Impact of anthropogenic noise on the welfare of zoo-housed animals

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ABSTRACT

Impact of anthropogenic noise on the welfare of zoo-housed animals

Catherine Pelletier

An increasing number of studies on animal welfare have been performed in zoos in the past decades. Some assessed the impact of noises on animals, but only considered sound frequencies within the human hearing range. Yet, most other animals' have a wider hearing range. This thesis analysed the effects of sounds and visitor attendance on the welfare of the five feline species of the *Panthera* genre at Zoo de Granby, Granby, Canada. Activity budget and space use collected with the focal sampling technique were compared to average sound levels, measured with an acoustic recorder, and visitor attendance. The results show that sound levels and visitors had effects on the felines' behaviors, but this varied between species. For example, during summer, an increase in sound levels increased more resting time for two species, but decreased resting time for the three other species. The sound levels' effects differed between seasons, calling for animal welfare management adapted to season (e.g. the two largest species of feline had opposite trends during winter when compared to summer for all their behaviors). Based on the "heat maps" of the specific locations the studied animals used, we believe the felines' space use was influenced by the enclosures' design and location of resting and shady areas rather than sounds and visitors. Noises and visitors had on some occasion opposite effects on the same behavior and species, suggesting these two factors should be monitored separately when assessing animal welfare. Overall, we did not find strong evidence of poor welfare for any feline species, with the exception of some individuals that showed signs of fearfulness. In an additional study, we evaluated the soundscape of the same Zoo by recording sounds in various locations in cycles of 24 hours. The 24h sound levels of most locations were not considered problematic for animal welfare, except some noisy indoor areas and near the water park. Ultrasounds were rare and not considered problematic to animal welfare, contrary to infrasounds that were loud and variable. Human activity increased sound levels and variability of noises, suggesting they could be detrimental to animal welfare. The soundscape did not change between seasons, meaning mitigation of noise pollution should be implemented at all time. More research is needed on the soundscape of zoos and its effects on animal welfare in a variety of taxa, with all sound frequencies that are in the hearing range of the studied animals.

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CONTRIBUTION OF AUTHORS

As the first author of this thesis, my responsibilities were the design of the project, data collection and analysis, and writing of the manuscripts for both chapters. Robert Weladji and Patrick Paré provided the original idea of the project, and they acted as mentors and supervisors. Statistical analyses were conducted with the guidance of Dr. Weladji. Louis Lazure provided help on setting up field work and collecting data, and with Patrick Paré provided background information on Zoo de Granby and acted as coordinators between the lab and the zoo staff. Dr. Weladji, Patrick Paré and Louis Lazure also reviewed and edited the manuscripts.

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GLOSSARY

Acoustic-related terms (de Queiroz, 2018; Long, 2014; McKenna, Shannon, & Fristrup, 2016; Pater, Grubb, & Delaney, 2009)

Bandwidth: a range of frequencies, usually within a given band.

Decibel: value measured as ten times the base-ten logarithm of the ratio of a quantity to a reference quantity. It is a dimensionless ratio and not a "true unit". It is commonly used in acoustics, with the quantities being pressure, in *Pascal* (Pa).

Equivalent continuous sound level (L_{eq}): a single value calculated from multiple sound level variations over a fixed time period, and has the same energy content of a continuous constant sound, therefore the same damage potential. It can be seen as time averaging of sound pressure level based on energy. Compared to a simple arithmetic average of sound levels, it emphasizes more on highest sound levels, even brief, which is more descriptive of the noise experienced by humans and animals.

Frequency (sound): property of sounds that determines the "pitch", noted in hertz (Hz).

Frequency weighting: algorithm of frequency-dependant filter simulating what is perceived by the study subject, based on its hearing sensitivity and hearing range. Common frequency weightings for humans are the A, B, C, and D weighting scales.

Infrasound: any sound whose frequency content is below the lowest frequency audible to human (around 20 Hz).

Maximum peak level (L_{max}): metric representing the highest absolute sound level recorded over a specific time period.

Minimum peak level (L_{min}): metric representing the lowest absolute sound level recorded over a specific time period.

Noise: unwanted sound.

Octave and third-octave band: standardised bands of constant-percentage width (an octave being a doubling in frequency) resulting in frequency bands that cover a wider range of frequencies as frequency increases. Each octave bands has a lower limit, a higher limit, and a center frequency. They can be further divided in three parts, called third-octave bands.

Peak-to-peak (L_{max}-L_{min}): the difference between the highest and lowest peak levels.

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

Sound level: the loudness or “volume” of a sound event, noted usually in decibel.

Sound metric: measurable parameter used to characterize or quantify a sound.

Sound Pressure Levels (SPL): metric used to quantify sound pressure relative to a reference quantity. It is in decibels, uses root-mean-square sound pressure, and the standard 20µPa is the reference quantity in air, which is the threshold of human hearing around 1 000Hz. It is noted as “dB (re: 20µPa)” or “dB SPL”.

Ultrasound: any sound whose frequency content is above the highest frequency audible to human (around 20 000 Hz).

GENERAL INTRODUCTION

Zoos and aquariums are important cultural institutions aiming to attain four main goals: education, entertainment, conservation and research (Barber & Mellen, 2013). Indeed, zoos are promoting conservation initiatives via captive breeding, financial supports, or educational programs; are providing research opportunities to various scientific domains; and are especially trying to optimize their species' welfare (Barber & Mellen, 2013). One major challenge in zoos is to keep a balance between the goals of education and entertainment for visitors, and keeping exhibited animals safe from stressing elements that could compromise their welfare (Fernandez, Tamborski, Pickens, & Timberlake, 2009). Animal welfare is defined as the individual's ability to cope with its environment (Broom, 1986; Hill & Broom, 2009), and is a spectrum between good and poor (Broom, 1991). It can be scientifically measured, as there are many indicators of welfare that can be evaluated, for instance: behavioral measures (e.g. captive animals' activity budget similar to the ones in the wilderness, presence or not of abnormal behaviors or stereotypies; change in behavioral patterns in different contexts), physiological measures (e.g. an increase in heart rate, blood pressure, or adrenal response indicative of stress), physical and mental health (e.g. presence of injuries or diseases that would indicate poor welfare), life expectancy, and reproductive success (Broom, 2007; Fraser, 2009; Hill & Broom, 2009).

Many studies have taken place in Zoological institutions in the past decades, especially in relation to potential threats to animal welfare. The most assessed potential stressing factor is the presence of high numbers of visitors (Davey, 2007), since it is the main aspect that differentiates zoos from other captive environments and the wilderness (Hosey & Druck, 1987). Multiple studies demonstrated that the visitors had negative impacts on animal welfare, with a few that found positive or no effect at all (reviewed by Davey, 2007; Fernandez et al., 2009; Hosey, 2000, 2008). However, most of these studies were largely focused on mammals, more specifically certain groups of charismatic species, such as primates, carnivores, or hoofed animals (Melfi, 2009). Other taxonomic groups were for the most part overlooked in the literature, as very few assessed the visitor effect on birds, reptiles, amphibians, fish or invertebrates, even though there are more individuals of these taxa present in zoos when compared to mammals (Melfi, 2009). Moreover, most studies on captive animal welfare assessed solely the visitor effect. Many other factors in captive environments could be detrimental to the housed species, such as restricted space, husbandry routine, presence of other species nearby, abnormal social groups, and other abiotic factors including artificial substrates, lights, odors and sounds (Morgan & Tromborg, 2007). There is a general consensus that in captive environments, the major aspect that can cause stress in an individual is its lack of control on these environmental factors (Broom, 1991; Carlstead, 1996; Morgan & Tromborg, 2007).

One aspect of the captive environment that has been increasingly studied in more recent years is noise pollution, whether generated by visitors themselves or other anthropogenic sources (Morgan & Tromborg, 2007). Indeed, there are many studies that demonstrated negative impacts of noise on laboratory animals, ranging from hearing losses, abnormal behaviors, physiological stress, and sleep deprivation (Kight & Swaddle, 2011; Slabbekoorn, Dooling, Popper, & Fay, 2018; Turner, Parrish, Hughes, Toth, & Caspary, 2005). Some of these negative behavioral and physiological effects were even found in wild populations, with additional negative effects such as communication interference (masking of biologically relevant sounds), lower reproductive success and fitness, and even death (Kleist, Guralnick, Cruz, Lowry, & Francis, 2018; Shannon et al., 2016; Slabbekoorn et al., 2018; Wright et al., 2007). In zoos, visitor noise negatively impacted welfare, with increased levels of alertness (Birke, 2002; Larsen, Sherwen, & Rault, 2014; Quadros, Goulart, Passos, Vecci, & Young, 2014), aggression (Chamove, Hosey, & Schaetzel, 1988; Sellinger & Ha, 2005), hiding (Farrand, 2007; Sellinger & Ha, 2005), stereotypy (Elias, 2012; Sellinger & Ha, 2005), abnormal behaviors (Cooke & Schillaci, 2007; Owen, Swaisgood, Czekala, Steinman, & Lindburg, 2004), and stress hormone (e.g. cortisol; Owen et al., 2004). Moreover, construction noise in zoos influenced animals by increasing alertness, hiding, and cortisol levels (Chosy, Wilson, & Santymire, 2014; Powell, Carlstead, Tarou, Brown, & Monfort, 2006). Therefore, it is clear that noise pollution of various sources can affect the welfare of captive animals.

However, many of these previous studies did not measure noises in frequencies outside of the human-hearing range, namely ultrasounds and infrasounds. A few studies performed in laboratories found several sources of ultrasonic noises that had high sound levels (Sales, Milligan, & Khirnykh, 1999; Turner et al., 2005), and these sources could also be present in a zoo setting (e.g. ventilation and heating systems, vehicles, cleaning equipment, electronic devices, or machinery). Other sources could also produce infrasounds and seismic vibrations, for instance construction activities, vehicles, or engines with pumps and filters (Morgan & Tromborg, 2007; Owen et al., 2004). These sources of potentially detrimental noises in low and high frequencies are of importance, since most species housed in zoological institutions are sensitive to these sound frequencies, especially non-human mammals (Fay, 1988; Heffner & Heffner, 2007). As it is difficult to retreat from irritating sounds, captive animals lack control on their acoustic environment, leading to potential stress (Broom, 1991; Morgan & Tromborg, 2007).

There is a gap in our knowledge of the acoustic environment in zoological institutions, particularly with high (ultra-) and low (infra-) sound frequencies. Therefore, this study assessed the acoustic environment in regards to zoo animal welfare, with noise measurements of a large sound frequency range covering most of the housed animals' hearing sensitivity. The first part of this thesis assessed the effects of sound levels and visitor attendance on the behavior and space use of large felines, selected because of their broad hearing frequency range (Heffner & Heffner, 1985) and their inclination to use hearing and sight to assess their surroundings (Norris, 2001). The second part of this thesis evaluated more precisely the acoustic environment of various types of locations and enclosures for cycles of 24h.

Chapter 1:

The effect of noise and visitor on the welfare of zoo-housed felines

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ABSTRACT

Studies on the impact of visitors and noise pollution on captive animal welfare have mostly reported negative effects, but the majority focused on recording sounds audible to humans. The impact of low (<100 Hz) and high frequency (>20 000 Hz) sounds is poorly understood, yet they are part of most other mammals' auditory ranges. This study analysed the impact of sound and visitors on the welfare of the five species of felines of the *Panthera* genre at Zoo de Granby, Granby, Canada. Activity budget and space use observations recorded using the focal animal sampling method were coupled to measurements of average sound levels over a large frequency range (17.5-90 510 Hz) and visitor density (between no visitors to large crowds). We found that sounds generally affected feline behaviors, but that these effects were different between the species. For example, during summer, an increase in sound levels increased resting time for two out of the five species. The sound effects on a behavior even differed between the summer and winter seasons for a same species (e.g. opposite trends during winter for resting time for lions [*Panthera leo*] and Amur tigers [*Panthera tigris altaica*]). Visitor density also affected feline behaviors differently between species and between seasons. This suggests that animal welfare management must be adapted to the season and species, or rather individuals. Higher sound levels and visitor attendance promoted the use of hiding places in the back zones of the enclosure for some species. However, based on the "heat maps" of the specific locations felines used, we believe that space use was influenced by the enclosures' design and location of resting and shady areas rather than sounds and visitors. Sound levels and visitor density, even if related, did not always have the same effect on activity budget or space use for the same species, suggesting we should consider these two factors as different aspects when managing the zoo animals' welfare. Overall, there was no evidence of poor welfare for any of the study species. However, our findings call for close monitoring of some individuals showing pacing and fearfulness signs. The study also calls for more awareness about noise issues to the zoo community in an attempt to enhance captive animals' welfare, with some suggestions of noise pollution mitigation methods. We also recommend recording all sound frequencies relevant to the study species when assessing the noise pollution issue in regards to animal welfare.

INTRODUCTION

For many zoos, captive animal welfare is an everyday issue, as keepers try to provide a great experience to the public while maintaining excellent captivity conditions to their housed species (Barber & Mellen, 2013). Animal welfare can be described as the degree to which an individual can cope with challenges in its environment (Broom, 1986), and it can vary from very good to very poor (Broom, 1991). This can be determined by a combination of measures of physical and mental health (Barber & Mellen, 2013), including behavior and physiological responses to the environment stimuli (Hill & Broom, 2009).

As an attempt to improve captive animal welfare, studies since the 1970s analysed potential stressors for various species (reviewed by Davey, 2007). The presence of visitors was the main factor studied, since it is one of the principal environmental feature of zoos that set them apart from the wild or laboratory conditions (Hosey & Druck, 1987). Some studies found no visitor effect, or even enriching ones, but in most cases these studies found that visitors negatively affected the welfare of animals (Fernandez et al., 2009; Hosey, 2000, 2008). Visitors' presence has also been linked to an increase in sound levels (de Queiroz, 2018; Quadros et al., 2014). Visitors who were more active and noisy, or busy days with intense noise levels, provoked an increase in negative-related behaviors in many captive species, including activity level (Cooke & Schillaci, 2007; Owen, Hall, Bryant, & Swaisgood, 2014), aggression (Chamove et al., 1988; Sellinger & Ha, 2005), vigilance (Birke, 2002; Larsen et al., 2014; Quadros et al., 2014), abnormal behaviors (Cooke & Schillaci, 2007), stereotypies (Mallapur & Chellam, 2002; Sellinger & Ha, 2005); increased stress hormone levels (e.g. cortisol; Owen et al., 2004; Powell et al., 2006; Wielebnowski, Fletchall, Carlstead, Busso, & Brown, 2002); and hiding from the public (Farrand, 2007; Sellinger & Ha, 2005; Suárez, Recuerda, & Arias-De-Reyna, 2017). Therefore, it is clear that the presence and noise pollution of visitors affect the behavior and welfare of captive animals.

While visitor noise is an important stressor for captive animals, other anthropogenic noises present in the zoo environment should also be assessed (Morgan & Tromborg, 2007), particularly those with frequencies outside of the human-hearing range, such as ultrasounds (>20 000 Hz, see Glossary). Multiple sources of elevated ultrasonic sound levels found in laboratories

(Sales et al., 1999; Turner et al., 2005) could also be present in a zoo setting, for instance electronic devices, machinery, equipment, ventilation systems, and vehicles. In addition, low frequencies (<100 Hz) and seismic vibrations sources could also be present, such as construction activities, trucks, pumps, filters or engines (Morgan & Tromborg, 2007; Owen et al., 2004). These could well be stressful for animals, as studies found that individuals negatively responded to high noise levels, including hearing loss, deprived sleep, abnormal social behavior, or elevated blood pressure and stress hormone levels (reviewed by Kight & Swaddle, 2011; Turner et al., 2005). Moreover, various species commonly housed in zoos are sensitive to high and low frequencies, notably most non-human mammals (Fay, 1988; Heffner & Heffner, 2007). As animals cannot retreat from irritating sounds, this lack of control on their surroundings is potentially a major stressful aspect in their captive lives (Broom, 1991; Morgan & Tromborg, 2007). Since the vast majority of zoo sound studies only assessed noises contained in the human-hearing frequency range (~20-20 000 Hz), more research is needed to describe the acoustic nature of zoo environments and its implication on animal welfare, particularly for high and low frequencies.

The aim of this study was to assess the impact of sounds from a large frequency range and visitor attendance on the welfare of captive animals. We selected the five feline species housed in Zoo de Granby, Granby, Canada, namely the African lion (*Panthera leo*), the Amur leopard (*Panthera pardus orientalis*), the Amur tiger (*Panthera tigris altaica*), the jaguar (*Panthera onca*), and the snow leopard (*Panthera uncia*). These large cats were selected because their enclosures were positioned in various locations within the zoo, with some of them close to potential sources of loud noises (e.g. water park for the lions, amusement park for the jaguars). Moreover, these species have a broad hearing range sensitivity, from 48 to 85 000 Hz (based on the domestic cat, Heffner & Heffner, 1985), making them one of the most sound-sensitive species housed in this zoological institution. They also rely primarily on their hearing and sight to assess their environment and when hunting (Norris, 2001). Felines' behavioral responses and space use were used as indicators of the animals' welfare, the former being a non-invasive and non-intrusive method that gives information on both physical and mental health (Dawkins, 2004). These indicators were compared to measures of average sound levels and number of visitors, the latter still being a major factor in captivity that could not be ignored. The sound frequencies' range recorded was between 17.5 and 90 510 Hz, covering infrasonic (17.5-100 Hz), audible (100-20 000 Hz) and ultrasonic (20 000-90 510 Hz) sounds. We collected data during the high touristic summer season as well as the low touristic winter season, to assess if the effects of noise and visitors would change between these two periods. This was done for expanding our knowledge of animal welfare during other time periods than only during the high touristic season, as that is what was mostly done in past studies (Brando & Buchanan-Smith, 2017). In addition, some data collection days were done when the zoo was closed to the public, as to have variety in the acoustic environment and presence of visitors.

We hypothesised that variation in sound levels and visitor attendance would affect the behavior and space use of captive felines. We predicted that higher average sound levels and visitor numbers would lower the occurrence of behaviors associated with good welfare (e.g. resting, exploration, or affiliative social behaviors), and would promote behaviors associated with poor welfare, such as aggression, stereotypy or vigilance (Mitchell & Hosey, 2005). A stereotypy is defined as a behavior with repetitive and invariant pattern, with seemingly no obvious goals or purposes, and is mostly associated with stress (Mason, 1991). In addition, high sound levels and visitor numbers would increase the use of retreat areas in the animals' enclosure. We hypothesised that activity budget would be similar between the species (they have similar behaviors in the wilderness [Norris, 2001]), as well as their space use (feline prefer to be on high ground [Lyons, Young, & Deag, 1997]). Therefore, we predicted that the effects of sound levels and visitor attendance on the felines' welfare would not differ between species. However, the felines were reported by zookeepers to be more active and explorative during the cold season. We therefore predicted that the felines' activity budget and space use would be different between seasons, with felines spending less time resting in favor of exploration and playing with enrichments during winter. We also predicted that the effects of sound levels and visitor attendance on the behavior and space use of the felines, if any, would be lower in the winter as compared to the summer, since felines seem more comfortable in colder temperatures than during the hot season, and therefore would be less affected by potential stressing elements.

METHODS

Subjects, Study area and Husbandry

Fifteen individuals of five species of felines (African lion, Amur leopard, Amur tiger, jaguar and snow leopard) were the subjects of this study (see Table 3.1 in Appendix A for more details on each individual). Distinguished facial traits and specific fur patterns were used to identify each individual. The animals were housed at Zoo de Granby in Granby, Canada, in two types of enclosures (outdoor and indoor). All outdoor enclosures, plus the jaguars' indoor enclosure, were visible by the public. All species except the jaguars had an off-exhibit indoor enclosure inaccessible to visitors (see Figures 3.1 to 3.9 for pictures and Table 3.2 for detailed characteristics of the enclosures in Appendix B). Generally, the outdoor enclosures consisted of grass, rocks, trees, climbing platforms, and vegetation. A water pool for swimming was present for the Amur tigers and jaguars. The indoor enclosures were areas on hard floor with water bowls, with the addition of artificial trees and climbing structures for the jaguars.

Data were collected between May and September 2018 for the summer season and between December 2018 and February 2019 for the winter. The summer season was separated in two periods: the first, in May and September, represented a condition when the park was not open to the public during the day (visitor absent). It is important to note that the no visitor scenario was in fact an observer only situation, with the observer hidden as much as possible. The second part of the summer, from June to August, represented the condition when the park was open and visitors were present. Felines were in their outdoor enclosures during the summer, with the exception of a few days for the jaguars where they were indoors. As for the winter season, the Amur tigers and snow leopards were still kept outside, since they can handle very well colder temperatures (Norris, 2001). The Amur leopards were not observed during the winter, because the individuals displayed were different from the ones during the summer. Jaguars and lions were kept inside during winter, meaning the jaguars were still subjected to visitors, as their indoor enclosure is visible to the public, contrary to the lions' indoor enclosure. This means that the visitor effect could not be tested for the lions during winter. In the cold season, the zoo was only open on the weekends and some weekdays during the holidays.

Zookeepers kept the same enrichment and feeding routine schedules during the study period, with enrichment's type of stimuli changing everyday (e.g. smells, toys, food hidden in logs or tubes). The Amur tigers and jaguars had enrichment periods animated by zookeepers during both seasons. There were also animations for the African lions and Amur leopards during the summer only, and for the snow leopards during the winter season only. All felines were fed daily for 6 days, before the park's opening, with Milliken Meat Products Ltd, which was processed horse meat added with cellulose, vitamins, minerals and fatty acid supplements. It did not contain bones, cartilage, organs, skin or connective tissues. The seventh day, felines were not fed, but given instead bones, usually a beef's femur, to keep them busy and clean their teeth. This was also to allow the animals to fast, mimicking the wilderness where carnivores do not necessarily have successful hunts every day (Norris, 2001). Felines were fed early in the morning in their indoor enclosure, while zookeepers cleaned the outdoor enclosure and placed enrichments. There was no behavioral observation during that period.

Behavioral Observation

Outdoor and indoor (jaguar) habitat observations were conducted from the public viewing areas. The indoor off-exhibit enclosure of the African lion observations were performed from the zookeepers' area behind a window. Data collection began when the felines were let out into the outdoor (or indoor) enclosure after being fed (around 9h00-10h00). Sampling continued until 19:00 in the summer and 16:00 in winter, following zoo opening hours' and sunset time. There was an hour break usually around 12:00 or 13:00, and a 5 minutes pause every hour. A pause was also taken during enrichment periods that were animated by a zookeeper (between 11:30-15:00 depending on the species, for a duration of 15 to 20 minutes), to avoid bias in behavioral data. With the ZooMonitor web application (Ross et al., 2016), the instantaneous focal sampling method was used to collect behavioral data (Martin & Bateson, 2007). A focal individual was observed for a period of ten minutes, with the main behavior recorded instantaneously every 15 seconds (a total of 40 observations per period). The ethogram used (Table 1.1) was based on the standardized feline ethogram developed by Stanton, Sullivan, & Fazio (2015) and personal observations made during a pre-sampling period. For each species, individuals were assigned a random number and sampled in numeric order, starting with a different individual each day. This ensured that each individual was observed at every time period, as to reduce error due to circadian variations in behaviors. One species at one enclosure was studied for a complete day, as to minimise relocation of the acoustic recording equipment (see below). There were species rotations every 2 to 4 days, allowing each species to be studied equally throughout the field seasons.

Space Use Data

Spatial distribution data were collected using the same focal sampling technique as the behavioral observations. Since we expected felines to be resting most of the time, the position of the focal individual was recorded only at 1 minute intervals (a total of 10 observations per sampling period). Positions were based on pre-established zonation: Front, Mid and Back of the enclosure, shown in Figures 1.1 to 1.5 for each outdoor enclosure. Typically, the Front zone represented the area close to the edges of the enclosure, near visitors' pathway, with little to no cover. The Mid zone was further back in the enclosure, with some level of cover (vegetation, shelters). The Back zone was the furthest from visitors, with more cover options (dense vegetation, shelters, hills). The zones were nearly equal in size. The zone division provided information on the functional use of the space available in the respective exhibits, and whether felines avoided or not the visitors or other possible sources of noises. There was space use observation for the indoor enclosure of the jaguars (not shown in figures), but not for the indoor enclosure of the African lions, since it was too small and without any substantial structures, and would therefore not be relevant. A feature of the ZooMonitor application (Ross et al., 2016) allowed us to generate "heat maps" of all the specific locations where each individual was during the focal sampling, using Figures 1.1 to 1.5 as the blueprints of the heat maps.

Sound Level Data

Sound levels were measured with a SM3BAT acoustic recorder equipped with sonic (SMM-A2) and ultrasonic (SMM-U1) microphones (Wildlife Acoustics Inc.). The microphones were attached on a tripod, approximately 1m above ground (see Figure 3.10 in Appendix C for an example of how the recorder was set during field work). The SM3BAT was installed at one of the 7 felines' enclosures (5 outdoor and 2 indoor enclosures). Since weather can affect sound propagation, it is recommended to install the microphones at the exact location of the study species (Pater et al., 2009). However, for technical and safety reasons, it was not possible to put the recorder inside the enclosures. Instead, they were installed as close as possible, between fences for the outdoor enclosures, or in the transfer zones adjacent to the indoor enclosures in their case. The sound levels were recorded for 2 minutes every 8 minutes, for a total of 12 minutes per hour. Because rains, strong winds or snow storms would have biased the sound recording (making unusual high sound levels), there were no data collection under those weather conditions. Sound recordings were regularly checked, and if there were any technical issues or biased sound levels because of weather condition, the involved sound files were removed from analysis. Microphones were calibrated in an anechoic chamber using professional calibrators at the beginning of the study, and were regularly checked for loss of sensitivity throughout the field work (see Figures 3.11 to 3.14 in Appendix D).

A number of sound studies lack in the description of their methodologies, preventing accurate comparisons between results (see reviews of Gill, Job, Myers, Naghshineh, & Vonhof, 2015; McKenna et al., 2016; Pater et al., 2009). Several recommendations are provided by these reviews on the information to report in a sound study (detailed in Chapter 2). In light of these recommendations, for this study, the chosen sound metric of average sound levels was the equivalent continuous sound level (L_{eq}), which is an energy-based average value over a fixed time period. This energy-based average value is ideal for ambient noises that are more or less constant in time, which was expected in a zoo setting (ventilation, office noise, busy day). It is also widely used in the literature, making comparisons of our results more accessible. The sound levels were measured in the common dB SPL scale, where the reference is 20 µPa (at 0 dB). L_{eq} was calculated and extracted for periods of 1 hour with the Kaleidoscope Pro Noise Analysis Module Version 5.0.3 (Wildlife Acoustics Inc., 2018). This software permits the extraction of L_{eq} in third-octave bands or standard human weighting scales (see Glossary). Since felines have a different hearing sensitivity than humans (Fay, 1988), we did not use human-based weighting scales, but rather specific unweighted third-octave bands (Pater et al., 2009). The bands we selected for analysis covered sound frequencies between 17.5 and 90 510 Hz. This frequency range was determined with the maximum hearing range of the domestic cat, which is around 85 000 Hz (Heffner & Heffner, 1985), and the recorder's available third-octave bands. The software therefore extracted L_{eq} values of 1 hour for each of the third-octave bands. Since we wanted to compare behaviors and space use for only one L_{eq} value, all these third-octave bands' L_{eq} outputs were combined into a single total L_{eq} value covering the whole frequency range using equation 2.62 from Long (2014):

$$SPL_{total} = 10 \log \left(10^{\frac{SPL_1}{10}} + 10^{\frac{SPL_2}{10}} + \cdots \right) dB$$

Where SPL_{total} is the total sound pressure level (L_{eq}) of all third-octave bands (measured in dB SPL), and SPL_1, SPL_2, and so forth, are all the sound pressure levels (L_{eq}) of each third-octave bands. It was this L_{eq} (SPL_{total}) that was used for the statistical analysis, with each focal sample attributed its corresponding hourly L_{eq}.

We initially measured the Peak-to-peak (L_{max}-L_{min}) sound levels as an indication of variability in soundscape (more detailed in Chapter 2). This was based on Rabat's studies (2004, 2007), where the sleep quality of animals was more disturbed under variable noises than a constant and steady continuous background noise of the same loudness. Therefore, we expected that animals would be negatively impacted by a variable soundscape or frequent bursts of loud noises, rather than constant background sounds. However, due to high correlation with L_{eq}, this sound metric was not used in the analysis. We favored L_{eq} since it was more intuitive to interpret, and because it is more widely used in the literature, making comparisons of our results more accessible.

Visitor attendance Data

The observer evaluated the total number of visitors present at the felines' enclosure for the whole duration of the 10 minute focal, and noted the result in different categories of "density". These categories were initially divided in eight levels: no visitor, between 1 and 10, between 11 and 20, between 21 and 30, between 31 and 40, between 41 and 50, between 51 and 60, and more than 60 visitors. At the 60+ visitors point, it was too difficult to know exactly the number of visitors due to the large crowd while also trying to focus on the felines at the same time. However, for simplicity in the statistical analysis, these categories were later merged into three levels: "no visitor", "between 1 and 30 visitors", and "more than 30 visitors". These densities represented a no visitor condition (when the zoo was closed), a few visitors (between 1 and 30) and a more substantial crowd (more than 30). Another reason for this final three-level division is that the frequency of observation of each category was more or less equal for all levels, as shown in the histogram (Figure 3.15 in Appendix E).

Statistical Analysis

Proportion data of a given behavior or position during each focal (number of observation of a behavior or position / total number of observation possible in a focal) were used as response variable for the following five sets of generalized linear mixed models (GLMM) with a binomial distribution and logit link function. The individual ID was also added as a random factor to account for pseudoreplication in all models. For simplicity, and because some behaviors were similar in terms of welfare implication, Rest and Sleep were combined to form "Rest/Sleep"; and Exploratory behavior, Play with object, and Hunting were combined as "Active behaviors". Vigilance, Locomotion, Stereotypy (pacing), Affiliative social behaviors, and Agonistic social behaviors were kept separate. All other behaviors that were rarely observed and with low welfare relevance were combined into the "Others" category. Grooming was initially considered important for welfare, as an excessive display of this behavior indicates stress in felines (Willemse & Spruijt, 1995). However, it was rarely observed, and therefore was also included in "Others".

The first GLMMs tested the effect of activity type, species, and the interaction between those two variables, on the proportion of occurrence of behaviors for each season separately. We were interested in the interaction term, as it would indicate, if significant, that the activity budgets would be different between species. The second GLMMs tested the effect of activity type, the season, and the interaction between those two variables, on the proportion of occurrence of behaviors for each species separately. We were again interested in the interaction term, as it would indicate, if significant, that the activity budget would be different between the summer and winter season. Accordingly, we tested the effect of noise and visitors on the animals' welfare for each season separately in further models. Similar GLMMs were made, but for space use data instead, with the same predictors and interactions. Pairwise comparisons with the Tukey-Kramer correction were performed on the interaction terms to find which of the behaviors or zones were more often observed in the different scenarios (activity budget and space use between species for each season, or between seasons for each species).

The following models were performed for each season separately for various reasons: we suspected that activity budget and space use of the felines would be vastly different between the seasons, altering the effect of noise and visitors on the animals' welfare (see predictions); some species were housed in different enclosures depending on season (indoor for lions and jaguars during winter instead of outdoor like in the summer); and not only does the climate changes substantially, but opening hours and routine husbandry were also different between the seasons. Considering all these differences and our predictions, we therefore tested each season separately.

The third set of GLMMs tested the effect of activity type, sound level (L_{eq}), and the interaction between those two variables, on the proportion of occurrence of behaviors. In this model, the interaction term was the main interest, as it would indicate whether the sound levels affected differently the proportion of each activity type. If significant, it would also support the further analysis of the sound variable. An iteration of this interaction model was performed, but with visitors' presence, a factor with two levels ("present", "absent"), instead of L_{eq}. This was also done with space use (position) proportion data as the response variable.

For the fourth set of GLMMs, specific behaviors of welfare interest (Rest/Sleep, Vigilance, Active behaviors, Pacing, Affiliative social and Agonistic social behaviors) were each analysed for all species combined, but separated by season. Only behaviors representing at least 1% of the activity budget were analysed. Therefore, we did not test for any of the social behaviors since they were too rare. These models tested the effect of sound level (L_{eq}), visitor density, the interaction between species and sound level (L_{eq}), and the interaction between species and visitor density, on the proportion of occurrence of the behavior analysed. Visitor density was a categorical factor of three levels (No visitor, number between 1 and 30, number greater than 30), as explained earlier. The interaction terms were tested to assess whether the effect of sound levels or visitors would differ between the species. Moreover, in all these models, we also controlled for species and time of day, the latter being a categorical variable divided in three blocks: AM (between 9:00-12:00), PM (12:00-16:00), and Evening (16:00-19:00). All possible variable combinations were made to create several competing models, with the final model selected being the one with the lowest Akaike information criterion (AIC). Since models within 2AIC are equivalent in explaining variation in the response variable (Burnham &

Anderson, 2002), we selected the model with the fewest parameters when two or more models within 2AIC were present.

Finally, for the fifth GLMMs, space use was analysed with the same predictors including covariates as the fourth GLMMs, but with proportion of occurrence in a zone as the response variable. All selected models (fourth and fifth sets of models) with those within 2AIC or the second nearest model are presented in Table 3.3 in Appendix F. After all models of the behavioral and space use analysis were generated, pairwise comparisons of the involved categorical variables were performed using the Tukey-Kramer correction. All tests were performed at the 5% level of significance using R 3.4.3 statistical software (R Core Team, 2017).

RESULTS

Approximately 300 hours during summer and 110 hours during winter of behavioral and space use observations were conducted for all felines. The means and standard deviations of sound levels (L_{eq}) of all the felines' enclosures for both seasons are reported in Table 1.2.

Activity budget and space use

The activity budget of the five species of felines, for each season, is presented in Figure 1.6. For all species, the dominant behavior was Rest/Sleep, and the social behaviors (Affiliative and Agonistic) were very rare. For both seasons, the interaction between activity type and species was significant, meaning the activity budget differed significantly between species (summer: $\chi^2_{(28)} = 4378.94$, $p<0.001$; winter: $\chi^2_{(21)} = 3139.348$, $p<0.001$). For example, tigers and jaguars were generally more active than the other species, especially in the summer. In general however, the species showed some similar activity budgets, at least in the hot season (Figure 1.6). Furthermore, for each species, the interaction between activity type and season was significant, meaning the activity budget for a same species was different between the seasons (lion: $\chi^2_{(7)} = 355.5733$, $p<0.001$; tigers: $\chi^2_{(7)} = 1906.7901$, $p<0.001$; jaguars: $\chi^2_{(7)} = 1551.7815$, $p<0.001$; snow leopards: $\chi^2_{(7)} = 2936.642$, $p<0.001$). For example, there was a significant decrease in Rest/Sleep in favor of the other behaviors for the Amur tigers, jaguars and snow leopards during winter when compared to summer (Figure 1.6)

Figure 1.7 shows the space use "budget" for each species and season. For both seasons, the interaction between position and species was significant, meaning space use differed significantly between species (summer: $\chi^2_{(8)} = 4827.8$, $p<0.001$; winter: $\chi^2_{(4)} = 345.443$, $p<0.001$). For example, all species spent more time in the Back zone during summer, with the exception of the tigers who used more often the Mid zone (Figure 1.7). Furthermore, for each species, the interaction between position and season was significant, meaning the space use for a same species was different between the seasons (tigers: $\chi^2_{(2)} = 1302.4937$, $p<0.001$; jaguars: $\chi^2_{(2)} = 47.417$, $p<0.001$; snow leopards: $\chi^2_{(2)} = 765.48$, $p<0.001$). For example, tigers and snow leopards used significantly less often the Back and Mid zones in favor of the Front zone during winter compared to summer (Figure 1.7). The more exact locations where the felines were positioned are shown in the "heat maps" in Appendix G (Figures 3.16-3.22). These figures show that felines were mostly in elevated places or beneath shelters and shady areas in the summer, or shelters and heating rocks during winter.

Effects of noise and visitors on behavior and space use

For the third GLMMs, sound levels affected differently behaviors depending on the activity type for the felines both in the summer ($\chi^2_{(7)} = 429.34$, $p<0.001$) and the winter ($\chi^2_{(7)} = 274.32$, $p<0.001$). Visitors' presence also affected differently behaviors depending on the activity type both during summer ($\chi^2_{(5)} = 1973.1$, $p<0.001$) and winter ($\chi^2_{(5)} = 262.92$, $p<0.001$). Space use was affected differently by sound levels depending on position type (Front, Mid, Back) during both summer ($\chi^2_{(2)} = 47.93$, $p<0.001$) and winter ($\chi^2_{(2)} = 39.32$, $p<0.001$), as well as by the presence of visitors in both summer ($\chi^2_{(2)} = 31.13$, $p<0.001$) and winter ($\chi^2_{(2)} = 86.79$, $p<0.001$).

For all behaviors and zone used, the full model (all predictors and interactions) was always the selected model (lowest AIC) in both seasons. All effects and their significance levels are shown in Table 1.3. The interactions between species and sound levels or visitor density were always significant in all cases, meaning the feline species were not affected similarly by these two factors. However, the main effects of sound levels or visitor density were not always significant. Indeed, during summer, the main effect of sound levels and visitor density was not significant on Pacing, and the main effect of sound levels had also no effect on the use of the Front zone. During winter, the main effect of sound levels was not significant on Pacing and the use of the Mid zone, and the main effects of sound levels and visitor density were also not significant for the use of the Back zone. To visualise the trends and effects of sound levels and visitor density on each behavior and zone used, see Figures 1.8-1.10 for the summer period, and Figures 1.11-1.13 for the winter period. Sound levels had both positive, negative, or no relationship with a specific behavior or zone used, depending on the season and species. The same observation can be made for visitor density's effect. For more details on the estimates and standard errors of sound levels' effects depending on species for each behavior and zone used, see Table 3.4 in Appendix F.

DISCUSSION

Research on the acoustic environment of zoological institutions is needed to assess the implication of anthropogenic noises on the welfare of housed animals, especially in sound frequencies that are outside of the human-hearing range, but well within the hearing range of most non-human mammals (Morgan & Tromborg, 2007). In this study, we evaluated the activity budget and space use of five species of large cats (African lion, Amur leopard, Amur tiger, jaguar, snow leopard), and assessed if average sound levels and visitor density had any effect on their welfare. We also studied these felines in different contexts (open or closed zoo days, summer or winter seasons), as to have a broader image of animal welfare in various scenarios.

Activity budget

For the five species, rest and sleep were the dominant behaviors. This is in accordance with the literature, as studies in the wild found that leopards (*Panthera pardus*) and leopard cats (*Prionailurus bengalensis*) were resting most of the day, with activities such as hunting, feeding, patrolling, exploring or courting mostly at night and crepuscular time (Bailey, 1993; Grassman Jr, 2000). However, these wild animals presented arrhythmic activity levels, with the most inactivity in the afternoon (Bailey, 1993; Grassman Jr, 2000; Rabinowitz, 1990). These activity patterns were also found in our captive felines, as they were active in the morning after being fed and released in their enclosure, or after an enrichment period in the afternoon, or later in the evening. For the social behaviors, they were rarely observed. This is not surprising, as felines tend to be solitary animals, with the exception of lions, one of the only social felines existing (Norris, 2001). This could explain why our lions performed affiliative social behaviors more often than the other species, except the jaguars, who were also more social, probably because they formed a couple. Weather variables such as temperature, precipitation, cloud cover or wind velocity also had little influence on wild felines' behavior, with the exception of hot temperature, which provoked more resting time (Bailey, 1993). This could explain why our captive felines were mostly resting in their shelters or shady areas in the afternoon due to higher temperature, and why most species were sleeping and resting more often during summer when compared to winter.

Since felines generally spend a majority of their time resting, we considered that more rest was a sign of good welfare for them, as it would indicate a relaxed attitude rather than apathy.

Moreover, felines in captivity are generally less active than their wild counterparts, probably because of the non-necessity of hunting in captivity (Weller & Bennett, 2001). However, we would still consider the felines to have good welfare if they traded rest time for other good welfare-related behaviors, such as exploring, hunting, affiliative social behaviors or mating (Mitchell & Hosey, 2005). On the contrary, we would not consider the felines to have good welfare if they traded rest time for aggression, vigilance (fearfulness) or pacing, because these behaviors are related to poor welfare (Mitchell & Hosey, 2005). With that said, for the effect of sound levels on Rest/Sleep, we obtained both positive and negative trends depending on the species. This effect was accentuated for jaguars and changed direction for the other species when comparing winter to summer (excluding Amur leopards, since they were not observed during winter). The visitor effect was more one sided during summer: as density increased, or when visitors were present at least, the proportion of time spent resting also increased. This suggests the felines are potentially habituated to visitors, or at least do not seem disturbed by their presence, contrary to noise levels in some instances. On the contrary, during winter, two out of three species spent less time resting when visitors were present (the visitor effect could not be tested for lions and Amur leopards during the cold season).

As for Vigilance, we obtained again a mix of positive and negative slopes for the effect of L_{eq} on the rate of this behavior. For the visitor effect on Vigilance, this behavior was less often observed only when a large crowd was present. Since being more often vigilant is considered an indication of poor welfare, especially in captivity, as it is related to stress and indicates either that animals are not comfortable in their situation or consider visitors as a threat (Mitchell & Hosey, 2005; Morgan & Tromborg, 2007; Tromborg & Coss, 1995), our results suggest that the felines were not necessarily paying attention to the crowd as it tended to get bigger and were not fearful of visitors.

Active behaviors are considered indicators of good welfare, as it means animals are enough comfortable to explore their environment, play with enrichments, and display other natural behaviors such as hunting or patrolling its territory (Mitchell & Hosey, 2005). In that regards, the effect of L_{eq} was mostly negative in both seasons: as sound levels increased, the rate of active behaviors decreased for most species. During summer, the trend was not biologically relevant (small slope) for tigers and jaguars. The trend was only positive for lions and jaguars during winter. The visitor effect was also negative for three of the species during summer, where as visitor density increased, the amount of active behaviors decreased. On the contrary, active behaviors increased with larger crowds during winter. For the most part, these results suggest that noise levels and visitor density did not promote exploration or playing with objects in our captive felines, especially during summer.

The most prominent stereotypy in captive carnivores is pacing (Clubb & Mason, 2003). Stereotypic behaviors are diverse in nature, and the cause is not always well understood. It has been suggested that it could be caused by lack of stimulation, and therefore be performed as a "do-it-yourself" enrichment, or a calming coping mechanism ("mantra effect") in stressful environments, or an anticipatory behavior like food anticipation (Carlstead, 1998; Mason, 1991; Mason & Latham, 2004). Pacing in felines is not found in the wild, but only in captivity, which is also why it is considered detrimental to animals (Carlstead, 1996). Similar to the ocelots in Weller & Bennett's study (2001), our felines were observed pacing, except the African lions who almost never performed this behavior (<1% of activity budget). Again, pacing both increased and decreased as sound levels increased. When looking at the visitor effect during summer, pacing decreased as visitors' density increased for the Amur leopards, but increased for the snow leopards. During winter, pacing decreased when visitors were present for the tigers.

Space use

For all species during summer, the Back zone was the most used sector of their enclosure, except for the tigers who favored the Mid zone. Sound levels had both positive and negative slopes when compared to proportion of time spent in the Back zone in the summer. During winter, the effect of sound levels was not biologically important, except a decrease for snow leopards. As for visitor density, the results are mixed, but overall felines spent more time in the Back zone when visitors were present in both seasons. For the other zones, the trends are all mixed between species and seasons. The results generally suggest that most of these large cats were more prone on hiding from the public (Back zone). However, when looking specifically at the space use "budget", the enclosures' design and the "heat maps" in Appendix G, it demonstrates clearly that the felines tended to spend a great deal of time in their shelters or in shady areas produced by trees and dense vegetation during summer, and in their shelters or on their heating rocks during winter. Felines prefer to be on higher grounds for a better view of their territory (Lyons, Young, & Deag, 1997), and the way the enclosures were designed, the elevated areas were in the Back zones, as well as most shelters and dense vegetation. For the tigers, their shelters were in the Mid zone, which would explain why they were mostly found there rather than the Back zone. The tigers and snow leopards also had heating rocks or platforms that were closer to visitors (Front zone), and they spent a lot of time there during winter. This would also explain why there was an increase of the usage of this zone during winter compared to summer. Felines were also more explorative during winter, hence the shift in their space use (the three zones are more equally used). Based on these observations, it appears that the felines' space use, since they spent most of their time resting, was more dictated by the location of the shelters, shady areas or heating platforms to sleep, rather than actually trying to hide from the public.

Overall effect of sound and visitor

Our predictions were that higher sound levels and visitor density would increase the proportion of time spent pacing, hiding, being vigilant and aggressive, while decreasing time spent resting, exploring and performing affiliative social behaviors. We did not always find these trends in our results, as sound levels and visitor density had positive, negative or no relationships depending on the species. We also found that the effect of sounds on activity budget and space use was different between seasons. Indeed, contrary to our predictions, some effects of sounds during winter were accentuated compared to their summer counterpart, for example Rest/Sleep for jaguars, and Active behaviors for jaguars and snow leopards. However, most of the time, the effect of sound levels on behaviors and space use actually changed direction between the seasons, as was the case for all the behaviors tested for the lions and tigers. It is possible that the felines, since they were more active and comfortable in colder temperatures, were less affected by negative environmental factors than when they were in the heat during summer. This is seen in the results, where there were more often negative effects of noise on the felines' welfare during summer (e.g. for most species, higher sound levels decreased time resting and exploring to promote vigilance). Considering these results, we recommend that animal welfare management be adapted depending on season. For example, managers could increase the amount of fresh water pools and shady areas in the enclosure to offer more cover from the heat to the felines.

In addition, and more importantly, for the same behavior, species and season, sound levels and visitors density had sometimes opposite relationships (e.g. Vigilance for Amur leopards; Rest/Sleep for tigers; Rest/Sleep, Vigilance and Pacing for jaguars; Vigilance and Pacing for snow leopards). This is surprising, as we thought they would share similar effects due to their correlation, based on a study where as visitors density increased, so did the sound levels (Quadros et al., 2014). In addition, other studies found that the average sound levels increased between zoo open days and closed days, or "quietest versus loudest" days (de Queiroz, 2018; Owen et al., 2014). However, these studies only recorded sounds in frequencies based on human-hearing range. It is possible that since we acknowledged the felines' hearing sensitivity in terms of sound frequencies recorded, we were able to lower the two factors' relationship, because visitor-related noises (e.g. talking, walking, pushing children in strollers, eating) only produce sounds of certain frequencies in the human hearing range (Kryter, 1985). Indeed, we monitored a large range of frequencies (up to 90 510 Hz) that felines can hear very well, and that were caused by many other sources of noises unrelated to the visitors themselves, such as electronic or cleaning devices, music, vehicles, ventilation and heating systems, lights, or other engines. These other anthropogenic noises potentially explain the difference in the animals' response when comparing the effects of sound levels and visitor density. Therefore, one should not assume that both factors will have the same impact on captive animals, even if related, and one should consider sound levels in species-relevant frequencies and visitors separately when assessing animal welfare. As to why they would have opposite effects, it is possible that the animals might not always react similarly to these two factors, because they might treat and cope with these environmental cues differently (e.g. hearing versus sight, or what the individual considers to be a threat; de Queiroz, 2018).

Felines' welfare concerns and solutions

Overall, even if we found some negative effects of sound levels or visitor density on behaviors and space use, we did not consider any species to have poor welfare. Lions mostly spent their time resting, performed some mating behaviors, and almost never paced. Amur tigers only showed welfare-related negative effects of noise in the summer, contrary to winter. This suggests they might be more uncomfortable during the hot season because of the high temperatures, and should be more closely monitored during that season. The jaguars presented mixed results, with more negative effects of noises during the summer. This is perhaps because of the presence of the amusement park nearby, which increased sound levels in general (the jaguars' outdoor enclosure had one of the loudest soundscape of the five species). However, we do not think the jaguars had welfare problems, as they were more active in general, while still resting the majority of their time, and because their reproductive behaviors suggest otherwise (successful reproduction prior to field season, and mating was often observed). The snow leopards rested most of the time in the summer, and were very active during winter. The results also suggest snow leopards were not necessarily disturbed by visitors, but more so by noises in general, especially in the summer (e.g. high increase in Vigilance with louder noises).

We denote however indicators of poor welfare for a few individuals. The Amur leopards, even if they had some positive effects on their welfare when looking at the visitor density (lower Vigilance and Pacing), spent most of their time in the Back zone behind dense vegetation to sleep and hide from the public and the heat. One female in particular, named Hope, was very fearful and hid most of the time. When she was not hiding, she was instead pacing. This is probably because she was newly introduced in her enclosure, and was not comfortable enough to explore or show herself in front of visitors. Two males, namely Baïko and Argoun, were hiding less often and were more active, but they also showed higher levels of pacing. For the jaguars, the male Kuwan was also the only feline to present an abnormal behavior, which was suckling excessively his tail to the point of injury that required medical treatment. It was attributed to digestive problems, but he did not show this behavior during winter, suggesting this was no longer an issue. The young snow leopard male Kang showed some fearfulness signs during summer. It is possible that he was still not comfortable in his environment, as he was transferred to the zoo only the year prior to the field season.

Solutions could be implemented to limit anthropogenic noise pollution. For example, researchers tested sound barriers of different materials and found that some were efficient in reducing sound levels, up to 12.2 dB (Orban, Soltis, Perkins, & Mellen, 2017). These barriers, accompanied with dense vegetation, could be placed around the enclosures that are near noisy features (e.g. amusement park, engines, or roads used by the staff). Educative signs indicating the impact of noise pollution could be installed at enclosures that are housing sensitive animals, as to encourage visitors to be quiet when in proximity with these animals (Birke, 2002; Fernandez et al., 2009). Signs have been used in some studies, and the results show promising avenues with a reduction in visitor noise levels (Dancer & Burn, 2019; Kratochvil & Schwammer, 1997). For indoor habitats, sound absorbing or attenuating materials, doors and walls could be installed (National Research Council, 2011). The employees could keep at a minimum the noise they produce when in proximity with animals. Cleaning routines could be made in the absence of animals nearby, as these routines produce high noise levels (Sales et al., 1999; Sales, Wilson, Spencer, & Milligan, 1988). Finally, any equipment producing noises and vibrations could be kept in separate rooms when possible.

Limitations of the study

As in most zoo studies, the small number of individuals observed makes generalization of the results more difficult. We found many differences between species in our results (activity budget, space use, and the effects of noise and visitors on these two aspects), but we suspect these differences were due to the individuals and were not a general species effect. Indeed, for each of our five species, we observed only between 2 and 4 individuals. Based on personal observations and feedback given by the zookeepers, we attribute these differences to the personalities of each individual. For example, some were clearly more fearful than others, due perhaps to their shyness or being in a new environment (less habituation and comfort). We however did not measure personality traits specifically, but it is possible and encouraged to do so (see Pankhurst, Knight, Walter, & Waters, 2009). Our study sheds light on the potential impact of noises and visitors on large felines overall, but we recommend assessing these potential stressing factors more on the individual level. When looking back at its definition, welfare is the degree to which an individual can cope with challenges in its environment (Broom, 1986), and each individual can cope and react in different ways when subjected to stressing factors (de Queiroz, 2018). Studies of the influence of personality, or which personalities are more likely able to cope with stressing elements, are of interest in future projects.

Moreover, behavior and space use are not the only information one can collect to assess animal welfare. An ideal situation would be to collect an ensemble of criteria of different sources to better confirm an actual effect of noise or other stressing elements. Indeed, even if activity budget is an excellent, easy and cheap method to measure welfare, some animals have evolved methods of hiding signs of pain or struggles, because it would be disadvantageous for them to display to predators or competitors that it is experiencing problems and difficulties (Hill & Broom, 2009). A combination of behavioral measures with other measures, such as physiological (e.g. cortisol or other stress hormone levels, heart rate, blood pressure), could confirm with more certainty if an animal is having welfare problems or not, rather than relying all the interpretation of the results on only one indicator (Hill & Broom, 2009).

Concluding remarks, implication on animal welfare and conservation

This study had a broad objective of raising awareness of the issue of noise pollution, especially to include all frequencies that can be heard by animals when assessing their welfare. The zoo and aquarium community should take into account their species' hearing sensitivity while managing their health in an attempt to improve it. Keepers and managers should not assume that noise levels and visitors are the same factor, as there are many other sources than the visitors' that can produce noises, especially in sound frequencies that we cannot hear and therefore often forget exist.

By contributing to our knowledge of the zoo's complex acoustic environment and how these sounds might affect captive animals, zookeepers will be able to develop effective strategies for mitigating such effects. Healthier and less stressed animals can lead to higher reproductive success (Cyr & Romero, 2007; Kleist et al., 2018), therefore improving the conservation and management of endangered species that are frequently housed in zoos. Indeed, for some species, their survival is highly dependent on successful breeding programs in captivity, as the wild populations are too small or scattered because of habitat destruction, climate change, or human activity (Groom, 2006; Halley & Iwasa, 2011; Pimm, 2008). That is the case of the Amur leopard, considered Critically Endangered on the IUCN Red List of Threatened Species, with less than 60 individuals left in the wild (Jackson & Nowell, 2008; Stein et al., 2016). The Amur tiger is also classified as Endangered, with estimation of 360 individuals left in the wild (Miquelle, Darman, & Seryodkin, 2011). More research on noise pollution in zoos should therefore be made, especially in less studied taxa, such as birds, reptiles, amphibians, and fish (Melfi, 2009).

CONCLUSION

This study assessed the impact of sound levels and visitor density on the welfare of fifteen individuals of five species of large felines, using activity budget and space use. Sounds and visitors had both positive and negative effects on the behaviors. However, we did not consider these felines to have serious welfare problems, except for some individuals to an extent. We also found differences in the effect of sound levels when comparing between seasons, indicating that managing noise in terms of the animals' welfare should be adapted to season. As for space use, even if noise and visitors had significant effects, we denote that the animals' positions were more influenced by the enclosure design than by environmental disturbances. The effects of sound levels and visitor density were not always pointing in the same direction for the same behaviors or space use of a species; therefore we should consider these environmental cues as separate factors when managing the animals' welfare. In fact, it is imperative to take into account all sound frequencies that the study animal can hear, and not just sounds that humans are sensitive to. Finally, the effect of noise and visitors varied between species and individuals. It is therefore important to perform our investigation at the individual level when assessing the welfare of animals. This is in an attempt to improve each individual's welfare and increase the chance of reproduction of endangered species.

TABLES AND FIGURES

Table 1.1: The ethogram of behaviors recorded during the sampling period for all five feline species, based on the standardized feline ethogram by Stanton, Sullivan, & Fazio (2015) and personal observations. Excessive grooming is often regarded as a sign of stress in felines (Willemse & Spruijt, 1995), and is therefore separated from the category "Maintenance".

Behavior	Description of behavior
Rest	Absence of movement or activity. Individuals are lying down, sitting or standing on four legs, but immobile. Ears are slightly up, but not pointing forward. Facial expression and general attitude show lack of alertness, fear or curiosity. Eyes are open, but in this case do not focus on any particular disturbance (i.e. does not include Vigilance). The animal can be observing his surroundings in a neutral way, but is not in an alert state.
Sleep	Absence of movement or activity. Individuals are lying down, with eyes closed. Head can be up or down.
Vigilance	Individual is in an alert state in order to increase awareness of immediate surroundings. Head position is always upright, with the neck elongated (tense). The ears are up and pointing forward (i.e. towards the source of disturbance). Eyes are open; the gaze is focused on a specific disturbance. Head can be either motionless (when observing the disturbance) or in rapid movement (when looking for the disturbance). Individual may be standing on four legs, sitting or lying down.
Locomotion	Traveling from point A to point B by rapidly or slowly walking using four limbs and tail for increased stability. Includes walking, swimming, running, trotting, jumping or climbing. Does not include pacing, exploratory or hunting (see below).
Self-grooming	The use of the tongue for licking any body part for comfort or hygiene purposes.
Exploratory behavior	Scent marking, searching or smelling an object or substrate while moving around or immobile.
Play with object	Playing with or using an object or an enrichment (but not conspecific, see below in affiliative social interaction).
Hunting	The body is prone or in low position as to hide, the animal is visibly staring intensely at an animal (e.g. wild bird, squirrel, hare, animals in other enclosures), then it slowly approaches the animal, and could try to catch it with the paws or jaws. Hunting also includes rapid movement (locomotion) when the animal is visibly excited and stimulated by the "prey".

Table 1.1: Continued

Behavior	**Description of behavior**
Affiliative social behaviors	Engaging in non-aggressive social interaction with a conspecific, whether or not the animal is the one that initiated it. Includes allogrooming (giving or receiving), playing, smelling, nuzzling, touching others, or vocalizing in a non aggressive way. Courtship behaviors and copulation are included. Playing is in a "non-serious" way, with no intention to harm (claws are not out, and teeth are generally not showing). If the animals are resting close together, it is considered as Rest or Sleep and not Affiliative social behaviors.
Agonistic social behaviors	Engaging in aggressive social interaction with a conspecific, whether or not the animal is the one that initiated it. Includes biting, clawing, snarling, hissing, growling, snapping or chasing. Mouth is open, with teeth usually showing, and ears are flat or backwards. The intention is to threaten or harm another.
Stereotypy (pacing)	Moving around the enclosure, usually in a straight line along the fence, with a non-purposeful walk on four limbs, defined by a distinct repetitive pattern (back and forth). At least two repetitions.
Abnormal behavior	Any behavior deemed abnormal to perform, such as self-mutilating, tail sucking, fur-plucking or vomiting.
Maintenance	Consuming food or water, defecating, urinating, stretching, and sharpening the claws. Does not include grooming.
Not visible	Individual is not visible to the observer during the focal sample.
Other	All other behaviors not defined above.

Table 1.2: Feline enclosures' equivalent continuous sound levels (L_{eq}) during behavioral observations, in both summer and winter seasons, at Zoo de Granby, Granby, Canada. Sound levels are measured between 17.5 and 90 510 Hz in unweighted dB SPL (re: 20µPa). There was no observation of Amur leopards during winter.

Enclosure	**Seasons**	**L_{eq} (mean ± sd)**
African lion outdoor	Summer	77.18 ± 4.45
African lion indoor	Winter	65.78 ± 2.88
Amur leopard outdoor	Summer	70.84 ± 2.47
Amur tiger outdoor	Summer + Winter	69.98 ± 5.44
Jaguar outdoor	Summer	77.94 ± 4.39
Jaguar indoor	Summer + Winter	65.63 ± 3.35
Snow leopard outdoor	Summer + Winter	69.65 ± 5.45

Table 1.3: Effects of sound levels (L_{eq}), visitor density and their interaction with species on each behavior and zone used for all species of felines, in the summer and winter seasons. The full model (all predictors and their interactions) was always the selected model (lowest AIC). Interactions are represented by « * » in the table, and degrees of freedom are noted « DF ». Significant effects are in bold.

Season	Behavior or Zone used	Effect	Chi square	DF	P value
Summer	Rest/Sleep	**Leq**	**75.541**	**1**	**<0.001**
		Visitor	**376.0113**	**2**	**<0.001**
		Leq*Species	**183.514**	**4**	**<0.001**
		Visitor*Species	**591.0209**	**8**	**<0.001**
	Vigilance	**Leq**	**14.2514**	**1**	**<0.001**
		Visitor	**45.1627**	**2**	**<0.001**
		Leq*Species	**101.711**	**4**	**<0.001**
		Visitor*Species	**130.4913**	**8**	**<0.001**
	Active behaviors	**Leq**	**43.207**	**1**	**<0.001**
		Visitor	**273.02**	**2**	**<0.001**
		Leq*Species	**122.251**	**4**	**<0.001**
		Visitor*Species	**616.906**	**8**	**<0.001**
	Pacing	Leq	2.4464	1	0.12
		Visitor	5.3688	2	0.07
		Leq*Species	**140.5094**	**4**	**<0.001**
		Visitor*Species	**394.0833**	**8**	**<0.001**
	Front zone	Leq	0.3392	1	0.56
		Visitor	**18.653**	**2**	**<0.001**
		Leq*Species	**37.5817**	**4**	**<0.001**
		Visitor*Species	**78.8092**	**8**	**<0.001**
	Mid zone	**Leq**	**28.475**	**1**	**<0.001**
		Visitor	**65.546**	**2**	**<0.001**
		Leq*Species	**175.998**	**4**	**<0.001**
		Visitor*Species	**606.686**	**8**	**<0.001**
	Back zone	**Leq**	**23.896**	**1**	**<0.001**
		Visitor	**69.792**	**2**	**<0.001**
		Leq*Species	**200.277**	**4**	**<0.001**
		Visitor*Species	**551.55**	**8**	**<0.001**

Table 1.3: Continued (winter season)

Season	Behavior or Zone used	Effect	Chi square	DF	P value
Winter	Rest/Sleep	**Leq**	**67.128**	**1**	**<0.001**
		Visitor	**107.12**	**2**	**<0.001**
		Leq*Species	**728.324**	**3**	**<0.001**
		Visitor*Species	**277.66**	**3**	**<0.001**
	Vigilance	**Leq**	**5.5285**	**1**	**0.02**
		Visitor	**60.5538**	**2**	**<0.001**
		Leq*Species	**118.8502**	**3**	**<0.001**
		Visitor*Species	**40.4675**	**3**	**<0.001**
	Active behaviors	**Leq**	**20.727**	**1**	**<0.001**
		Visitor	**285.004**	**2**	**<0.001**
		Leq*Species	**461.661**	**3**	**<0.001**
		Visitor*Species	**370.603**	**3**	**<0.001**
	Pacing	Leq	2.4018	1	0.12
		Visitor	**7.5035**	**2**	**0.02**
		Leq*Species	**37.788**	**3**	**<0.001**
		Visitor*Species	**44.2346**	**3**	**<0.001**
	Front zone	**Leq**	**4.4191**	**1**	**0.04**
		Visitor	**43.8512**	**2**	**<0.001**
		Leq*Species	**93.2414**	**2**	**<0.001**
		Visitor*Species	**262.0112**	**3**	**<0.001**
	Mid zone	Leq	2.6295	1	0.10
		Visitor	**54.2557**	**2**	**<0.001**
		Leq*Species	**25.0115**	**2**	**<0.001**
		Visitor*Species	**139.2934**	**3**	**<0.001**
	Back zone	Leq	0.166	1	0.68
		Visitor	0.362	2	0.83
		Leq*Species	**48.3588**	**2**	**<0.001**
		Visitor*Species	**102.295**	**3**	**<0.001**

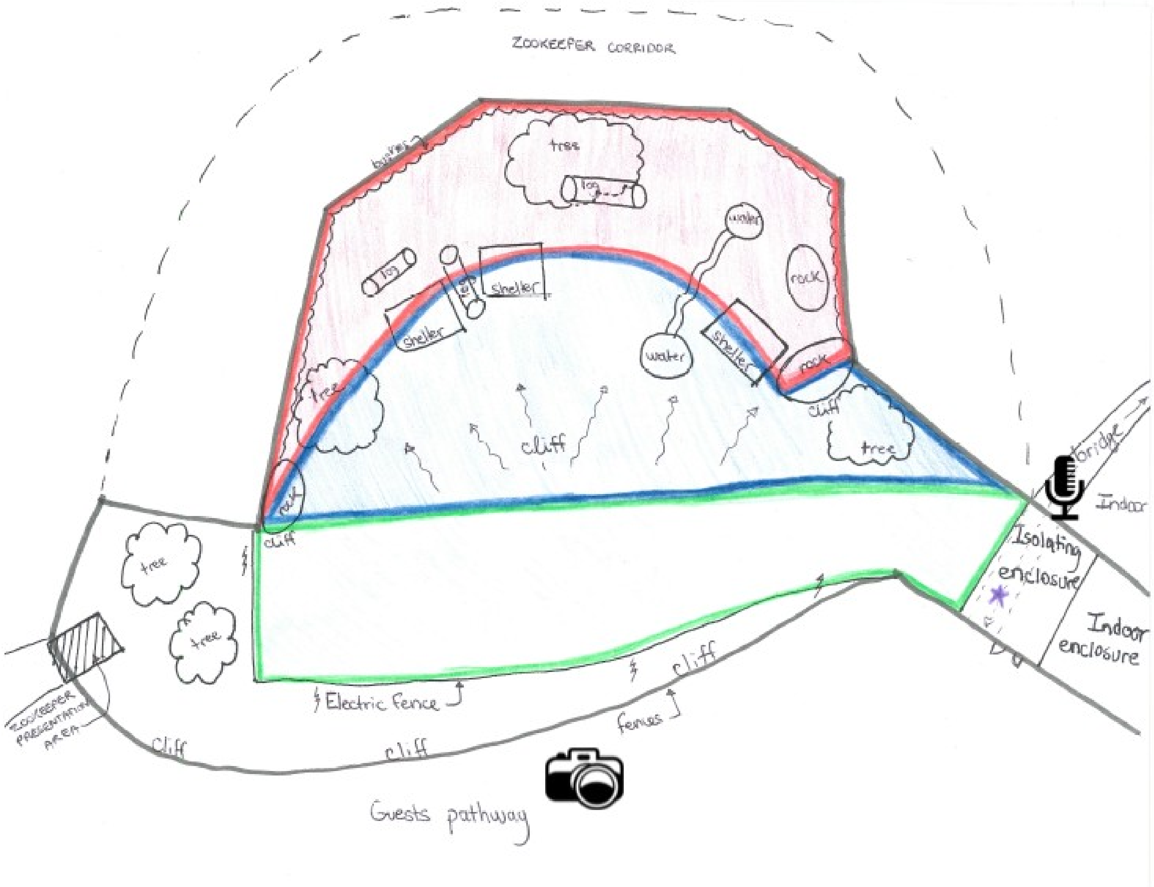

Figure 1.1: A top-view schematic image of the different zones in the African lions' outdoor enclosure located at Zoo de Granby in Canada. The front zone (green) is an uncovered zone bordering the public view area. The mid zone (blue) provides some open areas and covers (shelter, trees), is further from the public and is slightly elevated. The back zone (red) is elevated, far from the public and provides cover with trees, logs and vegetation. The zookeeper area is for the animated presentations zookeepers offer to the public when feeding the felines. The microphone pictogram represents where the acoustic monitor was placed during the experiment. The camera pictogram represents where the photographer was standing when taking the picture for Figure 3.1 (Appendix B).

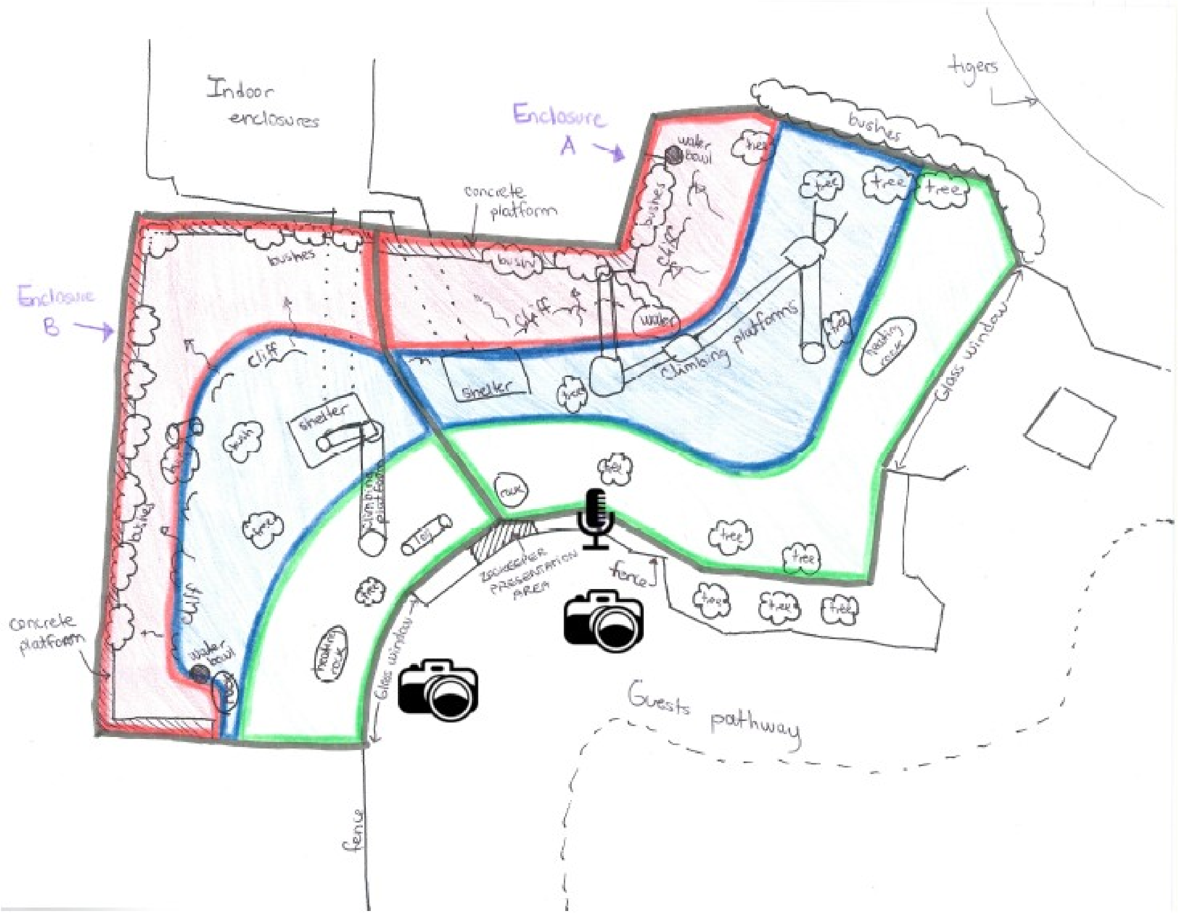

Figure 1.2: A top-view schematic image of the different zones in the Amur leopards' outdoor enclosures (A and B) located at Zoo de Granby in Canada. The front zones (green) are an uncovered zone bordering the public view area. The mid zones (blue) provide some open areas and covers (shelter, climbing structures), and are further from the public. The back zones (red) are elevated, far from the public and provide cover with dense vegetation. The zookeeper area is for the animated presentations zookeepers offer to the public when feeding the felines. The microphone pictogram represents where the acoustic monitor was placed during the experiment. The camera pictogram represents where the photographer was standing when taking the picture for Figures 3.2 and 3.3 (Appendix B).

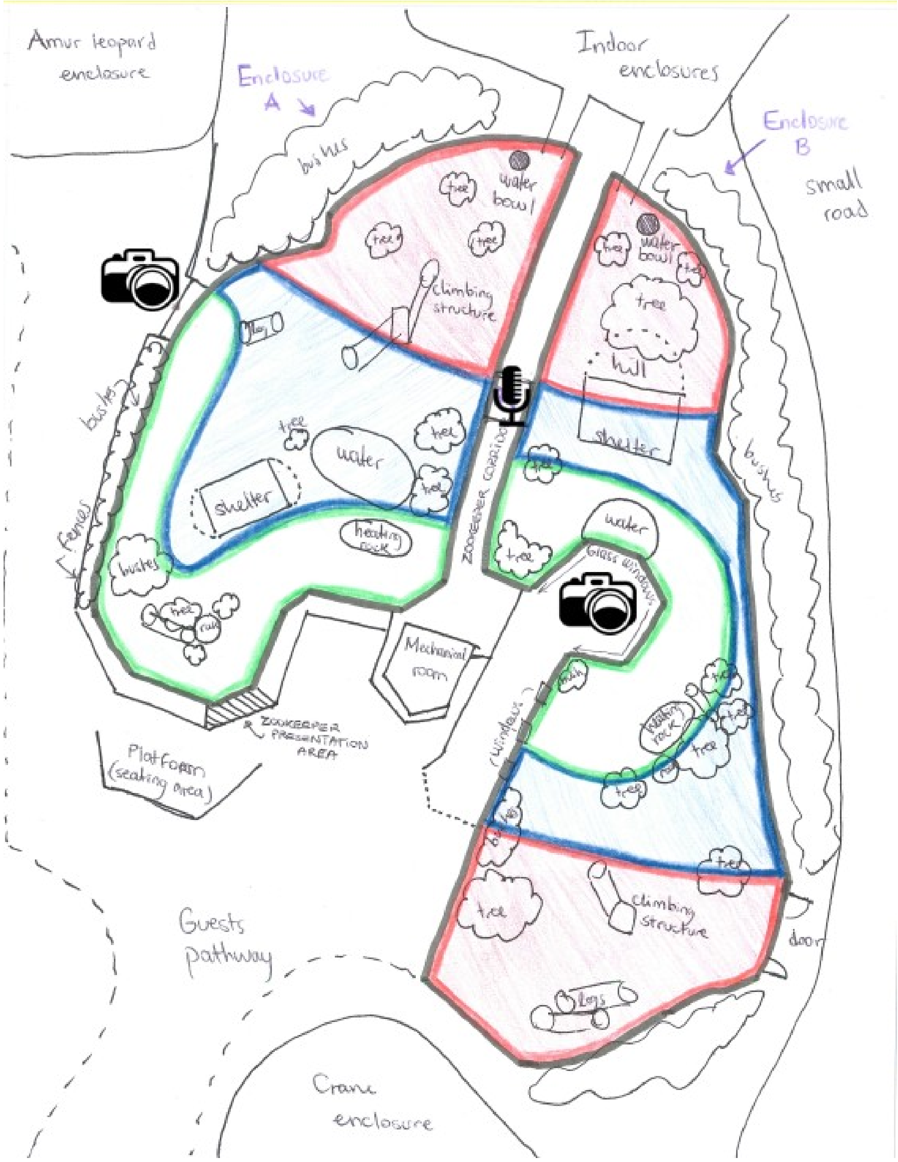

Figure 1.3: A top-view schematic image of the different zones in the Amur tigers' outdoor enclosures (A and B) located at Zoo de Granby in Canada. The front zones (green) are an uncovered zone bordering the public view area. The mid zones (blue) provide some open areas and covers (shelter, trees), and are further from the public. The back zones (red) are far from the public and provide cover with vegetation, logs climbing structures or hills. The zookeeper area is for the animated presentations zookeepers offer to the public when feeding the felines. The microphone pictogram represents where the acoustic monitor was placed during the experiment. The camera pictogram represents where the photographer was standing when taking the picture for Figures 3.4 and 3.5 (Appendix B).

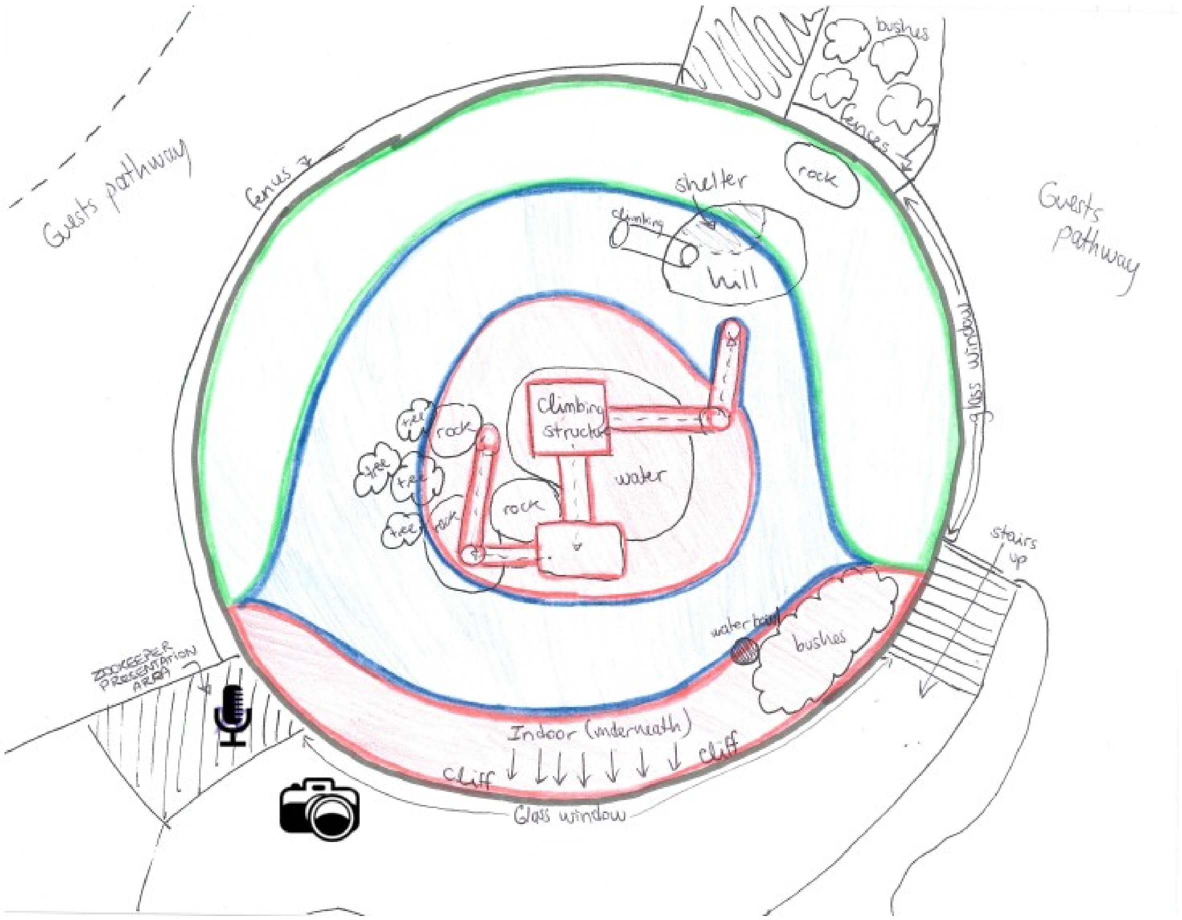

Figure 1.4: A top-view schematic image of the different zones in the jaguars' outdoor enclosure located at Zoo de Granby in Canada. The front zone (green) is an uncovered zone bordering the public view area. The mid zone (blue) provides some open areas and covers (trees, vegetation, rocks, shelter), and is further from the public. The back zone (red) is further from the public (in the center of the enclosure, or beneath the concrete wall cliff near the transfer leading to the indoor enclosure), and provides cover with vegetation, climbing structures, rocks and walls. The zookeeper area is for the animated presentations zookeepers offer to the public when feeding the felines. The microphone pictogram represents where the acoustic monitor was placed during the experiment. The camera pictogram represents where the photographer was standing when taking the picture for Figure 3.6 (Appendix B).

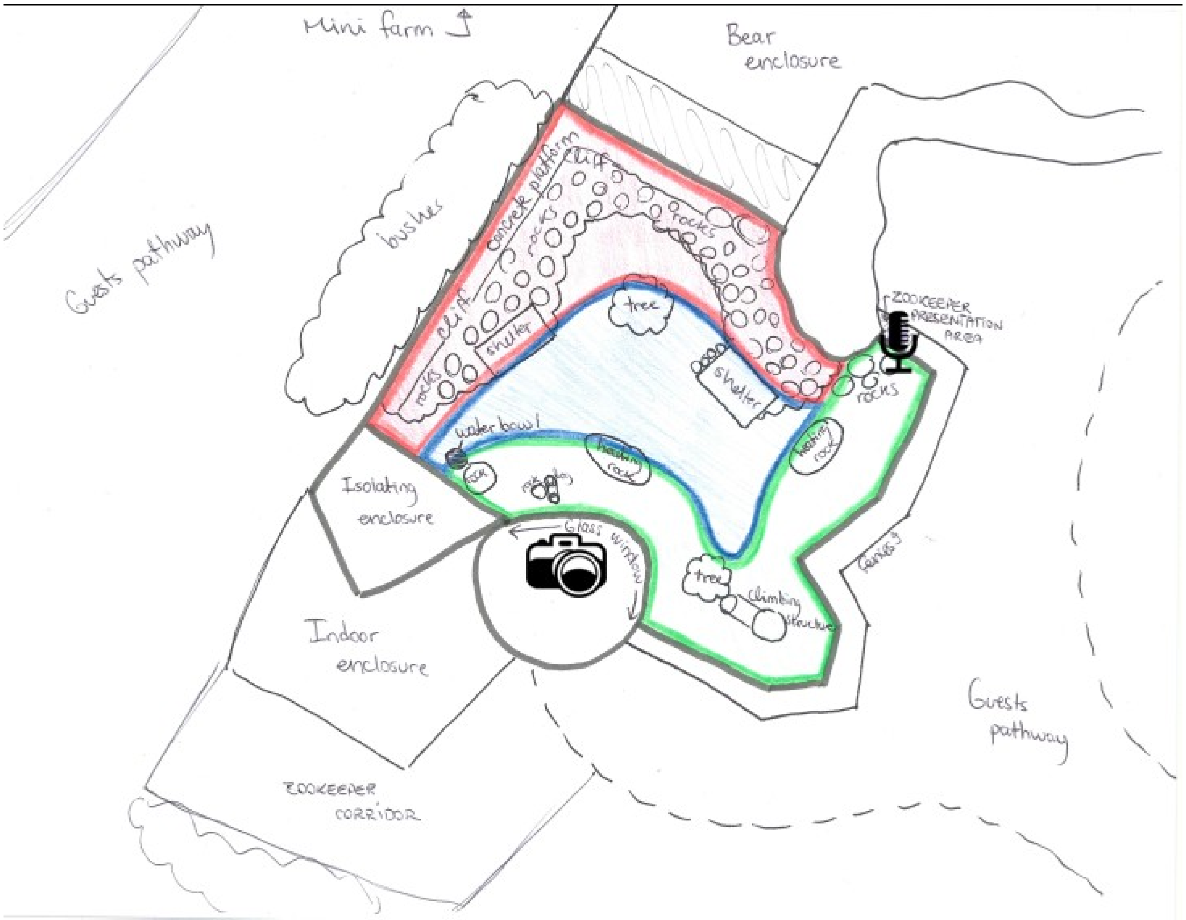

Figure 1.5: A top-view schematic image of the different zones in the snow leopards' outdoor enclosure located at Zoo de Granby in Canada. The front zone (green) is an uncovered zone bordering the public view area. The mid zone (blue) provides some open areas and covers (shelter, tree), and is further from the public. The back zone (red) is elevated, far from the public and provides cover with rocks, vegetation and a shelter. The zookeeper area is for the animated presentations zookeepers offer to the public when feeding the felines. The microphone pictogram represents where the acoustic monitor was placed during the experiment. The camera pictogram represents where the photographer was standing when taking the picture for Figure 3.7 (Appendix B).

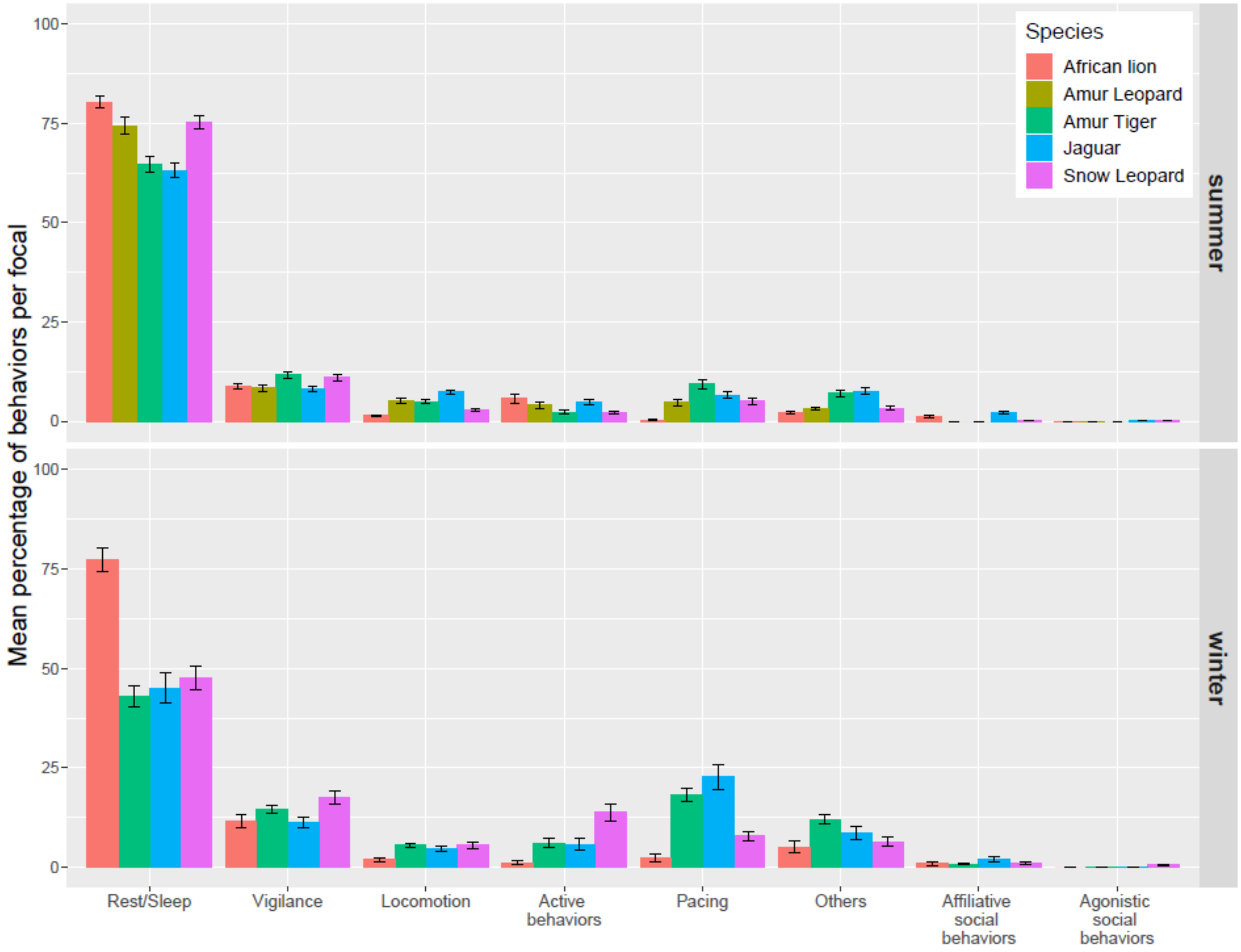

Figure 1.6: Activity budget of all feline species at Zoo de Granby, Granby, Canada. Data are from summer 2018 (upper panel) and winter 2019 (lower panel). Mean percentage of behavioral occurrences per focal are shown, with error bars representing standard errors of the mean. The activity budgets are separated by species and season. The Amur leopards were not observed during the winter. For the same season, activity budget differs significantly between species. For the same species, except the Amur leopards, the activity budget also significantly changes between seasons.

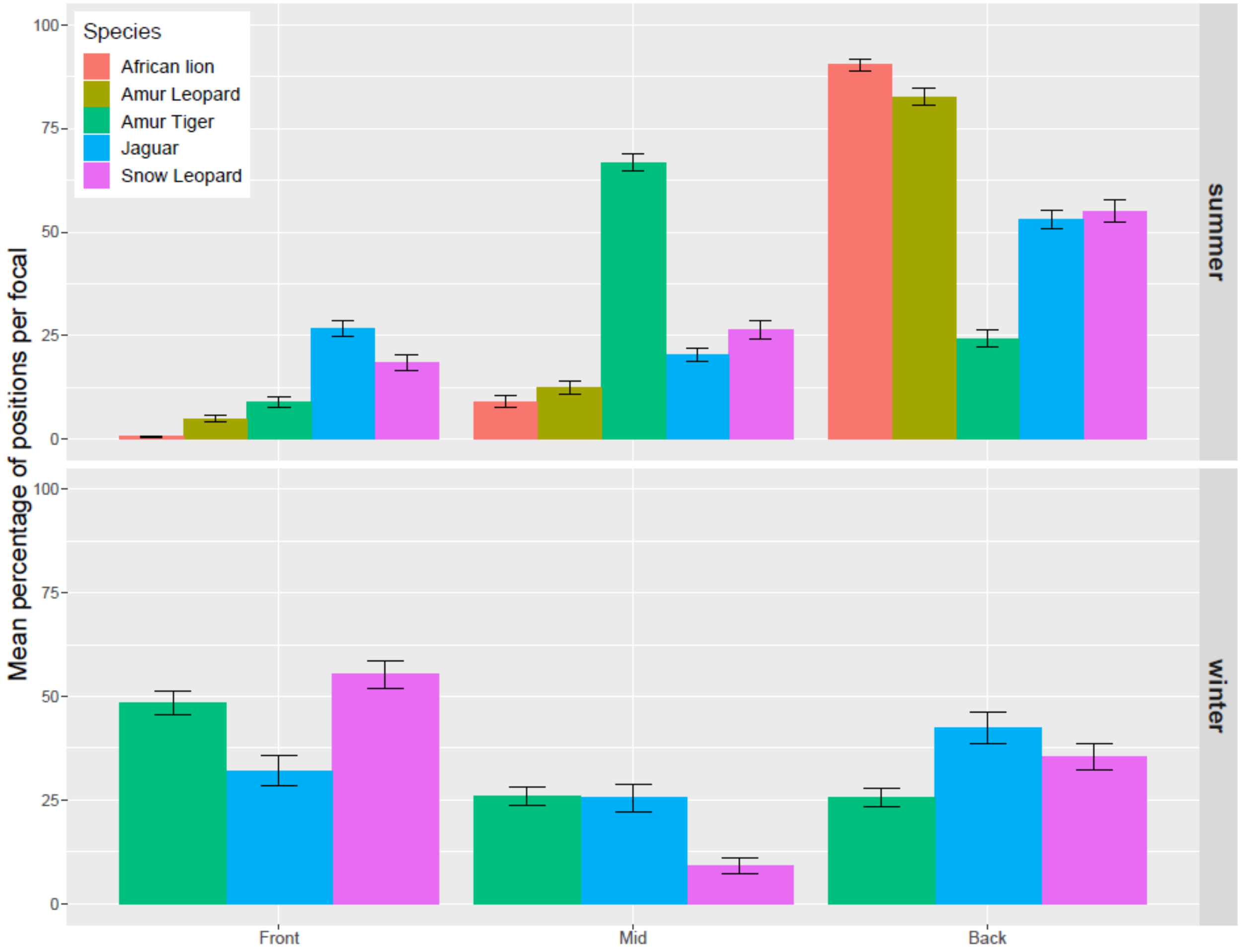

Figure 1.7: Position occupied by all feline species at Zoo de Granby, Granby, Canada. Data are from summer 2018 (upper panel) and winter 2019 (lower panel). Positions are based on pre-established zones in the respective enclosure that are shown in Figures 1.1 to 1.5. Mean percentage of position occurrences per focal are shown, with error bars representing standard errors of the mean. Space use is separated by species and season. The Amur leopards were not observed during the winter, and space use was also not recorded for the lions during winter. For the same season, space use differs significantly between species. For the same species, except the Amur leopards and lions, the space use also significantly changes between seasons.

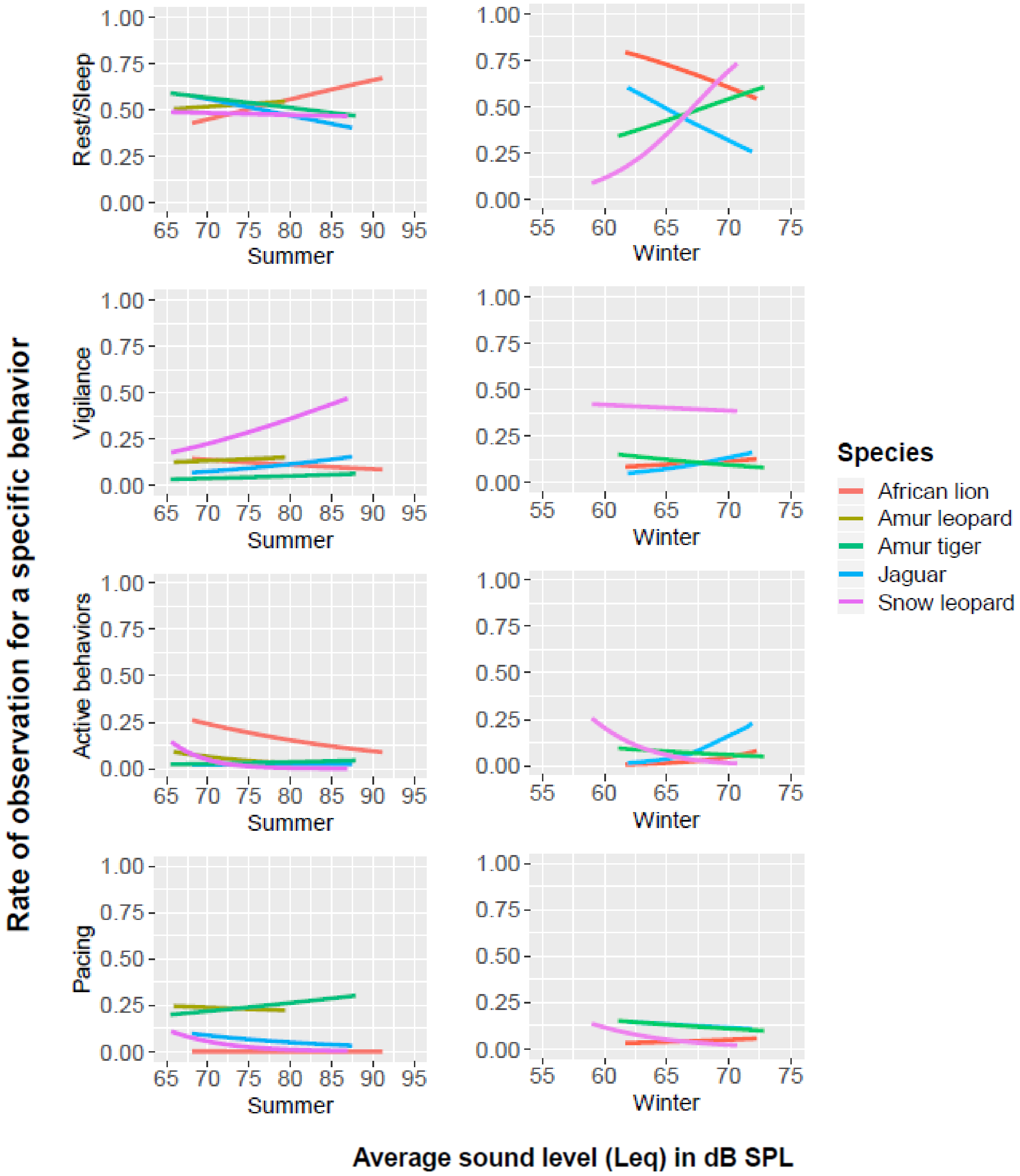

Figure 1.8: Effect of sound level (L_{eq}) on the rate of Rest/Sleep, Vigilance, Active behaviors and Pacing, for the five feline species during summer (left panels) and winter (right panels). L_{eq} is measured in unweighted dB SPL (re: 20µPa), between 17.5- 90 510 Hz. There was no observation of Amur leopards during the winter season.

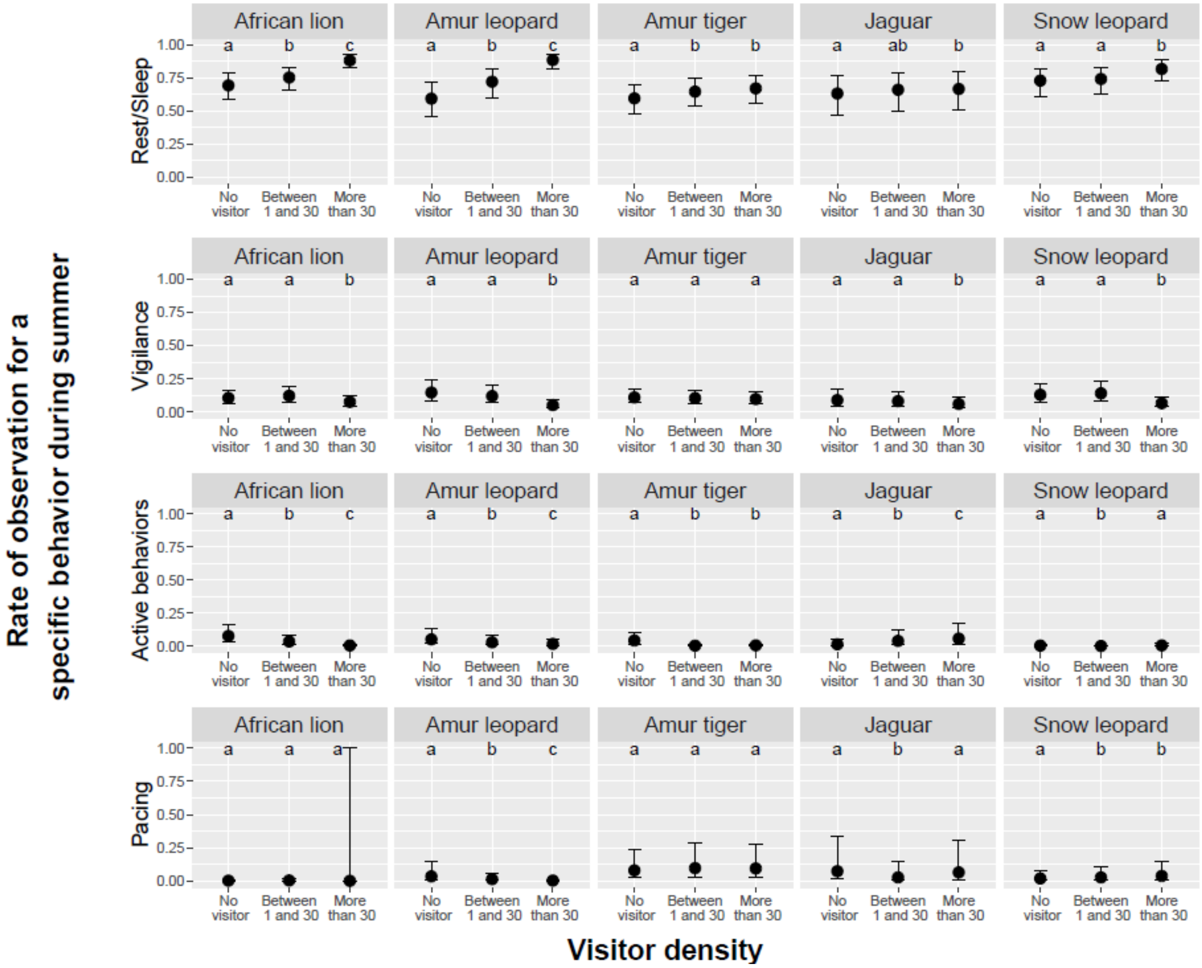

Figure 1.9: Pairwise differences between least square means for the rate of Rest/Sleep, Vigilance, Active behaviors and Pacing, with their 95% confidence intervals, versus the three categories of visitor density, for each feline species during the summer season. Different letters between the three categories of visitor density indicate significant differences. A Tukey-Kramer correction was used.

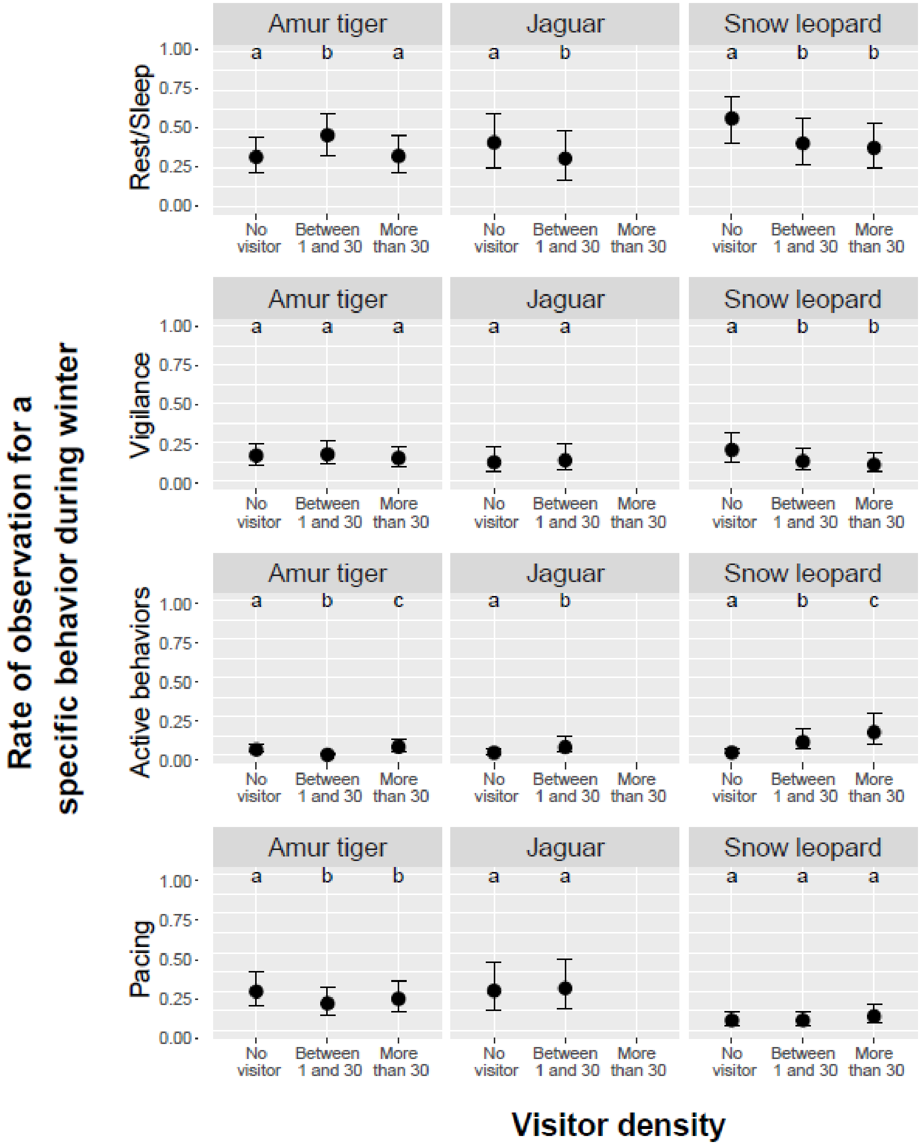

Figure 1.10: Pairwise differences between least square means for the rate of Rest/Sleep, Vigilance, Active behaviors and Pacing, with their 95% confidence intervals, versus the three categories of visitor density, for each feline species during the winter season. Different letters between the three categories of visitor density indicate significant differences. A Tukey-Kramer correction was used. Lions were off-exhibit in their indoor enclosure during winter, and Amur leopards were not observed during the winter season either, hence why there is no possible effect of visitors on them. For jaguars, there was no case when the visitors' number exceeded 30 people; therefore this level was not possible to test.

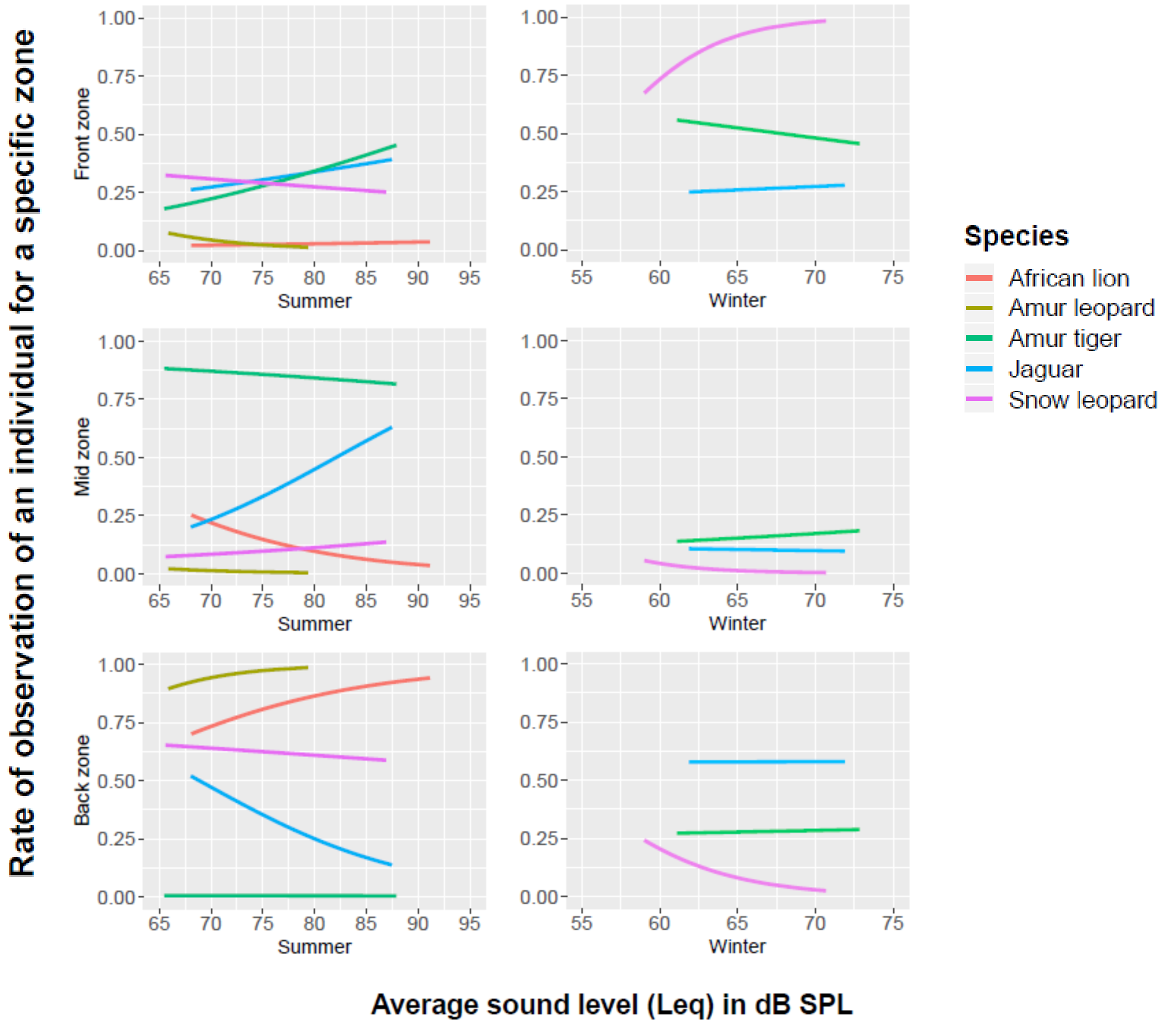

Figure 1.11: Effect of sound level (L_{eq}) on the rate of observation of an individual in a specific zone (Front, Mid or Back) for the five feline species in summer (left panels) and winter (right panels). L_{eq} is measured in unweighted dB SPL (re: 20µPa), between 17.5- 90 510 Hz. There was no space use data taken for the lions during winter because of its irrelevance in their indoor enclosure, and Amur leopards were also not observed during that season.

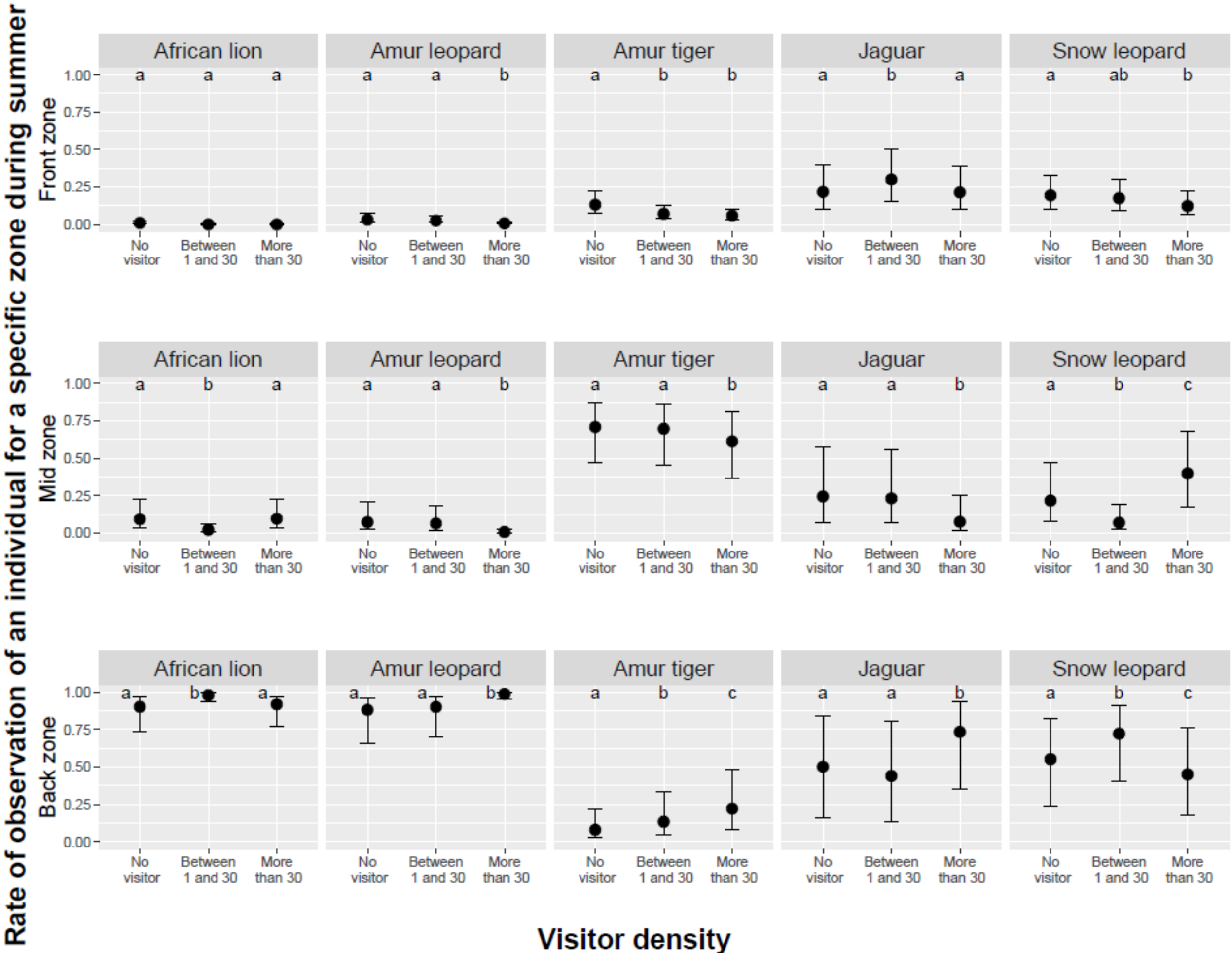

Figure 1.12: Pairwise differences between least square means for the use of the Front, Mid and Back zones, with their 95% confidence intervals, versus the three categories of visitor density, for each feline species during the summer season. Different letters between the three categories of visitor density indicate significant differences. A Tukey-Kramer correction was used.

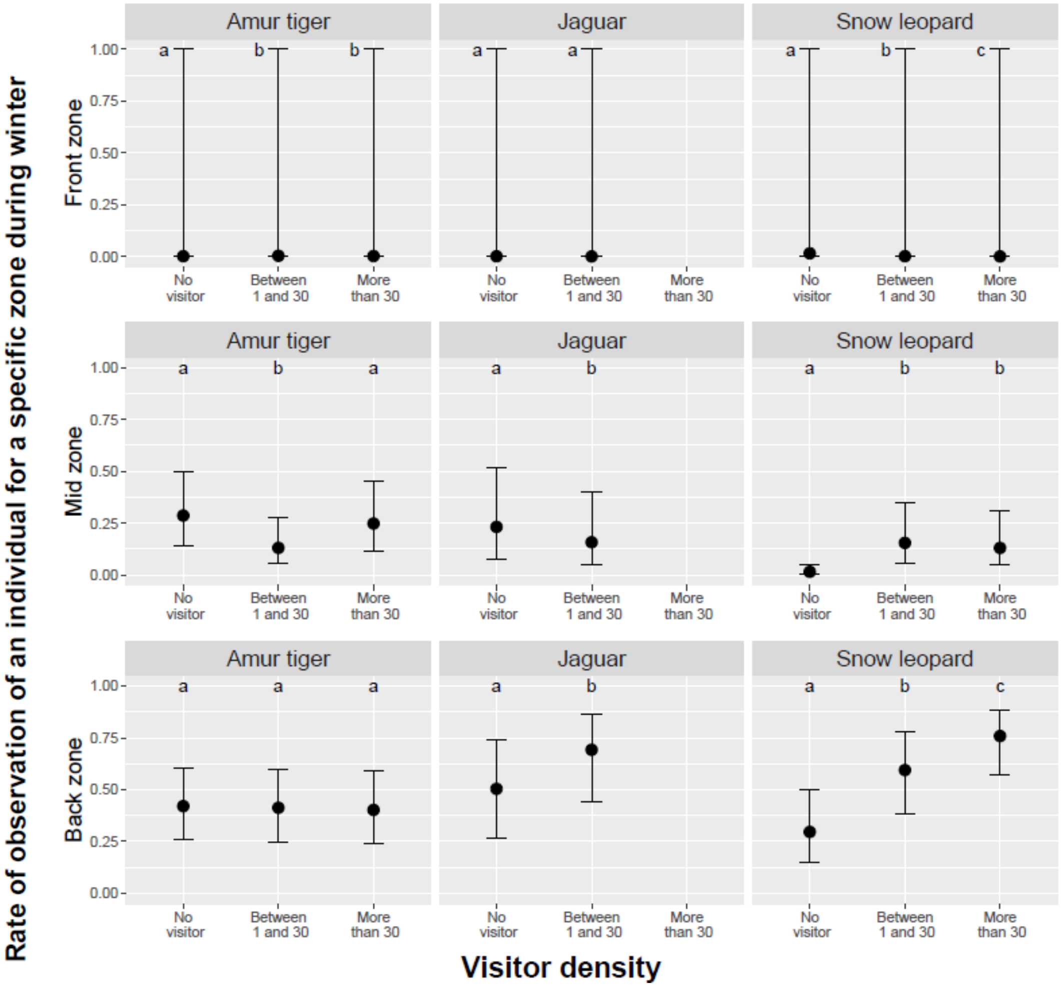

Figure 1.13: Pairwise differences between least square means for the use of the Front, Mid and Back zones, with their 95% confidence intervals, versus the three categories of visitor density, for each feline species during the winter season. Different letters between the three categories of visitor density indicate significant differences. A Tukey-Kramer correction was used. There was no space use data taken for the lions during winter because of its irrelevance in their indoor enclosure, and Amur leopards were also not observed during that season either. For jaguars, there was no case when the visitors' number exceeded 30 people; therefore this level was not possible to test. For the Front zone, there were a lot of 0% and 100% of occurrences in the data in a more or less equal frequency, hence the large confidence intervals.

Chapter 2:

Environmental sound levels in an urban zoo setting: a 24h evaluation of the soundscape, from low to high frequencies

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ABSTRACT

One potential stressing factor for captive animals is noise. Most studies assessed this factor in relation to animal welfare measuring only sound frequencies in the human-hearing range, and not frequencies outside of this range, such as infrasounds and ultrasounds. Many species of non-human mammals can hear very well these frequencies, and since high sound levels and variability of noises are potentially detrimental for the animals' health, this overlooked aspect of their acoustic environment could have important impacts on their welfare. This study evaluated the soundscape of Zoo de Granby in a large frequency range (17.5-90 510 Hz), by measuring average sound levels, and the difference between highest and lowest sound levels as a measure of variability in the soundscape. Sound data were collected during the summer period at 25 locations using cycles of 24h, with locations representing different contexts, such as being indoor or outdoor, as well as being near or away from noisy features. Data were also collected both when the zoo was open and when it was closed. Furthermore, four of these locations were also evaluated again during the winter season. The results demonstrate that the soundscape (frequencies present, sound levels, variability of noises) varied between locations. There were a few indoor locations and the water park that were rather noisy, but generally the zoo's acoustic environment was not considered problematic for animal welfare when looking at average sound levels. Ultrasounds were generally rare, had low sound levels, and were not variable in time. Infrasounds were present in all locations, and were the loudest and most variable sound frequencies, suggesting they could be stressful for animals that are sensitive to them. Therefore, future studies and animal welfare assessments should always record and analyse the infrasonic components of the soundscape, not just sound frequencies in the human-hearing range. The sound levels and variability of noise events increased during the day and when visitors were present, suggesting that human-related activities were the sources of these increases, and could therefore potentially be stressful for animals. The sounds in indoor environments were generally louder than outdoor environments, but were less variable in time. The noisy features selected did not differ from the other environments in terms of average sound levels or variability, but they had high sound levels during the day, suggesting they should be installed in areas far from any animal enclosure. The soundscape did not change between seasons, suggesting mitigation of noise pollution is not a problem only associated with the high touristic season. Several mitigation solutions could be implemented.

INTRODUCTION

Modern zoological institutions aim to improve the well-being of their housed animals to achieve their goal of individual welfare and conservation (Young, 2003). Despite this, there remain many challenges, since captive environments can be stressful for animals, due for example to the presence of visitors, husbandry routine, restricted space or disruptive abiotic components (Davey, 2007; Morgan & Tromborg, 2007).

One of the main potential stressing factors for captive individuals is the acoustic environment. Indeed, research found that animals negatively responded to high noise levels, including hearing loss, deprived sleep, abnormal social behavior, or elevated blood pressure and stress hormone levels (reviewed by Kight & Swaddle, 2011; Turner et al., 2005). Since sound levels in urban environments are higher than natural habitats, this could well be stressful for animals (Morgan & Tromborg, 2007). For example, rainforests, riverines and savannahs present sound levels around 23 to 40 dB SPL, mostly produced by wind, birds and insects (Waser & Brown, 1986). Harrison, Clark, & Stankey (1980) found sound levels between 20 and 50 dBA for various types of forests, grasslands and deserts. In comparison, laboratories present sound levels up to 130 dB SPL, produced by cleaning devices, lab apparels or electronics (Sales et al., 1999, 1988; Turner et al., 2005). Most high sound levels in labs were also associated with human activity or the animals themselves (Milligan, Sales, & Khirnykh, 1993; Peterson, 1980; Pfaff & Stecker, 1976; Turner et al., 2005). These sources of high sound levels could also be found in zoos, for example machinery and equipment, husbandry, construction work, or ventilation systems. Moreover, studies found that the sleep quality of animals was more negatively impacted by unpredictable noises and a variable soundscape, compared to a constant and stable one, for the same average sound level (Rabat, 2007; Rabat et al., 2004). Zoos can present sudden bursts of noise, such as door banging, construction, visitors talking or shouting, cleaning and husbandry routines, or electronic devices going on and off. Therefore, the captive environment could also be stressful because of its variable soundscape (Brumm, 2013).

Despite this, only a few studies monitored the acoustic environment in a zoo setting, and the potential impact it could have on captive animals. Orban et al. (2017) compared sound levels in a giant anteater (*Myrmecophaga tridactyla*) exhibit between periods with and without construction work. They found that sound levels were higher during construction work, and that after removing the individual to a quieter place, its welfare seemed to have improved. A study with giant pandas (*Ailuropoda melanoleuca*) found similar results, where the animals showed stress-related behaviors and physiological changes with construction noise (Powell et al., 2006). Other studies also found that average sound levels were higher when the zoo was open or with a lot of visitors (de Queiroz, 2018; Owen et al., 2014, 2004; Quadros et al., 2014; Tromborg & Coss, 1995). All these studies generally measured sound frequencies between 16 and 16 000 Hz, which corresponds approximately to the human hearing range (an average adult human can hear well between 31 and 17 600 Hz; Heffner, 2004; Jackson, Heffner, & Heffner, 1999).

Various species commonly housed in zoos are sensitive to high and low frequencies, notably most non-human mammals (Fay, 1988; Heffner & Heffner, 2007). However, very few studies have taken into account other sound frequencies that cannot be heard by humans, like the zoo studies mentioned above. This could be of importance for other mammals, as this lack of information on a zoo setting could have major consequences in managing the animals' welfare, by ignoring a portion of their perception of their environment (Morgan & Tromborg, 2007). Knowing which feature in a zoo setting produces the most noise, in certain frequencies, and knowing which animals are more affected by them, is essential for improving the individuals' welfare. Therefore, more research is needed to describe the acoustic nature of zoo environments and its implication on animal welfare, particularly with high and low frequencies.

This study took place at Zoo de Granby, Granby, Canada, with the main objective to evaluate the zoo's soundscape at multiple locations. Specifically, measures of equivalent continuous sound levels (L_{eq}), and maximum and minimum sound levels (L_{max} and L_{min}), were taken for a large frequency range (between 17.5-90 510 Hz). L_{eq} was used as a measure of average sound levels, and the difference between L_{max} and L_{min} was used as a measure of variability in the acoustic environment, where a higher difference would represent a more variable soundscape. A special interest was in detecting and locating sources of infrasonic and ultrasonic sounds. The sound levels were measured in cycles of 24 hours at each selected location, in different types of environments or near noisy sources across the zoo, namely an amusement park, a water park, and a "dinosaur themed" park. These three noisy sources will be called “touristic features” in this chapter. Some 24h cycles were done when the zoo was opened, others when the zoo was closed. Data collection was also done in two seasons: the high touristic summer season, and the low touristic winter season, allowing us to generate a more complete “sound map” of the zoo, with the goal of detecting potential areas where noises could be negatively affecting the welfare of animals.

We hypothesised that sound levels would change depending on the sound frequency, time of day, the visitor attendance, the type of environment and the season. We predicted there would be higher average sound levels in lower frequencies, because they are more present in urban settings (Blickley & Patricelli, 2010; McKenna et al., 2016), and they can travel much further in air than high frequency sounds (Blickley & Patricelli, 2010; Bowles, 1995; Pater et al., 2009). We predicted that sound levels during the day, with visitors, near the touristic features then outdoor environments, and during the summer, would also be higher. Indeed, during the day, employees are present and human activity is generally higher than at night time, with the zoo being in an urban area. Moreover, it is expected to have higher sound levels when visitors are present (Quadros et al., 2014). Touristic features are suspected to produce high sound levels (rollercoaster, music, wave pool). Contrary to outdoor environments, indoor environments are separated from the outdoor with windows and walls, therefore filtering a certain amount of noise. Even with background sound of ventilation systems that we found in indoor environments, we predicted they would still be quieter than outdoor environments subjected to visitors and urban area noises, since sounds produced by environmental-control devices (e.g. ventilation or heating systems) are generally of low levels (Milligan et al., 1993; Sales et al., 1999). Finally, the summer period corresponds to the high touristic season, with more visitors compared to the winter and more construction, therefore higher sound levels. We predicted that the variability of sound levels would increase during the day, with visitors present, near touristic features then in outdoor environments, and during the summer. The reasons behind these predictions are similar to the average sound levels’ predictions: noises associated with human activity (zookeeper, visitors, construction during the day, more visitors during the summer) would not only increase the sound level, but also the variability of the soundscape. Touristic features and outdoor environments would also produce more variable noises compared to the more stable and constant noises of ventilation systems found in indoor environments.

METHODS

Study site and locations

This study was performed between May and August 2018 for the summer season, and December 2018 and February 2019 for the winter season. It was located in Zoo de Granby, Granby, Canada. Founded in 1953 at the heart of the city, it is one of the most important zoological institution in Canada, in terms of numbers of animals present. More than 1000 animals of 200 species, mostly exotic, are housed all year round in the zoo, with special installations to accommodate those who cannot thrive in colder weather. With its 862 460 visitors in 2018, the park is set in an urban area, and also includes additional touristic features such as an amusement park, a water park, and a dinosaur themed park, called "Dinozoo", containing animatronics ("robots" that emulate realistic animals, accompanied with movements and noises).

Typically, the animals are housed in two types of enclosures: outdoor and indoor. All outdoor enclosures are visible by the public, whereas some indoor enclosures are not. Depending on the season, animals have access to only one or both of their enclosure. Furthermore, some enclosures that were visible by the public during the summer season were no longer visible during the winter season, and vice-versa. The touristic features mentioned above were also not functioning during the winter season.

For the purpose of this study, we selected 25 locations for the summer season, based on various criteria: a combination of outdoor and indoor environments, a combination of areas visible and non-visible to visitors, areas covering evenly the entire park, areas representing a variety of animals with different hearing sensitivity, and areas potentially noisy, such as the touristic features. To complement with the first chapter, all felines' enclosures (indoor and outdoor) were also selected. For the winter season, we selected only 4 of the 25 summer locations, with 2 indoor and 2 outdoor areas, and with 2 visible and 2 non-visible to visitors (more details for each location selected in Table 2.1).

Data collection

Sound levels were measured using the SM3BAT acoustic recorder equipped with sonic (SMM-A2) and ultrasonic (SMM-U1) microphones (Wildlife Acoustics Inc.). The microphones were attached on a tripod, approximately 1m above ground (see Figure 3.10 in Appendix D), and away from walls or big trees. For each cycle, the SM3BAT and microphones were placed at one of the 25 locations, out of reach of the animals and the public. Since received sound levels can be affected by many factors such as weather, atmosphere attenuation, distance from the sources or terrain, it is ideal to place the acoustic recorder at the exact location occupied by the study species (Pater et al., 2009). However, for technical and safety reasons, it was not possible for most locations to place the equipment inside the enclosures with the animals. Instead, it was placed as much as possible near the enclosure in outdoor areas, or in the transfer zones adjacent to the enclosure in indoor areas.

The equipment was set to record sounds during 5 minutes, followed by a pause of 25 minutes, and repeated constantly for 24h. After each 24h cycle, the equipment was installed at another location before recording again, after changing batteries and memory cards when necessary. Each location was only sampled once for a 24h cycle. Constant verification of the quality of the sounds recorded were performed to ensure data were not corrupted by technical problems or biased by external factors affecting the sound level, such as strong winds, rains or snow storms. If any problem occurred, all data from that cycle were disregarded, and the 24h cycle was done again at the same location on another day.

A description of the measurements and metrics used is often lacking in many sound level studies in the literature, making it difficult to compare the results (see reviews of Gill et al., 2015; McKenna et al., 2016; Pater et al., 2009). In these reviews, the authors recommend reporting the following information in a sound study:

1. State what sound metrics (parameters) were used to quantify and characterize sound events;
2. State what reference quantity was used for all the measurements, since sound levels are usually quantified in decibels (dB), a logarithmic ratio;
3. Specify what time period or interval was used for each metric, since time plays important roles in the calculation of sound metrics;
4. Characterize the spectrum, stating which sound frequencies were recorded, and at what sampling frequency (similar to a “time resolution”). It is important that

studies on the impacts of sound on animals measure a frequency range that the subjects of the study can hear;

5. State which frequency weighting, if any, was used. Sound measurements can be more meaningful if the way the sounds are *perceived* by the subjects is taken into account. Not all species have the same hearing sensitivity, therefore frequency weightings are tools that attenuate (filter) certain frequencies to simulate what is truly heard by the study subjects;
6. State how the instruments were calibrated, if they were at all. It is highly recommended to calibrate regularly microphones to make sure the results are reliable and accurate, and it is necessary for comparisons over time and between locations, instruments and studies.

In light of these recommendations, here are the metrics and methods used in this study:

1. Two sound metrics were chosen. First, an average sound level value, using the equivalent continuous sound level (L_{eq}; see Glossary). It is ideal for ambient noises that are more or less constant, which was expected in a zoo setting (ventilation, office noise, busy day). However, L_{eq} is not always adequate for short bursts of noise, such as a door banging or an animal vocalizing, and does not give information on the variability of the soundscape. Therefore, a second metric, the Peak-to-peak (L_{max}-L_{min}), was also used to account for when ambient noises were more variable, where a higher Peak-to-peak would mean a more variable soundscape;
2. All sound metrics were measured in sound pressure levels, with the standard dB SPL scale, where the reference is 20 µPa (mostly used for sound propagation in air);
3. The sound metrics were analysed and extracted with the Kaleidoscope Pro Noise Analysis Module Version 5.0.3 (Wildlife Acoustics Inc., 2018). The software calculates sound pressure levels in 1 second increments over a chosen sample period, in this case 1 hour for all acoustic metrics, then calculates average (L_{eq}), maximum (L_{max}) and minimum (L_{min}) sound levels from those 1 second increments;

4. The range of sound frequencies covered by both microphones was between 17.5 and 90 510 Hz, covering all the housed animals' hearing sensitivity, except for the Jamaican fruit bats (*Artibeus jamaicensis*), which can hear up to 141 000 Hz (Heffner, Koay, & Heffner, 2003). Since the sampling frequency must be at least twice the maximum sound frequency to be recorded (McKenna et al., 2016), the sampling frequency was set at 192 000 Hz;
5. Unweighted third-octave bands were used for sound analysis. A common practice is to use the A-weighting scale, which corrects the sound levels of lower frequencies to match the hearing sensitivity curve of humans (Pater et al., 2009). However, most animals have a different hearing sensitivity than humans, and this sensitivity differs even between species (Fay, 1988). The A-weighting is also inappropriate for sound frequencies outside of the human hearing range, such as frequencies above 20 000 Hz (Leighton, 2007). The same conclusions could be drawn for the other weighting scales provided by the Kaleidoscope software, hence why none were used;
6. Microphones were calibrated in an anechoic chamber before the study (see Appendix D), and were regularly checked for any loss of sensitivity throughout the field season. Professional calibrators were used to emit a pure tone of known frequency and level to measure the microphones' sensitivity.

Statistical Analysis

The software extracted all the sound metrics (L_{eq}, L_{max} and L_{min} of 1hour in unweighted dB SPL) for each of the 37 standardized third-octave bands selected, covering roughly 17.5 to 90 510 Hz. For simplicity in data analysis, the bands were combined into five groups of frequency range: "Very low", "Low", "Mid", "High" and "Very high". Each frequency range per group is summarized in Table 2.2. The first four groups were recorded with the acoustic microphone SMM-A2, the fifth being recorded with the ultrasonic microphone SMM-U1. The first four divisions were based on the available third-octave bands, previous studies, and animal hearing sensitivity ranges. For example, most mammals have their best hearing sensitivity between 1 000 and 8 000 Hz (Fay, 1988), which was covered by the "Mid" frequency group. The "Very low" frequencies did not just contain infrasounds (<20 Hz), because the effect of low frequency noise in the range 20-100 Hz has much greater significance for non-human mammals than only infrasound noise (Broner, 1978). Since "Very high" frequencies (fifth group) were recorded with a different microphone, and were rarely present, they were separated in their own group. Noises of different frequencies are additive, therefore for each frequency group and hour, we did not calculate the mean sound pressure levels of their included third-octave bands, but rather the total sound pressure level value. This was made for each output (L_{eq}, L_{max}, L_{min} of 1 hour) following equation 2.62 from Long (2014):

$$SPL_{total} = 10\log\left(10^{\frac{SPL_1}{10}} + 10^{\frac{SPL_2}{10}} + \cdots\right) dB$$

Where SPL_{total} is the total sound pressure level of the frequency group, and SPL_1, SPL_2, and so forth, are all the sound pressure levels of all the third-octave bands included in the group. We also estimated the hourly SPL_{total} of L_{eq}, L_{max} and L_{min} of all the 37 third-octave bands combined with this equation for a more general description of the soundscape.

For the "Very high" frequencies, the SMM-U1 microphone used had a high noise floor, which corresponds to random noises created by the electronics of the microphone that do not represent an actual recorded sound. The noise floor's "L_{eq}" was around 56 dB SPL for all third-octave bands' outputs of this microphone (this value was determined in the anechoic chamber when we calibrated the microphones). Since these were not actual ultrasounds, we removed all third-octave bands' hourly data outputs (L_{eq}, L_{max} and L_{min}) when their L_{eq} was equal to 56 ± 1 dB SPL, before calculating the SPL_{total} of the sound metrics for this frequency group. This also means that ultrasounds that were below 57 dB SPL were unfortunately undetected by the recorder and consequently removed from analysis.

Following all locations' calculation of SPL_{total} for each sound metric (L_{eq}, L_{max} and L_{min}) per frequency group and hour, two linear mixed models were run to compare L_{eq} and Peak-to-peak (L_{max}-L_{min}) between these six categorical factors: the frequency group, time of day, hour, visitor condition, location type, and season. Frequency group was the five divisions as explained earlier. Time of day contained two levels: "daytime" (between 7h00 and 20h59) and "night time" (21h00-6h59). Hour was each of the 24 hours of the cycle. Visitor condition was a binary variable (“presence” or “absence”), based on if the location was accessible or not to visitors during the respective hour. Location type was categorical with three levels: “indoor environment”, “outdoor environment”, or “touristic features” for the sites near the amusement park, the water park and the animatronics (locations #11-12-13, see Table 2.1). Finally, season was a binary variable: “summer” and “winter”. In all models, the location of the cycle (29 in total: 25 during summer and 4 in winter) was included as a random factor to account for pseudoreplication, since all sound levels taken at one location, the same day, are not independent. For the Peak-to-peak model, log transformation of the response variable was necessary to achieve normality of residuals. In both models, Time of day was removed because of its high (>10) Variance Inflation Factor (VIF), since a VIF above 5 indicates a problematic amount of collinearity (James, Witten, Hastie, & Tibshinari, 2013). Pairwise comparisons of the least square means were performed using a Tukey-Kramer correction for all categorical variables. All tests were performed at the 5% level of significance with the R 3.4.3 statistical software (R Core Team, 2017).

RESULTS

General observations of the soundscape

There was a wide range of sound levels when looking at all the locations, with some of the lowest L_{eq} recorded at the indoor (around 60 dB SPL) and outdoor enclosures (around 58-68 dB SPL) of the snow leopard. Some of the highest L_{eq} recorded were all in indoor environments, such as the elephant house (around 82 dB SPL), the aquarium (around 77 dB SPL) and the veterinary facility (around 77 dB SPL). Table 2.3 summarises the ranges of L_{min}, L_{eq} and L_{max} recorded during the 24h cycles for the 25 summer locations, when considering all frequencies (SPL_{total} of all the 37 third-octave bands). Figure 2.1 illustrates a "sound map" of the zoo, with all locations represented in circles of various colours (location type) and sizes (mean 24h L_{eq} of all frequencies). It also shows that the locations were evenly spread throughout the whole park to represent various areas, and that indoor environments (in red) seemed to be louder than outdoor environments (yellow). Figure 2.2 shows the distribution of L_{eq} values for each location during their 24h cycle, for all sound frequencies combined, and it appears that the soundscape varied between locations. It also shows that L_{eq} in indoor environments, with the exception of one (#25), seem less variable than outdoor environments and near touristic features. Figure 2.3 is similar to Figure 2.2, but with the distribution of Peak-to-peak values instead, where a majority of the locations had these values above 10 dB SPL, except most indoor areas.

Figure 2.4 illustrates the mean and standard error of the L_{eq} values per hour of all locations, separated by location type and frequency group. This figure shows that the patterns of sound levels differed between location types, for every frequency group. Few outdoor locations presented ultrasounds ("Very high" frequencies) as shown by the blue dots (a same location did not have ultrasounds for every hour; therefore a line could not be made). This was also the case for the touristic features, where only the amusement park had ultrasounds. The "Very high" frequencies were however more present in indoor environments. The other sound frequencies were always present in all environments.

Effect of frequency range, hour, visitor attendance, location type and season

As sound frequency increased, the sound levels (L_{eq}) significantly decreased from one level to the next, with the exception of the "Very high" frequencies group ($F_{(4,\ 3423)} = 2302$,

$p<0.001$; Figure 2.5). The L_{eq} slightly increased between 7h00 and 16h00 ($F_{(23, 3423)} = 10.55$, $p <0.001$; Figure 2.6). There was a significant increase of L_{eq} when visitors were present ($F_{(1, 3447)} = 109.76$, $p<0.001$; Figure 2.7). Indoor environments presented significantly higher sound level values than outdoor environments, with touristic features not differing from either ($F_{(2, 25.1)} = 9.42$, $p=0.001$; Figure 2.8). There was no significant effect of season on the sound levels ($p=0.94$). The marginal r-squared of the model was 0.68, whereas the conditional r-squared was 0.78.

Logged Peak-to-peak values (L_{max}-L_{min}) were significantly higher for "Very low" frequencies compared to "Low", "Mid" and "High" frequencies, with the "Very high" frequencies showing the lowest Peak-to-peak values ($F_{(4, 3423)} = 503.6$, $p<0.001$; Figure 2.5). The Peak-to-peak levels increased between 5h00 and 20h00 ($F_{(23, 3424)} = 30$, $p<0.001$; Figure 2.6), and increased when visitors were present ($F_{(1, 3440)} = 49.7$, $p<0.001$; Figure 2.7). Indoor environments presented significantly lower Peak-to-peak levels than outdoor environments, with touristic features not differing from either ($F_{(2, 25)} = 5.2$, $p=0.01$; Figure 2.8). There was no significant effect of season ($p=0.1$). The marginal r-squared was 0.45, whereas the conditional r-squared was 0.56.

DISCUSSION

With a global objective of improving captive animal welfare, this study evaluated the soundscape of 25 locations for periods of 24h during two seasons. The goal was to characterize the acoustic environment, with special emphasis on sound frequencies outside of the human hearing range, which has not been done in a zoological institution yet. Considering these frequencies can be heard by many species, especially other mammals, and that noise pollution can be stressful for animals, it is important to account for their hearing sensitivity when dealing with animal welfare. The locations were a combination of various environments (indoor, outdoor, near noisy touristic attractions) and presence of visitors, so as to have a more complete sound characterization in different contexts. Average sound level (L_{eq}) and difference between highest and lowest sound level (Peak-to-peak: L_{max}-L_{min}) metrics were used to describe the soundscape, in unweighted dB SPL (re: 20μPa), between 17.5 and 90 510 Hz.

In general, a problematic soundscape would be one that has high L_{eq} and Peak-to-peak values. Acoustic-related negative effects on animals' health, such as hearing loss, sleep deprivation or elevated cortisol levels, are associated with noise levels above 85 dB SPL for long periods of time (Kight & Swaddle, 2011; Rabat, 2007; Turner et al., 2005). It is recommended for humans that the working environment should be below 85 dB SPL, or even 75 dB SPL, to prevent discomfort or hearing losses (National Institute of Health Consensus Report, 1990; Sales et al., 1999). Since the basic mechanisms that lead to damage appear to be similar in all mammalian ears (de Queiroz, 2018; National Institute of Health Consensus Report, 1990), we can assume that mammals have the same damage hearing response as humans, as suggested by Anthony (1963) and the National Institute of Health Consensus Report (1990). Therefore, the 85 dB SPL threshold should also be appropriate for all mammals, although this has yet to be more studied for confirmation (Sales et al., 1999; Slabbekoorn et al., 2018; Trahiotis, 1976). Furthermore, it is expected that animals are more negatively impacted by unpredictable and variable noises, rather than constant and stable background sounds (Blickley, Blackwood, & Patricelli, 2012; Rabat, 2007; Rabat et al., 2004). A high Peak-to-peak level would mean higher variation between the maximum and minimum sound levels, indicating a more variable soundscape. There is no standard for a threshold of acceptable Peak-to-peak level, but an augmentation of 10 dB is *perceived* as doubling the noise level for humans (Pater et al., 2009), and potentially for other mammals too.

The soundscape of the zoo differed between all locations, but when only looking at L_{eq}, a majority of them were comprised between 58 to 75 dB SPL throughout the 24h cycle. Since most locations did not have L_{eq} above 85 or even 75 dB SPL, we suggest that the soundscape in this zoo is potentially not detrimental to the animals' welfare. However, some particular locations could be improved. For instance, the loudest location was the Elephant house, with L_{eq} slightly above 80 dB SPL for the whole cycle, and therefore close to the recommended maximum 85 dB SPL threshold. These high sound levels were especially produced in the "Very low" frequencies, which elephants can hear very well (*Elephas maximus*, Heffner & Heffner, 1982). The veterinary facility had high sound levels (L_{eq} around 76-77 dB SPL), and considering animals can be housed there for medical reasons and might already be stressed, it would be important to mitigate the noise levels there. The aquarium also presented high sound levels (around 77 dB SPL), but for further confirmation that this could cause problems for the fish and invertebrates, a hydrophone should be used in the water tanks to measure the sound levels in water. The Goeldi's marmoset (*Callimico goeldii*) location presented very high sound levels in all frequencies (reaching 106.1 dB SPL), mostly due to the primates' vocalizations. There was also a notable noisy touristic attraction, the water park, with L_{eq} values between 69.3 and 85.8 dB SPL.

As for Peak-to-peak levels, they varied between locations, but most of them had levels above 10 dB SPL, which means that bursts of noise were at least *perceived* twice as loud as the minimal background sounds. The majority of the locations with these variable soundscape were outdoor environments and near touristic features, contrary to most indoor environments that had Peak-to-peak values below 10 dB SPL. The exceptions were with the Goeldi's marmoset and bat cavern indoor locations that contained very high Peak-to-peak values, due to the animals' vocalizations. Most noises in outdoor areas and near noisy features were associated with human activity. Therefore, because of their variable nature, the human-related noises of captive environments could be detrimental to animal welfare, contrary to undisturbed wild habitats.

The results of the “Very high” frequencies (ultrasounds) were of great interest in this study, since they have to our knowledge never been recorded before in a zoo setting, even if they are within the hearing range of many species. The results suggest that these frequencies were very rare if not absent in outdoor environments. This is not surprising, considering that ultrasounds do not travel far in air because of atmosphere attenuation (Blickley & Patricelli, 2010; Bowles, 1995; Pater et al., 2009; Slabbekoorn et al., 2018). These frequencies were also rare near touristic features, with only the amusement park showing some ultrasounds between 11h00 and 15h00. Only in indoor environments were ultrasounds found, with levels below 80 dB SPL produced by environmental-control systems, zookeeper activity (e.g. door banging, cleaning devices) or animal vocalization (Goeldi’s marmosets, bats). However, when present, these frequencies were louder than some of the other frequency groups. One explanation is that as frequency augments, so does the bandwidth of the third-octave bands. When bandwidth augments, it “catches” more sound, increasing the level (Salomons & Janssen, 2011). This group had by far the largest bandwidth, which could explain partially the higher results. Another explanation is that the SMM-U1 microphone had a high noise floor. As explained in the Methods section, no ultrasounds below 56 dB SPL were detected, meaning that noise levels could have been lower than what the results suggest. It is also possible that ultrasounds were more present in the outdoor environments than the data suggest, but at low sound levels. As for the results of the Peak-to-peak values, ultrasounds were the less variable in time when compared to the other frequency groups. To summarize, while “Very high” frequencies can be heard by non-human mammals, they do not seem to be as present nor potentially stressful for captive animals in a zoo, suggesting that ultrasounds found in laboratories (Milligan et al., 1993; Sales et al., 1999, 1988) are not necessarily found or nearly as loud in a zoo setting (e.g. these studies found ultrasounds reaching up to 130 dB SPL).

The other frequency group that was of interest was the “Very low” frequencies (~infrasounds). They were present in all locations, which was not surprising, as infrasounds are prominent in urban areas (Blickley & Patricelli, 2010; McKenna et al., 2016) and can travel far in the ground and atmosphere (Blickley & Patricelli, 2010; Bowles, 1995; Pater et al., 2009; Slabbekoorn et al., 2018). These frequencies were also the highest in terms of L_{eq}, which is in accordance with our predictions, and had also higher Peak-to-peak levels. They are therefore potentially stressful for animals. However, many non-human mammals cannot hear these frequencies, or at least are not as sensitive to them, especially for small to medium sized animals (Heffner & Heffner, 2008). Zoological institutions should therefore be careful about these sound frequencies for bigger animals that can hear them very well, such as large ungulates (Fay, 1988), and future studies should always assess this group of frequencies, not just frequencies in the human-hearing range.

As for all the other frequencies, they were present in all locations. They showed various patterns in terms of L_{eq}, depending on the location type. Indeed, for the outdoor environments and near touristic attractions, all frequencies followed an increase of sound levels in a bell-shaped curve during the day, which can be associated with human activities (e.g. visitor noise, construction noise, touristic features being active). This was more pronounced with the touristic features, with some noises going past 80 dB SPL. For indoor environments, most frequencies' L_{eq} were stable during the 24h cycle (no change in noises produced by environmental-control devices), with a slight increase during daytime, associated with some levels of human activity (e.g. zookeepers passing by, muffled sound of visitors). The exception was with the "High" frequencies' L_{eq}, which were low most of the time, but had a more pronounced increase during the day. These "High" frequencies are possibly negligible in most environments, and are solely produced by human activity. These types of results, with groups of relevant frequencies, are crucial to managing animal welfare, since species are housed in different enclosure types or areas, and because they have different hearing sensitivity (Fay, 1988).

The hour of the day had a significant effect on the L_{eq} and Peak-to-peak sound levels. Indeed, both analyses presented an increase in these sound metrics that loosely followed working or opening hours. The same increases for both L_{eq} and Peak-to-peak values were observed with the presence of visitors. This suggests that human activity was responsible for most of these high sound levels and variability in the soundscape. This is in agreement with our predictions, as well as the literature. Many studies found that during working hours the sound levels increased significantly (Milligan et al., 1993; Peterson, 1980; Pfaff & Stecker, 1976). Most noises were produced by workers' activities. Animals also tended to make more vocalization in the presence of humans (Coppola, Enns, & Grandin, 2006; Peterson, 1980; Turner et al., 2005). Moreover, during opening hours, visitors also increased the sound levels (de Queiroz, 2018; Owen et al., 2014; Quadros et al., 2014), and this could be disruptive for animals. Indeed, several zoo studies suggested that animals were negatively affected by visitor noise, with increased vigilance (Birke, 2002; Cooke & Schillaci, 2007; Dancer & Burn, 2019; Farrand, 2007; Larsen et al., 2014; Quadros et al., 2014), stereotypy (Sellinger & Ha, 2005), hiding (Farrand, 2007) and cortisol level (Owen et al., 2004). As the presence of visitors is one of the major differences between the zoo and the wilderness or laboratory (Hosey & Druck, 1987), it is imperative that their noise pollution be taken into account when dealing with the animals' welfare.

Indoor environments had significantly higher L_{eq} than outdoor environments, which was contrary to our predictions. The results suggest that environmental-control devices produced higher sound levels than anticipated, when compared to Sales et al. (1999). This is in accordance with the study of de Queiroz (2018), suggesting that in temperate climate zoos, ventilation and heating systems dominate the soundscape in indoor environments, rather than visitor noises for instance. It is worth noting that environmental control devices are active all day long, whereas at night time outdoor environments get quiet, which could explain why, in a 24h average, indoor environments were louder. Moreover, sound propagation in indoor environments was probably more intense because of the reverberation and echoing properties of solid walls, floors and ceilings (Turner et al., 2005). However, indoor environments were found to be more stable than outdoor environments when looking at the Peak-to-peak results. This suggests that even if indoor areas were louder in average, they are likely less stressful for animals because of their low variability in time. In the case of indoor areas, sound attenuation solutions could be implemented to reduce the average sound levels, which will be briefly discussed below. As for the touristic features, and contrary to our predictions, they did not differ in their average L_{eq} and Peak-to-peak values from neither indoor nor outdoor environments. It is rather surprising, considering that they were highly suspected to produce loud noises. However, when looking at each hour, especially during daytime, these attractions produced very high sound levels (L_{eq} reaching the 85 dB SPL threshold). Therefore, even if they were not significantly louder than the other location types on average, the touristic features are potentially stressful for sensitive species, and should be placed in isolated areas far from any animal enclosure.

Contrary to our prediction, the effect of season on both L_{eq} and Peak-to-peak was not significant. It is possible that the four winter locations did not yield enough data to detect a difference. Also, since two out of four winter locations were in indoor environments, the variation in sound levels between summer and winter was probably very low, since environmental-control devices that contribute to most of the soundscape did not greatly vary between the hot and cold season. As for the outdoor environments, they both seemed to be slightly quieter during winter, probably due to fewer visitors and urban noises. However, combined with the indoors, the difference was probably not enough to find a significant effect. In any case, this means that noise pollution should not be mitigated only during the high touristic season, but rather throughout the year. This is also concomitant with chapter 1's discussion, where felines were generally less negatively affected by sound levels during winter. If the soundscape is not different between seasons as is demonstrated by this chapter's results, it suggests that the felines were more comfortable during winter because of the climate and were therefore less bothered by noises of similar levels.

Sound mitigation solutions

Several solutions could be made to mitigate noise pollution. Orban et al. (2017) tested different types of sound absorbing barriers that were very efficient in reducing the sound levels recorded, going from 1 dBC to 12.2 dBC, depending on the sound frequency (more effective with higher frequencies). This could be a simple solution for outdoor environments. For the indoor enclosures, installing special sound absorbing materials could help reduce the noises and echoing properties of solid floors, walls and ceilings. Other indoor infrastructures (e.g. walls of concrete block filled with sand, masonry walls, sound attenuating doors, double-door entry vestibules) could be installed (National Research Council, 2011). Noisy equipment or animals should be as much as possible isolated in their own area, far from animal enclosures. Finally, old equipment producing vibrations should also be replaced with more modern silent equipment.

CONCLUSION

This study measured equivalent continuous (L_{eq}), maximum (L_{max}) and minimum (L_{min}) sound levels at 25 locations within a zoological park to evaluate its soundscape in different context (time of day, open park versus closed, location type, season) in a large frequency range (17.5-90 510 Hz). Very few studies assessed sound frequencies outside of the human-hearing range, but well within the hearing range of most non-human mammals, and this could be potentially negative for their welfare.

We found that the soundscape varied between locations, but with the exception of a few areas (mostly indoor), the zoo had sound levels (L_{eq}) below what is considered to be a nuisance for humans and other animals (<85 dB SPL). The "Very high" frequencies that are outside of the human hearing range, but still within most other mammals', were rare in outdoor environments, but present in some indoor environments, with low sound levels and Peak-to-peak values. Therefore, the ultrasounds do not seem to pose a threat for the animals in this zoo. As for the "Very low" frequencies, they were more variable and louder, and should be mitigated for large animals that can hear them well. The sound levels and variability of the zoo's soundscape increased during daytime and with the presence of visitors, suggesting that most noises were human-related (e.g. zookeeper, employees, urban noises, visitors) and could be potentially stressful for animals. Indoor areas were louder than outdoor areas, demonstrating the environmental-control devices that are active all day long play a major role in the soundscape of these indoor areas. They were however less variable in time, suggesting they are probably not as stressful, since animals are less affected by a low variable soundscape. As for noisy features (e.g. water park, amusement park), they produced high sound levels when they were functioning during the day, and we recommend installing them away from any animal enclosure. Finally, the soundscape of the zoo did not change between the hot and cold season, meaning that similar noises were present all year and that mitigation of noise pollution is not only required during the high touristic season, but also the low touristic season. Several solutions could be made to mitigate noise pollution, such as sound barriers or sound absorbing materials.

TABLES AND FIGURES

Table 2.1: Sound locations selected in Zoo de Granby for the 24h cycles. Specific location describes precisely where the acoustic recorder was set during the cycle. The four locations selected again during the winter 2019 season are in bold (#15, 21, 22, 25). If applicable, the nearest animals housed are identified, with their maximum hearing sound frequency noted. If there was no published data on maximum hearing frequency for a particular species, a similar species of the same size and same Family or Order was chosen instead. Hearing data are based on the works of: Coles & Guppy (1986), Fay (1988), Flydal, Hermansen, Enger, & Reimers (2001), Heffner & Masterton (1980), Heffner (2004), Heffner & Heffner (1982, 1983, 1985, 1990), and Heffner et al. (2003). Visitor condition indicates if visitors were present at some point during the cycle (daytime).

#	Location name	Location type	Specific location	Species housed nearby	Max hearing frequency (kHz) of the species	Visitor condition
1	Amur leopard (I)	Indoor	Transfer zone	Amur leopard	85	No
2	Amur leopard (O)	Outdoor	Next to the enclosure	Amur leopard	85	Yes
3	Amur tiger (I)	Indoor	Transfer zone	Amur tiger	85	No
4	Amur tiger (O)	Outdoor	Next to the enclosure	Amur tiger	85	Yes
5	Snow leopard (I)	Indoor	Transfer zone	Snow leopard	85	No
6	Snow leopard (O)	Outdoor	Next to the enclosure	Snow leopard	85	Yes
7	Lion (I)	Indoor	Transfer zone	African lion	85	No
8	Lion (O)	Outdoor	Next to the enclosure	African lion	85	Yes
9	Jaguar (I)	Indoor	Transfer zone	Jaguar	85	Yes
10	Jaguar (O)	Outdoor	Next to the enclosure	Jaguar	85	Yes
11	Dinozoo	Touristic feature	Behind an animatronic	NA	NA	Yes
12	Water Park	Touristic feature	Behind the wave pool	NA	NA	Yes
13	Amusement Park	Touristic feature	Near the dodgem cars	NA	NA	Yes

Table 2.1: Continued

#	Location name	Location type	Specific location	Species housed nearby	Max hearing frequency (kHz) of the species	Visitor condition
14	Veterinary	Indoor	Empty enclosures used for quarantine	NA	NA	No
15	**Australia**	**Outdoor**	**Inside open enclosure**	**Eastern grey kangaroo, Bennett's wallaby**	**~30, ~30**	**Yes (summer) No (winter)**
16	Aquarium	Indoor	Aquarium, on the zookeepers' side	Various fish and invertebrates	Various (~2)	No
17	Mini farm	Outdoor	Inside the petting zone, next to a barn	Bunny, Sheep, Cow, Horse, Goat	61, 45, 37, 35, 40	Yes
18	Japanese Macaque	Outdoor	Next to the enclosure	Japanese macaque	34.5	Yes
19	Red panda	Outdoor	Behind the enclosure, on the zookeepers' side	Red panda	probably ~40	Yes
20	Bat cavern	Indoor	Inside the enclosure	Jamaican fruit bat	141	Yes
21	**Elephant house**	**Indoor**	**Inside the building, next to the enclosure**	**African elephant, Giraffe**	**12, ~25**	**No (summer) Yes (winter)**
22	**Savannah**	**Outdoor**	**Next to the enclosure**	**African elephant, Giraffe, Ostrich, Zebra, White rhinoceros, Thompson's gazelle, Common eland**	**12, ~25, ~6, ~35, ~20, ?, ~49**	**Yes (summer) Yes (winter)**
23	Construction road	Outdoor	On the side of the road behind the Asia sector	NA	NA	No
24	Gorilla	Indoor	Elevated transfer zone	Western lowland gorilla	probably ~30	No
25	**Marmoset**	**Indoor**	**Transfer zone**	**Goeldi's marmoset**	**probably ~40**	**Yes (summer) No (winter)**

Table 2.2: Frequency groups used for the 24h cycle sound analysis. Each group contained specific standardized third-octave bands that determined the lower and higher limits of the frequency range. Based on Long (2014), to calculate the lower limit, the center frequency of the lowest third-octave band of the group was divided by $\sqrt[6]{2}$. For the higher limit, the center frequency of the highest third-octave band of the group was multiplied by $\sqrt[6]{2}$.

Group name	Lower limit (Hz)	Higher limit (Hz)	Microphone
Very Low	17.5	110	SMM-A2
Low	110	890	SMM-A2
Mid	890	8 980	SMM-A2
High	8 980	17 960	SMM-A2
Very High	17 960	90 510	SMM-U1

Table 2.3: General soundscape of the 24h cycles of all the locations in Zoo de Granby, Granby, Canada. All frequencies (17.5-90 510 Hz) were combined according to equation 2.62 from Long (2014). Only the summer season is presented. The L_{min}, L_{eq} and L_{max} columns represent the total range of all the 24 hours of each metric. Sound levels are measured in unweighted dB SPL (re: 20µPa).

#	Location name	Location type	L_{min}	L_{eq}	L_{max}
1	Amur leopard (I)	Indoor	59.9-60.5	62.5-77.1	64.9-95.7
2	Amur leopard (O)	Outdoor	57.3-59.7	58.8-69.6	62.2-84.1
3	Amur tiger (I)	Indoor	66.6-67.2	69.9-74.2	72.7-94.7
4	Amur tiger (O)	Outdoor	56.8-58.9	58.5-70.1	62.4-93.3
5	Snow leopard (I)	Indoor	58.1-60.0	59.4-62.0	61.4-72.4
6	Snow leopard (O)	Outdoor	56.8-60.9	58.2-68.7	60.2-83.5
7	Lion (I)	Indoor	65.2-67.5	68.0-84.4	70.8-96.1
8	Lion (O)	Outdoor	60.1-67.1	64.0-71.8	68.6-87.6
9	Jaguar (I)	Indoor	61.2-66.6	63.6-70.0	65.4-92.2
10	Jaguar (O)	Outdoor	58.4-63.3	60.7-75.9	64.7-89.5
11	Dinozoo	Touristic feature	58.3-62.2	60.3-75.4	62.6-85.9
12	Water Park	Touristic feature	63.6-78.9	69.3-85.8	75.2-93.4
13	Amusement Park	Touristic feature	56.3-65.2	57.9-77.6	60.7-89.2
14	Veterinary	Indoor	72.1-73.0	76.3-77.9	81.4-83.7
15	Australia	Outdoor	57.7-60.0	60.1-75.3	62.3-86.4
16	Aquarium	Indoor	75.7-75.9	77.1-77.3	78.6-81.6
17	Mini farm	Outdoor	57.7-60.8	60.2-77.0	63.3-94.1
18	Japanese Macaque	Outdoor	58.2-69.9	60.0-85.0	63.0-93.1
19	Red panda	Outdoor	59.1-61.5	60.7-67.7	62.4-83.0
20	Bat cavern	Indoor	57.5-67.9	65.7-80.1	77.5-95.1
21	Elephant house	Indoor	76.2-77.1	81.9-82.3	86.5-91.1
22	Savannah	Outdoor	57.8-62.7	59.7-75.9	64.1-91.3
23	Construction road	Outdoor	59.9-63.3	67.2-82.6	78.2-94.9
24	Gorilla	Indoor	67.5-68.7	68.8-71.8	70.7-77.5
25	Marmoset	Indoor	61.1-74.1	64.0-85.9	67.8-106.1

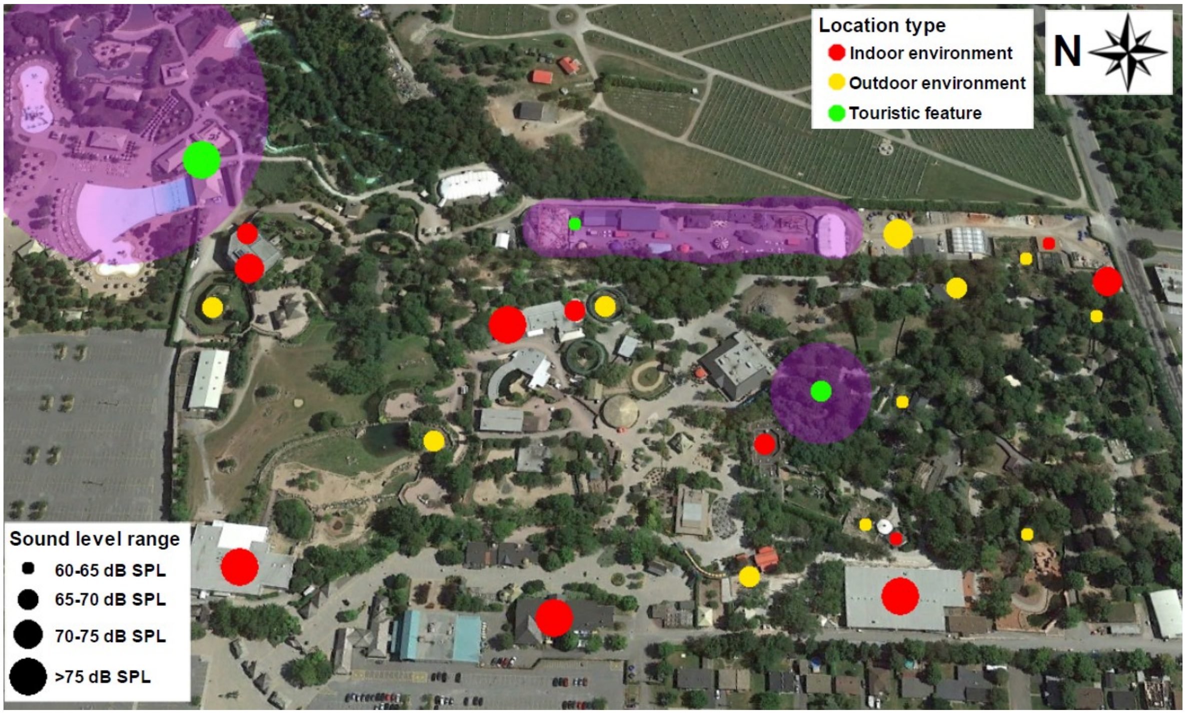

Figure 2.1: Satellite view of the 25 locations selected for the 24h evaluation of the soundscape of Zoo de Granby, Granby, Canada. The red, yellow and green dots represent indoor environments, outdoor environments and touristic features, respectively. The size of the dot is determined by the 24h average of the L_{eq} of each location, for all sound frequencies combined (17.5-90 510 Hz). The purple zones represent the water park, the amusement park and the Dinozoo park. Photo credit: ©Google Earth, version 7.3.2 (2019).

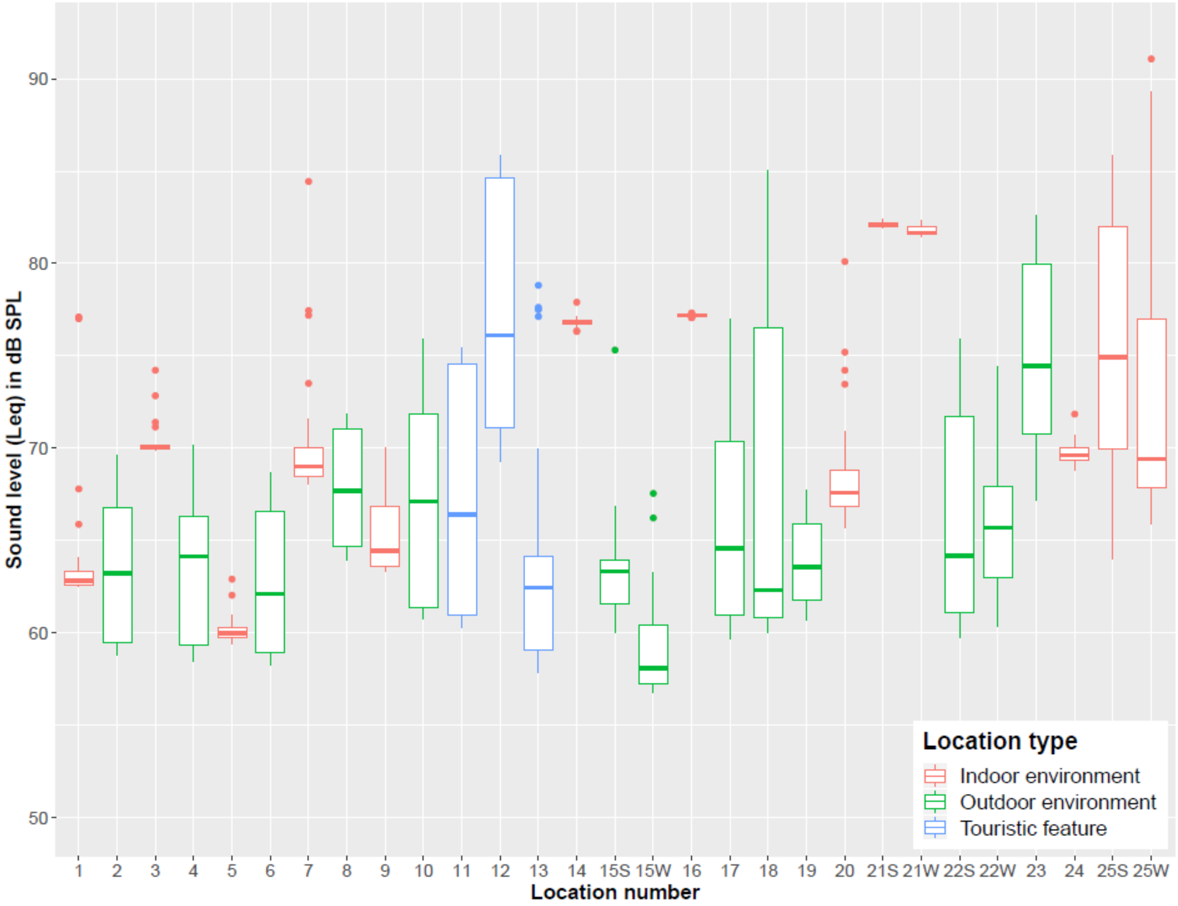

Figure 2.2: Boxplot of all locations' equivalent continuous sound level (L_{eq}) of all 24 hours, with location type specified. The letter "S" indicates the summer season and "W" indicates the winter season for the four locations that were done in both periods (locations #15, 21, 22 and 25). L_{eq} is measured in unweighted dB SPL (re: 20µPa), between 17.5- 90 510 Hz. The location number corresponds to the ones used in Tables 2.1 and 2.3.

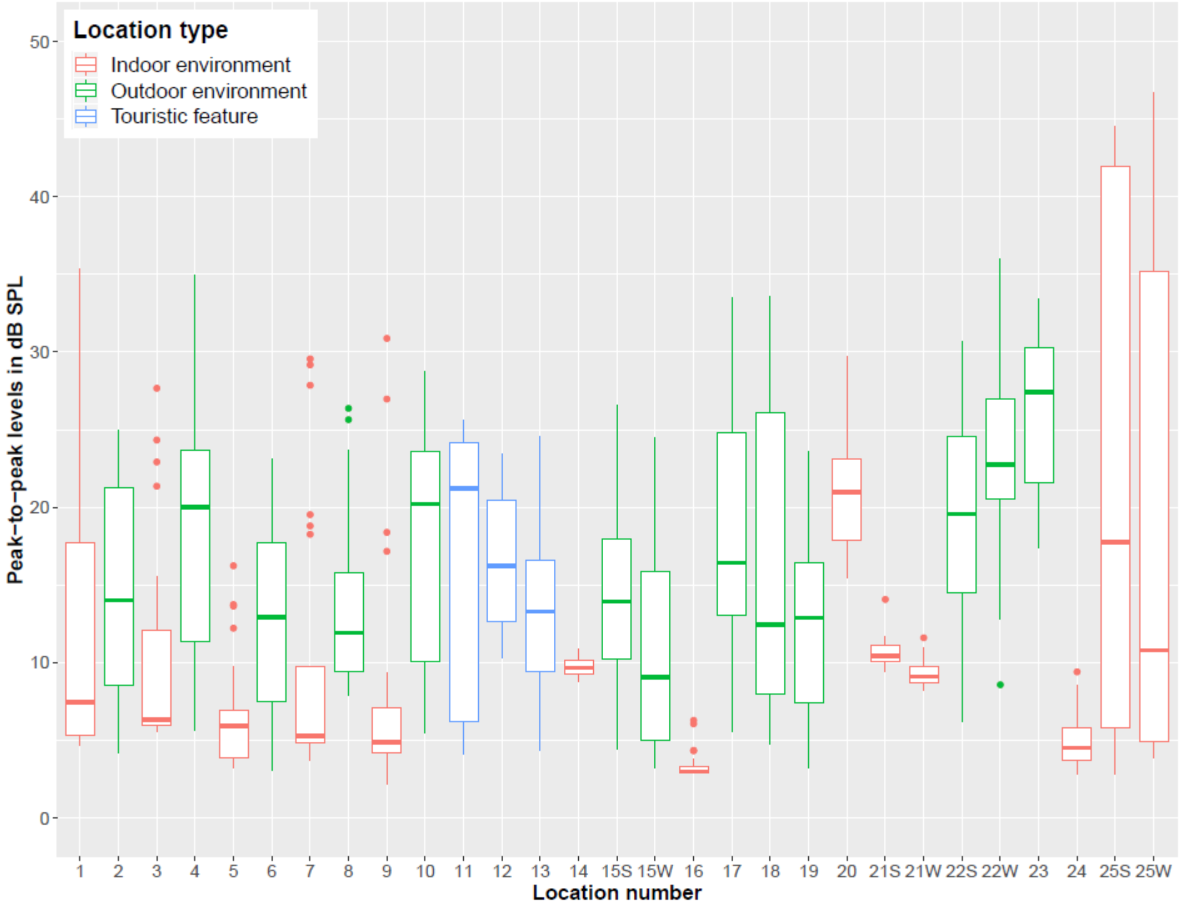

Figure 2.3: Boxplot of all locations' Peak-to-peak sound levels (L_{max}-L_{min}) of all 24 hours, with location type specified. The letter "S" indicates the summer season and "W" indicates the winter season for the four locations that were done in both periods (locations #15, 21, 22 and 25). Peak-to-peak is measured in unweighted dB SPL (re: 20μPa), between 17.5-90 510 Hz. The location number corresponds to the ones used in Tables 2.1 and 2.3.

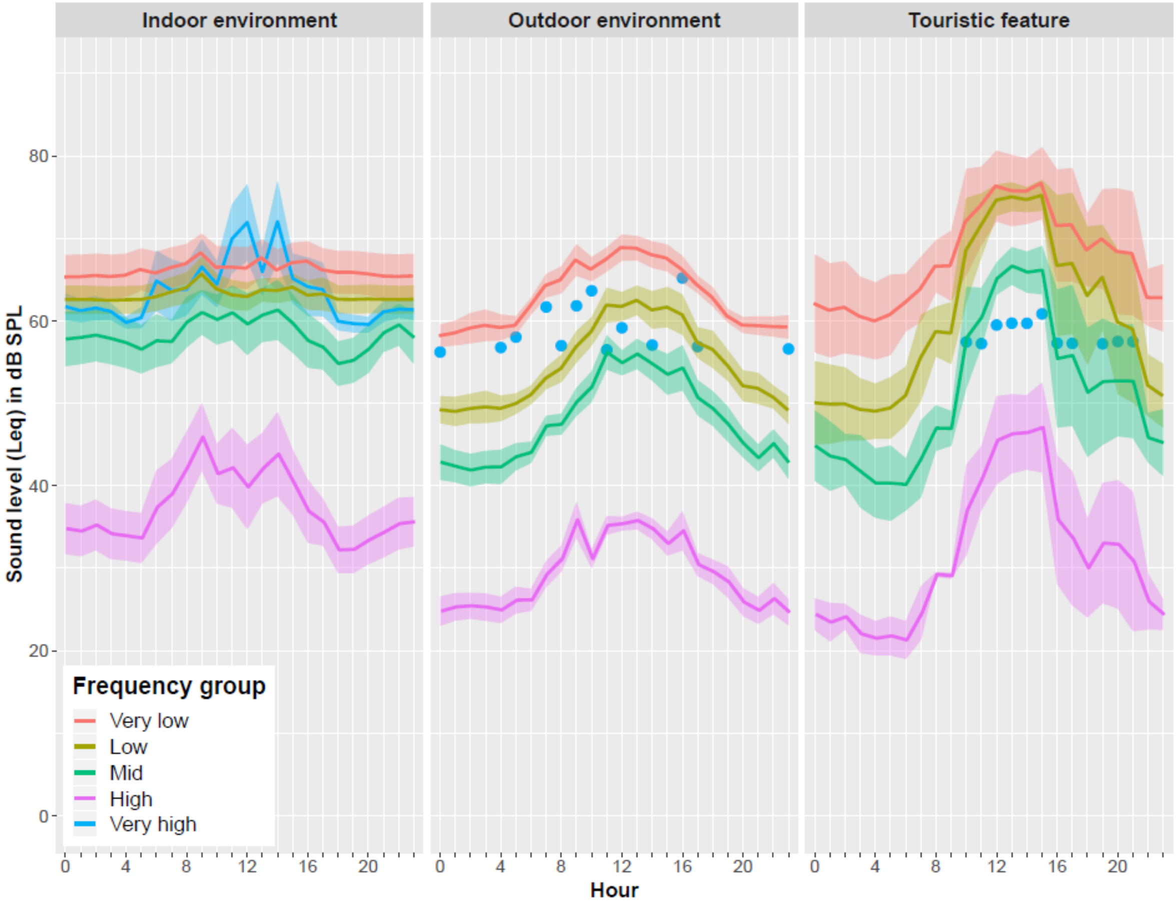

Figure 2.4: Temporal soundscape of all the locations in Zoo de Granby, separated by frequency group and location type (Left panel: Indoor environment; Center panel: Outdoor environment; Touristic features: Right panel). The equivalent continuous sound level (L_{eq}) is measured in unweighted dB SPL (re: 20µPa) between 17.5-90 510 Hz. The frequency groups correspond to the ones described in Table 2.2. The thick bold lines represent the hourly mean L_{eq} of all locations in their corresponding frequency group and location type combinations, with the clear-colored bands around the lines representing standard errors of the mean values. For the “Very high” frequencies in blue, in outdoor environments and near touristic features, there were no noises of that frequency group detected during all 24 hours, therefore a line was not made. The few instances when these frequencies were present are shown in blue dots instead (only representing the mean L_{eq}).

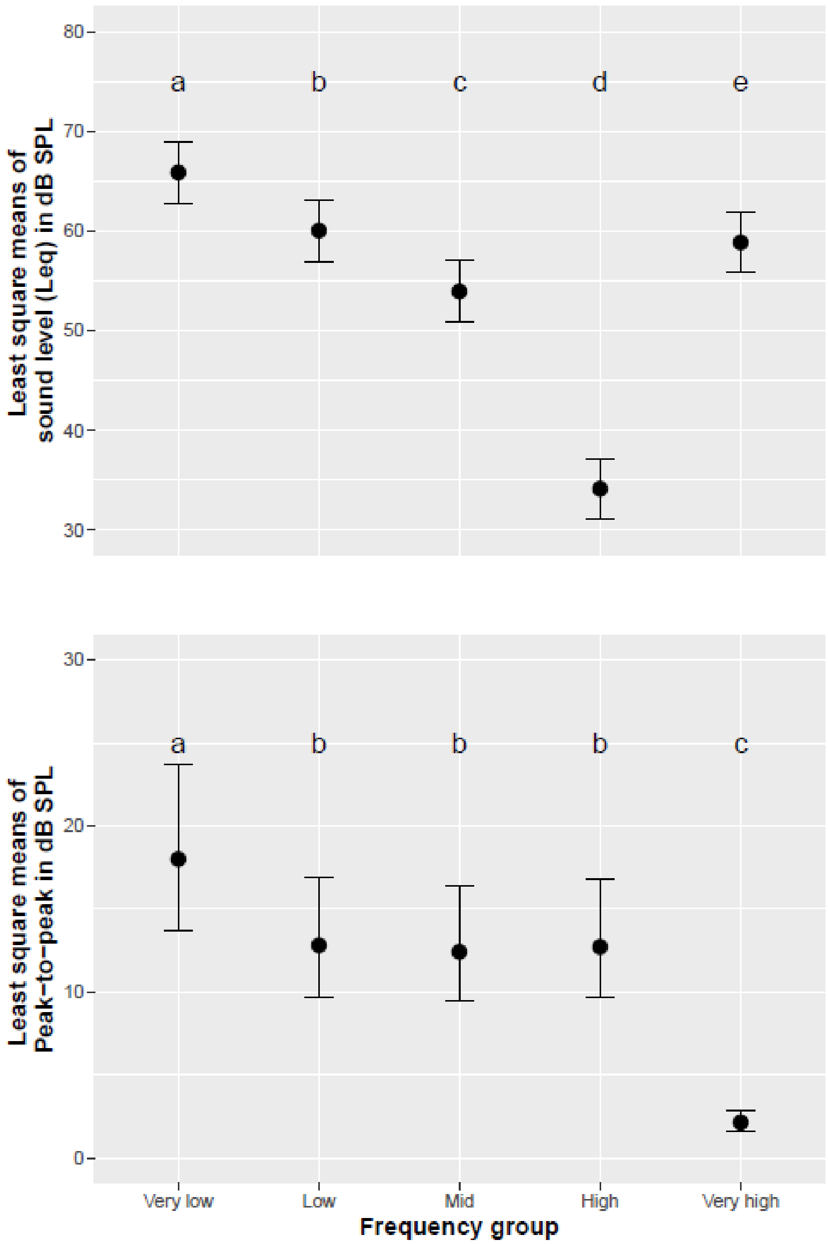

Figure 2.5: Pairwise differences between least square means for equivalent continuous sound levels (L_{eq}) (upper panel) and logged Peak-to-peak (L_{max}-L_{min}) (lower panel), with their 95% confidence intervals, versus the five frequency groups. For the Peak-to-peak, the log values of the Y-axis were transformed back to their original scale in the figure for a more intuitive interpretation. Different letters between the frequency groups indicate a significant difference. A Tukey-Kramer correction was used. Sound levels are measured in unweighted dB SPL (re: 20µPa).

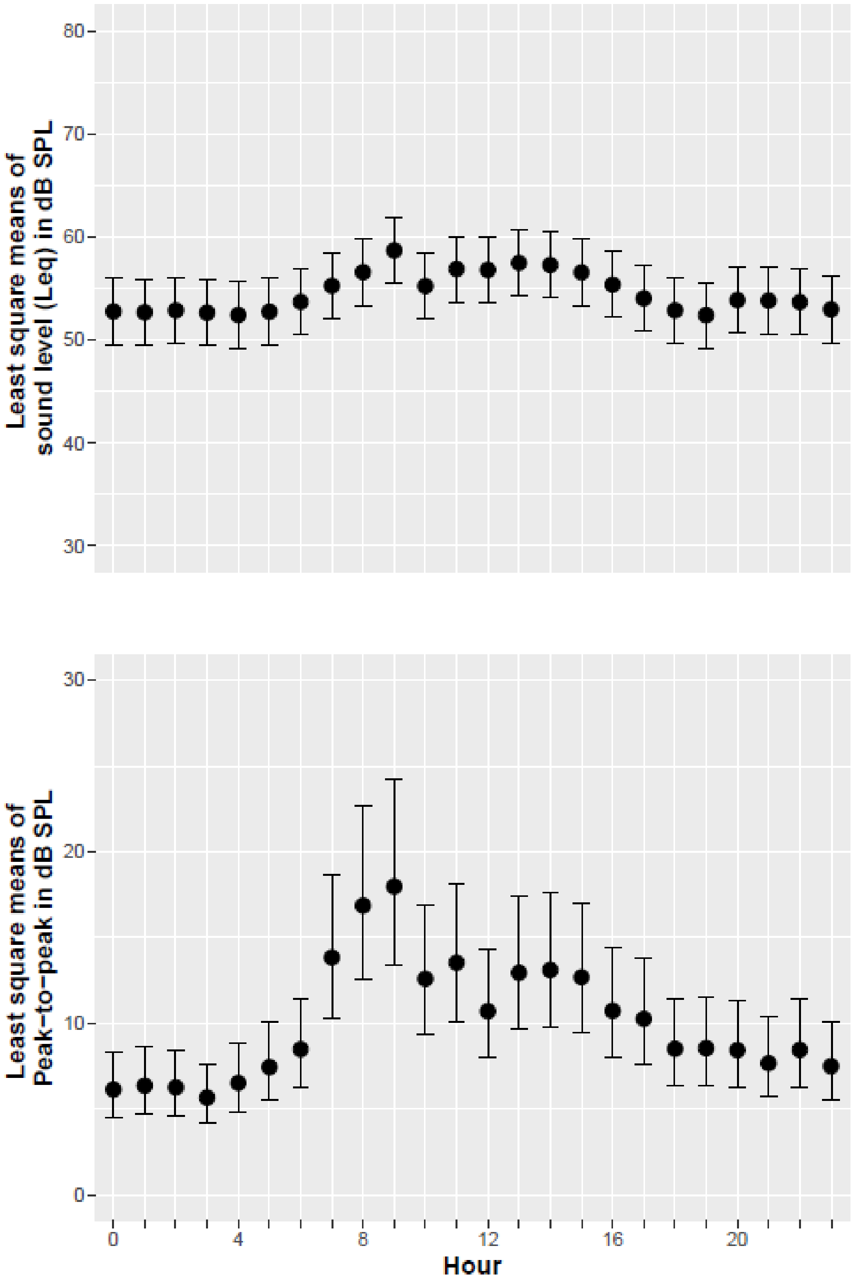

Figure 2.6: Pairwise differences between least square means for equivalent continuous sound levels (L_{eq}) (upper panel) and logged Peak-to-peak (L_{max}-L_{min}) (lower panel) with their 95% confidence intervals, versus the hour of the day. For the Peak-to-peak, the log values of the Y-axis were transformed back to their original scale in this figure for a more intuitive interpretation. Sound levels are measured in unweighted dB SPL (re: 20μPa), between 17.5-90 510 Hz.

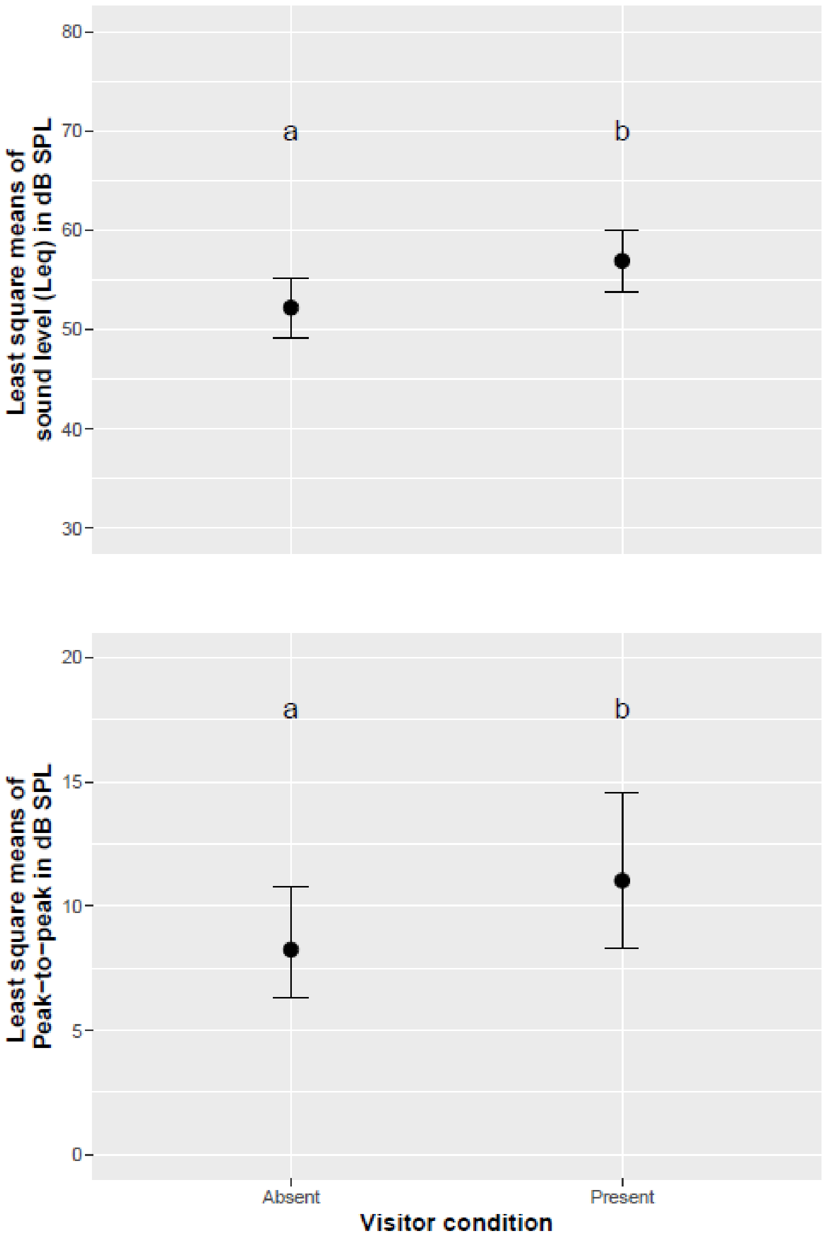

Figure 2.7: Pairwise differences between least square means for equivalent continuous sound levels (L_{eq}) (upper panel) and logged Peak-to-peak (L_{max}-L_{min}) (lower panel), with their 95% confidence intervals, versus the visitor condition. For the Peak-to-peak, the log values of the Y-axis were transformed back to their original scale in this figure for a more intuitive interpretation. Different letters between the frequency groups indicate a significant difference. A Tukey-Kramer correction was used. Sound levels are measured in unweighted dB SPL (re: 20µPa), between 17.5-90 510 Hz.

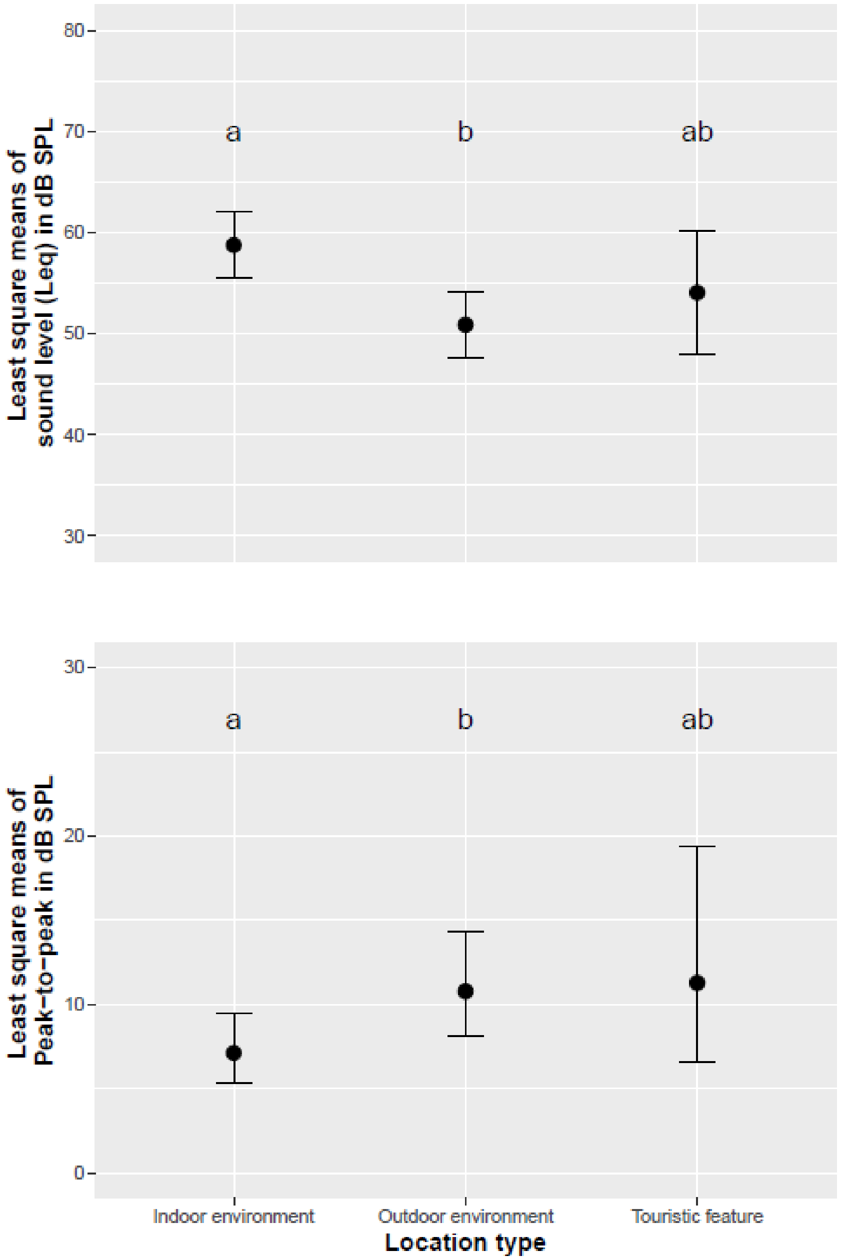

Figure 2.8: Pairwise differences between least square means for equivalent continuous sound levels (L_{eq}) (upper panel) and logged Peak-to-peak (L_{max}-L_{min}) (lower panel), with their 95% confidence intervals, versus the location type. For the Peak-to-peak, the log values of the Y-axis were transformed back to their original scale in this figure for a more intuitive interpretation. Different letters between the frequency groups indicate a significant difference. A Tukey-Kramer correction was used. Sound levels are measured in unweighted dB SPL (re: 20µPa), between 17.5-90 510 Hz.

GENERAL CONCLUSION

This thesis assessed, in its first chapter, the effects of sound levels and visitor attendance on the welfare of captive felines using measures of behavior and space use, at Zoo de Granby in Canada. Both sound levels and visitor attendance had positive, negative or no effects on the felines' welfare, with the sound levels' and visitors' effects differing between species and seasons. This suggests that animal welfare management should be adapted to season and the species, or rather the individual. We did not denote however any welfare problems for these species, with the exception of some individuals that should be more closely monitored because of their pacing and signs of fearfulness. The sound levels and visitor effect did not always have concomitant effects on the same behavior and space use. Therefore, we recommend evaluating separately these two factors when assessing animal welfare, and to especially record all sound frequencies that are part of the hearing range of the study species.

The second part of this thesis evaluated with more details the acoustic environment of multiple locations within the zoo for cycles of 24 hours. The locations were a combination of indoor areas, outdoor areas, and areas near noisy sources (water park, amusement park, animatronics park). In general, our results suggest that the soundscape varied between the locations, but based on their average sound levels, were not considered problematic for animal welfare. There were however some areas that should be more closely monitored, mostly indoor locations with high sound levels. We also recommend installing the noisy sources in areas far away from any animal enclosure. Ultrasounds were rare and were not considered to be detrimental to animals. However, infrasounds were prominent in all areas, and presented the highest sound levels and variability, suggesting they are potentially stressful for animals that are sensitive to them. Human activity was associated with an increase in sound levels and variability in the soundscape, suggesting they could also be detrimental to animal welfare. The acoustic environment did not change between high and low touristic seasons, meaning mitigation of noise pollution should be implemented at all time.

Our findings did not suggest strong evidence of poor animal welfare, even when including sound frequencies outside of the human-hearing range. However, it does not mean this is the case for all animals and all locations, as welfare is an individual measure (Broom, 1991). Future assessments of captive animal welfare in regards to noise pollution should monitor closely each individual, with relevant sound frequencies recorded, especially in areas presenting high sound levels. Several solutions could be implemented to prevent poor welfare, such as sound barriers, sound absorbing materials, or educative signs indicating visitors to be quieter when observing sensitive species. More studies should be made to further assess the acoustic environment, especially for species that are rarely monitored, such as birds, reptiles, amphibians and fish (Melfi, 2009). This study calls for more awareness about the noise pollution issue in zoos and aquariums in an attempt to enhance animal welfare and conservation goals.

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APPENDIX A – Feline study subjects

Table 3.1: Information chart on the studied feline individuals housed at Zoo de Granby, Granby, Canada. All animals are captive born and none are hybrids. The age is calculated as in the end of 2018. The IUCN statuses are based on the IUCN Red list of threatened species^{TM}, and are categorized as follow: Near Threatened (NT), Vulnerable (VU), Endangered (EN), and Critically Endangered (CR). The year the animals were transferred to Zoo de Granby (if not born there) is also noted as an indication of habituation to their new environment. Rearing condition is by hand (humans), by the animals' parent (mother) or unknown. The lions Congo and Cecilia are brother and sister. The Amur leopard Hope was new in her enclosure at the beginning of the experience, and was to form a possible couple with Baïko. The tiger Spoutnik is the son of Mazyria and Jack, and the latter was to form a new couple with Simsa as of 2019. The jaguars formed a couple and had already a cub, which was transferred to a new zoo before the experience began. The snow leopard Elsa is the daughter of Snowflake, and is to eventually form a couple with Kang.

Local ID Number	Species	Name	Sex	Age	Rearing condition	IUCN status	Date arrived at Zoo de Granby
M02003	African Lion	Kao	F	16	Hand	VU	Born in Granby 2002
M14029	African Lion	Congo	M	4	Unkown	VU	March 2016
M15042	African Lion	Cecilia	F	3	Unkown	VU	March 2016
M12016	Amur leopard	Argoun	M	6	Parent	CR	October 2013
M15025	Amur leopard	Baïko	M	3	Parent	CR	Born in Granby 2015
M15047	Amur leopard	Hope	F	3	Unkown	CR	May 2017
M07015	Amur tiger	Mazyria	F	11	Parent	EN	Born in Granby 2007
M07037	Amur tiger	Jack	M	11	Parent	EN	February 2009
M10049	Amur tiger	Simsa	F	8	Parent	EN	March 2014
M13008	Amur tiger	Spoutnik	M	5	Parent	EN	Born in Granby 2013
M12012	Jaguar	Taiama	F	6	Unkown	NT	May 2013
M13031	Jaguar	Kuwan	M	5	Unkown	NT	August 2014
M05031	Snow leopard	Snowflake	F	13	Parent	VU	March 2006
M15016	Snow leopard	Elsa	F	3	Parent	VU	Born in Granby 2015
M15049	Snow leopard	Kang	M	3	Parent	VU	July 2017

APPENDIX B – Felines enclosures (summer/outdoor and winter/indoor)

Table 3.2: Description of all feline enclosures at Zoo de Granby, Granby, Canada. Each outdoor and indoor enclosures are separated by a transfer zone (around 10-48 m²). The Amur leopards and tigers have two outdoor enclosures next to each other, coded A and B. Contrary to all other felines, the jaguars' indoor enclosure is visible from the public. Characteristics describe the environmental condition the felines are living in (substrate, objects). The border type is describing what material is used to separate the public or keepers from the animals, between walls, fences, windows or a combination of them.

Species	Enclosure	Area (m²)	Characteristics	Border type
African Lion	Outdoor	710	Grass, rocks, steep slope, branches, trees, water	Fences
African Lion	Indoor	100	Hard floor, water bowl	Walls and fences
Amur leopard	Outdoor A	550	Grass, dense vegetation, rocks, steep slope, heating rock, water, water bowl	Fences and windows
Amur leopard	Outdoor B	425	Grass, dense vegetation, rocks, steep slope, heating rock, water bowl	Fences and windows
Amur leopard	Indoor	230	Hard floor, water bowl	Walls and fences
Amur tiger	Outdoor A	1227	Grass, dense vegetation, rocks, heating rock, pool of water, water bowl	Fences
Amur tiger	Outdoor B	1468	Grass, dense vegetation, rocks, heating rock, pool of water, water bowl	Fences and windows
Amur tiger	Indoor	150	Hard floor, water bowl, tables	Walls and fences
Jaguar	Outdoor	390	Grass, vegetation, climbing structures, pool of water, water bowl	Fences and windows
Jaguar	Indoor	80	Hard floor, water bowl, climbing structures	Windows and walls
Snow leopard	Outdoor	433	Rocks, grass, trees, steep slope, heating rocks, sand, water bowl	Fences and windows
Snow leopard	Indoor	40	Hard floor, water bowl	Walls and fences

Figure 3.1: Panoramic view of the African lions' outdoor enclosure. It consisted of a 710m² habitat surrounded by fences and a wall (where the visitors had an elevated point of view on the enclosure). It contained grass, trees, three shelters, rocks, a small water pool, logs, and a hill in the back.

Figure 3.2: Panoramic view of the Amur leopards' outdoor enclosure A. The enclosure consisted of a 550m² habitat surrounded by mostly fences, and some windows (in the background on the right of the picture). It contained dense vegetation, trees, grass, climbing structures, heating rock, a shelter, a small water pool, and a hill in the back.

Figure 3.3: Front view of the Amur leopards' outdoor enclosure B, both in the summer (top) and winter (bottom) seasons. It consisted of a 425m^2 habitat surrounded by fences and windows. It contained dense vegetation, trees, grass, rocks, shelter, climbing structures, a heating rock (seen in the front on the bottom picture) and a hill in the back.

Figure 3.4: Panoramic view of the Amur tigers' outdoor enclosure A in both the summer (top) and winter (bottom) seasons. It consisted of a 1227m² habitat surrounded by fences. It contained trees, vegetation, grass, rocks, logs, shelter, climbing structures, heating rock, and a water pool.

Figure 3.5: Panoramic view of the Amur tigers' outdoor enclosure B. It consisted of a 1468m² habitat surrounded by fences and windows (as seen in the picture). It contained trees, vegetation, grass, rocks, logs, shelter, climbing structures, heating rock, and a water pool.

Figure 3.6: Panoramic view of the jaguars' outdoor enclosure. The enclosure consisted of a 390m² circular habitat surrounded by windows and fences. It contained climbing structures, grass, vegetation, trees, rocks, and a large water pool. The large wall formation on the right was elevated from the publics' point of view, and underneath was another fence, separating the outdoor enclosure from the indoor enclosure (transfer).

Figure 3.7: Front view of the Snow leopards' outdoor enclosure in both the summer (top) and winter (bottom) seasons. It consisted of a 433m² habitat surrounded by fences and windows. It contained rocks, trees, grass, sand, two shelters, heating rocks (seen in the front right) and a hill in the back.

Figure 3.8: Panoramic view of the Amur tigers' indoor enclosure, where the African lions were housed during the winter season (the lions' indoor enclosure was at that time under renovation). It consisted of three connected small enclosure of hard floor and walls, separated by rigid fences. It contained water bowls, enrichment objects and tables.

Figure 3.9: Panoramic front view of the jaguars' indoor enclosure, as seen from the public's point of view. It consisted of an 80m² habitat surrounded by walls and windows. It contained climbing structures and gave access to the transfer areas, or the outdoor enclosure when temperature was warmer during the winter season.

APPENDIX C – Acoustic monitor and microphones settings

Figure 3.10: Picture of the acoustic recorder's setting (SM3BAT, Wildlife Acoustics Inc.) during the felines' observation and the 24h cycles. The recorder was hidden under the blue and white umbrella in outdoor environments, to protect it from overheating in the sun and losing too much battery. During the winter season, the monitor was elevated on a small plastic box, to prevent it from touching snow and ice. The two microphones (SMM-U1 and SMM-A2, Wildlife Acoustics Inc.) were attached to a camera tripod approximately 1m above ground, and were pointing towards the enclosure (in this picture, the jaguars' outdoor enclosure).

APPENDIX D – Calibration of the microphones

Figure 3.11: Calibration of the SMM-A2 acoustic microphone in an anechoic chamber. The professional calibrator produced a 1 000 Hz sine wave of 94 dB (re: 20μPa).

Figure 3.12: Calibration of the SMM-U1 ultrasonic microphone in an anechoic chamber. The professional calibrator (Wildlife Acoustics Inc.) produced a 40 000 Hz sine wave of 75 ± 3 dB (re: 20µPa). It was mainly used to assess the quality of the microphone rather than precisely indicating the sensitivity of the microphone. A "sensitivity" above -38dBV meant that the microphone was still of good quality. Since this was the case, we based this microphone's sensitivity on the chart provided by Wildlife Acoustics (Figure 3.13 below) for the sound pressure levels adjustments.

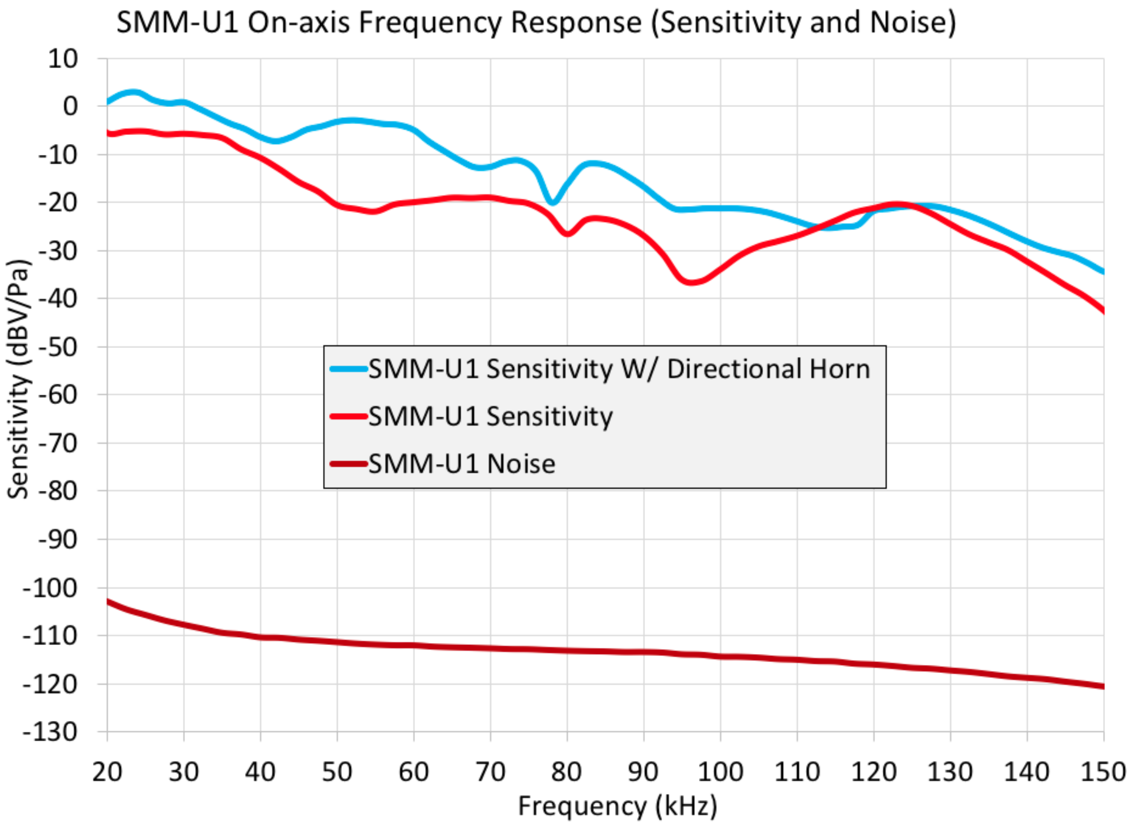

Figure 3.13: Sensitivity chart of the SMM-U1 microphone provided by Wildlife Acoustic inc. that was used for the correction of sound pressure levels' output. No directional horn was used. The SMM-U1 Noise line represents the noise floor of the microphone for a bandwidth of 1 Hz.

```
MICROPHONE CALIBRATE
          @1    @40  kHz
Ch 0: -75.2 -75.2dBV
█h 1:  -4.2 -57.1dBV
```

Figure 3.14: Example of the calibration mode of the SMM-A2 acoustic microphone with the calibrator producing a sine wave of 1 000 Hz. The microphone is represented by the channel 1, and under the column @1 kHz the sensitivity is indicated (-4.2 dBV, which was later applied to correct the sound level recorded). This microphone was not sensitive to 40 000 Hz, therefore any result under that column was disregarded. The channel 0 represents the SMM-U1 ultrasonic microphone, but it was not sensitive to 1 000 Hz sound waves, and therefore could not be tested for this particular calibrator (shown in Figure 3.11). It was tested with a professional ultrasonic calibrator (shown in Figure 3.12).

APPENDIX E – Visitor density categories

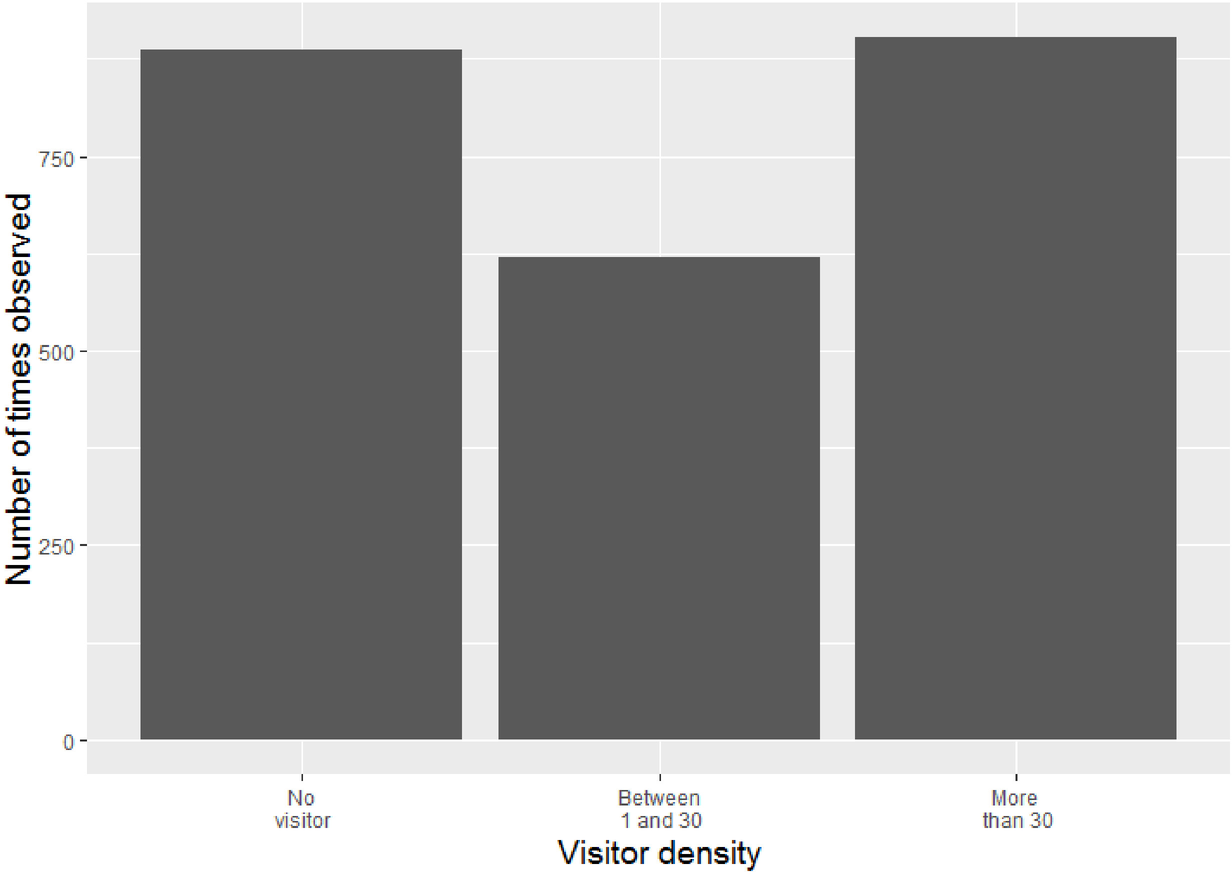

Figure 3.15: The frequency of the final three levels of the visitor densities used for statistical analysis after combining the original eight categories. These densities represent a no visitor condition (when the zoo was closed), a few visitors (between 1 and 30) and a dense crowd (more than 30).

APPENDIX F – Model selection and estimates

Table 3.3: Model selection based on AIC to explain the variability of behaviors of interest and space use for the five species of feline combined during the summer and winter season. Models within 2AIC or the two models with the lowest AIC are presented. Selected models are bolded and interactions are represented by « * » in the table.

Season	Model	Leq	Visitor	Leq*Species	Visitor*Species	Species	Time of day	AIC	ΔAIC
Summer	Rest/Sleep								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**43832**	**0**
	2	X	X		X	X	X	44013	181
	Vigilance								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**16040**	**0**
	2	X	X		X	X	X	16136	96
	Active behaviors								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**12645**	**0**
	2	X	X		X	X	X	12777	132
	Pacing								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**16825**	**0**
	2	X	X		X	X	X	16966	141
	Front zone								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**8358.7**	**0**
	2	X	X		X	X	X	8389.2	30.5
	Mid zone								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**11735**	**0**
	2	X	X		X	X	X	11912	177
	Back zone								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**13679**	**0**
	2	X	X		X	X	X	13884	205

Table 3.3: Continued (winter season)

Season	Model	Leq	Visitor	Leq*Species	Visitor*Species	Species	Time of day	AIC	ΔAIC
	Rest/Sleep								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**19837**	**0**
	2	X	X	X		X	X	20112	275
	Vigilance								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**6514.2**	**0**
	2	X	X	X		X	X	6548.8	34.6
	Active behaviors								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**6877.1**	**0**
	2		X		X	X	X	7313.2	436.1
	Pacing								
Winter	**1**	**X**	**X**	**X**	**X**	**X**	**X**	**11269**	**0**
	2	X	X		X	X	X	11302	33
	Front zone								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**5253.6**	**0**
	2	X	X		X	X	X	5350.2	96.6
	Mid zone								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**3296.1**	**0**
	2		X		X	X	X	3317.8	21.7
	Back zone								
	1	**X**	**X**	**X**	**X**	**X**	**X**	**4642.8**	**0**
	2	X	X		X	X	X	4689.6	46.8

Table 3.4: Estimates and standard errors of the sound level effects for each species, for all behaviors and zone used tested, in the summer and winter season. All species' estimates and standard errors are compared to the African lions'. For space use during winter, the estimates and standard errors are compared to the Amur tigers'. Interactions are represented by « * » in the table, and significant effect are in bold. Amur leopards were not observed during winter.

Season	Behavior or Zone used	Effect per species	Estimate	Std Error	Z value	P value
Summer	Rest/Sleep	**Leq (African lion)**	**0.215**	**0.025**	**8.691**	**<0.001**
		Leq*Amur leopard	**-0.154**	**0.051**	**-3.012**	**0.003**
		Leq*Amur tiger	**-0.324**	**0.032**	**-9.989**	**<0.001**
		Leq*Jaguar	**-0.393**	**0.030**	**-12.952**	**<0.001**
		Leq*Snow leopard	**-0.236**	**0.038**	**-6.185**	**<0.001**
	Vigilance	**Leq (African lion)**	**-0.124**	**0.033**	**-3.775**	**<0.001**
		Leq*Amur leopard	**0.201**	**0.074**	**2.718**	**0.007**
		Leq*Amur tiger	**0.267**	**0.044**	**6.121**	**<0.001**
		Leq*Jaguar	**0.351**	**0.044**	**7.900**	**<0.001**
		Leq*Snow leopard	**0.450**	**0.048**	**9.309**	**<0.001**
	Active behaviors	**Leq (African lion)**	**-0.276**	**0.042**	**-6.573**	**<0.001**
		Leq*Amur leopard	-0.160	0.105	-1.530	0.13
		Leq*Amur tiger	**-0.324**	**0.077**	**5.510**	**<0.001**
		Leq*Jaguar	**0.299**	**0.059**	**5.057**	**<0.001**
		Leq*Snow leopard	**-1.079**	**0.154**	**-6.993**	**<0.001**
	Pacing	Leq (African lion)	-0.221	0.141	-1.564	0.12
		Leq*Amur leopard	0.174	0.162	1.076	0.28
		Leq*Amur tiger	**0.342**	**0.146**	**2.349**	**0.02**
		Leq*Jaguar	-0.075	0.145	-0.519	0.60
		Leq*Snow leopard	**-0.606**	**0.164**	**-3.689**	**<0.001**
	Front zone	Leq (African lion)	0.120	0.205	0.582	0.56
		Leq*Amur leopard	**-0.768**	**0.269**	**-2.855**	**0.004**
		Leq*Amur tiger	0.175	0.214	0.816	0.41
		Leq*Jaguar	0.033	0.209	0.158	0.87
		Leq*Snow leopard	-0.202	0.216	-0.933	0.35
	Mid zone	**Leq (African lion)**	**-0.479**	**0.090**	**-5.336**	**<0.001**
		Leq*Amur leopard	-0.103	0.154	-0.666	0.51
		Leq*Amur tiger	**0.362**	**0.099**	**3.641**	**<0.001**
		Leq*Jaguar	**0.968**	**0.099**	**9.732**	**<0.001**
		Leq*Snow leopard	**0.638**	**0.108**	**5.910**	**<0.001**
	Back zone	**Leq (African lion)**	**0.416**	**0.085**	**4.888**	**<0.001**
		Leq*Amur leopard	**0.375**	**0.141**	**2.652**	**0.008**
		Leq*Amur tiger	**-0.458**	**0.100**	**-4.553**	**<0.001**
		Leq*Jaguar	**-0.905**	**0.093**	**-9.747**	**<0.001**
		Leq*Snow leopard	**-0.480**	**0.099**	**-4.819**	**<0.001**

Table 3.4: Continued (winter season)

Season	**Behavior or Zone used**	**Effect per species**	**Estimate**	**Std Error**	**Z value**	**P value**
Winter	Rest/Sleep	**Leq (African lion)**	**-0.329**	**0.040**	**-8.193**	**<0.001**
		Leq*Amur tiger	**0.605**	**0.047**	**12.980**	**<0.001**
		Leq*Jaguar	**-0.108**	**0.053**	**-2.046**	**0.04**
		Leq*Snow leopard	**1.176**	**0.058**	**20.285**	**<0.001**
	Vigilance	**Leq (African lion)**	**0.121**	**0.051**	**2.351**	**0.02**
		Leq*Amur tiger	**-0.298**	**0.061**	**-4.898**	**<0.001**
		Leq*Jaguar	**0.258**	**0.066**	**3.914**	**<0.001**
		Leq*Snow leopard	**-0.160**	**0.070**	**-2.278**	**0.02**
	Active behaviors	**Leq (African lion)**	**0.722**	**0.158**	**4.553**	**<0.001**
		Leq*Amur tiger	**-0.897**	**0.165**	**-5.444**	**<0.001**
		Leq*Jaguar	0.165	0.167	0.990	0.32
		Leq*Snow leopard	**-1.579**	**0.174**	**-9.094**	**<0.001**
	Pacing	Leq (African lion)	0.169	0.109	1.550	0.12
		Leq*Amur tiger	**-0.295**	**0.113**	**-2.613**	**0.009**
		Leq*Jaguar	**-0.273**	**0.116**	**-2.345**	**0.02**
		Leq*Snow leopard	**-0.704**	**0.132**	**-5.347**	**<0.001**
	Front zone	Leq (Amur tiger)	**-0.103**	**0.049**	**-2.102**	**0.04**
		Leq*Jaguar	0.147	0.082	1.792	0.07
		Leq*Snow leopard	**0.950**	**0.099**	**9.593**	**<0.001**
	Mid zone	Leq (Amur tiger)	0.086	0.053	1.622	0.1
		Leq*Jaguar	-0.121	0.100	-1.207	0.23
		Leq*Snow leopard	**-0.898**	**0.180**	**-4.985**	**<0.001**
	Back zone	**Leq (Amur tiger)**	0.020	0.049	0.497	0.68
		Leq*Jaguar	-0.018	0.089	-0.204	0.84
		Leq*Snow leopard	**-0.658**	**0.098**	**-6.714**	**<0.001**

APPENDIX G – Felines' space use ("heat maps") in summer and winter (outdoor)

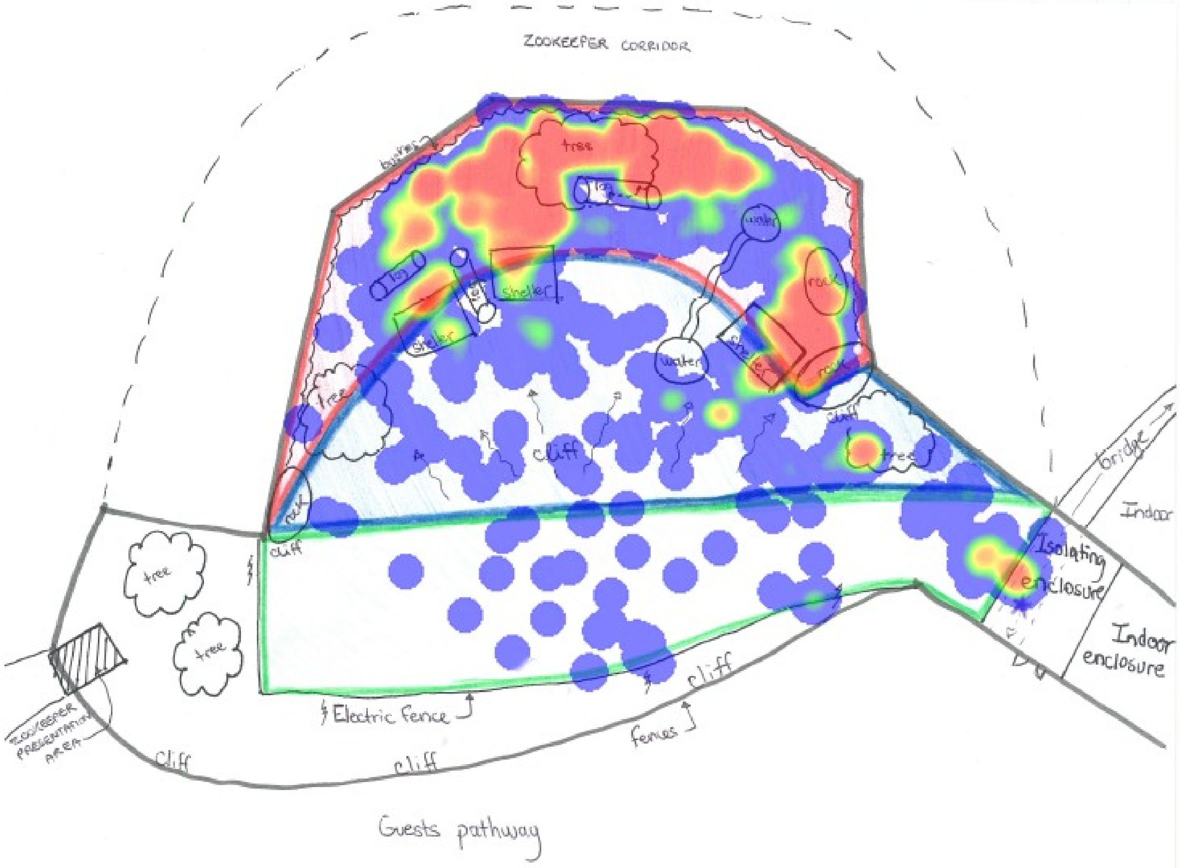

Figure 3.16: Heat map of the space use of the African lions during summer 2018 at Zoo de Granby, Granby, Canada. The map was extracted with the ZooMonitor web application (Ross et al., 2016). Each circle represents a data point, and the more the data points there were in a specific location, the more red this location becomes.

Figure 3.17: Heat map of the space use of the Amur leopards during summer 2018 at Zoo de Granby, Granby, Canada. The map was extracted with the ZooMonitor web application (Ross et al., 2016). Each circle represents a data point, and the more the data points there were in a specific location, the more red this location becomes.

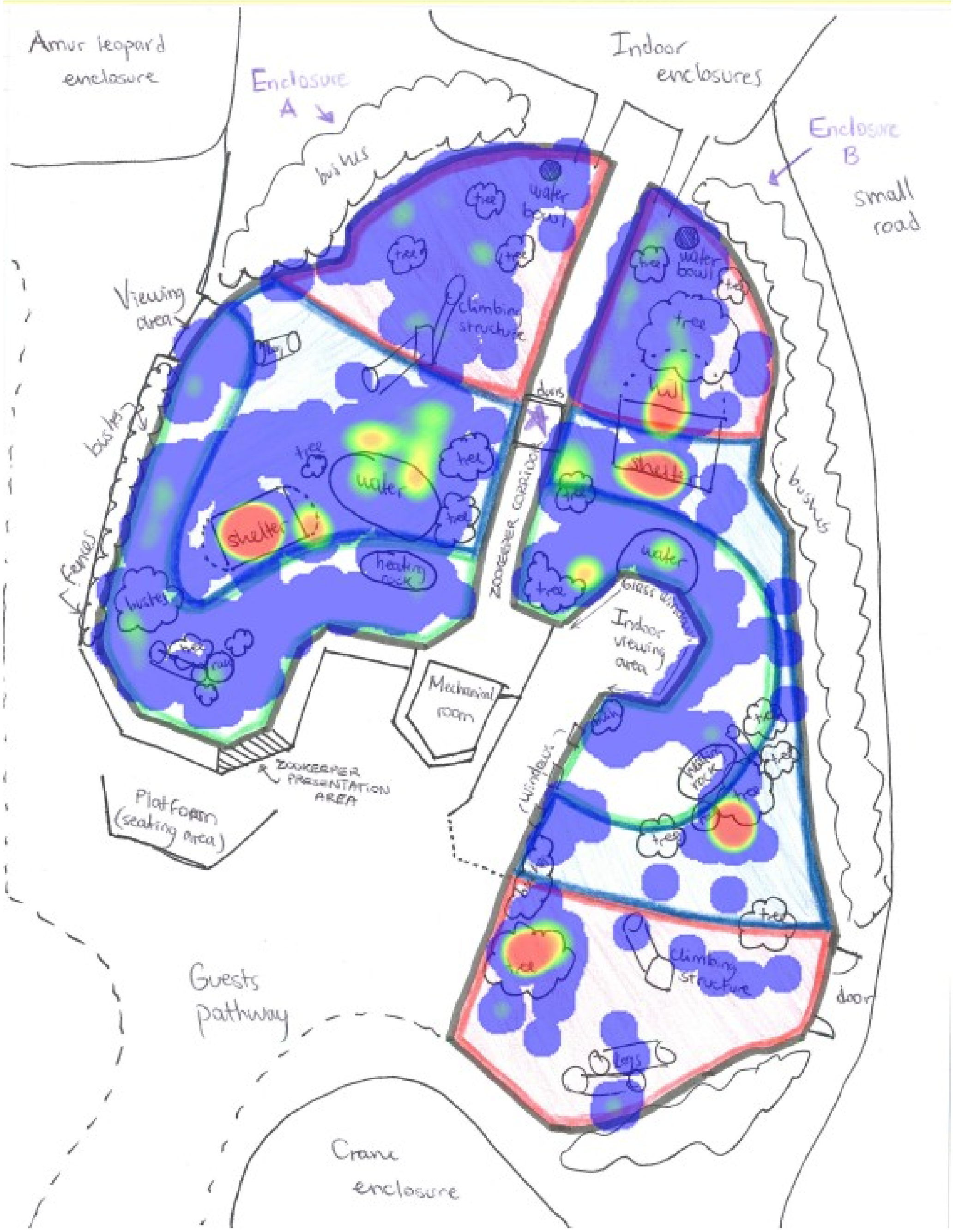

Figure 3.18: Heat map of the space use of the Amur tigers during summer 2018 at Zoo de Granby, Granby, Canada. The map was extracted with the ZooMonitor web application (Ross et al., 2016). Each circle represents a data point, and the more the data points there were in a specific location, the more red this location becomes.

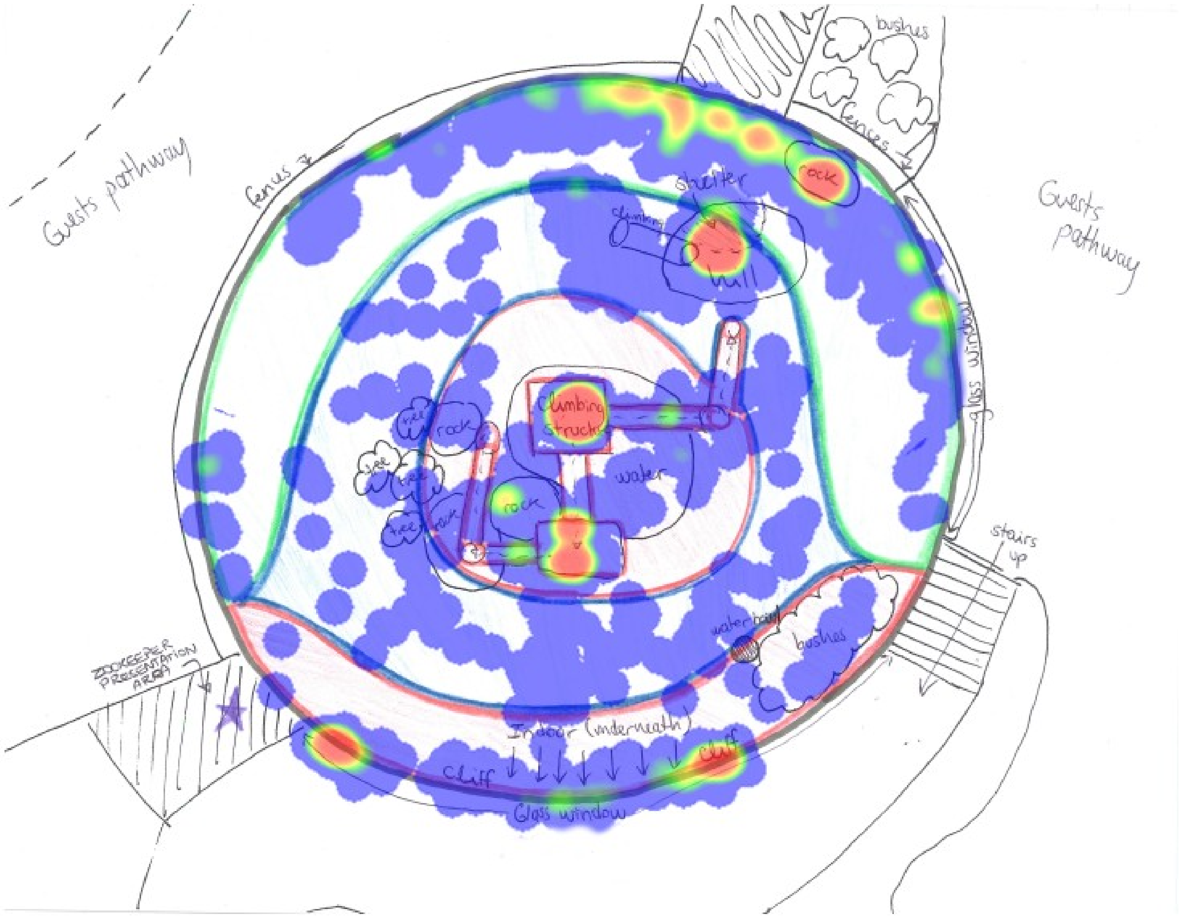

Figure 3.19: Heat map of the space use of the jaguars during summer 2018 at Zoo de Granby, Granby, Canada. The map was extracted with the ZooMonitor web application (Ross et al., 2016). Each circle represents a data point, and the more the data points there were in a specific location, the more red this location becomes.

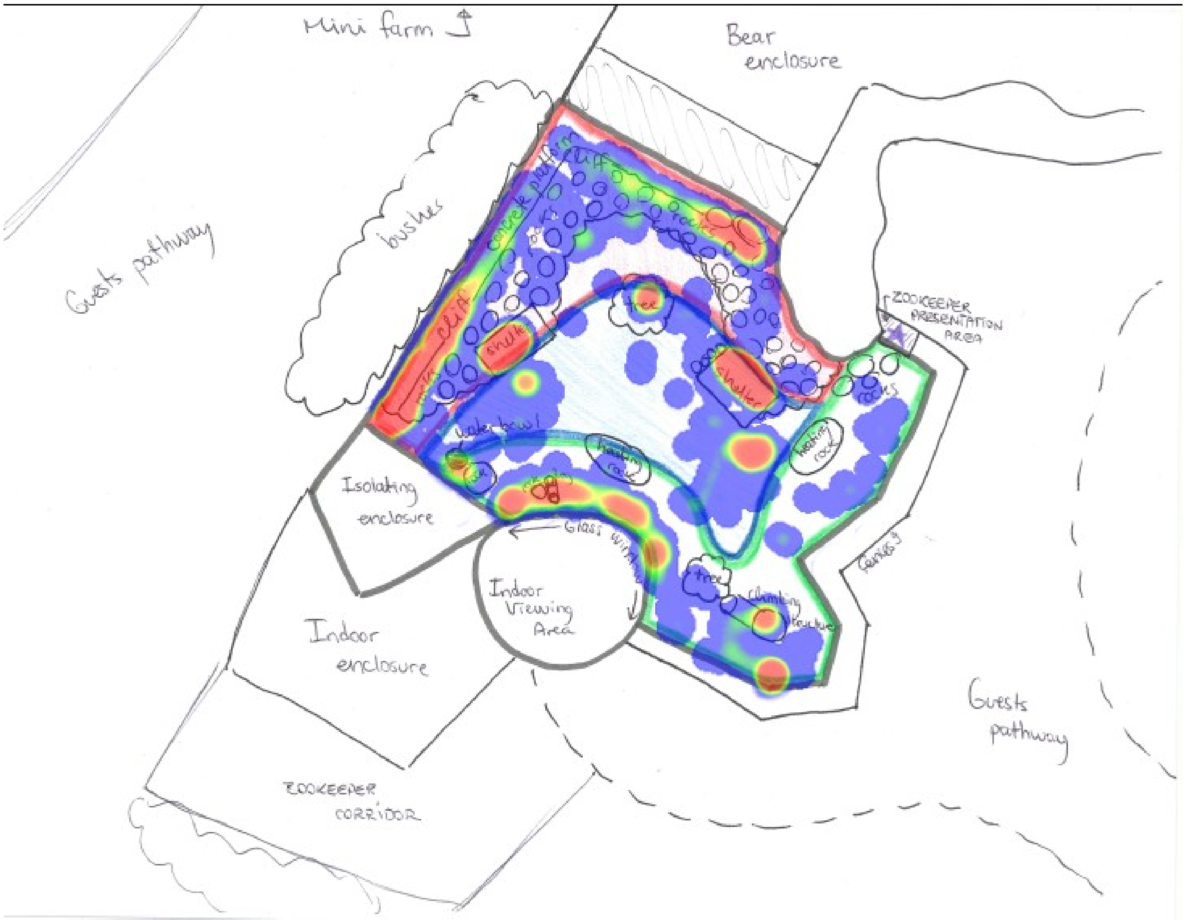

Figure 3.20: Heat map of the space use of the snow leopards during summer 2018 at Zoo de Granby, Granby, Canada. The map was extracted with the ZooMonitor web application (Ross et al., 2016). Each circle represents a data point, and the more the data points there were in a specific location, the more red this location becomes.

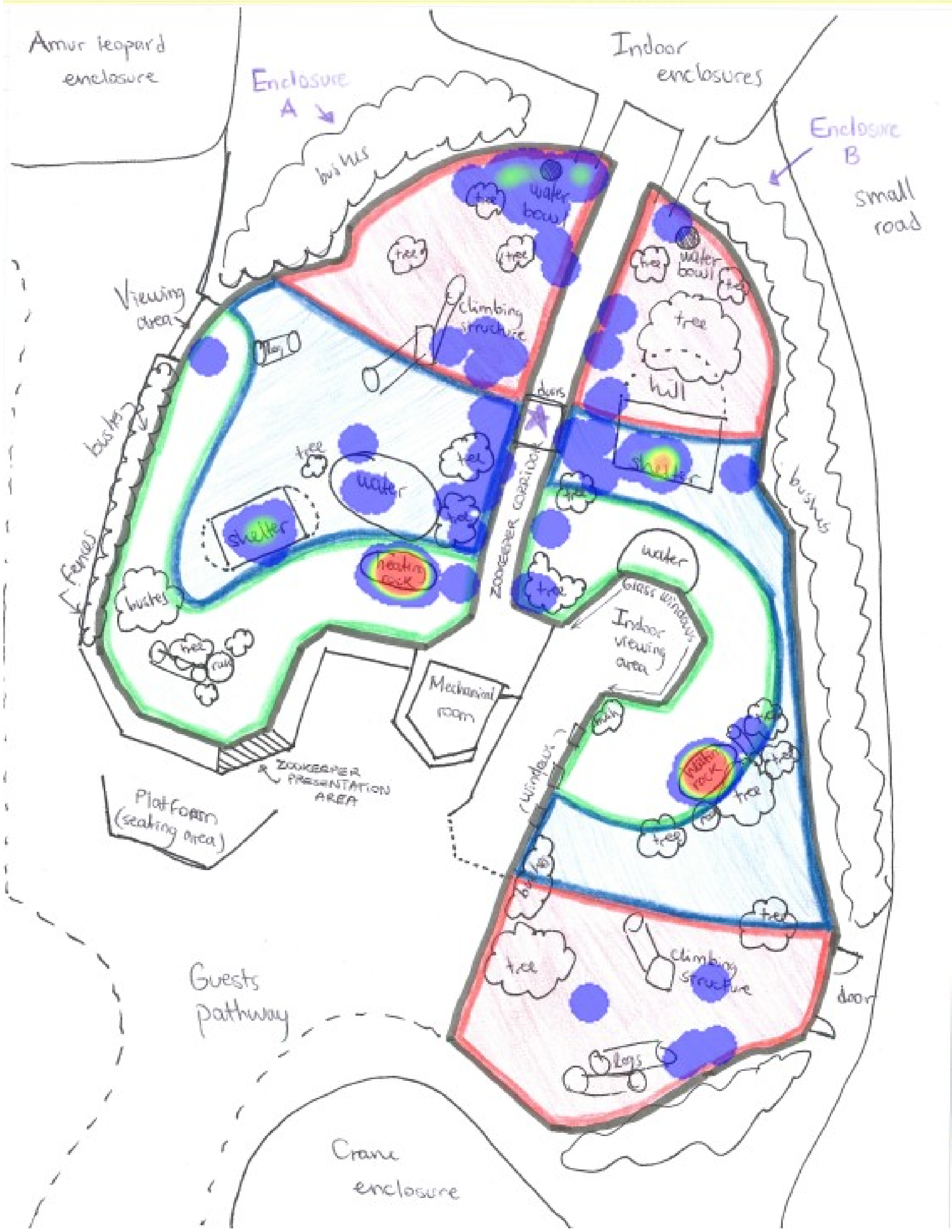

Figure 3.21: Heat map of the space use of the Amur tigers during winter 2019 at Zoo de Granby, Granby, Canada. The map was extracted with the ZooMonitor web application (Ross et al., 2016). Each circle represents a data point, and the more the data points there were in a specific location, the more red this location becomes.

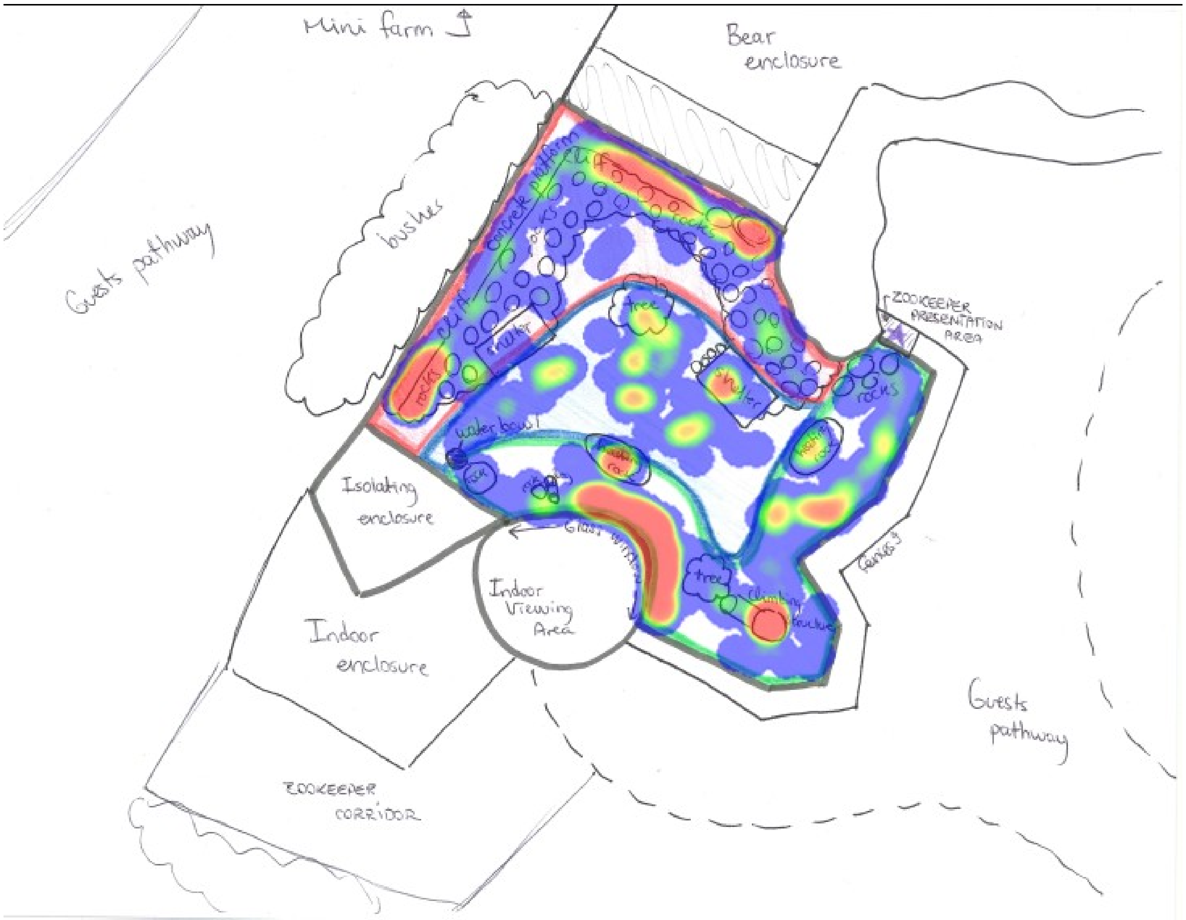

Figure 3.22: Heat map of the space use of the snow leopards during winter 2019 at Zoo de Granby, Granby, Canada. The map was extracted with the ZooMonitor web application (Ross et al., 2016). Each circle represents a data point, and the more the data points there were in a specific location, the more red this location becomes.