is also narrower than humans, as a rule of thumb it can be assumed that they can hear the frequencies of their vocalisations, so it can be accepted that the same mistake could happen when studying this group.

Table 1. Comparison of the weighting frequency filter according to the animal group (percentage of studies found in the literature; N = 112)

Groups	ND[1]	Z[2]	A[3]	C[4]	SS[5]
Amphibians (%)	18	18	27	37	0
Birds (%)	15	17	58	14	4
Mammals (%)	43	19	38	5	5

[1] not described. [2] Z-weighted filter (including flat, linear, and unweighted). [3] A-weighted filter. [4] C-weighted filter. [5] Species-specific weighted filter. The exceed 100% in some cases, is due to the use of more than one filter in the same study.

Seeking a better understanding of animal response to noise, authors have developed species-specific weightings for some species, such as Mexican spotted owls (*Strix occidentalis lucida*) (Delaney et al., 1999), red-cockaded woodpeckers (*Picoides borealis*) (Delaney et al., 2011), and Sonoran pronghorn (*Antilocapra americana sonoriensis*) (Krausman et al., 2004), which is an adequate solution to ideally assess the animal's perception and reaction to noise. The species-specific weighting can be created based on audiograms. The aim of the audiograms is to understand, correctly, which frequency range and sound amplitudes the species respond to in terms of noise. There are numerous wildlife species audiograms in the literature, which could help to develop these specific weightings (Table 2). However, it will not be possible to produce an audiogram of all species to develop the species-specific weightings, due to the endangered status of some species or for ethical reasons to manipulate the animals (it is usually necessary to maintain animals in captivity to produce audiograms; Heffner and Heffner (2007)). In these cases, an alternative could be the use of Z-weighting filters. This metric includes all frequencies in the range of the sound level meter, not including any weighting in any frequency (IEC 61672-1, 2013). The Z-weighting filter was yielded to represent a flat response between 8 Hz and 20 kHz, so it is still not a good tool when evaluating animal response to high-frequency sounds.

Table 2. Wildlife species audiograms found in the literature.

Animal (scientific name)		Reference
Hedgehog (*Hemiechinus auritus*)		Ravizza et al. (1969)
Primates	**(*Pan troglodytes*)**	Elder (1934) and Kojima (1990)
	(*Macaca fascicularis*)	Stebbins et al. (1966)
	(*Macaca nemestrina*)	Stebbins et al. (1966)
	(*Galago senegalensis*)	Heffner et al. (1969)
	(*Nycticebus coucang*)	Heffner and Masterton (1970)
	(*Perodicticus potto*)	Heffner and Masterton (1970)
	(*Lemur catta*)	Gillette et al. (1973)
	(*Aotus trivirgatus*)	Beecher (1974a)
	(*Saimiri sciureus*)	Beecher (1974b) and Green (1975)
	(*Macaca mulatta*)	Pfingst et al. (1975), Pfingst et al. (1978), Lonsbury-Martin and Martin (1981), and Bennett et al. (1983)
	(*Papio cynocephalus*)	Hienz et al. (1982)
	(*Cercopithecus mitis*)	Brown and Waser (1984)
	(*Cercopithecus aethiops*)	Owren et al. (1988)
	(*Cercopithecus neglectus*)	Owren et al. (1988)
	(*Macaca fuscata*)	Owren et al. (1988) and Jackson et al. (1999)
Racoon (*Procyon lotor*)		Wollack (1965)
Weasel (*Mustela nivalis*)		Heffner and Heffner (1985)
Reindeer (*Rangifer tarandus*)		Flydal et al. (2001)

2.5. Authors' expertise

In the literature, most published papers about the influence of noise on wildlife were published by authors associated with biological-related areas (according to the authors' contact address in the papers). Biological-related authors wrote more than 84% of the papers, and authors with multidisciplinary expertise areas published only 11% of the studies. Sound analysis involves a specific knowledge that is not commonly covered in biological courses. Thus, it is important to include professionals with particular skills in the area to improve the methods and to achieve high-quality results.

The improvement that partnership between different study areas brings to the studies is visible. Papers published by authors of multidisciplinary areas are often more descriptive regarding the methodologies applied (see Tables 2, 3, and 4). Some studies found in the literature did not use any equipment to measure the noise when evaluating its influence on wildlife and some did not mention which device was used to measure the noise. This lack of information reduces the applicability of the results because they cannot be compared or reproduced correctly. Confidence of the results is of major importance for science, and the reproducibility is a current concern by researchers (Baker, 2016) since it is an important way to achieve confidence in results. Another important information that is often omitted in studies is the mention of the calibration of the equipment. As discussed before, sound measurement equipment, such as sound level meters, need to be calibrated before and after every measurement, which can influence the quality of the data produced. The absence of routine when checking the equipment calibration could lead to inaccurate and unreliable measurement data (Beyers, 2014). Concerning these topics, there are clear dissimilarities between papers produced by authors with only biological expertise and papers produced by multidisciplinary expertise authors (Table 3 and 4) with the latter producing more scientifically robust results.

Table 3. Comparison of the use of equipment by authors' expertise (percentage of studies found in the literature; N = 108)

Authors expertise	**NA**[1]	**ND**[2]	**NM**[3]	**OT**[4]
Biological (%)	20	3	62	15
Multidisciplinary (%)	0	0	78	22

[1] subjective evaluation of noise. [2] not described. [3] use of noise meters. [4] use of another kind of equipment and/or software to measure noise.

Table 4. Comparison of the noise measurement equipment calibration by authors' expertise (percentage of studies found in the literature; N = 79)

Authors expertise	**YES**[1]	**ND**[2]
Biological (%)	7	93
Multidisciplinary (%)	75	25

[1] authors have mentioned the calibration of the noise measurement equipment. [2] authors have not mentioned the calibration of the noise measurement equipment.

The same pattern of variation in methodology can also be seen when evaluating the acoustic metrics mentioned in the articles. Most articles published by authors with biological expertise expressed the sound levels mentioning only dB (decibels). Expressing the specific acoustic metric used is as relevant as the description of the equipment used. In the same way, the lack of this information can influence the assessment of the work done and the possibility to repeat the methods in future studies (Table 5).

Table 5. Comparison of the acoustic metrics used by authors' expertise (percentage of studies found in the literature; N = 86)

Authors expertise	ND[1]	dB[2]	SPL[3]	L_{eq}[4]	OT[5]
Biological (%)	0	36	32	17	24
Multidisciplinary (%)	0	0	0	78	78

[1] not described. [2] authors have mentioned only decibels. [3]: sound pressure levels. [4]: equivalent sound levels. [5]: another kind of metrics. The exceed 100% in some cases, is due to the use of several metrics in the same study.

2.6. Review papers already published

Since 1974, thirteen review papers were published on noise topics related to wildlife (Table 6). Most of them have focused on the noise source, but some have focused on its effect on a specific animal group. The first review paper was by Brewer (1974), who summarises, in a superficial way, five different cases about the impact of aircraft noise related to farm animals (hatchability of eggs, the effect on poultry, the effect on breeding mink, the effect on pregnant mink, and the effect on pregnant and lactating mink). He concluded that the animals studied are adapted to noise, but he required considerably more studies to extrapolate the information reviewed to other animals.

Reijnen et al. (1997), Brumm (2006), Patricelli and Blickley (2006), Slabbekoorn and Ripmeester (2008), and Francis (2015) published review papers about the sound pollution effect in birds but with different approaches in the matter. The paper of Reijnen et al. (1997) showed, based on the literature, the influence of traffic noise on breeding birds' density close to roads. The authors tried to find possible explanations for alterations in density, such as decreasing reproductive success or, simply, stress. In addition, they also discussed the consequences of traffic disturbances for breeding bird populations. In conclusion, they suggested ways to reduce the noise effect along roads, such as the construction of noise barriers (despite some issues such as the ideal length and high of the barriers and how they could potentially be another source of disturbance to the birds) and the construction of roads at a sufficient distance from important areas for breeding birds. In his review, Brumm (2006) did a brief summary of a few studies about the influence of urban and natural sounds on the adaptation of birds' communication, such as changes in the frequency of the songs. In the same vein, Patricelli and Blickley (2006) gave an overview of the communication of birds in an urban noise environment. They discussed what features of birds' vocalisation are adjusted to reduce masking, how the adjustments happen, and what the consequences of these changes are for the individual and the population. All these points were discussed based on the available literature. Slabbekoorn and Ripmeester (2008) addressed how birds are affected by anthropogenic noise, how they counteract the noise conditions, and what the options are to combat the negative impact of anthropogenic noise on bird species. The last review paper covering this topic was by Francis (2015) who used published papers to look for factors that explain birds' responses to anthropogenic noise. One interesting point of this paper is that the author could not use the acoustic data in the papers to help him assess the noise effects because of the lack of information in the papers' methods sections regarding the production of data values (i.e., a lack of reproducibility).

Another set of review papers investigated the sound pollution issue without a focus on a specific animal group, treating sound pollution subject from different perspectives. One of these articles discussed the problems of aircraft noise on human health and wildlife (Pepper et al., 2003). Regarding wildlife impact, the authors made an overview of studies concerning this subject. They summarised the type of responses that were evaluated in animals, such as behavioural or physiological responses (e.g., feeding patterns, productivity, reproduction, distinguishing between farm animals and wildlife). The paper also shows some methods for controlling the noise but focus on human health. Finally, it suggested further studies to evaluate the impact of aircraft noise on the environment, especially multidisciplinary ones. The literature reviewed by Barber et al. (2010) lead to a presentation of the impact of noise levels on different taxa, and how the animals are affected (the responses found were based on foraging and anti-predator behaviour, reproductive success, density, and community structure). Kight and Swaddle (2011) recapitulated the literature findings of the impact of biotic and abiotic noise in the neuroendocrine system, reproduction, metabolism, cardiovascular health, cognition and sleep, audition, immune system, and DNA integrity, all done in laboratory, domestic, or free-living animals. Their aim was to show the results of previous studies and to identify new possibilities for future studies. Another paper has detailed the impacts of noise on wildlife (e.g., behavioural changes, distribution alterations, and physiological responses) and provided some suggestions for data collection, such as the use of correct frequency weighting filters and a better description of the acoustic metrics used (Francis and Barber, 2013). In addition, the review paper by Naguib (2013) focused on finding in the literature the indirect effects of noise on animal communication such as distraction, attention, population density, individual spacing, and social networks. Gill et al. (2015) highlighted the importance of a complete data collection, and stated some points in bioacoustics that are essential to consider (i.e. the variation of noise over time and space, the proper evaluation of the frequency range of the noise, and the use of equipment to quantify the noise) when studying noise impact on wildlife.

In search of a validation in acoustic studies related to wildlife, Pater et al. (2009) produced an article with acoustical considerations and suggestions of research techniques to help future studies in using suitable methods to achieve an appropriate assessment of noise impacts on wildlife. This paper was cited more than fifty times. But has it changed the scenario of the description of the methods in studies associated with acoustics and wildlife?

Table 6. Number of papers used in each review article cited (based on the number of papers referenced, because not all articles are systematic reviews mentioning the number of papers used)

Reviews	**Number of papers**
Brewer, W.E. (1974) Effects of Noise Pollution on Animal Behavior. *Clinical Toxicology,* 7, 179-189.	2
Reijnen, R., Foppen, R. & Veenbaas, G. (1997) Disturbance by traffic of breeding birds: Evaluation of the effect and considerations in planning and managing road corridors. *Biodiversity and Conservation,* 6, 567-581.	62
Brumm, H. (2006) Animal communication: City birds have changed their tune. *Current Biology,* 16, R1003-R1004.	13
Patricelli, G.L. & Blickley, J.L. (2006) Avian communication in urban noise: Causes and consequences of vocal adjustment. *Auk,* 123, 639-649.	85
Slabbekoorn, H. & Ripmeester, E.A.P. (2008) Birdsong and anthropogenic noise: implications and applications for conservation. *Molecular Ecology,* 17, 72-83.	116
Francis, C.D. (2015) Vocal traits and diet explain avian sensitivities to anthropogenic noise. *Global Change Biology,* 21, 1809-1820.	51
Pepper, C.B., Nascarella, M.A. & Kendall, R.J. (2003) A review of the effects of aircraft noise on wildlife and humans, current control mechanisms, and the need for further study. *Environmental Management,* 32, 418-432.	90
Barber, J.R., Crooks, K.R. & Fristrup, K.M. (2010) The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology & Evolution,* 25, 180-189.	100
Kight, C.R. & Swaddle, J.P. (2011) How and why environmental noise impacts animals: an integrative, mechanistic review. *Ecol Lett,* 14, 1052-1061.	99
Francis, C.D. & Barber, J.R. (2013) A framework for understanding noise impacts on wildlife: an urgent conservation priority. *Frontiers in Ecology and the Environment,* 11, 305-313.	51

Naguib, M. (2013) Living in a noisy world: indirect effects of noise on animal communication. *Behaviour,* 150, 1069-1084.	91
Gill, S.A., Job, J.R., Myers, K., Naghshineh, K. & Vonhof, M.J. (2015) Toward a broader characterization of anthropogenic noise and its effects on wildlife. *Behavioral Ecology,* 26, 328-333.	63
Pater, L.L., Grubb, T.G. & Delaney, D.K. (2009) Recommendations for Improved Assessment of Noise Impacts on Wildlife. *Journal of Wildlife Management,* 73, 788-795.	60

It is possible to notice some changes in the literature after 2009. More studies were made using equipment to measure the noise; and fewer studies were made evaluating noise in a subjective way, such as the use of absence or presence of sound source or proximity to the sound source (see Table 7). Regarding the calibration of equipment, there was no difference in the description of this (Table 8). Table 9 shows a trend towards using the more useful L_{eq} instead of simple SPL. However, the proportion of studies using the much less useful unspecified dB has increased, remaining roughly constant at around a third of the literature.

Table 7. Comparison of the use of equipment before and after 2009 (percentage of studies found in the literature; Before N = 60, After N = 48)

	NA[1]	**ND**[2]	**NM**[3]	**OT**[4]
Before (%)	28	3	64	5
After (%)	10	2	61	27

[1] subjective evaluation of noise. [2] not described. [3] use of noise meters. [4] use of another kind of equipment and/or software to measure noise.

Table 8. Comparison of the noise measurement equipment calibration before and after 2009 (percentage of studies found in the literature; Before N = 43, After N = 36)

	YES[1]	**ND**[2]
Before (%)	14	86
After (%)	14	86

[1] authors have mentioned the calibration of the noise measurement equipment. [2] authors have not mentioned the calibration of the noise measurement equipment.

Table 9. Comparison of the acoustic metrics used before and after 2009 (percentage of studies found in the literature; Before N = 43, After N = 43)

	dB[1]	SPL[2]	L_{eq}[3]	OT[4]
Before (%)	26	37	16	30
After (%)	37	23	30	28

[1] authors have mentioned only decibels. [2] sound pressure levels. [3] equivalent sound levels. [4] another kind of metrics. The exceed 100% in some cases, is due to the use of several metrics in the same study.

The findings from the present review provide some support for the current discussion about the importance of the complete description of methods to help guarantee the reproducibility of science. It is apparent that the literature affords sources of knowledge about the use of acoustic methods for biological studies; however, it is also important to investigate the reliability of the studies already done and to discuss how suboptimal methods can limit the usefulness of results. This review intends to make available a simple source of acoustic methods to contribute to future studies on the current topic.

2.7. Relevant standards and guidance

A way to assist and guarantee a common sense in the use of the acoustics practices is the consultation of the standards and guidance in the area. Standards are public consensus agreements that establish safety and technical specifications and precise criteria to be used consistently as rules and to ensure the reliability of material, products, processes, and services people uses every day.

In the case of the biological studies regarding noise measurements, the standards can provide the researchers with a basis for mutual understanding, and can be used as a tool to facilitate the communication and reliability in the use of equipment and of the measurements. Table 10 presents a list of useful standards and guidance to be consulted during the research planning and development.

Table 10. List of important standards and guidance for use in biological and acoustics related studies planning and development.

Standards number and guidance	Title
ISO 1996-1:2016	Acoustics -- Description, measurement and assessment of environmental noise -- Part 1: Basic quantities and assessment procedures.
ISO 1996-2:2017	Acoustics — Description, measurement and assessment of environmental noise — Part 2: Determination of sound pressure levels.
ISO 9613-2:1996	Acoustics -- Attenuation of sound during propagation outdoors -- Part 2: General method of calculation.
ASTM C634-13	Standard Terminology Relating to Building and Environmental Acoustics.
BS EN 61672-1:2013	Electroacoustics. Sound level meters. Specifications.
BS 7580-1:1997	Specification for the verification of sound level meters. Comprehensive procedure.
BS 7580-2:1997	Specification for the verification of sound level meters. Shortened procedure for type 2 sound level meters.
BS 7445-1:2003	Description and measurement of environmental noise. Guide to quantities and procedures.
Important guidance	Calculation of road traffic noise. (Department of transport) Calculation of Railway noise. (Department of transport) Green Book. Environmental Noise Measurement Guide. (ANC)* Guidelines for community noise. (WHO)** Planning policy guidance 24.Planning and noise.

*Association of noise consultants. **World Health Organization

2.8. Conclusions

The diversity of studies is great, and the impact of sound pollution is well explored (Appendix 1). However, there is a consensus on the findings of this review and other review papers in the literature: the absence of consistency among the methods applied makes the comparison between studies a real challenge. As a suggestion to increase the consistency of future papers, editors of biology-related journals could seek reviewers with acoustic measurement expertise to review these papers and advise the authors. In addition, researchers from a biologic background should seek collaborators with expertise in acoustics to help design experiments and advise on collection and analysis of noise data.

In view of all that has been mentioned before, the analyses show that only 7% of the papers assessed in this review present a well-described methodology, regarding the important acoustic points for an acceptable investigation of noise effects on wildlife. These papers have used suitable equipment for noise measurements, they have mentioned the calibration of the equipment and the calibration of the sound when playback experiments were applicable, they have used adequate acoustic metrics according to the source of noise that was evaluated, and they have used a frequency filter that fits the animal group studied.

As the main goal of the current review, I would like to propose a simple guideline for future studies with points that need to be followed when producing a paper about the impact of noise on wildlife. A complete description of the methods used will help in a validation of the work done, will avoid unnecessary replication of studies because of the lack of information found in the literature, and will support future researchers to understand how the study was developed. Since there are already valuable references in the literature that could guide in how to assess the effect of noise on animals (Brown et al., 1999, Chen and Koprowski, 2015, Delaney et al., 1999, Delaney et al., 2011, Gill et al., 2015, Grubb et al., 2013, Krausman et al., 2004, Pater et al., 2009, Quadros et al., 2014, Shannon et al., 2014), it was reviewed and assembled the principal points to consider in a study of noise and wildlife, and important standards and guidance for consultation were indicated, here it is going to be highlighted the topics that should be fully described in the paper's methodology, regarding the noise evaluation:

- The acoustic related equipment used in the study and the software and tests used to analyse the acoustic data.
- The calibration of the equipment, how many times it was calibrated, and when during the study.

- The calibration of the sound in case of playback experiments and the equipment that was used for this calibration.
- The acoustic metrics that were chosen. In this case, it is essential to verify if the metrics will represent correctly the noise source studied and if they are appropriate for the animal group in focus. This should include a discussion of the frequency weighting chosen.

Section 3. Effect of noise on zoo mammals' behaviour and enclosures soundscapes

The zoo visitors effect

The presence and behaviour of zoo visitors are commonly associated with changes in the behaviour and physiology of captive animals (Davey, 2007, Davis et al., 2005). Studies on this topic present contradictory results (positive and/or negative) of how the public affects animal well-being. A clear example of this conflict is a study with green monkeys (*Chlorocebus sabaeus*), in which the same response to visitors can be interpreted in two different manners (Hosey, 2000). When visitors throw food inside the enclosures, the monkeys become more active to gain an advantage in obtaining the food, which can be interpreted as a positive outcome. However, according to the study, the monkeys could be taking time away from other important behaviours, such as socialisation, for example.

Recent evidence of the positive effect of visitors on animal welfare was reported by Gorecki et al. (2012); they studied how exposure to humans affects the activity of European souslik (*Spermophilus citellus*) and noted that these animals do not present negative behaviour, such as predator vigilance in human presence. The squirrels were most 'relaxed' when visitors were present. This hypothesis was confirmed when it was found that human presence reduces predation in wild monkeys and reduces their vigilance behaviour (Isbell and Young, 1993). However, most studies indicate negative effects of zoo visitor presence, as it will be discussed below.

Studies with gorillas (*Gorilla gorilla gorilla*) revealed an increase in aggressive and abnormal behaviours, high levels of auto grooming, and that the animals became less visible in the presence of visitors (Carder and Semple, 2008, Kuhar, 2008, Wells, 2005). Other studies with lion-tailed macaques (*Macaca silenus*) (Mallapur et al., 2005) and on leopard behaviour (*Panthera pardus*) (Mallapur and Chellam, 2002) found similar results. According to the authors, leopards expressed more stereotyped behaviour and rested more to avoid visitors. When people are noisy, numerous, and interact with animals (screaming and staring) some primate species respond with aggression, less social behaviours, and more abnormal behaviours (Fernandez et al., 2009), which are signs of poor well-being (Young, 2003). This also suggests that in addition to the presence of visitors the noise made by them also has an important influence on animal behaviour (Birke, 2002). Nevertheless, despite this conclusion about visitors' noise, few studies have actually quantified the change in sound pressure levels.

Minimizing the zoo visitor effect

Almost all studies that measured the effect of zoo visitors on captive animals had the same conclusion: enclosure modifications are necessary to minimise the sound pressure levels (i.e. noise) created by visitors. Visitors may significantly increase the noise around the zoo enclosures (Quadros et al., 2014) and, possibly, the animals' behaviour and welfare are significantly affected by them and by the sound pollution produced during their presence. Contact with the public may be a complex form of stimulation, but ultimately, zoo animals often do not have a means to escape from it if they so desire (Wells, 2005). Environments that are more natural and some methods that help animals to escape from adverse stimuli produced by the public could reduce negative stress and increase visitor enjoyment (Fernandez et al., 2009, Kuhar, 2008).

Another means to decrease the stress caused by zoo visitors is environmental education. Kratochvil and Schwammer (1997) working in an aquarium used signs with phrases ("only loonies would knock"; "knocking kills fish"; and "please don't knock on the glass") to try decreasing visitors' "knocking behaviour" in Vienna Zoo. The visitors' knocking behaviour stimulates fishes in a negative way and the signs were efficient in decreasing knocking; thus, supporting the suggestion that a variety of educational strategies may be effective in reducing some adverse stimuli for zoo animals produced by visitors. However, this kind of study has not been repeated in other countries with different cultures (culture could affect visitors' responses to the applied interventions).

The sound effect

Several researchers think that captive animals have a better quality of life and enhanced longevity living in zoos than in the wild because of the availability of water and food, veterinary care, and the protection against predators (Tidiere et al., 2016). But many factors can stress zoo animals such as sound and light levels, odours, thermal and tactile comfort, substrate, movement restriction, absence of escape opportunities, forced human contact, routine husbandry (such as fixed regimes), and restricted opportunities for feeding and foraging (Hosey, 2005, Morgan and Tromborg, 2007, Quadros et al., 2014).

The influence of noise on zoo animals' welfare has been discussed by many researchers (Birke, 2002, Carder and Semple, 2008, Chosy et al., 2014, Cronin et al., 2018, Gorecki et al., 2012, Kratochvil and Schwammer, 1997, O'Donovan et al., 1993, Owen et al., 2004, Powell et al., 2006). However, most of them measured noise in a subjective way (i.e. the researcher's personal perception of noise) and few measured noise with appropriate equipment (i.e. sound level meters), which may cause a significant influence on the outcomes found. Another difficulty in such studies is that certain sounds that do not affect humans such as high-frequency (e.g. ultrasound from security cameras circuit and fluorescent lamps) and low-frequency sounds (e.g. infrasound from ventilation, extractor fans, construction sites, and cars), could affect a variety of animals, as it was discovered for giant pandas (*Ailuropoda melanoleuca*) (Owen et al., 2004). Kight and Swaddle (2011) affirm that stress caused by anthropogenic noise can influence various animal systems, such as DNA integrity and genes, cells structure, physiological systems, behavioural ecology, and community ecology.

Objectives

The present study aims to investigate the effects of sound on zoo mammals' behaviour and, by this means, try to assess the impact of environmental sound on mammal's welfare. The innovative approach of this research is to collect the data with appropriate equipment, using the correct acoustic metrics and weighting filters. This is because my previous analysis of the sound literature showed that only 7% of published studies have been conducted correctly from an acoustics point of view (see Section 2), which means that the conclusions of previous studies may not be scientifically robust.

3.1. Subjects of study

The investigation of the mammals' behavioural response to noise was made by the observation of four different species in Chester Zoo, UK (aye-aye - *Daubentonia madagascariensis*, black rhinos - *Diceros bicornis*, okapi - *Okapia johnstoni*, and two-toed sloths - *Choloepus didactylus*). The choice of the species was established by the suggestions from the Chester Zoo staff. Their suggestions were based on species that the zoo was more concerned about their welfare regarding the environmental sound and on the enclosures that were considered noisier in the zoo.

3.1.1. Aye-aye (Daubentonia madagascariensis)

The aye-aye is a nocturnal lemur species from Madagascar classified as endangered by the IUCN Red List (Andriaholinirina et al., 2014). It is different from every other lemur species due to its highly specialised dentition, exceptionally large ears, and an elongated middle digit. The last two features are specifically used to detect (by hearing the sound produced by the insects), capture (by "excavating" the trunks and branches), and consume insect prey (Mittermeier et al., 2008). During the foraging, the aye-aye is able to focus several senses (e.g. sight, smell, and hearing) on the activity (Erickson, 1995). It is considered a noise-sensitive species due to the characteristic of using its hearing sense to locate insect larvae inside the trunks and branches of trees.

At Chester Zoo, one male individual, called Raz (Date of Birth (DOB): 23/11/2007), housed in a "night enclosure", that is, with a reversed light cycle, was the subject of the study. The aye-aye's enclosure is fully closed where visitors have viewing access to the animal by glass windows (Figure 1).

Figure 1. Visitors' area of the aye-aye's enclosure at Chester Zoo, UK.

3.1.2. Black rhinos (Diceros bicornis)

According to the IUCN Red List (Emslie, 2012), the black rhino is critically endangered as the wild population has dropped drastically in the past 50 years. In Chester Zoo, the species is part of a conservation project in Kenya and Tanzania, and the specimens kept in the zoo are listed in the European Endangered Species Breeding Programme.

During the study, two females were observed (Female 1: Kitani, DOB: 16/06/1997 and Female 2: Ema Elsa, DOB: 02/11/2002), the second with a male calf (Gabe, DOB: 16/01/2016). The rhinos' indoor enclosure is a paddock where visitors have free-viewing access to the animals and are separated from the rhinos by a fence (Figure 2). The animals have access to an outside area, which was not investigated during this study due to logistic reasons, such as the large size of the area that would require acoustic mapping, the use of more equipment, and installation of video cameras to record the animals' behaviours.

Figure 2. Visitors viewing perspective in the black rhinos' paddock at Chester Zoo, UK.

3.1.3. *Okapi (Okapia johnstoni)*

Okapi are animals from the same family of the giraffes (Giraffidae). They are usually solitary animals, and due to loss and degradation of habitat, the species is considered endangered (Mallon et al., 2015). In Chester Zoo, this species is also part of the European Endangered Species Breeding Programme, and the zoo supports a conservation project in the Democratic Republic of Congo.

One male called Usala (DOB: 30/04/2015) was the object of study. The animal is housed in a paddock enclosure where visitors can observe the animal by windows protected with a stand-off barrier (Figure 3). The animal also has access to an outside area, which was not investigated during this study due to the reasons explained in Section 3.1.2.

Figure 3. Visitors’ area of the okapi’s enclosure at Chester Zoo, UK.

3.1.4. Two-toed sloths (Choloepus didactylus)

The two-toed sloth is a species widely distributed in South America, which leads to its least concern classification in the IUCN Red List (Chiarello and Plese, 2014).

At Chester Zoo, one male called Rico (DOB: 08/08/1999) and one female called Tina (DOB: 02/07/2010) were observed. The sloths are kept in an indoor enclosure with a high ceiling where animals move around using ropes and have access to an area on the floor (Figure 4).

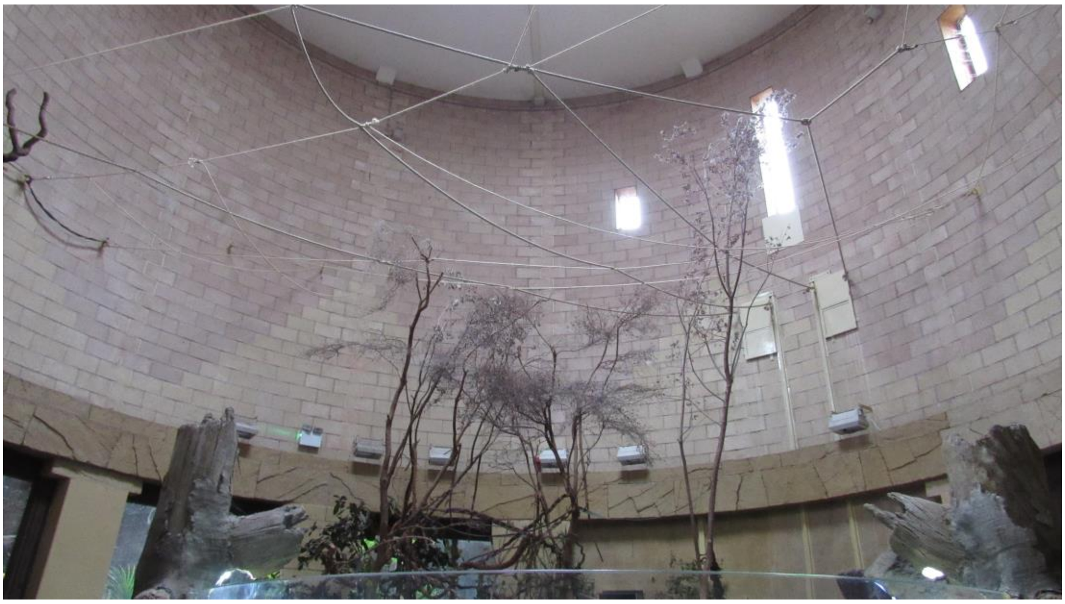


Figure 4. Visitors viewing perspective in the two-toed sloths' area at Chester Zoo, UK.

3.2. Data collection

For all species, data collection occurred in two seasons, high visitor season (from June to September) and low visitor season (from November to February), during five continuous days for each season (always including weekends in the data collection), five hours a day (early morning, late morning, lunchtime, early afternoon, and late afternoon). These resulted in a total of 25 hours of behavioural data per species per season. This design permitted a variability of animal observations, which is expected in animals behaviour studies (Dawkins, 2007), such as different sound conditions throughout the day and different days (week and weekend days).

The behavioural data were recorded using focal or scan sampling method (depending on the number of animals in each enclosure) with instantaneous recording every 30 seconds using a general ethogram previously produced to attend the different species behaviours (Table 11). Visitors that entered the viewing area of the enclosure were counted and recorded cumulatively every ten minutes.

Table 11. General ethogram used to study the responses of mammals to visitor noise at Chester Zoo, UK.

Behaviours	Description
Locomotion	The animal is moving from one location to another.
Feeding-related behaviours	The animal is actively consuming food, drinking water, or foraging.
Grooming	The animal grooms itself using tongue, teeth, mouth, or hands.
Excretion	The animal is eliminating faeces or urine.
Rest	The animal is stationary with eyes open or closed but no movements from head or ears. The animal may be sitting or lying down.
Rest alert	The animal is sitting or lying down with eyes open and alert to surroundings. The animal is directing ears and head in the direction of sounds.
Stand	The animal is standing on all four limbs with eyes open or closed. The animal is not directing ears and head in the direction of sounds.
Stand alert	The animal is standing on all four limbs with eyes open and alert to surroundings, directing ears and head in the direction of sounds.
Interaction	The animal interacts with another individual in the same enclosure.
Abnormal	Repetitive and non-wild type behaviour.
Other	Other behaviours not described in the ethogram.
Non-visible	The animal is not visible, is in the enclosure outside area, or is inside dens.

Sound data were collected using a sound level meter (SLM) (Svantek SVAN 957) and a recorder (Wildlife Acoustics Song Meter SM3) installed inside the animal’s enclosure, which registered the sound perceived by the animals. Both types of equipment measured and recorded the sound during the days of behavioural data collection, 24 hours a day, and the SLM was programmed to register the sound pressure levels using an integration period of 30 seconds. This 30 seconds interval follows the behavioural record and permits a comparison of the expressed behaviour and the sound levels at the moment. The SLM device was calibrated before and after the measurement period using the calibrator included in the SVAN 957 kit.

This specific meter model permits the simultaneous record of numerous acoustic metrics, such as L_{eq}, L_n, in the 1/3 octaves frequency bands, and all required sound level weighting filters (A, C, and Z). This wide range of acoustic metrics was used in the statistical analysis; this allowed the use of a better metric to explain the species' responses to noise. The acoustic recorder was used to identify the source of the noise in case of a single decibel measurement.

For animals that had access to an outside area of the enclosure (rhinos and okapi), the weather was recorded (cloudy, rain, or sunny) during the observation hour and, during the high season, a temperature data logger was used (Testo 174T): one in the indoor enclosure and one in the outside area.

3.3. Statistical analysis

Sound pressure levels data were processed in two different ways. First, for the analysis of the difference between the sound levels when the zoo was open and closed and between the two studied visitors seasons. For this, the sound data was logarithmically averaged per hour ($L_{Aeq,1hour}$, $L_{A10,1hour}$, and $L_{A90,1hour}$). Second, for the analysis of the animal's response to noise, the sound data related to the time of the behavioural observations were logarithmic averaged in blocks of ten minutes to match with the visitor count data ($L_{Aeq,10min}$, $L_{A10,10min}$, $L_{A90,10min}$, $L_{Zeq,10min}$, $L_{Z10,10min}$, and $L_{Z90,10min}$).

The differences between sound pressure levels when the zoo was open and closed and between visitor seasons were verified using a Kruskal-Wallis test, a rank-based nonparametric test (because sound data did not meet the requirements for parametric statistics). The result of this test (expressed as H) indicates how large the discrepancy among the compared ranks is.

Before carrying out the statistical tests, the observed behaviours were grouped due to their high number in the ethogram and to avoid a statistical error during the repetition of tests since each behaviour is analysed separately. Therefore, it was decided to cluster the behaviours in the following categories: Active (Locomotion, Grooming, Excretion, Interaction, Abnormal, and Other), Inactive (Stand and Rest), Feed, Alert (Stand alert and Rest alert), and Non-visible (Non-visible for the aye-aye, Animal in the outside area, for okapi and rhinos; Animal inside the den, for the sloths). Behaviours were summed in blocks of ten minutes to match with the visitor count data.

The behavioural data presented a non-normal distribution, because of this, the relationship between the behaviours and other variables, such as sound pressure levels, number of visitors, individual (when there was more than an animal being observed), and weather (when animals had access to an outside area) were investigated using a generalised linear model (GLM) with a Poisson distribution (Zuur et al., 2009). The Poisson distribution is used for count data and assumes the logarithm of its expected value following the equation $Y = e\^(\beta_0 + \beta_1 X)$. In practical terms, when the explanatory variable (X) increases by a unit of 1, the mean of the response variable (Y) is multiplied by the exponential of β_1 (Zuur et al., 2009).

For each GLM model, behaviours were used as the response variable and the other variables were used as explanatory variables. In cases when the sound pressure levels and the number of visitors presented high correlation factor (as tested by Pearson’s correlation), only SPL was used in the model to avoid multicollinearity (Allen, 1997, Zuur et al., 2009). In addition, to decide which acoustic metrics (L_{Aeq}, L_{A10}, L_{A90}, L_{Zeq}, L_{Z10}, and L_{Z90}; see Section 2 for definition of these metrics) would be used in the model as the sound pressure level explanatory variable, a correlation matrix was constructed and the acoustic metric that had the highest correlation factor for each behaviour was used in the model.

Prior to the final analysis, the GLM models were selected considering overdispersion and the relevance of the variables to the test with the aim of finding the optimal model. When an overdispersion of data was detected, the standard errors were corrected using a quasi-GLM model. Following this, when some terms were not significant a selection criterion was made using the command “drop1“ (in RStudio), which drops one explanatory variable, in turn, and each time applies an analysis of deviance test (Zuur et al., 2009).

All analyses were conducted in RStudio (RStudio Team, 2016).

3.4. Results

General sound pressure levels

The four enclosures studied present different patterns of environmental sounds and sound sources that dominated the sonic environment.

The aye-aye’s enclosure was generally louder during the low season compared to the high season (L_{Aeq}: H=78.12, $p<0.000$). During the low season, there was no difference in sound pressure levels when the zoo was open or closed (L_{Aeq}: H=0.60, $p=0.437$; L_{A10}: H=0.13, $p=0.717$; L_{A90}: H=1.61, $p=0.204$). During the high season there was no difference in the background noise when the zoo was open or closed (L_{A90}: H=2.43, $p=0.119$); however, the zoo tended to be louder when open than when closed (L_{Aeq}: H=3.93, $p=0.048$; L_{A10}: H=4.63, $p=0.031$) (Figure 5). The correlation coefficients between the number of visitors and the acoustic metrics were low (below 0.2) in both seasons.

Figures 6 and 7 show that ventilation and heating system dominated the soundscape of the aye-aye enclosure, specifically, during low season when the heating system was on during the whole day. This explains the small amplitude range of the sound in this season of about 9.1 dB when the zoo was open and 13.9 dB when the zoo was closed (Figure 5 and 7). During the high season, the ventilation system was on most of the time, both day and night, but other kinds of sounds were also perceived, such as public conversation and birds singing in the early morning (Figure 6). The amplitude range was found to be high when the zoo was closed (30.8 dB) and moderate when the zoo was open (17.6 dB).

There was no difference in the sound pressure levels of the black rhino's enclosure between seasons (L_{Aeq}: H=0.17, p=0.679). In both seasons, there was no difference in the background noise (L_{A90}) when the zoo was open or closed (High season: H=0.01, p=0.942; Low season: H=0.18, p=0.674). However, the equivalent noise levels (L_{Aeq}) were higher when the zoo was open (High season: H=53.17, p<0.000; Low season: H=33.48, p<0.000) and higher amplitudes of the sound, represented by L_{A10}, were registered more frequently when the zoo was open (High season: H=50.51, p<0.000; Low season: H=40.64, p<0.000) (Figure 8). The correlation coefficient between the number of visitors and the background noise (L_{A90}) was low (0.31) during low season and moderate during high season (0.53). The number of visitors and the other two metrics (L_{Aeq} and L_{A10}) have a moderate correlation in low (0.53) and high (0.67) season.

As per the aye-aye's enclosure, the rhinos' paddock soundscape was dominated by ventilation and heating systems (Figure 9 and 10). During the high season, the ventilation system was on all day, which reflected in a small to moderate amplitude range of the sound (13.1 dB closed zoo and 19.8 dB open zoo). Due to the arrangements of the enclosure, where the visitors and animals are not isolated (i.e. no glass barrier), the visitors' conversation was louder during the time the zoo was open, compared to the aye-aye enclosure. During the low season, the heating system was not on the whole day, which caused higher amplitude range of the sound compared to high season (67.6 dB closed zoo and 41.3 dB open zoo). Sounds coming from the public was also perceived, and it is interesting to see in Figure 10 that public conversation was considerably louder when the heating system was on compared to when it was off.

The okapi enclosure was generally louder during the low season compared to the high season (L_{Aeq}: H=22.97, $p<0.000$). With an exception of the background noise during low season, when there was no difference in the sound levels during open and closed times at the zoo (L_{A90}: H=3.12, p=0.078), the enclosure was noisier when the zoo was open compared to closed in both seasons (High season: L_{Aeq}: H=27.95, $p<0.000$; L_{A10}: H=34.72, $p<0.000$; L_{A90}: H=5.85, $p=0.0156$ - Low season: L_{Aeq}: H=38.43, $p<0.000$; L_{A10}: H=41.79, $p<0.000$) (Figure 11). The number of visitors had a low correlation with the background noise in low (0.49) and high (0.44) seasons, and a moderate correlation (0.7) with the other metrics (L_{Aeq} and L_{A10}) in both seasons.

Figures 12 and 13 show that the soundscape in the okapi enclosure was dominated by the ventilation and heating system when the zoo was closed and by the public conversation when the zoo was open (i.e. no glass barrier). Amplitude ranges were considerably higher in both seasons and when the zoo was open or closed: a mean of 33.4 dB.

The sloths' area presented higher sound pressure levels during the high season (L_{Aeq}: H=7.01, $p<0.009$). In both seasons, the zoo was louder when open compared to when closed independent of the acoustic metrics used for the analysis (High season: L_{Aeq}: H=67.75, $p<0.000$; L_{A10}: H=68.09, $p<0.000$; L_{A90}: H=68.77, $p<0.000$ - Low season: L_{Aeq}: H=63.69, $p<0.000$; L_{A10}: H=63.69, $p<0.000$; L_{A90}: H=63.69, $p<0.000$) (Figure 14). All acoustic metrics were strongly correlated with the number of visitors in both seasons (values between 0.72 and 0.87).

The sloths' enclosure was the only studied area where the sound from ventilation or heating systems was not perceived. In both seasons, when the zoo was open, the soundscape was dominated by the public conversation and by an educational video recording that plays in a room next to the sloths' area. As can be seen in Figures 15 and 16, the amplitude range was higher when the zoo was open during high season (42.3 dB) compared to the low season (33.6 dB).

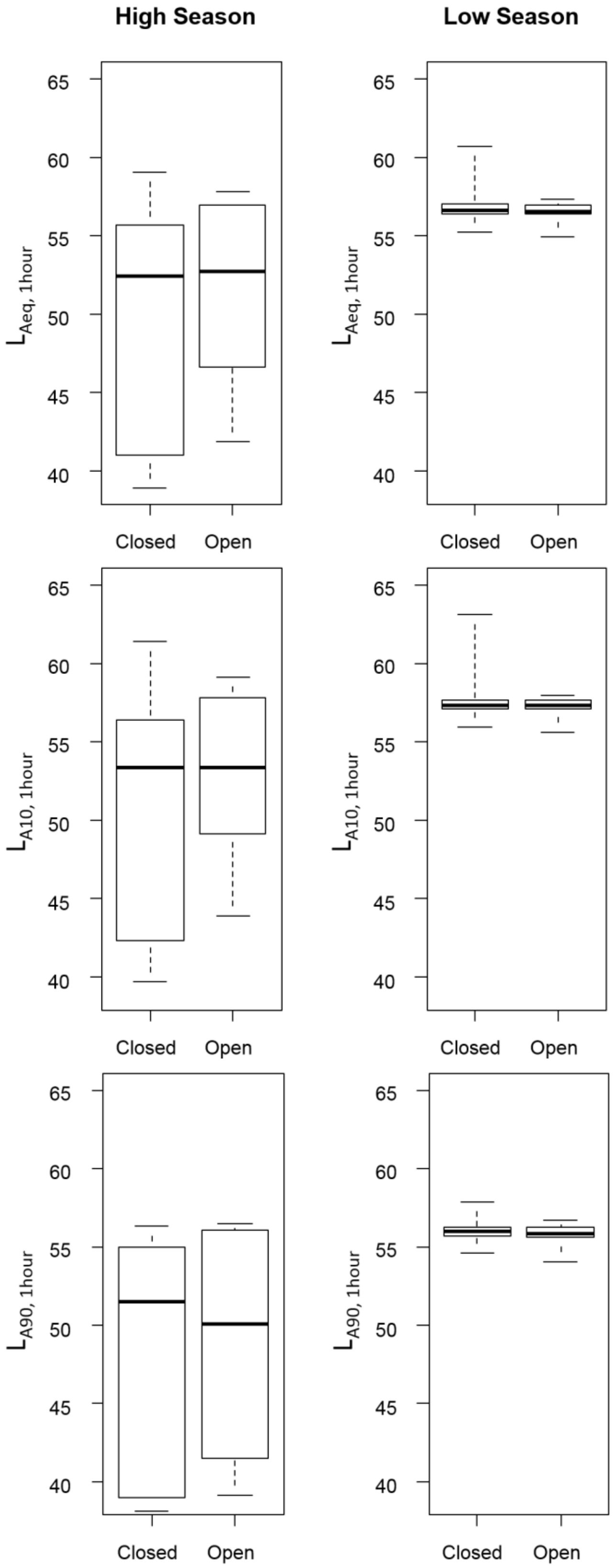


Figure 5. Sound pressure levels ($L_{Aeq,1hour}$, $L_{A10,1hour}$, and $L_{A90,1hour}$) in the aye-aye's enclosure. Comparisons between high and low seasons and times when Chester Zoo, UK, is open and closed to the public. High season public opening times: from 10:00 to 17:00. Low season public opening times: from 10:00 to 16:00.

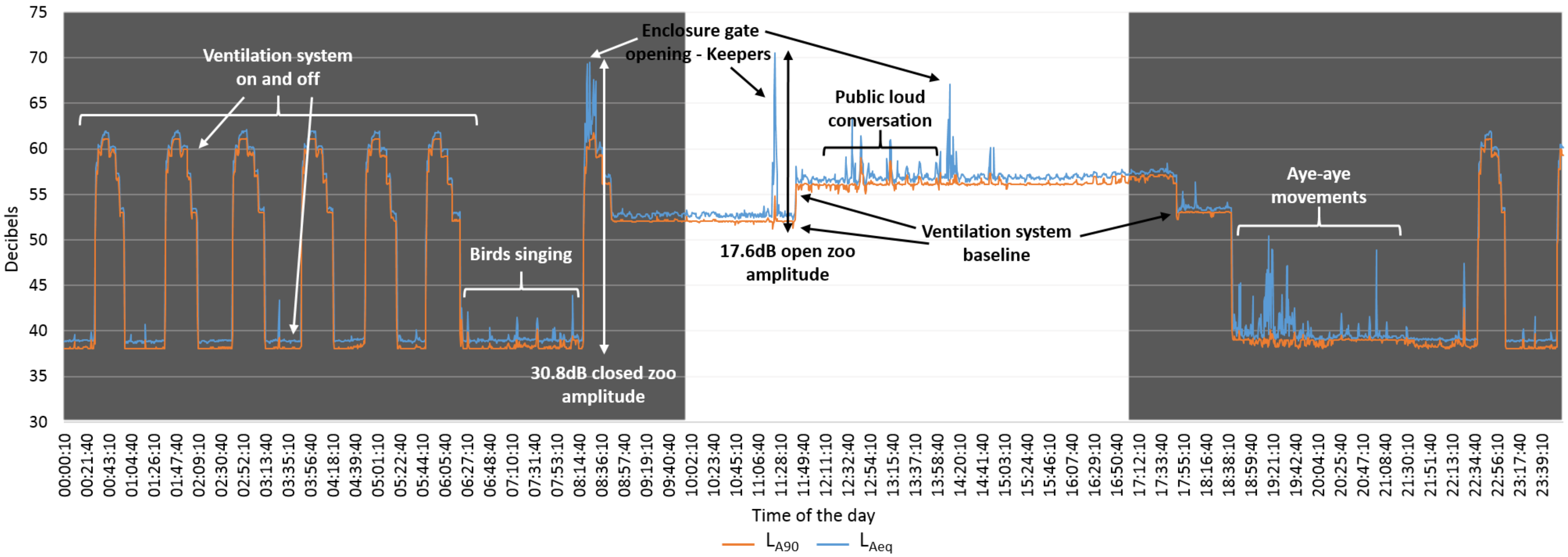


Figure 6. Aye-aye's enclosure sound pressure levels on the busiest visitor day during the high season data collection at Chester Zoo, UK. Hours when the zoo was open to the public are represented in white background (from 10:00 to 17:00) and hours when the zoo was closed to the public are represented in grey background. Average equivalent sound levels (L_{Aeq}): for the day 55.3 dB, open zoo 56.9 dB, closed zoo 54.6 dB.

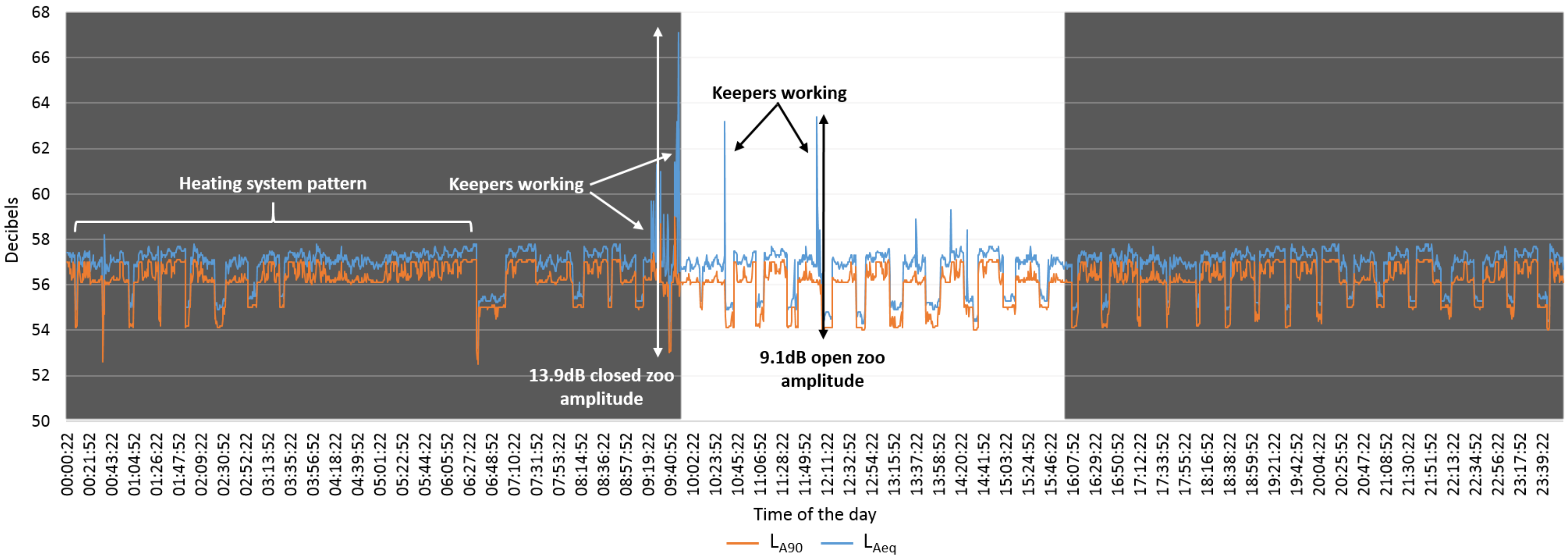


Figure 7. Aye-aye's enclosure sound pressure levels on the busiest visitor day during the low season data collection at Chester Zoo, UK. Hours when the zoo was open to the public are represented in white background (from 10:00 to 16:00) and hours when the zoo was closed to the public are represented in grey background. Average equivalent sound levels (L_{Aeq}): for the day 56.9 dB, open zoo 56.7 dB, closed zoo 56.9 dB.

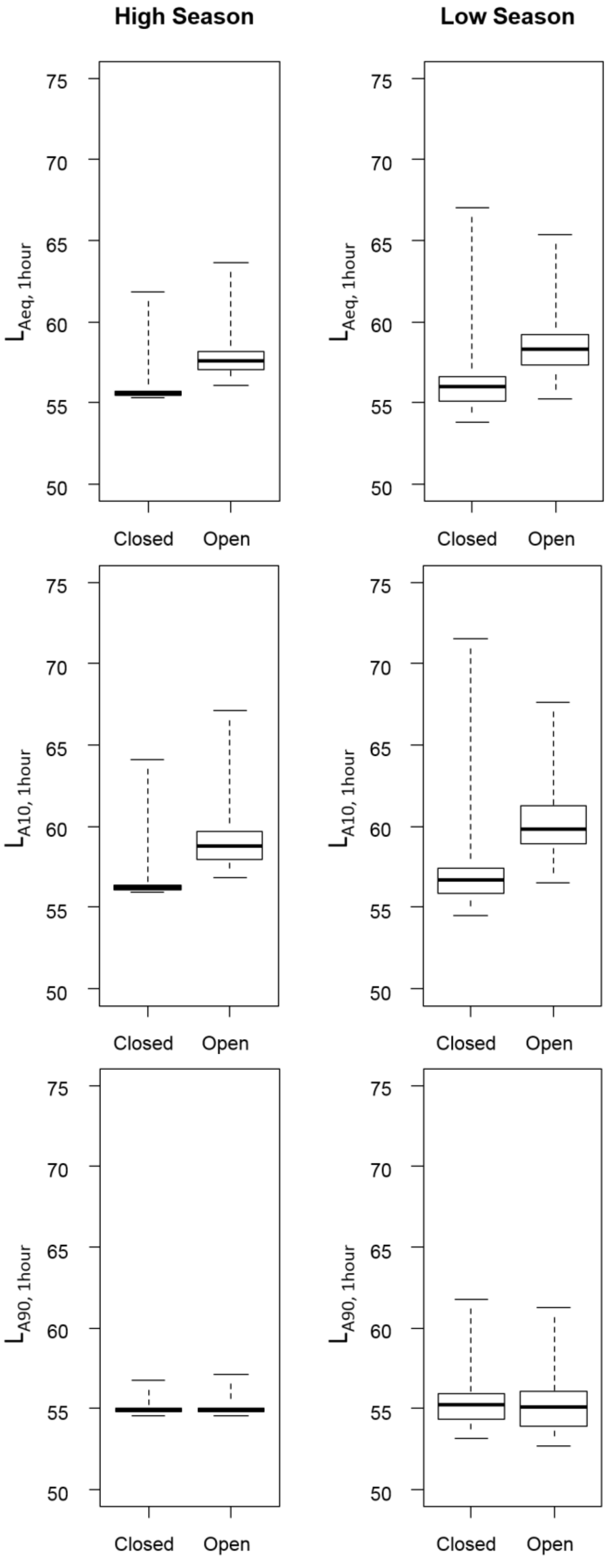


Figure 8. Sound pressure levels ($L_{Aeq,1hour}$, $L_{A10,1hour}$, and $L_{A90,1hour}$) in the black rhinos' enclosure. Comparisons between high and low seasons and times when Chester Zoo, UK, is open and closed to the public. High season public opening times: from 10:00 to 18:00. Low season public opening times: from 10:00 to 16:00.

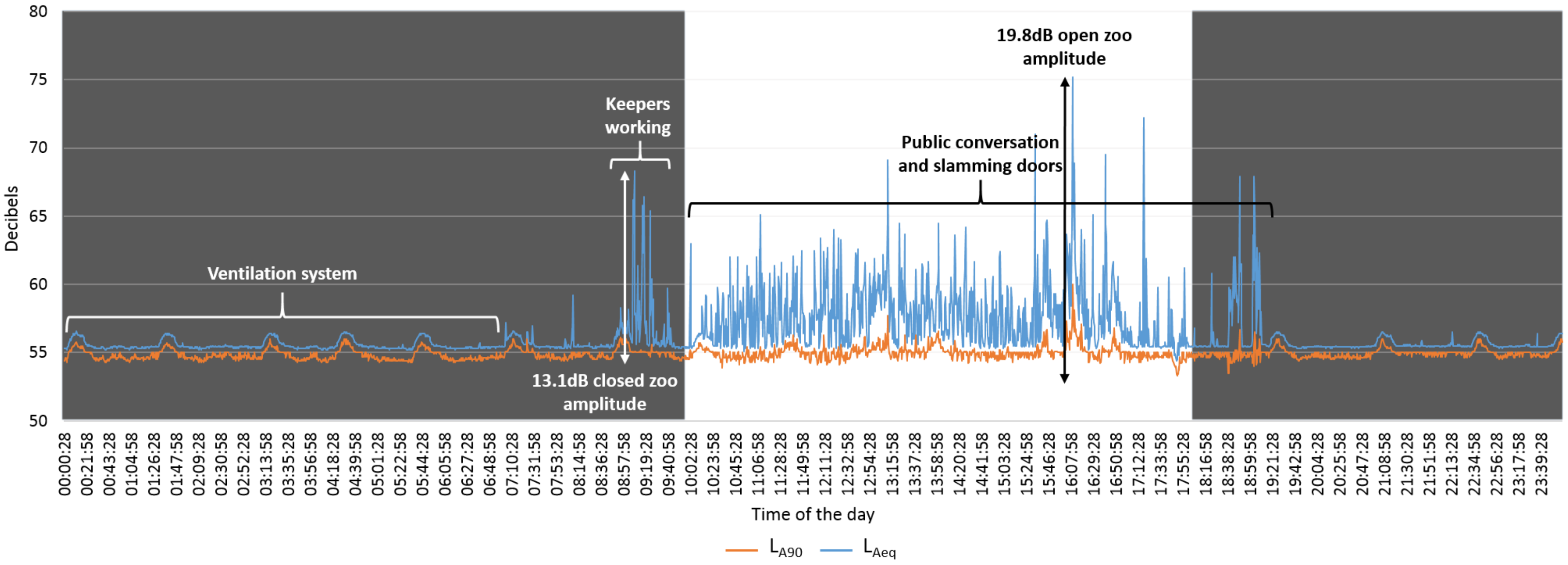


Figure 9. Black rhinos' enclosure sound pressure levels on the busiest visitor day during the high season data collection at Chester Zoo, UK. Hours when the zoo was open to the public are represented in white background (from 10:00 to 18:00) and hours when the zoo was closed to the public are represented in grey background. Average equivalent sound levels (L_{Aeq}): for the day 57.2 dB, open zoo 58.8 dB, closed zoo 56.1 dB.

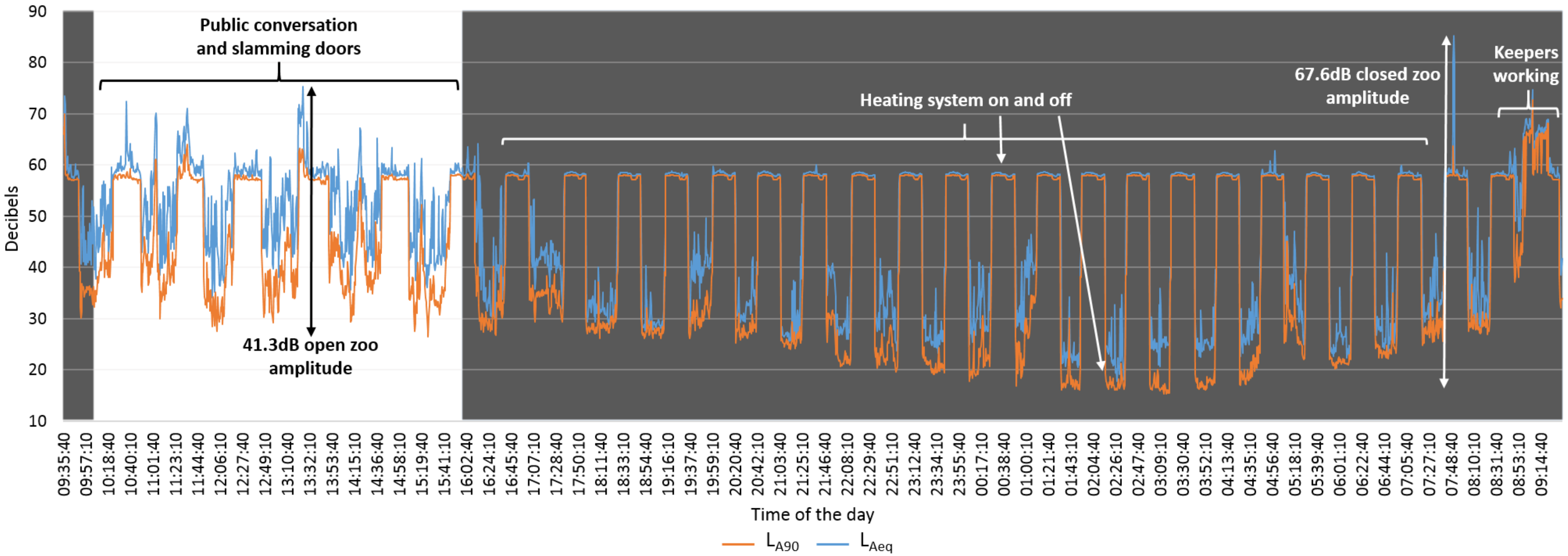


Figure 10. Black rhinos' enclosure sound pressure levels on the busiest visitor day during the low season data collection at Chester Zoo, UK. Hours when the zoo was open to the public are represented in white background (from 10:00 to 16:00) and hours when the zoo was closed to the public are represented in grey background. Average equivalent sound levels (L_{Aeq}): for the day 59.0 dB, open zoo 59.2 dB, closed zoo 58.9 dB.

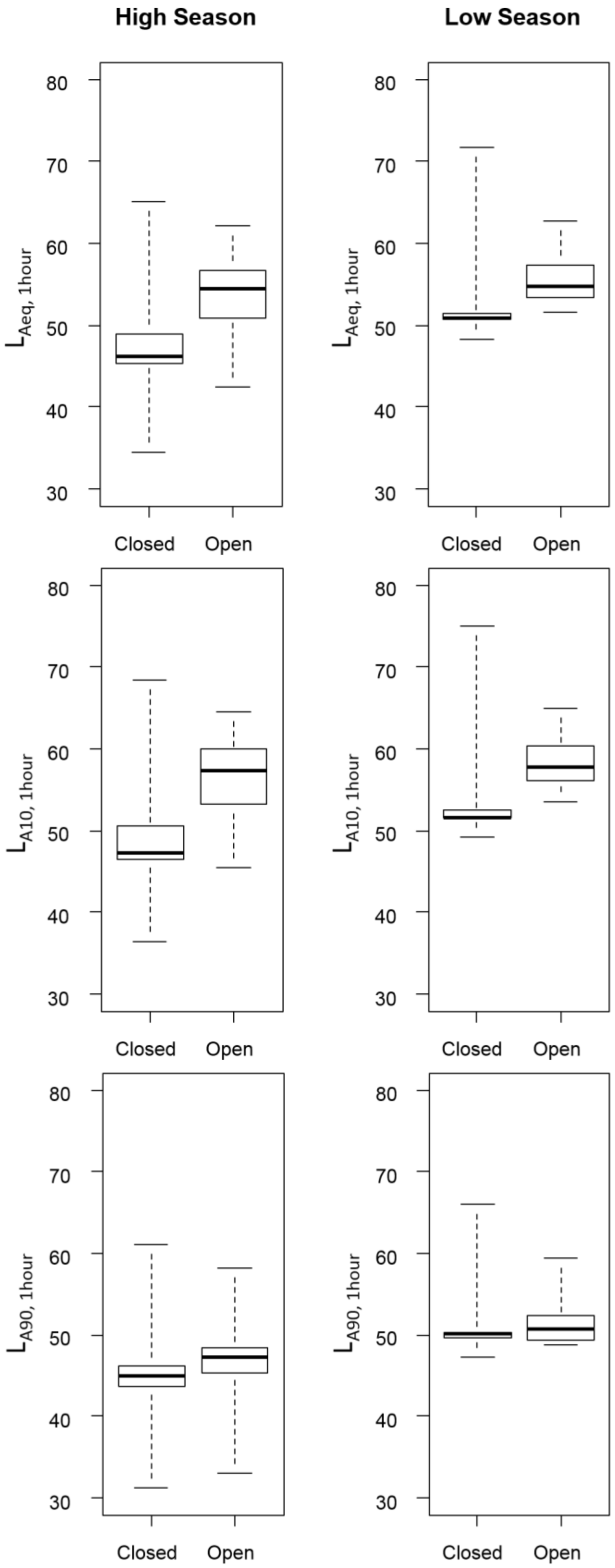


Figure 11. Sound pressure levels ($L_{Aeq,1hour}$, $L_{A10,1hour}$, and $L_{A90,1hour}$) in the okapi's enclosure. Comparisons between high and low seasons and times when Chester Zoo, UK, is open and closed to the public. High season public opening times: from 10:00 to 17:00. Low season public opening times: from 10:00 to 16:00.

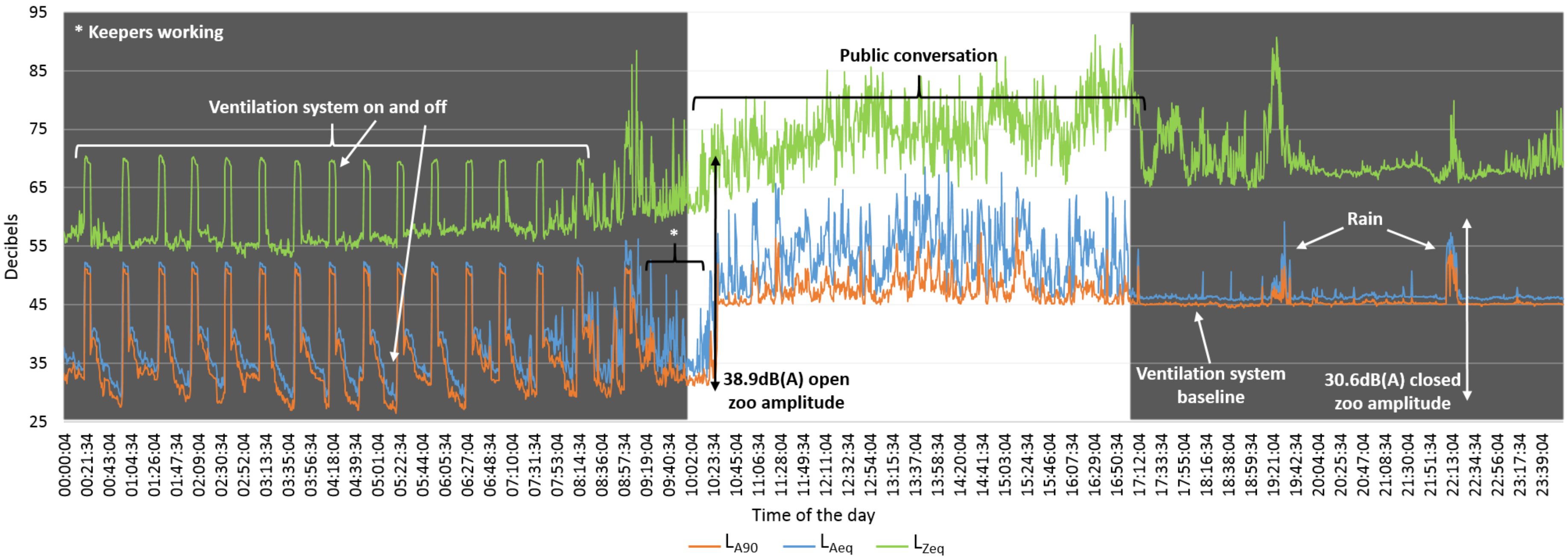


Figure 12. Okapi's enclosure sound pressure levels on the busiest visitor day during the high season data collection at Chester Zoo, UK. Hours when the zoo was open to the public are represented in white background (from 10:00 to 17:00) and hours when the zoo was closed to the public are represented in grey background. Average equivalent sound levels (L_{Aeq}): for the day 52.1 dB, open zoo 56.6 dB, closed zoo 46.0 dB.

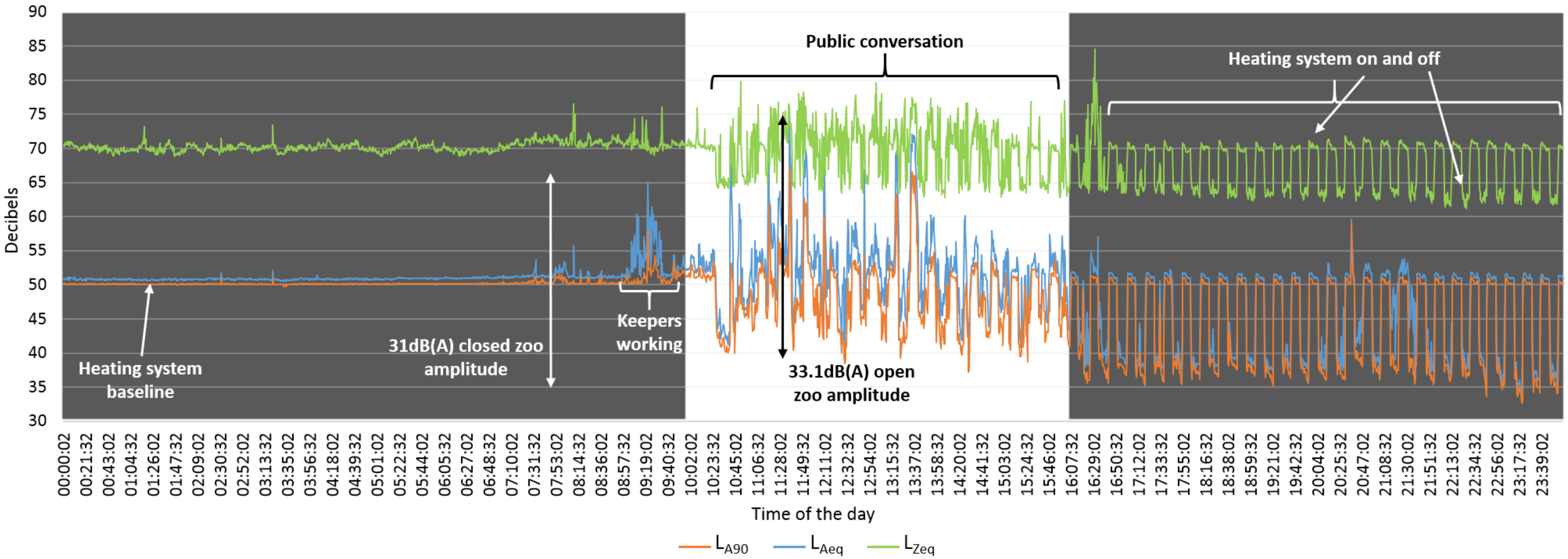


Figure 13. Okapi's enclosure sound pressure levels on the busiest visitor day during the low season data collection at Chester Zoo, UK. Hours when the zoo was open to the public are represented in white background (from 10:00 to 16:00) and hours when the zoo was closed to the public are represented in grey background. Average equivalent sound levels (L_{Aeq}): for the day 53.9 dB, open zoo 58.1 dB, closed zoo 50.6 dB.

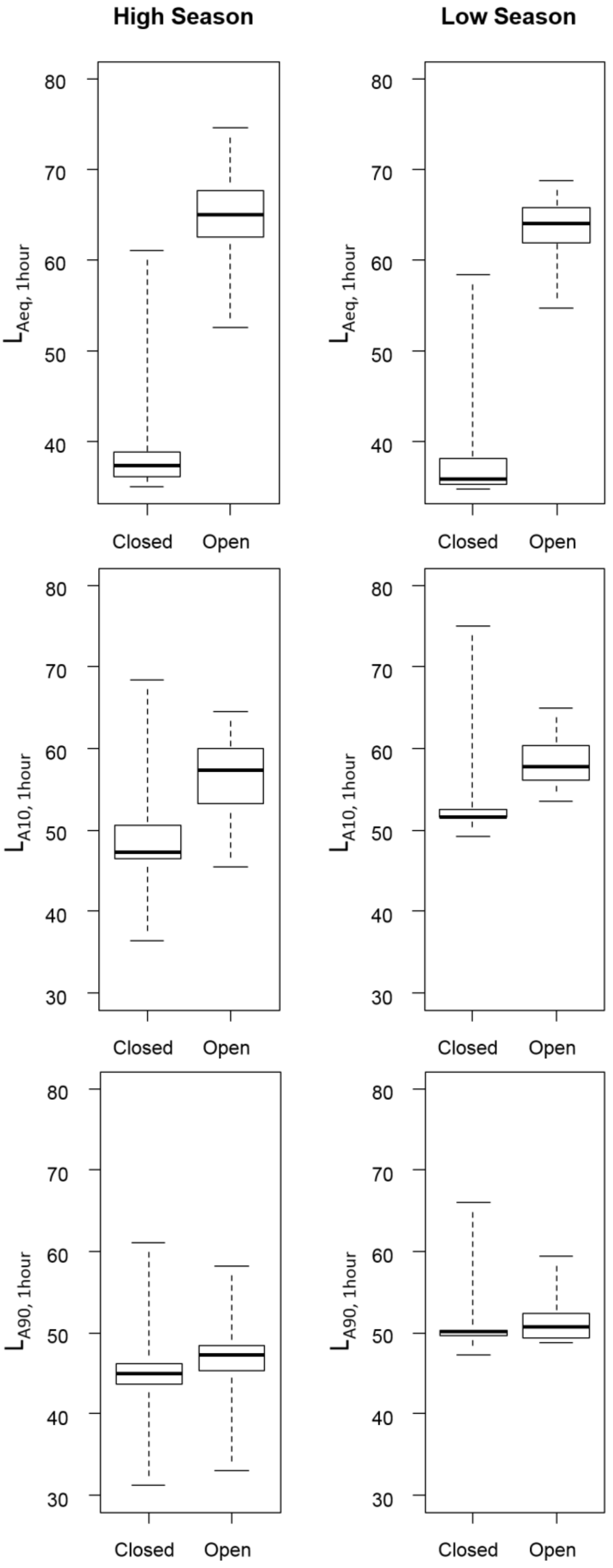


Figure 14. Sound pressure levels ($L_{Aeq,1hour}$, $L_{A10,1hour}$, and $L_{A90,1hour}$) in the two-toed sloths' enclosure. Comparisons between high and low seasons and times when Chester Zoo, UK, is open and closed to the public. High season public opening times: from 10:00 to 18:00. Low season public opening times: from 10:00 to 16:00.

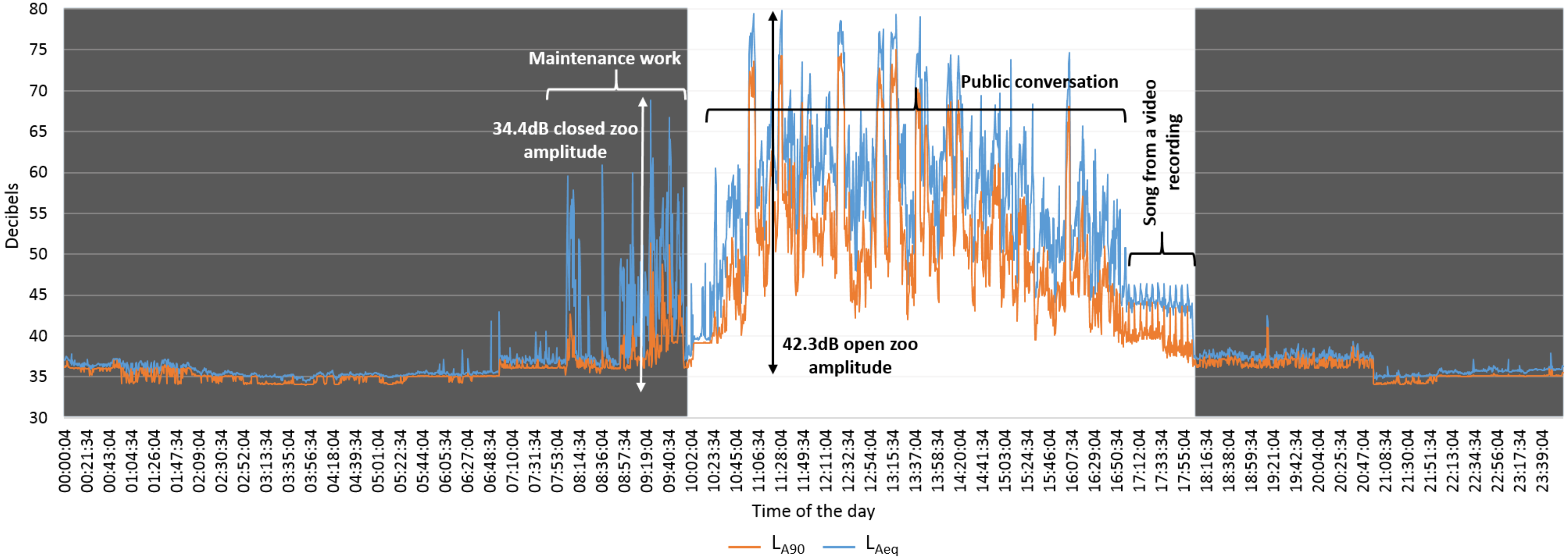


Figure 15. Two-toed sloths' enclosure sound pressure levels on the busiest visitor day during the high season data collection at Chester Zoo, UK. Hours when the zoo was open to the public are represented in white background (from 10:00 to 18:00) and hours when the zoo was closed to the public are represented in grey background. Average equivalent sound levels (L_{Aeq}): for the day 61.6 dB, open zoo 66.9 dB, closed zoo 43.8 dB.

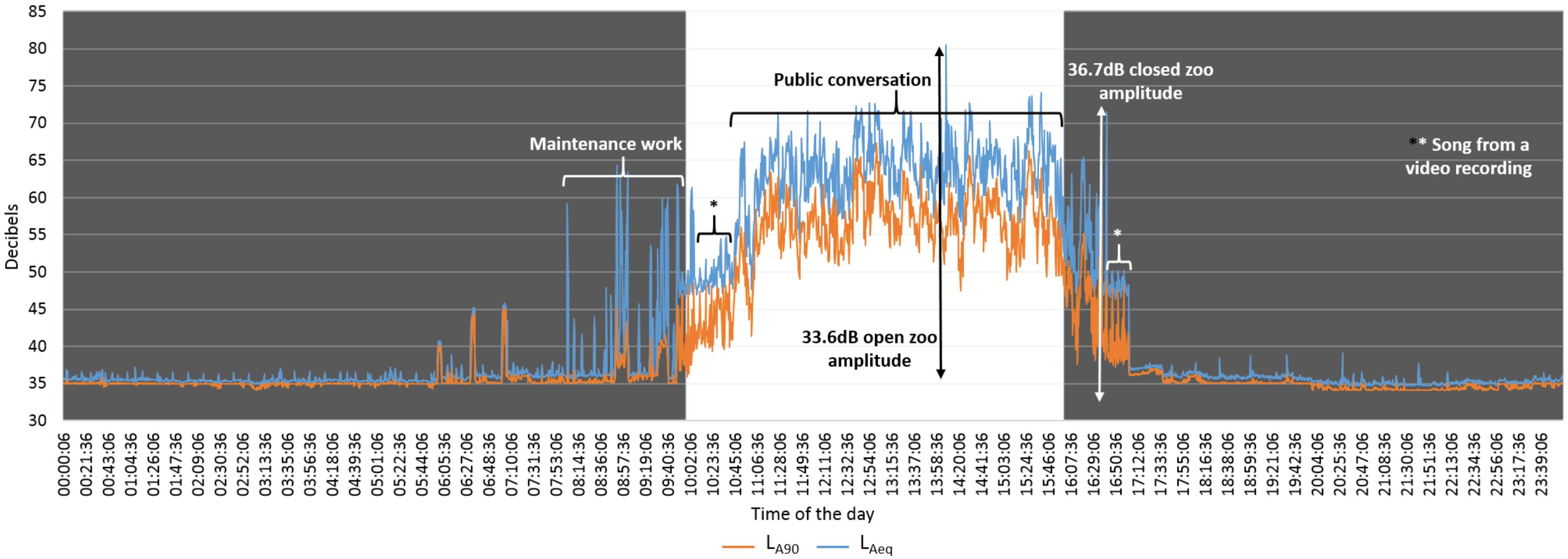


Figure 16. Two-toed sloths' enclosure sound pressure levels on the busiest visitor day during the low season data collection at Chester Zoo, UK. Hours when the zoo was open to the public are represented in white background (from 10:00 to 16:00) and hours when the zoo was closed to the public are represented in grey background. Average equivalent sound levels (L_{Aeq}): for the day 59.3 dB, open zoo 65.1 dB, closed zoo 46.5 dB.

3.4.1. Aye-aye

The data in Table 12 indicates that the aye-aye's behaviour was only affected by visitor presence and not by noise. Some behaviours during high and low season were slightly influenced by the presence of visitors. In general, the behaviours listed in Table 12 were altered around 1% of their frequency per visitor (Exponential coefficient column in Table 12). This means that, in the case of this animal, only a group of numerous visitors could cause a perceivable change in behaviour, such as making the animal hide more, and be less active during high season, or be more inactive and feed more in the low season (Figures 17 and 18).

Table 12. GLM results for the optimal models describing the relationship between the aye-aye's behaviours and the independent variable (visitors count) during high and low seasons in Chester Zoo, UK.

Season	Behaviour	Independent variable	Estimate coefficient[1] (±SE)	Exponential coefficients[2]	t values[3]
High	Active	Visitors	-0.003894(±0.001507)	0.9961136	-2.583*
	Non-visible	Visitors	0.009553(±0.003636)	1.009599	2.627*
Low	Active	Visitors	-0.007673(±0.002500)	0.9923564	-3.069**
	Inactive	Visitors	0.023136(±0.008276)	1.023406	2.796**
	Feed	Visitors	0.010477(±0.003152)	1.010532	3.324**

[1] Model results for each variable. [2] Results exponentially transformed according to Poisson regression equation. [3]. Standard deviations distance from the mean (z values from GLM Poisson and t values for quasi-GLM Poisson). * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

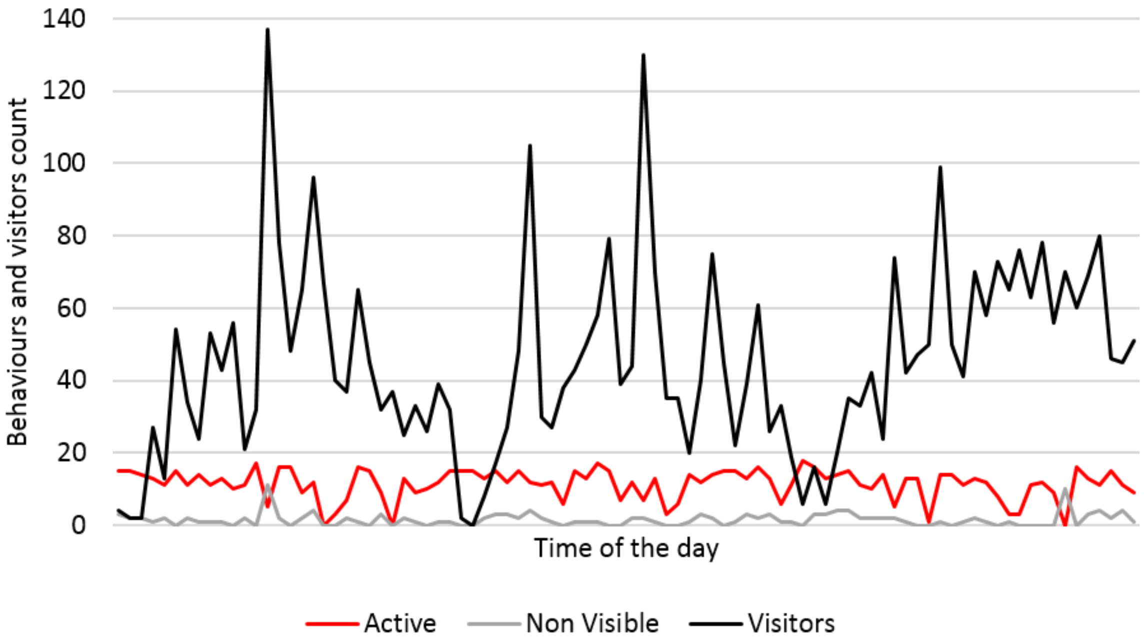


Figure 17. Aye aye's behaviours and visitors count during high season data collection at Chester Zoo, UK.

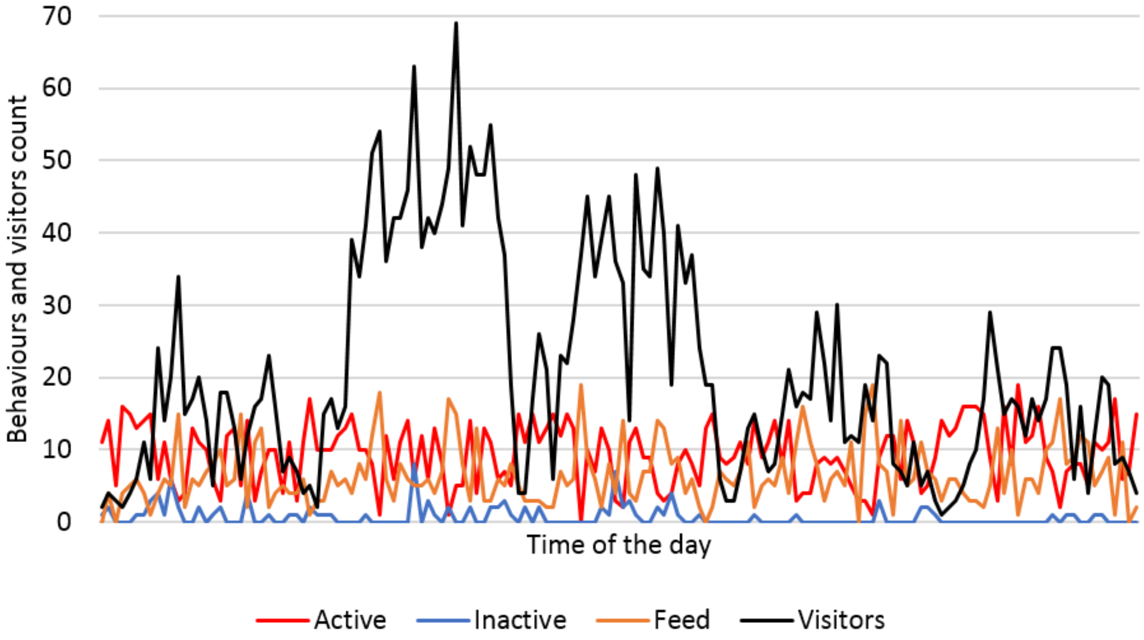


Figure 18. Aye aye's behaviours and visitors count during low season data collection at Chester Zoo, UK.

3.4.2. Black rhinos

The black rhinos stayed in the outside area of their enclosure during the whole time of the high season observations, consequently, the behavioural responses are only from low season observations (Table 13 and Figure 19). In this case, the different individuals in the enclosure were used as an independent variable, as well as the weather when analysing the "animal in the outside area" behaviour category.

Equivalent sound levels negatively impacted inactive behaviour of all individuals. Animals decreased in around 4% the expression of inactive behaviour per increase of one decibel (Exponential coefficient column in Table 13).

Even though significantly different, feed related behaviours were only slightly influenced by visitors' presence.

Animals were less alert with more visitors inside the paddock and more alert in situations of high equivalent sound levels. Furthermore, alert behaviour presented different responses to equivalent sound levels depending on the individual (Figure 20). Female 1 was the most alert individual due to an increase in the sound pressure levels, followed by Female 2.

The rhinos spent more time in the outside area when the background sound levels were high in the paddock. An increase of one decibel in the background sound increased by 2% the chance of an individual being outside. There was also an influence of the weather in the preference for the outside area: sunny weather was preferred for being outside.

Inherent individual differences in inactive and feed behaviours expression can be visualised in Table 13.

Table 13. GLM results for the optimal models describing the relationship between black rhinos' behaviours and the independent variables ($L_{Aeq,10min}$, $L_{A90,10min}$, visitors count, individual, and weather) during low season in Chester Zoo, UK.

Season	Behaviour	Independent variables	Estimate coefficient[1] (±SE)	Exponential coefficients[2]	t values[3]
Low	Inactive	L_{Aeq}	-0.03280(±0.01178)	0.9677321	-2.785**
		Male calf	0.39296(±0.13724)	1.481359	2.863**
		Female 2	-0.03799(±0.15140)	---	-0.251
	Feed	Visitors	0.005599(±0.001942)	1.005615	2.883**
		Male calf	-0.364582(±0.128258)	0.6944869	-2.843**
		Female 2	0.087203(±0.113671)	---	0.767
	Alert	Visitors	-0.011898(±0.005779	0.9881725	-2.059*
		L_{Aeq}	0.120936(±0.038882)	---	3.110
		Male calf	7.084890(±2.904960)	---	2.439
		Female 2	2.513562(±3.583715)	---	0.701
		L_{Aeq}*Male calf	-0.127846(±0.050351)	0.8799889	-2.539*
		L_{Aeq}* Female 2	-0.057263(±0.061557)	---	-0.930
	Animal outside	L_{A90}	0.02849(±0.01264)	1.0289	2.253*
		Cloudy weather	-0.34582(±0.19117)	---	-1.809
		Rainy weather	-1.88707(±0.61301)	0.1515151	-3.078**

[1] Model results for each variable. [2] Results exponentially transformed according to Poisson regression equation. [3]. Standard deviations distance from the mean (z values from GLM Poisson and t values for quasi-GLM Poisson). * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

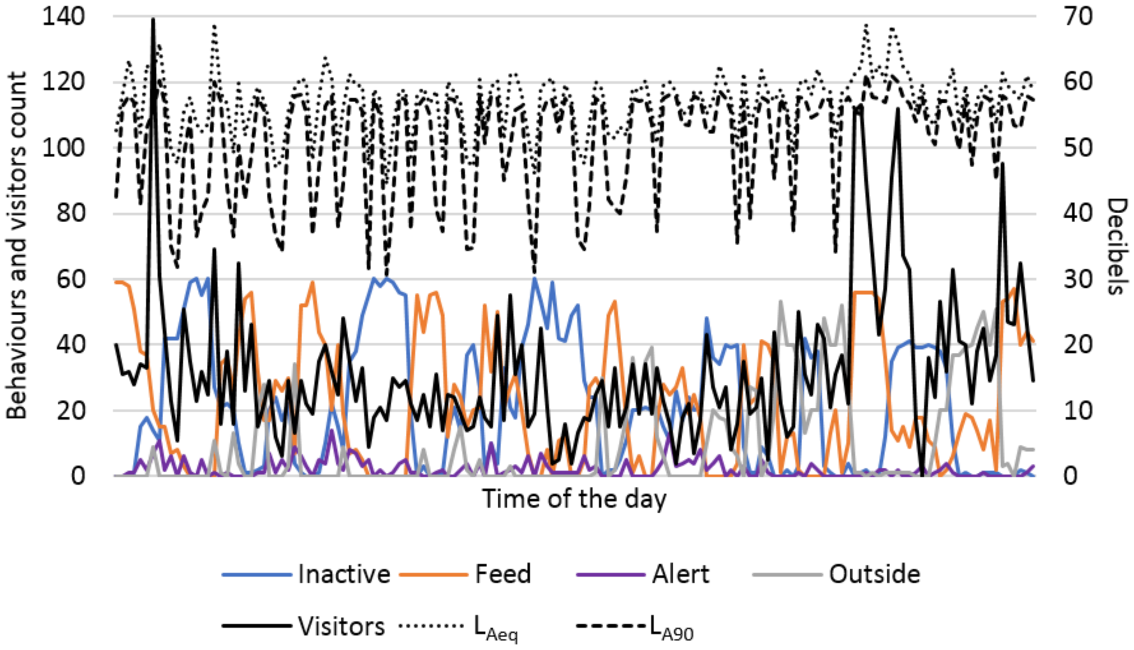


Figure 19. Black rhinos' behaviours and visitor count, and decibels levels ($L_{Aeq,10min}$ and $L_{A90,10min}$) during the low season data collection at Chester Zoo, UK.

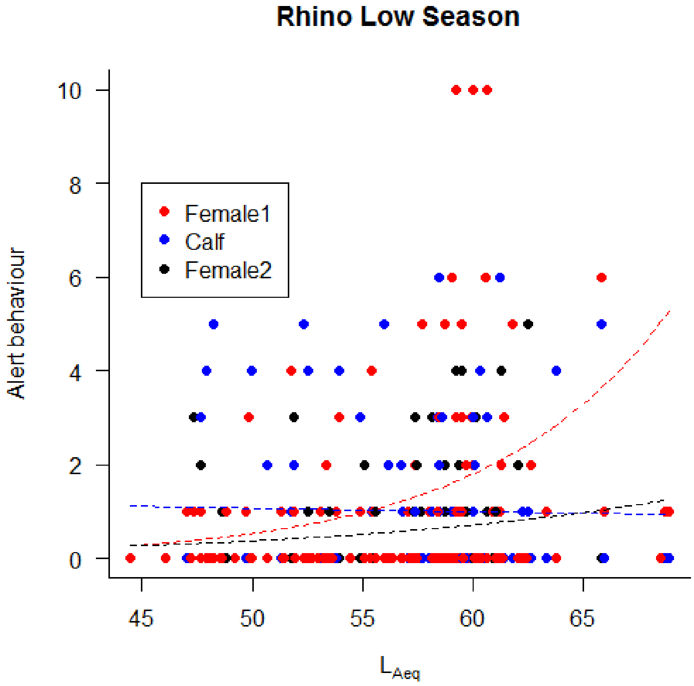


Figure 20. Black rhinos' alert behaviour response to $L_{Aeq,10min}$ by individual, during low season in Chester Zoo, UK. Trend curves based on GLM result: Female 1 – Alert behaviour = e^(-6.669857+0.120936*L_{Aeq}); Calf – Alert behaviour = e^(0.415033-0.00691*L_{Aeq}); Female 2 – Alert behaviour = e^(-4.156295+0.063673*L_{Aeq}).

3.4.3. Okapi

Differently, from previous species, the okapi stronger responses were found according to equivalent sound levels with flat frequency weighting (Z) (Table 14 and Figures 21 and 22). Number of visitors had a low correlation coefficient with the Z-weighting metrics, so both variables were included in the GLM models, in addition to the weather conditions for "animal in the outside" behaviour.

In the high season, all behaviour categories were affected by equivalent sound levels. Active, inactive, feed, and alert behaviours presented a frequency decrease in response to the increase in the level of decibels. On the contrary, the okapi preferred to stay more time outside when the sound levels were high. Interestingly, the effect of visitors, when it happened, was the opposite of the noise effect: the animal was more active, more alert, and spent less time outside in the presence of visitors. In addition, visitors' impact (around 1%

per visitor increase) was lower than the sound levels impact (around 11% per dB). Regarding the weather, the okapi spent more time outside when it was sunny.

During the low season, active, feed, and alert behaviours were affected by equivalent sound levels. Different from what was found before, the okapi was more active and more alert and fed less with increasing sound pressure levels. Active behaviour was also slightly and negatively impacted by visitor presence.

Table 14. GLM results for the optimal models describing the relationship between the okapi's behaviours and the independent variables ($L_{Zeq,10min}$, visitors, and weather), during high and low seasons in Chester Zoo, UK.

Season	Behaviour	Independent variables	Estimate coefficient[1] (±SE)	Exponential coefficients[2]	z or t values[3]
High	Active	Visitors	0.019263(±0.003186)	1.01945	6.047^{t}***
		L_{Zeq}	-0.114574(±0.025034)	0.8917459	-4.577^{t}***
	Inactive	L_{Zeq}	-0.17389(±0.03507)	0.8403893	-4.959^{t}***
	Feed	L_{Zeq}	-0.05018(±0.02432)	0.9510582	-2.063^{t}*
	Alert	Visitors	0.013404(±0.003991)	1.013494	3.358^{z}***
		L_{Zeq}	-0.116944(±0.028804)	0.889635	-4.060^{z}***
	Animal outside	Visitors	-0.014055(±0.005127)	0.9860433	-2.742^{t}**
		L_{Zeq}	0.122480(±0.019594)	1.130297	6.251^{t}***
		Cloudy weather	-1.514899(±0.357925)	0.2198304	-4.232^{t}***
		Rain weather	-1.767899(±0.412461)	0.1706912	-4.286^{t}***
Low	Active	Visitors	-0.022786(±0.006761)	0.9774716	-3.370^{t}***
		L_{Zeq}	0.292725(±0.051002)	1.340074	5.740^{t}***
	Feed	L_{Zeq}	-0.08575(±0.03986)	0.9178237	-2.151^{t}*
	Alert	L_{Zeq}	0.3960(±0.1519)	1.485869	2.607^{t}**

[1] Model results for each variable. [2] Results exponentially transformed according to Poisson regression equation. [3]. Standard deviations distance from the mean (z values from GLM Poisson and t values for quasi-GLM Poisson). * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

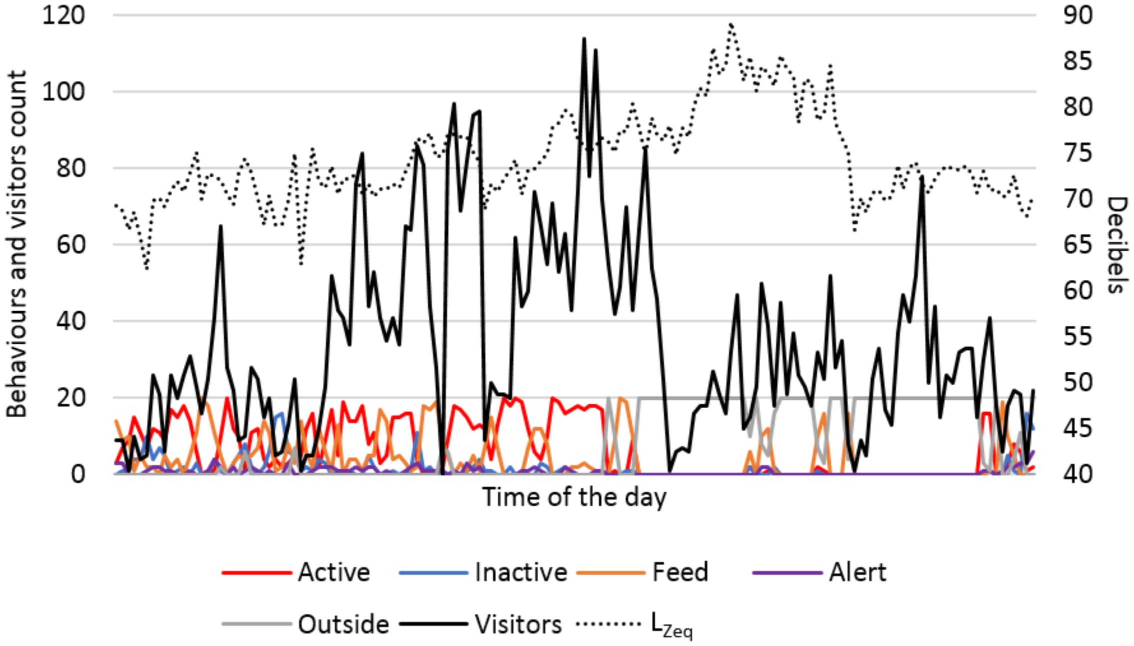


Figure 21. Okapi's behaviours and visitor count, and decibels levels ($L_{Zeq,10min}$) during the high season data collection at Chester Zoo, UK.

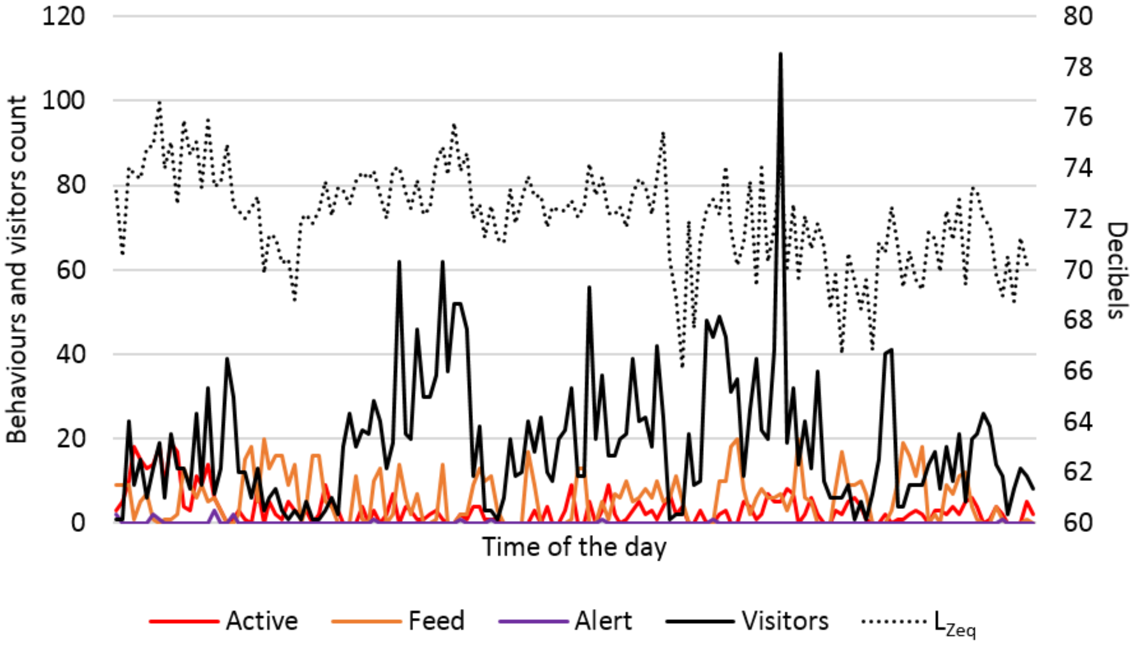


Figure 22. Okapi's behaviours and visitor count, and decibels levels ($L_{Zeq,10min}$) during the low season data collection at Chester Zoo, UK.

3.4.4. Two-toed sloths

In the analysis of the sloths' behaviour, visitor number was not included in the models because of its high correlation with SPL. Active, inactive, and alert behaviour were expressed differently between individuals during high season according to the equivalent sound levels. An increase in the sound pressure levels resulted in a more active and more alert male in comparison to the female response (Figures 23 and 25). In a response to an increase in the noise levels, inactive behaviour decreased for both animals; however, the male response was less strong than the female's response (Figure 24). Animals did not use the den in response to noise, but the female used it more frequently than the male.

During low season, the male was more active than the female, regardless of the analysed variable. The female sloth presented a decrease in the expression of inactive and alert behaviours in high equivalent sound levels, compared to the male sloth (Figure 26 and 27). This possibly reflected the female's strong preference to use the den in high sound levels situations compared to the male (Figure 28). All the results described here can be seen in Table 15.

Table 15. GLM results for the optimal models describing the relationship between the sloths' behaviours and the independent variables ($L_{Aeq,10min}$ and individuals), during the high and low seasons in Chester Zoo, UK.

Season	Behaviour	Independent variables	Estimate coefficient[1] (±SE)	Exponential coefficients[2]	z or t values[3]
High	Active	L_{Aeq}	-0.03301(±0.03537)	---	-0.933
		Individual – Male	-4.47998(±2.52023)	---	-1.778
		L_{Aeq}*Male	0.09635(±0.04027)	1.101144	2.393^{t*}
	Inactive	L_{Aeq}	-0.10216(±0.03368)	---	-3.033^{t}
		Individual – Male	-2.26078(±2.11502)	---	-1.069
		L_{Aeq}*Male	0.07617(±0.03595)	1.079146	2.119^{t*}
	Alert	L_{Aeq}	-0.06637(±0.03478)	---	-1.908
		Individual – Male	-2.87216(±2.32612)	---	-1.235
		L_{Aeq}*Male	0.07787(±0.03823)	1.080982	2.037^{t*}
	Use of den	Individual – Male	-3.72668(±0.36883)	0.02407262	-10.10^{t***}
Low	Active	Individual – Male	0.7341(±0.1963)	2.083606	3.741^{t***}
	Inactive	L_{Aeq}	-0.05985(±0.01684)	---	-3.554^{t}
		Individual – Male	-2.76959(±1.36572)	---	-2.028^{t}
		L_{Aeq}*Male	0.05283(±0.02225)	1.05425	2.374^{t*}
	Alert	L_{Aeq}	-0.27821(±0.07171)	---	-3.879^{t}
		Individual – Male	-14.76961(±4.27903)	---	-3.452^{t}
		L_{Aeq}*Male	0.28495(±0.07698)	1.329696	3.701^{t***}
	Use of den	L_{Aeq}	0.07437(±0.02413)	---	3.082^{t}
		Individual – Male	5.13677(±2.98925)	---	1.718^{t}
		L_{Aeq}*Male	-0.10623(±0.04813)	0.8992178	-2.207^{t*}

[1] Model results for each variable. [2] Results exponentially transformed according to Poisson regression equation. [3]. Standard deviations distance from the mean (z values from GLM Poisson and t values for quasi-GLM Poisson). * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

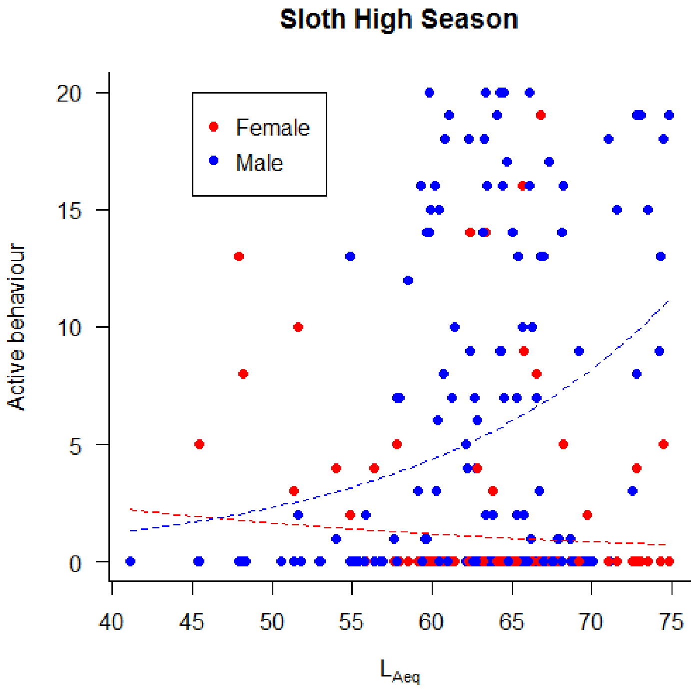


Figure 23. Sloths' active behaviour response to $L_{Aeq,10min}$ by individual, during high season in Chester Zoo, UK. Trend curves based on GLM result: Female – Active behaviour = e^(2.15242-0.03301*L_{Aeq}); Male – Active behaviour = e^(-2.32756+0.06334*L_{Aeq}).

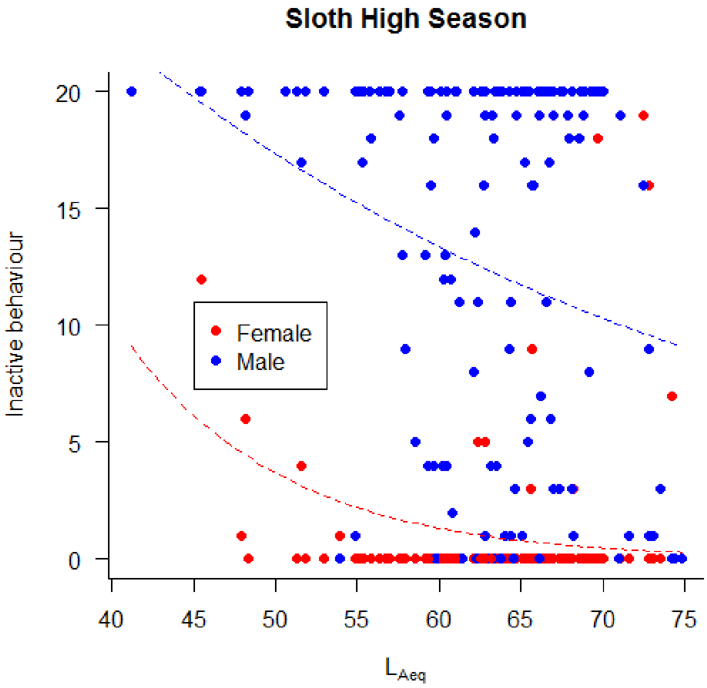


Figure 24. Sloths' inactive behaviour response to $L_{Aeq,10min}$ by individual, during high season in Chester Zoo, UK. Trend curves based on GLM result: Female – Inactive behaviour = e^(6.41371-0.10216*L_{Aeq}); Male – Inactive behaviour = e^(4.15293-0.02599*L_{Aeq}).

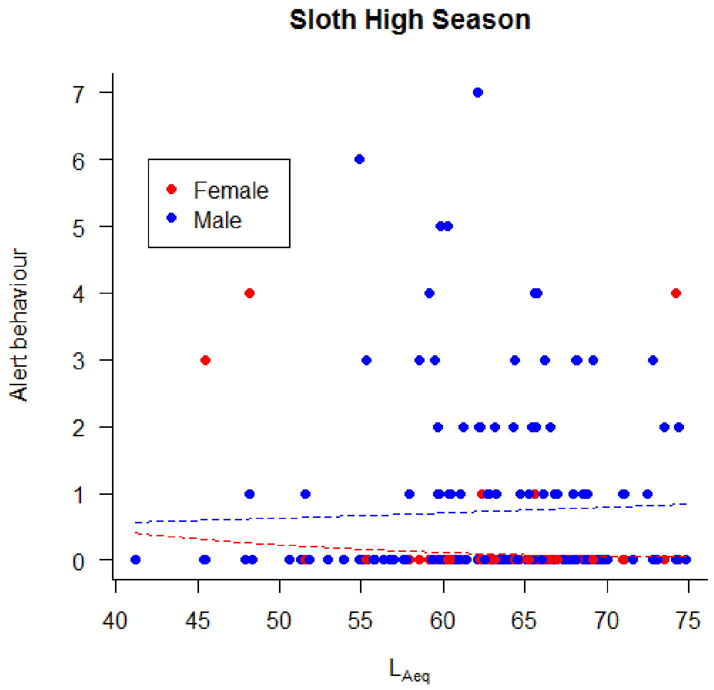


Figure 25. Sloths' alert behaviour response to $L_{Aeq,10min}$ by individual, during high season in Chester Zoo, UK. Trend curves based on GLM result: Female – Alert behaviour = e^(1.83739-0.06637*L_{Aeq}); Male – Alert behaviour = e^(-1.03477+0.0115*L_{Aeq}).

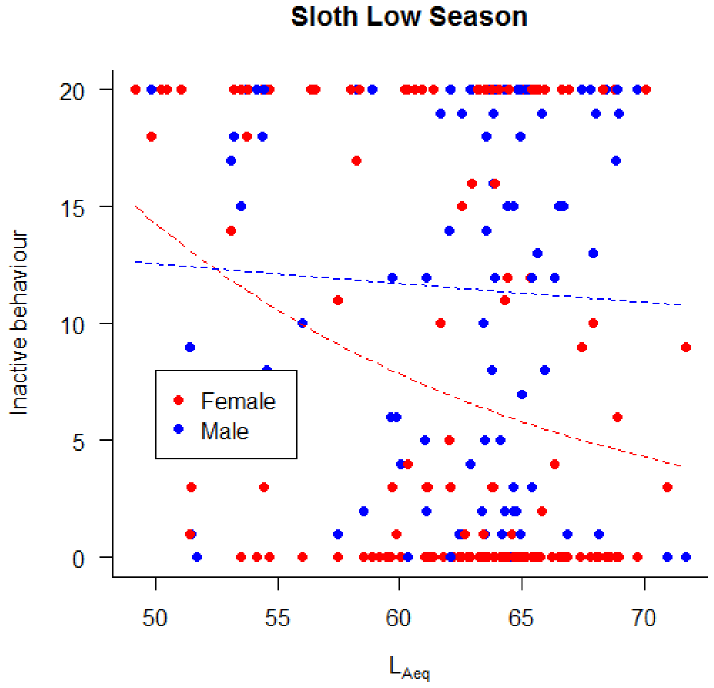


Figure 26. Sloths' inactive behaviour response to $L_{Aeq,10min}$ by individual, during low season in Chester Zoo, UK. Trend curves based on GLM result: Female – Inactive behaviour = e^(5.65154-0.05985*L_{Aeq}); Male – Inactive behaviour = e^(2.88195-0.00702*L_{Aeq}).

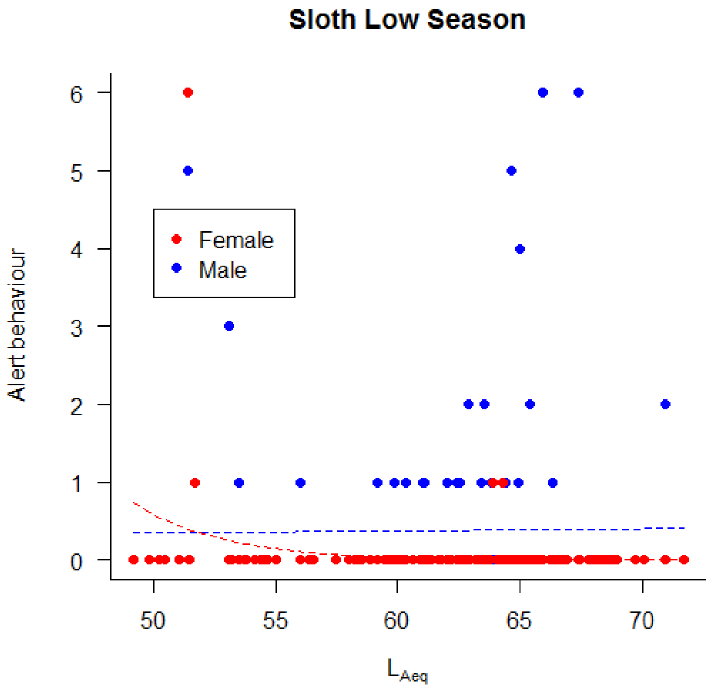


Figure 27. Sloths' alert behaviour response to $L_{Aeq,10min}$ by individual, during low season in Chester Zoo, UK. Trend curves based on GLM result: Female – Alert behaviour = e^(13.38498-0.27821*L_{Aeq}); Male – Alert behaviour = e^(-1.38463+0.00674*L_{Aeq}).

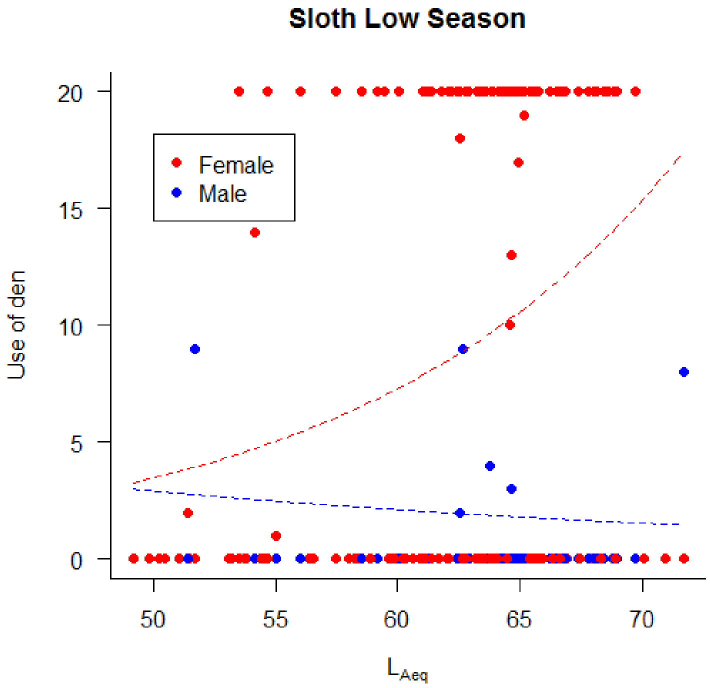


Figure 28. Sloths' use of den response to $L_{Aeq,10min}$ by individual, during low season in Chester Zoo, UK. Trend curves based on GLM result: Female – Use of den = e^(-2.47372+0.07437*L_{Aeq}); Male – Use of den = e^(2.66305-0.03186*L_{Aeq}).

3.5. Discussion

General sound pressure levels

The results of the sound pressure levels study for each enclosure indicate that different characteristics of an area can influence the sound levels that reach the animals and the source of noise that dominates the sonic environment. For example, the presence or not of a glass barrier separating the animals from the public.

Due to the large number of visitors during the high season in the zoo, which causes a constant movement and events around the venue, there was an expectation of higher levels of sound pressure in the high season compared to the low season. Surprisingly, this expectation was only found in the sloths' enclosure. The okapi and aye-aye's enclosures presented higher sound pressure levels in the low season, and in the rhinos' enclosure, sound levels were similar in both seasons (low and high). This interesting finding (e.g. low season louder than high season) can be explained by the heating system. As can be seen in Figures 7 and 13, the soundscape of both enclosures was dominated by the heating system sound, which was around 50 dB(A) for the okapi, and around 57 dB(A) for the aye-aye. During high season, even though there was an action of the ventilation system, the system was switched on for a shorter period and the baseline noise of the system was quieter (around 53 dB(A) for the aye-aye and 45 dB(A) for the okapi).

Another expectation, which was not true for all enclosures, was the anticipation of the zoo being louder during visitor opening times compared to closed times. The aye-aye's enclosure was the only one where there was no difference in the sound levels comparing opening and closed times of the zoo, in this case during low season. As it was mentioned before, during low season the aye-aye sonic environment was dominated by the heating system during the day, which could have caused a masking of other sounds during the day and implicated in a very low sound levels variation during this season between opening and closed times.

In all situations described here, the sound pressure levels found in the animals' enclosures were always higher than the sound pressure levels usually found in their natural environments, contrasting severely with what the animals would encounter if they were in the wild. For instance, the black rhinos in Chester Zoo are facing an average sound pressure levels of more than 50 dB(A); in savannahs, the average noise levels are expected to be around 30 dB(A) (Morgan and Tromborg, 2007).

Moderate to high Pearson's correlation factors showed that the visitors were probably responsible for most of the sound produced in the black rhinos, okapi, and sloths' enclosures during opening times of the zoo, in agreement with other studies (Larsen et al., 2014, Morgan and Tromborg, 2007, Quadros et al., 2014). The only exception was the aye-aye's area, where the correlation factor between sound levels and number of visitors was very low. This can be explained by a possible masking of the visitors' sound caused by the ventilation and heating systems. Another explanation is that different characteristic of the aye-aye's area with glass barriers, which are not present in the other species' enclosures, can be protecting the aye-aye from the visitors' noise because glass can be a good sound insulation in some situations as in double lead and sealed frame (Marsh, 1971).

One curious pattern that can be observed in Figures 10, 12, and 13 is that an increase in the background noise (L_{A90}, the orange lines), triggered by the heating and ventilation systems, made the public speak louder than moments when the systems were switched off. This pattern is an indicator of the Lombard effect, which is an involuntary vocal response to the background noise (Zollinger and Brumm, 2011).

3.5.1. Aye-aye

The aye-aye behaviour was only affected by the presence of the visitors and not by sound. The architecture of this enclosure with glass barriers between the visitors and the animal's area can explain the lack of influence of the sound pressure levels on the aye-aye behaviour. In addition, the constant sound coming from the heating and ventilation system, besides being able to mask the visitors' conversation, it could have created a continuous and unchangeable sonic environment, that is not causing any kind of behavioural reaction in consequence to the sound.

In both, low and high seasons, the presence of visitors caused a decrease in the aye-aye activity, making the animal hide more, and be more inactive. The same response was found in cats (leopards and jaguars); animals were more visible and possibly rested less as a way to avoid visitors (Mallapur and Chellam, 2002, Sellinger and Ha, 2005). These effects should be observed more carefully during high season when almost 140 visitors can pass through the aye-aye area in a ten-minute interval, which is about the double compared to the investigated low season. Feeding-related behaviour was also affected in the way that, during the low season, the aye-aye tends to eat more in the presence of more visitors. This result agrees with the finding of another study in which orang-utans also increased feeding behaviours in presence of visitors (Choo et al., 2011). In the case of the present result, as it was discussed before, probably the feeding behaviour could have attracted more visitors to watch the aye-aye (i.e. positive feedback at play). The food resources in the aye-aye enclosure were commonly located in places close to the visitors' viewing windows. Since the aye-aye is most of the time hard to spot in the dark, when the animal was engaged in feeding behaviour visitors were likely to spend more time observing the aye-aye and attracting other visitors to do the same.

3.5.2. Black rhinos

The black-rhinos rested less with an increase of the equivalent sound levels. Following the information in Figure 10, equivalent sound levels could vary by more than 40 dB(A) when the zoo was open, which resulted in significantly less rest time for the rhinos on busy visitor days at the zoo. The same restless response to noise was also found in captive giant pandas during noisy days in zoos (Powell et al., 2006).

The influence on feeding-related behaviours was similar to the aye-aye, where the animal expressed this behaviour more in the presence of more visitors. However, in the rhinos' case, the influence is too slight to be a focus of concern for the zoo, less than one per cent increase in feed behaviour frequency per visitor. In addition, rhinos usually spent a good deal of the active time in feeding-related behaviours (Hutchins and Kreger, 2006, Mukinya, 1977), confirming that this increase should not be a source of concern for zoos.

Interestingly, the alert behaviour presented different responses to visitors and to equivalent sound levels. An increase in the number of visitors made the rhinos less alert. In contrast, an increase in the decibel levels made the rhinos, specifically the females, more alert, which is a result consistent with the literature (Francis and Barber, 2013, Larsen et al., 2014, Mansour et al., 2000). Possibly the rhinos do not feel threated by visitors, which did not cause a vigilance arouse. However, a noisy environment can prevent the animals from hearing important sounds (e.g. calf vocalisation), causing a masking effect (Barber et al., 2010, Francis and Barber, 2013) which can intensify vigilance behaviour. This increase in vigilance in response to noise was also found in gorillas (Clark et al., 2012).

The preference for the outside was influenced by the background noise and by the weather. The background noise, dominated by the heating system varied around 30 dB(A) during the opening times of the zoo (Figure 10), consequently, from the moment the heating system was switched off from the moment it was switched on, this change of more than 20 dB(A) in the sound levels, increases in 40% the animals' preference for being outside. This result also accords with another study in which pandas increased the apparent effort of leaving the enclosure in noisier days (Owen et al., 2004) and also with a study that proved noise as an important factor influencing marmoset's choice of area (Duarte et al., 2011).

Based on the analysis of the low season data, the fact that the rhinos had stayed in the outside area most of the time during the high season may have happened due to the high decibels levels caused by the ventilation system switched on during the entire day (Figure 9). However, the outside area was not investigated during this study, meaning that the sound pressure levels were not measured outside, therefore, this is only speculation.

3.5.3. Okapi

The okapi behaviour responses being more strongly related to the equivalent sound levels with Z weighting (L_{Zeq}) could be associated to this species sensitivity to low-frequencies sounds, not heard by humans, as it was found by Lindsey et al. (1993). The sound level meter used in this study measures sound in Z weighted filter with flat response from 10Hz to 20kHz, differently from the A-weighted filter, used with the other species, in which there is a very low sensitivity to lower frequencies. The okapi behavioural variation being higher in association with the Z-weighted sound pressure levels can indicate that these lower frequencies are a potential source of annoyance for this animal.

During the high season, the okapi decreased the expression of all observed behaviours and preferred to be in the outside area due to an increase in decibel levels. This could mean that in a moment of intensification of sound pressure levels, the animal interrupted any behaviour being expressed to move to the outside area. The same pattern was observed in the rhinos' behavioural analysis (see Sections 3.4.2 and 3.5.2) and, as it was mentioned before, it is in accordance with another study (Owen et al., 2004).

In the low season data collection, it was possible to notice that in some moments of the day the zookeepers closed the okapi access to the outside area to prevent the animal of having continuous contact with the low temperatures in the outside. This situation can explain the increase in active and alert behaviours according to an increase in the sound levels, contrary to what has happened during the high season. As the okapi could not escape from the high sound levels in the inside, the animal moved more around the enclosure (i.e. increase in the active behaviour) possibly trying to find a quieter area (Francis and Barber, 2013, Owen et al., 2004). The animal was also more vigilant (increase in the alert behaviour), possibly due to sound masking caused by the high internal sound levels (Francis and Barber, 2013, Larsen et al., 2014).

Visitors' impact on animals' behaviour was the opposite of the impact caused by the sound. For the animal, visitors could be a distraction from the sound or maybe this okapi feels more comfortable around quiet visitors. Forced husbandry condition in zoos, can make the animals become more tolerant to humans (Mansour et al., 2000). However, further research would be necessary to better understand this difference.

In all cases, the influence of visitors on the animal behaviour was substantially lower than the influence caused by sound. Therefore, the zoo should focus firstly on mitigating the sound effect and then consider or even re-investigate the visitors' effect in the future. In addition, further investigation should be done to detect the emitted frequency of some devices inside the animal area (such as CCTV and air system) and check if these devices could be a source of stress to this species.

3.5.4. Two-toed sloths

The male's active response to noise during the high season is in agreement with studies found in the literature (Owen et al., 2004, Powell et al., 2006) and should be taken carefully into consideration when sound levels are high. An increase in locomotion behaviour can be reckoned as an indicator of stress (Francis and Barber, 2013, Owen et al., 2004).

Vigilance response to noise (increase in alert behaviour) even though significant should not be of great concern due to its small variation according to noise levels (Figures 25 and 27).

As it was discussed for the rhinos and the okapi, the sloths also rested less following an increase in the sound levels. Figures 15 and 16 presented a high sound variation of the sound during opening times of the zoo (42.3 dB(A) during high season and 33.6 dB(A) during low season). These results could be a major source of concern of the zoo for the reason that the high sound levels can be preventing the sloths of expressing a natural resting behaviour (e.g. sloths are usually active for only 25% of the time - Adam (1999)).

During the low season, the female sloth used the den more frequently in response to the high equivalent sound levels. This behavioural response confirms the importance for some animals of having the option to escape from the noise and how noise can be involved in alterations of animals' spatial distribution (Duarte et al., 2011, Francis and Barber, 2013).

3.6. Conclusions

The present study had the attempt of identifying enclosures sonic characteristics that can affect the animals and identify animals' behavioural aspects that are normal in a zoo environment and that can be used in an effort to improve animal well-being.

It is clear from the present study results that ventilation and heating systems are a common source of sound in some Chester Zoo enclosures and it is probably a common source of sound in temperate weather countries zoos as well. This is different from findings of tropical countries where the source of sound in zoos comes mainly from visitors (Quadros et al., 2014). The main problem perceived here caused by the constant sound of these mentioned systems is the Lombard effect in the visitors' conversation when people tended to speak louder in a compensation of the high background noise. Therefore, these higher sound pressure levels had the effects previously discussed on the animals. Different barriers to diminish the sound coming from ventilation and heating system were already tested and proved to be effective in reducing decibel levels and can be used to cover the systems (Orban et al., 2017).

The continuous on-off noise during the whole day (including during the night) caused by the ventilation/heating system, could be triggering some sleeping disturbance in the animals. The present study did not investigate behavioural data during the night, but for humans, sleeping in an environment of more than 55 dB is considered a health hazard (Hume et al., 2012) and the guidance on sound insulation and noise reduction for buildings recommends 30 dB(A) (BS 8233, 2014). For humans, the contact with chronic stressors can induce changes in the brain structure, immune system, and can cause cardiovascular diseases (Mariotti, 2015). In animals, this is not different and chronical sources of stress can also cause changes in the immune system (Martin et al., 2011) and cardiovascular disorders (Golbidi et al., 2015), for example. The aye-aye, okapi, and the rhinos are facing this situation during the night, which is certainly different from their natural environment and should be taken into consideration in the zoo management plans.

The masking effect mentioned previously during the discussion sections may be a source of problem for some animals. The increase in the background noise turns the acoustic signal ambiguous to some animals. This ambiguity can make animals want to leave the noisy area, or in more complicated cases animals can cease their sonic communication, which can be a source of stress (Wright et al., 2007).

The aye-aye enclosure with glass barrier is a good example of a way to protect the animals from the visitors' sound, however, even in this area, the animals were constantly exposed to high sound levels from the ventilation and heating systems. The aye-aye did not present a behavioural response to sound, but as it is known that anthropogenic noise can cause stress in form of physiological responses (Kight and Swaddle, 2011), that should be further explored.

Individual behavioural responses to noise were expressed in rhinos and sloths, and it is in agreement with other studies. Owen et al. (2004) have found different behavioural responses to noise between a male and a female panda. Likewise, Clark et al. (2012) have also found different behaviour expressions to the same stimulus in a group of gorillas. Individual differences in animals are expected, due to individual characteristics that can influence sensibility to noise. For instance, Cronin et al. (2018) have discussed that habituation to determined situations could be a reason for different behavioural responses to noisy events.

The small number of individuals studied here makes a generalization of species responses to noise impossible to perform. However, the present study shed a light on the importance of exploring the sound sources of an area where an animal will spend most of its life, and how the individuals can perceive and respond to this noise. Behavioural responses can be used as a sign of an early stress-related issue that when not well investigated might lead to serious effects in the future (Mansour et al., 2000). A better and stronger understanding of the noise sources and effects is important to serve as a base for mitigation strategies in animal stress and for a continuous work on animal welfare.

Section 4. Effect of noise on zoo mammals' glucocorticoid metabolites (GCM) levels

Along with the study of animal welfare through the investigation of behavioural responses, the use of stress hormones products, such as corticoids, can be powerful tools to complete the understanding of how animals cope with stress in captivity (Ganswindt et al., 2012, Touma and Palme, 2005). Animals, like humans, may behaviourally habituate to high sound pressure levels, but humans often also display physiological responses to increases to sound pressure levels. For example, a person can learn to sleep in a house on a noisy road, but their blood pressure will rise during sleep in response to increases in noise (Dratva et al., 2012). Thus, it is important to measure both behavioural and physiological responses to stressors such as noise.

Many researchers have measured animal welfare (and stress) by measuring corticoid levels (i.e. stress hormone levels). The most common and non-invasive way to evaluate physiological stress is through the measurement of glucocorticoid metabolites from faeces, though such stress measurements can be done from urine, saliva, or even milk (Mostl and Palme, 2002, Touma and Palme, 2005). Nevertheless, these last three options require some manipulation of the animal, which may be avoided with the use of faecal samples. The disadvantage of using faecal samples is it provides only a mean 24-hour measurement of stress and does not provide information in terms of time-specific stressors (Palme et al., 2005).

The analysis of glucocorticoids can answer questions about the animals stress related to husbandry practices (Bashaw et al., 2016, Kumar et al., 2014), to the occurrence of stereotypic behaviours (Brand et al., 2016), to constructions (Chosy et al., 2014, Powell et al., 2006), to environmental variables (visitors number and noise levels) and modifications (Clark et al., 2012, Owen et al., 2004, Ozella et al., 2017), and to social rank groups (Escobar-Ibarra et al., 2017). As an example of the effectiveness of this methodology: the effect of construction noise on captive giant panda (*Ailuropoda melanoleuca*) welfare was analysed and the results were that the corticoid levels, followed by behaviours related to stress and anxiety, increased due to the effect of high-frequency noise (Powell et al., 2006). Another project on giant pandas found that females expressed more stress-related behaviour and an increase in corticoid levels on noisy days at the zoo (Owen et al., 2004). Spider monkeys (*Ateles goeffroyii rufiventris*) (Davis et al., 2005) and wolves (*Canis lupus baileyi*) (Pifarre et al., 2012) had their levels of cortisol measured from urine and faeces, respectively, and these increased with the increase in the number of zoo visitors.

Based on this successful use of GCM for the study of animal welfare, the objective of this section is to investigate the faecal GCM response of two different species (okapi - *Okapia johnstoni* and orang-utans - *Pongo pygmaeus*) in two different circumstances: during different periods of the year in Chester Zoo, UK, and during summer live music events in Twycross Zoo, UK. The use of faecal corticoid metabolites was chosen instead of urine, blood, or saliva, for example, because of its advantage of being a simple non-invasive sampling technique. In this method, the results are not interfered since the animals are not manipulated during samples collection (samples can be collected during normal enclosure management) (Mostl and Palme, 2002, Touma and Palme, 2005).

4.1. Subjects of study

The choice of species was based on the interest and concern of the zoos. In Chester Zoo, only one species was chosen for the GCM analysis. The animals in Chester Zoo was being studied on a chronic stress level -- the environmental sound during the year. Chronic stress usually leads to a stabilization of the GCM levels (Mormede et al., 2007), however, there is no consensus in how wild animals' endocrine system responds to chronic stimuli (Dickens and Romero, 2013). For this reason, one species was chosen to test the stabilization hypothesis.

In Twycross Zoo, the summer live music happens once a year, characterizing an acute stress event. The orang-utans is the species with the enclosure closest located to the concert stage. For this reason, the zoo staff was interested in the investigation of the effect of the concerts on the orang-utans welfare.

4.1.1. Okapi (Okapia johnstoni)

In Chester Zoo, the okapi was chosen for the study (see Section 3.1.3 for species details).

4.1.2. Bornean orang-utans (Pongo pygmaeus)

The Bornean orang-utans are the largest arboreal animals in the world. They are considered critically endangered by the IUCN Red List, and climatic change and human pressure are the main reasons for this (Ancrenaz et al., 2016).

During the executed research, Twycross Zoo housed 6 individuals: one adult male called Batu (DOB: 25/05/1989), one adult female called Kibriah (DOB: 23/01/0977) with an infant (undetermined sex; DOB: 16/06/2017), one adult female called Maliku (DOB: 10/06/1994) with a male infant (DOB: 27/03/2017), and one juvenile female called Molly (DOB: 24/01/2011). The infants were not included in the present study.

4.2. Data collection

4.2.1. Okapi

The okapi hormone response to environmental noise during different periods of the year was investigated alongside with the behavioural study described in Section 3. Usala's faecal samples were collected by the giraffe keeper team daily in the morning after the days of behavioural data collection (five samples during low season and five samples during high season). Thus, the samples are representative of the day of sound data collection (Touma and Palme, 2005). Faecal samples were individually stored in labelled hermetic plastic bags and immediately frozen for later GCM extraction (Touma and Palme, 2005). No control in GCM measurements was possible to be done since Chester Zoo is open throughout the whole year. Therefore, it was not possible to investigate how is the animal response to noise without the zoo visitors' interference.

The sound data used for this investigation are the same data collected and described in Sections 3.2 and 3.4.

4.2.2. Orang-utans

The orang-utans' hormone response to noise was investigated during four consecutive weekends when Twycross Zoo was hosting the "Summer Sundown" events. These events were live music nights, happening on Saturdays from 5 pm to 8:30 pm. The concert stage was next to the orang-utans' enclosure (Figure 29).

The orang-utans' faecal samples were collected by the ape keepers team every Friday, Saturday, Sunday, and Monday, samples representing the GCM response from Thursday, Friday, Saturday, and Sunday (Touma and Palme, 2005, Weingrill et al., 2011). However, due to logistical and management reasons, some samples from some animals were not collected in all specified days. The samples were collected for each animal individually (51 samples in total). To help the keepers identify the individuals' samples, the animals were fed with coloured food using eatable glitter (a different glitter colour for each individual) (Fuller et al., 2011). Faecal samples were individually stored in labelled hermetic plastic bags and immediately frozen for later GCM extraction (Touma and Palme, 2005). Likewise Chester Zoo, Twycross Zoo is open throughout the year, which made it difficult to have a GCM baseline for the orang-utans with no intense influence over the environmental sound.

Therefore, the GCM levels were collected with the aim to make a comparison between event and non-event days.

The sound pressure levels that reached the orang-utan's enclosure were measured using a sound level meter (SLM) (Svantek SVAN 957) installed inside the animals' enclosure. A passive sound recorder (Wildlife Acoustics' Song Meter SM3) was also installed. Both equipments measured and recorded the sound 24 hours a day from Thursday to Monday. Equipment settings were the same as described in Section 3.2.

Figure 29. Summer event in Twycross Zoo, UK. Stage concert located next to the orang-utans' enclosure (light-orange building).

4.3. Extraction of GCM

Using the methanol-based protocol (Palme et al., 2013), a portion of 0.5 g of each well-homogenised sample was extracted. 5 ml of 80% methanol was added and shaken in a multivortex for about 1.5 minutes. After centrifugation for 15 minutes, aliquots (0.5 ml in duplicates) were dried and sent to the University of Vienna's School of Veterinary Medicine, Vienna, Austria for measurement of the GCM with a cortisone enzyme immunoassay (EIA) previously developed and validated for use in both species. Glucocorticoid metabolites measures are given in nanograms per gram of faeces (ng/g).

4.3. Statistical analysis

All data described below presented a normal distribution, which permitted the use of parametric statistical tests. All analyses were performed in RStudio (Team, 2016).

4.3.1. Okapi

Sound levels were logarithmically averaged per day using the values of the opening times of the zoo ($L_{Zeq,open\ zoo}$, $L_{Z10,open\ zoo}$, $L_{Z90,open\ zoo}$). Sound levels with Z-weighting response were chosen due to the okapi stronger behavioural reaction to this acoustic metric as verified in Section 3.4.3., T-tests were made to investigate if the sound levels, total number of visitors, and the GCM levels varied significantly between high and low visitor seasons. In addition, the L_{Zeq} values and the total number of visitors for the experiment days were used in multiple linear regressions to verify the influence of the sound pressure levels on the GCM measurements.

4.3.2. Orang-utans

Sound levels were logarithmically averaged per day using the values of the opening times of the zoo ($L_{Aeq,open\ zoo}$, $L_{A10,open\ zoo}$, $L_{A90,open\ zoo}$). Equivalent sound levels with A-weighting response were chosen in this case because the orang-utans are from a primate group phylogenetically close to humans with a hearing system also anatomically similar (Masali et al., 1992). T-tests were made to investigate if the sound levels and the GCM levels varied significantly on the days of the events compared to non-event days. In addition, the L_{Aeq} values for the experiment days were used in linear regressions to verify the influence of the sound levels in the GCM measures.

4.4. Results

4.4.1. Okapi

The description of the soundscape of the okapi enclosure during high and low visitor seasons can be found in Section 3.4 (Figures 11, 12, and 13).

T-tests results show that sound levels with Z-weighted response ($L_{Zeq,open\ zoo}$ and $L_{Z10,open\ zoo}$) during opening times of the zoo did not differ between high and low seasons (L_{Zeq}: t=1.386, df=8, *p*=0.203; L_{Z10}: t=1.832, df=8, *p*=0.104). However, when the background noise levels (L_{Z90}) during opening times were tested, sound pressure levels were found higher during low season compared to high season (L_{Z90}: t=-2.867, df=8, *p*=0.021) (Figure 30). The total number of visitors was almost significantly higher during high season compared to low (t=2.035, df=8, *p*=0.076).

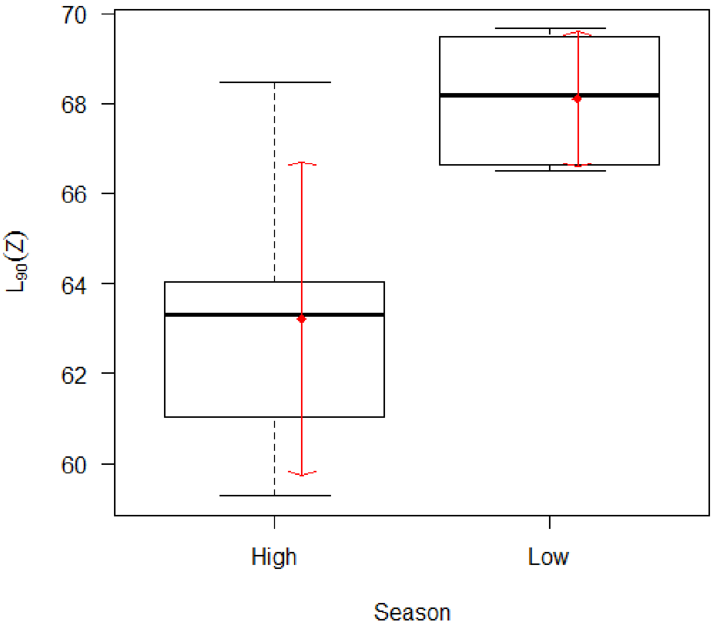


Figure 30. Background noise levels ($L_{Z90,open\ zoo}$) during zoo opening times of the high and the low seasons at the okapi enclosure in Chester Zoo, UK. Red dots represent the mean values and the red arrows represent the standard deviation values.

GCM levels along the different seasons can be seen in Figures 31 and 32, where the values are given in two different valid EIAs (72a and 72T); no significant differences in the

GCM levels was found between seasons (72a: t=-0.445, df=8, *p*=0.668; 72T: t=0.987, df= 8, *p*=0.3524).

Further linear regression analysis revealed that zoo opening times equivalent sound levels ($L_{Zeq,open\ zoo}$) and total number of visitors can predict the GCM levels (72T EIA) in the okapi specimen studied, with the following equation: GCM=-320.94+5.30*L_{Zeq}+(-0.04)*visitors (Table 16). The GCM levels using the 72a EIA did not present an association with the sound and visitors variables.

Table 16. Multiple linear regression results relating the okapi's glucocorticoid metabolites (GCM) using 72T enzyme immunoassay to equivalent sound levels ($L_{Zeq,open\ zoo}$) during the opening hours and daily total number of visitors in Chester Zoo, UK.

Model fit R^2 (R^2 adj.)	F-statistics	Independent variable	Linear regression coefficient (±SE)	t-value
0.61(0.50)	5.40*	L_{Zeq}	5.30(±1.85)	2.867*
		Visitors	-0.04(±0.02)	-2.536*

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

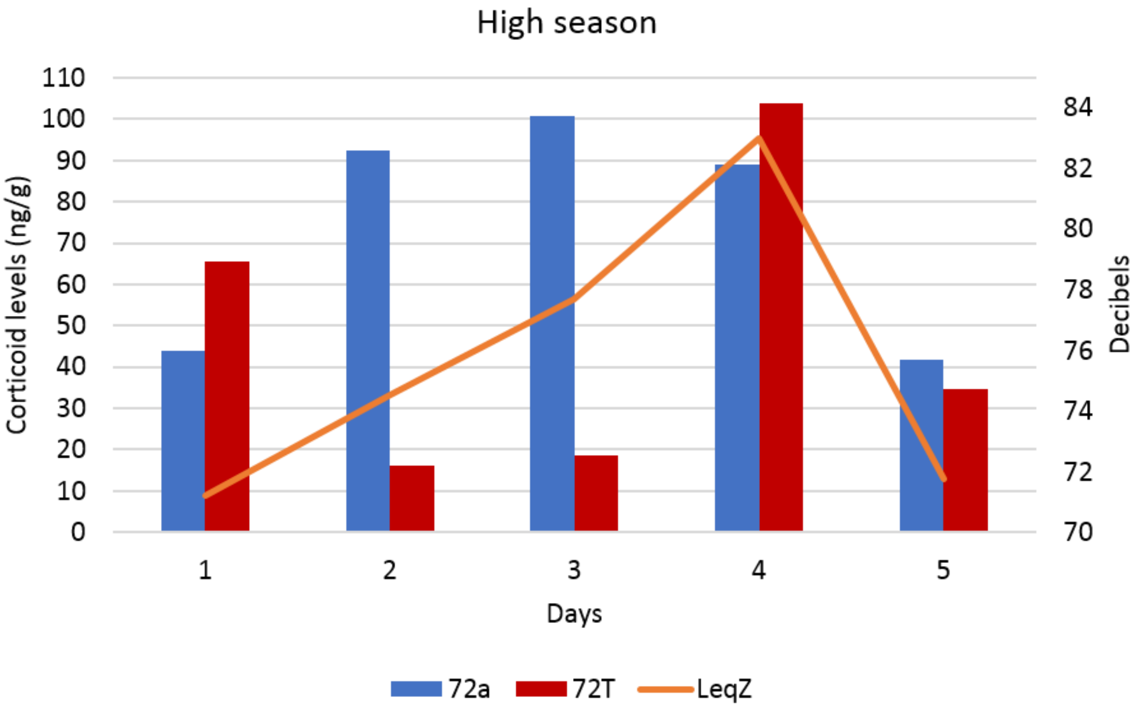


Figure 31. Okapi's glucocorticoid metabolites (GCM) levels in two different enzyme immunoassay (72a and 72T) for the five days of data collection during high season in Chester Zoo, UK. The orange line represents the equivalent sound levels ($L_{Zeq,open\ zoo}$) during opening times of the zoo.

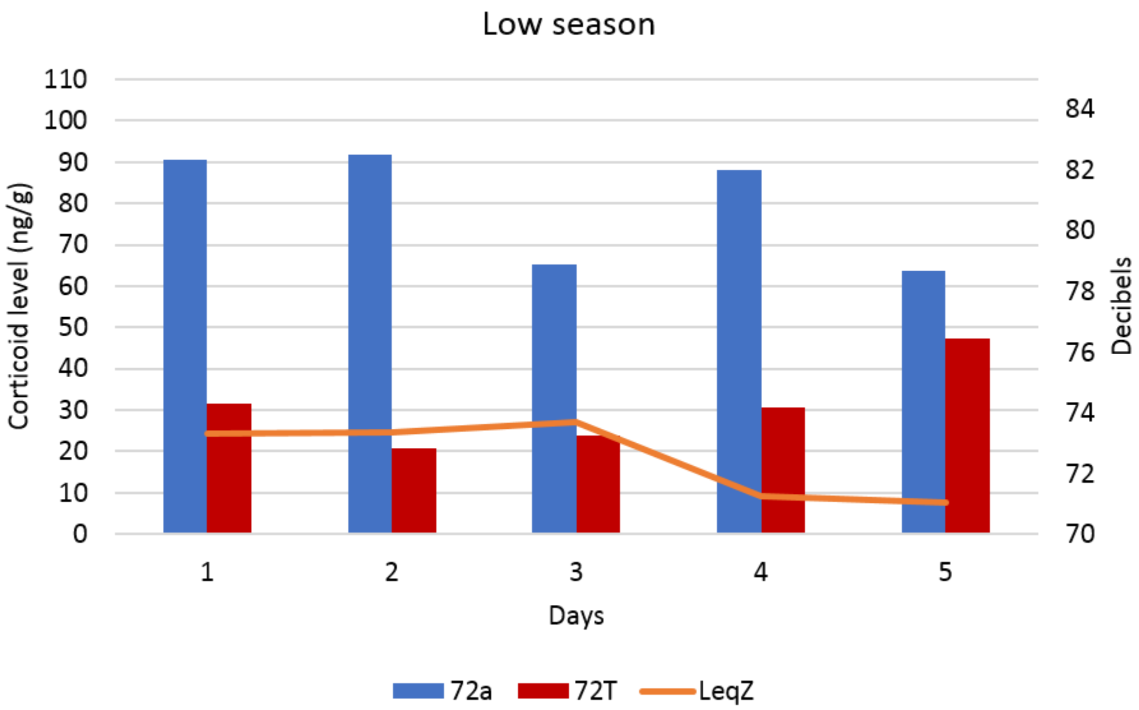


Figure 32. Okapi's glucocorticoid metabolites (GCM) levels in two different enzyme immunoassay (72a and 72T) for the five days of data collection during low season in Chester Zoo, UK. The orange line represents the equivalent sound levels ($L_{Zeq,\text{open zoo}}$) during opening times of the zoo.

4.4.2. Orang-utans

In Figure 33, there is a graphic representation of the orang-utan enclosure soundscape. It is possible to perceive that the sonic environment is mostly dominated by the ventilation system. Even when the live music was happening, the sound levels did not transpose the upper limit of the sound levels produced by the air system.

The statistical analysis revealed that sound pressure levels ($L_{Aeq,\text{open zoo}}$, $L_{A10,\text{open zoo}}$, $L_{A90,\text{open zoo}}$) were slightly higher during event days compare to non-event days; however, this difference was not statistically significant (Figure 34 for $L_{Aeq,\text{open zoo}}$) (L_{Aeq}: t=-0.597, df=11, *p*=0.563; L_{A10}: t=-1.16, df=11, *p*=0.271; L_{A90}: t=-1.384, df=11, *p*=0.194). The same pattern was found in individuals and group averaged GCM levels, which was also higher during event days but not statistically different between event and non-event days (Figure 35) (Batu:

t=-0.890, df=12, *p*=0.391; Kibriah: t=-0.973, df=10, *p*=0.354; Maliku: t=-1.874, df=11, *p*=0.088; Molly: t=-0.367, df=10, *p*=0.722; Group: t=-1.287, df=12, *p*=0.222). Figure 36 presents an overview of the GCM response for each individual and for the group average and the daily equivalent sound levels ($L_{Aeq,open\ zoo}$) during the four studied weekends.

Linear regression analysis showed that two individuals (Batu and Kibriah) presented the GCM levels increased according to noisier days at the zoo (Table 17 and Figures 37 and 38). No other individual nor the group averaged GCM levels were significantly related to sound pressure levels.

Table 17. Linear regressions results relating the orang-utans' glucocorticoid metabolites (GCM) to the averaged equivalent sound levels ($L_{Aeq,open\ zoo}$) during opening hours in Twycross Zoo, UK.

Model fit R^2 (R^2 adj.)	F-statistics	Orang-utan	Independent variable	Linear regression coefficient (±SE)	t-value
0.48(0.44)	10.51**	Batu	L_{Aeq}	45.62(±14.07)	3.242**
0.40(0.33)	5.89*	Kibriah	L_{Aeq}	35.38(±14.58)	2.427*

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

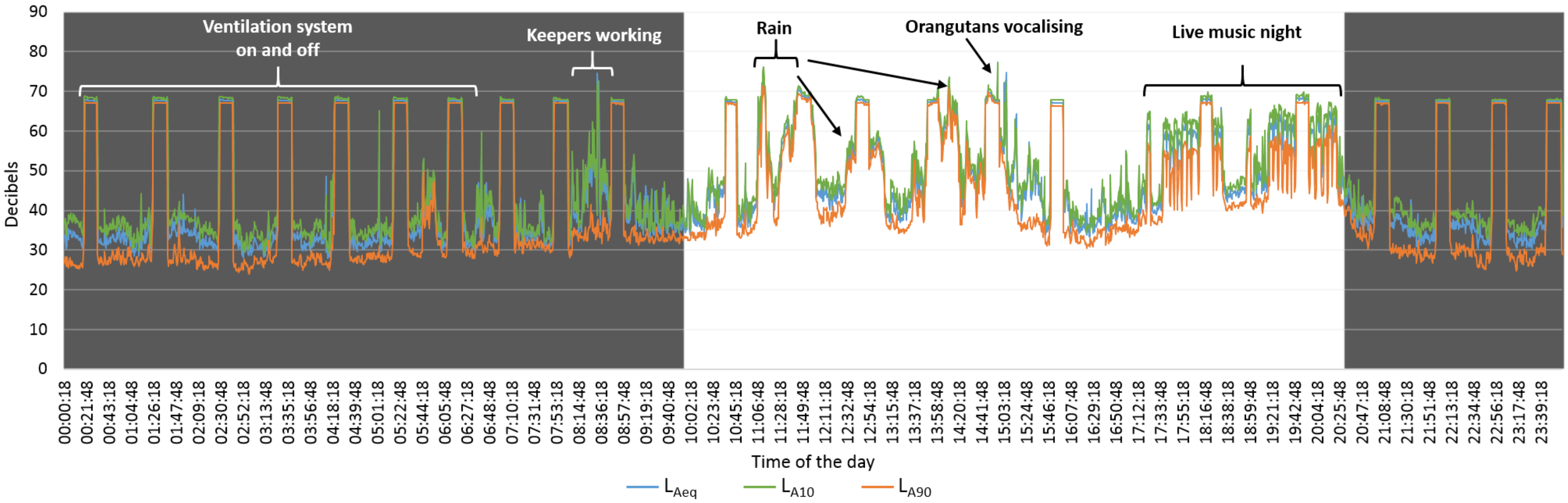


Figure 33. Orang-utans' enclosure sound pressure levels during a summer event day in Twycross Zoo, UK. Hours when the zoo was open to the public are represented in white background (from 10:00 to 20:30) and hours when the zoo was closed to the public are represented in grey background.

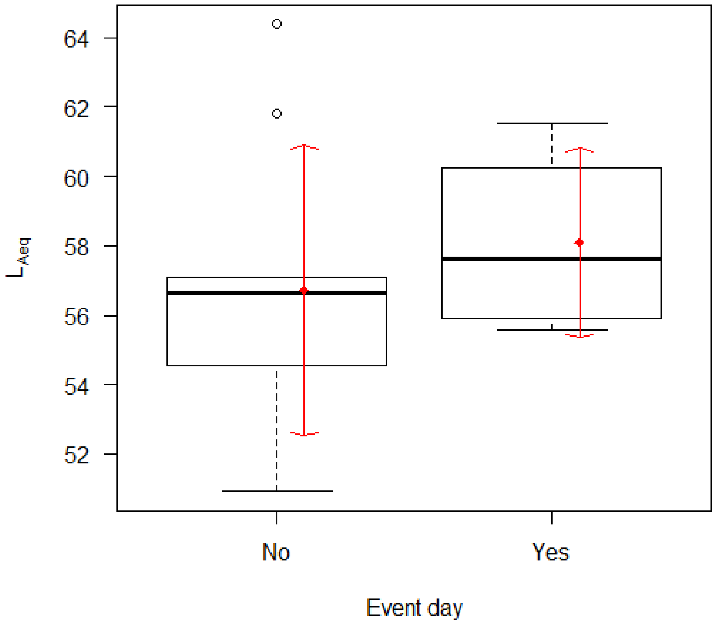


Figure 34. Equivalent sound levels ($L_{Aeq,open\ zoo}$) during opening times of the zoo in non-event and event days at the orang-utan enclosure in Twycross Zoo, UK. Red dots represent the mean values and the red arrows represent the standard deviation values.

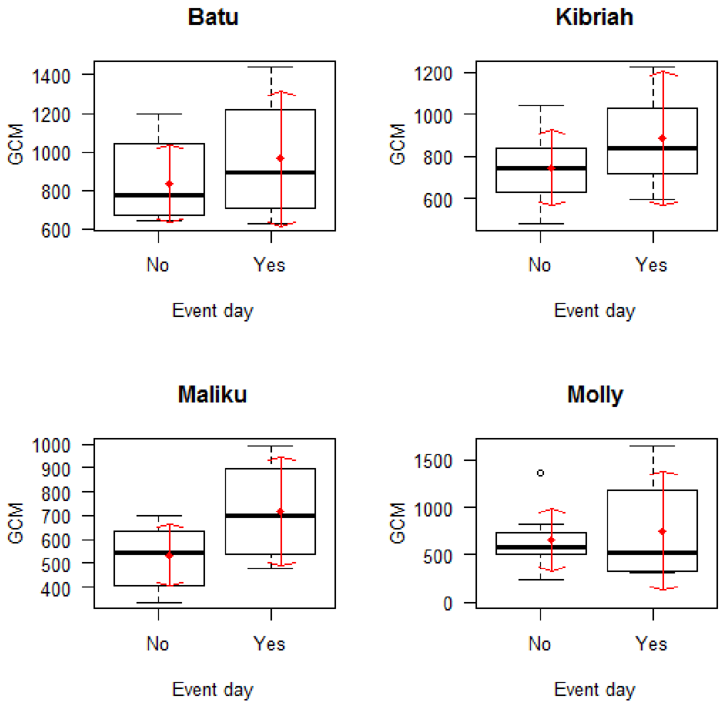


Figure 35. Orang-utans' glucocorticoid metabolites (GCM) levels for non-event and event days in Twycross Zoo, UK. Red dots represent the mean values and the red arrows represent the standard deviation values.

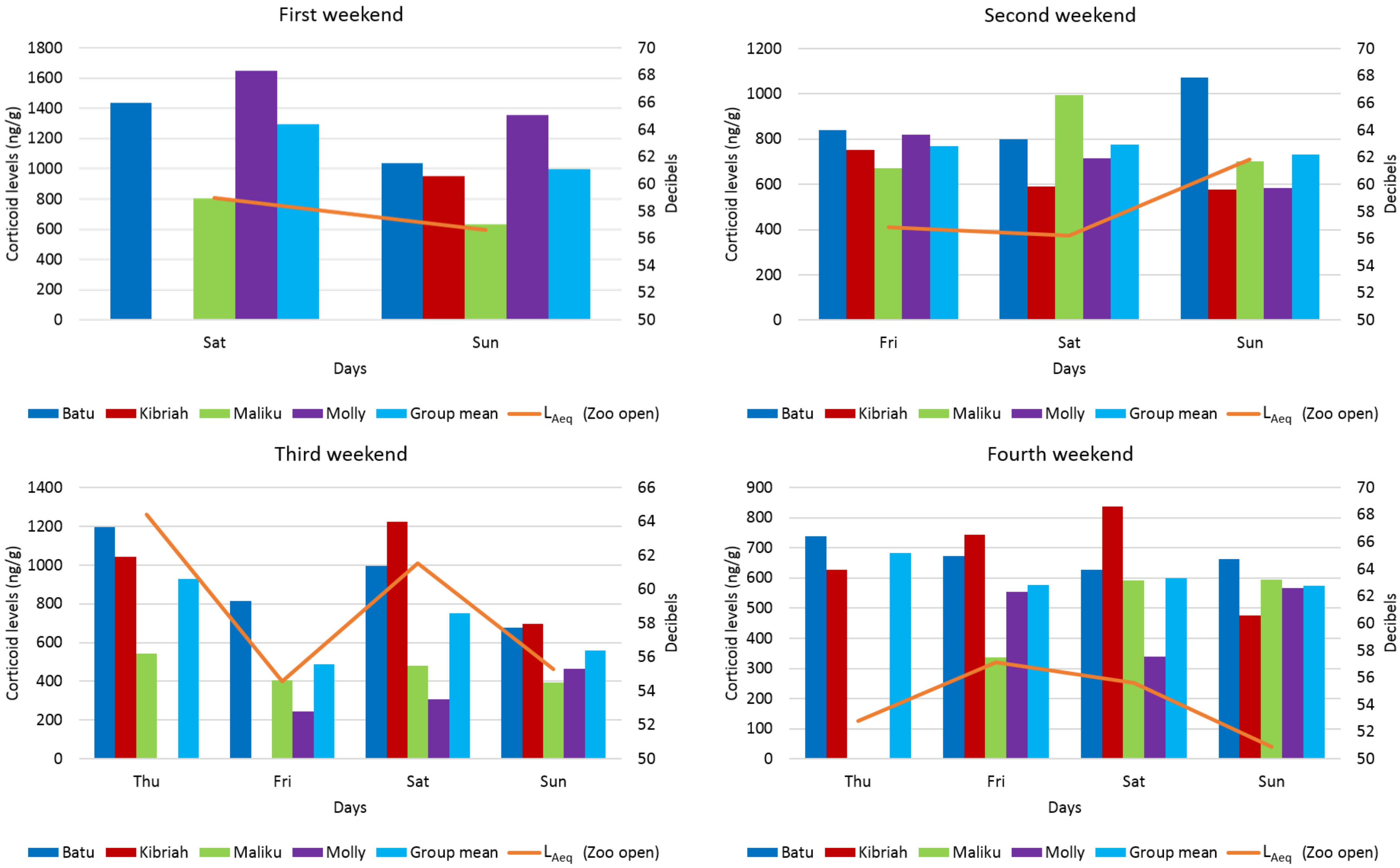


Figure 36. Glucocorticoid metabolites (GCM) levels for each individual orang-utan and for the group average during the four studied weekends in Twycross Zoo, UK. The orange line represents the equivalent sound levels ($L_{Aeq,open\ zoo}$) during opening times of the zoo.

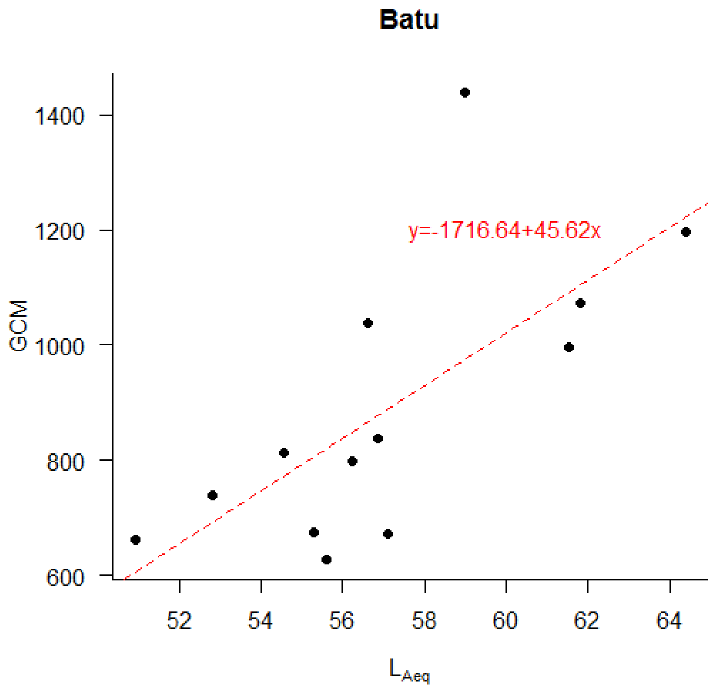


Figure 37. Batu's (adult male orang-utan) glucocorticoid metabolites responses (GCM) according to equivalent sound levels ($L_{Aeq,open\ zoo}$) in Twycross Zoo, UK. Trendline based on linear regression result: GCM = -1716.64+45.62*L_{Aeq}.

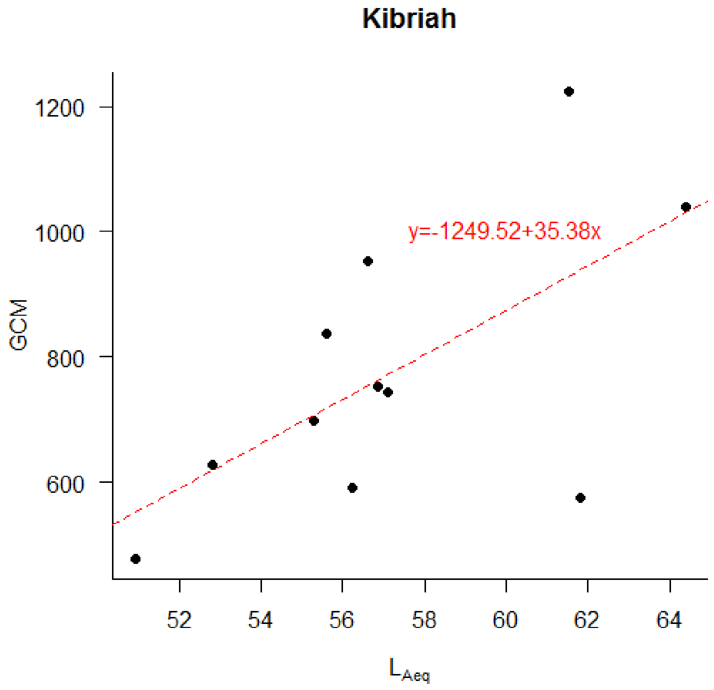


Figure 38. Kibriah's (adult female orang-utan) glucocorticoid metabolites responses (GCM) according to equivalent sound levels ($L_{Aeq,open\ zoo}$) in Twycross Zoo, UK. Trendline based on linear regression result: GCM = -1249.52+35.38*L_{Aeq}.

4.5. Discussion

It was not found significant differences between the GCM levels for both studied species in the investigated conditions: high and low visitor seasons for the okapi and event and non-event days for the orang-utans.

For the okapi situation, maybe the fact that the sound pressure levels were not completely different between the seasons it did not cause a clear different effect in the animal response along the year. Alternatively, maybe the experiment design chosen was not effective to answer the research question. Further examination could be done measuring the noise in different periods of the high and low seasons and collecting the faecal samples together to test this hypothesis again.

In the case of the orang-utans, there was a tendency of higher GCM levels on event days compared to non-event days, but not statistically different. This trend would agree with a study in which elephants exposed to public events presented higher GCM during and following the event (Kumar et al., 2014). It was possible to perceive that the sound pressure levels produced by the summer night events in Twycross Zoo did not increase the environmental sound inside the orang-utans’ enclosure. The domination of the enclosure environmental sound by the ventilation system caused a masking effect that “protected” the animals from the concerts noise.

Despite the animals affectless to the specific investigated conditions, the okapi had an associative GCM response to the open zoo noise levels and to the total number of visitors, and two orang-utans (Batu and Kibriah) had a GCM variation according to the open zoo noise levels. This GCM response to loud noises was also found in pandas (Owen et al., 2004, Powell et al., 2006).

Interestingly, the okapi GCM response to noise had a similar pattern to the behavioural response presented in Section 3.4.3. Sound and visitors had a contrary effect on GCM responses. The result established in this section corroborates what was discussed before; the okapi may feel comfortable around quiet visitors, which can cause kind of a compensation in the high levels of GCM caused by the high sound pressure levels.

The individual differences in the GCM responses within the orang-utan group corroborate with the literature and with the individual behavioural differences discussed in Section 3. Powell et al. (2006) have presented that pandas had different timeframes to return the GCM levels to a baseline after determined stimuli. They discussed that animals show different regulating mechanisms and, therefore, they deal differently with stress. In addition, Owen et al. (2004), who also found different corticoid responses also in pandas, discuss that differences in age and environmental ability perception to noise may account for this variable responses. These findings indicate the importance of understanding the individualities of the animals for a good species management in zoos.

4.6. Conclusions

Despite the advantages of being a non-invasive technique, the use of faecal GCM has its limitations, such as not allowing the monitoring of short-term environmental alterations (Touma and Palme, 2005). This is because the GCM levels in faeces are a cumulative response from around 20 hours before (depending on the species) (Palme et al., 2005). In the case of the orang-utans, the night events were an example of a short-term stimulus in which the GCM from faecal samples did not present itself as a perfect option for this investigation. The use of urine samples could be an option for showing the animals' physiological response for this acoustic event since they could be collected right after the event and they would represent the GCM response from the short period before collection (Palme et al., 2005).

However, this option would not be a completely non-invasive technique, as the keepers would need to enter the enclosure on specific moments that would not be expected by the animals causing an unnecessary disturbance.

Even without the expected result to the investigated conditions (night events and high and low visitor seasons), the result presented here of the GCM levels being higher in response to loud days at the zoo can be of great use of the zoos. Knowing a potential source of stress for captive animals is the first step in the search of a good welfare for these specimens. A study made with leopard cats (*Felis bengalensis*) discovered that improvements in the complexity of the environment induced a decrease in the cortisol concentrations (Carlstead et al., 1993). The authors discussed that the animals engaged in more behavioural options in a response to the improved environment, which resulted in a decreased GCM. Chester Zoo and Twycross Zoo could invest in environmental enrichment on the days of expected higher sound pressure levels to prevent the okapi and orang-utans from facing stressful situations or even help the animals to better cope with stress.

The small sample used here (one okapi and four orang-utans) are not enough for a generalization of the results for the species. However, in zoological studies, it is common to find different individual responses (Chosy et al., 2014, Clark et al., 2012, Owen et al., 2004, Powell et al., 2006), and this could be a valuable tool for zoos during animals’ management.

Section 5. Soundscape perception by zoo visitors

When studying the acoustic environment of a zoo it is obvious to concentrate on the effect of sound or “noise” on the main subjects of interest to the zoo: the animals. However, the visitors also play a significant role in a zoo environment (Lee, 2015, Luebke and Matiasek, 2013, Schultz and Joordens, 2014, Smith, 2013, Therkelsen and Lottrup, 2015). They participate actively in increasing the profit of the zoo by paying for the entrance fee, buying food and souvenirs, and by talking about the zoo when leaving the place (Fernandez et al., 2009). In simple terms, the study of the visitors’ perspective is equally important for the reason that they are contributors to the financial maintenance of zoos. A way to assess the well-being of a zoo visitor related to the acoustic environment, as an option to investigate beyond the noise levels, is the use of a common tool in this research area —soundscape studies.

These studies often use the paradigm of the soundscape as environmental sounds within a location (simulated, outdoor, or indoor) perceived, experienced, and understood by an individual or society (BS ISO 12913-1, 2014). Soundscapes of different places may cause various effects on humans, including relaxation and restoration (e.g. urban parks), vitality and excitement (e.g. street markets), and social connection (e.g. a busy town square) (Davies et al., 2013). In addition, not only the place but also the context and even the activity being developed can inspire the preference for a particular soundscape (Brown et al., 2011, Chau et al., 2010, Vianna et al., 2015). Moreover, in some cases, people can perceive the environment as noisy, but do not feel irritated or stressed by it, making the assessment of human acoustic comfort a complex subject (Yang and Kang, 2005).

Studies developed in amusements and theme parks are a good example of the influence of the soundscape in the public experience and perception of the venue. A study made in different theme parks in Orlando that analysed the soundscape characteristics of the parks found out that the environmental sound is loud but exciting (Kaiser and Rohde, 2013). It was concluded, in agreement of another study (Mackenzie et al., 2016), that the soundscape of these theme parks dominated by musical and human sounds, with some influence of technological sounds can produce a lively combination for the visitors. However, special attention should be taken to the general sound levels. A well-planned soundscape design can improve considerably the individual experience of a specific place (see Parsons and Taylor (2017)).

Considering soundscape studies as the individual's perception of the sonic environment, the topic has been studied by different onsite and offsite approaches. As onsite examples, interviews and questionnaires applications (Brambilla and Maffei, 2010, Chau et al., 2010, Shepherd et al., 2013) and soundwalk methods (Hong and Jeon, 2013, Kang and Zhang, 2010, Nilsson et al., 2012) are commonly used (17/30342414 DC, 2017). Interviews and questionnaires are methods of randomly choosing participants in a targeted location to answer their transient perception of the sonic environment. In soundwalk experiments, recruited participants follow a pre-defined route and evaluate the soundscape quality in specific locations and in an atmosphere of high attention to the environmental sound (Adams et al., 2008, Davies et al., 2007).

As an offsite approach, listening tests are used as a method of soundscape evaluation (Davies et al., 2014, Payne, 2013, Sudarsono et al., 2016). However, the evaluation of recordings during listening tests does not always represent the real experience of field surveys. To ensure the ecological validity of the listening test, the reproduction method during the experiment must suit the objectives of the study (i.e. the sound samples: music, indoor, or outdoor environments) (Guastavino and Katz, 2004). For instance, Guastavino et al. (2005) proved that for the analysis of sound source and background noise of urban environments, a reproduction of the sound using a 2D and 3D ambisonic system in a neutral environment (where speakers are not visible) is ecologically valid compared to the experiment in the real environment. On the other hand, Sudarsono et al. (2016) discuss that soundscape reproduction using a 2D ambisonic system and soundscape in the real location produce different semantic scales evaluation (rating scales designed to measure the meaning and concepts of things).

In a zoological park, visitors are exposed to a variety of different sources of sound (e.g. animals' calls, conversation, machinery, and music) in indoor and outdoor environments. These diverse characteristics make the reproduction of the zoo soundscape difficult to perform under laboratory conditions. Furthermore, the landscape of zoos plays the main role in the visitors' experience in this venue (Botteldooren et al., 2012, Liu et al., 2013, Liu et al., 2014). Another feature that could impede a valid soundscape reproduction, in this case, is the influence of the different smells present in a zoo. A study has found that expectations of sound and smell can be highly influential in the perception and experience of an urban environment (Henshaw & Bruce, 2012, cited in Thibaud and Siret, 2012). Therefore, in the present study, the visitors' perception of the zoo soundscape was explored by the use of the soundwalk method, in which it was possible to investigate diverse locations with different physical and sound characteristics.

This section aims to understand how the zoo's visitors perceive environmental sound around the zoo and how different physical aspects of an area can influence the individual's perception of sound by the application of soundwalks through Chester Zoo, UK.

5.1. Data collection

5.1.1. Participants

The participants were recruited with the support of the zoo staff, who helped to distribute an invitation letter (Appendix 2) and an information sheet (Appendix 3) about the project. Zoo volunteers and members were invited to take part voluntarily in the study. Twenty-seven participants (18 women, 8 men, and 1 not declared, age over 18) attended the walks allocated on nine different days. The effectiveness of the chosen number of participants and soundwalks were based on previous studies (Jeon et al., 2010, Jeon et al., 2011, Jeon et al., 2014, Jeon and Hong, 2015, Liu et al., 2014) and on the availability of the volunteers. A sample of thirty participants proved to be enough for reliable analysis, and developing the soundwalks in different days avoided the possibility of exploring the environment in an atypical day. On each the day of the soundwalk the participants walked together, guided by the researcher.

5.1.2. Soundwalks

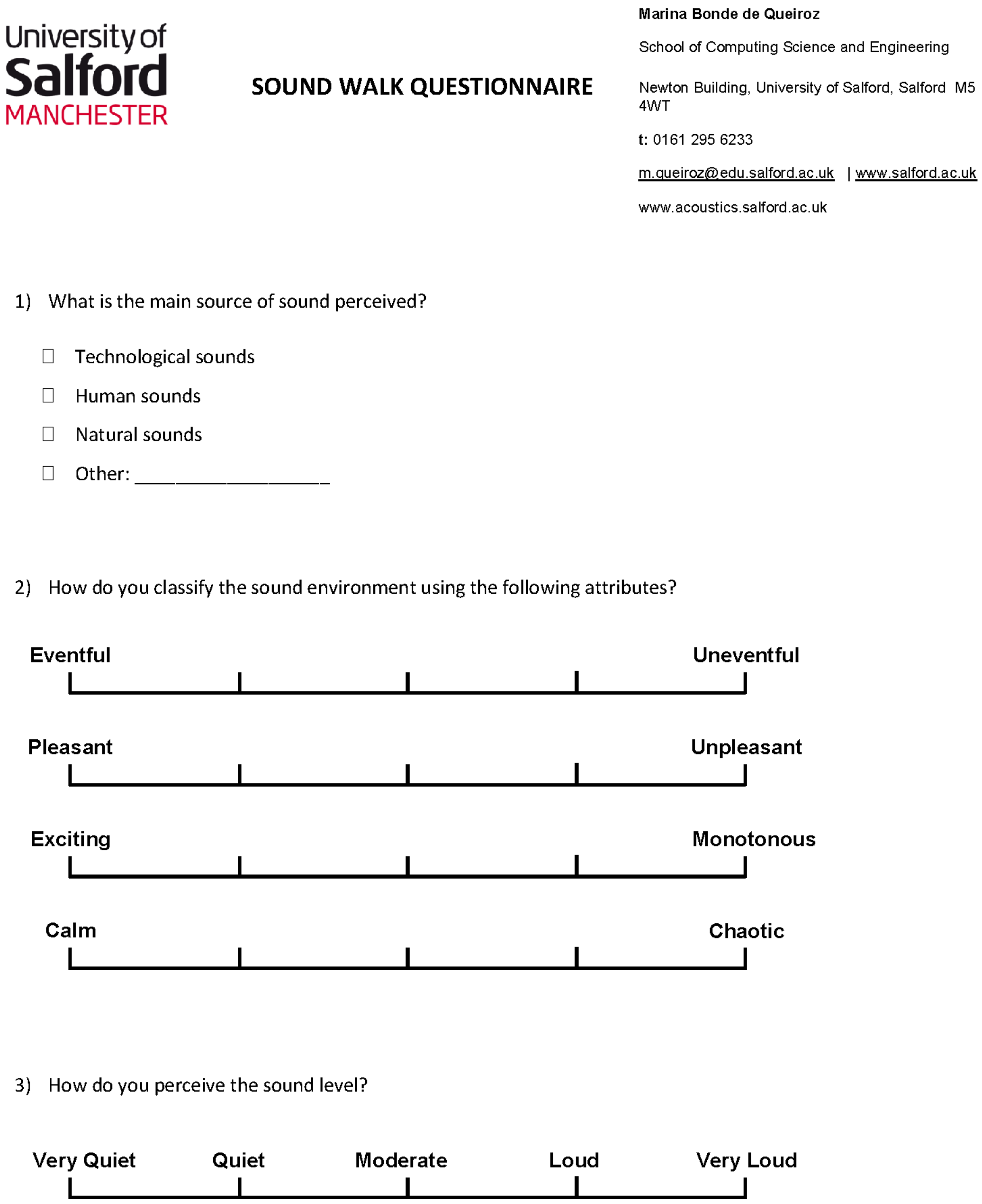
The soundwalks happened during high visitor season at the morning time, following a pre-established route passing through nine different locations (Table 18 and Figure 40 and 41) and lasting for around 45 minutes. The locations were chosen based on the species studied in Section 3 and on other areas of interest of the zoo. On each day, the walk started in a different location to avoid an influence due to sequential bias.

At each location, participants were asked to listen to the environmental sound for about 40 seconds and then fill a questionnaire (Figure 39) with three questions. The first question addresses the main source of sound perceived by the participants. The participants could choose between three possible answers (technological, human, or natural), which are the most commonly used sound classification in soundscape studies (Payne et al., 2009). This kind of taxonomy allows the comparison between sound sources and other evaluations of the soundscape, such as pleasantness and sound levels, for example. The second question involves four semantic scale classification, using eight attributes (pleasant, unpleasant, eventful, uneventful, exciting, monotonous, calm, and chaotic) suggested by Axelsson et al. (2010) and is frequently applied in soundscape studies (Jeon et al., 2014, Jeon and Hong, 2015, Nilsson et al., 2012, Steele et al., 2016). Participants had access to a concept list of these semantic scale terms (Appendix 4). The third question was a subjective evaluation of the sound level, which participants classified the sound levels at a 5-point scale from very quiet to very loud. This question was used to understand how people perceive noise comparatively to other soundscape assessments.

Table 18. Description of the location of the locations used in the soundwalks at Chester Zoo, UK.

Locations number	Location
1	Main entrance of the zoo (outdoor area)
2	Tropical Realm (indoor area)
3	Aye-ayes' enclosure (indoor area)
4	Spirit of the jaguar – Sloths' area (indoor area)
5	Madagascar play area (outdoor area)
6	Lions' enclosure (outdoor area)
7	Capybaras' enclosure (outdoor area)
8	Tsavo black rhino reserve (indoor area)
9	Okapi's enclosure (indoor area)

Before the beginning of the walk, participants were asked to sign a consent form (Appendix 5) and to fill a participant information sheet (Appendix 6). After that, details of the experiment were explained to the participants. During the walk, a sound level meter (Svantek SVAN 957) was used, which was set to record sound and to register sound pressure level in decibels every 10 seconds ($L_{Aeq,10sec}$). The meter was calibrated before and after each soundwalk, using the calibrator included in the SVAN 957 kit.



University of Salford MANCHESTER

SOUND WALK QUESTIONNAIRE

Marina Bonde de Queiroz
School of Computing Science and Engineering
Newton Building, University of Salford, Salford M5 4WT
t: 0161 295 6233
m.queiroz@edu.salford.ac.uk | www.salford.ac.uk
www.acoustics.salford.ac.uk

1) What is the main source of sound perceived?

- ☐ Technological sounds
- ☐ Human sounds
- ☐ Natural sounds
- ☐ Other: ___________________

2) How do you classify the sound environment using the following attributes?

Eventful – **Uneventful**

Pleasant – **Unpleasant**

Exciting – **Monotonous**

Calm – **Chaotic**

3) How do you perceive the sound level?

Very Quiet **Quiet** **Moderate** **Loud** **Very Loud**

Figure 39. Soundwalk questionnaire used in Chester Zoo, UK.

Figure 40. Soundwalks route and locations in Chester Zoo, UK. The black line represents the route and the white numbers represent the locations where the participants filled each questionnaire.

Figure 41. Photographs of the soundwalk locations at Chester Zoo, UK. Location 1 (Main entrance of the zoo), location 2 (Tropical Realm), location 3 (Aye-ayes' enclosure), location 4 (Spirit of the jaguar – Sloths' area), location 5 (Madagascar play area), location 6 (Lions' enclosure), location 7 (Capybaras' enclosure), location 8 (Tsavo black rhino reserve), location 9 (Okapi's enclosure).

5.2. Statistical analyses

To check the variance between the participants, a Kruskal-Wallis test was performed (a non-parametric test was chosen due to the non-normal distribution of the data set, which prevents the use of a simple analysis of variance). Kruskal-Wallis is a rank-based nonparametric test in which the result (expressed as H) indicates how large the discrepancy among the compared ranks is. This test was used to investigate if there was a significant difference in the semantic scales attributes among the soundwalk days for each of the nine locations. The internal consistency was found to be high since most of the tests were non-significant. This means that, in general, the participants' evaluations of the soundscape did not vary greatly among the different soundwalk days, in other words, the participants highly agreed on most of the evaluated attributes. Figure 42 shows four graphs, one for each evaluated attribute, where the soundwalks were put together by location. Eventful-uneventful and the exciting-monotonous attributes evaluation did not differ significantly among the soundwalks in any of the nine locations. The evaluation of pleasant-unpleasant attribute was significantly different among soundwalks in locations 1, 6 and 7 (1: H=16.533, p=0.03536; 6: H=15.931, p=0.04337; 7: H=15.642, p=0.04781) (Figures 43 to 45). For the calm-chaotic attribute, a significant difference was only found in location 1 (H=16.37, p=0.03738) (Figure 46).

The soundscape of the zoo was analysed by a principal component analysis (PCA) of the nine locations altogether using a mean of the four semantic scales results for each location. The attributes values were coded as a continuous data from 0 to 10, where 0 represents the first term of the scale and 10 represents the second term (e.g. for the Calm-Chaotic attribute, Calm was considered 0 and Chaotic was considered 10). The relationship between the principal components, sound attributes, sound pressure levels, sound level perception, sound source, and enclosure area was investigated using inter-correlations (Pearson's correlation) among the variables. In addition, to evaluate the direct effect of the acoustic measures, sound sources, and enclosure area on the principal components, stepwise multiple regression analyses were conducted.

Separately, a correlation matrix was produced (Pearson's correlation), for each of the nine locations, using the soundscape attributes, acoustic measures, and sound sources. To avoid the statistical "type 1" error due to the high number of correlations, the Holm's correction was used (Holm, 1979), which is considered more powerful and less conservative than the more common Bonferroni correction (Aickin and Gensler, 1996).

All statistical analyses were performed using RStudio (RStudio Team, 2016). The PCA analyses were made using the FactoMineR package (Le et al., 2008) and the correlation matrix with adjusted p values was produced using psych package (Revelle, 2017).

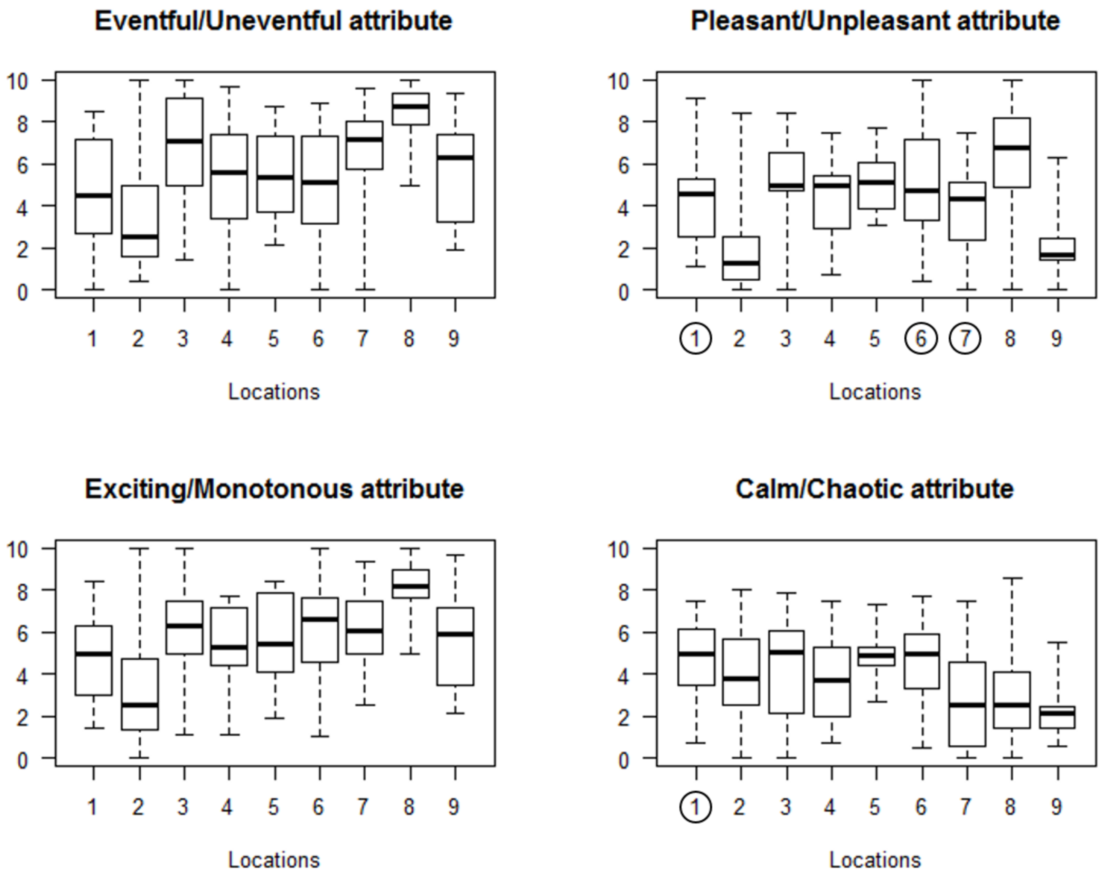


Figure 42. Soundwalks participants' responses for the four scale attributes by locations in Chester Zoo, UK. The circled locations are the attributes evaluations that were significantly different among soundwalks.

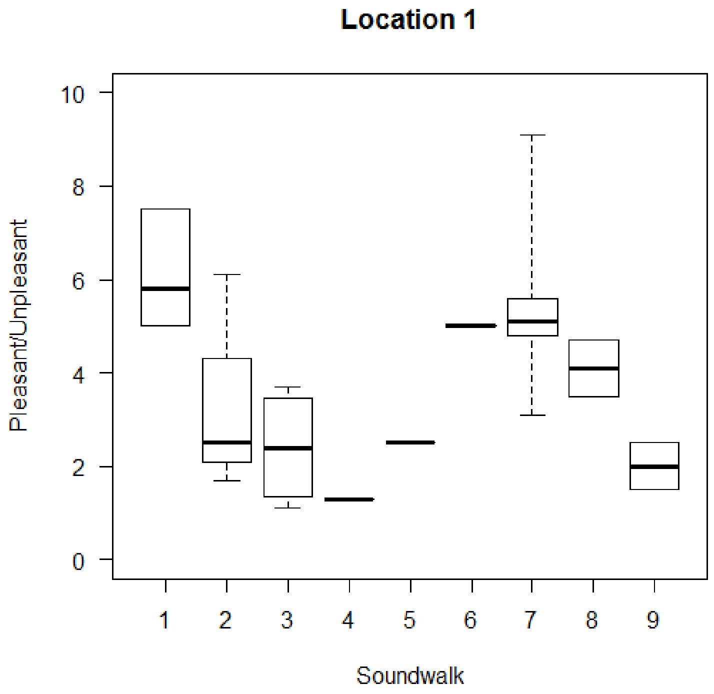


Figure 43. Participants’ responses to the Pleasant/Unpleasant attribute by each of the nine soundwalk days at location 1 (Main entrance) in Chester Zoo, UK.

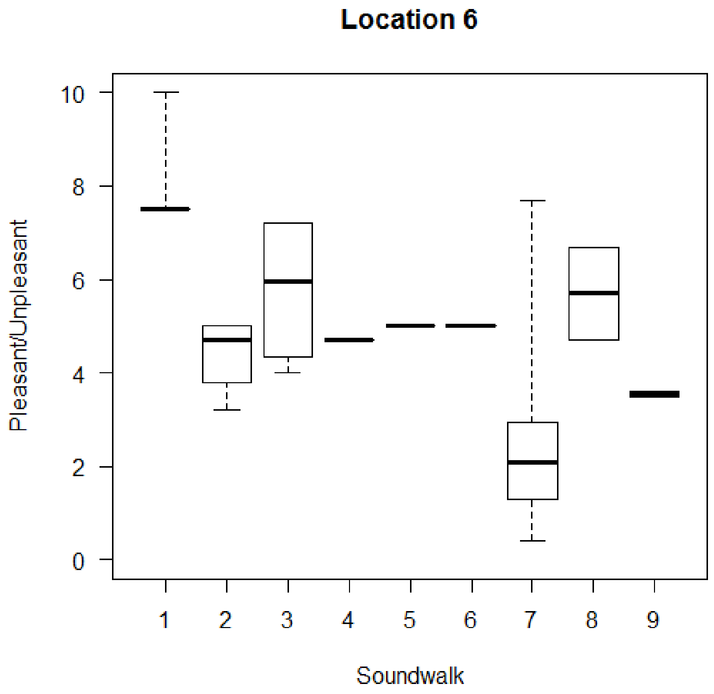


Figure 44. Participants’ responses to the Pleasant/Unpleasant attribute by each of the nine soundwalk days at location 6 (Lions’ enclosure) in Chester Zoo, UK.

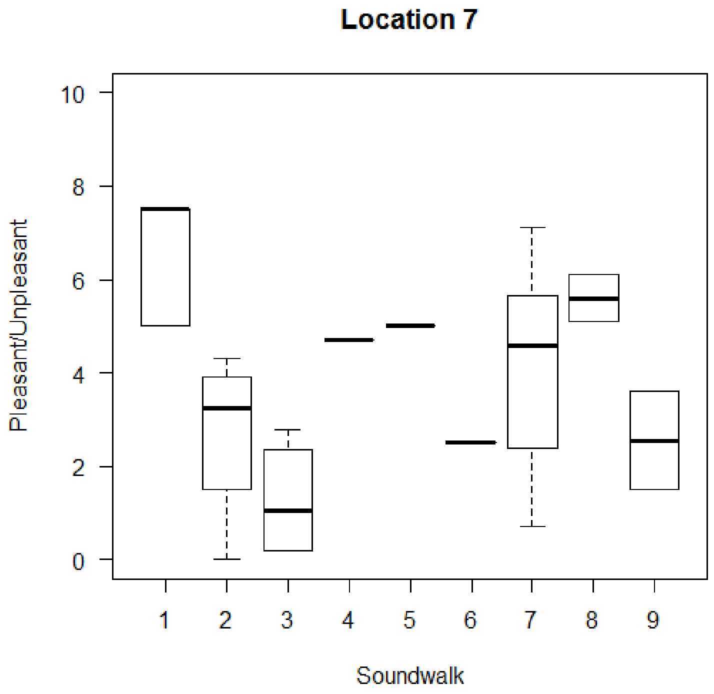


Figure 45. Participants' responses to the Pleasant/Unpleasant attribute by each of the nine soundwalk days at location 7 (Capybaras' enclosure) in Chester Zoo, UK.

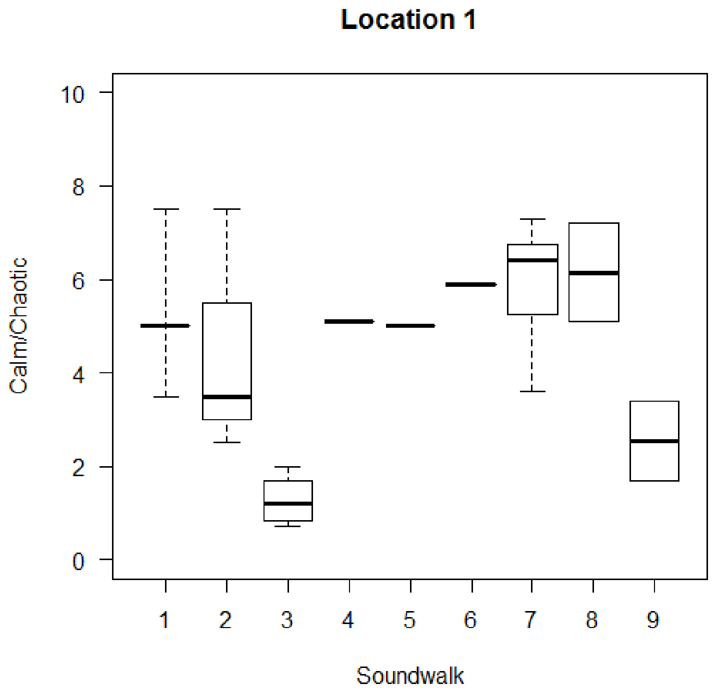


Figure 46. Participants' responses to the Calm/Chaotic attribute by each of the nine soundwalk days at location 1 (Main entrance) in Chester Zoo, UK.

5.3. Results

Sound pressure levels varied among some of the locations during the soundwalks (Figure 47). Most of the locations presented a logarithmic average of the sound levels below 60 dB(A). Only the Tropical Realm (Location 2), the sloths' area (Location 4), and the play area (Location 5) presented sound levels logarithmic average above 60 dB(A). The Madagascar play area is an outdoor, open space. The outlying high level in the play area (Location 5; see Figure 47) was due to a particular child playing in the area at the moment of the soundwalk.

The participants' perception of the sound levels did not follow the real sound levels in decibels (Figures 48). Locations 4 and 5, for example, were classified as loud and location 3, which had the lowest average sound levels (55.8 dB(A)), was more times classified as loud compared to the locations previously mentioned. The main sources of sound perceived by the soundwalk participants for each location can be seen in Figure 49.

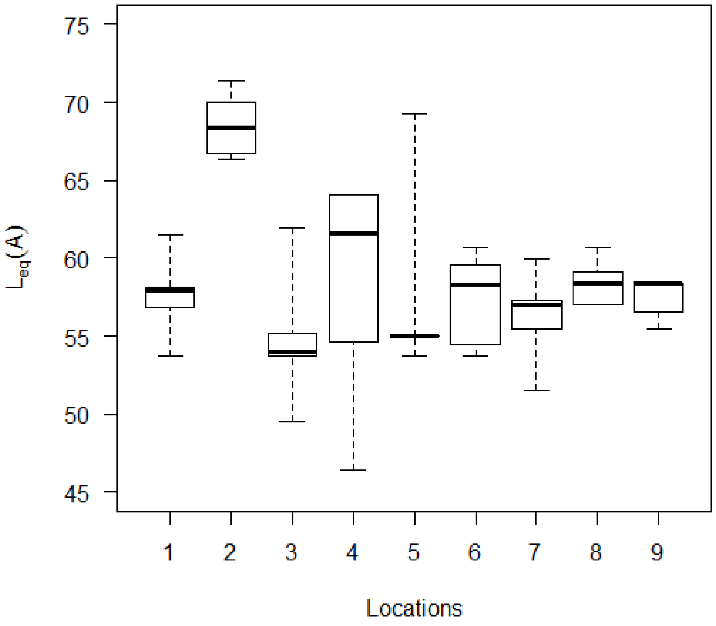


Figure 47. Equivalent sound levels in the nine locations over the conducted soundwalks in Chester Zoo, UK.

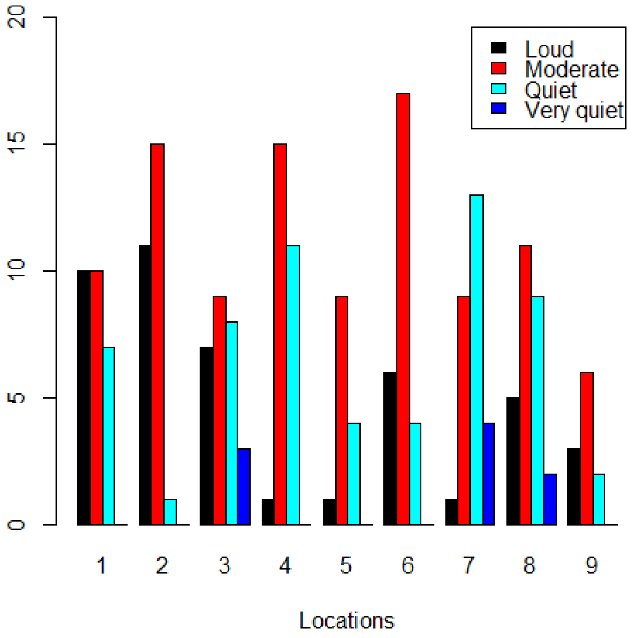


Figure 48. Sound level perception by the participants in the nine locations during the soundwalks in Chester Zoo, UK (none of the locations was classified as very loud).

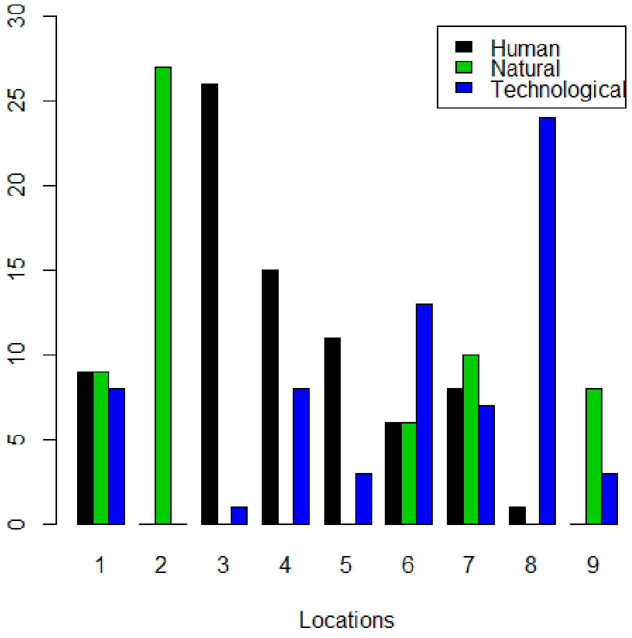


Figure 49. Main source of sound perceived by the participants in the nine locations during the soundwalks in Chester Zoo, UK.

Overall evaluation of the zoo soundscape

An overview of the attributes results of the zoo soundscape can be found in Figure 50. Principal component analysis (PCA) of the semantic scales indicates that the four attributes used to classify the zoo soundscape can be reduced to three (Figure 51 and 52): eventfulness (eventful-uneventful and exciting-monotonous attributes), calmness (calm-chaotic attribute), and pleasantness (pleasant-unpleasant attribute). The first component, related to eventfulness, includes mainly the eventful-uneventful and exciting-monotonous attributes, which are almost overlaid in the PCA graph (Figure 51). This component explained 68.21% of the data variance. The second component included only the calm-chaotic attribute, which did not cause any variable's reduction. This component explained 30.44% of the data variance. Since pleasant-unpleasant and calm-chaotic attributes were not clearly related as a second component of the PCA (Figure 51), they were considered separately as calmness and pleasantness for further discussion.

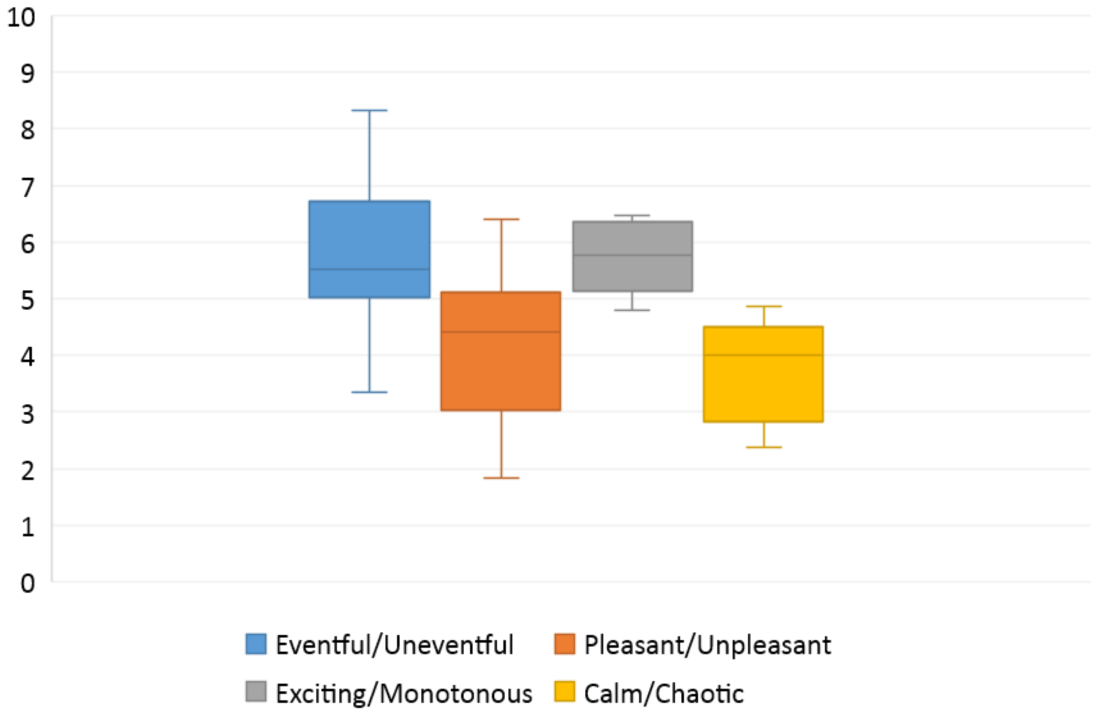


Figure 50. Soundscape evaluation ratings for Chester Zoo, UK (all locations together).

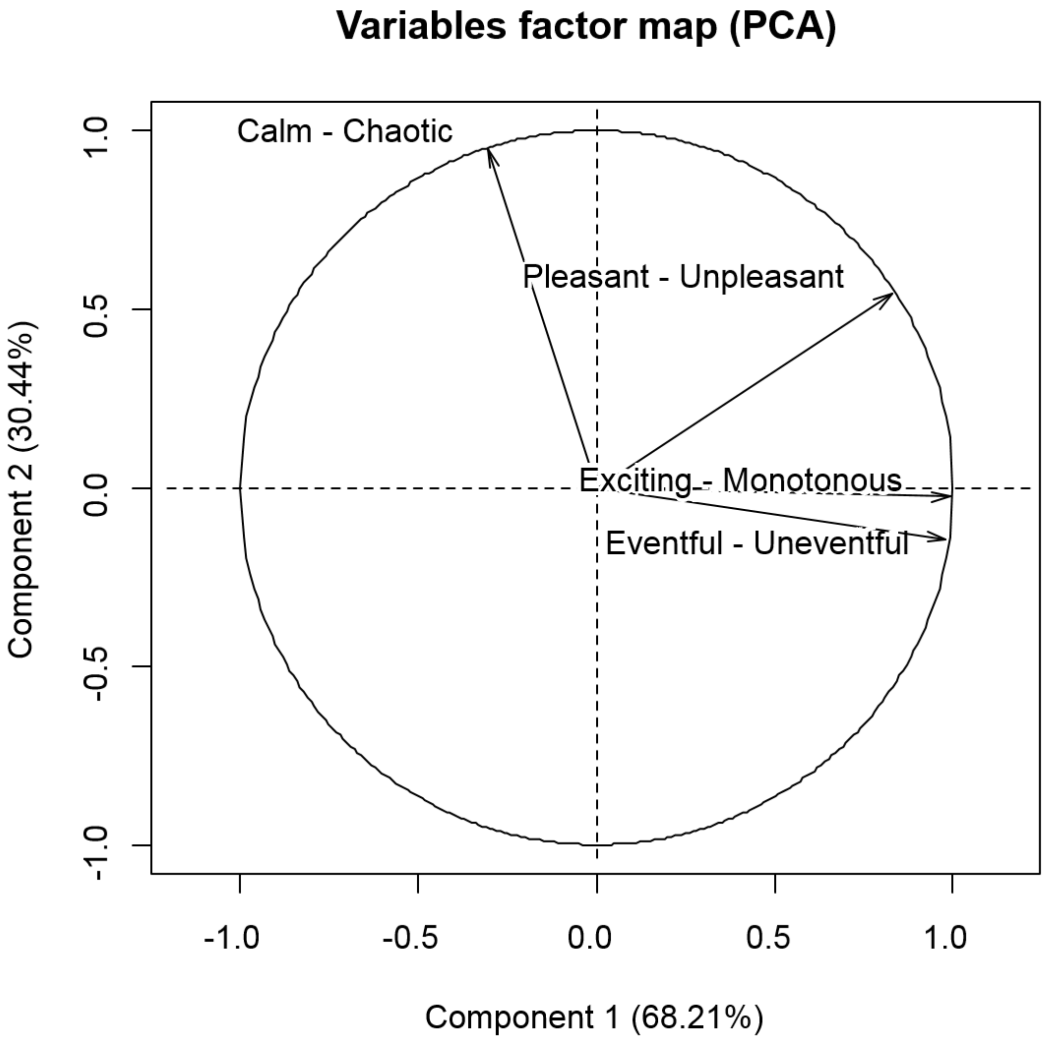


Figure 51. Principal component analysis result for the soundscape evaluation of Chester Zoo, UK. Component 1 eigenvalue: 2.73. Component 2 eigenvalue: 1.22.

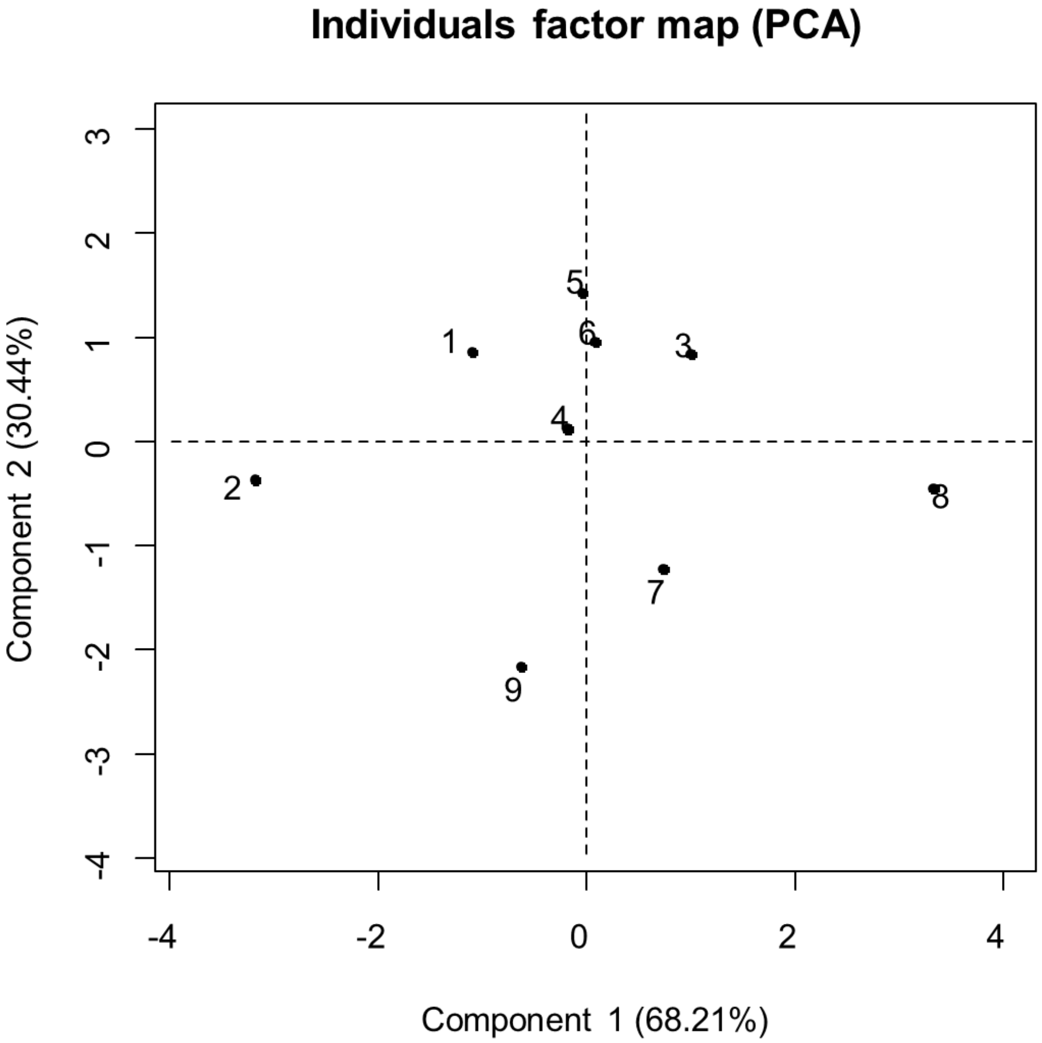


Figure 52. Principal component analysis result by locations for the soundscape evaluation of Chester Zoo, UK. Component 1 eigenvalue: 2.73. Component 2 eigenvalue: 1.22.

Table 19 shows that although there were few significant correlations, many correlation factors can be considered moderate to high (values higher than 0.5) and they were better investigated by multiple regression analysis. The regressions made with the three reduced soundscape attributes (eventfulness, calmness, and pleasantness) indicated a cause and effect relationship among them and the sound and ambient characteristics with a considerably high explained variance, as can be seen in Tables 20, 21, and 22.

High correlation coefficients (higher than 0.7) in Table 19, even though not significant, indicate some interesting patterns in the importance of natural sounds in the evaluation of the soundscape attributes in the zoo. For instance, in the absence of natural sounds, the participants evaluated the soundscape as more uneventful, unpleasant, and monotonous. In addition, there is an implication of the occurrence of technological sounds in the eventfulness of the zoo soundscape and in the assessment of the environmental sound as monotonous and uneventful in the presence of this kind of sound. Another interesting correlation is a negative one between real and perceived sound level and eventfulness, showing that places classified as uneventful and monotonous were places where the sound levels were not high and people perceived as quiet.

Multiple regression analysis for eventfulness shows that technological sound is the only variable that explains the variance of this attribute in the zoo soundscape. An environment dominated by technological sounds tends to be perceived as more uneventful and monotonous. In contrast, calmness can be explained and, consequently, influenced by the sound levels (real and perceived), human sounds, and the characteristics of the area. When the equivalent sound levels are high and participants perceived the sound levels as high, the soundscape was evaluated as chaotic. Likewise, environments dominated by human sounds incline to receive the same evaluation. In addition, taken into consideration the locations assessed in this study, indoor areas were evaluated more frequently as calm than outdoor areas. The last attribute, pleasantness, can be explained only by sound sources, being positively correlated with human and technological sounds. This means that, in the zoo, places dominated by these sounds are usually evaluated as unpleasant.

Table 19. Pearson’s coefficient of correlation among the principal component scores (C1 and C2), soundscape attributes (eventful/uneventful, pleasant/unpleasant, exciting/monotonous, and calm/chaotic), acoustics measures (L_{Aeq} and sound level perception), sound source categories, (human, natural, and technological) and enclosure area (indoor and outdoor).

	C1	C2	E/U[1]	P/U[2]	E/M[3]	C/C[4]	L_{Aeq}	SLP[5]	Human[6]	Natural[7]	Technol. [8]	Indoor[9]
C2	0.00											
E/U[1]	**0.98*****	-0.14										
P/U[2]	*0.83*	0.54	0.73									
E/M[3]	**0.99*****	-0.03	**0.97*****	*0.80*								
C/C[4]	-0.30	**0.95****	-0.42	0.25	-0.32							
L_{Aeq}	-0.66	0.08	-0.68	-0.46	-0.69	0.25						
SLP[5]	-0.67	0.10	*-0.71*	-0.50	-0.63	0.29	0.50					
Human[6]	0.19	0.54	0.20	0.40	0.15	0.50	-0.38	-0.40				
Natural[7]	*-0.76*	-0.32	*-0.70*	*-0.79*	*-0.77*	-0.08	0.65	0.56	-0.53			
Technological[8]	*0.72*	-0.01	0.63	0.66	*0.71*	-0.28	-0.31	-0.25	-0.31	-0.39		
Indoor[9]	0.04	-0.41	0.13	-0.19	0.03	-0.40	0.18	0.16	-0.01	0.05	-0.04	
Outdoor[10]	-0.04	0.41	-0.13	0.19	-0.03	0.40	-0.18	-0.16	0.01	-0.05	0.04	-1.00

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Eventful/Uneventful attribute. [2] Pleasant/Unpleasant attribute. [3] Exciting/Monotonous attribute. [4] Calm/Chaotic attribute. [5] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [6] Soundscape dominated by human sounds, dichotomous coded (0, 1). [7] Soundscape dominated by natural sounds, dichotomous coded (0, 1). [8] Soundscape dominated by technological sounds, dichotomous coded (0, 1). [9] Location in an indoor area, dichotomous coded (0, 1). [10] Location in an outdoor area, dichotomous coded (0, 1).

Table 20. Stepwise multiple linear regression relating Eventfulness attribute to acoustics measures (sound level perception) and sound source categories (natural and technological).

Model fit, R^2 (R^2 adj.)	**F-statistics**	**Independent variables**	**Multiple regression Coefficient (±SE)**	**t-value**
0.86 (0.78)	10.58*	SLP[1]	-1.7228(±1.0554)	-1.632
		Natural[2]	-0.0785(±0.0421)	-1.865
		Technological[3]	**0.1142(±0.0423)**	**2.703***

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [2] Soundscape dominated by natural sounds, dichotomous coded (0, 1). [3] Soundscape dominated by technological sounds, dichotomous coded (0, 1).

Table 21. Stepwise multiple linear regression relating Calmness attribute to acoustics measures (L_{Aeq} and sound level perception), sound source categories (human, natural, and technological), and enclosure area (indoor).

Model fit, R^2 (R^2 adj.)	**F-statistics**	**Independent variables**	**Multiple regression Coefficient (±SE)**	**t-value**
0.99 (0.98)	59.57*	**L_{Aeq}**	**0.1342(±0.0163)**	**8.232***
		SLP[1]	**1.7529(±0.1824)**	**9.610***
		Human[2]	**0.1051(±0.0092)**	**11.400****
		Natural[3]	-0.0174(±0.0096)	-1.807
		Technological[4]	0.0350(±0.0095)	3.690
		Indoor[5]	**-0.9867(±0.0923)**	**-10.689****

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [2] Soundscape dominated by human sounds, dichotomous coded (0, 1). [3] Soundscape dominated by natural sounds, dichotomous coded (0, 1). [4] Soundscape dominated by technological sounds, dichotomous coded (0, 1). [5] Location in an indoor area, dichotomous coded (0, 1)

Table 22. Stepwise multiple linear regression relating Pleasantness attribute to sound source category (human and technological).

Model fit, R^2 (R^2 adj.)	**F-statistics**	**Independent variables**	**Multiple regression Coefficient (±SE)**	**t-value**
0.85 (0.80)	17.23**	**Human[1]**	**0.1175(±0.0288)**	**4.080****
		Technological[2]	**0.1717(±0.0325)**	**5.290****

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Soundscape dominated by human sounds, dichotomous coded (0, 1). [2] Soundscape dominated by technological sounds, dichotomous coded (0, 1).

5.3.1. Location 1 (Main entrance)

As can be seen in Figure 53, the soundscape attributes for the sonic environment of the main entrance were varying in the middle of the scales, which makes its classification hard. By observing the results in Table 23, people tended to evaluate the soundscape as pleasant in the presence of natural sounds. There is in this location a positive correlation between human sound and equivalent sound levels. There is also an interesting correlation between sound level perception and sound source; in this area, the visitors classify the sound levels as loud in the absence of natural sounds and presence of technological sounds.

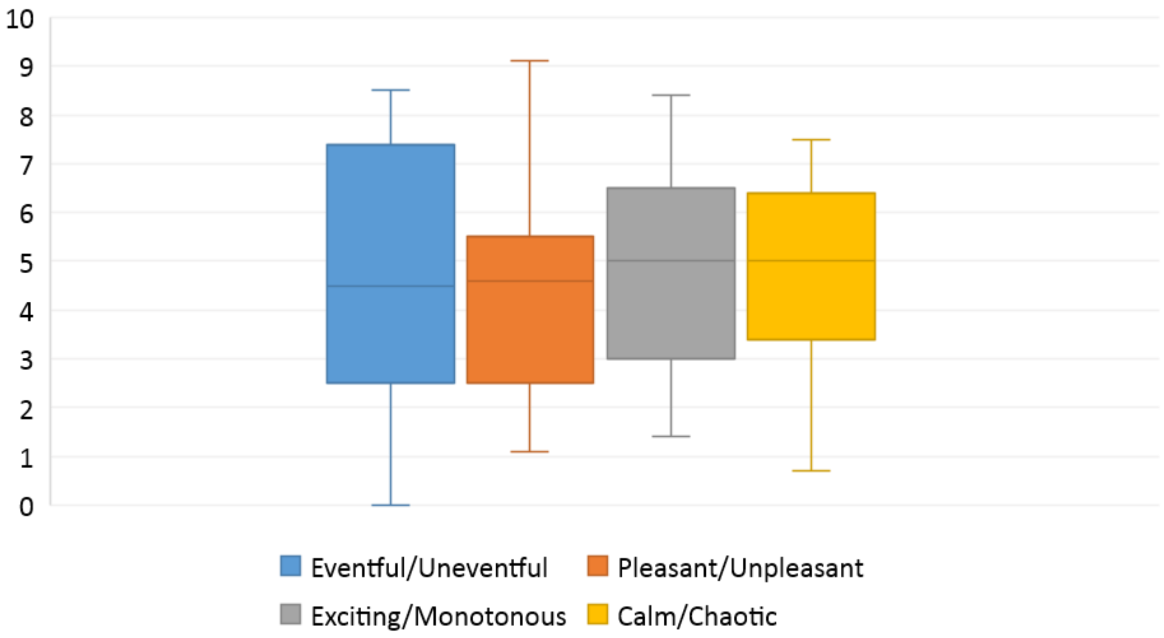


Figure 53. Soundscape evaluation ratings for location 1 (Main entrance) in Chester Zoo, UK.

Table 23. Pearson’s coefficient of correlation among the soundscape attributes (eventful/uneventful, pleasant/unpleasant, exciting/monotonous, and calm/chaotic), acoustics measures (L_{Aeq} and sound level perception), and sound source categories (human, natural, and technological) for location 1 (Main entrance) in Chester Zoo, UK.

	E/U[1]	P/U[2]	E/M[3]	C/C[4]	L_{Aeq}	SLP[5]	Human[6]	Natural[7]
P/U[2]	-0.09							
E/M[3]	0.52	0.18						
C/C[4]	-0.40	0.41	-0.35					
L_{Aeq}	-0.31	0.54	0.09	0.19				
SLP[5]	-0.43	0.50	-0.09	0.52	0.36			
Human[6]	-0.33	0.26	-0.14	0.14	**0.59****	0.10		
Natural[7]	0.28	**-0.62***	0.14	-0.51	-0.50*	**-0.71*****	-0.53	
Technological[8]	0.05	0.37	0.00	0.38	-0.07	**0.63***	-0.49	-0.49

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Eventful/Uneventful attribute. [2] Pleasant/Unpleasant attribute. [3] Exciting/Monotonous attribute. [4] Calm/Chaotic attribute. [5] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [6] Soundscape dominated by human sounds, dichotomous coded (0, 1). [7] Soundscape dominated by natural sounds, dichotomous coded (0, 1). [8] Soundscape dominated by technological sounds, dichotomous coded (0, 1).

5.3.2. Location 2 (Tropical Realm)

The tropical realm was mostly evaluated as eventful, pleasant, exciting, and calm place (Figure 54). Table 24 shows that all correlations with the acoustic parameters were small and non-significant.

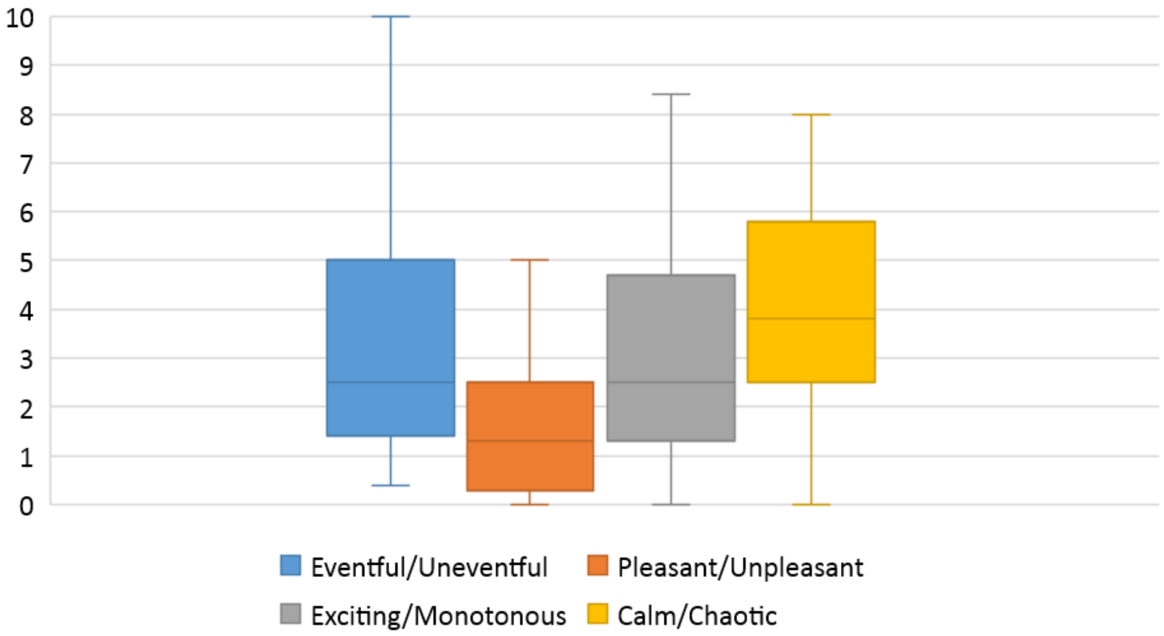


Figure 54. Soundscape evaluation ratings for location 2 (Tropical Realm) in Chester Zoo, UK.

Table 24. Pearson's coefficient of correlation among soundscape attributes (eventful/uneventful, pleasant/unpleasant, exciting/monotonous, and calm/chaotic), and acoustics measures (L_{Aeq}) for location 2 (Tropical Realm) in Chester Zoo, UK.

	E/U[1]	P/U[2]	E/M[3]	C/C[4]	L_{Aeq}
P/U[2]	0.47				
E/M[3]	**0.68*****	**0.71*****			
C/C[4]	-0.36	0.22	-0.18		
L_{Aeq}	0.16	0.07	0.18	-0.27	
SLP[5]	-0.16	0.25	-0.15	0.24	-0.15

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Eventful/Uneventful attribute. [2] Pleasant/Unpleasant attribute. [3] Exciting/Monotonous attribute. [4] Calm/Chaotic attribute. [5] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4).

5.3.3. Location 3 (Aye-ayes' enclosure)

In the aye-ayes' enclosure, the participants mostly evaluated the sound environment as uneventful and monotonous (Figure 55). In addition, the perception of the sound levels is negatively correlated with the exciting-monotonous attribute and a positively correlated to calm-chaotic one (Table 25). This means that, in this area, when the participants perceived the sound as quiet they considered the soundscape monotonous and calm.

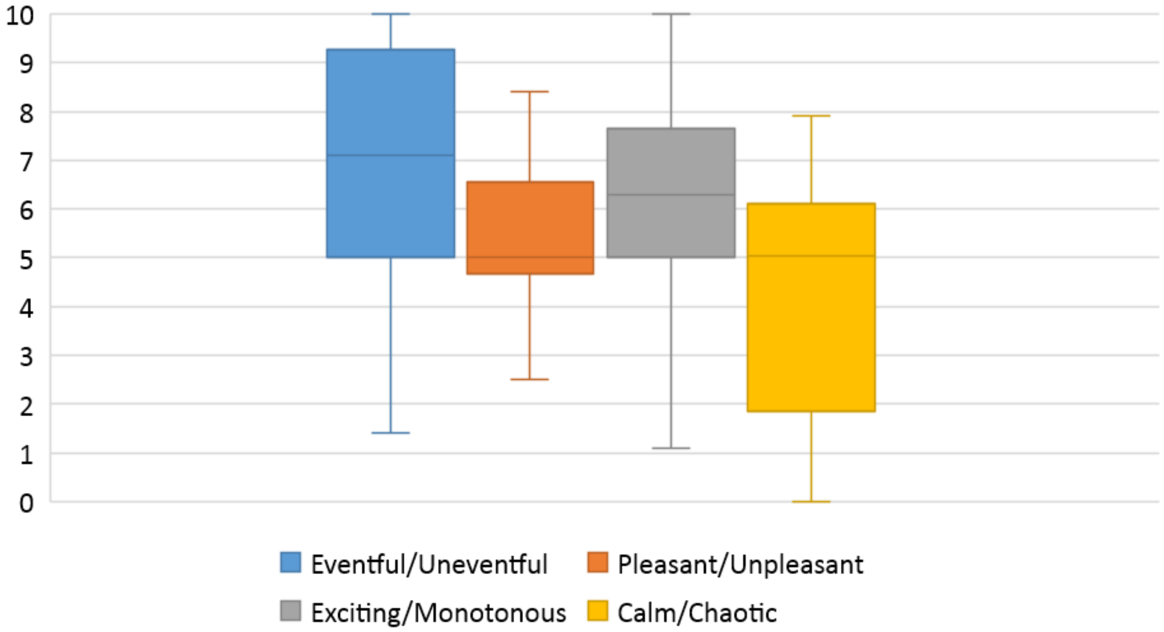


Figure 55. Soundscape evaluation ratings for location 3 (Aye-ayes' enclosure) in Chester Zoo, UK.

Table 25. Pearson's coefficient of correlation among soundscape attributes (eventful/uneventful, pleasant/unpleasant, exciting/monotonous, and calm/chaotic), acoustics measures (L_{Aeq} and sound level perception), and sound source categories (human and technological) for location 3 (Aye-ayes' enclosure) in Chester Zoo, UK.

	E/U[1]	P/U[2]	E/M[3]	C/C[4]	L_{Aeq}	SLP[5]	Human[6]
P/U[2]	-0.09						
E/M[3]	**0.68*****	-0.08					
C/C[4]	-0.43	**0.67*****	-0.49				
L_{Aeq}	-0.32	0.01	-0.39	0.20			
SLP[5]	-0.57	0.54	**-0.64****	**0.84*****	0.52		
Human[6]	-0.25	0.01	-0.33	-0.05	0.03	0.15	
Technological[7]	0.25	-0.01	0.33	0.05	-0.03	-0.15	**-1*****

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Eventful/Uneventful attribute. [2] Pleasant/Unpleasant attribute. [3] Exciting/Monotonous attribute. [4] Calm/Chaotic attribute. [5] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [6] Soundscape dominated by human sounds, dichotomous coded (0, 1). [7] Soundscape dominated by technological sounds, dichotomous coded (0, 1).

5.3.4. Location 4 (Spirit of the jaguar – Sloths' area)

This indoor enclosure is generally classified as calm (Figure 56). Similar to what happened in Location 2, there were non-significant correlations between the attributes and the acoustic characteristics (Table 26).

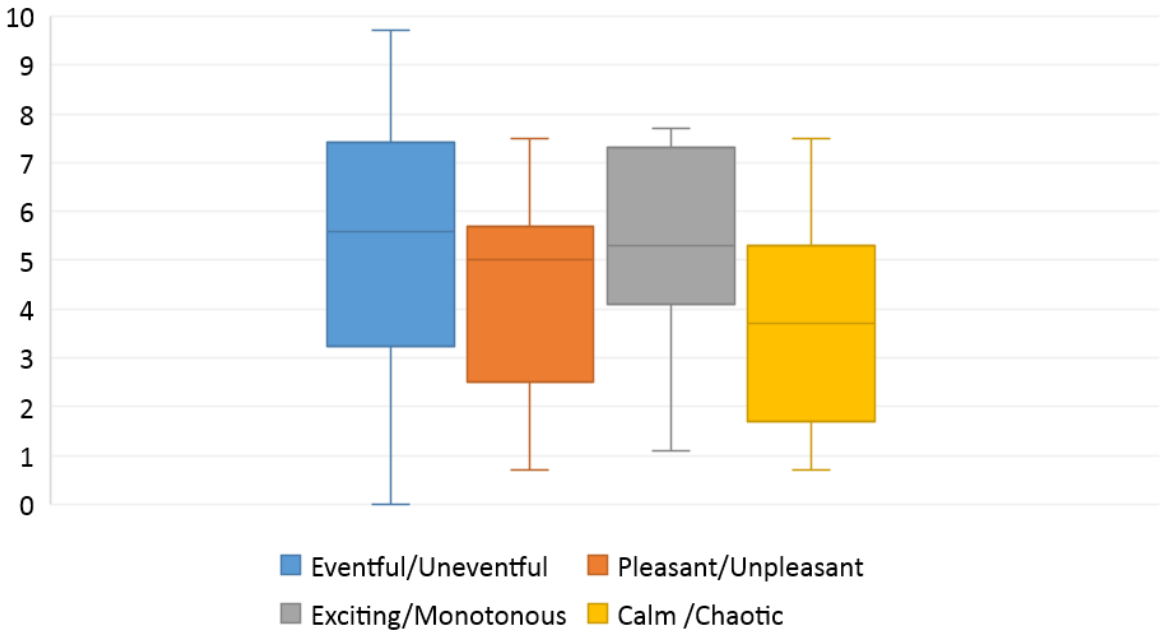


Figure 56. Soundscape evaluation ratings for location 4 (Sloths' area) in Chester Zoo, UK.

Table 26. Pearson's coefficient of correlation among soundscape attributes (eventful/uneventful, pleasant/unpleasant, exciting/monotonous, and calm/chaotic), acoustics measures (L_{Aeq} and sound level perception), and sound source categories (human and technological) for location 4 (Sloths' area) in Chester Zoo, UK.

	E/U[1]	P/U[2]	E/M[3]	C/C[4]	L_{Aeq}	SLP[5]	Human[6]
P/U[2]	-0.09						
E/M[3]	0.16	**0.58***					
C/C[4]	-0.31	**0.62***	0.38				
L_{Aeq}	-0.13	-0.02	-0.14	-0.02			
SLP[5]	-0.43	0.23	0.08	0.51	0.31		
Human[6]	-0.11	0.51	0.39	0.30	0.00	0.26	
Technological[7]	0.11	-0.51	-0.39	-0.30	-0.00	-0.26	**-1.00*****

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Eventful/Uneventful attribute. [2] Pleasant/Unpleasant attribute. [3] Exciting/Monotonous attribute. [4] Calm/Chaotic attribute. [5] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [6] Soundscape dominated by human sounds, dichotomous coded (0, 1). [7] Soundscape dominated by technological sounds, dichotomous coded (0, 1).

5.3.5. Location 5 (Madagascar play area)

Figure 57 shows that the play area, like Location 1, had soundscape evaluations fluctuating in the middle of the semantic scales. None of the variables was significantly correlated, as can be seen in Table 27.

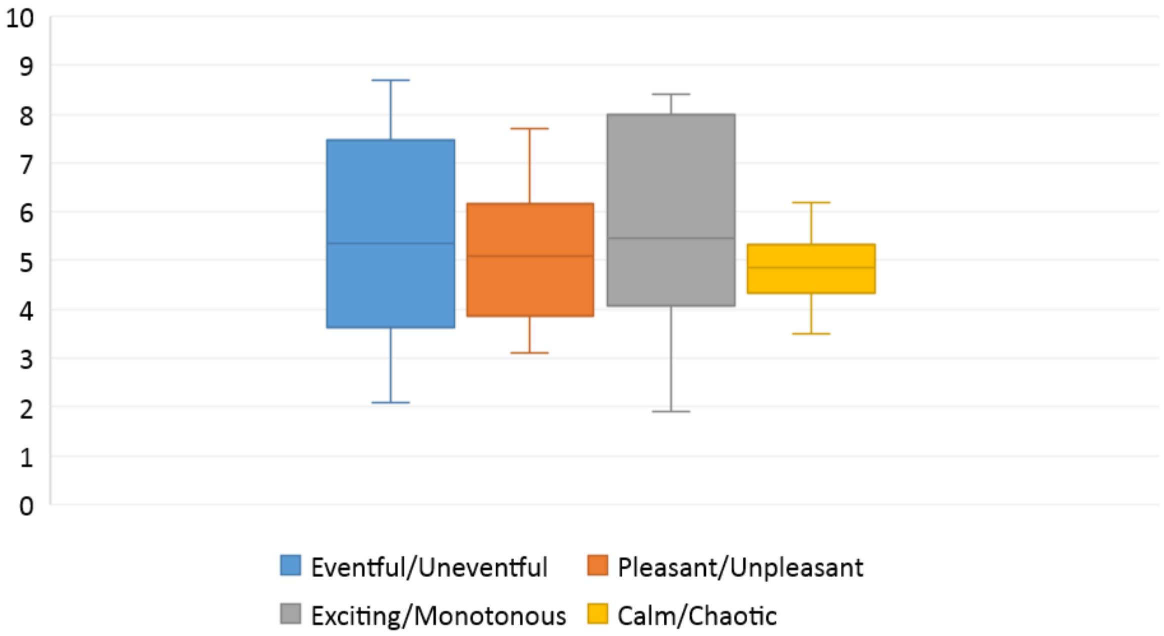


Figure 57. Soundscape evaluation ratings for location 5 (Madagascar play area) in Chester Zoo, UK.

Table 27. Pearson's coefficient of correlation among soundscape attributes (eventful/uneventful, pleasant/unpleasant, exciting/monotonous, and calm/chaotic), acoustics measures (L_{Aeq} and sound level perception), and sound source categories (human and technological) for location 5 (Madagascar play area) in Chester Zoo, UK.

	E/U[1]	P/U[2]	E/M[3]	C/C[4]	L_{Aeq}	SLP[5]	Human[6]
P/U[2]	0.67						
E/M[3]	**0.91*****	0.71					
C/C[4]	-0.25	0.29	-0.18				
L_{Aeq}	0.29	-0.11	0.03	-0.32			
SLP[5]	-0.30	-0.05	-0.38	0.43	0.40		
Human[6]	-0.18	-0.61	-0.11	-0.39	0.25	-0.20	
Technological[7]	0.18	0.61	0.11	0.39	-0.25	0.20	**-1*****

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Eventful/Uneventful attribute. [2] Pleasant/Unpleasant attribute. [3] Exciting/Monotonous attribute. [4] Calm/Chaotic attribute. [5] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [6] Soundscape dominated by human sounds, dichotomous coded (0, 1). [7] Soundscape dominated by technological sounds, dichotomous coded (0, 1).

5.3.6. Location 6 (Lions' enclosure)

The area around the lions' enclosure was mostly perceived as monotonous to the participants (Figure 58). Table 28 shows that the pleasant-unpleasant attribute evaluation was positively correlated with the sound levels and negatively with natural sounds. This means that, in this location, participants identified the area as unpleasant when the equivalent sound levels were high and in the absence of natural sounds. Natural sounds also correlated negatively with the calm-chaotic attribute and with equivalent sound levels. This means that the soundscape is more frequently evaluated as chaotic in the absence of natural sounds and that natural sounds were not responsible for the higher sound levels in this location.

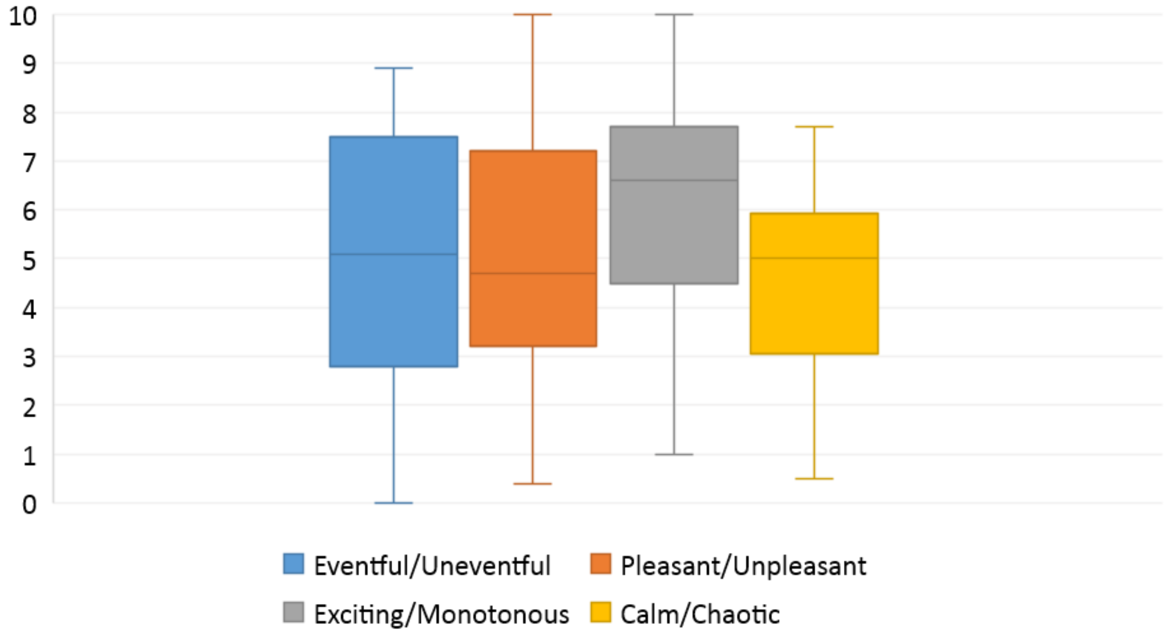


Figure 58. Soundscape evaluation ratings for location 6 (Lions' enclosure) in Chester Zoo, UK.

Table 28. Pearson's coefficient of correlation among soundscape attributes (eventful/uneventful, pleasant/unpleasant, exciting/monotonous, and calm/chaotic), acoustics measures (L_{Aeq} and sound level perception), and sound source categories (human, natural, and technological) for location 6 (Lions' enclosure) in Chester Zoo, UK.

	E/U[1]	P/U[2]	E/M[3]	C/C[4]	L_{Aeq}	SLP[5]	Human[6]	Natural[7]
P/U[2]	-0.36							
E/M[3]	0.32	0.49						
C/C[4]	**-0.44***	**0.62***	-0.01					
L_{Aeq}	-0.26	**0.66****	0.35	0.53				
SLP[5]	-0.43	0.48	0.19	0.53	0.34			
Human[6]	-0.10	0.08	-0.29	0.56	0.24	0.23		
Natural[7]	0.30	**-0.72*****	-0.16	**-0.66***	**-0.67***	-0.37	-0.32	
Technological[8]	-0.17	0.55	0.38	0.08	0.41	0.12	-0.59	-0.50

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Eventful/Uneventful attribute. [2] Pleasant/Unpleasant attribute. [3] Exciting/Monotonous attribute. [4] Calm/Chaotic attribute. [5] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [6] Soundscape dominated by human sounds, dichotomous coded (0, 1). [7] Soundscape dominated by natural sounds, dichotomous coded (0, 1). [8] Soundscape dominated by technological sounds, dichotomous coded (0, 1).

5.3.7. Location 7 (Capybaras' enclosure)

Figure 59 illustrates the soundscape evaluation of the visitors' area around the Capybaras' enclosure, where the participants considered the sonic environment as uneventful, pleasant, monotonous and calm. Several significant correlations were found in this location (Table 29). The eventful-uneventful attribute was negatively correlated with sound level perception and human sounds, which means that participants classified the environmental sound as more uneventful when they perceived the ambient as quiet and with no human sounds. Pleasant-unpleasant and calm-chaotic attributes were both positively correlated with sound level perception and negatively correlated with natural sounds. This can be interpreted in the way that the area was assessed as pleasant and calm when the participants perceived a quiet environment and in the presence of natural sounds.

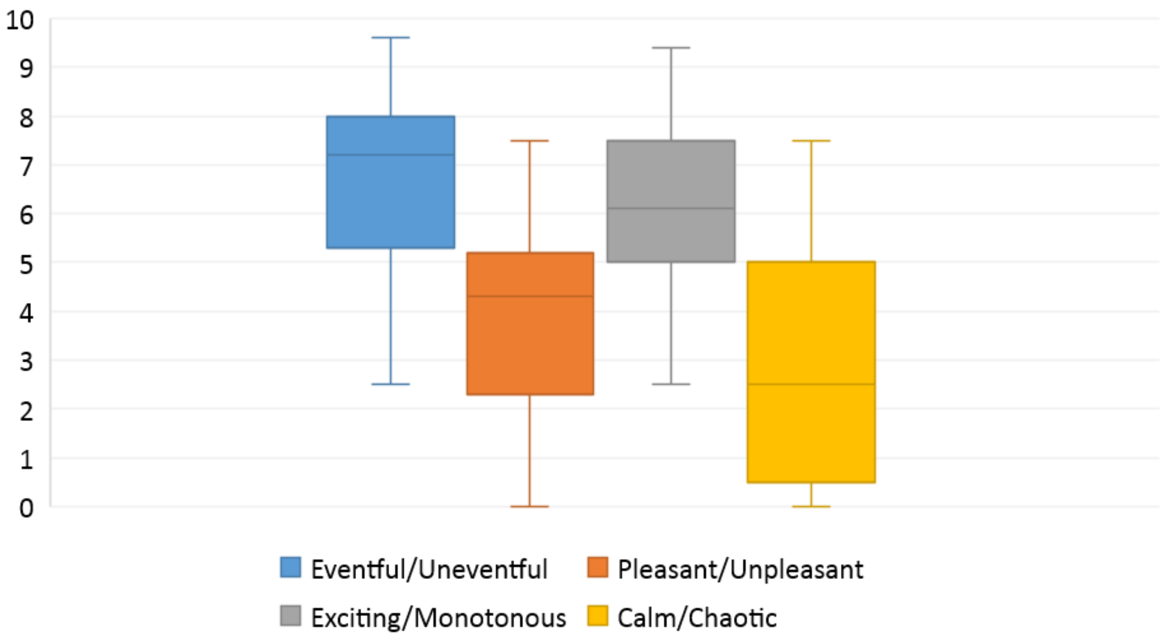


Figure 59. Soundscape evaluation ratings for location 7 (Capybaras' enclosure) in Chester Zoo, UK.

Table 29. Pearson's coefficient of correlation among soundscape attributes (eventful/uneventful, pleasant/unpleasant, exciting/monotonous, and calm/chaotic), acoustics measures (L_{Aeq} and sound level perception), and sound source categories (human, natural, and technological) for location 7 (Capybaras' enclosure) in Chester Zoo, UK.

	E/U[1]	P/U[2]	E/M[3]	C/C[4]	L_{Aeq}	SLP[5]	Human[6]	Natural[7]
P/U[2]	-0.42							
E/M[3]	**0.61***	0.13						
C/C[4]	**-0.64****	**0.81*****	-0.32					
L_{Aeq}	-0.57	0.31	-0.32	0.39				
SLP[5]	**-0.58***	**0.74*****	-0.24	**0.77*****	0.18			
Human[6]	**-0.59***	0.31	-0.35	0.47	0.39	0.29		
Natural[7]	0.32	**-0.78*****	-0.04	**-0.60***	-0.17	-0.58	-0.56	
Technological[8]	0.26	0.53	0.40	0.17	-0.17	0.34	-0.43	-0.51

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Eventful/Uneventful attribute. [2] Pleasant/Unpleasant attribute. [3] Exciting/Monotonous attribute. [4] Calm/Chaotic attribute. [5] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [6] Soundscape dominated by human sounds, dichotomous coded (0, 1). [7] Soundscape dominated by natural sounds, dichotomous coded (0, 1). [8] Soundscape dominated by technological sounds, dichotomous coded (0, 1).

5.3.8. Location 8 (Tsavo black rhino reserve – indoor area)

The black rhino indoor enclosure was mostly evaluated as uneventful, unpleasant, monotonous, and calm place (Figure 60). The only significant correlation found was between pleasant-unpleasant attributes and sound level perception, which shows that participants felt the soundscape as unpleasant in this area when they perceived loud sound levels (Table 30).

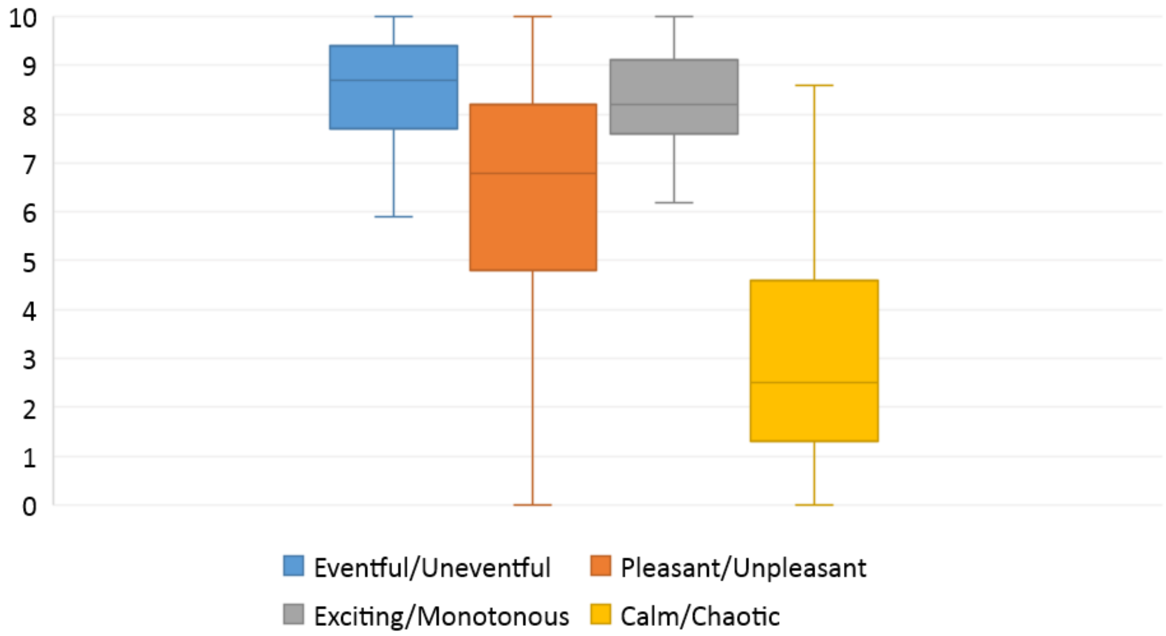


Figure 60. Soundscape evaluation ratings for location 8 (Tsavo black rhino reserve) in Chester Zoo, UK.

Table 30. Pearson's coefficient of correlation among soundscape attributes (eventful/uneventful, pleasant/unpleasant, exciting/monotonous, and calm/chaotic), acoustics measures (L_{Aeq} and sound level perception), and sound source categories (human and technological) for location 8 (Tsavo black rhino reserve) in Chester Zoo, UK.

	E/U[1]	P/U[2]	E/M[3]	C/C[4]	L_{Aeq}	SLP[5]	Human[6]
P/U[2]	-0.06						
E/M[3]	0.30	**0.60***					
C/C[4]	-0.26	0.45	0.04				
L_{Aeq}	-0.02	-0.48	-0.30	-0.37			
SLP[5]	-0.28	**0.59***	0.43	0.34	-0.35		
Human[6]	-0.44	-0.25	-0.49	0.06	NA	-0.17	
Technological[7]	0.44	0.25	0.49	-0.06	NA	0.17	**-1.00*****

$* p \leq 0.05$, $** p \leq 0.01$, $*** p \leq 0.001$

[1] Eventful/Uneventful attribute. [2] Pleasant/Unpleasant attribute. [3] Exciting/Monotonous attribute. [4] Calm/Chaotic attribute. [5] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [6] Soundscape dominated by human sounds, dichotomous coded (0, 1). [7] Soundscape dominated by technological sounds, dichotomous coded (0, 1). NA: test not possible to perform.

5.3.9. Location 9 (Okapi's enclosure)

Figure 61 shows the semantic scales results of the Okapi enclosure, where the participants evaluated the soundscape as pleasant and calm and tended to evaluate as uneventful and monotonous. Although the only significant correlations were found between the equivalent sound levels and the source of sound (showing that natural sounds were responsible for the high sound levels in this area), the sound sources also presented an interesting high correlation factor with two attributes, eventful-uneventful and exciting-monotonous (Table 31). This implies that for the participants the sonic environment was more uneventful and monotonous in the absence of natural sounds and occurrence of technological ones.

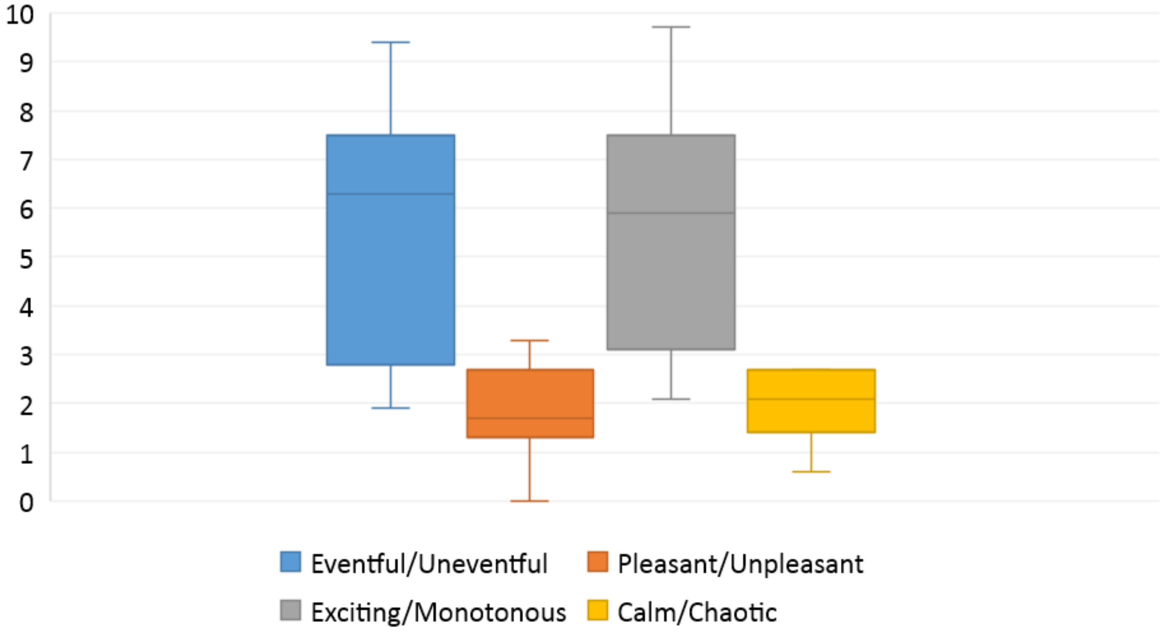


Figure 61. Soundscape evaluation ratings for location 9 (Okapi's enclosure) in Chester Zoo, UK.

Table 31. Pearson's coefficient of correlation among soundscape attributes (eventful/uneventful, pleasant/unpleasant, exciting/monotonous, and calm/chaotic), acoustics measures (L_{Aeq} and sound level perception), and sound source categories (natural and technological) for location 9 (Okapi's enclosure) in Chester Zoo, UK.

	E/U[1]	P/U[2]	E/M[3]	C/C[4]	L_{Aeq}	SLP[5]	Natural[6]
P/U[2]	0.54						
E/M[3]	0.77	0.74					
C/C[4]	-0.02	0.48	0.16				
L_{Aeq}	-0.65	-0.67	-0.80	-0.10			
SLP[5]	-0.37	0.12	-0.14	-0.15	0.31		
Natural[6]	*-0.71*	-0.59	*-0.78*	-0.06	**0.87****	0.39	
Technological[7]	*0.71*	0.59	*0.78*	0.06	**-0.87****	-0.39	**-1*****

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[1] Eventful/Uneventful attribute. [2] Pleasant/Unpleasant attribute. [3] Exciting/Monotonous attribute. [4] Calm/Chaotic attribute. [5] Sound level perception coded as very quiet (1), quiet (2), Moderate (3), and Loud (4). [6] Soundscape dominated by natural sounds, dichotomous coded (0, 1). [7] Soundscape dominated by technological sounds, dichotomous coded (0, 1).

5.4. Discussion

In some locations during the soundwalk, the participants' perception of sound levels did not match the real sound levels in decibels. Some places, like the Tropical Realm and the sloths' area, for example, presented equivalent sound levels above 60 dB(A), which is considered above the human threshold of annoyance (according to the WHO (1999)). The noisier features of the Tropical Realm is justified by its indoor area with free-living birds who vocalise constantly and by a waterfall which sound prevails over the environment. The sloths' area is also an indoor enclosure with a high ceiling that causes reverberation of the sound. The largest amplitude range of the sound in this area can be explained by different conditions faced during the different soundwalks, such as moments with few visitors and moments with school groups. However, these places were never classified as very loud and were less classified as loud compared to the moderate classification. This finding agrees with two different studies developed in a zoo and in public urban parks (Soares et al., 2012, Vianna et al., 2015), where individuals considered the overall sound low or acceptable and the environment silent, despite the fact that the sound levels were registered above the legislation recommendation limits.

This difference in the sound level perception and the real sound levels could happen due to the expectation of the participant in face of the evaluated area. The soundwalk participants are used to visit the zoo, therefore, their prior experience at the venue could have caused some expectation of what would be heard during the experiment and additionally this prior experience could have been used as a base of soundscape evaluation during the soundwalks (Bruce and Davies, 2014). Another study made in urban parks with water fountains has found that people do not go to some areas expecting a quiet experience, as a result, the appropriateness of the soundscape was not negatively influenced by the high sound levels in the area (Steele et al., 2016). Considering this, in a loud area of the zoo as the

Tropical Realm, participants could have been influenced by previous experiences and expectations when evaluating the sound levels as moderate more frequently than as loud. In addition, the complexity of the physical (trees, free animals, waterfall, lakes, people, built environment materials) and sonic (birds singing, waterfall, ventilation system, conversation, room reverberation) features of the environments in this indoor area, can be interpreted differently by each participant and can distract them from the sound perception. Research about the landscape effects on assessments discusses that visual characteristics of the environment can direct people's perception of the soundscape (Liu et al., 2013, Nilsson et al., 2012).

The analysis of the zoo soundscape revealed three principal attributes that can be used in its evaluation: eventfulness, calmness, and pleasantness. This result is different from other studies that found only eventfulness and pleasantness as factors of a soundscape evaluation of urban open areas, parks, and green areas (Axelsson et al., 2010, Jeon et al., 2014, Jeon and Hong, 2015, Radsten-Ekman et al., 2013). This dissimilarity in the number of the main soundscape attributes may have happened due to significant differences in the locations evaluated in Chester Zoo in terms of the type of sound sources, as well as different physical characteristics of the locations.

In corroboration with another study (Berglund and Nilsson, 2006), multiple regression analysis revealed that sound levels have a direct effect on the calmness and not on the pleasantness of a zoo environment. Usually, pleasantness has a strong association with the quality of the soundscape and sound pressure levels can be amplified by both pleasant and unpleasant sounds. The effect of sound levels (used here as L_{Aeq} values) in the calmness is understandable since equivalent sound levels are commonly used as an indicator of environmental quietness (Jeon and Hong, 2015).

In the zoo, the sound sources used in the questionnaires (natural, human, and technological) are highly correlated with some attributes of the sonic environment (Table 19 to 22) and can be used in comparison to other soundscape studies. In the present study, it was found, in agreement with other authors (Axelsson et al., 2010, Axelsson et al., 2014, Jeon et al., 2014, Nilsson et al., 2007) that technological sounds have an implication in the eventfulness and pleasantness of the soundscape and have a positive correlation with uneventful, unpleasant, and monotonous attributes, meaning a bad sound quality. For instance, in the present study, the black rhino's area (Tsavo black rhino reserve – location 8) soundscape was mostly classified as uneventful. The soundscape of this area, during many soundwalks, was dominated by the ventilation system (technological sound). Probably, the participants were not expecting to enter the rhino enclosure and to perceive a soundscape dominated by technological sounds, and this expectation breach could have caused the uneventful characterisation of the acoustic environment (Bruce and Davies, 2014). On the other hand, also in agreement with the literature (Axelsson et al., 2010, Axelsson et al., 2014, Chau et al., 2010, Colleony et al., 2017, Yang and Kang, 2005), natural sounds have a positive correlation with the attributes associated with a good sound quality (eventful, pleasant, and exciting), which was also found here in the Tropical Realm (location 2). This location soundscape, dominated by natural sounds, was mostly classified as eventful, pleasant, and exciting.

The association of human sounds and the calmness and pleasantness attributes, found here as a positive correlation (human sounds linked with chaotic and unpleasant evaluations), finds corroborations in other studies (Axelsson et al., 2010, Colleony et al., 2017, Jeon et al., 2014, Viollon and Lavandier, 2000). In a zoo environment, human sounds can be perceived as positive or negative depending on the characteristics of the location and the number of people. Colleony et al. (2017) have found that some enclosures that can cause strong reverberation of the sound, especially when crowded, make visitors avoid the area; conversely, people find enriching to hear other visitors talking about their experience at the zoo. In Chester Zoo, the sloths' area (Location 4) has this characteristic of reverberating the sound, and this can explain the moderate positive correlation between human sounds and unpleasant attribute (Table 26). Another location, the Madagascar play area (Location 5), is a place for leisure and mostly where families spend time to rest and interact. In this case, human sounds present a positive correlation with pleasant attribute (Table 27).

5.5. Conclusion

The findings of this study have important implications for improving the understanding of the sonic environment in a zoo. The results show that zoos should be more careful about the environmental sound of places with predominant technological sounds.

Since it was found in the present study that natural sounds are correlated with soundscape attributes typical of a good quality environment, these sounds could be used to mitigate the undesirable effects of the technological sounds. Some water sounds (e.g. stream and waterfall) are commonly perceived as high pleasant sounds and can be used to improve the overall quality and acoustic comfort of an environment (Kang and Zhang, 2010, Radsten-Ekman et al., 2013). Although the incorporation of water sound may be of great use, the zoo should be careful whether this kind of sound causes an impact on the animals in the area. In addition, water sounds can mask both desirable and undesirable sounds sources, so in planning of using them, it is important to balance the positive effects of masking technological sounds (related to unpleasant and uneventful perceptions) and the negative effect of masking other natural sounds, such as animals' vocalizations (related to pleasant perceptions) (Axelsson et al., 2014).

In general, human sounds were associated with a chaotic sound environment. However, depending on the circumstances, the visitors can perceive this sound source, inherent in the zoo soundscape, as positive. Therefore, an educational work to moderate the level of noise coming from visitors, which is already being undertaken by Chester Zoo in some areas, shows itself important for the maintenance of the good quality of the sonic ambient (especially in places where there are no other sounds to mask the effect of the visitors' sound).

The purpose of the current study of investigation of the visitors' perception of the soundscape can be of important application for zoos around the world. The identification of sonic aspects of zoo areas, such as sound sources and sound pressure levels, may be used to mitigate some undesirable sound effects in areas already existed and may also be used in the planning of new enclosures and visitor common areas in zoological parks.

Section 6. Conclusions

6.1. Discussion

In zoos, sound pressure levels differ completely from sound levels in nature (Morgan and Tromborg, 2007). In a natural situation, animals can run away from or seek protection when facing an adverse condition like an undesirable sound source. In a captive situation, animals do not have this option. Moreover, this lack of control over an aversive situation can lead individuals to express a variety of stress responses, such as behavioural changes and increase in physiological stress levels.

Visitors are expected to be the main source of noise in a zoo (Quadros et al., 2014), but the findings of the present study found a difference to previous studies. Ventilation and heating systems of the enclosures investigated here dominated the sonic environment. This result indicates that zoos from temperate regions face different noise issues compared to zoos from tropical regions. Temperate regions, such as the UK, usually encounter along the year a large temperature range going sometimes from negative degree Celsius to about 30ºC during a year (Met Office, 2010). This reality necessitates the use of heating systems, for many animal species, during winter times and ventilation system during summer times, which results in continuous noise throughout the year. This situation is compounded by the use of glass barriers, which allow visitors to view animals and protect against visitor noise, but create a sound reflective surface for the aforementioned heating and ventilation systems. The situation in some tropical regions, such as in the city studied by Quadros et al. (2014) (Belo Horizonte, Minas Gerais, Brazil) where the temperature range is smaller, from around 13ºC to 28ºC (INMET, 1990), is different. Due to this, the use of the ventilation/heating systems is unnecessary, and visitors are the main source of noise, especially as glass barriers are not used to maintain temperatures

The ventilation/heating system noise does not exclude the issues of the noise produced by the visitors where glass barriers are not present in temperate countries, because the aforementioned systems can cause, in some situations, the visitors present near an enclosure to speak louder than they probably would without such high background noise; this is known as the Lombard effect (Zollinger and Brumm, 2011).

This combination of findings about the ventilation/heating systems provides support about the importance of the use of barriers to mitigate internal and external sound in zoo enclosures, thereby reducing the impact of the produced noise in the animals' welfare. Zoos should also purchase or design quieter ventilation/heating systems (see "Buy Quiet" in HSE (2018)). A quieter system may be more expensive, however, is more economical to invest in quieter equipment than to work on reducing the noise after equipment purchase. In cases, when a sound barrier cannot be used or a better ventilation/heating system cannot be purchased, zoos should consider factors affecting visitor behaviour to prevent the potential increase of the sound levels due to the Lombard effect. This could be done by environmental education programs around the zoo (i.e. signs but also install visible warnings, such as lights or LED information boards, that sound pressure levels have exceeded thresholds considered good for animal welfare). The effectiveness of such environmental education should, of course, be tested.

This work is a relevant piece to zoos and other captive facilities in temperate countries (e.g. animal shelters), which should be more aware of the constant and loud noise produced by the ventilation and heating systems. The situation found here could be the source of chronic stress for non-zoo animals housed in temperate countries.

During the study of the behavioural and physiological animal responses to noise, individual responses were found in all investigations. These findings indicate that mammals are likely to present individual differences to sound stimuli and this needs highlighting to zoos. For example, studies in humans indicate that 10 to 20 per cent of the population are noise sensitive and that this, probably, has a genetic basis (Andersson et al., 2002, Heinonen-Guzejev et al., 2005, Paulin et al., 2016). Thus, zoos could use this information to start considering the individual's characteristics when planning their husbandry approaches, such as enclosure design planning. For example, the use of sound deadening substrates (e.g. wood chip), quiet fans/heaters (for heating and ventilation systems) and locating sensitive species or individuals in enclosures where they are less likely to be visited by the public.

Technological sounds are a proven source of concern in zoos regarding both, the animals and the visitors. Animals, as was discussed before can be behaviourally and physiologically adversely affected by this source of noise (ventilation/heating systems). In addition, the findings in Section 5 showed that visitors are also affected by this sound source because technological sounds were highly correlated with unpleasant, uneventful, and monotonous soundscape attributes, which are associated with bad quality of the sonic environment.

Soundscape perception results presented in Section 5 showed that for humans the sound level influence part of the soundscape perception but is not the principal point of evaluation of soundscape quality. From the three attributes considered for a zoo soundscape evaluation, only calmness is explained by equivalent sound levels (L_{Aeq}). This outcome of the soundwalks, in agreement with other studies (Axelsson et al., 2010, Axelsson et al., 2014, Jeon et al., 2014, Nilsson et al., 2007, Soares et al., 2012, Steele et al., 2016, Vianna et al., 2015), indicates that humans perception of the soundscape are more influenced by the type of sound source, and maybe by expectations, than by the sound levels.

The results taken together suggest that the zoos could improve the visitor experience in some areas by actively designing the soundscape with techniques of noise control and masking. Noise control can be made by reducing the level of detrimental sound (HSE, 2018);

as it was mentioned before, by using barriers, more efficient ventilation/heating systems, or environmental education. The sound masking can be energetic or informational (Pollack, 1975). In the energetic masking, the masking sound is louder than the masked sound, such as the use of fountains to overcome traffic or other undesirable sounds (Kang and Zhang, 2010, Radsten-Ekman et al., 2013, Steele et al., 2016). In the informational masking, the masking sound is more salient than the masked sound, it attracts attention, such as speech content, for example (Kidd and Colburn, 2017).

For animals, the data produced here indicates that sound levels are an important influence in their response to noise. However, future studies could be done by manipulating the source of the produced sound in the animal's enclosure to check if they would present different behavioural and physiological responses to different sources of sound. This kind of research would be interesting to investigate if the use of natural sounds, which are commonly seen as pleasant by humans and can be used to mask uncomfortable sounds, could also have the same effect on animals. For example, music or natural sounds are often used as environmental enrichment, but with varying degrees of effectiveness in changing an animal’s welfare status (see Wells (2009), for a review). This variation in animal response could be due to the sound source but also to the sound pressure level, which should be carefully measured (Wells, 2009).

6.2. Recommendations for each studied species

6.2.1. Aye-aye

1. Control the noise coming from the ventilation/heating system by changing the systems for a more silent one or using soundproof barriers.
2. After the noise control of the ventilation/heating system, sound measurements should be done inside the animal enclosure to check if the mentioned systems were masking

the visitors sound or if the glass barrier in the enclosure is really protecting the animal from the visitors sound.

6.2.2. Black rhinos

1. Control the noise coming from the ventilation/heating system by changing the systems for a more silent one or using soundproof barriers.
2. After the noise control of the ventilation/heating system, sound measurements should be done inside the animal enclosure to check the influence of visitors in the sound levels.
3. Environmental education activities could be made with the visitors to help decrease the sound produced by them. These activities could use the outcomes from the sound measurements and animal behaviour studies, to facilitate the visitors visualize and understand the real effect of their attitude inside an animal enclosure.

6.2.3. Okapi

1. Control the noise coming from the ventilation/heating system by changing the systems for a more silent one or using soundproof barriers.
2. This animal stronger response to equivalent sound levels with Z weighting indicates its sensitivity to low-frequencies sounds. Therefore, it is important to verify the emitted frequency of the devices inside the animal area (such as CCTV and air systems) that can be a source of stress to this animal.
4. After the noise control of the ventilation/heating system, sound measurements should be done inside the animal enclosure to check the influence of visitors in the sound levels.
5. Environmental education activities could be made with the visitors to help decrease the sound produced by them. These activities could use the outcomes of the sound

measurements, behavioural and physiological studies, to facilitate the visitors visualize and understand the real effect of their attitude inside an animal enclosure.

6.2.4. Two-toed sloths

1. In this enclosure, the environmental sound is completely dominated by the visitors' conversation, sometimes reaching significant high levels. For this reason, a continuous educational work with the visitors in this enclosure is necessary to decrease the noise pollution levels. The educational activities could use the outcomes of the sound measurements and behavioural studies, to facilitate the visitors visualize and understand the real effect of their attitude inside an animal enclosure.
2. The sloths tend to search for a shelter when sound levels are high. Thus, soundproof dens could be a sensible option for improvements in the animals welfare when sound levels are high.

6.2.5. Orang-utans

1. Control the noise coming from the ventilation/heating system by changing the systems for a more silent one or using soundproof barriers.
2. Invest in environmental enrichment on the days of expected higher sound pressure levels to prevent the orang-utan group from facing stressful situations or even help the animals to better cope with stress.

6.3. Recommendations for further work

1. The small sample size in both, behavioural and physiological (Sections 3 and 4) studies, limited a possible generalization of the results on a species basis. In zoos, the number of individuals available is a common challenge faced by researchers (Kuhar, 2006). The observation of a single animal cannot be used to generalise the results but can be used to provide an insight about how an animal can react to determined

stimuli. The present study discussed that individual responses to noise are of great importance to zoos when caring and planning management for the animals. For humans, it is common the use of questionnaires to identify the sensitivity to noise (Schutte et al., 2007a, Schutte et al., 2007b, Zimmer and Ellermeier, 1999). These questionnaires are used as a tool of global noise sensitivity. As a continuation of my thesis results about individual variation in response to noise, future research could be done with the aim to develop a similar questionnaire to identify zoo animals' individual sensitivity to noise. Psychometric tests are methods already suggested in the context of zoos to evaluate the human-animal bond (Hosey et al., 2018). A section about the animals' reactions to noise could be added to this kind of questionnaires to help the zoos to identify the animals' individual response to noise.

2. During the study of two different species, the okapi and the black rhinos, the outside area in the animal's enclosure was not investigated due to logistical reasons mentioned in Sections 3.1.2 and 3.1.3. This lack of information about the sound levels in the outside and about the animal behaviour while staying in this area limited the complete evaluation of the animal response to noise by knowing how the same animal could respond to the noise stimulus in different places. Ideally, future studies could sound map the outside enclosures and observed the animals in this location as well to have a complete evaluation of individuals response to noise.
3. During the analysis of the collected sound data (Sections 3 and 4), it was found high sound levels during the night in the enclosures with ventilation/heating systems. This finding can lead to a study of the effect of noise in the sleep pattern of captive animals. The study could be done to check if the continuously on-off sequence of the ventilation/heating system during the night is causing a disturbance in an animal's

sleep. Sleep disruption is known to have a severe impact on the physical and psychological well-being of humans (Colten and Altevogt, 2006).

4. The small number of faecal samples probably limited the okapi GCM response to noise between different periods of the year (Section 4). Multiple faecal samples throughout different weeks during low and high visitor seasons could be more effective for the differentiation of the okapi response between different times of the year. Zoos could use more frequently faecal samples usually collected during enclosure management to analyse the species responses to different environmental conditions throughout the year.
5. In the case of the orang-utans' response to the summer night events, the use of another source of GCM could help better understand the animal’s physiological response to specific noise production (Section 4). Faecal samples, when collected in the morning, represent an accumulative stress response from the day before (Palme et al., 2005). This delay in the response could have caused an influence on the lack of effect of the events over the GCM levels. The use of urine sample collected right after the events could give a more realistic GCM response to the summer night events due to the short GCM extraction delay (Palme et al., 2005). However, it is important to bear in mind that this method could be invasive, differently from the faecal samples method, and could increase the animal disturbance. Animals training can avoid undesirable disturbance to the individuals and can also open new opportunities for GCM analysis from urine and saliva, for example.
6. In addition to the recommendation above, techniques of remote physiological monitoring could be used to investigate the animals welfare without minimum manipulation. Some devices can monitor not only the physical characteristics of the

environment, but also the animal's reactions to it (Ropert-Coudert and Wilson, 2005), and this could be of great use in a zoo environment.

7. In Section 5, the different conditions during the different soundwalks, such as presence of school groups and variability of the function of the ventilation system in some enclosures, are probably the reason why soundscape evaluation was not perfectly consistent between the soundwalk days. This kind of variation across different days of data collection is practically impossible to control for *in-situ*. Nevertheless, a study could be done in laboratory using recordings from the zoo soundscape and a virtual environment, but this type of approach would lose some important features of the zoos like the animals' smells, other visitors' behaviours, visual enclosure features, etc.
8. More studies that measure response of both visitors and zoo animals to different characteristics of the environment should be done more frequently. The zoo is a space commonly used by these two groups (visitors and animals), so reactions from both of them should be taken into account when planning new enclosures and when managing the zoo environment. Having this in mind, for zoos it is necessary to understand more about how the same stimulus can influence animals and visitors.

6.4. Final conclusion

The analysis of sonic environment is of great importance when evaluating the animals' and the visitors' experience in a zoo. For the animals, sound levels and the visitors can be a source of stress that causes variations in the expression of behaviour and in physiological stress levels. However, this effect caused by sound seems to be greatly influenced by individual variation. Many previous studies present their results as a group of animals (Birke, 2002, Choo et al., 2011, Cronin et al., 2018, Larsen et al., 2014, Liu et al., 2017, Mallapur and Chellam, 2002, O'Donovan et al., 1993, Quadros et al., 2014, Wells et al., 2006), and important variation is probably being discarded; this approach is surprising considering animal welfare should be measured at the level of an individual and not the group (Brand et al., 2016, Chosy et al., 2014, Clark et al., 2012, Cooke and Schillaci, 2007, Ogden et al., 1994, Owen et al., 2004, Powell et al., 2006, Sellinger and Ha, 2005).

Zoos in temperate countries should be more aware of the consequences of the constant use of ventilation/heating systems onto the behaviour and welfare of their animals and seek for advice of acousticians when purchasing/replacing the system or when looking for ways to reducing the noise impact. Furthermore, temperate country zoos should not forget about the influence that the visitors also have in their animals outside of the sonic stimuli (Birke, 2002, O'Donovan et al., 1993, Sellinger and Ha, 2005).

Zoo visitors can also be influenced by the venue soundscape. However, differently, from animals, this influence is caused mostly by the variable source of noise and less by the sound levels since zoo visitors are protected by health and safety standards (WHO, 1999) and due to other influences such as activity being undertaken and sound expectation, for example. Visitors are one of the main financial source funding zoos around the globe. The quality of their visit to a zoo is of great importance to encourage the visitors to spend more time on their visit, which, consequently, increases visitor satisfaction. It is interesting to reflect that there is only a requirement for zoo architects to consider the sonic environment of zoo visitor areas and not those of the animals. If zoo architects thought of animal enclosures as ‘homes’ then many of the problems found in this thesis in relation to the sonic environment of zoo enclosures would be eliminated.

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Appendices

Appendix 1. Overview of the literature evaluated in the review paper reported in Section 2.

Authors	**Year**	**Title**	**Journal**	**Type of noise**	**Acoustic metrics**	**Animal group**	**Evaluation of animal response**
Andersen, D.E. Rongstad, O.J. Mytton, W.R.	1989	Response of Nesting Red-Tailed Hawks to Helicopter Overflights	Condor	Aircraft	NA	Aves	Behavioural
Bakken, M. Moe, R.O. Smith, A.J. Selle, G.M.E.	1999	Effects of environmental stressors on deep body temperature and activity levels in silver fox vixens (*Vulpes vulpes*)	Applied Animal Behaviour Science	Aircraft Anthropogenic	"dB"	Mammalia	Behavioural Physiological
Barber, J.R. Crooks, K.R. Fristrup, K.M.	2010	The costs of chronic noise exposure for terrestrial organisms	Trends in Ecology & Evolution	Anthropogenic	Review	Review	Review
Barber, J.R. Burdett, C.L. Reed, S.E. Warner, K.A. Formichella, C. Crooks, K.R. Theobald, D.M. Fristrup, K.M.	2011	Anthropogenic noise exposure in protected natural areas: estimating the scale of ecological consequences	Landscape Ecology	Aircraft Anthropogenic Traffic	L_{eq} (unweighted and A-weighted) L_{day}	-	-
Bee, M.A. Swanson, E.M.	2007	Auditory masking of anuran advertisement calls by road traffic noise	Animal Behaviour	White noise	L_{eq} (C-weighted)	Amphibia	Behavioural
Birke, L.	2002	Effects of browse, human visitors and noise on the behaviour of captive orangutans	Animal Welfare	Anthropogenic	NA	Mammalia	Behavioural
Bleich, V.C. Bowyer, R.T. Pauli, A.M. Nicholson, M.C. Anthes, R.W.	1994	Mountain Sheep Ovis-Canadensis and Helicopter Surveys - Ramifications for the Conservation of Large Mammals	Biological Conservation	Aircraft	NA	Mammalia	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
Bleich, V.C. Bowyer, R.T. Pauli, A.M. Vernoy, R.L. Anthes, R.W.	1990	Responses of Mountain Sheep to Helicopter Surveys	California Fish and Game	Aircraft	NA	Mammalia	Behavioural
Blickley, J.L. Blackwood, D. Patricelli, G.L.	2012	Experimental Evidence for the Effects of Chronic Anthropogenic Noise on Abundance of Greater Sage-Grouse at Leks	Conservation Biology	Anthropogenic Traffic	L_{eq} (unweighted) L_{max}	Aves	Behavioural
Blickley, J.L. Word, K.R. Krakauer, A.H. Phillips, J.L. Sells, S.N. Taff, C.C. Wingfield, J.C. Patricelli, G.L.	2012	Experimental Chronic Noise Is Related to Elevated Fecal Corticosteroid Metabolites in Lekking Male Greater Sage-Grouse (*Centrocercus urophasianus*)	Plos One	Anthropogenic Traffic	L_{eq} (unweighted) L_{max}	Aves	Physiological
Brewer, W.E.	1974	Effects of Noise Pollution on Animal Behavior	Clinical Toxicology	Aircraft	Review	Aves Mammalia	Review
Brown, B.T. Mills, G.S. Powels, C. Russell, W.A. Therres, G.D. Pottie, J.J.	1999	The influence of weapons-testing noise on Bald Eagle behavior	Journal of Raptor Research	Anthropogenic	Peak SPL (unweighted)	Aves	Behavioural
Brown, C.L. Hardy, A.R. Barber, J.R. Fristrup, K.M. Crooks, K.R. Angeloni, L.M.	2012	The Effect of Human Activities and Their Associated Noise on Ungulate Behavior	Plos One	Traffic	“dB”	Mammalia	Behavioural
Brumm, H.	2004	The impact of environmental noise on song amplitude in a territorial bird	Journal of Animal Ecology	Environmental	SPL (A-weighted)	Aves	Behavioural
Brumm, H.	2006	Animal communication: City birds have changed their tune	Current Biology	Anthropogenic Environmental	Review	Review	Review
Brumm, H. Todt, D.	2002	Noise-dependent song amplitude regulation in a territorial songbird	Animal Behaviour	White noise	SPL (Linear weighted)	Aves	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
Brumm, H. Voss, K. Kollmer, I. Todt, D.	2004	Acoustic communication in noise: regulation of call characteristics in a New World monkey	Journal of Experimental Biology	White noise	SPL (Linear weighted)	Mammalia	Behavioural
Byrnes, P. Goosem, M. Turton, S.M.	2012	Are less vocal rainforest mammals susceptible to impacts from traffic noise?	Wildlife Research	Traffic	“dB” (A-weighted)	Mammalia	Behavioural
Chen, H.L. Koprowski, J.L.	2015	Animal occurrence and space use change in the landscape of anthropogenic noise	Biological Conservation	Traffic	L_{eq} (A-weighted) L_{max} (A-weighted)	Mammalia	Behavioural
Conomy, J.T. Collazo, J.A. Dubovsky, J.A. Fleming, W.J.	1998	Dabbling duck behavior and aircraft activity in coastal North Carolina	Journal of Wildlife Management	Aircraft	L_{eq} (A-weighted) SEL (A-weighted)	Aves	Behavioural
Conomy, J.T. Dubovsky, J.A. Collazo, J.A. Fleming, W.J.	1998	Do black ducks and wood ducks habituate to aircraft disturbance?	Journal of Wildlife Management	Aircraft	L_{eq} (A-weighted)	Aves	Behavioural
Cooke, C.M. Schillaci, M.A.	2007	Behavioral responses to the zoo environment by white handed gibbons	Applied Animal Behaviour Science	Anthropogenic	“dB”	Mammalia	Behavioural
Cote, S.D.	1996	Mountain goat responses to helicopter disturbance	Wildlife Society Bulletin	Aircraft	NA	Mammalia	Behavioural
Cote, S.D. Hamel, S. St-Louis, A. Mainguy, J.	2013	Do Mountain Goats Habituate to Helicopter Disturbance?	Journal of Wildlife Management	Aircraft	NA	Mammalia	Behavioural
Crino, O.L. Johnson, E.E. Blickley, J.L. Patricelli, G.L. Breuner, C.W.	2013	Effects of experimentally elevated traffic noise on nestling white-crowned sparrow stress physiology, immune function and life history	Journal of Experimental Biology	Traffic	L_{eq} (A-weighted) L_{max} (A-weighted)	Aves	Physiological
Cynx, J. Lewis, R. Tavel, B. Tse, H.	1998	Amplitude regulation of vocalizations in noise by a	Animal Behaviour	White noise	SPL (A-weighted)	Aves	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
		songbird, *Taeniopygia guttata*					
Delaney, D.K. Grubb, T.G. Beier, P. Pater, L.L. Reiser, M.H.	1999	Effects of helicopter noise on Mexican spotted owls	Journal of Wildlife Management	Aircraft Anthropogenic	L_{eq} (Species-specific weighted) SEL (Species-specific weighted)	Aves	Behavioural
Delaney, D.K. Pater, L.L. Carlile, L.D. Spadgenske, E. W. Beaty, T.A. Melton, R.H.	2011	Response of Red-Cockaded Woodpeckers to Military Training Operations	Wildlife Monographs	Aircraft Anthropogenic	L_{eq} (Species-specific weighted) SEL (unweighted and Species-specific weighted)	Aves	Behavioural
Derose-Wilson, A. Fraser, J.D. Karpanty, S.M. Hillman, M.D.	2015	Effects of overflights on incubating Wilson's plover behavior and heart rate	Journal of Wildlife Management	Aircraft	L_{max} (A-weighted) SEL (A-weighted)	Aves	Behavioural Physiological
des Aunay, G.H. Slabbekoorn, H. Nagle, L. Passas, F. Nicolas, P. Draganoiu, T.I.	2014	Urban noise undermines female sexual preferences for low-frequency songs in domestic canaries	Animal Behaviour	White noise	SPL (A-weighted)	Aves	Behavioural
Ditmer, M.A. Vincent, J.B. Werden, L.K. Tanner, J.C. Laske, T.G. Iaizzo, P.A. Garshelis, D.L. Fieberg, J.R.	2015	Bears Show a Physiological but Limited Behavioral Response to Unmanned Aerial Vehicles	Current Biology	Aircraft	“dB” (A-weighted)	Mammalia	Behavioural Physiological
Duarte, M.H.L. Sousa-Lima, R.S. Young, R.J. Farina, A.	2015	The impact of noise from open-cast mining on Atlantic forest biophony	Biological Conservation	Anthropogenic	L_{eq} (unweighted)	-	-

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
Vasconcelos, M. **Rodrigues, M.** **Pieretti, N.**							
Egnor, S.E.R. **Wickelgren, J.G.** **Hauser, M.D.**	2007	Tracking silence: adjusting vocal production to avoid acoustic interference	Journal of Comparative Physiology a-Neuroethology Sensory Neural and Behavioral Physiology	White noise	SPL (Flat weighted)	Mammalia	Behavioural
Francis, C.D.	2015	Vocal traits and diet explain avian sensitivities to anthropogenic noise	Global Change Biology	Anthropogenic	Review	Aves	Review
Francis, C.D. **Barber, J.R.**	2013	A framework for understanding noise impacts on wildlife: an urgent conservation priority	Frontiers in Ecology and the Environment	Review	Review	Review	Review
Frid, A.	2003	Dall's sheep responses to overflights by helicopter and fixed-wing aircraft	Biological Conservation	Aircraft	NA	Mammalia	Behavioural
Fuller, R.A. **Warren, P.H.** **Gaston, K.J.**	2007	Daytime noise predicts nocturnal singing in urban robins	Biology Letters	Anthropogenic	"dB" (A-weighted)	Aves	Behavioural
Giese, M. **Riddle, M.**	1999	Disturbance of emperor penguin *Aptenodytes forsteri* chicks by helicopters	Polar Biology	Aircraft	SPL (A-weighted)	Aves	Behavioural
Gill, S.A. **Job, J.R.** **Myers, K.** **Naghshineh, K.** **Vonhof, M.J.**	2015	Toward a broader characterization of anthropogenic noise and its effects on wildlife	Behavioral Ecology	Anthropogenic	Review	Review	Review
Goldstein, M.I. **Poe, A.J.** **Cooper, E.** **Youkey, D.** **Brown, B.A.** **McDonald, T.L.**	2005	Mountain goat response to helicopter overflights in Alaska	Wildlife Society Bulletin	Aircraft	NA	Mammalia	Behavioural
Gorecki, M.T.	2012	Exposure to Humans and Activity Pattern	Zoo Biology	Anthropogenic	NA	Mammalia	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
Juszkiewicz, A. **Graclik, A.** **Kala, B.**		of European Souslik (*Spermophilus citellus*) in Zoo Conditions					
Goudie, R.I.	2006	Multivariate behavioural response of harlequin ducks to aircraft disturbance in Labrador	Environmental Conservation	Aircraft	L_{max} (A-weighted)	Aves	Behavioural
Goudie, R.I. **Jones, I.L.**	2004	Dose-response relationships of harlequin duck behaviour to noise from low-level military jet over-flights in central Labrador	Environmental Conservation	Aircraft	L_{max} (A-weighted) L_{90} (A-weighted)	Aves	Behavioural
Grace, M.K. **Anderson, R.C.**	2015	No frequency shift in the "D" notes of Carolina chickadee calls in response to traffic noise	Behavioral Ecology and Sociobiology	Traffic	SPL (A-weighted)	Aves	Behavioural
Grafe, T.U. **Preininger, D.** **Sztatecsny, M.** **Kasah, R.** **Dehling, J.M.** **Proksch, S.** **Hodl, W.**	2012	Multimodal Communication in a Noisy Environment: A Case Study of the Bornean Rock Frog *Staurois parvus*	Plos One	Environmental	Peak SPL (A-weighted)	Amphibia	Behavioural
Grubb, T.G. **Pater, L.L.** **Gatto, A.E.** **Delaney, D.K.**	2013	Response of Nesting Northern Goshawks to Logging Truck Noise in Northern Arizona	Journal of Wildlife Management	Aircraft Traffic	L_{eq} (unweighted, A-weighted, and C-weighted)	Aves	Behavioural
Habib, L. **Bayne, E.M.** **Boutin, S.**	2007	Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocapilla*	Journal of Applied Ecology	Anthropogenic	NA	Aves	Behavioural
Hanna, D. **Blouin-Demers, G.** **Wilson, D.R.** **Mennill, D.J.**	2011	Anthropogenic noise affects song structure in red-winged blackbirds (*Agelaius phoeniceus*)	Journal of Experimental Biology	Traffic White noise	SPL (C-weighted)	Aves	Behavioural

Authors	**Year**	**Title**	**Journal**	**Type of noise**	**Acoustic metrics**	**Animal group**	**Evaluation of animal response**
Hanna, D.E.L. Wilson, D.R. Blouin-Demers, G. Mennill, D.J.	2014	Spring peepers *Pseudacris crucifer* modify their call structure in response to noise	Current Zoology	White noise	SPL (C-weighted)	Amphibia	Behavioural
Harms, C.A. Fleming, W.J. Stoskopf, M.K.	1997	A technique for dorsal subcutaneous implantation of heart rate biotelemetry transmitters in Black Ducks: Application in an aircraft noise response study	Condor	Aircraft	“dB”	Aves	Physiological
Harrington, F.H. Veitch, A.M.	1992	Calving Success of Woodland Caribou Exposed to Low-Level Jet Fighter Overflights	Arctic	Aircraft	NA	Mammalia	Behavioural
Hillman, M.D. Karpanty, S.M. Fraser, J.D. Derose-Wilson, A.	2015	Effects of Aircraft and Recreation on Colonial Waterbird Nesting Behavior	Journal of Wildlife Management	Aircraft	L_{max} (A-weighted) SEL (A-weighted)	Aves	Behavioural
Hu, Y. Cardoso, G.C.	2010	Which birds adjust the frequency of vocalizations in urban noise?	Animal Behaviour	Anthropogenic	“dB” (A-weighted)	Aves	Behavioural
Karp, D.S. Root, T.L.	2009	Sound the stressor: how Hoatzins (*Opisthocomus hoazin*) react to ecotourist conversation	Biodiversity and Conservation	Anthropogenic	“dB”	Aves	Behavioural
Kight, C.R. Swaddle, J.P.	2011	How and why environmental noise impacts animals: an integrative, mechanistic review	Ecology Letters	Anthropogenic Environmental	Review	Review	Review
Krausman, P.R. Harris, L.K.	2002	Military jet activity and Sonoran pronghorn	Zeitschrift Fur Jagdwissenschaft	Aircraft Anthropogenic	NA	Mammalia	Behavioural
Krausman, P.R. Harris, L.K. Blasch, C.L.	2004	Effects of military operations on behavior and	Wildlife Monographs	Aircraft Anthropogenic	L_{eq} (A-weighted)	Mammalia	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
Koenen, K.K.G. Francine, J.		hearing of endangered Sonoran pronghorn			L_{max} (A-weighted) SEL (A-weighted and Species-specific weighted)		
Krausman, P.R. Wallace, M.C. Hayes, C.L. DeYoung, D.W.	1998	Effects of jet aircraft on mountain sheep	Journal of Wildlife Management	Aircraft	SPL	Mammalia	Behavioural Physiological
Landon, D.M. Krausman, P.R. Koenen, K.K.G. Harris, L.K.	2003	Pronghorn use of areas with varying sound pressure levels	Southwestern Naturalist	Aircraft Anthropogenic	SPL	Mammalia	Behavioural
Larsen, M.J. Sherwen, S.L. Rault, J.L.	2014	Number of nearby visitors and noise level affect vigilance in captive koalas	Applied Animal Behaviour Science	Anthropogenic	NA	Mammalia	Behavioural
LaZerte, S.E. Otter, K.A. Slabbekoorn, H.	2015	Relative effects of ambient noise and habitat openness on signal transfer for chickadee vocalizations in rural and urban green-spaces	Bioacoustics-the International Journal of Animal Sound and Its Recording	Environmental	SPL (Z-weighted)	Aves	Behavioural
Lengagne, T.	2008	Traffic noise affects communication behaviour in a breeding anuran, *Hyla arborea*	Biological Conservation	Traffic	L_{eq} (A-weighted)	Amphibia	Behavioural
Lengagne, T. Slater, P.J.B.	2002	The effects of rain on acoustic communication: tawny owls have good reason for calling less in wet weather	Proceedings of the Royal Society B-Biological Sciences	Environmental	SPL (Linear weighted)	Aves	Behavioural
Leonard, M.L. Horn, A.G.	2005	Ambient noise and the design of begging signals	Proceedings of the Royal Society B-Biological Sciences	Environmental White noise	SPL (C-weighted)	Aves	Behavioural

Authors	**Year**	**Title**	**Journal**	**Type of noise**	**Acoustic metrics**	**Animal group**	**Evaluation of animal response**
Leonard, M.L. **Horn, A.G.** **Oswald, K.N.** **McIntyre, E.**	2015	Effect of ambient noise on parent-offspring interactions in tree swallows	Animal Behaviour	White noise	SPL (C-weighted)	Aves	Behavioural
Luther, D. **Baptista, L.**	2010	Urban noise and the cultural evolution of bird songs	Proceedings of the Royal Society B-Biological Sciences	Anthropogenic	NA	Aves	Behavioural
Luther, D.A. **Derryberry, E.P.**	2012	Birdsongs keep pace with city life: changes in song over time in an urban songbird affects communication	Animal Behaviour	Anthropogenic	L_{dn} (A-weighted)	Aves	Behavioural
Luther, D. **Magnotti, J.**	2014	Can animals detect differences in vocalizations adjusted for anthropogenic noise?	Animal Behaviour	Anthropogenic	“dB”	Aves	Behavioural
Maia, C.M. **Volpato, G.L.** **Santos, E.F.**	2012	A Case Study: The Effect of Visitors on Two Captive Pumas With Respect to the Time of the Day	Journal of Applied Animal Welfare Science	Anthropogenic	NA	Mammalia	Behavioural
Maier, J.A.K. **Murphy, S.M.** **White, R.G.** **Smith, M.D.**	1998	Responses of caribou to overflights by low-altitude jet aircraft	Journal of Wildlife Management	Aircraft	L_{eq} (A-weighted and C-weighted) L_{max} (A-weighted and C-weighted) SEL (A-weighted and C-weighted)	Mammalia	Behavioural
McClure, C.J.W. **Ware, H.E.** **Carlisle, J.** **Kaltenecker, G.** **Barber, J.R.**	2013	An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road	Proceedings of the Royal Society B-Biological Sciences	Traffic	L_{eq} (A-weighted)	Aves	Behavioural
McIntyre, E. **Leonard, M.L.** **Horn, A.G.**	2014	Ambient noise and parental communication of predation risk in tree swallows,	Animal Behaviour	White noise	SPL (C-weighted)	Aves	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
		Tachycineta bicolor					
McLaughlin, K.E. **Kunc, H.P.**	2013	Experimentally increased noise levels change spatial and singing behaviour	Biology Letters	Anthropogenic	"dB" (A-weighted)	Aves	Behavioural
McMullen, H. **Schmidt, R.** **Kunc, H.P.**	2014	Anthropogenic noise affects vocal interactions	Behavioural Processes	Traffic	"dB" (A-weighted)	Aves	Behavioural
Meillere, A. **Brischoux, F.** **Angelier, F.**	2015	Impact of chronic noise exposure on antipredator behavior: an experiment in breeding house sparrows	Behavioral Ecology	Traffic	"dB" (A-weighted)	Aves	Behavioural
Merrill, S.B. **Erickson, C.R.**	2003	A GPS-based method to examine wolf response to loud noise	Wildlife Society Bulletin	Anthropogenic	"dB"	Mammalia	Behavioural
Miller, F.L. **Gunn, A.** **Barry, S.J.**	1988	Nursing by Muskox Calves before, during, and after Helicopter Overflights	Arctic	Aircraft	NA	Mammalia	Behavioural
Miller, M.W.	1994	Route Selection to Minimize Helicopter Disturbance of Molting Pacific Black Brant - a Simulation	Arctic	Aircraft	NA	Aves	Physiological
Montague, M.J. **Danek-Gontard, M.** **Kunc, H.P.**	2013	Phenotypic plasticity affects the response of a sexually selected trait to anthropogenic noise	Behavioral Ecology	Anthropogenic White noise	"dB" (A-weighted)	Aves	Behavioural
Naguib, M.	2013	Living in a noisy world: indirect effects of noise on animal communication	Behaviour	Review	Review	Review	Review
Naguib, M. **van Oers, K.** **Braakhuis, A.** **Griffioen, M.** **de Goede, P.** **Waas, J.R.**	2013	Noise annoys: effects of noise on breeding great tits depend on personality but not on noise characteristics	Animal Behaviour	White noise	"dB" (unweighted)	Aves	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
Owen, M.A. **Swaisgood, R.R.** **Czekala, N.M.** **Steinman, K.** **Lindburg, D.G.**	2004	Monitoring stress in captive giant pandas (*Ailuropoda melanoleuca*): Behavioral and hormonal responses to ambient noise	Zoo Biology	Anthropogenic	L_{day} (linear weighted) L_1 (linear weighted) L_{10} (linear weighted)	Mammalia	Behavioural Physiological
Padie, S. **Morellet, N.** **Cargnelutti, B.** **Hewison, A.J.M.** **Martin, J.L.** **Chamaille-Jammes, S.**	2015	Time to leave? Immediate response of roe deer to experimental disturbances using playbacks	European Journal of Wildlife Research	Anthropogenic	“dB”	Mammalia	Behavioural
Palmer, A.G. **Nordmeyer, D.L.** **Roby, D.D.**	2003	Effects of jet aircraft overflights on parental care of peregrine falcons	Wildlife Society Bulletin	Aircraft	SEL	Aves	Behavioural
Parris, K.M. **Velik-Lord, M.** **North, J.M.A.**	2009	Frogs Call at a Higher Pitch in Traffic Noise	Ecology and Society	Traffic	L_{10} (A-weighted)	Amphibia	Behavioural Physiological
Pater, L.L. **Grubb, T.G.** **Delaney, D.K.**	2009	Recommendations for Improved Assessment of Noise Impacts on Wildlife	Journal of Wildlife Management	Review	Review	Review	Review
Patricelli, G.L. **Blickley, J.L.**	2006	Avian communication in urban noise: Causes and consequences of vocal adjustment	Auk	Anthropogenic	Review	Aves	Review
Payne, C.J. **Jessop, T.S.** **Guay, P.J.** **Johnstone, M.** **Feore, M.** **Mulder, R.A.**	2012	Population, Behavioural and Physiological Responses of an Urban Population of Black Swans to an Intense Annual Noise Event	Plos One	Anthropogenic Traffic	“dB” (A-weighted)	Aves	Behavioural Physiological
Penna, M. **Hamilton-West, C.**	2007	Susceptibility of evoked vocal responses to noise exposure in a frog of the temperate austral forest	Animal Behaviour	White noise	SPL	Amphibia	Behavioural

Authors	**Year**	**Title**	**Journal**	**Type of noise**	**Acoustic metrics**	**Animal group**	**Evaluation of animal response**
Penna, M. Pottstock, H. Velasquez, N.	2005	Effect of natural and synthetic noise on evoked vocal responses in a frog of the temperate austral forest	Animal Behaviour	Environmental White noise	SPL	Amphibia	Behavioural
Pepper, C.B. Nascarella, M.A. Kendall, R.J.	2003	A review of the effects of aircraft noise on wildlife and humans, current control mechanisms, and the need for further study	Environmental Management	Aircraft	Review	Review	Review
Pohl, N.U. Leadbeater, E. Slabbekoorn, H. Klump, G.M. Langemann, U.	2012	Great tits in urban noise benefit from high frequencies in song detection and discrimination	Animal Behaviour	White noise	SPL (A-weighted)	Aves	Behavioural
Pohl, N U. Slabbekoorn, H. Klump, G.M. Langemann, U.	2009	Effects of signal features and environmental noise on signal detection in the great tit, *Parus major*	Animal Behaviour	White noise	SPL (A-weighted and C-weighted)	Aves	Behavioural
Potvin, D.A. MacDougall-Shackleton, S.A.	2015	Experimental chronic noise exposure affects adult song in zebra finches	Animal Behaviour	Traffic	L_{eq} (A-weighted) SPL (A-weighted)	Aves	Behavioural Physiological
Potvin, D.A. Mulder, R.A. Parris, K.M.	2014	Silvereyes decrease acoustic frequency but increase efficacy of alarm calls in urban noise	Animal Behaviour	Anthropogenic	SPL (A-weighted)	Aves	Behavioural
Quadros, S. Goulart, V.D.L. Passos, L. Vecci, M.A.M. Young, R.J.	2014	Zoo visitor effect on mammal behaviour: Does noise matter?	Applied Animal Behaviour Science	Anthropogenic	L_{eq} (A-weighted) L_{50} (A-weighted)	Mammalia	Behavioural
Quinn, J.L. Whittingham, M.J. Butler, S.J. Cresswell, W.	2006	Noise, predation risk compensation and vigilance in the chaffinch *Fringilla coelebs*	Journal of Avian Biology	White noise	“dB” (A-weighted)	Aves	Behavioural
Rabin, L.A. Coss, R.G.	2006	The effects of wind turbines on	Biological Conservation	Anthropogenic	SPL (Linear	Mammalia	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
Owings, D.H.		antipredator behavior in California ground squirrels (*Spermophilus beecheyi*)			weighted)		
Reijnen, R. **Foppen, R.** **Veenbaas, G.**	1997	Disturbance by traffic of breeding birds: Evaluation of the effect and considerations in planning and managing road corridors	Biodiversity and Conservation	Traffic	Review	Aves	Review
Salaberria, C. **Gil, D.**	2010	Increase in Song Frequency in Response to Urban Noise in the Great Tit *Parus major* as Shown by Data from the Madrid (Spain) City Noise Map	Ardeola	Anthropogenic	L_{den}	Aves	Behavioural
Shannon, G. **Angeloni, L.M.** **Wittemyer, G.** **Fristrup, K.M.** **Crooks, K.R.**	2014	Road traffic noise modifies behaviour of a keystone species	Animal Behaviour	Traffic	L_{eq} (A-weighted)	Mammalia	Behavioural
Sherwen, S.L. **Magrath, M.J.L.** **Butler, K.L.** **Phillips, C.J.C.** **Hemsworth, P.H.**	2014	A multi-enclosure study investigating the behavioural response of meerkats to zoo visitors	Applied Animal Behaviour Science	Anthropogenic	“dB” (A-weighted)	Mammalia	Behavioural
Shier, D.M. **Lea, A.J.** **Owen, M.A.**	2012	Beyond masking: Endangered Stephen's kangaroo rats respond to traffic noise with footdrumming	Biological Conservation	Traffic	“dB”	Mammalia	Behavioural
Slabbekoorn, H. **Peet, M.**	2003	Ecology: Birds sing at a higher pitch in urban noise - Great tits hit the high notes to ensure that their mating calls are heard above the city's din	Nature	Anthropogenic	“dB”	Aves	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
Slabbekoorn, H. Ripmeester, E.A.P.	2008	Birdsong and anthropogenic noise: implications and applications for conservation	Molecular Ecology	Anthropogenic	Review	Aves	Review
Stalmaster, M.V. Kaiser, J.L.	1997	Flushing responses of wintering bald eagles to military activity	Journal of Wildlife Management	Aircraft Anthropogenic	NA	Aves	Behavioural
Stockwell, C.A. Bateman, G.C. Berger, J.	1991	Conflicts in National-Parks - a Case-Study of Helicopters and Bighorn Sheep Time Budgets at the Grand-Canyon	Biological Conservation	Aircraft	NA	Mammalia	Behavioural
Stone, E.	2000	Separating the noise from the noise: A finding in support of the "Niche Hypothesis," that birds are influenced by human-induced noise in natural habitats	Anthrozoos	Anthropogenic	NA	Aves	Behavioural
Summers, P.D. Cunnington, G.M. Fahrig, L.	2011	Are the negative effects of roads on breeding birds caused by traffic noise?	Journal of Applied Ecology	Traffic	“dB”	Aves	Behavioural
Sun, J.W.C. Narins, P.A.	2005	Anthropogenic sounds differentially affect amphibian call rate	Biological Conservation	Aircraft Traffic	Peak SPL (C-weighted)	Amphibia	Behavioural
Swaddle, J.P. Page, L.C.	2007	High levels of environmental noise erode pair preferences in zebra finches: implications for noise pollution	Animal Behaviour	White noise	“dB” (C-weighted)	Aves	Behavioural
Tempel, D.J. Gutierrez, R.J.	2003	Fecal corticosterone levels in California spotted owls exposed to low-intensity chainsaw sound	Wildlife Society Bulletin	Anthropogenic	“dB” (A-weighted)	Aves	Behavioural Physiological
Tracey, J.P.	2007	Behavioural responses of feral	Applied Animal	Aircraft	NA	Mammalia	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
Fleming, P.J.S.		goats (*Capra hircus*) to helicopters	Behaviour Science				
Trimper, P.G. **Standen, N.M.** **Lye, L.M.** **Lemon, D.** **Chubbs, T.E.** **Humphries, G.W.**	1998	Effects of low-level jet aircraft noise on the behaviour of nesting osprey	Journal of Applied Ecology	Aircraft	L_1	Aves	Behavioural
Troianowski, M. **Melot, G.** **Lengagne, T.**	2014	Multimodality: A way to cope with road traffic noise? The case of European treefrog (*Hyla arborea*)	Behavioural Processes	Traffic	"dB" (C-weighted)	Amphibia	Behavioural
Ward, D.H. **Stehn, R.A.** **Erickson, W.P.** **Derksen, D.V.**	1999	Response of fall-staging brant and Canada geese to aircraft overflights in southwestern Alaska	Journal of Wildlife Management	Aircraft	NA	Aves	Behavioural
Ware, H.E. **McClure, C.J.W.** **Carlisle, J.D.** **Barber, J.R.**	2015	A phantom road experiment reveals traffic noise is an invisible source of habitat degradation	Proceedings of the National Academy of Sciences of the United States of America	Traffic	L_{eq} (A-weighted)	Aves	Behavioural Physiological
Weisenberger, M.E. **Krausman, P.R.** **Wallace, M.C.** **DeYoung, D.W.** **Maughan, O.E.**	1996	Effects of simulated jet aircraft noise on heart rate and behavior of desert ungulates	Journal of Wildlife Management	Aircraft	SPL	Mammalia	Behavioural Physiological
Wollerman, L.	1999	Acoustic interference limits call detection in a Neotropical frog *Hyla ebraccata*	Animal Behaviour	Environmental	SPL (Flat weighted)	Amphibia	Behavioural
Wollerman, L. **Wiley, R.H.**	2002	Background noise from a natural chorus alters female discrimination of male calls in a Neotropical frog	Animal Behaviour	Environmental	SPL (Flat weighted)	Amphibia	Behavioural

Authors	Year	Title	Journal	Type of noise	Acoustic metrics	Animal group	Evaluation of animal response
Wood, W.E. Yezerinac, S.M.	2006	Song sparrow (*Melospiza melodia*) song varies with urban noise	Auk	Anthropogenic	"dB" (A-weighted)	Aves	Behavioural

Appendix 2. Invitation letter

Bill Davies

School of Computing Science and
Engineering
Newton Building, University of Salford,
Salford M5 4WT

t: 0161 295 5986

w.davies@salford.ac.uk | www.salford.ac.uk

www.acoustics.salford.ac.uk

INVITATION LETTER

We are looking for volunteers to help us with an experiment being conducted by a PhD researcher from the University of Salford. The study is designed to learn more about the soundscape in zoos, particularly how the environmental sound is perceived by the zoo visitors. The results will be used to develop improvements in zoos.

You are invited to take part on a sound walk through Chester Zoo lasting 40 to 50 minutes. During the activity, you will be asked to concentrate on the sound around you and fill a questionnaire form about it.

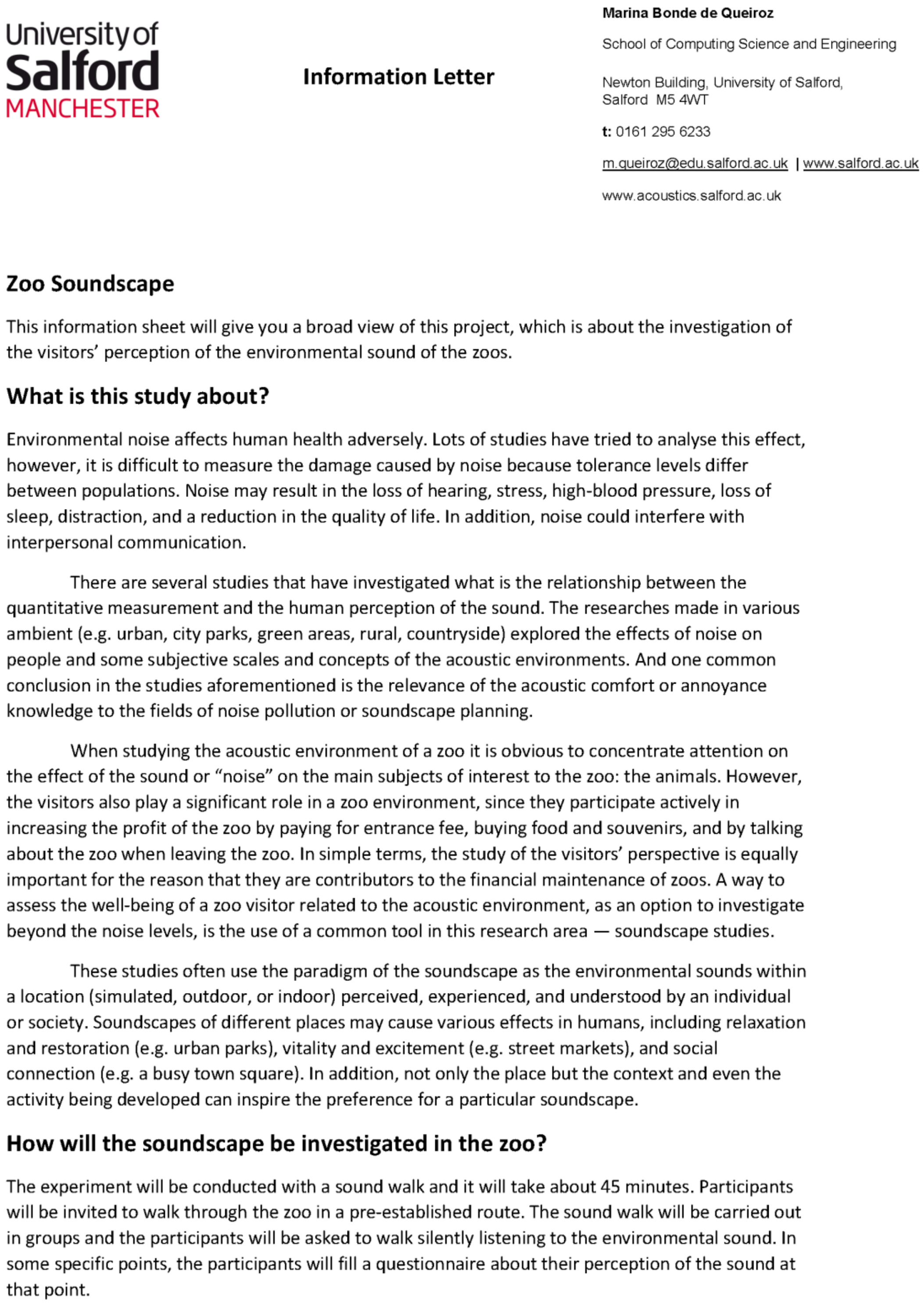
You can decide to change your mind and withdraw from the study at any time without having to give a reason for it. If you decide to withdraw from the study for any reason or at any time, any data already collected will be deleted and any paper copies destroyed.

All the data produced will be anonymised and publically available through the University of Salford research data management system.

For further information and to be involved, please contact;

Marina Bonde de Queiroz
Acoustics Research Centre
University of Salford
M.Queiroz@edu.salford.ac.uk
0161 295 6233

Appendix 3. Information sheet



University of
Salford
MANCHESTER

Marina Bonde de Queiroz

School of Computing Science and Engineering

Newton Building, University of Salford,
Salford M5 4WT

t: 0161 295 6233

m.queiroz@edu.salford.ac.uk | www.salford.ac.uk

www.acoustics.salford.ac.uk

Information Letter

Zoo Soundscape

This information sheet will give you a broad view of this project, which is about the investigation of the visitors' perception of the environmental sound of the zoos.

What is this study about?

Environmental noise affects human health adversely. Lots of studies have tried to analyse this effect, however, it is difficult to measure the damage caused by noise because tolerance levels differ between populations. Noise may result in the loss of hearing, stress, high-blood pressure, loss of sleep, distraction, and a reduction in the quality of life. In addition, noise could interfere with interpersonal communication.

There are several studies that have investigated what is the relationship between the quantitative measurement and the human perception of the sound. The researches made in various ambient (e.g. urban, city parks, green areas, rural, countryside) explored the effects of noise on people and some subjective scales and concepts of the acoustic environments. And one common conclusion in the studies aforementioned is the relevance of the acoustic comfort or annoyance knowledge to the fields of noise pollution or soundscape planning.

When studying the acoustic environment of a zoo it is obvious to concentrate attention on the effect of the sound or "noise" on the main subjects of interest to the zoo: the animals. However, the visitors also play a significant role in a zoo environment, since they participate actively in increasing the profit of the zoo by paying for entrance fee, buying food and souvenirs, and by talking about the zoo when leaving the zoo. In simple terms, the study of the visitors' perspective is equally important for the reason that they are contributors to the financial maintenance of zoos. A way to assess the well-being of a zoo visitor related to the acoustic environment, as an option to investigate beyond the noise levels, is the use of a common tool in this research area — soundscape studies.

These studies often use the paradigm of the soundscape as the environmental sounds within a location (simulated, outdoor, or indoor) perceived, experienced, and understood by an individual or society. Soundscapes of different places may cause various effects in humans, including relaxation and restoration (e.g. urban parks), vitality and excitement (e.g. street markets), and social connection (e.g. a busy town square). In addition, not only the place but the context and even the activity being developed can inspire the preference for a particular soundscape.

How will the soundscape be investigated in the zoo?

The experiment will be conducted with a sound walk and it will take about 45 minutes. Participants will be invited to walk through the zoo in a pre-established route. The sound walk will be carried out in groups and the participants will be asked to walk silently listening to the environmental sound. In some specific points, the participants will fill a questionnaire about their perception of the sound at that point.

Is there any risk?

There is no risk. The walk will happen at a normal pace, and the participants will be asked to listen to the environment and fill a questionnaire.

Confidentiality

The consent forms with the name of the participants will be held in a locked cabinet at the University of Salford. The questionnaires filled during the sound walk will not be named, they will contain general data, such as age and gender.

Comments you make to the researcher may be anonymised and quoted in publications, to add a personal perspective/personal experience to the results. This will only be done if you agree to it and your name will not be attributed to it.

What will happen to the study results?

The results from this study will be used to learn more about the zoo soundscape and how it can influence the zoo experience for the visitors.

Some results will be published in academic journals and the complete set of anonymised test results will be made publically available through the University of Salford research data management system.

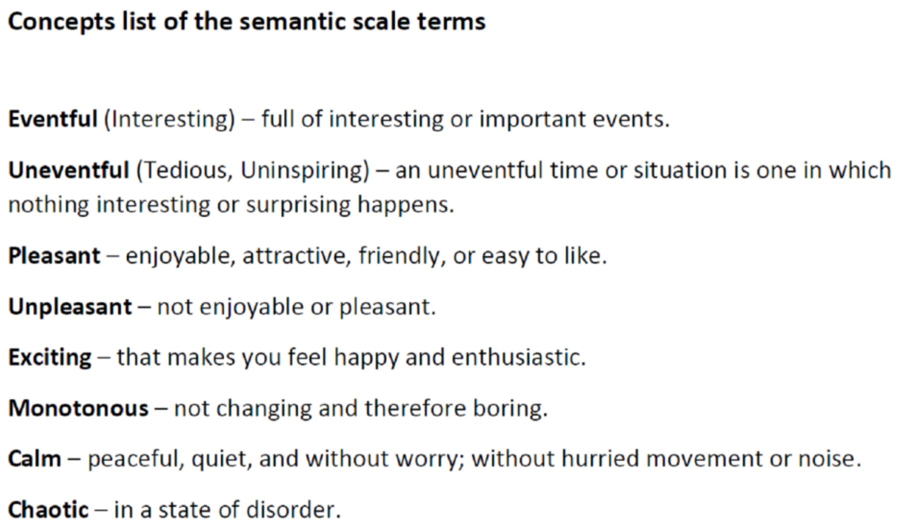
What happens if I no longer want to take part?

You can decide to change your mind and withdraw from the study at any time without having to give a reason for it. If you decide to withdraw from the study for any reason or at any time, any data already collected will be deleted and any paper copies destroyed.

Please do not hesitate to contact the researcher in the case of any question.

Marina Queiroz
0161 295 6233
M.Queiroz@edu.salford.ac.uk

Appendix 4. Concepts list



Concepts list of the semantic scale terms

Eventful (Interesting) – full of interesting or important events.

Uneventful (Tedious, Uninspiring) – an uneventful time or situation is one in which nothing interesting or surprising happens.

Pleasant – enjoyable, attractive, friendly, or easy to like.

Unpleasant – not enjoyable or pleasant.

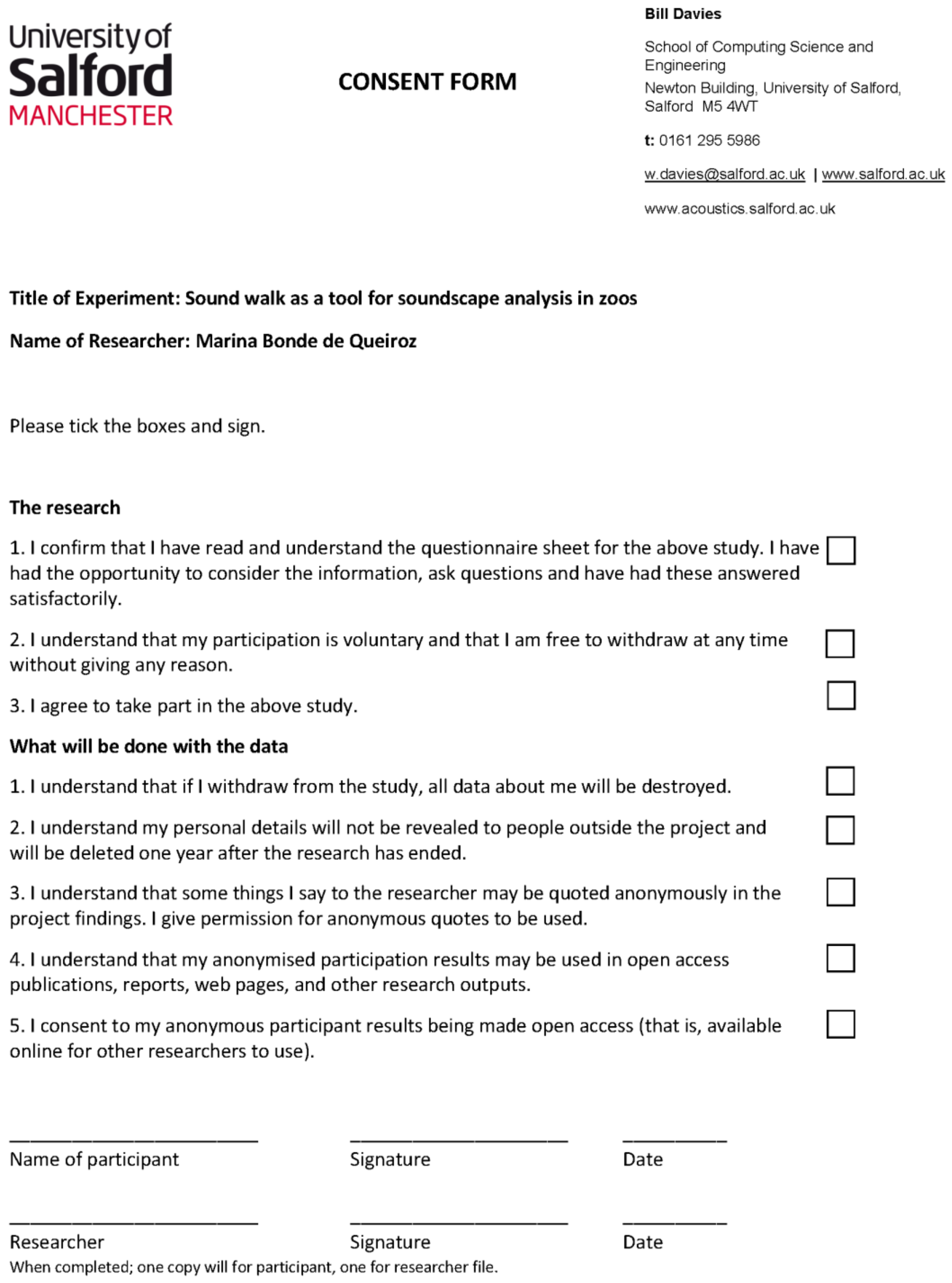
Exciting – that makes you feel happy and enthusiastic.

Monotonous – not changing and therefore boring.

Calm – peaceful, quiet, and without worry; without hurried movement or noise.

Chaotic – in a state of disorder.

Appendix 5. Consent form



University of
Salford
MANCHESTER

CONSENT FORM

Bill Davies

School of Computing Science and Engineering
Newton Building, University of Salford,
Salford M5 4WT

t: 0161 295 5986

w.davies@salford.ac.uk | www.salford.ac.uk

www.acoustics.salford.ac.uk

Title of Experiment: Sound walk as a tool for soundscape analysis in zoos

Name of Researcher: Marina Bonde de Queiroz

Please tick the boxes and sign.

The research

1. I confirm that I have read and understand the questionnaire sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. ☐

3. I agree to take part in the above study. ☐

What will be done with the data

1. I understand that if I withdraw from the study, all data about me will be destroyed. ☐

2. I understand my personal details will not be revealed to people outside the project and will be deleted one year after the research has ended. ☐

3. I understand that some things I say to the researcher may be quoted anonymously in the project findings. I give permission for anonymous quotes to be used. ☐

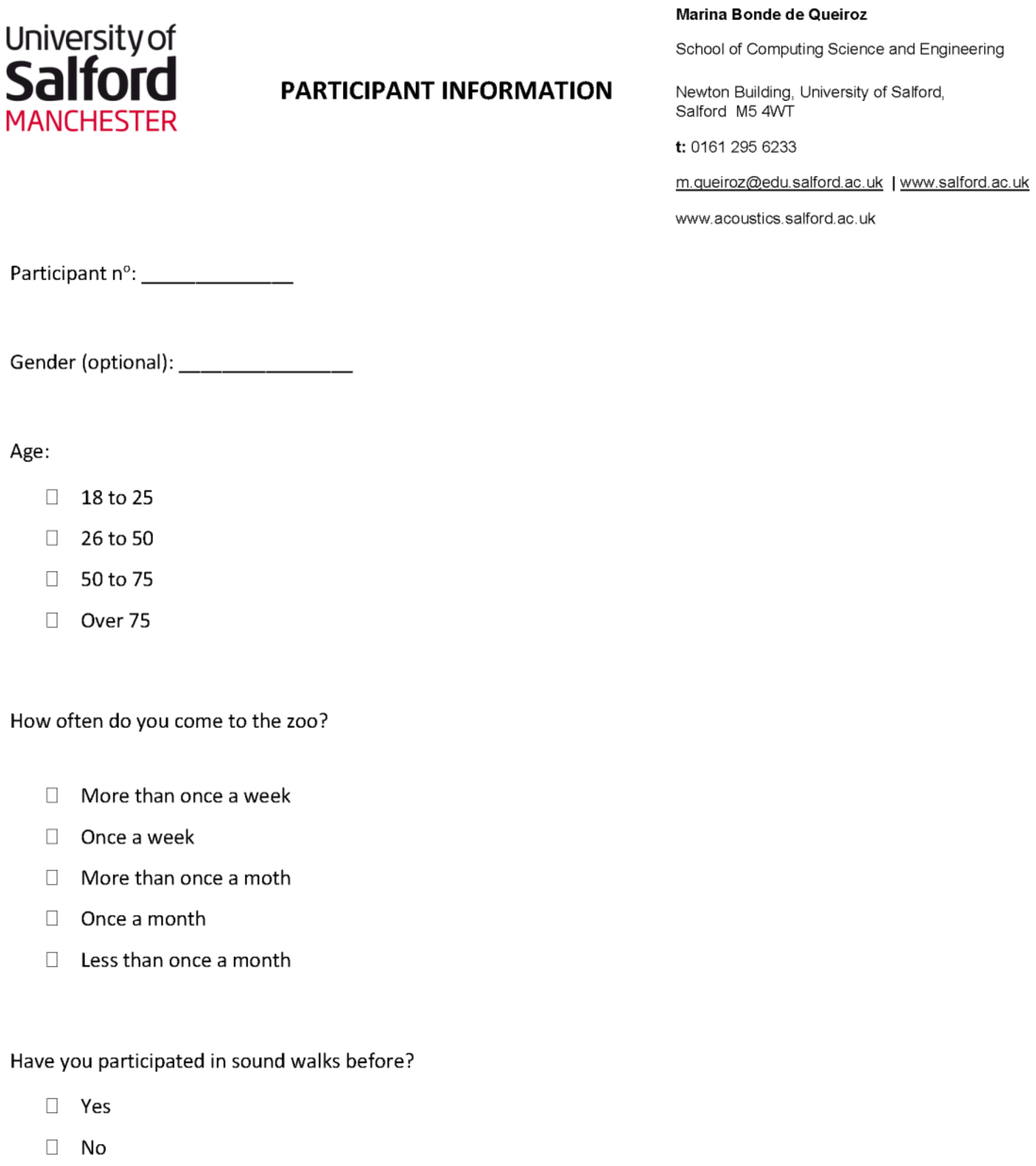
4. I understand that my anonymised participation results may be used in open access publications, reports, web pages, and other research outputs. ☐

5. I consent to my anonymous participant results being made open access (that is, available online for other researchers to use). ☐

________________________	_____________________	__________
Name of participant	Signature	Date
________________________	_____________________	__________
Researcher	Signature	Date

When completed; one copy will for participant, one for researcher file.

Appendix 6. Participant information sheet



University of Salford MANCHESTER

PARTICIPANT INFORMATION

Marina Bonde de Queiroz

School of Computing Science and Engineering

Newton Building, University of Salford,
Salford M5 4WT

t: 0161 295 6233

m.queiroz@edu.salford.ac.uk | www.salford.ac.uk

www.acoustics.salford.ac.uk

Participant nº: ______________

Gender (optional): ________________

Age:

- ☐ 18 to 25
- ☐ 26 to 50
- ☐ 50 to 75
- ☐ Over 75

How often do you come to the zoo?

- ☐ More than once a week
- ☐ Once a week
- ☐ More than once a moth
- ☐ Once a month
- ☐ Less than once a month

Have you participated in sound walks before?

- ☐ Yes
- ☐ No