Measuring a Soundscape of the captive Southern White Rhinoceros *(Ceratotherium simum simum)*

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ABSTRACT

Many creatures, including the myopic rhinoceros, depend upon hearing and smell to determine their environment. Nature is dominated by biophonic and geophonic sounds quickly absorbed by soil and vegetation. Anthrophonic urban soundscapes exhibit vastly different physical and semantic characteristics: reflections from hard geometric surfaces, multi-path propagation and reverberation, and often increased sound pressure levels compared to nature, in addition to much anthropogenic noise not found in nature. Noise damages humans physiologically, including reproductively, and likely damages other mammals. Rhinos vocalize sonically and infrasonically but audiograms are unavailable. They generally breed poorly in urban zoos, where infrasonic noise tends to be chronic. Biological and social factors have been studied but little attention if any has been paid to soundscape. To comprehensively describe the rhinos' acoustic environment at Fossil Rim Wildlife Center, one of the few U.S. facilities to successfully breed white rhinos in recent years, its broadband sound metrics were studied throughout a week of normal park activities. Further analysis will seek particular parameters known to be injurious to humans, plus those already known to invoke response in animals. Later, a variety of other facilities could be recorded to seek correlations between their soundscapes and the health and well-being of the creatures within their care.

Keywords: Soundscape, Ecology, Rhinoceros
I-INCE Classification of Subjects Number: 56.3 Soundscapes

1. INTRODUCTION

Many creatures depend on an acute sense of hearing and smell more than on sight. Thus their soundscape (what they hear around them) is more crucial than their landscape (what they see).

Some rhinos and other species are ever more endangered in the wild but tend to breed poorly in zoos, jeopardising gene pools and risking extinction. Herd size and composition, the age and experience of potential mates, substrate, exhibit design, diet and other factors have been studied but little attention has been paid to their soundscape. The World Health Organisation (1) highlights how noise damages humans physiologically, with certain parameters such as impulse and fluctuating noise being particularly injurious. Might noise impact other mammals just as much, particularly those with exquisite hearing? Are injurious acoustic parameters that are within the hearing sensitivity of specific species present in zoo soundscapes, although such facilities may seem quiet to humans? Animals are known to respond to particular aspects of sounds, such as the spectral distribution of sound energy (2). Are certain species held within soundscapes that may not be appropriate for them?

This project develops a methodology to characterize one environment in which the Southern white rhinoceros *(Ceratotherium simum simum)* is held, so that later a uniform method can be used to compare the soundscapes of other such facilities, and eventually to explore any correlations that might become evident between specific acoustic parameters and the health, well-being and reproductive success of the animals within their care.

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2. BACKGROUND

Studies show substantial changes in foraging and anti-predator behavior, reproductive success, habitat selection, vulnerability, longevity, abundance and community structure in a number of species exposed to human-perceived noise (3) and certain laboratory animals exposed to chronic sonic and ultrasonic noise have been shown to exhibit many physiologically similar responses as humans (4).

In general, zoo soundscapes have received little detailed analysis, especially in the infra- and ultra-sonic ranges. Even if they were considered, most hardware and software is optimized to operate within the human hearing bandwidth, and systems capable of accurately recording the entire spectrum are expensive, often poorly understood, and not readily available. Much remains unknown about the auditory sensitivities of species and thus about potential risks to their hearing. Yet captive animals are often exposed to high levels of unnatural noise at frequencies and pressure levels that would never exist in the wild.

A relatively few studies have recorded and correlated ambient zoo noise with the behavioural and sometimes the physiological responses of a target species or of individual animals. Documentation methods have varied in technique, resolution and duration, some simply notating noises heard over short periods. Often they have been just a minor component of a wider focus – such as the search for a range of factors that may stress zoo animals, from the structure of their exhibits and housing, to the activities of zoo visitors. The only study that has examined the ambient noise that zoo rhinoceri have been exposed to appears to be a portion of work on the black rhinoceros in U.S. zoos (5).

Nature is dominated by biophonic (biologically produced) and geophonic (geophysically produced) sounds that are quickly absorbed by soil and vegetation (6). Krause's "niche hypothesis" states that the biophony of any natural place is measurably unique due to its creatures, vegetation, terrain and previous levels of disturbance, with various insects, birds, mammals and amphibians occupying their own bandwidths where there is no competition (7). Animals evolved to vocalize within available niches in the soundscape in order to be heard by others of their kind. They competed for and cooperated for bandwidth as much as for food and habitat (6,8,9). This makes pollution of the soundscape as critical as pollution of food and water, and helps explain why forcing wildlife into a strange habitat often fails—or may cause the demise of an original component of that habitat. Krause was the first to attempt to properly quantify the biological attributes of a soundscape (10), examining many sources of sound across different ecosystems and establishing new research techniques (11). Natural soundscapes are information-rich and directly and indirectly essential to survival (12), being the basis of diverse essential behaviors (13). Urban soundscapes are anthrophonic, with vastly different physical and semantic characteristics and information is buried in the pervasive noise. Sound reflects off hard geometric surfaces, distorts and reverberates. Much of it is infrasonic or ultrasonic, too low or too high for humans to perceive but well within the hearing range of other species. Urban zoos tend to be enveloped in these anthrophonic soundscapes.

So how might the soundscapes of zoos in which rhinos (and other species) breed well, differ from soundscapes where they do not? The first step to finding out is to develop a reliable methodology by which each may be measured and then compared.

3. METHODOLOGY

Following about three weeks of pilot measurements in May and October, this project continuously recorded for a week and is now comprehensively analyzing and documenting the infrasonic, sonic and seismic soundscape around the white rhino enclosure at Fossil Rim Wildlife Center in Texas, one of the few U.S. facilities to successfully breed white rhinos in recent years.

Rhinos have been recorded vocalizing in zoos from 5 Hz or even lower (14) up to almost 8 kHz (15). Anecdotal evidence exists of high whistles of glee (16), suggesting they may perceive infrasonically, sonically and possibly ultrasonically, thus frequencies from 0.1 Hz to 22.05 kHz were analyzed. In addition to acoustic parameters, humans have been shown to respond adversely to vibration. Certain species including elephants and rhinos appear to communicate by stomping their hooves and "listening" to sensations they feel in the ground (17-21). This indicates they are likely to be sensitive to ground vibration. Seismic noise was therefore also considered in this project.

3.1 Equipment

A Roland R26 and two SongMeter SM2+ sonic acoustic recording systems with ten microphones in total, two being Earthworks M23, were used, as located in Figure 1. All were weatherproofed and powered by 12 volt batteries supported by solar panels. They recorded one side of the rhino enclosure intermittently for a ten-day pilot period followed by a week of continuous recording. The latter is the subject of analysis here. Reftek geophysical infrasonic and seismic data acquisition systems with six IML LAX Infrasonic Sensors plus a Geospace GS-11 Tri-axis 10 Hz Geophone were also deployed. An HD Hero 1080 GoPro and a Drift-HD720 video cameras recorded one frame per minute in daylight from each end of the enclosure while a ProWeather weather station monitored local atmospheric conditions to complement comprehensive reports from Weather Underground station KTXGLENR3 at The Overlook education center and café, 1.6km south and 75m above the enclosure. Figure 1 shows the equipment layout. Raven Pro 64 1.5 Sound Analysis Software, Matlab Student 2011, RStudio Open Source, and Microsoft Excel 2013 were used for data analysis.

Figure 1 – Equipment layout at Fossil Rim Wildlife Center

3.2 Study Site

Fossil Rim Wildlife Center is one of six Conservation Centers for Species Survival in USA, renowned for research into the improvement of captive management of endangered species and their further conservation in natural habitats. By combining joint scientific research with joint management expertise, these Centers are creating self-sustaining populations of some of the world's most endangered animals. Fossil Rim comprises about 700 hectares where the majority of 1,100 animals of 50 species are semi-free ranging in large fenced pastures through which the public may drive. It is located in a predominantly rural area in relatively hilly terrain about four miles southwest of the township of Glen Rose, Texas and a little over 70 miles southwest of Dallas.

Fossil Rim maintains a crash of six white rhinos: a bull, four cows and a calf, born in 2011 to the oldest white rhino mother in the country. Their 3.6 hectare enclosure near the main entrance is bound by steel posts spaced wide enough to permit other animals such as blesbok, blackbuck, ostriches and wildebeest to enter freely. A gravel trail invites guests to idle downhill along the western side, while a staff road leads to the southern end and the utilities buildings. On the eastern side is a run about 6m wide and a kilometer long with a 2.5m high wire fence supported by star pickets. Behind this is "no man's land" where dense thorny scrub dominated by mesquite and ashe juniper acts as a wide buffer between the wildlife park and the county road. The recording equipment was placed along this fenceline.

3.3 Challenges and Observations during Recording

In order to keep out of reach of ostriches and park animals on one side, and to be unattractive to deer, coyotes, foxes, raccoons, armadillo and other free roaming creatures on the other, equipment had to be attached on top of three metre star pickets or well back from the fence in sturdy boxes. Ground a couple of metres around each sensor had to be cleared so trees would neither interfere with recordings nor cause acoustic artifacts. Thirty metre cables had to be strung high through the scrub to separate the external microphones as far as possible, in order to obtain a more widely-distributed recording aperture, at seven locations along the approximately one kilometre fence line. It was necessary to cut paths between the trees and over rocks to carry 12 volt batteries, solar panels, ladders and everything else into the sites, which were otherwise inaccessible. Since the intent was to learn what the rhinos hear, omnidirectional microphones were used to sense the soundscape in all directions, apart from the directional XY microphones built into the Roland R26, which faced west and north across the enclosure from about the center of the fenceline. The placement of the sensors reflects the local variation in sounds, particularly higher frequencies which attenuate more rapidly with distance than lower frequency sounds.

The remote location made it difficult to monitor battery levels, data storage capacity and equipment status more than a couple of times a day. It was also difficult not to adulterate the soundscape as occasionally occurred when placing a ladder against unstable fence wire to remove plastic weatherproofing to view the digital screens in bright sunlight high above one's head. In heavy rain and wind this was impossible. In addition, it was necessary to carefully judge when to change SD cards as the area could not be accessed after dark. The recordings were as broadband and high resolution as possible and hence took significant time to download the SD cards onto an external hard drive between maintenance runs. Three days were interspersed with heavy rain and high winds, which made it impossible to change the Roland's SD cards safely, so there were several hours where it could no longer record due to full memory.

Equally concerning was estimating the wind speeds and direction well ahead and determining whether to add additional foam windscreens. Fossil Rim is prone to strong winds that can arise or change direction quickly. One evening after dark, when the recording sites were inaccessible, the wind jumped from calm to 53 kph in about 15 minutes. In calm periods heavy windscreens are undesirable as they reduce the microphone sensitivity. However without screens, high winds cause direct invasive wind noise (IWN), mechanical vibration of the microphones and distortion or possibly total masking of other sounds. It was decided early in the project that since it would be impossible to change windscreens at night or even relatively quickly during the day, it would be necessary to compromise with a standard windscreen at all times, and to note when heavier screens were added to alternate sonic microphones after strong winds were predicted. One of each pair of sonic mics retained just the standard windscreen in the hope of continuing to capture low pressure signals with one sensor leading up to or between the strong winds, while lessening the IWN on the other sensor. Even with the additional windscreen however, the microphones were still susceptible to IWN. The data does therefore include some IWN, most notably on the Roland R26's internal microphones. It was decided to notate but not to remove these sections of recordings as, in part, there are many of them and valuable data about the soundscape could still be heard above or between the gusts. The main impact was usually masking other low frequency sounds. Since the project seeks to examine infrasonic noise as much as sonic, the low frequency wind data remains valuable if it does not cause mechanical buffeting of the microphones. Depending on the wind direction, usually some sensors were impacted while others were not, so comparable and fully viable metrics were generally accrued overall. Clipping was rare, occurring most often when it seems that birds, insects or hail struck the screened microphones directly.

It was interesting how much the soundscape changed according to wind speed and direction. Some sounds from further upwind were only audible during the stronger winds, sometimes just before or after IWN. During later, more detailed analysis, these can be separated out and studied collectively and individually.

Another weather related issue was reduced microphone sensitivity caused by the windscreens when they were wet. In simulated calibration tests, it was discovered that a heavy dew condition on the Roland's internal microphone foam windscreen only reduced the microphone sensitivity by approximately 0.1 dB, but in some cases a soaking wet windscreen could reduce it as much as 3.7 dB. Again, since it was not possible to determine the exact times or rates at which the windscreens became damp or dried out, and the dew-laden sensitivity reduction is essentially negligible, no corrections were made. Note though, that during heavy rains, the recordings likely bear a systematic error, under-recording levels by approximately 4 dB. However the weather data indicates the dew point and precipitation for the area every five minutes, so accounting for these effects could be done in more detailed analysis.

Inaccessibility was an issue for the GoPro camera in particular as its slowest setting was one frame minute, but its battery lasted less than three hours and only one spare battery was available. The batteries could only be recharged in the camera so only about six hours could be recorded at a time. The Drift was powered by a solar supported external battery and energy was never an issue.

Long periods of inaccessibility might not be much of a concern if recording a considerably smaller zoo enclosure since that would probably require fewer sensors and it would not take long to move from one to the other. There may also be more sheltered locations for microphones. Night access may be granted as most zoos have night security staff in the vicinity who are frequently interested in new projects and who may agree to accompany the researcher when necessary. Thus it would be easier to fit appropriate windscreens for changing weather conditions and to avoid disturbing the equipment or adulterating the soundscape to change batteries or SD cards as frequently.

Obtaining low-frequency calibration of the acoustic recorders is difficult. Most manufacturers do not provide frequency responses below 20 Hz. The calibration facility at UT Austin is only capable down to 200 Hz, so they could not be calibrated in-house. The most reliable low-frequency sensor were the Earthworks mics, which bear a factory calibration down to 9 Hz.

3.4 Analysis

In all, about 1.5TB of sound files, photographs and weather data were collected. The seismic and infrasound data have not yet been analyzed, so this paper reports only the preliminary analysis of the acoustic data. Unfortunately acoustic analysis is not yet as automated as other forms of remote sensing analysis, particularly broadband acoustic analysis of entire soundscapes (as opposed to searching for particular sounds such as a species' vocalization). Raven Pro Sound Analysis Software, developed by the Cornell Lab of Ornithology's Bioacoustics Research Program, was initially selected to analyze the data, but it soon became apparent that Raven could not process more than a couple of minutes of this data at a time however, and many weeks were consumed fine tuning various options to maximize the analysis without too much loss of resolution, or the range of measurements. Eventually about 4.25 minutes from a pair of sensors could be measured consecutively without the program becoming unstable on the computer platform available for this project. Matlab was used to convert the Reftek files (a proprietary format used by the seismic recorders) to .wav format for use in Raven.

In Raven, measurements were made in each 4.25 minute selection to calculate the signal energy, average power, peak power, aggregate entropy, average entropy, peak and center frequencies, bandwidth 90% (the difference between the 5% and 95% frequencies), peak amplitude, root-mean-square (RMS) amplitude, the sound exposure level (SEL), and the equivalent continuous noise level (Leq). The interested reader is referred to the Raven user manual, freely available online, for the mathematical definitions of these metrics. The amplitude-related metrics were calibrated for each sensor, and measurements compared. The power measurements have not yet been absolutely calibrated, so relative measurements of power are currently being used. In addition to the automatic measurements, the time series and spectrograms were inspected visually, and the recordings were listened to by headphones. Analysis in Raven is still proceeding in order to determine the broad range of acoustic parameters that may eventually be needed to identify variations in the types of soundscapes, which prove more or less appropriate for particular species.

Certain aspects of the datasets are incomplete or not pristine due to the challenges already discussed .In addition, there were some unexplained intermittent data dropouts from the proWeather station. The weather station was sited atop a star picket, with its power unit and remote sender suspended in bushes below it. The data storage unit was in a substantial weatherproof box some distance away, in another tree, making its own weather readings and receiving the outside data wirelessly. That unit was designed to collect weather observations indoors for later comparison with the outdoor observations, and operated perfectly throughout. It seems that the mounting of the power unit in the bushes below the weather station may have led to its intermittent readings, perhaps due to movement caused by the sometimes extremely strong winds, or perhaps due to animal disturbance. In addition to photos being missed by the GoPro, the Drift video camera froze up inexplicably from time to time, particularly during the pilot period. Batteries and SD cards of different specifications were replaced in the field and data streams largely returned to normal.

4. RESULTS

Fossil Rim proved relatively characteristic of a natural soundscape rather than an anthrophonic one, particularly in the absence of visitors and staff. This is despite some anthrophonic noise being audible much of the day and night. Vegetation and soil likely attenuate much, from lawn mowers and machinery to county and local traffic. Nightly keynotes were clearly visible in the spectrograms, predominantly wind (geophonic); insects, birds, Fossil Rim's and free-ranging animals (all biophonic). Domestic dog barks and occasional domestic cattle vocalizations in the distance could be considered anthrophonic since those species are not found in the rhino's natural habitat. Transportation was another dominant keynote – occasional vehicles on the nearby county road and the more frequent hum of traffic on the Farm to Market Road (FMR) 2 km away, on the other side of a small hill and forest. Generally road noise (the drumming of tyres) from large trucks was discernable on the FMR road more than engine noise.

Depending on the wind strength and direction and the density of air traffic in the Dallas region, there was sometimes a preponderance of aircraft overhead, some too high to be readily noticeable. Jets, turboprops and small piston powered aircraft could be clearly identified from the recordings, at times just two minutes apart but occasionally concurrently. Investigation revealed that 7.4 km east of Fossil Rim's entrance is a major navigation aid, a VOR (Very high frequency Omni directional Radio range device). When so directed, all aircraft approaching the Dallas region from the southwest quadrant must overfly that point, or possibly go into a holding pattern at a nominated altitude, until they can be slotted into an approach for their chosen airport. Overhead the VOR, aircraft are required to turn to a heading of 039° and be at 3350 m within 24 km of the navigation aid, or else to be extremely high (perhaps 9000 – 12000 m) if they do not plan to land in the region. This heading of 039° takes the aircraft to within almost 3 km of Fossil Rim at close to 500 kph and little more than 3,000 m above the terrain. The noise received at the site is only about as loud as traffic on the FMR. One day a small general aviation aircraft flew low, apparently sightseeing to observe the animals. Planes are permitted as low as 150 m above the terrain in this part of the Texas.

Although the soundscape at night has a high ratio of geophonic and biophonic sounds, the nights are not quiet. It is as though some of the insects and animals can then give voice without being masked by anthrophonic noise. In fact the evenings following a loud day (for example Monday 21st) can be louder than most. Coyotes sometimes yip shrilly in the hills surrounding the Center, and many birds are active at night, not only owls and those expected to be nocturnal. Some shriek following a sudden relatively loud noise, followed by some communal chattering.

The prevalence of low frequency noise throughout almost all the recordings was noteworthy. Much has yet to be identified. While each sonic sensor generally recorded similar low frequency bandwidths such as insect and bird niches, they also revealed certain biophonic and anthrophonic activities peculiar to their areas, particularly higher frequency vocalisations and sounds that did not carry as far as the other sensors.

Dominant daytime sound signals comprise recognizable keepers' vehicles and voices, zoo safari bus tours, and maintenance and visitors' vehicles and voices.

Also evident was that the rhinos utilize a far broader band of frequencies than the previously published 5 Hz to 8 kHz (14,15). Vocalisations frequently reached 15 kHz. Once the data from the infrasonic sensors has been further examined a determination of the lower limit can be made.

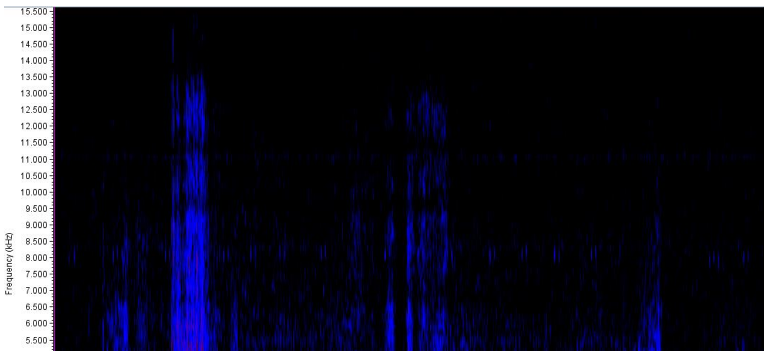


Figure 2 – Rhino vocalizing in a far broader bandwidth than previously published, with acoustic energy visible up to 15 kHz, although it is weak at the top of its range.

4.1 Comparative Snapshots

As an example of how the activities of two days can be meaningfully but simply compared, a summary of Friday 18th and Monday 21st October 2013 are presented (Figures 5 to 8). No precipitation was recorded by the Fossil Rim weather station (see the flat green line in Figure 4), however the acoustic data revealed a brief local rain squall lasting only a few minutes around 5am, and distant rolling thunder just after midnight, around 5am and again around 10:30pm. Shortly before midnight there was the sound of either very heavy individual raindrops or possibly hail striking the microphones nearest the utility buildings.

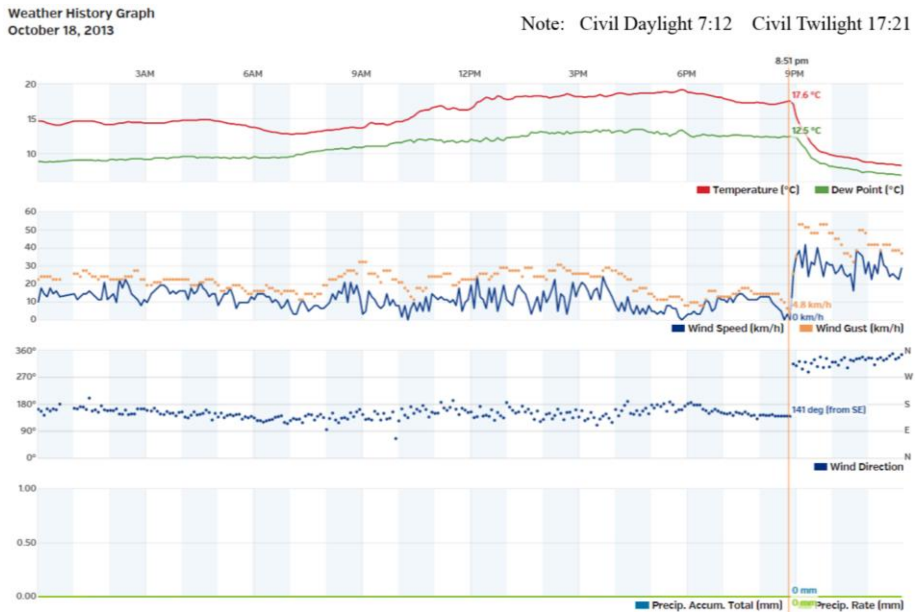
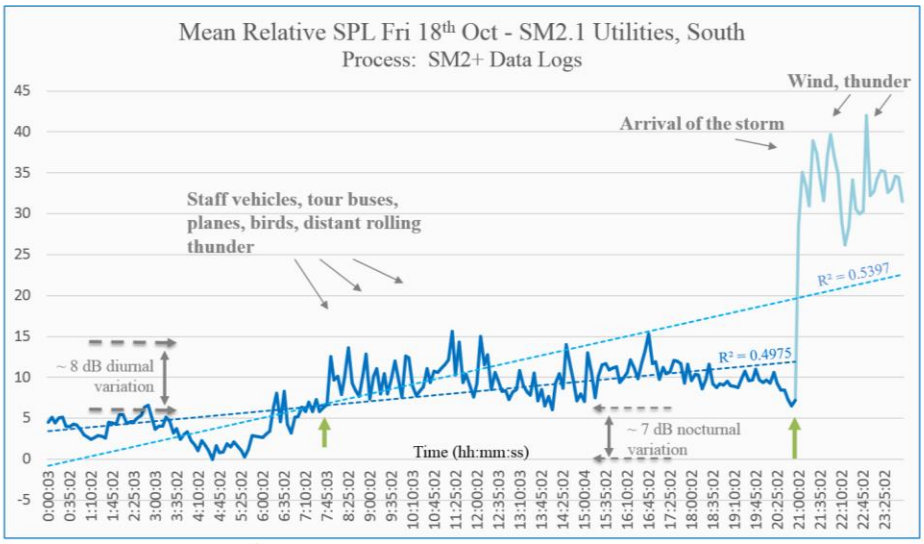


Figure 4 –The 24 hour report from Weather Underground station KTXGLENR3 (22) located at The Overlook, 1.6 km south and 75 m above the rhino enclosure, shows the sudden change when a front hit at 9 pm on Friday 18th (shown by the vertical orange line). Within just a few minutes the temperature (red line) and dew point (top green line) plummeted, the wind gusts (orange dashes) and wind speed (top navy line) jumped from calm to 53 kph and 42 kph respectively, and the wind swung 180° from SE to NW (navy dotted line). All microphones recorded the dramatic change.

Apart from the sudden weather change, Friday appeared to be a relatively normal day at Fossil Rim, with maintenance chores including lawn mowing and weed trimming for much of the time. A number of days were considerably quieter. Monday 21st was the loudest day documented. Following the storms of the week before, the roads around the rhino enclosure were graded and filled. Figures 7 and 8 illustrate the progress of the road crews as they left the utilities buildings around 9:30am and began working from the northern end of the rhino enclosure back towards the south.

5. CONCLUSIONS

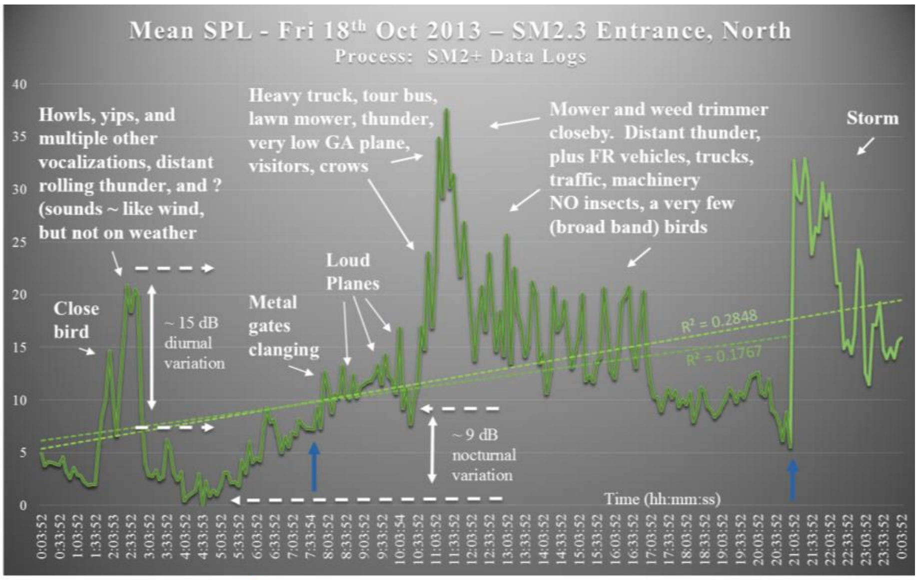
While Fossil Rim Wildlife Center demonstrates a high ratio of biophony and/or geophony at most times and many other characteristics of a natural soundscape, it also shares characteristics of an anthropogenic environment, with almost ever present anthrophony of varying degrees both day and night. Judging from its world renowned record in conservation, this has not prevented the breeding of the species on site, including the Southern white rhinoceros. Few places on earth retain purely natural soundscapes (7). There is a continuum of natural to anthrophonic soundscapes almost everywhere. Future research may seek to determine whether there is a point on that continuum where the well-being of individual animals or species declines, or whether specific acoustic parameters such as the ratio of noise at frequencies at the auditory thresholds of specific species plays a greater or lesser role, if any.



Diurnal Trend: ~ 7:45 – 20:55 (dawn chorus till storm)

	Mean SPL Interval	Trendline	Minimum	Maximum	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
Incl Storm	5 minutes SM2+data log	$R^2 = 0.5397$	0 dB at 4:35	42.0 dB at 22:55	~ 8 dB		10.9 dB	9.23 dB
Before Storm		$R^2 = 0.4975$		15.6 dB at 11:15		~ 7 dB	7.7dB	3.5 dB

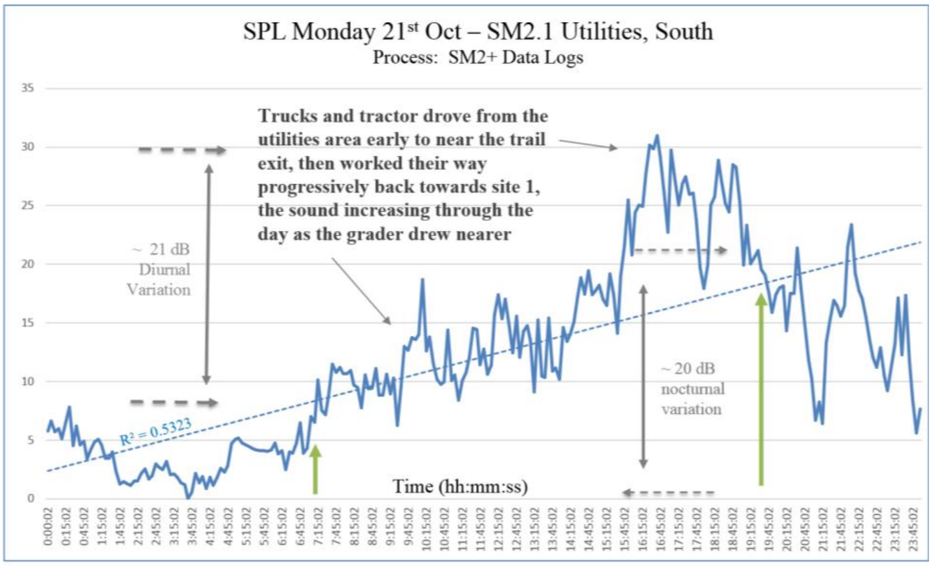
Figure 5 – Following a relatively quiet day near the utilities building, where the loudest sounds were vehicles, aircraft and crows, the 9pm weather front was a major contrast



Diurnal Trend: ~ 7:53 – 20:53 (dawn chorus till storm)

	Mean SPL Interval	Trendline	Minimum	Maximum	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
Incl Storm	5 minutes SM2+data log	$R^2 = 0.2848$	0 dB at 4:53		~ 15 dB		12.4 dB	7.6 dB
Before Storm		$R^2 = 0.1767$		37.6 dB at 11:18		~ 9 dB	11.1 dB	6.9 dB

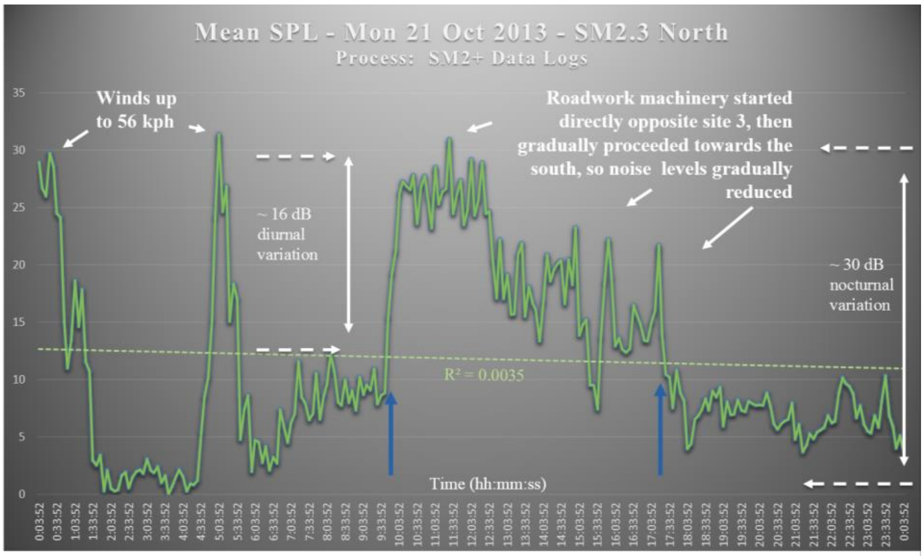
Figure 6 – At the northern end of the enclosure late morning there was simultaneous activity – lawn mowing, heavy machinery, vehicles on the road and entering the carpark, a tour bus, and crows – creating as much noise together as the arrival of the weather front that night.



Diurnal Trend: ~ 7:00 – 19:30 (arrival of utilities crews, to end of machinery and quick end of evening commute)

Mean SPL Interval	Trendline	Minimum	Maximum	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
5 minutes SM2+data log	$R^2 = 0.5323$	0 dB at 3:40	31 dB at 16:40	~ 21 dB	~ 20 dB	12.1 dB	0.9 dB

Figure 7 – The sensors nearest the utilities buildings show increasing noise as the road crews worked steadily towards them throughout the day



Diurnal Trend: ~ 9:30 – 19:25 (start of roadwork, to end of evening commute)

	Mean SPL Interval	Trendline	Minimum	Maximum	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
Incl Storm	5 minutes SM2+data log	$R^2 = 0.0035$	0 dB at 3:38	31.4 dB at 5:03	~ 16 dB	~ 30 dB	11.8 dB	8.2

Figure 8 – The sensors reflect the proximity of the road crews as they progressed from one end of the rhino enclosure to the other.

Understanding the soundscapes to which we expose animals, and their suitability, could lead to modification of the acoustic environment of zoos just as other aspects of exhibits have been developed in recent decades. Even relatively simple analysis such as offered here leads to greater understanding of the issue. Unfortunately thorough analysis is time and labor intensive, but as appreciation of the soundscape within which one operates increases, software advances are sure to accelerate, much as geographic information systems (GIS) and remote sensing have become extremely sophisticated.

Once a reliable methodology has been proven to measure and characterize the sonic, infrasonic and seismic soundscape of a captive animal facility, a wide range of soundscapes can be explored and compared, and associations with the animals' physiological and behavioral status could be explored. Problematic acoustic parameters can then be addressed and ameliorated.

So knowing what rhinos hear in areas where they are held captive and correlating these acoustic parameters with their health, well-being, longevity and reproductive success will teach us to think anew about the implications of soundscapes and guide us to study them not only for endangered species, but for all captive animals in conservation, agricultural and even domestic environments, and for wildlife in parts of the world that are being increasingly encroached upon by man.

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REFERENCES

1. World Health Organisation expert task force. Guidelines for Community Noise. 1999(4/19/2012):1-21.
2. Pater LL, Grubb TG, Delaney DK. Recommendations for improved assessment of noise impacts on wildlife. The Journal of Wildlife Management 2009;73(5):788-795.
3. Barber JR, Crooks KR, Fristrup KM. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology & Evolution 2010;25(3):180-189.
4. Milligan SR, Sales GD, Khirnykh K. Sound levels in rooms housing laboratory animal: an uncontrolled daily variable. Physiology & Behavior 1993;53:1067-1076.
5. Carlstead K, Fraser J, Bennett C, Kleiman DG. Black rhinoceros (Diceros bicornis) in US zoos: II. Behavior, breeding success, and mortality in relation to housing facilities. Zoo Biol 1999;18(1):35-52.
6. Krause BL. Bio-acoustics: habitat ambience & ecological balance. Whole Earth Review 1987.
7. Krause B. Loss of Natural Soundscape: Global Implications of Its Effect on Humans and Other Creatures Prepared for San Francisco World Affairs Council, 31 January 2001. 2001.
8. The Niche Hypothesis: A virtual symphony of animal sounds, the origins of musical expression and the health of habitats. Soundscape Newsletter, World Forum for Acoustic Ecology, Simon Fraser, Univ; 1993.
9. Krause B. Sounds from The Great Animal Orchestra (Enhanced): Air. : Little, Brown; 2012.
10. Krause B, Krause BL. Wild soundscapes: Discovering the voice of the natural world. : Wilderness Press; 2002.
11. Krause B, Gage SH, Joo W. Measuring and interpreting the temporal variability in the soundscape at four places in Sequoia National Park. Landscape Ecol 2011:1-10.
12. Wilson EO. Biophilia. : Harvard Univ Press; 1984.
13. McKenna MF, Mennitt DJ, Lynch E, Joyce D, Fristrup KM. Patterns in bioacoustic activity observed in US National Parks. J Acoust Soc Am 2013;134(5):4175-4175.
14. Baskin Y. The Rhino's Silent Call. Discover Magazine 1992;April(April 1992).
15. Policht R, Tomasova K, Holeckove D, Frynta D. The vocal repertoire in Northern white rhinoceros Ceratotherium simum cottoni as recorded in the last surviving herd. Bioacoustics 2010;18(1):69.
16. Grubic J. June 2003. Personal communication
17. Arnason BT, Hart LA, O'Connell-Rodwell CE. The properties of geophysical fields and their effects on elephants and other animals. Journal of Comparative Psychology 2002;116(2):123.
18. Drake N. Stealth percussionists of the animal world. 2011; Available at: http://blogs.scientificamerican.com/guest-blog/2011/03/22/stealth-percussionists-of-the-animal-world/. Accessed 1 August 2014, March 22.
19. O'Connell-Rodwell C, Hart L, Arnason B. Exploring the potential use of seismic waves as a communication channel by elephants and other large mammals. Am Zool 2001;41(5):1157-1170.
20. O'Connell-Rodwell CE. Keeping an "ear" to the ground: seismic communication in elephants. Physiology (Bethesda) 2007 Aug;22:287-294.
21. Payne K. September 2010. Personal communication.
22. Fossil Rim Wildlife Center Weather | Personal Weather Station: KTXGLENR3 by Wunderground.com | Weather Underground. Available at: http://www.wunderground.com/personal-weather-station/dashboard?ID=KTXGLENR3#history/s2041/e2041/mdaily. Accessed 1 August 2014.