MEASUREMENT AND CHARACTERIZATION OF A SOUNDSCAPE OF CAPTIVE SOUTHERN WHITE RHINOCEROS *(Ceratotherium simum simum)* AT A WILDLIFE PARK CONSERVATION CENTER

by

Susan M. Wiseman, B.A., Grad.Dip.(Bus), M.E.S.

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Committee Members:

John P. Tiefenbacher, Chair

Alberto Giordano

Ronald R. Hagelman

Preston S. Wilson

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DEDICATION

I dedicate this work and my future career to my long suffering, wonderfully supportive, highly knowledgeable and loving husband Monty Suffern and to the five dogs who accompanied me throughout this journey, regularly checking on me at the computer and insisting I join them on their walks in the country to keep my balance and to watch, sniff and listen to the changing world. They and all the dogs, cats, and horses I've loved throughout my life taught me how much can be learned by listening attentively, attuning our ears to the slightest sounds. PupPup also led me away from certain chemicals to which I react. As my service dog she shared my adventures, from occasionally sleeping under a desk when she insisted I was too ill to drive home, to patrolling our recording equipment along the rhino's fenceline. I am so grateful to MrBlue for laughs and his eagerness to take over from PupPup – although she has taught him well, she refuses to stand aside; to Onyx for managing the household with firm but fair expectations of us all; to Goldie for a million wags and the sharpest hearing of any dog I've known; and to Rika for keeping my feet warm under the desk on cold, never ending nights.

I also dedicate this to Dad, whose saddest day was when he was withdrawn from school aged 13 and sent 800 miles from home to a tiny country town and the last job in the banking industry at the start of the Great Depression. Dad longed for education and read every newspaper before breakfast but was never able to return even to high school. His greatest dream was to provide his children the education he missed.

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This research would never have been achievable without the interest, unending support, instructional guidance, and wisdom of Preston Wilson, my outside adviser, let alone without the equipment he so willingly obtained and lent me. When door after door closed due to circumstances outside our control, Dr. Wilson's door always remained open. I will be forever grateful that he made this project possible. I would also like to thank my departmental advisers, in particular the chair of my committee John Tiefenbacher for his guidance and for his patience in reading and commenting on this work. I greatly appreciate the encouragement and insight of Alberto Giordano and Ron Hagelman at the times I needed it, and also of Allison Glass-Smith who so willingly and knowledgeably listened to and advised us graduate students no matter how much time pressure she might be under herself.

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ABSTRACT

Many animals, including the myopic rhinoceros, depend on hearing and smell for navigation and to interpret their environment. For them, the "soundscape" and "scentscape" are equivalent to our landscape. Noise damages humans physiologically, including reproductively, and likely damages other mammals. Rhinos vocalize sonically and infrasonically but audiograms are unavailable. Infrasonic noise tends to be chronic in urban areas, which frequently surround city zoos. Rhinos' biological and social management have been studied but little attention, if any, has been paid to their soundscapes. This project develops a standard by which such soundscapes may be measured, documented, and compared, so that once a wide range of rhino facilities have been similarly investigated, correlations could be sought between their sound metrics and the health and well-being of their animals.

The interests of geographers overlap many disciplines, but the questions raised by, and the approaches of geographers frequently differ from those addressed by the original specialists, so a broader understanding of the soundscape and ways to record it may well add value to acoustic studies while simultaneously deepening geographic knowledge.

This research asks: How can a soundscape of captive southern white rhinoceros (*Ceratotherium simum simum*) be comprehensively measured and characterized? What does doing so inform about their environment of captivity? How can this method be

employed to understand the contrasts of the soundscapes of captivity and natural habitats? To begin to answer these questions, the following goals are addressed:

1. To develop a series of procedures to comprehensively record, measure, analyze, and characterize a broadband white rhino soundscape;
2. To note their vocalizations, and to roughly estimate the bandwidth used by these particular animals;
3. By demonstrating that techniques and language not normally used in the discipline of Geography could broaden its scope and expand the tools available to those investigating their environment, to invite geographers and others from non-acoustic backgrounds to become aware of the soundscape and to pose new questions;
4. To demonstrate how the processing and analysis of the data collected at FRWC can be formulated to characterize the soundscape that their rhinos experience.

This study is undertaken at the white rhinoceros enclosure of Fossil Rim Wildlife Center (FRWC), one of nine U.S. facilities to breed this species in recent years. Fossil Rim's white rhino soundscape was recorded continuously throughout a week of normal park activities by five acoustic, infrasonic and seismic acquisition systems to sense frequencies from 0.1 Hz to 22,020 kHz, and the resultant broadband sound metrics were measured. It is not within the scope of this project to publish all the possible results, but a sample is provided to illustrate the use and effectiveness of the system. Friday 18th

October, 2014 was subjectively analyzed via a sound event log before recordings were processed using Raven Interactive Sound Analysis Software, and by SongMeter SM2+ Data Logs. Data from three infrasonic channels were averaged and preliminarily processed in Matlab, as were the three geophone seismic channels. For perspective, Friday was compared to a preliminary sonic analysis of Monday 21st October. It was ascertained that the FRWC white rhinoceros enclosure retains many characteristics of a natural environment, despite being exposed to some form of anthrophonic noise much of the time. Once a wide variety of rhino enclosure soundscapes have been measured, if relationships are discovered between certain acoustic parameters and the health and well-being of their animals, the soundscapes of other captive species could be similarly examined and acoustic environments could be modified to better suit the species concerned.

1. INTRODUCTION

Many animals 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). If their soundscape varies substantially from one in which they can readily communicate, interpret their environment and operate, this could cause unrecognized stress or, at an extreme or in predator/prey relationships, even death. Nature is dominated by biophonic and geophonic sounds, and soil and vegetation absorb them more quickly than occurs in an environment of impervious surfaces. Anthrophonic urban soundscapes exhibit vastly different physical and semantic characteristics, with reflections from hard geometric surfaces, multi-path propagation and reverberation, and often increased sound pressure levels compared to those in nature, in addition to the dominance of anthropogenic noise.

In 1976, former U.S. Surgeon General William H. Stewart reiterated the World Health Organization's evaluation when he warned that "Calling noise a nuisance is like calling smog an inconvenience. Noise must be considered a hazard to the health of people everywhere" (Goines and Hagler 2007). Goines and Hagler expand on the notion that noise pollution is another form of air pollution that threatens health and well-being and is increasingly severe and ubiquitous, particularly in urban areas. They demonstrate many ways in which loud and/or chronic noise (defined as unwanted sound) has been shown to harm human health. An increasing number of studies suggest that loud noise, especially of high or low frequency, increases the risk of fetal loss and growth retardation. The U.S. Government's Oak Ridge National Laboratory Materials Science and

Technology Division reminds that levels safe for adults may not be safe for children and especially for the unborn (Jankovic and Drake 1996). Little is known about safe sound levels for animals, let alone safe frequency exposure.

It was noted in one Texas zoo that certain white rhinoceri appeared to demonstrate some similar symptoms to humans exposed to chronic or loud noise, despite living in a zoo that generally seems quiet to humans (Wiseman 2009). Does noise harm non-human mammals in a similar manner? Might zoo soundscapes that seem quiet to humans contain noise that is outside the human auditory range but impacts other species? Since zoos are human creations and frequently enveloped within even more-human urban environments, and as such are distinctly artificial habitats for animals, how significantly do their soundscapes differ from natural habitats, and how suitable are these anthropogenic sound environments for captive-born and especially for wild-born animals? Rhinos are under ever-increasing threat in the wild due to poaching and habitat loss, but relatively few are born in zoos, due in part to the large areas and the management resources required to enable natural social structures. Would amelioration of their soundscapes improve captive animals' health, well-being, reproduction, and natural behavior? If so, the effect might not only add conservational value, but also educational value to zoo visitors.

Infrasound travels great distances through air and earth. It travels even further through water. Its long sound waves are less prone to being hindered by physical obstacles. Whales are thought to use infrasound to communicate halfway around the globe. Elephants have been shown to respond to playback calls over 10 km, which explains how widely separated herds synchronize their travel and reunification. Similar coordinated movement by female northern white rhinos has also been observed and it is suspected that they use infrasonic communication similarly, and over similar distances (Langbauer et al. 1991; Baskin 1992; Larom et al. 1997; Personal interview Katy Payne, Elephant Listening Project, Cornell University 2010). All elephant species utilize infrasound. Savannah elephants make most of their low frequency, long distance calls during temperature inversions (The Elephant Listening Project http://www.birds.cornell.edu/brp/elephant/cyclotis/language/infrasound.html (last accessed 5 November 2014)) to potentially expand their listening areas of typical dry season days from about 30 km^2 at midday to 300 km^2 during the evening inversions (Larom et al. 1997). Other species such as lions, coyotes, and wolves that inhabit regions with strong crepuscular and nocturnal inversions show similar calling patterns, and it is thought that dawn and evening choruses of birds, frogs, and insects use atmospheric conditions that influence low and high frequency sound propagation according to their needs (Larom et al. 1997).

All rhinoceros species have been recorded vocalizing in the range of 5 Hz, possibly even lower (Baskin 1992) and up to at least 8 kHz (Policht 2008). By comparison, few human bass singers can reach below 100 Hz, and even a healthy human baby with perfect hearing only responds down to about 20 Hz. So while we may think certain rhinos are living in a blissfully peaceful zoo environment, if there should be a great deal of low frequency transmission near them, it is possible that the animals themselves could be experiencing never-ending noise – it might be comparable to humans being imprisoned in a discotheque. If rhinos and other animals use a bandwidth that is so crowded with noise that their natural communications, including mating and specific-needs vocalizations, are masked, this could cause chronic stress and hinder general well-being and successful reproduction. Von Muggenthaler explains that unlike some other animals, rhinos don't send obvious (to us) physical signals when in estrus (Baskin 1992,). If their infrasonic communication is masked, it is possible that males are not appropriately attracted and prepared. Stress-provoking aspects of captive environments have been implicated as potentially serious obstacles to successful captive breeding programs (Carlstead 1996).

Policht et al. (2008) studied the social behavior of the world's last surviving crash (herd) of the northern white rhinoceros (Ceratotherium simum cottoni) at Zoo Dvur Kralove in Prague, the only zoo where northern whites have ever bred successfully. This crash was eight individuals; one was a hybrid northern-southern white. They identified four classes of infrasonic vocalizations in this group, but questioned the role of infrasonics in signaling communication for either rhinos or elephants, assuming they were simply produced due to their enormous body size. Payne (Payne, Langbauer, and Thomas 1986; Payne 1998; Personal interview Katy Payne, Elephant Listening Project, Cornell University 2010) believes however that infrasonics are an essential component of elephant safety and well-being, enabling extended families to disperse over wide distances to access scarce resources while maintaining regular communication and finely coordinating migration patterns, so they can quickly re-unite at times of danger, distress or when one group discovers abundant food or water. She believes that rhinos use infrasonic communication similarly (Personal interview Katy Payne, Elephant Listening Project, Cornell University 2010). I believe it may be that within the confines of the zoo, rhinos have little need of low frequency, long distance communication so do not use it enough for it to have been studied. (The literature reviewed for this project has only revealed actual rhino recordings within a zoo setting.)

The mission of most modern zoos includes conservation and the education of city dwellers about the species within their care. Many zoos participate in an international breeding program, particularly for endangered species. Due to poaching, habitat loss, disease and other factors, the survival of an increasing number of the world's species relies on their ability to reproduce in captivity. For some species, zoo populations already provide the only remaining examples. The International Species Identification System (ISIS) reports that 82% of mammals, 64% of birds, and the majority of reptile species are now born in captivity (ISIS 2012). Yet some endangered species breed poorly in captivity and are becoming even rarer. Thus understanding all factors that limit captive breeding is more crucial today than ever before. Herd size and composition, the age of potential mates when first introduced or when breeding is enabled, and substrate and enclosure structure have been studied but little attention, if any, has been paid to their soundscape.

Few species of rhinoceri remain in the wild. Today they breed more successfully than previously including in zoos, due to redesigned enclosures, improved crash structure, improved management and diet, artificial insemination and other interventions. Considerable progress has been made in the last few years, but could the soundscape also influence successful reproduction? Do soundscapes differ significantly between captive facilities where rhinos experience greater well-being and health, and /or have or have not bred successfully?

In order to compare soundscapes at different facilities, it is first necessary to standardize a process by which such soundscapes can be comprehensively recorded, measured, characterized, and compared. This dissertation aims to develop such a process that can be readily adapted to other animal care environments, and eventually to recording other species. The first steps are to begin to answer these questions: How can a soundscape be comprehensively measured and characterized for the captive southern white rhinoceros (*Ceratotherium simum simum*)? What does doing so tell us about their environment of captivity? How can this method be employed to understand the contrasts of the soundscapes of captivity and natural habitats? These questions will be answered by analyzing the soundscape of the southern white rhinoceros enclosure of Fossil Rim Wildlife Center (FRWC) near Glen Rose, Texas, where its most recent (and unexpected) captive bred calf was born in October 2011.

The following chapter provides background and explains the acoustic terms and concepts encompassed in this project. Chapter 3 discusses the literature that was reviewed relating to the topic, chapter 4 outlines the conceptual framework and the objectives of the research, chapter 5 describes the research site at Fossil Rim Wildlife Center, chapter 6 the research methods including the way data was analyzed, chapter 7 outlines the results of that analysis, and chapters 8 and 9 provide discussion of the results, and conclusions, respectively.

2. BACKGROUND

Acoustic Terms and Concepts

Acoustics is the science of sound, how it is produced and propagated, and how it is affected by and how it affects the environment around it (ANSI S1.1 2004). Acoustic analysis considers the sound source, the receiver (the hearer of the sound), and the path between them via which the sound travels. Sound metrics are measurable parameters used to characterize and quantify sound events. Standard measurements and processing have been developed to generate many of them in a repeatable manner. This research project will abide by the definitions and recommended procedures published by the American National Standards Institute (ANSI).

Sound waves vibrate through any medium and humans and most mammals are adapted to sense sound in air and/or water. Ambient sound most commonly and easily travels through air and water, exhibiting intensity (in layman's terms often thought of as loudness), frequency (related to musical pitch and timbre), periodicity, and duration. Intensity or amplitude is measured in decibels (dB) on a logarithmic scale that represents the ratio of actual sound intensity to a reference sound intensity. The symbol LdB is sometimes use to stand for the words "decibel level". A 3 dB increase describes a doubling of the sound intensity, but may not be perceived by humans as a doubling of loudness, depending on the frequencies involved. Since humans need more intensity to hear high and low frequencies, the decibel scale is frequently adjusted toward those extremes, resulting in the A-weighted decibel scale (dBA) to indicate the relative loudness of sounds in air as perceived by the average normal human ear. The dBA scale was designed so that 0 dBA represents the lowest sound pressure that a typical young healthy human is able to detect. For mammals, frequency domain representations of sounds are intuitively interpretable as they perform their own spectrum analysis in their cochleae to convert vibrations of the eardrum into neural impulses. Thus we base our auditory perception on a frequency domain representation of sounds (Charif, Waack, and Strickman 2010).

Sound intensity received at a point away from the sound source is generally referred to as its sound pressure level (SPL). It varies according to the strength and frequency of the source emission, its directivity, the distance from the source to the receiver, the sound absorbing terrain, ground cover, and any other media it passes *en route*, as well as the weather (Pater, Grubb and Delaney 2009).

The absolute threshold of hearing, also known as the auditory threshold, is the minimum sound level of a pure tone that an average young, healthy, undamaged ear of any particular species can detect when there is no background noise. Technically, it is expressed as the RMS sound pressure of 20 micropascals at standard atmospheric pressure at 25 °C. It is both frequency and pressure dependent, and in humans is often measured as the quietest sound a young person with undamaged hearing can detect at 1 kHz. Human ears are particularly sensitive to the 1 to 5 kHz range, but in perfect circumstances can detect from 20 Hz to 20 kHz. As humans age the range shrinks, particularly if their hearing has ever been compromised.

In acoustics, the RMS Amplitude is often considered the "effective" amplitude since it can be clearly defined even for complex, non-repeating waveforms like noise, and has physical significance. To measure sounds that are relatively constant, such as from heavy traffic, constant speed machinery, or equipment such as air conditioners, and generally for ambient noise, a filter is often used to provide an equivalent average or continuous sound level (Leq), also known as a constant tone equivalent, over a specified time period such as a few seconds, a work shift, or day versus night. The time period over which the Leq is to be measured can be pre-set and logged at the time of recording, or else can be calculated from finer resolution recordings at the time of analysis. Pre-setting Leq periods simplifies analysis and interpretation, and also significantly reduces the requisite data storage capacity.

Since we do not know the auditory threshold and frequency range of rhinoceros hearing, the unweighted or linear scale of decibel levels will be used throughout this research project in place of the commonly used dBA scale that was optimized for human hearing. This is termed the absolute sound pressure level.

Sound is an essential and dynamic characteristic of virtually every living landscape, even if the sound is as miniscule as in a barren desert on a windless day. Tiny sounds can be as important as loud sounds, but we may have to attune ourselves to hear them. Flying insects, sand-mining ants, a zephyr passing between rocks, a snake slithering – each generates sound and informs about the landscape and its occupants. Sounds often provide information that cannot be collected visually, especially if the producer of the sound is tiny, underground, hidden in foliage, or possibly even invisible (as is wind).

R. Murray Schafer formalized the concept of soundscape to describe the ‘‘auditory properties of landscapes’’ and chose key acoustic terms to parallel visual elements of a landscape (Schafer 1977):

- Soundmark – unique to and characteristic of a place, like a landmark;
- Keynote – heard by a particular community frequently enough to form a background against which other sounds are perceived;
- Sound Signal – that an individual must listen for since it conveys specific information, like a foreground.

Each of these elements may be clouded by or possibly even obliterated by noise (similar to the effect of fog masking a landscape). Noise may damage the perceiver’s senses not only due to physical parameters such as excessive sound levels, duration, and frequencies, but also due to non-physical parameters.

Individuals and communities with compromised physical capabilities (due to older age, disease, or hearing damage perhaps), with varying prior experiences or with different cultural backgrounds may perceive the same soundscape (or a landscape) differently – and experience varying physical and non-physical responses. Thus the interpretation, meaning, and impact of a soundscape depend significantly on the relationship between the perceiver and that environment.

Soundscape Ecology and Acoustic Ecology

Growing out of an interest in the ways musical composition could mimic real life, and exploring how people respond to such sounds, Schafer began to develop acoustic ecology studies in the late 1960s to investigate how people perceive, interpret and are affected by the sounds they hear. Today the discipline largely considers the perceiver's subjective viewpoint and is most frequently focused in social science or the humanities.

Schafer characterized particular soundscapes as the unique music of a place, and demonstrated how the study of sound of a particular environment provides important clues as to the characteristics and activities of those within it. He termed this "Soundscape Ecology" (Truax 1978). Over time it has grown as a parallel to landscape ecology.

Generally, soundscapes are examined for the data they reveal. Reconstructing the soundscape of a past age or environment is considered "acoustic ecological archeology".

Since the acoustic properties of cities affect their residents' quality of life, urban planners have long employed sound engineers, and sound and noise control has become an integral part of urban architecture and urban landscape design. This has helped direct soundscape studies into the realm of more quantitative sciences.

While most nature recordists focus on sounds made by an individual animal or perhaps by a particular species, Krause has long recorded entire soundscapes and analyzed how wildlife makes use of available bandwidths. He terms this work soundscape ecology, and urges that it should be used as a tool to assess the health of marine and terrestrial habitats (Krause 1993). In recent years studies have begun doing just that: using sound assessments as remote sensing analyses are used, as proxies to represent the presence, abundance, health, movements, and behavior of particular species.

Soundscape ecology is now regarded as the study of sound and the way it operates within a landscape, the relationship of sound to the organisms within that landscape, and the spatial and temporal interactions of sounds and their sources. Every landscape has a unique acoustical pattern that changes not only over time and space, but also dynamically according to changes within the environment. That includes changes in the atmosphere, the biosphere, the hydrosphere, and the geosphere.

To describe "wild soundscapes" – those settings in which no modern human-generated sounds are perceivable (note: indigenous people living according to their ancient traditions are considered "wild") – Krause (1993) established a number of terms to reflect the sources of particular sounds:

- Biophony — that portion of a soundscape generated by nonhuman animals;
- Geophony – sounds generated by the physical environment; and
- Anthrophony – those sounds generated by humans.

He explains that soundscape ecology is "based on the causes and consequences" of these three factors within a particular place, and of their inter-relationships (Pijanowski et al. 2011; Krause and Krause 2002).

The first attempts to properly quantify various biological attributes of a biophonic soundscape were undertaken in 2002 by Krause for the National Park Service in Sequoia National Park. He examined many sources of sound across different ecosystems and established several new research techniques (Krause, Gage, and Joo 2011).

Climate, land transformations, biodiversity patterns, timing of life-history events, and human activities all impact a dynamic soundscape and impart a unique sense of its geographic place. Modern soundscape ecology is seen by many to be based on the intellectual foundations of spatial ecology, bioacoustics, urban environmental acoustics, and acoustic ecology; therefore many geographic principles come into consideration. (Note: Bioacoustics tends to study animal communication, generally of a single species or individual, whereas biophony considers the community-level components of a landscape's ecology.) Pijanowski et al. (2011a) include psychoacoustics as a disciplinary component (Figure 1) vital to a potential integrative framework (Figure 2) since the implications of sounds vary according to individual perception and experience.

Pijanowski and his colleagues are participating with other North American scientists in collaboration with soundscape ecologists in Europe and Australia to develop ISO international standards relating to soundscape research. The project is substantially supported by the U.S. National Science Foundation (NSF). This international team recommends that soundscape ecology be taken to a higher level, one that emphasizes the ecological characteristics of sounds, their spatial-temporal patterns and their effects. They suggest that spatial considerations should include the effects of such factors as elevation, latitude, and edge-core situation on acoustical processes. They propose that a research agenda for soundscape ecology should consider measurement and analytical challenges, spatio-temporal dynamics, soundscape linkage to environmental covariates, human impacts on the soundscape, soundscape impacts on people, and soundscape impacts on ecosystems.

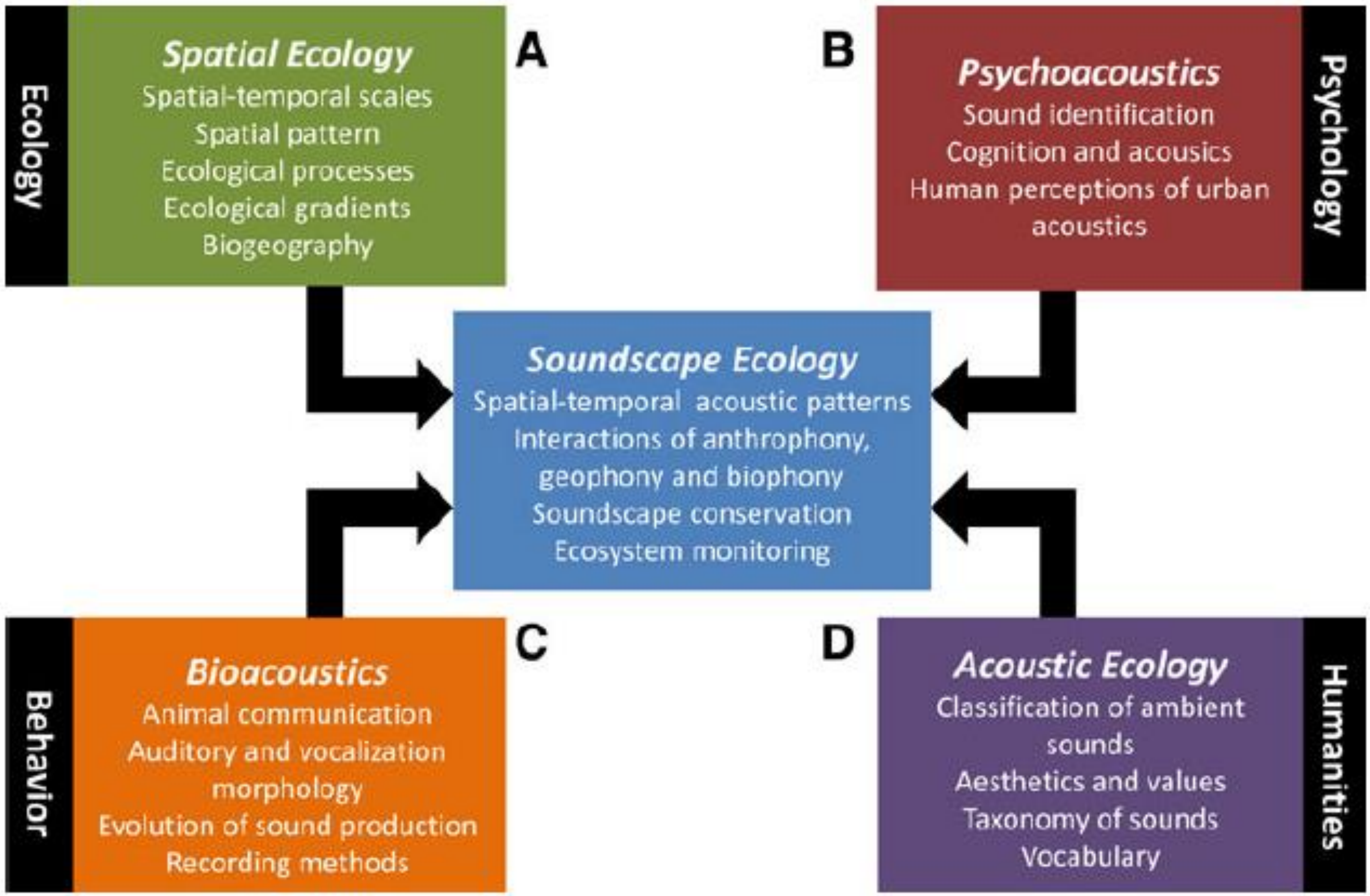


Figure 1: **Intellectual foundations of soundscape ecology**. Colors of the boxes indicate which discipline contributes to the integrative framework contained in Figure 2 (Pijanowski et al. 2011a, 3). Figure used with permission of the author.

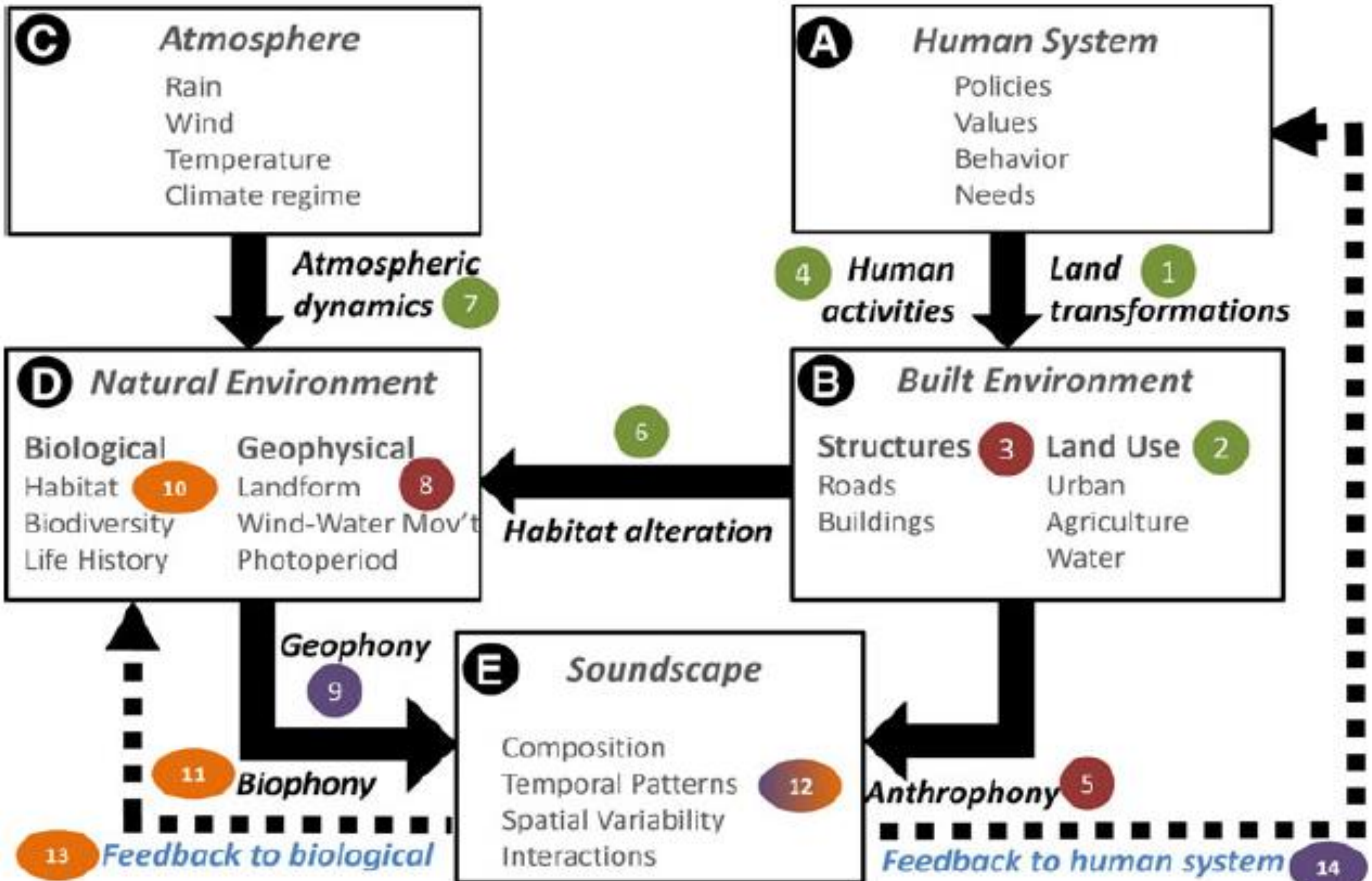


Figure 2: **Conceptual framework describing the underlying processes of the soundscape**. Labels and color coding refer to the information presented in Figure 1 (Pijanowski et al. 2011a, 5) Figure used with permission of the author.

Noise

Noise is unwanted sound, so depends on the viewpoint of individual receivers. Some consider noise a form of air pollution that can be pervasive, may stem from numerous sources simultaneously and in a variety of forms, can be persistent, and unless directly managed locally, generally increases due to population growth, urbanization, and the ever growing use of highly mobile and more powerful equipment.

Transportation noise (especially from highway, rail, and air traffic) is a major constituent of noisy soundscapes. Its sound extends over enormous distances due to the wide distribution of its sources, its low frequency components, and its frequent dispersal across wide open spaces having little vegetation or other barriers to sound propagation, or, in the case of aircraft, through uninterrupted atmosphere.

Not only is transportation noise pervasive, it frequently includes very rapid sound pressure pulses (referred to in acoustics as impulse noise, particularly when the impulses increase the sound pressure repeatedly by more than 30 decibels in less than a second, often within a millisecond). Transportation examples include most forms of engines, helicopter and propeller blades, train and road vehicle wheels in contact with uneven roads, bridges or rail track, and the compression of the atmosphere, which can be appreciated *en masse* when standing in an underground train or road tunnel where the effect is amplified by the closeness of walls. Recreational vehicles often move this noise into otherwise remote wilderness sites along waterways, tracks, and over snow. Transportation noise emissions are rarely regulated sufficiently to counter their increase in quantity, distribution, changes in character, and equipment degradation, so the emissions often increase and spread further afield. Resource extraction is another major source of noise, with similar characteristics to transportation but also including equipment noise from cutting devices, drilling devices, and subsurface displacement.

Maritime shipping noise travels enormous distances through water. Up to ten ships per square degree of Earth's ocean surface can be encountered in regions with heavy shipping traffic (Office of Marine Programs 2011). It has been estimated that the keynotes of northern hemisphere oceans are increasing at an average of three decibels per decade, and are increasingly characterized by impulse noise, low frequencies and vibration – mainly from shipping, oil and gas exploration and drilling, wind farm construction, and to a lesser extent wind farm operation (Malakoff 2010). Early this decade the U.S. Navy estimated that its underwater acoustic activity resulted in temporary or permanent hearing loss for more than 250,000 sea mammals per year, a number that continues to rise. In May 2012, the Navy disclosed draft environmental impact statements for Atlantic and Pacific operations that stated that planned expansions could raise hearing losses to more than one million additional sea mammals annually (Broad 2012). In 2014, a number of conservation organizations began suits against the National Marine Fisheries Services for violating the Marine Mammal Protection act due to their role in permitting a series of planned underwater activities, including open-sea bombing drills and sonar activities, that, by the Navy's own account, will jeopardize millions of marine mammals if the U.S. Navy carries out its plans to increase its sonar training activities by 1,100 percent between 2014 and 2018 above the rate of the previous five years. Because sound waves from these activities travel such long distances and the sources themselves are mobile, many protected habitats and endangered species are likely to be impacted (Nature World News 2014).

Wild soundscape recorder Bernie Krause found while working in remote regions of Africa in the 1980s that it took him an average of 500 hours to successfully collect 15 minutes of quality recordings that do not include intrusive anthropogenic background noise (Krause 1993). Twenty years later he said it was almost impossible even in the middle of the Amazon or in remote Arctic regions to obtain a sufficient gap in anthropogenic keynotes to record entire natural sequences, even short ones, due to mechanical noise, albeit distant, such as from traffic (air, road, snowmobile, or boat) and chain saws (Krause and Krause 2002). The detection of signals in noise is a complex topic, beyond the scope of the present work, but in general, as noise levels increase relative to signals with stationary levels, it will become harder to detect them.

Noise Control in USA

Noise considerations are often further down the list of priorities than other environmental considerations, hence there are many cases where better noise control would result in a healthier environment. Just as the dangers of tobacco smoke are now more readily recognized, so too are the dangers of noise pollution, which has been shown to affect human physical, mental, and emotional well-being, particularly via psychological annoyance, interference with verbal communication, sleep disturbance, disruption of cognitive processes, short term to permanent hearing disorders, and interference with the cardiovascular and endocrine systems (Goines and Hagler 2007).

Both noise and tobacco smoke are unwanted airborne pollutants produced by others, imposed on and shared with communities and individuals without their consent and often against their wills, and at times, in places, and at quantities over which they have no control.

The U.S. Constitution guarantees "domestic tranquility" and every state's laws echo this in some form, but perhaps not defined as the peacefulness that the term suggests. Under the 1972 Noise Control Act, "The Congress declares that it is the policy of the United States to promote an environment for all Americans free from noise that jeopardizes their health or welfare" (U.S. EPA 1972). In 1978 the Quiet Communities Act enabled the Environmental Protection Agency (EPA) Office of Noise Abatement and Control to coordinate federal noise control. Neither act has been rescinded, but funding for their enforcement was withdrawn in 1982. Responsibility was passed to state and local authorities, resulting in widely varying interpretations of the regulations. In many places they are completely ignored. As a result, noise regulation in much of the rest of the world is far more stringent. For example, it was reported that by 1997 "Health legislation laws in most countries forbid pregnant women to work in surroundings with a high noise level (80 dB continuous noise and/or rapid impulse noise changes of 40 dB). As of 2003, there are no such regulations in …the United States" (Michigan State University College of Human Medicine 2003).

3. LITERATURE REVIEW

The term “soundscape” appears to have been first coined by Michael Southworth in 1969. An urban planner, he explored how blind people drew on acoustic properties to recognize and relate to particular “sonic identities” or “soundscapes” of various parts of Boston, and how these varied over time and space (Southworth 1969; Pijanowski et al. 2011). A professor of musical composition at Simon Fraser University in British Columbia in the 1960s, R. Murray Schafer adopted the term then expanded on the concept. He was concerned about noise pollution and the lack of awareness of modern city dwellers about their acoustic surroundings. Musicians, he believed, should constantly and consciously listen to everything around them, but many of his students and audiences did not do so, so he developed classes to help them. He formalized the concept of soundscape to describe the ‘‘auditory properties of landscapes’’ and created terms analogous to those already used to describe landscape (Schafer 1977). His first major exercise was The World Soundscape Project in which he studied the unique sonic characteristics of five European villages. These villages have recently been revisited and their current soundscapes have been analyzed and compared to the same places a quarter century earlier. This appears to be the only case where the same comprehensive soundscape study has been repeated after such a length of time to compare temporal changes (Järviluoma et al. 2009).

To enable more effective discussion and measurement of soundscapes, over the past decade there have been ongoing attempts to clarify and standardize definitions and terms (Schomer et al. 2010), not only in specific fields such as architecture and engineering or within regions, but from interdisciplinary and international perspectives (Schulte- Fortkamp and Kang 2010). Differences in the viewpoints of individuals, including about what comprises useful environmental sound versus noise, about priorities, even cultural preferences are being identified and studied, such as the acoustic character of a typical elevator in Japan being significantly quieter than a typical U.S. elevator. Psychoacoustics is providing a better understanding that a soundscape cannot be simply measured and its data calculated. The perception of the inhabitants of each soundscape must be considered in order to assess the sound quality and effectiveness in context (Genuit 2012). Schulte-Fortkamp (2014 a, 2014b) stresses the importance of interdisciplinarity to appreciate the broad roles of soundscapes and the need for a common language to discuss, as well as measure, varying soundscape techniques. Geographers are appropriately skilled to help draw together and cohesively build on concepts from these fields.

Soundscape Ecology and the Discipline of Geography

While many questions investigated within soundscape science overlap with the interests of geographers, their concern regarding soundscapes has largely remained within acoustic ecology, considering the subjective viewpoint of (human) listeners, and is limited to a largely social science perspective. Porteous and Mastin (1985) even confined the definition of soundscape to “the overall sonic environment”, a very human approach, rather than including infra- and ultra-sonic ranges. They thereby exclude consideration of many of the non-human listeners that may be integral, both as listeners and contributors to soundscapes. They and others considered the soundscapes of particular places, how they vary over space and time, and the feelings they evoke (Schafer 1977; Truax 1978; Truax 1996; Matlessa 2005; Guastavino 2006; Järviluoma et al. 2009; Truax and Barrett 2011). Garrioch (2003) describes the importance of sound, from church bells to town criers, as the key information system within early modern European towns and how it welded inhabitants into an 'auditory community' and how over time the changing role of urban noise reflected changes in social and political organization and in attitudes. A number of studies consider cultural expressions such as music (Smith 1994) as embodying the places where sounds are either created or heard (Smith 1994; Krause 2001; Jazeel 2005; Saldanha 2009). A frequent theme is the intrusion of traffic noise into otherwise comfortable environments (Nilsson and Berglund 2006; Berglund and Nilsson 2006), or subjective comparisons of urban spaces (Kang and Zhang 2010; Schulte-Fortkamp and Fiebig 2006). Acoustic ecologists often undertake sound walks, where perceived variations in soundscapes are noted and may be mapped. These sound walks are sometimes used as a teaching tool, including in geography education, as in the example of Staub and Sanchez (2012).

A few perceptually based social science reports explored how blind people rely on particular acoustic cues to both navigate and to relate to particular places (Southworth 1969, Golledge 1993) but more have incorporated measurable techniques and an approach more aligned with soundscape ecology, pairing acoustic cues with common geographic concepts such as GPS and GIS to demonstrate how technology can assist visually impaired people to find their way (Loomis, Golledge and Klatzky 1998;

Loomis, Klatzky and Golledge 1999; Marston et al. 2000, 2007; Loomis and Golledge 2001; Rice et al. 2005) or with suggestions for urban planners (Marston, Golledge and Costanzo 1997; Golledge et al. 1998). While urban planners and architects tend to incorporate both the perception of noise and physical measurements of sound levels and a number of other parameters, it is generally from an engineering rather than a soundscape perspective. However some focus just on the former (Raimbault and Dubois 2005) or look at soundscapes as an art form, molding and creating them to form a new identity (Blesser and Salter 2007).

Bioacousticians generally focus on the location and vocalizations of certain species and may use acoustics to track, to determine and sometimes to map geographical variation but those like Krause (1987, 1993, 1999, 2000, 2008, 2012), landscape ecologist Pijanowski and their colleagues (Pijanowski and Villanueva-Rivera 2013; Villanueva-Rivera et al. 2011; Dumyahn and Pijanowski 2011; Pijanowski and Farina 2011; Dumyahn and Pijanowski 2011; Pijanowski et al. 2011; Pijanowski et al. 2011; Sueur et al. 2012; Depraetere et al. 2012) measure spatial and temporal variability in the biophonic and geophonic soundscape, some trying to avoid accidentally recording anthrophonic disturbance, and often taking into account in their analysis geophysical features such as geology and soils.

Traditionally geographers have focused on landscape more than on soundscape, and those that have contributed to soundscape science have frequently done so from the perspective of acoustic ecology, the social sciences, and human perception. However geographers could just as readily contribute insights and skills and many of the spatial measurement techniques and concepts on which soundscape ecology has been built. There is great scope for interdisciplinary collaboration.

Impact of the Soundscape on Humans

E.O. Wilson suggested that the natural world is the most information-rich environment, not only for animals but also for humans (Wilson 1984). People who grew up in rural areas or natural habitats value and carefully and constantly monitor their soundscape since it provides invaluable cues that may lead to success or failure, possibly even directly or indirectly to survival.

In contrast, Schafer (1977) asserts that urban soundscapes contain little acoustic information. This is a function of many factors, including ubiquitous masking noise, building designs that insulate people from the outside environment, and the repetitive nature of machine-made sounds. He suggests that people therefore find the soundscape is not worth listening to. Due to the emergence of so much noise since the Industrial Revolution, the lack of valuable audio content, and the inability to accurately decipher valuable sounds that have been masked by noise, urban dwellers now block out the majority of sound from their consciousness and instead rely more on visual cues.

Sounds of nature emote strong responses in humans, whether they indicate things that are desired (as are the pleasant, gentle, rehabilitative sounds of natural features like small waterfalls) or feared (such as sound generated by a hurricane or wildfire). The U.S. National Park Service recognizes that visitors desire and expect healthy natural soundscapes as part of their park experience, and aims to “restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise)" (National Park Service 2006). The FAA and commercial operators have redirected many flight paths to reduce disturbance in the most highly rated soundscapes of national parks and wilderness areas, such as at the Grand Canyon. Military exercises, however, are normally carried out over less populated areas (and therefore often over natural areas), as are tourist helicopter and light aircraft sightseeing flights and motorized boat cruises. These are often undertaken closer to the ground or to the water's edge and may be far louder than commercial aircraft overflights. Endangered species and non-endangered wildlife are rarely factored into noise management.

Like the animals they hunt, indigenous people rely for survival on audio information about their surroundings as much as on visual cues. Members of the Jivaro tribe of the Amazon Basin could be blindfolded and taken at night to any part of their known territory. Just by listening to their surroundings, they could discern subtle acoustic differences within mini-habitats and accurately identify their location within a forest to within 20 m^2, despite many areas appearing to contain the same biological and geological elements (Krause 1993).

For more than fifty years, the World Health Organization (WHO) (1999) has published warnings about the most common impacts of noise on human health, summarized here in seven categories. The young (including fetuses), the elderly, and those in poor health suffer the most severe symptoms:

1. Hearing impairment, including reduced threshold of hearing – related to sound levels, frequencies, and the period of exposure;

2. Interference with communication – causing misunderstanding, fatigue, irritation and thence stress and difficulty in concentration. The signal-to-noise ratio should be at least 10 dBA to ensure effective human communication (Evans and Lepor 1993 in Babisch 2005);
3. Significant physiological disturbance during sleep, despite the sleeper not waking – resulting mostly from low frequencies, fluctuating noise, vibration, and chronic noise of even 30 decibels (the equivalent of a quiet whisper about a meter away);
4. Cardiovascular disturbance – when disturbed by a sound our endocrine and autonomic nervous systems trigger physiological reflex responses, even during sleep or sedation, resulting in cardiovascular disturbance and disease that can be temporary or permanent, and can vary in symptoms and severity according to the sex and age of the hearer;
5. Impaired task performance – including impaired attention span, problem solving, learning ability, memory, cognitive and language development, feelings of helplessness, heightened stress hormones and blood pressure despite resting, and reduced immunity;
6. Negative social behavior and annoyance reactions – including anger, depression and exhaustion – that are similar to the effects of physical stressors, and increase significantly when accompanied by vibration, low frequencies, and impulse noise; and

7. Mental health – while noise has not been shown to be a sole cause of mental health issues, it does accelerate and intensify any latent problems, and certain sound parameters are significantly correlated with physical stress, headaches, emotional instability, argumentativeness, sexual impotence, mood changes, social conflict, increased accidents, and earlier death.

Goines and Hagler (2007) reported that more than 5000 citations in the National Library of Medicine relate to adverse health effects of noise. Even if a noise does not occur at a level harmful to the auditory system, it can still be perceived by the body (human or animal) as a danger signal, and this is true whether one is awake or asleep. While we may close or avert our eyes, we can't (without technology) close our ears. Twenty-four hour hearing is a survival mechanism shared by all animals. Even when people don't wake and don't think their sleep has been disturbed, their bodies usually respond with "flight or fight" and other psychophysical responses as reflected by the central nervous system, and by hormonal and vascular changes that can have far-reaching short- and long-term consequences (Babisch 2005).

A recently discovered impact of the soundscape is a link between the auditory sense and olfactory and taste sensations. Woods et al. (2011; Restaurant noise can alter food taste 2014) reported that sensations of sweetness and saltiness increase in quiet ambient sound and drop markedly in loud noise (such as in aircraft, where it is therefore almost impossible to avoid food tasting bland), while crunchiness is heightened in a loud environment. They also found a relationship between the degree to which those surveyed enjoyed the background sound, and the degree to which they enjoyed the food they ate. (Crisinel 2010) reported that study participants associated sweet odors to high-pitched music, and bitter odors to low pitches. This work was recently extended by Oxford University Crossmodal Laboratory (2014) which provided cinder toffee (sometimes known as honeycomb toffee) to study participants. According to whether high or low frequencies were played while they ate, the same food item was rated as sweet or bitter, respectively.

Since humans respond negatively to noise, and various other animals – especially those housed in laboratories – have shown evidence of similar responses to certain exposures, it is possible that rhinoceri and other mammals experience the negative effects of noise in a like manner. It may be worth investigating whether sound could impact their diet – possibly the plants they choose to graze on and thereby their nutritional status.

Impact of the Soundscape on Animals

Ambient sound is a central component of natural habitats (Gray et al. 2001). It provides continuous information about conspecifics and other species, potential prey and predators, weather and changing environmental factors, and is essential to wildlife survival. From wild born to domesticated animals, there is no adaptation to stop their constant auditory surveillance.

Ungulates and some other animals are very sensitive to ground vibrations, and in fact use them as a method of communication, particularly in times of stress or when locating other members of their species. When "listening" in this way, animals tend to stand with their weight on a single foreleg straightened to maximize the seismic vibrations running directly from their hoof up connecting bone structures to their skull. With the other front hoof they may stomp out a message to communicate their location (distance and direction), and warnings of threats unseen by others. It is believed that rhinos and elephants may communicate over enormous distances in this manner, and are extremely sensitive to ground vibration (O'Connell 2000; O'Connell-Rodwell, Hart, and Arnason 2001; Arnason, Hart, and O'Connell-Rodwell 2002; O'Connell-Rodwell 2007; Personal interview Katy Payne, Elephant Listening Project, Cornell University 2010; Drake 2011).

Sound of various frequencies and amplitudes is an established tool that humans and non-human animals use to attract or to herd prey, or to ward off threatening approaches. Sound that is difficult to bear is still used as a human weapon of war, causing disorientation or even the collapse of opponents. Some sounds automatically instigate an animal's "fight or flight" response, either way altering their adrenalin levels, energy budget, and causing stress, which over a long period of repeated exposures can severely impact health. Sounds that are not direct threats but evoke similar response in animals, also cause stress and may alter health if they occur too frequently.

Apart from communication, hunting, and avoiding predation, animals also use sound to navigate and locate resources. Homing pigeons are now believed to use infrasonic keynotes and soundmarks that travel thousands of miles, such as the sound of the ocean as heard from distant mountain ranges, of waterfalls, or today of traffic on highways (Hagstrum 2013).

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.

> In healthy habitats, certain insects occupy one sonic zone of the creature bandwidth, while birds, mammals, and amphibians occupy others not yet taken and where there is no competition. This biophony…serves as a vital gauge of a habitat's health. But it also conveys data about its age, its level of stress, and can provide us with an abundance of other valuable new information… (Krause 2001)

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. A species that could not find a sonic niche of its own in one place would not survive there (Krause 1993). Krause likens the result to a symphony of natural voices, each species acting as one type of instrument. The natural soundscapes of equatorial, rainforest, and desert regions today retain the greatest cohesion and structure (Krause 1987).

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 causes the demise of an original component of that habitat. When the niche hypothesis was first suggested, it encountered much controversy, but as noted practitioners like E.O. Wilson came to strongly endorse it, it has broadened the scope of evolutionary biology – and I would argue it should broaden biogeography also.

In nature, soundscapes are loudest in rain forest habitats as they support an abundance of wildlife among rich vegetation with leaves that rustle in the wind. In riverine habitats soundscapes are moderate as they also support leafy vegetation that can rustle, and may have an audible water source and considerable wildlife. Sound levels peak at times when birds and insects are most active. In savannah habitats however, sound levels generally remain low apart from during storms and floods, or when a predator catches its prey – although even then many animals remain almost mute. In a study of habitat acoustics and primate communication, it was discovered that ambient noise levels rose in a rainforest habitat from 27 dB at 06:00 to 40 dB at 15:00, in their riverine study area from 27 dB at 06:00 to 37 dB just an hour later, but dawn was significantly quieter in the savannah with 20 dB although it rose to 36 dB at midday due to wind (Waser and Brown 1986).

Studies reveal substantial changes in foraging and anti-predator behavior, reproductive success, habitat selection, abundance, and community structure in response to noise (Barber, Crooks, and Fristrup 2010). It has been shown that species that suffer from predation in the wild are especially prone to distress in response to unpredicted, high amplitude noise (Meyer-Holzapfel 1968). An increasing number of studies report alterations in animal behavior, health and well-being, reproductive processes, vulnerability, and longevity when exposed to either chronic or extreme noise. The impact of anthrophonic noise is increasingly investigated, particularly as it impacts urban wildlife, birds, and marine mammals, the latter enjoying substantial assistance from naval research grants. Even lobsters have been shown to stop feeding or to flee the noise of small, remotely operated vehicles (Spanier, Cobb, and Clancy 1994).

Swaddle (2012) noted birds' reduced reproductive rates in areas of high noise. In his Virginia study, 35% more bluebird chicks died in the nests most exposed to the sound of road traffic and other anthrophonic noise, than did those in nests in the same community but exposed to lower sound levels. It is hypothesized that the parents cannot hear the young begging and are less prompted to return to them quickly with food, or perhaps some parents become disoriented and do not immediately find food and their nests, or are possibly more cautious and therefore slower to return.

Creel correlated glucocorticoid enzyme stress levels in elk and wolves to snowmobile noise in Yellowstone and Voyageurs Parks (Creel et al. 2002). With wolves in Yellowstone, over the period of time that snowmobile traffic increased 25%, stress enzyme levels increased by 28%. Conversely, within Voyageurs Park, a 37% decline in snowmobile traffic between 1998 and 2000 correlated to a drop of exactly the same percentage in stress enzyme levels over the same period. These statistics are found to be comparable in elk (Krause 2001).

Whales use sound to find, follow and entrap prey as well as for communication, feeding, calf rearing and mating. In addition to causing generalized stress, noise is also believed to affect cetacean development and immune system health, and to cause populations to abandon valuable breeding or feeding grounds, possibly forcing them into conflict with conspecifics (Hildebrand 2009; Weilgart 2007).

Strandings and mortalities of beaked whales have in many cases been conclusively linked to noise events such as naval tactical sonars and seismic surveys, even when these were not considered to be loud enough to damage hearing. Thus even transient and localized acoustic impacts can have prolonged and serious population consequences (Weilgart 2007). Marine mammals live in an “acoustic-dominant world”, using sound as their primary means for interpreting and operating within their underwater environment. Chronic background noise for them would be like us living in a constant fog, with certain noises being the acoustic equivalent of a blindfold, completely masking vital information (Grossman 2010).

Similar findings have been reported in a number of bird and amphibian studies (Krause 1999). For terrestrial animals like rhinoceri that have limited vision and so rely on their soundscape, the same may be true.

Even domesticated animals start or may flee from unexpected, loud, or impulse sounds and from particular frequency ranges and vibrations – from similar sound qualities in fact that cause problems for humans. Pet owners can testify that many of the symptoms described by the WHO are evident in their own animals when exposed to chronic or extreme noise such as loud busses or trucks, during fireworks or thunder, or in earshot of a rifle range.

Brumm and Slabbekoorn (2005) claim that communication is the foundation upon which all social relationships between animals are built. The majority of communication is acoustic, and since this can be considerably impaired by environmental noise, some animals have evolved adaptations to counteract its masking effects, just as people have to shout or select different words to express themselves (Brumm et al. 2004).

When conspecifics cannot communicate due to masking of critical vocalizations, birds, primates, cetaceans, rodents, whales, and some other mammals have been observed to shift their vocalizations to another bandwidth, to alter their calls, to drop parts of their messages, and vocalize louder. However these efforts demand greater physical, emotional and intellectual energy which reduces their budgets for normal activities such as feeding or nursing, and yet they frequently *still* do not manage to convey their full intended message. This may have added significance if community members miss urgent information, or in breeding selection where the best mating calls are a major component of partner attraction. Some species abandon nests or valuable feeding grounds, partners and prime habitats due to noise ranging from even “quiet” white noise (which masks all frequencies) such as air conditioning fans, to periodic noise such as aircraft overflights, trains passing, or recreational vehicles 10 km away. Birds with lower frequency calls abandon areas exposed to low frequency noise (Barber, Crooks, and Fristrup 2010; Creel et al. 2002; Radle 2007; Pijanowski et al. 2011; Stone 2000). In these cases, it is unlikely they will find a suitable nesting place or habitat elsewhere, and are likely to come into conflict with those already residing there, who are likely to view the newcomers as invaders and threats to their food supply and other resources.

As noise impacts humans, so it apparently similarly influences non-human animals. Setting safe sound levels for humans is controversial (permissible levels in Europe and USA differ markedly), but far less is known about safe sound levels for other species. Clinical studies have revealed hearing loss in animals exposed to loud or chronic sound in laboratories, particularly in the young that are born there. Lab animals register blood pressure increases in response to noise, even during sleep or sedation (Song 2008). While some levels and frequencies have already been found unsafe, actual safe levels are generally unknown, and will vary from species to species.

Absolute levels of sound generated by machinery are unparalleled in natural environments. Rarely does nature produce similarly powerful amplitudes apart from a few immense waterfalls, earthquakes, massive storms, volcanic eruptions, or other extreme natural events – and those are all circumstances to be feared and avoided.

Natural soundscapes are dominated by biophonic and geophonic sounds. Urban soundscapes are dominated by anthrophonies with very different physical and semantic characteristics. As such, each is likely to result in distinctly different responses from the animals within them.

Not only are sound sources frequently unseen or unrecognized by captive animals, and sound levels are increased in urban environments, but sounds change characteristics after propagation due to the effects of irregularly shaped solid structures and large expanses of hard reflective surfaces. Long sound waves wrap around structures and continue in a distorted fashion, while short sound waves may be partly absorbed and/or reflected in different directions. In nature, sound tends to be absorbed and dissipated by vegetation and the soil. Thus the acoustic parameters of signal persistence, reverberation, and signal-to-noise ratio around an urban zoo are also markedly different from those recognized in nature (Kight, Hinders, and Swaddle 2012).

Recently researchers at the University of Missouri-Columbia reported that not only do animals respond to sound stimuli, even plants produce defense mechanisms when exposed to recordings of insects such as caterpillars munching on leaves. Yet when exposed to different vibrations, such as a breeze or even the sounds of other insects that share some acoustic features with caterpillar feeding vibrations, these plants did not increase their chemical defenses, indicating that plants are able to distinguish threatening sounds and vibrations from other common but safe sources" (Plants Know the Rhythm of the Caterpillar's Creep http://www.npr.org/2014/07/08/329884061/plants-know-the-rhythm-of-the-caterpillars-creep 2014; Plants Fight Harder When Feeling Fear http://www.counselheal.com/articles/10324/20140702/plants-fight-harder-when-feeling-fear.htm 2014).

Impact of the Soundscape on Captive Animals

Animals have no capacity to avoid unwanted sound except to flee from it. Captive animals can't move past their confines to avoid or to investigate the source of sounds to determine their meaning. In humans, unrecognized, uncontrollable, worrying, or feared noises cause the greatest stress responses, so this may also be the case for non-human animals.

Some animals will never see the source of many of the sounds they perceive in captivity, and may never be in a position to link positive emotions to them. The recognized sound of a friendly keeper's wheelbarrow bringing fresh food is likely to develop good connotations, but the sudden shrill high frequency reversing alarms of unseen trucks may always create fear and possibly even physical pain to some ears. For human safety, these alarms are generally mandated to exceed 90 or even 100 dB, depending on the state. Since many zoos are near public greenspace, they can be exposed to concerts, and to fireworks displays that may exceed 120 dB at numerous frequencies, especially low ones. Other common sounds are lawn mowers and maintenance tools, small construction equipment, pressure washers and floor scrubbers, the continuous hum of air and water pumps, fans, air conditioners and heaters.

Exhibit equipment that invades the soundscape of animals with higher hearing thresholds than humans includes computer monitors, closed-circuit security cameras, television, and fluorescent lights. They all produce constant ultrasonic hums. Sales et al. (1988) reported that 24 of 39 pieces of common zoo equipment added over 60 dB of sound at ultrasonic frequencies. Similar laboratory equipment has been found to produce in excess of 75 dB at over 60 kHz and in closed, reflective environments (Milligan, Sales, and Khirnykh 1993), and cleaning equipment in combination with ventilation appliances have been measured at over 100 dB (Sales et al. 1988). Animals held in these captive spaces usually cannot escape the noise, nor are they likely to gain relief from these sounds. It is generally unknown whether the hearing of these captive animals has been damaged.

Typical zoo animals that hear ultrasonically include hummingbirds, rats and mice, prairie dogs, bats, squirrels, some species of fish, dolphins, orca, hamsters, canids and voles. Infrasonic detectors are so far known to include elephants, rhinoceri, giraffes, cassowaries, hippopotami, pigeons, tigers, chameleons, alligators, moles, prairie dogs (which have an exceptionally wide hearing range), and okapi. Ground-burrowing animals like mole rats are particularly sensitive to seismic vibrations that humans cannot detect, relying on these for navigation, to hunt, and to avoid predation. When these tiny vibrations are masked by earth tremors – or by resource extraction, distant explosives, trains, or road traffic on uneven surfaces and especially on bridges, these animals may become disoriented and vulnerable to predators that rely on sight rather than sound or vibration (Narins and Willi 2012). Relatively few animals have been tested to determine their hearing ranges and seismic sensitivity, so the list above is likely to increase as further research is undertaken.

Another consideration for zoo directors must be the proximity of prey species to their natural predators. Many zoos locate animals from a particular region together to form artificial habitats, such as an "African Savannah" or "Amazon Rainforest." While this can seem logical and educational to humans, it may cause additional stress for the potential prey. Gibbons at Cameron Park Zoo that had never seen snakes, shrink from the smell of a snake skin (personal experience at Cameron Park Zoo, 2003). Captive (and protected) crows and mice act defensively at just the sound of raptors (Hauser and Caffrey 1994). Recently even plants have been shown to demonstrate stress when exposed to the recorded sound of caterpillars eating leaves.

While some species appear to adapt to some extent to increased noise levels, such as pet dogs habitually barking louder and more frequently than normal if they were raised in a noisy environment (Dehasse 1994), in other species it is apparent that sufficient adaptation is either not possible or has not taken place, as in parents not feeding chicks that they can't hear sufficiently when the chicks' frequencies are masked by anthrophonic noise (Swaddle et al. 2012). This can result in death for the chicks – or at least malnourishment, reduced immune systems, and greater vulnerability to predators.

In recent years, animal caretakers have started to use sound to help and comfort some captive animals, or to make them more productive. Studies show, for example, that certain types of classical music cause cows to relax and produce more milk, other types of music such as rock result in less milk (North and Hargreaves 2009). Recordings of young calves vocalizing also serve as a bioacoustic tool to increase milk production (McCowan et al. 2002). Specific types of music have been shown to calm a wide variety of animals, both wild and domesticated. Shelters and veterinarians have started using animal-specific music for those within their care, and have recognized an improvement in both desired behavior and in the animals' well-being and immune systems (Wells, Graham, and Hepper 2002). Music therapy for dogs is becoming popular, with specially composed and/or re-interpreted music becoming widely available to help them calm during periods of excitement or fear (Leeds and Wagner 2008). A tourist operator in Australia discovered certain music, such as AC/DC hits, attracts great white sharks without them becoming aggressive, and considers this more sustainable than throwing berley, which also attracts many other species and causes them to be attacked by the sharks (Australian Geographic 2011).

Ambient Noise in Zoos

Krause argues that audio media is potentially one of the most important, yet most overlooked elements of exhibit design for public spaces, especially zoos. No other single element is likely to

> …convey a sense of place like well-executed sound in an acoustically controlled environment…. Play the sounds of a tropical rainforest, with jaguars prowling and birds flying overhead, and it will evoke a sense of drama, place, and dynamism that no single graphic or visual component is capable of – and at a fraction of most traditional exhibit budgets. … Sound design is both a science and an art. … Well-conceived soundscapes in public spaces are acoustically

> planned with respect to the architecture of the space. They are biologically and culturally informed and designed to engage the public and deliver a compelling illusion – one in harmony with the overall goals of the venue. (Krause 2004, 14)

Not only will zoo visitors become more engaged and better educated about the exhibit, the animals that must live within the soundscape day after day will enjoy a more natural and pleasant experience.

Krause and some others have carefully analyzed the content and purpose of certain zoo exhibits, their structure, design and their wider environments, and installed meticulously controlled playback systems so zoo visitors can hear how a species' natural environment should sound, varying temporarily and spatially (Krause 1989). Excellent examples are at the South Carolina Aquarium (Charleston), and at Disney's Animal Kingdom.

In general however, zoo soundscapes have received little detailed analysis, especially in the infrasonic range. Even if considered, most hardware and software is optimized to operate within the bandwidths best heard by humans and systems capable of accurately recording the entire spectrum are expensive and not readily available.

Despite the considerable attention that biologists and zoologists have focused on the audio-vocal behavior of animals since the auditory sense is so critical to animal survival, much is unknown about the auditory ranges and sensitivities of most species and therefore, about the potential risks to their hearing. Yet most zoos produce high levels of unnatural noise at frequencies and pressure levels that would never exist in the wild.

A relatively small number of studies have recorded and correlated ambient zoo noise with the behavioral and sometimes the physiological responses of a target species or of individual animals. Recording methods have varied in technique, resolution and duration, and have often 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. Frequently the accuracy of equipment outside the normal range of human hearing has not been reported (or even assessed?) and in fact ultra- and infrasound have not generally been considered unless the recorded target species was known to use spectrum extremes, such as bats and elephants. However even then, most recordings have been of the animals themselves, rather than of their ambient surroundings.

The simplest technique remains an established “scan and notate” observation method that requires the investigator to note the environment and the animals’ behavior at fixed time intervals or whenever a certain situation occurs (such as a certain sound). Usually a single investigator must adhere to a firm self-imposed system and definitions or their work will develop a subjective bias and their notations will vary as they fatigue or over time. Due to the concentration involved and the difficulty in standardizing interpretations and sharing the workload, such studies tend to be of short duration.

An example of this method was a study of whether noise from the construction of a neighboring exhibit affected the behavior of three snow leopards at Basel Zoo. Their behavior and location were noted at one minute intervals during study sessions, as was whether the researcher determined the construction noise level at the time to be simply “noisy” or “quiet”, which seemed to be determined by whether listed machinery was being used during each observation. Noise from visitor and general zoo activity was not considered at all, as that was deemed unlikely to have changed from the norm (Sulser, Steck and Baur 2008).

In order to be less subjective, some sort of data logger – usually an SPL meter – can be utilized to determine ambient sound. These typically sample frequencies and sound pressure/amplitude, and may average these samples over a set period of time, for example over 30 second or one hour intervals.

Ambient noise may be sampled as a reference when the main purpose of a study is to record something specific without the aid of a soundproof studio, such as in determining an animal’s range of vocalizations or audiogram. Once it can be determined if the ambient noise frequencies directly overlap with the vocalization or with an intended sound stimulus, the risk of a possible masking effect can be assessed (Stansbury 2011).

Another purpose of recording ambient zoo sound has been to assess noise disturbance to a specific species or individuals, particularly if the animals are endangered and do not breed well in captivity. This testing has most commonly occurred during zoo reconstruction periods.

In a study of the effects of zoo visitors on the behavior of white handed gibbons at two Canadian zoos, sound levels immediately in front of their exhibit were sampled when visitors were present, and simply classified as either background noise level #1: 55 to 65 dB, level #2: 65 to 70 dB, or level #3: >70 dB. Amplitudes were shown to vary 60 to 65 dB at the Metro Toronto Zoo, and 55 to 65 dB at Ontario’s Bowmanville Zoo. Frequencies were not assessed (Cooke and Schillaci 2007).

A much longer and more sophisticated study was undertaken over four years at San Diego Zoo's Center for Reproduction of Endangered Species, focusing on a pair of Giant Pandas. This sought to determine whether short, loud bursts of noise were more disturbing than daily average levels, and whether frequencies were relevant to their behavioral and hormonal stress indices. The average noise amplitude was recorded across three bandwidths at least five days a week during various stages of the female's reproductive cycle, in conjunction with physical observations and hormonal tests. Only days of high or low ambient noise were included in the final analysis (Owen et al. 2004). At the end of four years of such monitoring, it was determined that anthropogenic noise may impact the Pandas' breeding and that ambient noise can have prolonged impact on stress indices. Behavioral distress resulted from even brief loud noise, especially while the female was in estrus or lactating, while longer lasting but even moderately loud noise resulted in more glucocorticoids being excreted. Loud low frequency noise had the greatest impact.

A similar method was used to assess the stress caused to another pair of Giant Pandas during the four month construction of a new exhibit at the Smithsonian Zoo in Washington in early 2003. Sound levels were measured and the pandas' behavior and cortisol levels were compared on construction days versus non-construction days. The mean amplitude each minute of the sampling periods was logged, resulting in levels from 30 to 110 LdB. The total amplitude over the entire broadband spectrum, as well as that of discrete frequency bands within the range of 516 Hz to 16 kHz were noted, then the data were averaged to produce a mean amplitude for each frequency of sound for each recording session. Again, these were correlated with the pandas' behavior and hormone levels (Powell et al. 2006).

A more recent study reported on a family of three Gabriella's crested gibbons at Niabi Zoo in Illinois, again during some reconstruction. Their behavior was observed and the ambient sound exposure levels (SEL) recorded in 90 second intervals over 15 minute blocks throughout the morning during seven days of baseline and eighteen days of construction noise. Baseline SEL ranged 70 to 94 dB with a mean of 87 dB, compared to the construction samples of 76 to 103 dB with a mean of 95 dB. They spent more time close to each other as the noise increased, vocalized less but significantly louder and with more repetition, and utilized only the most sheltered portions of their enclosure during the construction periods (Friel 2011).

Ambient sound pressure levels at the San Francisco and Sacramento Zoos fluctuate according to the numbers of zoo visitors and the intensities of their conversations, maintenance machinery, and proximity to water features and to transportation systems. Levels ranged from 62 to 72 dB with an average of 70 dB (Tromborg and Coss 1995).

The only study that has examined zoo rhinos' sensitivity to noise appears to be a portion of the work on the Black Rhinoceros in U.S. zoos (Carlstead et al. 1999). Seventeen zoos were visited and sound levels were measured in the center of each outdoor rhino enclosure four times for fifteen seconds prior to opening near dawn, twice during operating hours, and once after closing. Decibels were measured at their maximum and minimum sound pressure levels, and also their Leq. Frequency range was measured in eleven one-third octave-bands from 0 to 20 kHz. However they seem not to have studied infrasound at all, nor do they mention any sensitivity of their measuring equipment to the infrasonic range. Possibly due to the limitations of their sample size and sampling methods, this study did not produce statistically significant correlations but did indicate general trends that relate noise levels to early mortality, unnatural behavior, diminished well-being, and diminished reproductive success. The authors recommended further research to investigate these trends.

The study excluded measures of mechanical equipment and/or sudden sharp changes in sound levels. Their interest was the overall chronic exposure of the rhinos to zoo noise, which they seem to have largely interpreted as visitor noise. However I would argue that mechanical equipment is regularly used around zoos to move food and equipment, and sharp, sudden noises like the clanging of chains and heavy metal gate bars occur on an hourly basis so should be considered part of the average ambient-sound load. When metal hits metal it can be extremely loud, and even at a distance a wide range of harmonics in a wide range of frequencies typically ensue, unlike anything heard in a wild soundscape.

While zoo acoustic studies have mainly measured noise levels and certain frequency bands and bioacousticians mainly measure the vocalizations or an activity of an individual species, the measurement of wild areas, and in the past few years national parks, has highlighted soundscapes (Krause 2001; Krause and Krause 2002; Krause 2008; Krause, Gage, and Joo 2011; Krause 2012; McKenna et al. 2013). These are the relatively few teams of soundscape ecologists who have produced a number of useful techniques and are collaborating with soundscape ecologists in Europe and Australia to develop ISO international standards relating to soundscape research (Pijanowski and Farina 2011; Pijanowski et al. 2011; Pijanowski et al. 2011; Villanueva-Rivera et al. 2011; Mennitt 2011; Mennitt, Sherrill, and Fristrup 2014).

Conclusion

While the literature demonstrates that sound studies have been undertaken within the zoo environment, they have largely focused on recording specific animals rather than the soundscape, or on absolute sound levels rather than on the characterization of the soundscape, and largely only within the (human) sonic bandwidth. The few studies that assessed ambient sound for captive animals generally related to periods of construction, or else to equipment operating within animal housing. None of these attempted to describe the soundscape as a whole, particularly from the animals' viewpoint considering their auditory ranges and semantics. The panda studies were technically the most comprehensive and form a good basis to build on, and indicated that ambient noise does impact the behavior and stress levels of these animals, particularly during estrus and lactation. The single (but black) rhinoceros study compared the noise levels within a number of zoos, but sampled only for very short, non-consecutive periods and only when the recordists considered the sound environment to be "average." The results of that study did however indicate trends that require further research for full substantiation.

It is clear the soundscape can have a profound influence on humans and on animals both in the wild and in captivity. Since humans, pandas and rhinos are all mammals and share many physical and, it appears, psychological factors, the soundscape may influence white rhinos in a similar manner.

The factors that influence humans most, and are associated with stress and reproductive problems, include chronic noise, high amplitudes, low frequency and/or impulse noise, vibration, fluctuating noise, noise during sleeping periods, unrecognized sounds, and sounds that are likely to cause fear. The first three of these were shown to affect the pandas. It is not yet apparent whether these factors are present in the zoo or wildlife park environment, nor whether they correlate to a species' health. No study was found that compares soundscapes in such a manner.

This project provides a method whereby a soundscape, not just certain aspects of an animal enclosure, can be recorded and measured in a more comprehensive manner than has been reported in the past, and in such a way as to identify how that soundscape may relate to the likely acoustic sensitivity of the animals held captive, in this case the southern white rhinoceros (*Ceratotherium simum simum*). Once the data have been investigated, similarities and contrasts with natural soundscapes can be explored, although a number of those natural environments may also first need to be recorded to provide an accurate baseline. Acoustic parameters known to be harmful to humans or to cause response in animals can be investigated in depth to determine whether they are present and possibly significant. Apart from components of a soundscape being potentially harmful or healing, the soundscape can impart important information that the occupant may experience but animal-care managers may be unaware of, particularly sounds outside the range of human hearing or sounds that occur when staff are not in attendance, such as at night. This project offers a standard by which captive environments may be measured and characterized so that other facilities can be recorded similarly and the results compared. By seeking correlations between a wide range of acoustic parameters and the health and well-being of the particular animals held within each soundscape, greater understanding of factors that may prove influential to animal care is likely to ensue.

4. CONCEPTUAL FRAMEWORK AND RESEARCH OBJECTIVES

The Place of the Project in Geography

Of the four basic traditions of geography (Pattison 1964), this project to characterize and analyze the soundscape of a wildlife center extends the tradition that is at the heart of environmental geography: the relationship between people and the environment, or how the natural environment influences human behavior and how humans modify their environment. In this case however, it is a question of how a major aspect of a human landscape, the environment of captivity, may affect a non-human animal. This is an exploration of potential acoustic influences on occupants of Fossil Rim, in this case the white rhinoceros, rather than of the landscape influencing humans.

Just as beholding eyes may view ten or more versions of the same scene (Meinig 1976), so discerning ears may interpret different aspects of soundscapes. An element that merely represents a background keynote to one listener, possibly the sound of a staff truck, may be a tantalizing sound signal to the ears of a rhino if it announces their keeper's feed truck, approaching from the right direction at the right time and slowing in the right place, laden with fresh hay. The visitors who tour the trails at Fossil Rim may look on the center's landscape (and soundscape) from the viewpoint that it represents *nature*, as they enjoy an escape from "civilization" and imagine the various species as they might appear and sound in their original natural circumstances. The staff of Fossil Rim may respond to the property from the viewpoint that it is *habitat* for the animals within their care, and may listen to learn about the current state of that habitat and the activities within it. From my perspective listening to and analyzing hour after hour of audio files, it represents *artifact* and *place*. There is rarely a period without some aural artifact of humans in the area, but the soundmarks and keynotes of the highly visible and persistent bands of insects and birds and varied animal vocalizations stamp the soundscape as being “Fossil Rim”.

The Place of the Project in the Literature

Of the literature reviewed that analyzes the sounds heard in zoos (usually noise), none emanated from geographers. Yet the sounds at zoos and other places where animals are held strongly reflect the influence of local cultural and physical geography. Few if any of the articles regarding soundscapes emanated from geographers, yet soundscapes are as geographical as landscapes. It is hoped that once a soundscape has been accurately characterized, other geographers will appreciate them and start to consider their relevance; perhaps even use these methods for their own exploration.

Not only may Geography (the discipline) benefit from this new approach, but it is also hoped that facilities caring for animals will as well. Most zoos are distinctly anthropogenic. They attempt to simulate natural conditions to a considerable degree for the sake of their animals, but also to interest and educate visitors. However, budgets, lack of space, and other considerations enforce major constraints, especially in urban areas. Some species tend to breed poorly in urban zoos. For endangered or threatened species this is of particular concern. Great strides have been made in zoo facilities and management based on the biological and social needs of their animals, and on educational and aesthetic improvements to delight visitors, but the impact of the overall daily soundscape has been given little consideration. Management of zoo soundscapes could prove to be more effective and perhaps more cost-effective than many remaining areas of concern.

Objectives of this Project

Goal 1

The first goal of this project is to develop a standard that could be employed to comprehensively record, measure, analyze, and characterize the broadband soundscape of the white rhino and from the perspective of rhinos residing in the enclosure at FRWC over a one-week period of normal activities. Such a standard could be used in future projects to record and compare soundscapes at a variety of facilities holding the same species.

Since white rhinoceros audiograms are not available but it is believed that rhinos sense seismic vibration and may detect a very broad band of infrasonic, sonic, and possibly even lower ultrasonic frequencies, a series of recording systems was therefore selected that could collectively sense from 0.1 Hz up to 22,050 kHz. Appropriate equipment needed to accurately record absolute metrics (not adjusted to human perception), and be reliable, able to be weatherproofed safely, light enough to be carried some distance over difficult terrain, sturdy enough to withstand possible investigation by local wildlife, and relatively economical financially and in terms of energy and data storage requirements.

Rationale

Acoustic studies of zoos have tended to relate specifically to noise or are limited to recording a particular species. These studies have widely differing goals, techniques, and results. Few have been comprehensive (in terms of measuring the ambient environment), admittedly none have tried to be. Most have attempted measurements of sound environments for only short periods, although a few repeated their brief measurements over extended periods. Equipment has often been limited, and usually only SPL and frequencies have been considered. In addition, most studies have been restricted to sonic bandwidths, and many to quite narrow bands. The few that have considered low frequencies tended to target vocalizations of a specific animal. These studies have been well designed for their intended goals, but to characterize an entire soundscape, more metrics are required.

Goal 2

A subsidiary goal is to note the vocalizations of rhinos, to roughly estimate the bandwidth used by these particular animals. Close analysis of rhinos' vocalizations and other sounds made by them does not fall within the scope of this project, and since all measurements are to be taken at a distance from the animals, in uncontrolled circumstances, and with other sounds in the background, high resolution may not be accurately determined and their use of higher harmonics in particular may not be detected on the recordings. Whether high frequency rhino calls are recorded or not, if the animals are able to detect noise at those bandwidths, they should be considered to be part of their soundscape.

Rationale

Anthrophonic soundscapes differ in many characteristics from natural soundscapes. Some may prove more appropriate to some species and not others, according to the acoustic activity in the bandwidths to which a species is most sensitive. Since audiograms for many species have not yet been established, one generally accepted method of estimating the frequencies of most interest is to determine the bandwidth used by those animals for their own communication. This is likely to represent the area of that species' greatest auditory sensitivity, and also the frequencies in which masking of their communication and of important sound signals is likely to cause distress. The soundscape within that bandwidth could be investigated to a greater depth by a future researcher to determine its characteristics and sound metrics, and the dataset that will result from this project could be further analyzed for this purpose. The southern white rhinoceros has been reported to vocalize in the range of 5 Hz or a little lower (Baskin 1992) up to at least 8 kHz (Policht et al. 2008). However, those working with these animals for many years (but without sound recorders) anecdotally report rare high whistles of glee, particularly among the young (Personal interview Joe Grubic, Chief Mammal Curator, Cameron Park Zoo 2003; Personal email Dame Daphne Sheldrick, The David Sheldrick Wildlife Trust 2003; Personal interview Katy Payne, Elephant Listening Project, Cornell University 2010). This suggests they may perceive infrasonically, sonically, and possibly even at the lower reaches of the ultrasonic range. One goal of this project was to develop a rough estimation of the bandwidth that the rhinos of Fossil Rim use.

If rhinos are like elephants and use bioseismic cues for communication, and “listen” to their wider environment through sensations they feel in the ground (O'Connell 2000; O'Connell-Rodwell, Hart, and Arnason 2001; Arnason, Hart, and O'Connell-Rodwell 2002; O'Connell-Rodwell 2007; Personal interview Katy Payne, Elephant Listening Project, Cornell University 2010; Drake 2011), measurement of seismic noise needs to be considered. A series of recording systems was selected that collectively sense from 0.1 Hz up to 22,050 kHz. If rhinos do indeed utilize infrasonic, sonic, and possibly even lower ultrasonic bandwidths, then each must be measured by equipment that can be relied on to report absolute sound pressures accurately.

Goal 3

Another goal is to demonstrate that techniques and language not normally used in the discipline of Geography could broaden its scope and expand the tools available to those investigating their environment.

The literature shows that while much of the research into soundscapes has been geographic in nature and examining spatial and temporal variation, few formal geographers have transitioned from the largely visual examination of landscapes to the acoustic examination of their environment, and that which has been undertaken has been largely in the more qualitative field of acoustic ecology rather than in the more quantitative soundscape ecology. Certainly GPS, GIS and other forms of mapping have been incorporated, but apart from the work by famed geographer Golledge that was specifically focused on helping the visually impaired, and from urban planners, the greatest contributions to soundscape science have been from other disciplines.

This project aims to demonstrate that by physically measuring the acoustic parameters of a region, a great deal can be discovered about its spatial and temporal identity, with acoustic signatures proving similarly useful as spectral signatures are for remote sensing.

Rationale

To advance current techniques and to establish a uniform language, this project adheres to procedures that have been previously developed, albeit by others with other goals in mind. Analysis is undertaken by Raven Pro Interactive Sound Analysis software, which provides visualization of commonly used metrics in a manner more easily learned than Matlab and some other programs. Raven is accompanied by a comprehensive, logical manual that includes appendices explaining the digitization of sound and a biologist's introduction to spectral analysis. It assumes a basic understanding of acoustics, but this can be gained from other sources. Thus this method of measuring a soundscape can be accessible to those with little background in mathematics or physics. Raven was based on Matlab and was developed by the Bioacoustics Research Program at the Cornell University Laboratory of Ornithology to provide non-expert users with tools to uniformly measure sound in ways that meet a national standard. It is most often used to measure the vocalizations of a particular species or group, however, rather than an entire soundscape.

The use of recognized techniques and a uniform language can open the field to other disciplines such as Geography, and thereby advance both them and soundscape science with integrity. Advances have been made by researchers from the fields of engineering, physics, ecology, and biology. Geographers, to date, have not been participating, yet the soundscape is just as important to many animals, human and non-human, as is landscape; soundscape ecology can be as revealing as other forms of ecology within environmental geography; and despite being far less technically sophisticated to date, acoustics holds the potential to reveal many otherwise undetectable aspects of an environment. This burgeoning field of research may soon become as refined and as widely accepted in Geography as other forms of remote sensing, particularly since many projects already involve geographic concepts (Mennitt, Sherrill, and Fristrup 2014; McKenna et al. 2013; Mennitt 2011; Pijanowski et al. 2011; Villanueva-Rivera et al. 2011; Mennitt et al. 2013).

Like remote sensing and geographic information systems, acoustics is not learned overnight and requires dedicated study, however even a general appreciation of the depth and breadth of soundscape analysis can open doors for collaboration, the asking of new questions, and the appreciation and furthering of other researchers' discoveries.

Goal 4

The fourth goal is to demonstrate how the processing and analysis of the data collected at FRWC can be formulated to characterize the soundscape that their rhinos experience. Anthrophonic environments are usually dominated by anthrophonic sounds that mask other categories, while in natural environments biophonic and geophonic events dominate. In the past, natural environments might have been considered only those without any anthrophonic intrusion whatsoever, but such places are now rare anywhere on earth (Krause 2001). Most soundscapes lie somewhere on a continuum between natural and anthrophonic, and part of the characterization will be to determine where the rhino enclosure lies on that continuum. Diurnal and nocturnal patterns of energy will be sought, and after all the data have been processed, it will be possible to observe daily rhythms and whether they demonstrate any regularity. It will also be possible to divide the data into any time lengths to observe the characteristics of periods of day such as early morning, feeding times, work hours, visitation periods, evening, and night. Examples of the most apparent sound events in each category will be presented.

Mathematical measurement of the recordings will also identify characteristics unique to this soundscape. The soundscape can be averaged or compared over any length period, but for this demonstration it will be examined in short periods over the length of one day, with a preliminary comparison of a second day, which was the loudest of the week recorded. Since most people understand the concept of SPL more readily than some other parameters, that will be used to demonstrate initial ways in which each of the parameters could be investigated.

Rationale

Soundscapes in zoo and captive animal environments do not appear to have been examined from the perspective of Geography. Few take spatial and time scales into account, or do so only as a by-product of other goals. Most zoo noise research has focused on measuring sound levels within certain frequency bandwidths, not on actually recording the soundscape itself. By actually recording from a number of sites around the rhino enclosure over a continuous period, this project explores differences in the sites themselves but also enables the week to be retained in a manner that can be investigated both now and at any time in the future as new questions may arise. It makes possible assessment of the *type* of noise that is present, from exploration of various acoustic parameters such as its entropy, or the degree of disorder in the sound, to its semantic content, and the balance of biophonic and geophonic sound events as opposed to anthrophonic events, noting the intrusiveness of each into the soundscape at various places and times.

The analysis will commence with the simplest task, that of listening to each recording while watching its waveforms and spectrograms in order to log the sound events and at the same time to become familiar with their acoustic signatures. To start with, these will be categorized as anthrophonic, biophonic (but events relating to the rhinos will be separately noted) or geophonic, and the relationship between these categories will be assessed.

5. STUDY AREA – FOSSIL RIM WILDLIFE CENTER

Fossil Rim is a not-for-profit wildlife center located in relatively hilly terrain about 6.5 km southwest of the township of Glen Rose, Texas, 19 km south of Comanche Peak Nuclear Power Plant, 25 km southwest of limestone mines that were apparently abandoned during the study period, and about 115 km southwest of Dallas, (Figure 3). According to the U.S. Census Bureau, the population of Glen Rose fell from a July 2009 peak of almost 3,000 people to 2,434 two years later and has risen only fractionally since. The center encompasses about 700 hectares within a predominantly rural area, (Figures 3, 4, 5). The majority of its 1,100 animals of 50 endangered or threatened species range semi-freely in large fenced grassy pastures, through relatively rugged outcrops of Trinity Group limestone, sandstone and shale.

FRWC is one of six Conservation Centers for Species Survival (C2S2) in the United States, renowned for research into the improvement of captive management of endangered species, and for their further conservation of species in their natural habitats. By combining their joint scientific research with their joint management expertise, these C2S2 are creating self-sustaining populations of some of the world's most endangered animals. Visitors drive slowly through almost 16 km of gravel trails to view the animals (Figure 6).

It is one of nine U.S. facilities to breed this species in recent years. Fossil Rim maintains a crash of six white rhinos: a bull and three cows in addition to 42 year old Edith and her calf Ursula born in October 2011. Although an experienced mother, Edith was considered well past her reproductive capability when she was retired to Fossil Rim

Figure 3. **General location of FRWC**. The conservation center lies within a predominantly rural area southwest of Glen Rose township and the confluence of the Paluxy and Brazos Rivers. Comanche Peak Nuclear Plant lies 13 km to the north, and apparently abandoned limestone mines 19 km to the northeast. The white rhino enclosure is the gold diamond.

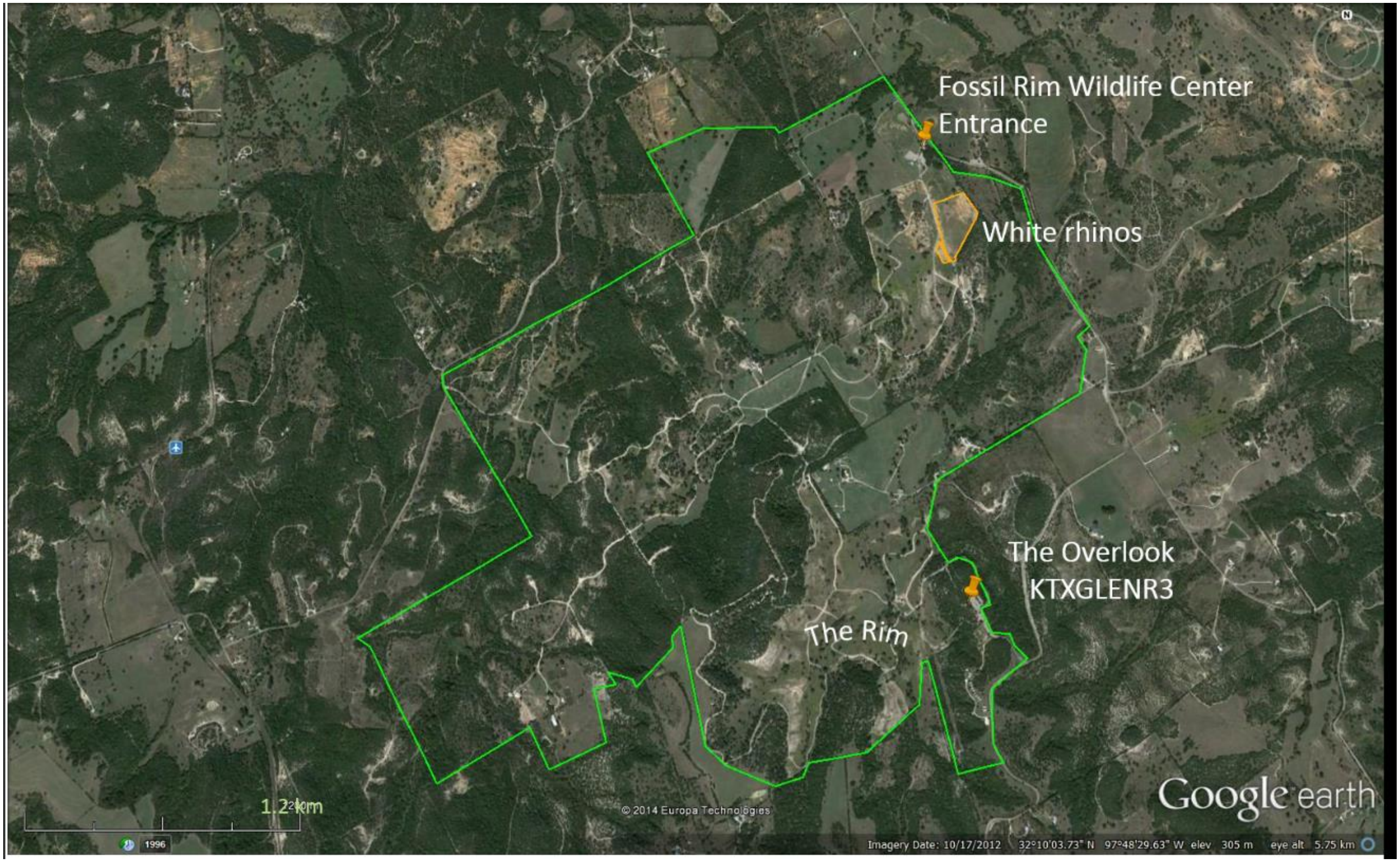


Figure 4. **Fossil Rim Wildlife Center.** FRWC lies in generally undulating ranchland. 2.2 km almost due south of the main entrance is The Overlook – a café, education center, gift store, nature walks, and an interlude for visitors touring the Center's trails. Also there is Weather Underground station KTXGLENR3. To its southwest and at about the same elevation, the cliffs of The Rim tower over and shelter the valley. 3.6 km east southeast of the white rhino enclosure lies the private airstrip of Wright Ranch

Figure 5. **View from the Overlook.** From here and the Rim, visitors gaze across Fossil Rim and neighboring ranchland. The white rhino enclosure lies in the valley to the right of this photograph. Comanche Peak Power Plant further down the valley may also be viewed from the property.

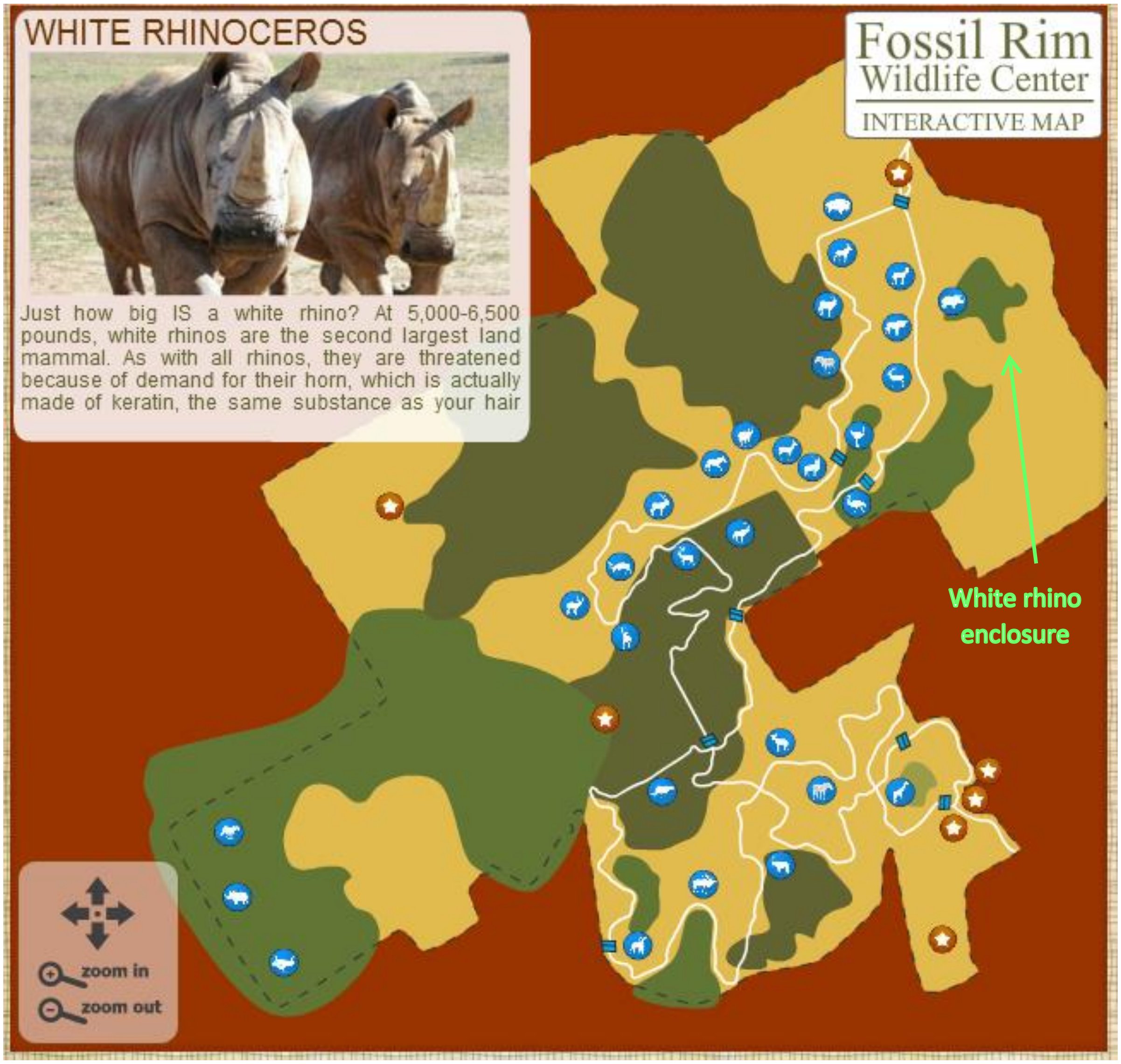


Figure 6. **The wildlife center's interactive map.** http://fossilrim.org/ia_map.php (last accessed 23 August 2014) This sketch map shows where visitors may drive along about 16 km of tracks among endangered or threatened indigenous and exotic animals

in 2008. Captive white rhino life expectancy is usually in the range of 35 to 40 years, although in the wild they have been known to live past 50. Edith is the oldest white rhino to give birth in this country, and Ursula was the first calf born at Fossil Rim in four years, was totally unexpected, and is therefore valued even more highly. Fossil Rim also holds a crash of black rhinoceros in another part of their facility.

White rhino soundscapes are good candidates for this study since, like other rhinos, these animals rely on their hearing and sense of smell almost completely, but they vocalize more frequently (Policht et al. 2008). This provides more opportunities to estimate the overall frequency range they may utilize. Rhinoceri are among the most acoustically sensitive animals so their soundscape is likely to be even more important to them than to other species. African trackers are known to observe rhinos in order to remotely identify other animals that may be approaching. Rhinos are reported to respond up to half an hour before a fast-moving giraffe or an elephant appears, even well before a quiet pride of lions or hyenas appear. Trackers can tell from the rhinos' behavior not only the species of the newcomer/s, but also whether the individuals are recognized and welcomed, or feared and to be shunned (Merz 1991).

Whites also differ from other rhinos in that they are considered more sociable due to their behavior (Owen-Smith 1973; Penny 1988) but also due to their variety and complexity of repertoire, and the frequent occurrence, repetition, and length of vocalizations (Cinkova and Policht 2014). Whites choose to inhabit open grassland savannahs, where wind turbulence in the hot grass causes irregular fluctuations of amplitude and thereby impedes the transmission of sound over long distances (Wiley and Richards 1978). It has been hypothesized that the white rhino's quick repetitions of short syllables across a range of frequencies would heighten detection between wind events (Davies, Krebs, and West 2012). Thus this project is interested to learn whether the white rhinos' vocalizations may be readily heard over or between the daily sound events in the wildlife center.

There has been considerable speculation about whether white rhinos actually communicate over long distances by using infrasound, like elephants. Although a black rhinoceros moan can be detected by geophone at 100 m (O'Connell-Rodwell, Hart, and Arnason 2001) and a white rhinoceros snarl can be heard by humans over 1 km away (Owen-Smith 1973), Policht et al. (2008) do not believe these calls are intended for long distance communication, but are simply infrasound components of calls that occur as a by-product of their extreme body size. Payne disagrees, having observed both elephant and rhino long distance social organization in their natural habitats for decades. It was she who first suspected, then confirmed that elephants use infrasound for communication (Payne 1998), and she believes rhinos appear to do so in a very similar manner (2010 personal).

Fossil Rim's white rhino enclosure lies in the northeast corner of the center. It is the last stop for visitors before the main exit/entrance. Most guests access the center from the northwest on County Road 2008, passing over low undulations through agricultural land and small forests, from US-67, about 1.75 km away (Figure 7). In the other direction from the main gate, some travelers skirt Fossil Rim and the rhinos, encountering two large bends before a steady climb south towards The Overlook and small property holdings. The county road runs within about 150 m of the rhinos' enclosure and vehicles are generally quite audible, but not loud to a city person's ears. Occasionally a truck may be heard changing gears for the climb. For short periods during the day, particularly as workers commute, a couple of cars per minute may be heard, but after midnight there may be just one vehicle per hour or two.

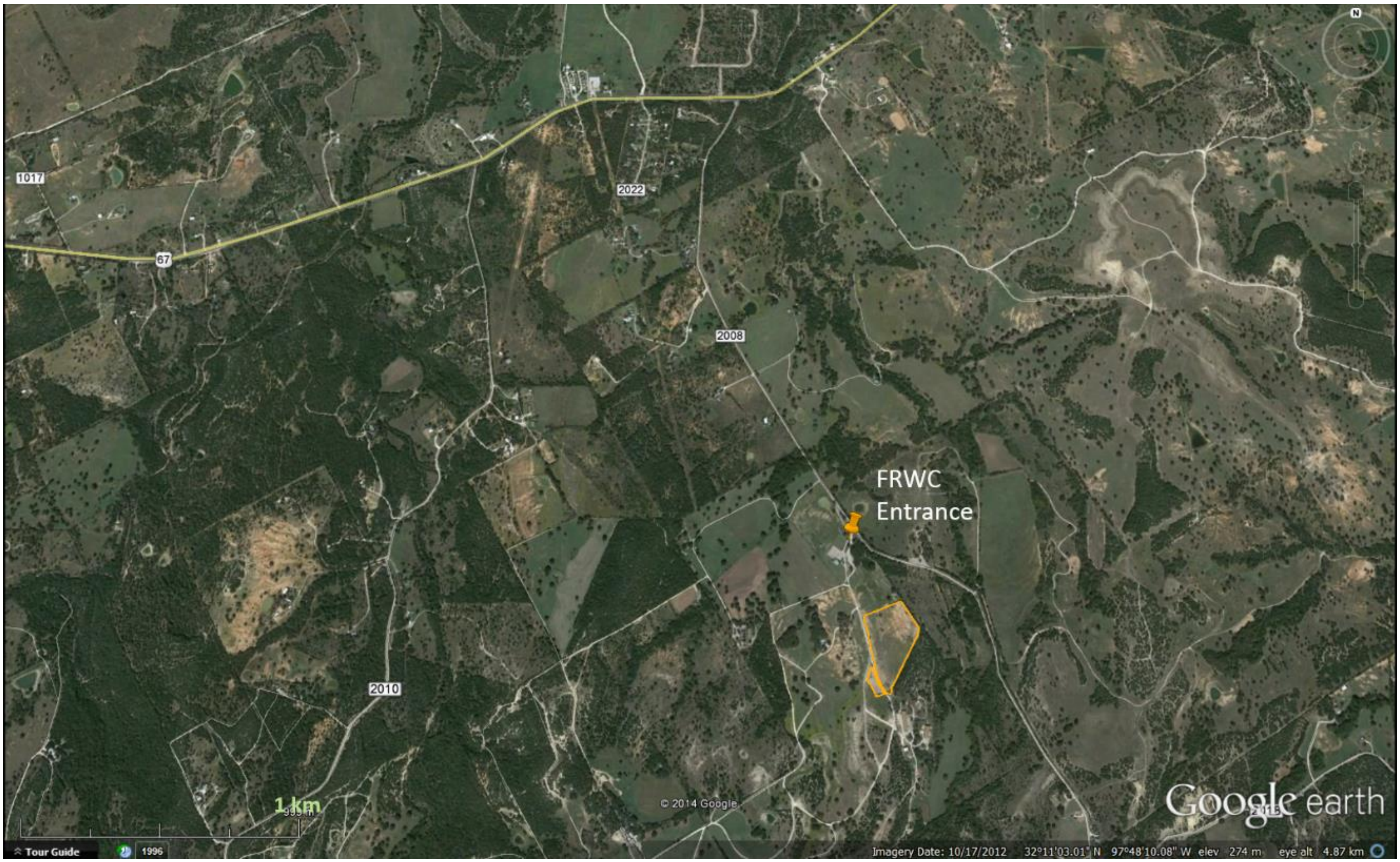


Figure 7. **Proximity to roads**. State Highway 67 runs about 1.75 km north of Fossil Rim, and County Road 2008 comes to within 150 m of the tip of the white rhino enclosure and partially skirts it before continuing south on a steady climb up towards the Overlook.

The whites’ 3.6 hectare enclosure near the main entrance is bound by steel posts spaced wide enough to permit 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 from whence zoo buses, heavy equipment, and machinery start the day. The four cows and the juvenile are generally held in the large enclosure, with the male, Tex, held separately in a much smaller yard on the far side of the staff road (Figure 8).

On the eastern side of the rhinos’ fence is a run that may average about 5 m wide, bound by a 2.5 m wire fence supported by star pickets, intended to keep out coyotes, raccoons, dogs or other animals that may be tempted to stray inside and could threaten Fossil Rim’s collection. 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. Deer, raccoons, foxes and a myriad of other wildlife live in this thicket that is rarely disturbed by humans, apart from auditorially.

In order for the recording equipment to be out of reach of Fossil Rim’s animals and generally out of sight of the public, it was necessary to place it along this eastern fence line. Due to the dense scrub, the equipment was driven into the utilities area and then carried on foot along deer trails, from whence rough paths between the rocks, mesquite, vines and ashe juniper were cut to access the fence area. Bright colored tape was tied to branches in order to relocate the sites more quickly. For each site, along these paths had to be carried a 40 to 45 kW solar panel, a ladder, one to three 12-volt batteries, and the data acquisition systems at set-up and break-down. Just a full backpack was

Figure 8. **The white rhino enclosures.** The females usually graze in the large diamond while the rhino bull Tex occupies the smaller yard. They are separated by a staff service road. Immediately to the west is the wide gravel and semi-sealed tourist trail, to the south by two staff roads that lead to the utilities buildings, and to the east by mesquite and ashe juniper.

required on the maintenance runs between the data downloads at Fossil Rim's Katy's Cottage, if everything was running smoothly. Ladders and any equipment that could distract visitors across the enclosure were stored behind trees when not in use.

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 wild creatures on the other, equipment had to be attached on top of three meter star pickets, or stored in sturdy boxes well back from the fence. Ground a couple of meters around each sensor had to be cleared so trees would neither interfere with recordings nor cause acoustic artifacts. Thirty meter cables had to be strung high through the thorns and vines to separate the SongMeter microphones as far as possible, in order to obtain a widely-distributed recording aperture along the fence line. The next chapter describes the methods by which the equipment at each site was used, and how the data that were collected were analyzed.

6. RESEARCH METHODS

In recognition of the need described in the literature (Schomer et al. 2010, Schulte-Fortkamp and Kang 2010, Genuit,and Fiebig 2014; Schulte-Fortkamp 2014a, 2014b) to standardize both the language and techniques of soundscape analysis, the methods incorporated in this project are not new in themselves. Their novelty lies in the manner in which they have been selected, combined, and incorporated to provide a relatively simple approach yet comprehensive results that can form a standard by which researchers from any background or discipline can compare their outcomes.

Pilot Studies

A pilot study was conducted from 3rd May to 7th May, 2013 to become familiar with the location, with Fossil Rim's protocols, and with the soundscape itself, to explore the best placement of equipment, and most of all to test possible recording settings, windscreens, and other potential options. Several one-day trials were conducted to test equipment and strategic options, but these were simply undertaken from the researcher's car on the tourist trail on the western side of the rhino enclosure that is accessible to the general public; it was not necessary to gain access to the staff-only area to the east of the enclosure for these trials. These trials increased familiarity with the animals likely to be heard on recordings, with the activities at FWRC (such as the Safari bus tours and staff movements in and out of the utilities area), and provided experience with the recorders, microphones, potential settings, and windscreen options. They also demonstrated that between visitors, rhinos' vocalizations could be readily recorded over a moderate distance.

A second pilot study began on 7th October and continued until all systems seemed to be working optimally. From Tuesday, 15th October to mid-morning Wednesday, 23rd October, most systems recorded continuously apart from some unforeseen conditions such as heavy rain and high winds that prevented the replacement of the SD cards in the R26 and the Drift. Further recordings were taken on Monday, 4th November to sample the monthly test of the nearby tornado and nuclear plant emergency siren.

Equipment and Data Collection

Sonic recorders were placed at sites 1, 2 and 3 towards the southern, the center, and the northern ends of the eastern fence of the white rhino enclosure, with the seismic and infrasonic systems at the "RefTek" site behind and slightly uphill from site 3. A video camera was placed at each end of the enclosure to provide one image per minute to aid in the identification of sound sources, and a ProWeather station was sited just past the southern end of the enclosure at the rear of the utilities buildings (Figure 9). For precise locations see Appendix A.

Utilities Site

Most of the equipment was driven into the area between the utilities buildings and the rhino enclosure. A ProWeather station (Tycon Power Systems 2014), such as commonly used by Weather Underground observers, was used to monitor local atmospheric conditions to complement comprehensive reports from Weather Underground station KTXGLENR3 at The Overlook education center and café, 1.6 km to the south and at an elevation 75 m above the enclosure (Figure 10).

Figure 9. **Equipment layout**

Figure 10. **Weather Underground station KTXGLENR3 at The Overlook**

The ProWeather unit was mounted atop a gate post separating the utilities area from the pasture surrounding the rhino enclosure. The gate was not opened during the project. Since the power and remote sending unit must be vertical, shaded, and generally rain protected (but not enclosed as it can be subject to overheating), and it must remain within several feet of the sensors, it was unfeasible to mount it on top of the fence, but it was also necessary that ostriches and other Fossil Rim animals that might pass would not be attracted to it or able to reach through the fence wire to reach it. It was therefore suspended inside a large and very sturdy cardboard box on the far side of a bush (Figure 11), out of sight of animals inside the fence and shaded by the bush for most of the day, but permitting air flow across the top of the box to keep it cool. The data display and storage unit were mounted in a substantial weatherproofed box in a tree about 50 meters further back in the utilities area, in order to gather its own internal weather readings, and to receive the outside data wirelessly. That unit was designed to collect

Figure 11. **The ProWeather station.** This was mounted atop the utilities fence, with the sender shaded and protected by being suspended in a sturdy cardboard box.

weather observations indoors for later comparison with the outdoor observations, and it operated perfectly throughout. However there were some unexplained data dropouts from the external hygrometer on the fence, generally for a few hours around midday. An example of both the ProWeather data and Weather Underground's official archive for Friday 18th October, appear in Appendix B.

An HD Hero 1080 GoPro video camera was mounted in its waterproof case onto a gate post by means of a gorilla tripod and bungee straps (Figure 12). It had a wide-angle

Figure 12. **GoPro Hero video camera.**

view along the staff service road, the rhino yards, the end of the run along which the rhinos returned to their nighthouse on evenings when it was predicted that the temperature might drop below 4.5^{o}C, the visitors' trail where it approached the rhino's boundary, and the southern end of the rhino enclosure (Figure 13). The two GoPro batteries could only be re-charged in the camera itself, taking a minimum of 4 hours if charged from a laptop on battery power, or 2.5 hours if the laptop was drawing power directly from an electricity outlet. At one frame per minute, it required about 0.5 GB of data storage in the time it took the batteries to become exhausted – about 2 to 3.5 hours, depending on temperature. The intent of the camera was to record one frame per minute in daylight from each end of the enclosure, but the GoPro's limited and inconsistent battery life meant that only about 6 hours were recorded most days.

Figure 13. **Dawn greets rhinos and staff.** Sunlight started filling the valley and evaporating dew by 8am.

Site 1

A Wildlife Acoustics SongMeter SM2+ autonomous recording unit (ARU) was mounted at site 1South. While like most sonic recorders, it claims to provide a flat acoustic response for the entire 20 Hz – 20 kHz range of human hearing, some reports doubt its precise accuracy below 200 Hz. It is difficult to calibrate sonic recorders at low frequencies since few anechoic chambers are large enough and well insulated enough to be rated for that purpose. If the SM2+s do develop inaccuracies below 200 Hz, they are likely to under-report the power of a low frequency sound event rather than over-reporting or including low frequency noise that does not exist. Due to this, and the desire to include all low frequency noise that occurs, this project did not eliminate the SM2+s' low frequency recordings. Digital band-pass filters eliminate frequencies below the high-pass filter and above the low-pass filter. The SM2+s do not provide many options so the high-pass filter was set at 3 Hz in order to include the lowest frequencies that the unit could record.

The SM2+ is NEMA 6 rated so can withstand harsh weather conditions. Its omni-directional SMX-II microphones are delivered weatherproofed, meaning they do not need to be wrapped in plastic rain-proofing, or to have heavy windscreens added unless winds become extreme. At such times it can be advisable to turn microphones downwards so they are not hit by hail, heavy windblown rain or debris, but this was not possible at the times this may have been desirable during the formal week of recording, so the microphones were left horizontal at all times, pointing across the rhino enclosure. The lack of additional weatherproofing permitted optimal reception at most times, but occasionally when the wind was already strong and predicted to increase considerably more, a standard Tour Grade Microphone Windscreen (a Guitar Center proprietary brand) was added to one of each pair of SMX-II microphones in case the other started to spike. Microphone 1/channel 1 South (hereinafter SM2.1S) was placed on a 3 m acoustic cable and attached horizontally in its spider shock mount atop a star picket above the ARU (Figure 14). The ARU was covered by rocks and then spikey branches to shade it, and to make it less obvious to and more difficult for small animals to move. This also helped maintain its ambient temperature rather than being exposed to sunlight. Microphone 2/channel 2 (SM2.1N) was placed on a 50 m cable and strung through branches and thorny vines to discourage ground based animals that might be tempted to nibble the cable, to another small clearing about 21 m north (site 1North), and attached to the top of another star picket. Although long acoustic cables may cause signal attenuation, Wildlife Acoustics guarantees no attenuation up to at least 100 m.

The SM2+ recorder was attached to an SM2 Power Adaptor and thence to a 12-volt battery. They were encased in a sturdy, waterproof plastic box with clips that would

Figure 14. **SongMeter SMX-II microphone SM2.1S.**

be difficult for a creature to open. The battery was supported by a solar panel (Figure 15). All 12-volt batteries used in the project were deep-cycle AGM lead acid. They were measured at least twice per day, 3 or 4 times on cloudy and especially rainy days, the power systems were checked, and the solar panels were cleaned of any debris or leaf litter and re-oriented towards the sun. No battery fell below its designated power at any time.

The SongMeter was set to record standard 16-bit PCM uncompressed .WAV files continuously but in order to manage file size, to start a new recording every 30 minutes. The sample rate was set at 44.1 kHz and the gain at 36 dB. Wildlife Acoustics suggests trying a gain of 48 dB when recording “average” wildlife in a quiet or forest setting, up to 60 dB if aiming to record specific very quiet animals with very little ambient sound,

Figure 15. **Recording site 1**.

with 36 dB in a noisy environment. Since at Fossil Rim the recorders would be left on the same setting for the entire week so that the soundscape could be directly compared between different time periods, and there was sometimes considerable ambient noise – whether anthrophonic, biophonic or geophonic – the pilot studies indicated that a gain of 36 dB seemed to provide the best compromise. It was essential to capture all possible low amplitude sound events that humans might not be aware of but the rhinos, with their acute acoustic sensitivity, are likely to hear. Many of these sound events emanated from the road on the western side of the enclosure. From the recording fenceline, it was often impossible to auditorily discern when the rhinos were being fed (Figure 16), or when visitors or staff drove past if they were gently rolling downhill.

Figure 16. **Morning feed.** This **is** the direction that omni-directional microphone SM2.1N received to the greatest degree**.** The female rhinos are drawn to the visitors' trail by breakfast around 8.15am each day

Site 2

At site 2, a Roland R-26 6-Channel Portable Recorder was mounted on a star picket, on a small rise overlooking the center section of the enclosure. During their Sound Recording Workshop summer school, this recording system was highly recommended by senior recording engineering staff at Cornell University's Lab of Ornithology as producing extremely high quality recordings in a lightweight and relatively inexpensive package (personal communication, June 2012). They rated the R-26's internal microphones as just starting to roll off a flat response at 10 Hz, and continuing flat well above 20 kHz. However the Earthworks microphones are calibrated from 9 Hz to 23 kHz and so form a bridge down to the infrasonic recording range.

The Roland contains two pairs of internal mics – omni-directional, and XY or directional microphones. Ten meter acoustic cables attached a pair of Earthworks M23 Measurement Microphones that were mounted on star pickets a little over 5 m north and south of the R-26 itself. In order to weatherize them, a Flents Finger Cover was taped over each microphone then an Earthworks OMW3 foam windscreen. Since the intent was to learn what the rhinos hear, omnidirectional microphones were used throughout to sense the soundscape in all directions, apart from these directional XY microphones built into the Roland R-26. The X microphone faced west and the Y microphone faced north across the enclosure, from about the center of the fenceline. The placement of all the sensors was to acquire the local variation in sounds, particularly higher frequencies since they attenuate more rapidly with distance than lower frequencies.

The recorder had to be covered by cardboard to prevent its digital screen from being damaged by prolonged sunlight, then wrapped in a sturdy Ziploc bag to protect it from rain and dew, covered with its foam windscreen, then mounted atop a star picket as seen in Figure 17. It had to be firmly wrapped in tape to prevent even heavy winds from vibrating the plastic or leads. The Earthworks microphones were connected to the R-26 by 10 m acoustic leads stretched north and south along the top of the fence. Figure 18 shows the recorder and acoustic leads in the process of being taped up. A power lead was strung to a tree away from the fence, thence down to a similar power system as for the SongMeters. Each time the SDHC card had to be checked or changed, the soundscape was adulterated as the ladder was set up and the recorder unwrapped. During the first pilot study the Roland R-26 had not been delivered and a Tascam had acted in its place. This had proven very sensitive to electrical noise from the inverter, so the power system design had been modified and the Roland recordings did not show evidence of this problem. The Roland R-26 was trialed on two day trips to FRWC prior to the October pilot study.

The foam windscreen that is sold with the R-26 was used at all times, partly to protect the sensitive microphones against insects or inquisitive birds, partly to prevent the Ziploc bag from vibrating in wind, and partly because it provided a compromise level of wind protection aimed at catering to a wide range of weather conditions during the week. It was decided not to use the Roland's OP-R26CW shaggy windscreen on the body of the R-26 since it attenuated too many quiet sounds most of the time, particularly if it was wet by rain. It would have made calibration difficult, not knowing the degree to which it was wet at varying times and how much it was modifying the recordings.

Figure 17. **The Roland R-26 at site 2.**

Figure 18. **Taping the cables at site 2**.

The R-26 recorded for 33 minutes 48 seconds at a time and then reset itself and started the next recording. The sample rate was 44.1 kHz as for the SM2+, but the gain was set at 50 dB as a midpoint that suited most conditions during the pilot studies, with the sensitivity set as High.

Site 3

A second SongMeter system was mounted at site 3North, at the northern tip of the enclosure, following the pattern of site 1. This area (Figure 19) was more open than site 1. The 50 m cable for microphone SM2.3S was strung through trees to a small clearing a little over 29 m south of the ARU (Figure 20).

Figure 19. **Looking away from the rhinos at site 3N.**

Figure 20. **Site 3S.**

Also at site 3N but 2.6 m further north again, was mounted the Drift-HD720 video camera 2. Like the GoPro, it took one frame per minute, but continuously day and night apart from when its SD card was changed. While the Drift itself was waterproof, in order to power it from a large external battery, the battery and SD card covers had to remain open for the power lead. It therefore had to be particularly well weatherproofed to withstand any conditions (Figure 21), but it had also to be readily opened to be monitored twice a day as it had exhibited puzzling behavior that the manufacturer could not assist with for some time, and it had frozen up quite a few times during the final pilot study. It turns out that certain brands of the new large capacity SDHC cards were incompatible with the Drift even though they were class 10. It generally performed well during the week of formal recording with a different brand of card.

From these sites 3S and 3N visitors could often be seen lingering at their last stop on the trail before departing Fossil Rim, particularly if they could hear the commentary from a zoo safari bus (Figure 22). Children's voices from car windows were regular soundmarks. Near the Drift was a wallow that formed during rain (Figure 23), which the rhinos enjoyed walking through and drinking from.

Class 10 SD and SDHC memory cards were used in all the audio equipment for maximum performance and reliability. They were pre-scanned for any faults since some tend to glitch at higher frequencies.

RefTek Site

The seismic and infrasonic component of this project was envisaged by the principal investigator, then designed and constructed by Frank Sepulveda, a PhD

Figure 21. **The waterproofed Drift video camera**.

Figure 22. **A typical final stop on the visitor trail, as viewed from site 3N.**

Figure 23. **A refreshing drink at the wallow that formed in front of the Drift camera after rain.**

Candidate in Geophysics at Baylor University, as a component of his doctoral research. Once acquired, the data were processed and analyzed by the principal investigator.

Seismic and infrasonic sensors were laid out in a clearing slightly southeast and above site 3S, and referred to as the RefTek site (Figure 24). Since wind noise provides copious low frequency noise at and below 2 Hz, the aim was to avoid trees and long grass that might rustle and increase this noise, causing the masking of sought-after sound signals.

Three RefTek 130-01 three channel broadband geophysical infrasonic and seismic data acquisition systems were loaned by the Geology Department of Baylor University. These were fed signals by six Miltec IML LAX Infrasonic Sensors. A Geospace GS-11 D Tri-axis 10 Hz Geophone in a GSC-3D (3C) case was also deployed. There are a

Figure 24. **Setting up the RefTek site.**

number of advantages of using geophysical acquisition systems and sensors – they are inherently ruggedized, draw low power, are GPS time accurate, and offer a known frequency response. In addition the seismic recorders and especially the solid state sensors produce better acuity than most low frequency acoustic recorders.

The usual protocol is to lay out at least ten sensors, with one in the center and the others in a nonagon around it. This array enables the direction of signals to be determined, as well as enabling the averaging out of the high sensitivity to wind noise below 2 Hz. With ten sensors, the effect of wind noise could be reduced by about 20 dB. Since only six sensors were available, the prescribed pattern was followed but with a pentagon (Figure 25), but the signal-to-noise ratio could not result in as much clarity. The sensors fed signals into a custom-built gain-control and filtering circuit board, and exhibited a flat frequency response from 0.1 to 100 Hz, providing good overlap from the Roland and SM2 sonic recorder and microphone systems.

Data Analysis

In all, about 1.5 TB of sound files, photographs, and weather data were collected during the pilot and final recording periods. Unfortunately acoustic analysis is not yet as automated as other forms of remote sensing analysis, particularly for broadband acoustic analysis of entire soundscapes (as opposed to simply searching for particular sounds such

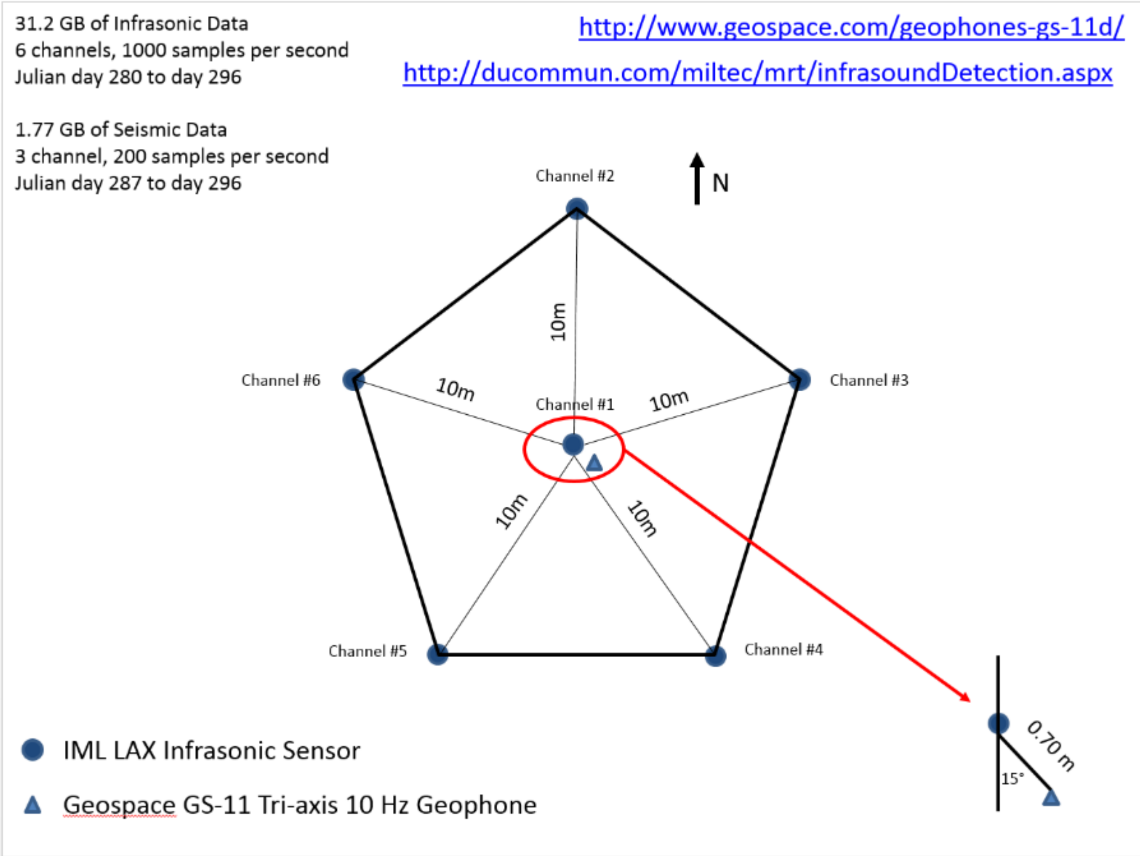


Figure 25. **The infrasonic and seismic acquisition system layout**. Due to the reduced number of sensors available, this pentagon layout was designed and drawn by Frank Sepulveda. Julian dates were displayed.

as a species' vocalization). Raven Pro 64 1.5 Beta Sound Analysis Software, Matlab R2011a Student Version technical computing package, R x64 3.1.0 and RStudio Open Source statistical language packages, and Microsoft Excel 2013 are the basis of the data analysis. The principal investigator did not write the required scripts, but learned to operate them and performed all steps of the analysis. The draft scripts were written by specialists and further information can be obtained upon request. Three well-specified home computers were used simultaneously as often as possible for the processing, the most powerful and constantly used one being an Alienware Aurora-R4 operating Windows 7 Professional with an Intel® Core i704820K CPU @ 3.70GHz with 32.0 GB of RAM and 64-bit Operating System. The following discussion relates to this computer, as the smaller ones performed more slowly.

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, and many weeks were consumed fine-tuning various options to maximize the analysis without too much loss of resolution or 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.

The sonic and visual equipment were synchronized with an atomic clock the night of 6th October, immediately before the final pilot study. Differences in timing were not noticeable at the end of the recording project.

The sample rate was set at 44.1 kHz for all the sonic recording systems. Their filename prefixes were set to reflect the sensor and the date and time of each recording.

Each half hour SongMeter setting produced a 310 MB, 29 minute 58 second stereo 16-bit PCM uncompressed .WAV file that combined the intake from the two sensors. A few seconds were not recorded while the unit reset itself then commenced the next recording. A data log text file was also produced for each set of recordings, and was updated recording after recording until activity was interrupted. A new data log file would start for the next series of recordings. These files provided the SM2+'s internal temperature readings at 5 minute increments. Apart from the first and about every sixth five-minute period they also provided the minimum, mean and maximum dB(V_{RMS}) signal levels on each channel, as observed since the previous log entry. The dB(V_{RMS}) values were measured over 1/10th of a second intervals, and the minimum, mean, and maximum values were calculated based on these 1/10th second measurements. The dB(V_{RMS}) used a reference voltage of V_0 = 1.0000 volt. To put this more precisely, and as calculated in this project, the sound level *L* in decibels is

$$L \text{ in dB} = 20 \cdot \log\left(\frac{V}{V_0}\right)$$

So the voltage V is

$$V = V_0 \cdot 10^{\frac{L \text{ in dB}}{20}}$$

The Roland R-26 was set to 0.5 GB file size rather than a recording length. This provided a file folder containing a 33 minute 48 second 24-bit PCM uncompressed .WAV file for each pair of microphones, with channel 1 being the internal directional XY microphones, channel 2 being the internal omni microphones, and channel 3 being the Earthworks M23 microphones. Included with these three files in the file folder was a text file but this did not provide any statistical analysis like that of the SM2+ files, it simply confirmed the Sample Rate of 48000 Hz, the recording format of WAV 24-bit, and which microphones were being used for which channels.

The RefTek provided 59 minute 59 second files listed by Julian date and time: ACCA seismic channels 1 to 3, ACCD from infrasonic channels 1 to 3, and ACCF from infrasonic channels 4 to 6. Matlab was used to convert the Reftek files (a proprietary format used by the seismic recorders) to wave format, and then these had to be further converted to an older form of PCM for use in Raven. The infrasonic files were converted using NCH Wavepad, the seismic using NCH Switch Sound File Converter Plus.

They were then sorted into Gregorian date and time so their results could be readily compared with the sonic files; Julian 291 for example, equates to 5am Friday 18th October. The researcher performed this processing and then treated them generally as for the other wave files.

All the wave files were downloaded into separate folders for each recorder then sorted by date and time. Since it took a great deal of study, reading, consultation with program developers and support staff, and much trial and error to develop efficient methods of processing the data, only an overview of a single day of recordings will be reported and evaluated here to prove the effectiveness of the protocol. A great deal more data can be mined from this one day later, as will eventually be mined from the entire week.

It was found that some metrics such as the dB(V_{RMS}) could be fairly readily ascertained via Matlab, but in order to create the visualization and so many other measurements offered as options in Raven, it appeared that, even for a competent programmer, Matlab was likely to take about the same amount of time to import each file into Raven, process just a small portion at a time, combine the resultant text files, and analyze the data. The novel aspect of this project is that it addresses such wide bandwidths and so much data must be actually measured, drawn, and processed in order to investigate an entire soundscape rather than something relatively narrow-band like the calls of a particular species. Other projects may have analyzed huge datasets, but most search in restricted bandwidths or otherwise narrow down the amount of calculation that is necessary, and they may draw on large institutional servers rather than private home computers. Most software processing packages, including both Matlab and Raven, find difficulty managing such large data files across such wide frequency ranges, causing the programs to become unstable and resulting in repeated unexpected errors and computers freezing.

In order to analyze each file using Raven Sound Analysis software, the Memory Manager was configured to the maximum possible setting, and the maximum heap size extended to 7,680 MB. Each Roland R-26 file was paged into a maximum length of 254 seconds (4 minutes 14 seconds), enabling its largest files to be divided into eighths. These were labelled “a” to “h”, and referred to as “sections” of the page. This length proved to be the largest sonic files that could be attempted multiple consecutive times without the program becoming unstable or the computer freezing, although this did occasionally occur if the computer was not rebooted every few hours. The 29 minute 58 second SongMeter files were also divided into eight equal sections, being 224.75 seconds long. Infrasonic files were paged to 5 minutes. Page and Step Increments were set at 100 percent to avoid overlap, so each point in time would be counted only once. Clock-time axis labels were used and the default file name template. After considerable refinement, a Window Preset was developed that would apply the same settings and layouts for each file no matter its source, with as many appropriate measurements that the computer and Raven program could manage efficiently. A Comment column was added to the default selection measurement table so an abbreviated overview of the sound events found within that page could be recorded within the resultant table.

The Window Preset included directions to measure and document:

- The View of the sound that was being measured (waveform, spectrogram, or selection spectrum);
- The Time that the selection started and finished within the file, and its delta time (length, in seconds);
- The total Energy within the selection bounds (in Raven dB);
- The Average Power – the value of the spectrogram's power spectral density in each pixel or bin, averaged over the selection (in Raven dB);
- The Peak Power – the maximum power in the selection (or the darkest point in a grayscale spectrogram) (in Hz);
- The Aggregate Entropy – the degree of disorder in a sound (in bits) – a pure tone with energy in only one frequency bin would have zero entropy. This was measured because negative physiological response to fluctuating or widely varying sound occurs in humans;
- The Average Entropy (in bits);
- The Peak Frequency – the frequency at which the peak power occurs, or if it occurs more than once, then the lowest of those frequencies (in Hz);
- The Center Frequency – the frequency that divides the selection into two frequency intervals of equal energy (in Hz);

- The Bandwidth 90% – a similar computation to the Center Frequency, but measuring the difference between the frequencies that divide off the top and bottom 5% energy intervals (in Hz);
- The Peak Amplitude – that which is the greater of the absolute values of the maximum amplitude and the minimum amplitude (in Raven units);
- The RMS Amplitude – the root-mean-square amplitude, sometimes termed the "effective amplitude" (in Raven units), key to calculating calibrated acoustic pressure and SPL;
- The SEL – sound exposure level, normalized to 1 second (in Raven dB);
- The LEQ – equivalent continuous noise level over a given period of time (in Raven dB).

The interested reader is referred to the Raven user manual, freely available online, for the mathematical definitions of these metrics.

Each page, or 4 minute 14 second selection, was inspected visually for anomalies that may need to be listened to in order to determine if the soundscape had been adulterated (for example by the investigator handling the recorder for maintenance purposes). If anomalies were discovered that should be removed from the ambient soundscape, they were removed from the selection prior to processing.

In most projects, invasive wind noise (IWN) would be considered an anomaly that should be removed. This occurs when wind directly buffets a microphone causing mechanical vibration and distortion or possibly the total masking of other sounds. Since the sensors were not readily accessible when this tended to occur, often for relatively short periods when the wind changed direction at night, windscreens could not be readily changed; there were a number of periods with IWN. However they occurred more during extreme gusts than during strong winds. When one or two microphones were affected by IWN, others generally were not, owing to their orientation along the fence and so their direction into the wind, to their distance from one another, and to the density and positioning of trees that may have shielded some microphones from certain winds. The documentation of the difference in the impact of the IWN at each site was in itself informative. Every recording proved site-specific. The inherent redundancy of systems therefore permitted the soundscape to be assessed despite a degree of IWN. Editing out all IWN and measuring the soundscape without it will be a goal of later data mining. With regard to the measurement of zoo soundscapes, the problem of IWN is likely to occur far less where there are fewer wide open spaces. With careful preparation, perhaps additional assistance, and access to the sensors at night, windscreens could be altered to suit developing weather conditions and thus to avoid this issue

The sound files were listened to while observing the spectrograms, and their contents noted. As analysis progressed certain acoustic signatures could be visually recognized. Interesting sound events and the first occurrence of an unidentified sound were documented as wave clips with their accompanying selection measurement tables, a brief description, and with screen prints of the waveforms, spectrograms and selection spectra zoomed to various scales for visual and statistical detail. These will be further investigated by comparing the same time period with recordings from other microphones and with the photos. If the sound remains unidentified, the researcher will consult with FRWC staff or volunteers, or with more experienced acousticians.

There are many instances of animal vocalizations that the researcher will need to confer about with the staff of FRWC. Identification of the vocalizations could help a researcher to confirm species on the recordings and their relative locations and distances from the microphones. Certain calls, particularly those of higher frequencies, were received at one or two sensors and not at others, or transitioned from one sensor to another. Exploring this may lead to not only more knowledge about the species and their activities (particularly their nocturnal habits), but might aid in developing alternative remote animal tracking techniques. Analysis of the contents of the sound files is a major project in itself.

Barring any anomalies, the full 4 minute 14 second page was selected, the Window Preset applied, and after a few minutes the selection spectra and measurement table would appear. The table was named to reflect the content. It and the sound file were saved. The file details, content, and any comments about that file were logged in a Sound Events Excel file. This process took about 15 to 20 minutes per ~ 4 minute sound page, but times could vary radically according to whether the contents were readily identifiable. This means that it takes about 100 hours just to process one 24-hour period for one sonic sensor, or about 4,500 hours for a week of sonic recordings. This does not include the time it takes to listen, re-listen, and notate the sound events. Matlab requires over a day of computing time just to convert one day's worth of the 9 channels of infrasonic and seismic RefTek files into wave format. It was discovered that errors crept in once the Matlab program had been working continuously for a few hours, with some sectors being skipped. Files had to be individually checked, and incomplete files re-processed. The computer was eventually rebooted after every second conversion process to avoid these accumulating errors and the need for repetition. The new wave files were then processed like the sonic files, taking a further 216 hours of computer time for Raven to process the recordings of six infrasonic sensors for a single day. As interest in analyzing entire soundscapes increases, these processes are likely to become automated just as many processes in remote sensing and geographic information systems have been automated.

Processing the infrasonic and seismic files does not require as much investigation or listening as the sonic files, since they are by definition inaudible to human ears unless the infrasonic files are played back at about twelve times the normal rate, to effectively raise their frequencies. However unusual waveforms do require investigation and it takes considerable time to manually synchronize them with the sonic files to explore links between sonic and infrasonic activity.

Once pages of sound are selected and processed, their measurements are saved by Raven into individual text files. A custom script was written for the investigator in RStudio, an open source statistical analysis language. This integrates hundreds of identically structured text files into a single excel spreadsheet, which makes the measurements contained in each file directly accessible and comparable. Once in Excel, calibration factors can be entered and the raven units converted into absolute decibel and power measurements.

Prior to the pilot studies and at a number of stages thereafter, the data acquisition systems were tested in the anechoic chamber at University of Texas' School of Mechanical Engineering to calibrate each item of equipment. This aided in the selection of windscreens, but it was discovered that there was low frequency noise within the chamber itself, possibly due to nearby construction, so amplitude calibration of the sonic systems was performed by Dr. Wilson elsewhere. The power values of the sonic instrumentation have not yet been absolutely calibrated so remain in Raven units and will not be reported within this dissertation, although these Raven units can still be meaningfully compared against each other. The RefTeks were calibrated at Baylor University and have demonstrated themselves to be inherently stable. The geophone has been calibrated for this work.

Due to the processing absorbing so much time and to the lack of calibration at earlier stages, an alternative and less comprehensive form of processing was also implemented to gain a quicker overview. This measures just the dB(V_{RMS}). The lowest dB(V_{RMS}) value can be referenced or deemed to be zero and the amount that all others are higher is calculated. These differences are then calculated into relative SPL and can be graphed and compared, with or without the full calibration of the sensors concerned. As the SongMeter registers, it logs metadata such as the time of each recording on that SD card, the temperature inside the unit (and outside if that option were to have been purchased), and the minimum, mean and maximum dB(V_{RMS})) signal levels on each channel as observed since the previous log entry. It calculates these dB(V_{RMS}) about ten times per second, and then averages those values over each five-minute interval apart from the start intervals for each ~30 minute file. Thus every sixth five-minute interval lacks dB(V_{RMS}) data. It is these measurements that were used to calculate the relative dB(V_{RMS}) and thence the relative SPL as just described. However this method results in a smoothing effect. In addition, the SM2+'s sampling method reduces the reporting of frequency energy below 10 Hz. Raven's method of calculation on the other hand is a more detailed analysis. As will be seen in the Results section, the resultant SPL curves are considerably different. Compare for example Figure 44 where the calibrated SPL for the SM2.1 files were processed in Raven, with Figure 54, the mean relative SPL as produced by the SM2+ data logs. Both the Raven process and the SM2+ data log method will be reported. In addition to processing and graphing the SPL, other acoustic measurements that have already been made within Raven could certainly be reported and graphed in this manner to provide relative trends. However they will not be fully meaningful until they have been accurately calibrated and so are not presented at this time.

Once the week of wave files on each of the five data acquisition systems are listened to by headphones and documented, the time series and spectrograms inspected visually, the wave files measured within Raven and calibrated, and all the measurements from each sensor and acquisition system synchronized, direct comparisons of various parts of the soundscape, periods of the day, sound events, and activities can be undertaken. The next chapter shows the results of these actions with an event log, discussion and examples of some of the main sound events, demonstration of two methods of analysis, and graphs of the SPL rhythm of Friday 18th. To put this day into some perspective, a brief analysis of Monday 21st October is also provided.

7. RESULTS

Sound Sources

<u>Sound Event Logs</u>

Sound event logs were developed as each recording was analyzed. A sample from SM2.1 for Friday, 18th October appears in Appendix C. Since the first 29 minute 58 second recording of the day begins at 00:20 and the last at 23:50, the last recording of the day before and a little of the next day appears in each individual daily log to provide continuity, but there are no repeats in the cumulative week-long log (not provided). The number of sections in which rhinos, anthrophonic, other biophonic, and geophonic sounds were logged were tallied for a single day (Figure 26).

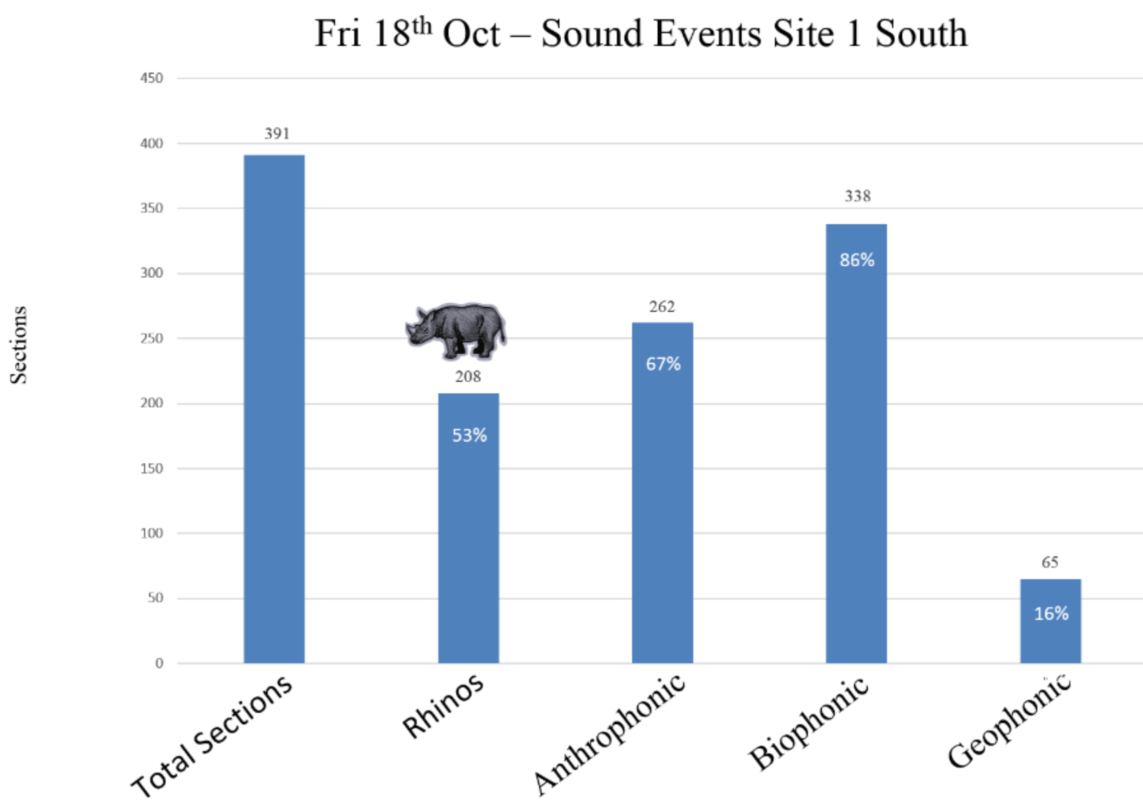


Figure 26. **The number of sections containing different categories of sound.** In this log, rhinos could be heard at least once in 208 sections or in 53 percent of the sections throughout the day. Anthrophonic events occurred in 67 percent, other biophonic in 86 percent, and geophonic in 16 percent of the sections.

Every time some sound belonging to one of these broad categories was heard in a section, it was logged; even if the sound was only a brief bark, moo, or clang. Each sound was given a specific descriptor. A "clang" indicated that heavy metal was struck. Such clangs were caused by a workman, by wind blowing metal sheets of the utilities building, or when a rhino clanged a steel rail with its horn. Since it was not possible to determine the cause of each clang, they were all noted as anthrophonic and were not tallied as a rhino in close proximity. A rhino "saw," however, was classed as "rhino proximity" since it was a clearly decipherable sound. This sound is produced when a rhino saws its horn along the fence rails (in an effort to gradually reshape its horn). "Car" refers to a vehicle on the county road, whereas "Veh" refers to a vehicle inside Fossil Rim. Sometimes it is apparent that they are driven by staff ("FRVeh") if they are close to the utilities area on the staff road. However some are difficult to determine and may be on either the staff road or the public trail, so they are simply classed as "veh". "Gravel" refers to the sound of tires on the gravel trail with no engine noise, as a vehicle slowly rolls downhill – usually it is a visitor. The number of times an event occurs within a section will also be determined and tallied, and the duration of events will also be noted as some events span two or more sections and so these will be regarded as a single occurrence.

Anthrophonic Sound Sources

Although specific sound events were logged for only 67 percent of the time, analysis showed a continual but varying low frequency band of noise that is likely to have a high anthrophonic component – possibly distant road or air transport or machine noise. It is unobtrusive, but is present. The recordings also reveal a faint but almost ever-present hum. Considering that, there seems to be no period, day or night, during which at least some anthrophonic noise was not audible. This is particularly true when domestic animals are included in this category since without humans these animals would not be where they are. Domestic animals were mainly heard at night since they were situated at a considerable distance on neighboring properties, and a bark, moo, or neigh during the day was generally masked by closer (and usually anthrophonic) noise. The dominant anthrophonic sound sources at any time were related to transportation (road, air, or, very rarely, a train whistle) or, during the day, related to staff and visitor activities within the Center.

The log reveals that on Friday 18th, of the 392 section recordings, 262 included an anthrophonic sound event at least once. The most dominant of these were 138 with cars on the county road, 101 with aircraft, 41 times with machinery or equipment, 38 with vehicles within FRWC, 35 with voices, 13 when cars rolled on the gravel without engine noise, and 10 with heavy trucks within the center. In ten sections at least one bark was heard, in 13 a moo, and in one a gunshot. Domestic animals are normally only heard at night, and then faintly, depending on the wind direction; but on this particular night they and all biophonic sources were drowned out by a storm, so they may not have communicated at all for some hours.

Air Transportation Sources

Fossil Rim's soundscape informs interested listeners to matters not otherwise apparent. In some conditions even live on-site, it was difficult to aurally differentiate planes, road traffic sounds, and thunder. Yet clear acoustic signatures in the spectrograms sometimes provided such differentiation when not masked by other noise, and the recordings often discriminated between jets, turboprops, and small piston-powered aircraft. Initially, when those Fossil Rim staff who were asked could not explain the air traffic – and in fact many people said they were not even aware of it – the investigator considered examining flight schedules to understand the plethora of aircraft on some days, and apparently none on others. Overflights can be irregular due to freight, charter, and military operations, as well as due to weather conditions, and air traffic density in nearby regions, so published schedules would be unlikely to provide an answer. A study of aviation charts revealed a major aviation navigation aid 7.6 km east of the rhino enclosure, but its mere presence did not explain the quantity or apparent irregularity of the air traffic, nor the great variety in the types of aircraft.

The aid is a VOR – a <u>V</u>ery high frequency <u>O</u>mni-directional <u>R</u>adio range device. In their most basic form, these enable instrument-rated aircraft to track from one VOR to the next by following an indicator in the airplane, even when in or above clouds and out of sight of the terrain. The routes they track are termed Victor airways, and this particular VOR (which has the identifier JEN) is a control for five Victor airways at various altitudes. Commercial aircraft cross the country using these devices, generally unheard due to their altitude if they are at 30,000 to 40,000 feet, so the quantity of audible air traffic near Glen Rose– sometimes one airplane every two to three minutes, and occasionally even concurrently – is not simply due to the VOR.

As well as guiding aircraft across the country, certain VORs are incorporated in approach or departure procedures to and from airports. In the case of Glen Rose VOR, extremely high overflying aircraft use its Victor airways for guidance in the normal way. However it may become a reporting point for aircraft from the southwest intending to land in the Dallas-Fort Worth area (DFW). Depending on the aircraft traffic flow and the wind (and thus the appropriate runway direction), DFW air traffic controllers use the Glen Rose approach to expedite the arrival of planes into the region. Once overhead this VOR, arriving aircraft are required to turn onto a heading of magnetic 039° (Figure 27). According to air traffic control's instructions they must be down to 12,000, 11,000, 7,000 or 6,000 feet within 15 statute miles of the aid and then begin a steady descent into DFW air space. Usually the largest aircraft are slotted into the highest altitude. This heading takes them within two miles of FRWC (Figure 28). The largest may pass at approximately 300 knots less than 10,000 feet overhead. At the same time, aircraft departing the DFW area towards the southwest may be slotted into the 8,000, 9,000 or 10,000 foot intervals if congestion occurs in other departure routes.

This VOR is also used as the holding point for aircraft if congestion is experienced in DFW. Then planes must follow a prescribed "racetrack" pattern of about 6 minute's duration overhead the VOR until they can be safely accommodated into the DFW traffic pattern. It is therefore likely that trainee pilots practiced their holding patterns at this particular VOR, usually in relatively small and less sophisticated airplanes unless training for an endorsement on a larger airframe. The timing and the ebb and flow of the sound of small general aviation (GA) planes on some recordings indicated this training was in progress.

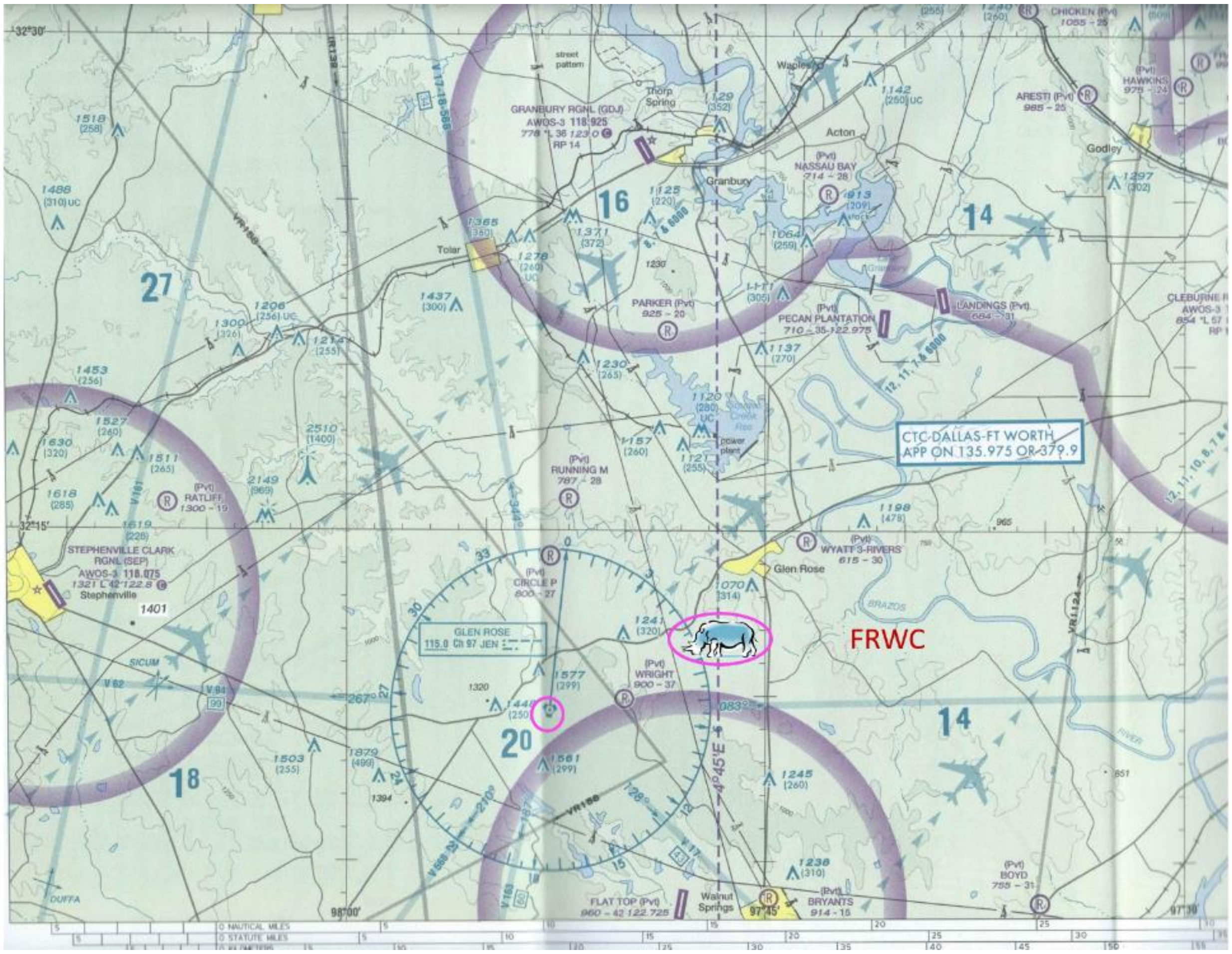


Figure 27. **DFW terminal area chart.** Glen Rose VOR is the center of the compass rose (shown in pink) instructing aircraft planning to land in the metroplex from the southwest, to fly along the dotted line heading northeast past FRWC (at the location of the rhino). Wright private airstrip lies between.

GA planes taking off or landing at nearby private airports such as Wright Ranch, halfway between the VOR and Fossil Rim, fly relatively low directly overhead if approaching or departing in that direction. During the week of recording, at least one light aircraft flew extremely low and toured Fossil Rim, apparently to observe the animals, since planes may legally fly as low as 500 feet above the terrain in this region.

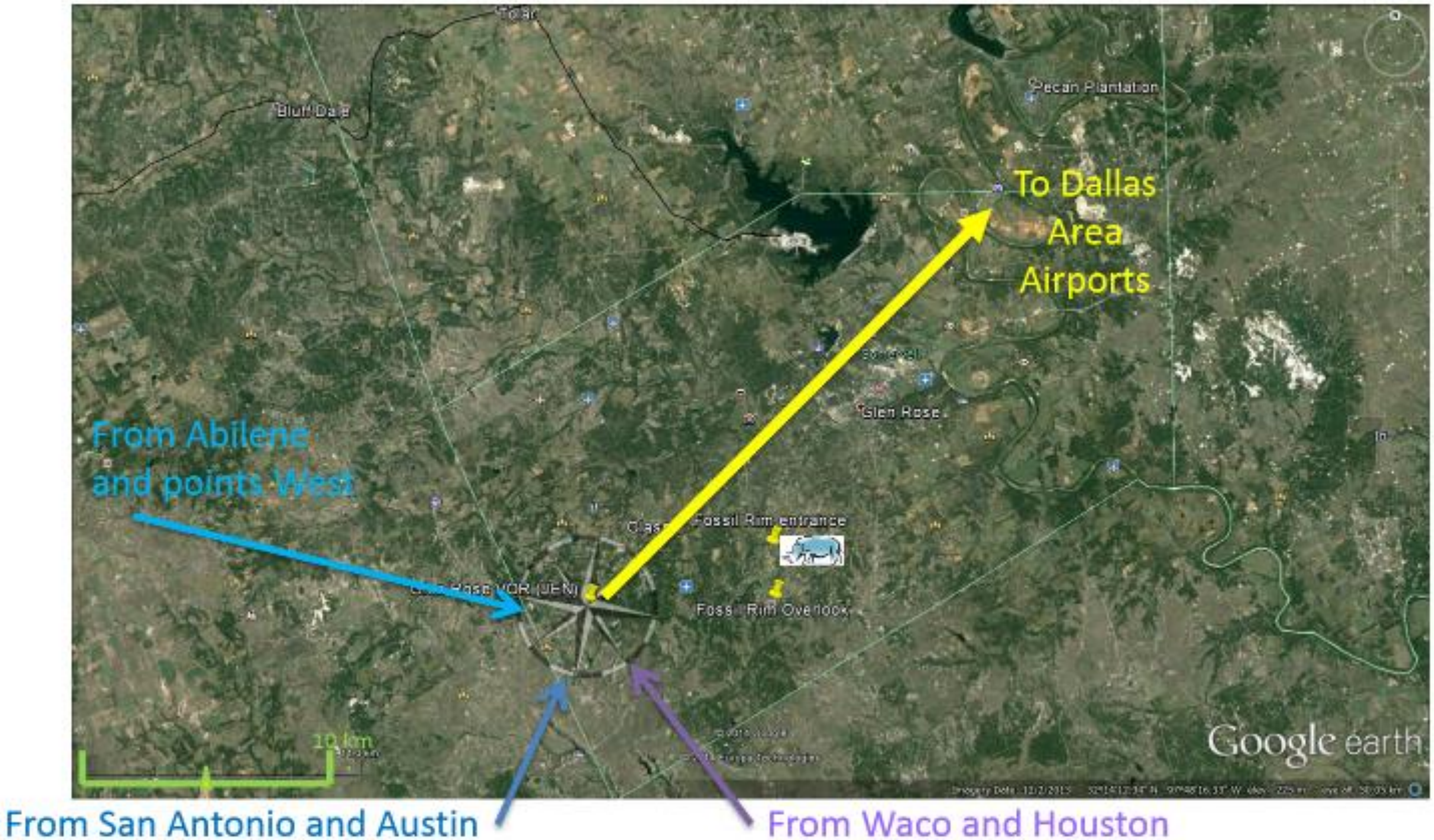


Figure 28. **Proximity of the VOR.** Aircraft pass within 2 miles of the rhinos on their descent into the DFW region.

Sometimes a series of planes appeared to be fairly distant but sounded far louder than normal. While aircraft that are particularly close usually increase the amplitude of the soundscape in relative terms, waveforms do not always indicate this, possibly due to an inversion or to them being masked by other noise. The general maintenance and traffic noise in the first third of the sound clip (including intense low frequency energy shown as yellow to white in the spectrogram) is far greater than that of the GA plane visible as the red energy hump in the spectrogram from 27m25s (Figure 29). The GA aircraft (Figures 30 and 31) flew far lower and make a sizable contribution to the soundscape. The turboprop appears to have been held over the JEN VOR and returned on its loop about a minute later, as would be expected in a holding pattern (Figure 31). The final turboprop signature may be the same plane held on another loop, or a new plane entering the pattern a couple of minutes later, which would be the required distance between planes in most instances.

Road Transportation Sources

Traffic on the county road that skirts Fossil Rim varies from one car every few minutes during an extended morning and evening commute, to one every couple of hours overnight. While never intrusive into human conversations, and apparently unnoticed by many Fossil Rim staff and visitors, these vehicles can be distinctly heard on the recordings. Although there are few cars at night, on some evenings the road noise from US-67, 1.75 km away, is a significant contrast to the otherwise quiet countryside. There are small rolling hills, farmland, and small forests between Fossil Rim and the highway which help absorb much of the noise, particularly the higher frequency engine noise.

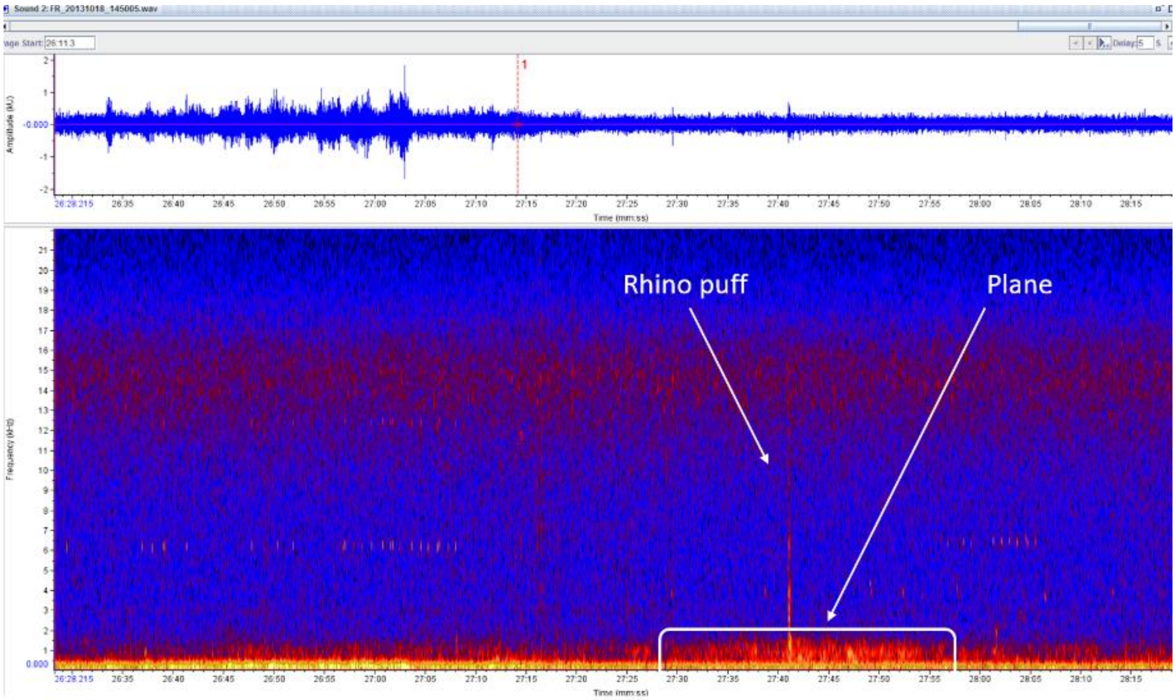


Figure 29. **GA aircraft with relatively low amplitude in an already noisy soundscape.** Despite the spectrogram indicating a considerable area of strong energy, the amplitude of the aircraft is not high in relative terms. The spike midway during the plane's passage is a rhino's "phew" vocalization.

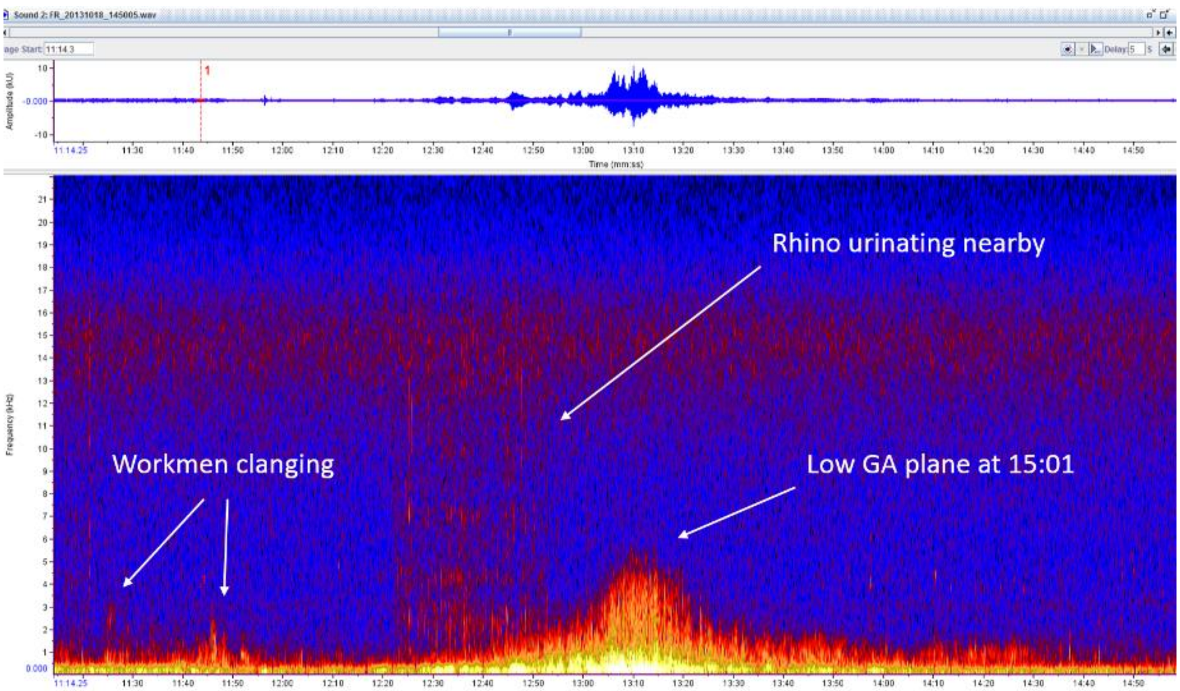


Figure 30. **Clear GA aircraft acoustic signature.** The spectrogram image provides a clear signature of a low flying, loud GA plane with little immediate background noise, with its steady rise as the plane approaches, its curved peak, and then a little more irregularity on its departure, all within a couple of minutes.

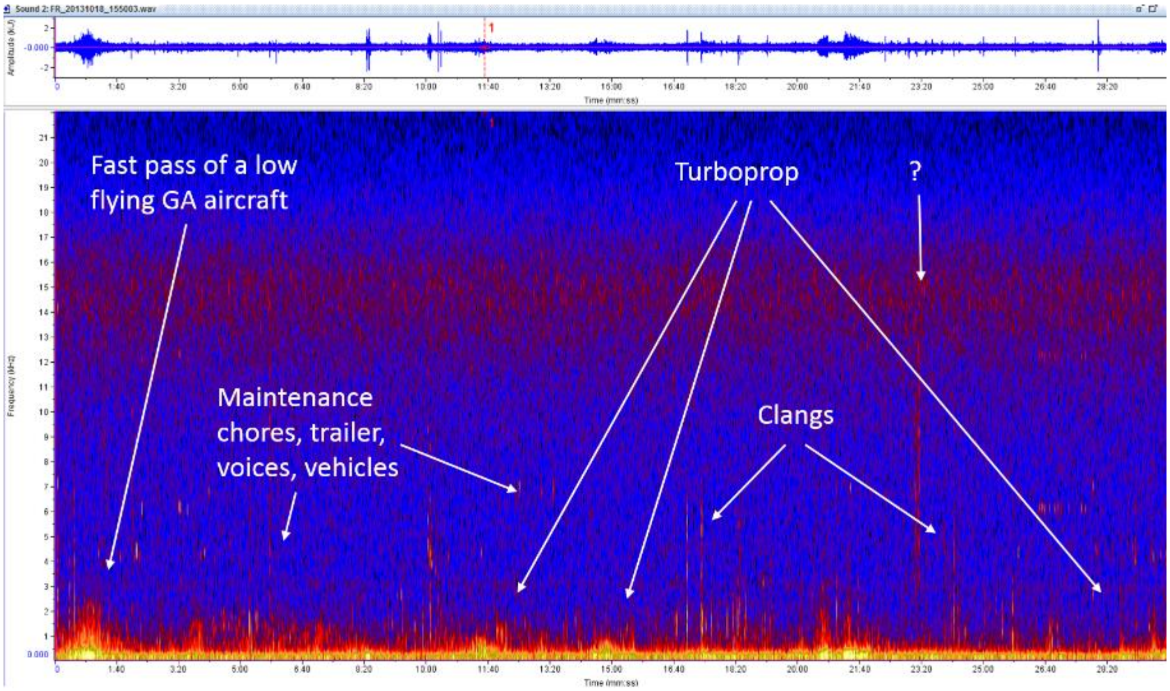


Figure 31. **Low flying GA plane followed by a turboprop apparently held over JEN VOR.** Each leg of a holding pattern would normally last about one minute.

The sound that permeates is generally the low frequency hum or drumming of heavy vehicles' tires on the road, combined with but not masked by dull engine noise.

Biophonic Sound Sources

Despite animals not being anywhere near a recorder most of the time, since they have a large area in which to graze, and although visitors may not hear the rhinos and many other species at FRWC vocalizing to a great degree, the recorders show evidence that the animals vocalize frequently. The higher harmonics of their calls attenuate over distance, but the low fundamental frequency nature of their expressions carries a considerable distance. Unlike some species, the rhinos do not appear to cease vocalizing during normal to relatively loud anthrophonic noise, although since this project is not to record the rhinos per se, it is not known whether they reduce their vocalizing during periods of high noise. However, their broadband acoustic signatures cut across other sound events and rise higher than much of the noise, so their calls are generally not masked (Figure 29).

Insects and birds were prolific and highly audible day and night. The biophony was dominated by insects during late afternoons and evenings, and by birds during the dawn chorus and into the day, but birds diminished as the day wore on, as would be expected in a natural soundscape. Both insects and birds appeared to cease vocalizing when there were high levels of sound from anthrophonic or geophonic sources. At these times, just birds with loud shrill calls could be heard, but even they generally vocalized during gaps in the noise.

It is not the purpose of this dissertation to identify the birds, animals, and insects whose voices are documented in these recordings. I will endeavor to avoid naming them until they are confirmed by specialists. However, the data are a potential resource for later investigation. It can be said that the October 2013 keynotes of Fossil Rim were dominated by katydids, crickets, and killdeer much of the day and night, behind the soundmark of animal vocalizations from the many species in the area, nocturnally including the howls of coyotes and other species that vocalized less frequently but whose voices penetrated the soundscape for great distances (Figures 32, 33).

Depending on weather and when there is not too much ambient noise, the keynote insects and birds can be seen in most spectrograms, so much so that even a glance at a typical spectrogram provides the experienced viewer with an immediate sense of place (Figure 34). The 4 to 5 kHz bird band, mainly the flight call of the killdeer, is strongest during the day but the 2 to 2.5 kHz band of insects is visible at all sites from late

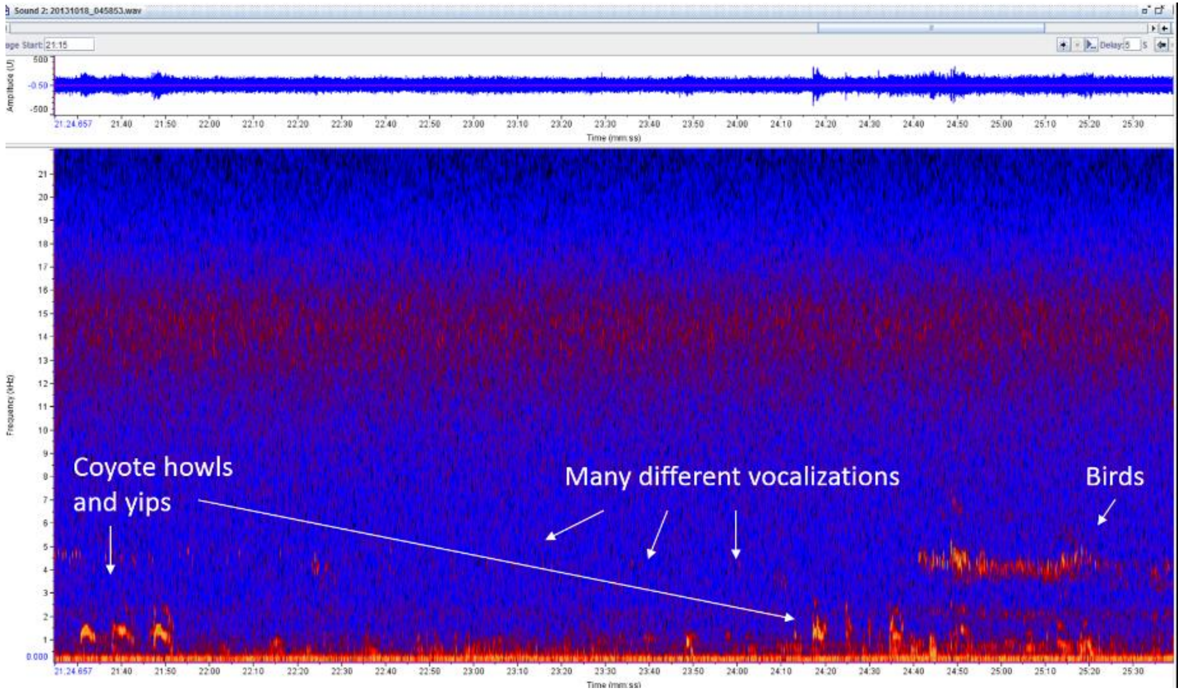


Figure 32. **Coyote howls with some yips towards the end.**

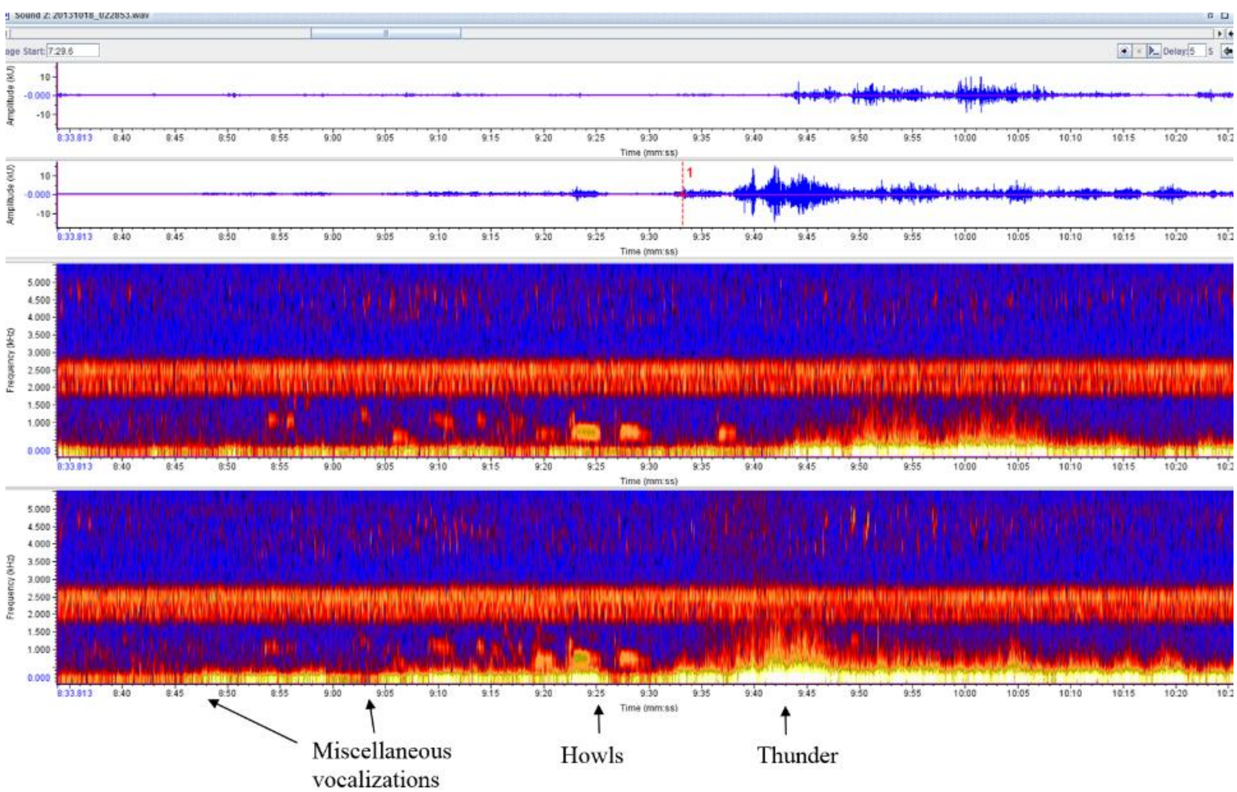


Figure 33. **The howls of another species**. Note their different shape.

afternoon until a few hours before dawn, at times being very intense. All the biophonic frequency bands vary in strength according to the weather, time of day, and one would expect also seasonally according to the life cycles and migrations of the species involved.

Higher frequency sound waves are absorbed more quickly than the longer low frequency sound waves, which tend to be deflected around obstacles, so high frequencies are not as detectable from some distance away. The spectrum below the spectrogram (Figure 34) reports the power of each frequency. Increases appear as humps for the frequencies with the most power and thus indicate the strength of (from left) the very low frequency noise band, the voices of mammals and other animals that are generally seen below 1.3 kHz due to only the lower frequencies carrying over this distance, insects in the band at the 2.25 kHz peak, and the birds at the ~ 4.7 kHz peak. Although bird calls are not as continuous as insects nor are they the lowest frequency noise, they contain a considerable amount of power. Note that the source of the strongest (reddest) animal call just before 1 minute was likely to be closer than the other vocalizers, as its spectrogram retains a higher frequency harmonic.

Six hours later this dominant 4 kHz band of bird calls had strengthened considerably so was still clearly visible even against the noise at sites 1 and 3 (Figure 35). Bands of insects, birds, and small animals (such as field mice) appear at different times of day or night, but tend to disappear during periods of high ambient noise. The wide but unidentified noise around 15 kHz that permeates the SongMeter files is suspected to be an artifact of those recorders, or possibly a result of their settings; it was not noticed in the initial trials. They may be faithfully reporting the noise in the soundscape, whether biophonic or anthrophonic, but this is conjecture and requires verification.

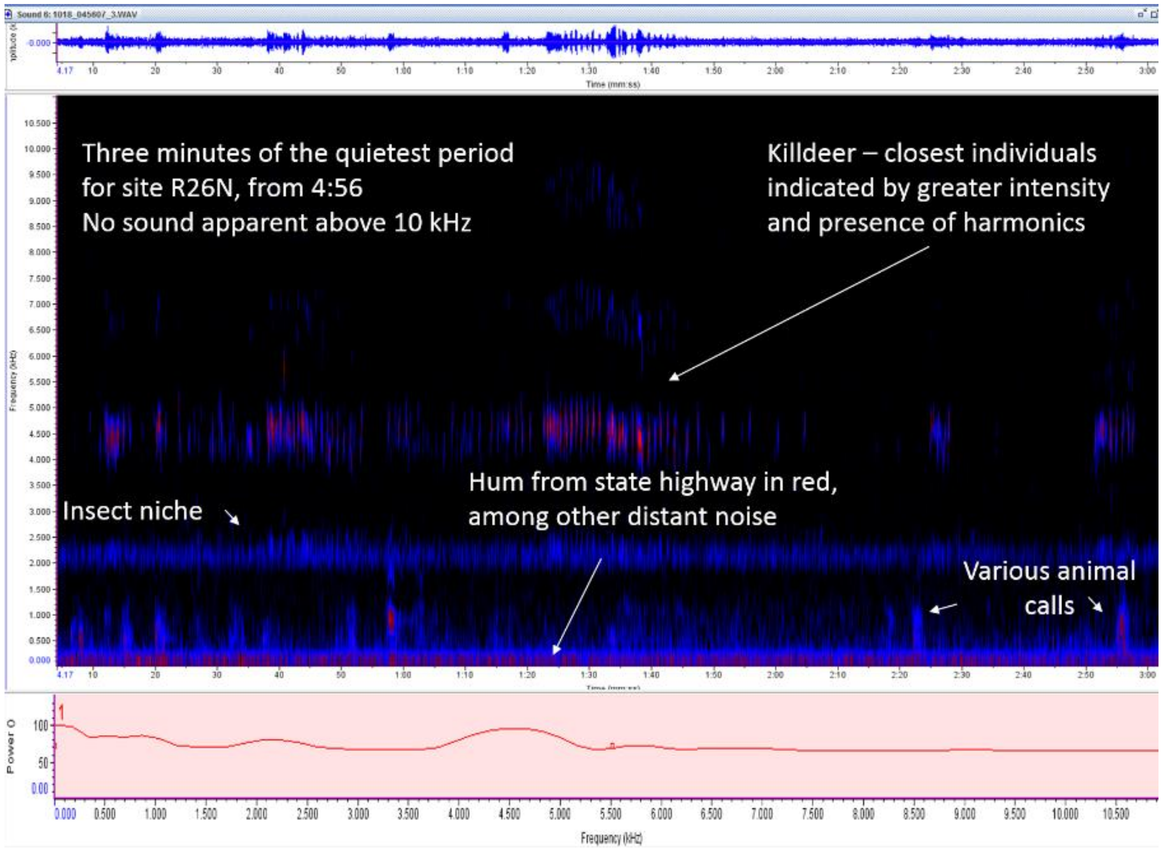


Figure 34. **Typical quiet night midfield.** This recording was from R26N at 5am, the quietest period of 18th October. Sites 1 and 3 usually exhibited similar but even more intense biophonic niches, especially early evening, possibly due to larger populations living in or near the more open ground. The SM2 sites were subject to more noise day and night, so these biophonic bands were not always as distinguishable there.

Another keynote was probably the northern mockingbird (Figure 36), seen particularly in the early mornings but may be heard at night as well. It can be difficult to identify them by sound alone or to count their calls as they vary quite widely and they mimic other birds' vocalizations as well. Crows were also frequently heard, the harmonics of their calls penetrating a wide frequency bandwidth. For many birds, including crows, their loudness appears to be associated with multiple, possibly resonant frequencies.

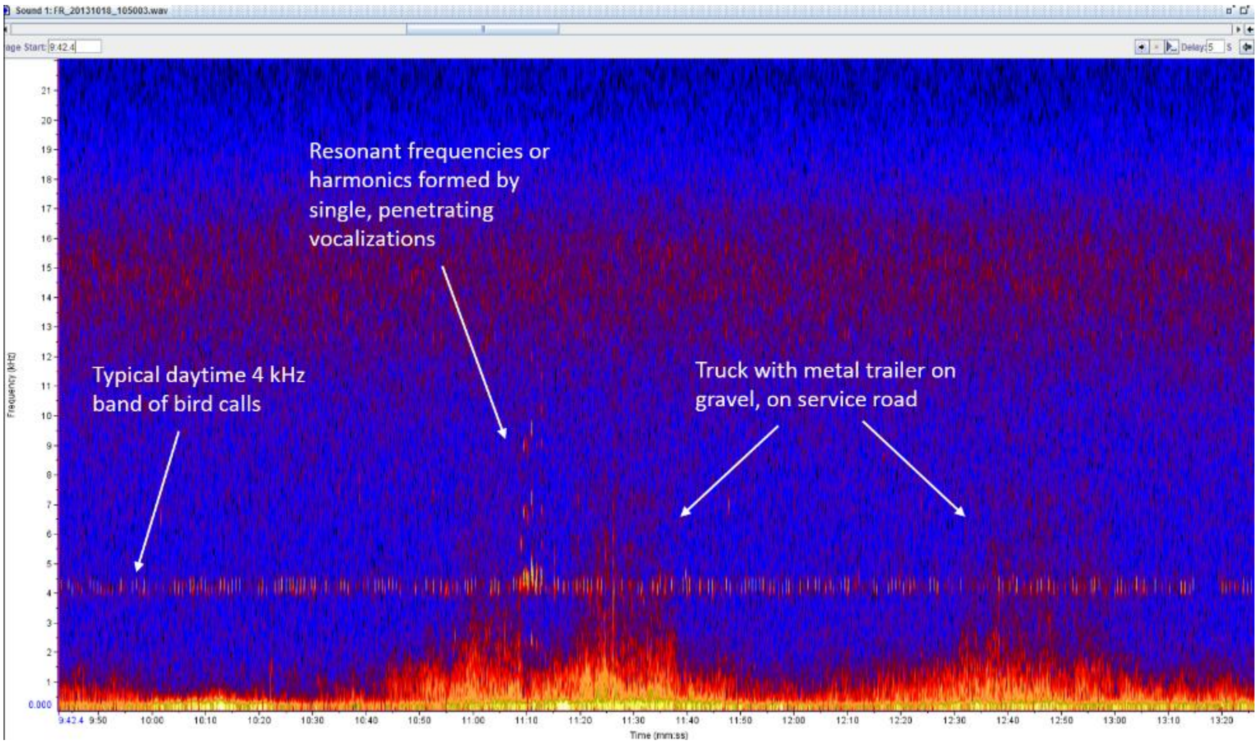


Figure 35. **Characteristic frequency bands.** By 11am the typical 4 kHz killdeer niche at sites 1 and 3, was stronger, as was the extremely low frequency band of noise.

One or more biophonic sound events appeared in 343 sections, but this number would have been higher on nights without so much wind noise. Birds were heard in 312, with crows in 53. Killdeer were seemingly ubiquitous, but these have not been separately counted due to doubts about accurately distinguishing them. All the calls that might have emanated from the northern mockingbird could not be identified from the recordings due to their diverse nature. Insects, especially the katydids and crickets, were dominant in 134 sections from late afternoon until a couple of hours before dawn.

White rhinos could be heard in 208 sections; 118 were at night (before civil daylight at 7:12 or after civil twilight at 19:21), which reveals their nocturnal habits and that neither Thursday nor Friday nights were expected to experience temperatures below 4.5^{o}C, a threshold at which the rhinos would be taken to their night-house.

Figure36. **Northern mockingbird near the utilities buildings.** Unless seen, it can be difficult to identify this species from the recordings or the spectrograms.

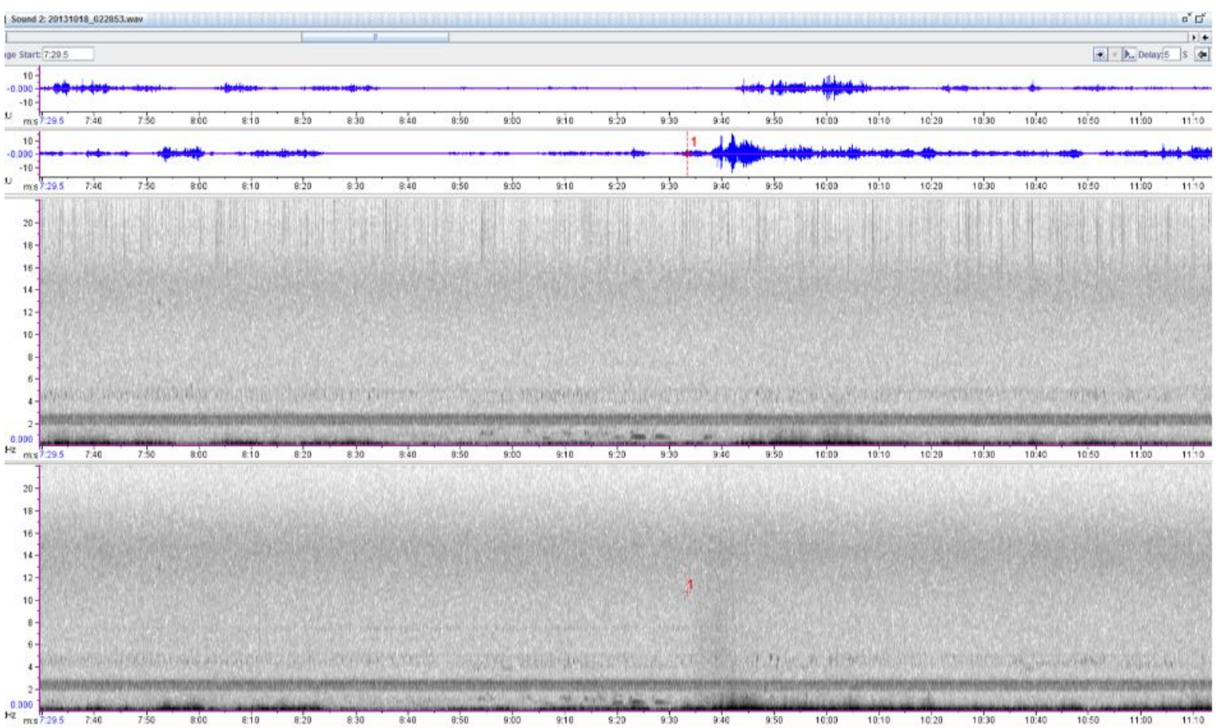


Figure37. **Hidden secrets.** The vertical pattern at the top of the spectrogram for SM2.3S may be bats.

The Southern White Rhinoceros (Ceratotherium simum simum)

While this project is not a study of rhino vocalizations *per se*, it provided many examples of grunts, puffs, growls, snorts, grouches, and pants that can later be further examined. Also recorded were their walking, trotting, grazing, and in particular, their sawing of horns against the fence rails. Their precise locations and activities were not determinable apart from aurally but one can distinguish which microphone they were nearest. While it is not be possible to use this database for more than a general survey, it is evident that they use a broader band of frequencies than the generally accepted 5 Hz to 8 kHz (Baskin 1992; Policht et al. 2008). Vocalizations were often found to reach at least 15 kHz, though faintly if they were not close (Figure 38) and sometimes 18 kHz

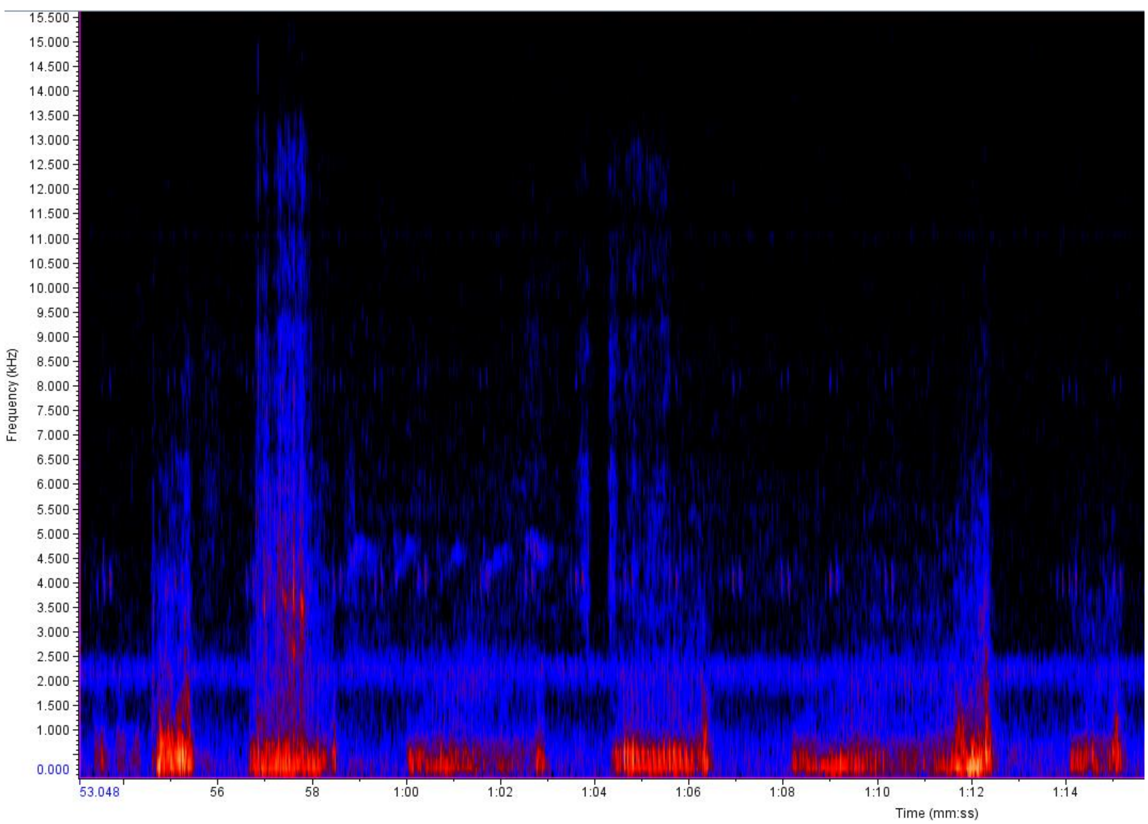


Figure 38. **White rhinoceros vocalizations**. Most rhino vocalizations demonstrated acoustic energy visible up to 15 kHz, although weakly at the top of its range. It may be that still higher frequencies were attenuated since it was not known how far the vocalizers were from the microphones.

or higher (Figure 39). To detect them in the highest frequencies, vocalizations require greater proximity to the microphones as the highest frequencies attenuate over distance. Proximity is difficult in this setting due to the size of their enclosure, but it might reveal that their vocalizations extend higher than generally acknowledged.

It appears that the rhinos use additional energy in the presence of high amplitude ambient noise (Figure 39). This sequence, which appears to be very similar on both microphones, starts with a loud truck and trailer, during which one or more rhinos growl and puff. Over the next minute there are at least six more puffs, each ending with clear lip trills, and the strongest, at 0m47secs, commences with what sounds like an inhale and then extends to 18 kHz, with possible harmonics higher still. There was rarely much other

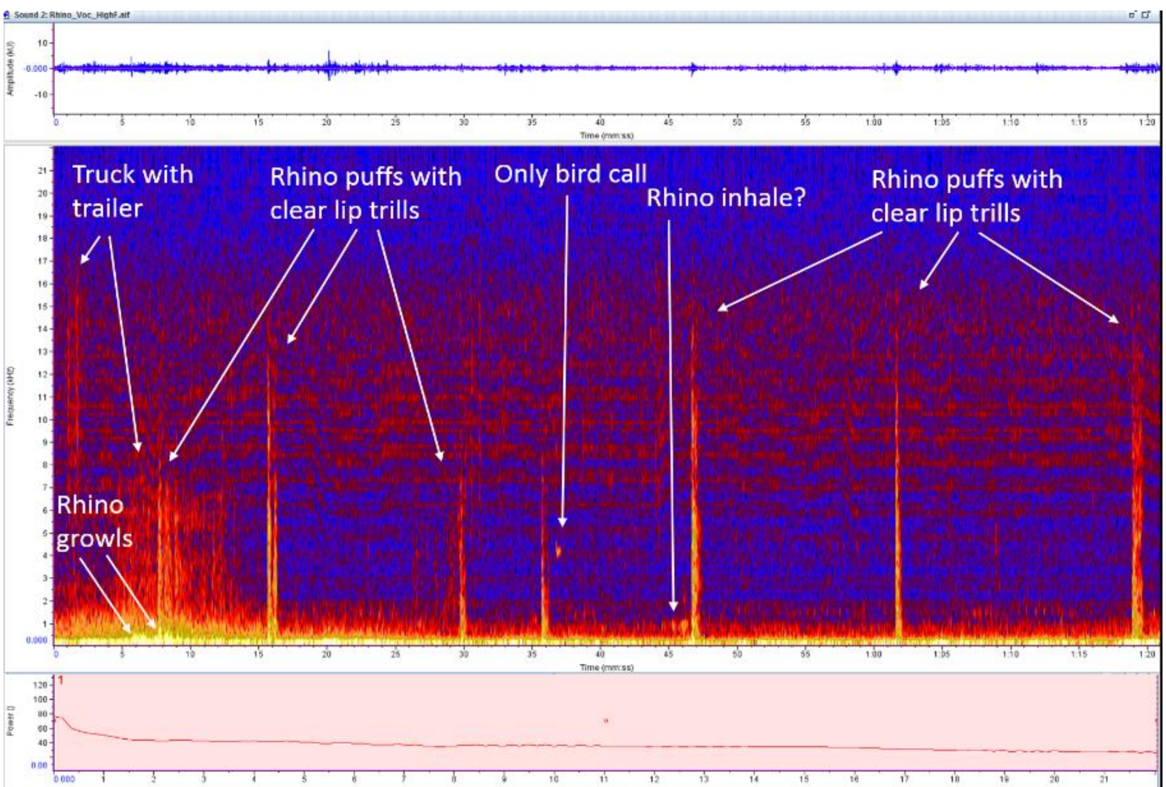


Figure 39. **Puffs against machine noise**. This series of vocalizations is against an interesting backdrop of machine noise but illustrates puff calls of intense low frequency energy, stretching up to 17 kHz and at 0m47secs to 18 kHz and possibly higher.

biophonic activity detectable during periods of loud machine noise, but there was one bird call in this sample. The highest amplitudes in the waveform do not necessarily correspond with the rhino vocalizations, although blips are evident each time. The waveform at 1m05secs lasts longer and is higher than that at 0m47secs, although the spectrogram shows that the latter vocalization covered a higher frequency range and appeared to cover a wider time as well. The low frequency noise in the spectrogram masks the rhinos' intense energy at low frequency. The lower limit of their vocalizations cannot be determined. Likewise, the highest amplitudes in the waveform were brief pulses and at least the one at 0m20secs did not seem to be reflected in the spectrogram. The selection spectrum below the spectrogram indicates the high power at low frequency that is typical of FRWC, but lacking the usual biophonic humps at 2 or 4 kHz – just a long slow decline of energy as the frequencies rise. A further observation was that as had already been hypothesized (Davies, Krebs, and West 2012), the rhinos' vocalizations with repetitions of short syllables across a range of frequencies does increase their detection in the face of ambient noise.

Once the data from the infrasonic sensors have been examined in detail, lower extents of the various rhino expressions can be explored, but in order to ascertain the full range of their vocalizations, a controlled study would be necessary. To establish a solid, basic understanding of their vocalizations, at a minimum the precise distance between the recorder and the animals must be determinable.

Geophonic Sound Sources

Atmospheric conditions played a major role in determining the distance and direction from which sound events could be heard, and not only due to the spatial relationships of sound sources to wind directions. The influence of atmospheric conditions at FRWC was apparent for certain anthrophonic events whose sound sources could be readily identified – for example heavy trucks on the state highway, or aircraft that could be seen but were sometimes heard and sometimes not. Further analysis will incorporate atmospheric conditions into the sound event logs. They will be synchronized to identify the temporal relationships of events and sounds at each sensor location, the weather conditions, and whether the sound event is accompanied by increased infrasonic and/or seismic activity.

At least one geophonic sound event appeared in 65 sections on Friday 18th. Five contained the sound of rain and five contained thunder (Figure 40). In three sections, there were strong wind gusts without sustained wind. When a weather front arrived around 9 pm, wind gusts topped 53 kph and the wind, later thunder as well, masked all other sounds for most of the evening.

Nocturnal Sound Sources

In contrast to the dominant anthrophonic daytime sound signals like keepers' vehicles and voices, zoo safari bus tours, and maintenance and visitors' vehicles and activities, and despite some anthrophonic noise being audible much of the night, the nocturnal soundscape was largely biophonic and geophonic, yet the nights were not quiet.

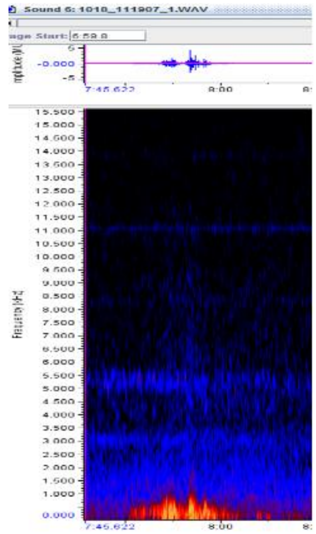


Figure 40. **A single peal of distant thunder.**

Wind was a regular nocturnal keynote, frequently strengthening overnight and diminishing before dawn. Katydids or crickets dominated the biophonic keynotes late afternoon until well after midnight. Individual vocalizations of rhinos and of Fossil Rim's semi free-ranging stock plus wildlife of various species could be heard each night and during the day when the ambient levels permitted. It seems they vocalized more often and with higher ambient SPL on evenings following a particularly loud day when they had been masked, such as Monday 21^{st}. While examples of this have been noted, further study of a number of other nights is required to confirm this trend.

Some sound signals were exclusively crepuscular or nocturnal, such as coyotes that sometimes yipped shrilly in the hills surrounding the center. Their howls and those of other species were heard infrequently but appeared to carry long distances. Even at night, birds could become active. After an extended period of quiet, a sudden noise may be followed by a bird shrieking and then some communal chattering, as if many had suddenly awoken. Sonograms often depict the nocturnal events quite clearly (Figures 41 and 42).

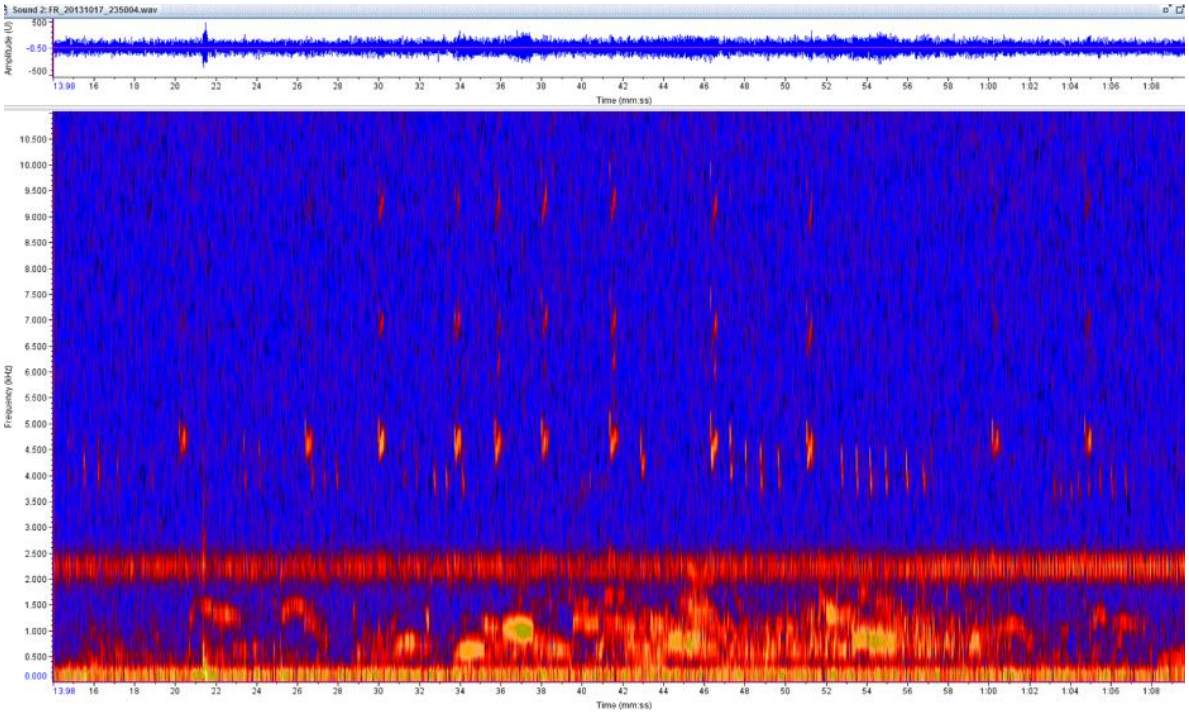


Figure 41. **Sudden nocturnal vocalizations.** This midnight sound event registered at site 1 on the morning of Friday 18th October. Much of the storyline can be read like a book once one zooms in to see individual features and the language, or waveforms and spectrogram shapes, have been learned. The sonogram follows an extended quiet period that ends with a few sudden killdeer chirps. Insects buzz strongly at 2 kHz throughout. A coyote joins the killdeer with a couple of yips. By 0m21secs these turn to howls and a bird with a penetrating broad band call spreads the word. Then a myriad of vocalizations from other species bursts forth like a conversation, starting with a very low moo-moan at 00m30secs. After about 30 seconds more, the vocalizations gradually subside.

Portrait of a Day – Friday 18th October

Friday appeared to be a cloudy to overcast day, fairly normal although not particularly peaceful, with maintenance equipment being loaded or used around the utilities area, staff vehicles on roads inside the center, and grass mowing and weed trimming for much of the afternoon. Some days were considerably quieter, according to the maintenance schedule. The audible "highlight" of Friday was the sudden arrival of a major weather front at 9pm. The official weather station on The Overlook recorded winds with gusts little below gale force at over 53 kph. In the valley, the ProWeather

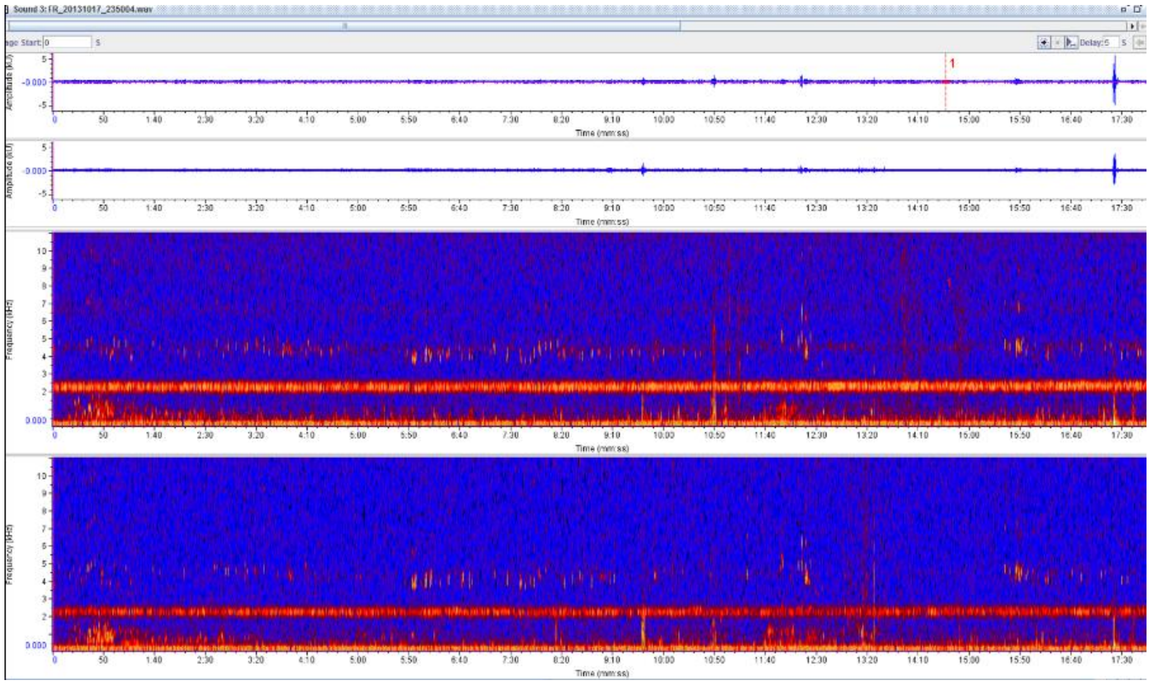


Figure 42. **Midnight as registered at site 1.** Each sonogram, like this 18 minute segment, tells a story. The period in Figure 41 is included at small scale at the start of Figure 42, which depicts 18 minutes from 23:50 to 00:08. Once the early burst of vocalizations subsides, at low frequency in the background one hears what sounds like a relatively high powered motor idling or the slow throbbing of a touring bike or sports car. This may have occurred on the county road to the east, behind the rhino enclosure, or to the west when FRWC interns drive through the pasture to their dormitory. Above the sound of the engine are bird calls, and interspersed throughout from time to time are individual barks and vocalizations. The car or bike changes gear a couple of times and then fades. In the remaining relative peace one hears the state highway road noise hum 1.75 km away, but no individual cars. At 8m18secs, 9m40secs,and 10m50secs a rhino grunts then huffs and starts to walk away, at 11m40secs a car passes on the county road. From 10m50secs and 13m10secs a rhino is heard grazing and walking closer, apparently past SM2.1N where she is heard initially, towards SM2.1S where by 13m50secs her grunt is only recorded there. At 12m20secs and 15m50secs a bird or two provides more intense chirps. In the background throughout, a dull semi-constant machine noise lifts and falls occasionally and becomes indistinguishable with the highway road noise. At 14m30secs a clang occurs, perhaps the rhino knocking the fence rail, and this is followed by huffs and urination. From 17m20secs a rhino still closer to SM2.1S growls to cause by far the greatest amplitude registered for the period, then huffs to close this sequence.

station near the utilities buildings logged just under 40 kph. However the speeds jumped from some hours of zero wind to gusts over 27 kph in several minutes, and swung from west to northwest. At The Overlook the wind swung from south southeast directly to north northwest then it gradually developed into a northerly wind. The utilities area was probably sheltered by The Rim to its south, and the ProWeather station by trees and to some extent utilities buildings to its south and southeast. The following audio snapshots demonstrate how widely the wind direction and strength vary due to the shielding of the bush over small areas even just on one side of the rhino enclosure, and how critical the orientation of even omni-directional microphones. Each recorder reflected the sudden onset of the wind. The R-26 Y microphone pointing west directly into the wind suffered IWN and clipping, and reported 93.8 dB while the southern SongMeter at site 3, which was partly shadowed by trees upwind along its fenceline and which faced southwest, registered only 68.7 dB.

No precipitation was recorded by the official Fossil Rim weather station at The Overlook (Figure 43), however both the acoustic data and the ProWeather station revealed a brief local rain squall in the valley around 9:30pm, registering just 0.5 mm. Distant rolling thunder was recorded for almost half an hour from about 10:30pm. Shortly before midnight there was what sounded like hail striking the microphones nearest the utility buildings. It might possibly have been a swarm of insects since the other microphones did not record the sound.

Raven Pro Interactive Sound Analysis Processing

This segment demonstrates how Raven software was used to process the recordings from SongMeter 1 and from the directional XY microphones of the Roland R-26. The Raven RMS were calibrated for each individual microphone in order to enable them to be directly compared as contemporaneous recordings from different sites (Figures 44, 45, 47, 48). Each is a snapshot of the day from the perspective of that site.

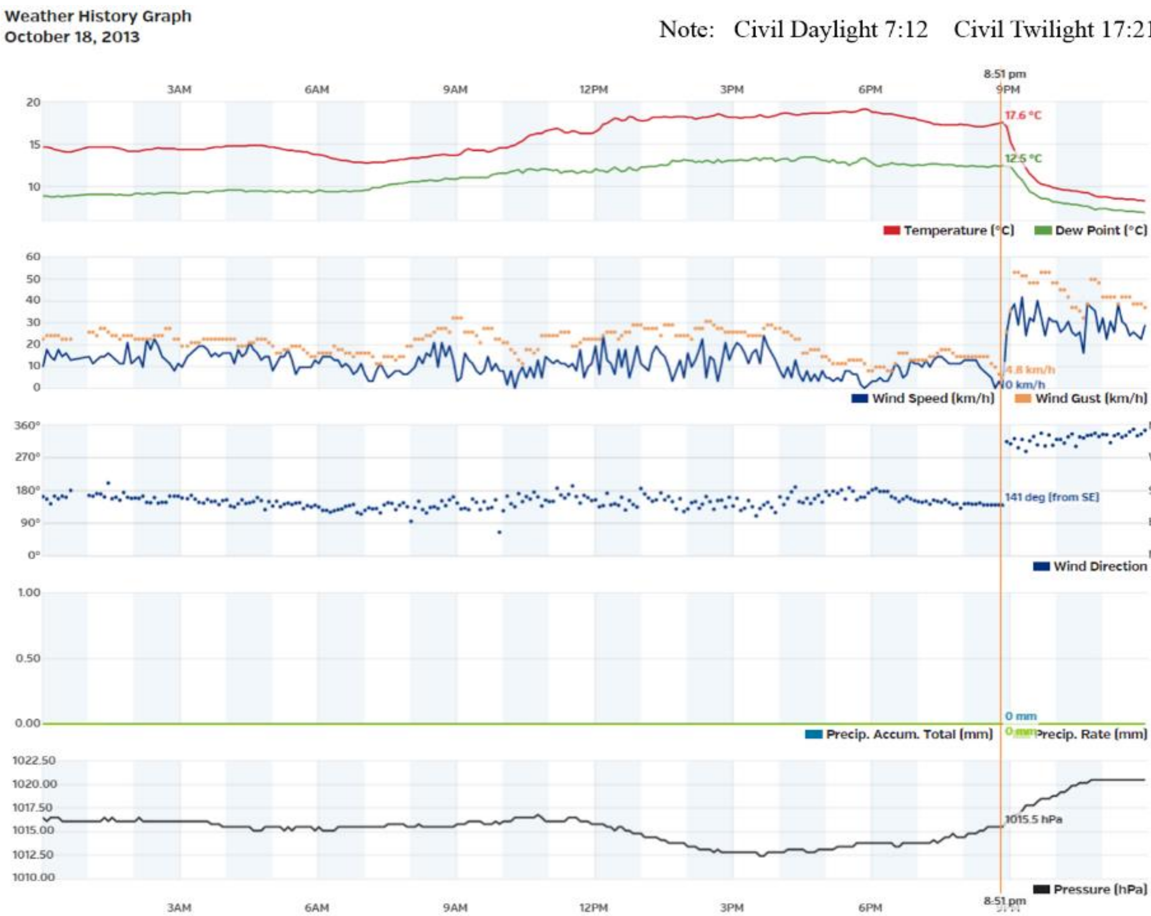
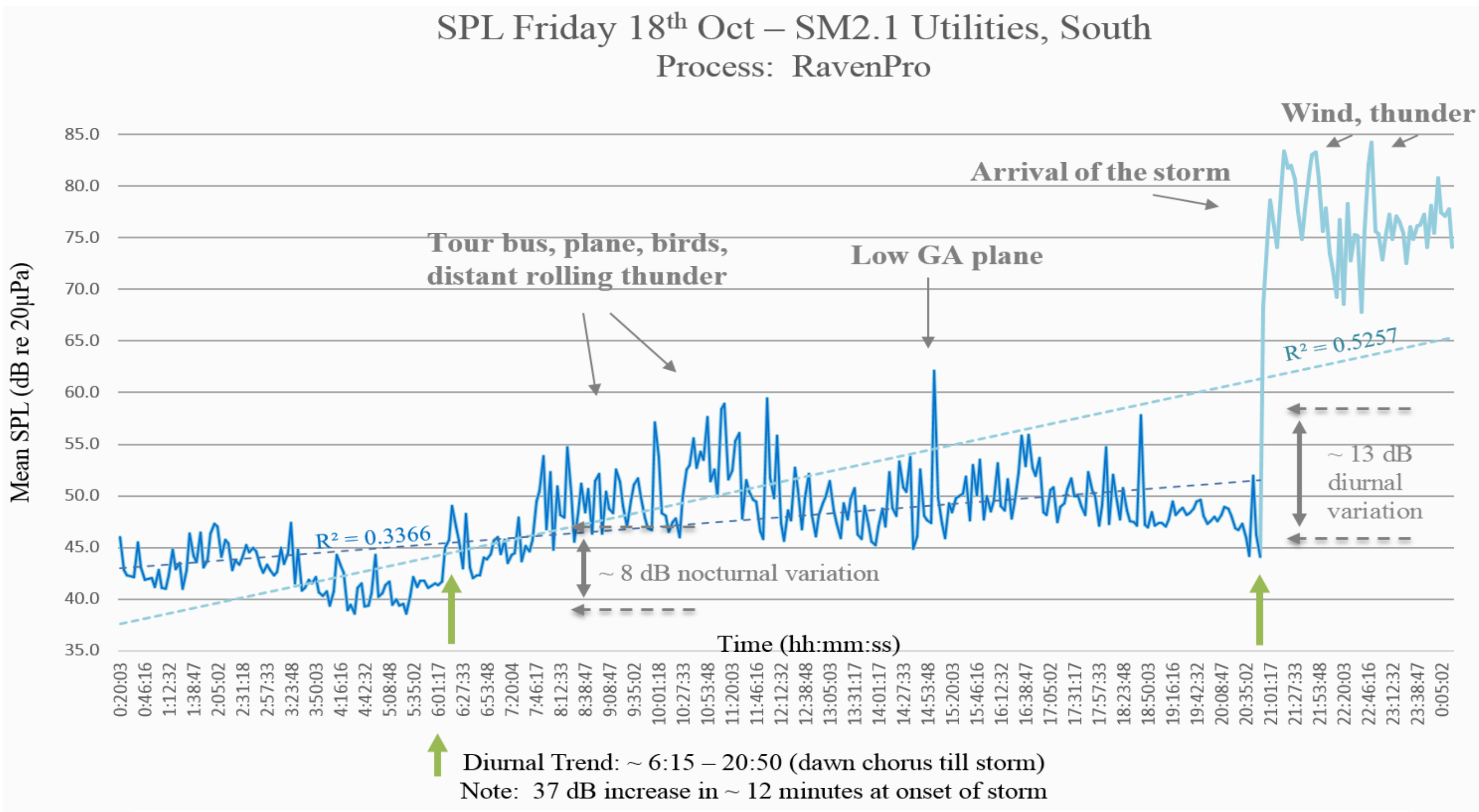


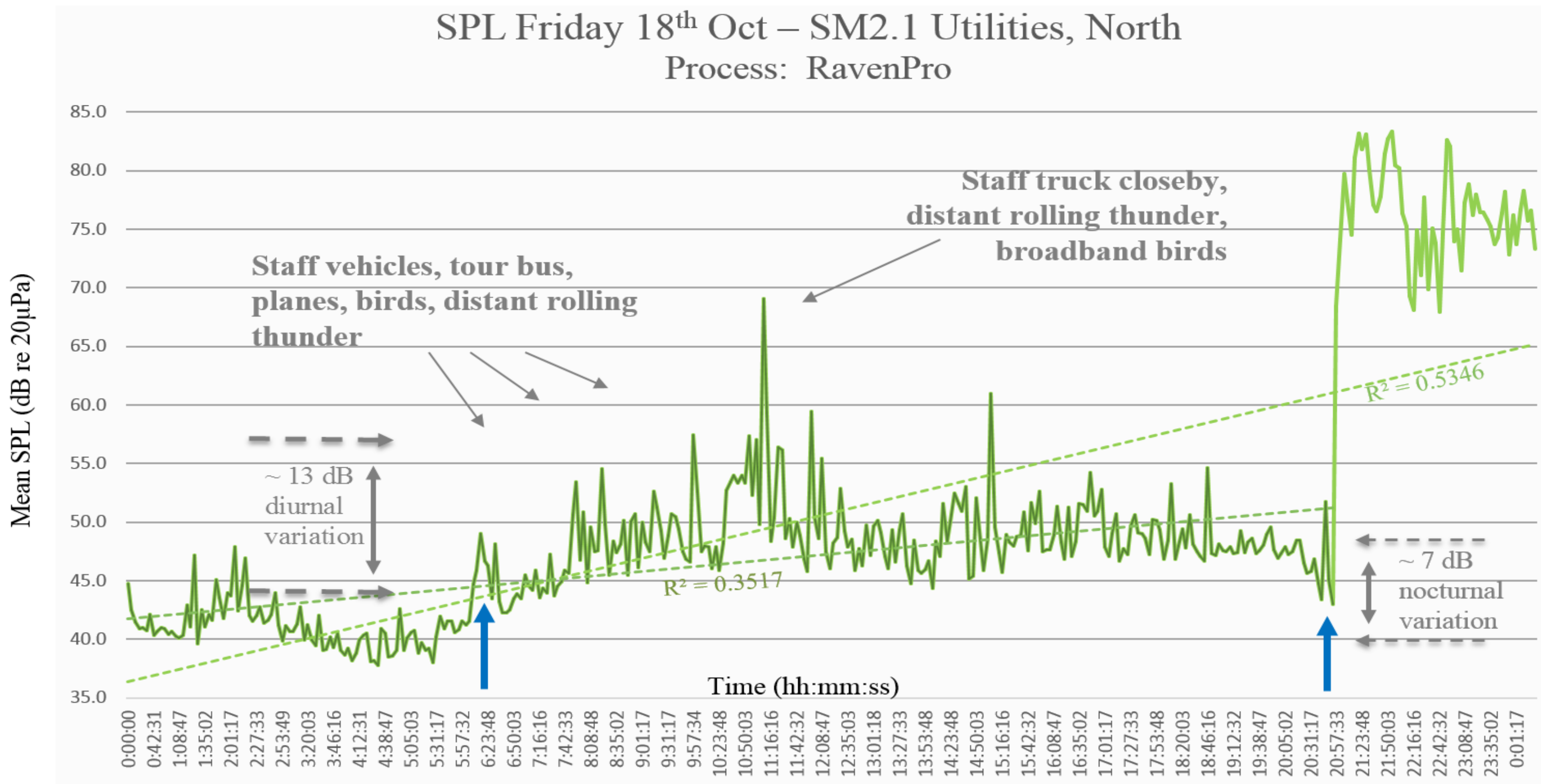
Figure 43. **The 24 hour report from Weather Underground**. Station KTXGLENR3 (http://www.wunderground.com/personal-weather-station/dashboard?ID=KTXGLENR3#history/s2041/e2041/mdaily last accessed 5 November 2014) located at The Overlook, 1.6 km south and 75 m above the rhino enclosure, shows the sudden change when a front hit at 20:56 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^{o} from SE to NW (navy dotted line). There was no precipitation recorded (flat green line near bottom). The atmospheric pressure rose as a result of the front. All microphones recorded the dramatic change.

The white backgrounds represent the site 1 / Utilities microphones, mid grey are the site 2 / midfield microphones, and the dark grey backgrounds represent site 3, near the County Road and the main entrance to Fossil Rim. The blue curves represent the southern of each pair of microphones, while the green curve is the northern microphone. Note the changing scales from image to image according to the noise exposure, the data



	Mean SPL Interval	Trendline	Minimum SPL	Maximum SPL	24 Hour Variation	Diurnal Variability	Nocturnal Variability	Average SPL	Standard Deviation
Incl Storm	4m14sec	$R^2 = 0.5257$	38.6 dB at 4:31, 5:27	84.2 dB at 22:50	45.7 dB	~ 13 dB		51.5 dB	11.1 dB
Before Storm		$R^2 = 0.3366$		62.1 dB at 13.01	23.5 dB		~ 8 dB	47.3 dB	4.2 dB

Figure 44. **Recorded nearest the utilities buildings.** Following a relatively quiet day near the utilities buildings, where the loudest sounds were normally vehicles, machinery, equipment, aircraft, and crows, the 9pm weather front was a major contrast.



Diurnal Trend: ~ 6:15 – 20:50 (dawn chorus till storm)
Note: loudest plane 1.1 dB quieter, and peaked a fraction later

	Mean SPL Interval	Trendline	Minimum	Maximum	24 Hour Variation	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
Incl Storm	4m14sec	$R^2 = 0.5346$	37.8 dB at 4:31	83.4 dB at 21:53	45.6 dB	~ 13 dB		50.8 dB	11.4
Before Storm		$R^2 = 0.3517$		69.1 dB at 11:08	31.3 dB		~ 7 dB	46.5 dB	4.6

Figure 45. **From SM2.1 North.**

acquisition system, and the activity registered at each location. To avoid over-crowding the graphs, identification of sound events is generally not repeated from one figure to the next but can be assumed where the SPL curve follows the same pattern and time frame.

Despite the microphones being omnidirectional, pointing directly across the rhino enclosure from the fence and only ~ 21 meters apart, it can be seen that the birds with narrow frequency-band calls at 4 kHz only register nearest the utilities buildings (Figure 46). They appear to a lesser degree at site 3 as well, possibly because these sites are close to open areas that may suit this particular species. Broadband vocalizations appear to contain more energy and penetrate the soundscape as is demonstrated by the same call being visible at both sites. Another characteristic attribute of the FRWC soundscape, particularly near the utilities area, is the sound of Fossil Rim staff vehicles, which are often towing metal trailers over gravel roads and this causes equipment to clang as it is loaded or as it bounces within them. The waveforms and spectrograms illustrate the travel of these trailers when their sound appears strongly at one site then progressively weakens there but intensifies at the next site. The power of even distant thunder is apparent; its very high intensity energy (white and yellow) is contained only at low frequencies so people may not perceive it to be loud, but it produces a brief, but higher, amplitude waveform than most other activities.

An uncommon sound event was registered by all the Roland microphones at site 2 at 11:45 during a period of relative quiet: following about half an hour of distant thunder and before birds and insects had recommenced in force, and while most of the maintenance crews appeared to be taking a lunch break. The sound is as if the microphones were being hit by flying insects, but the timing of the waveforms at each

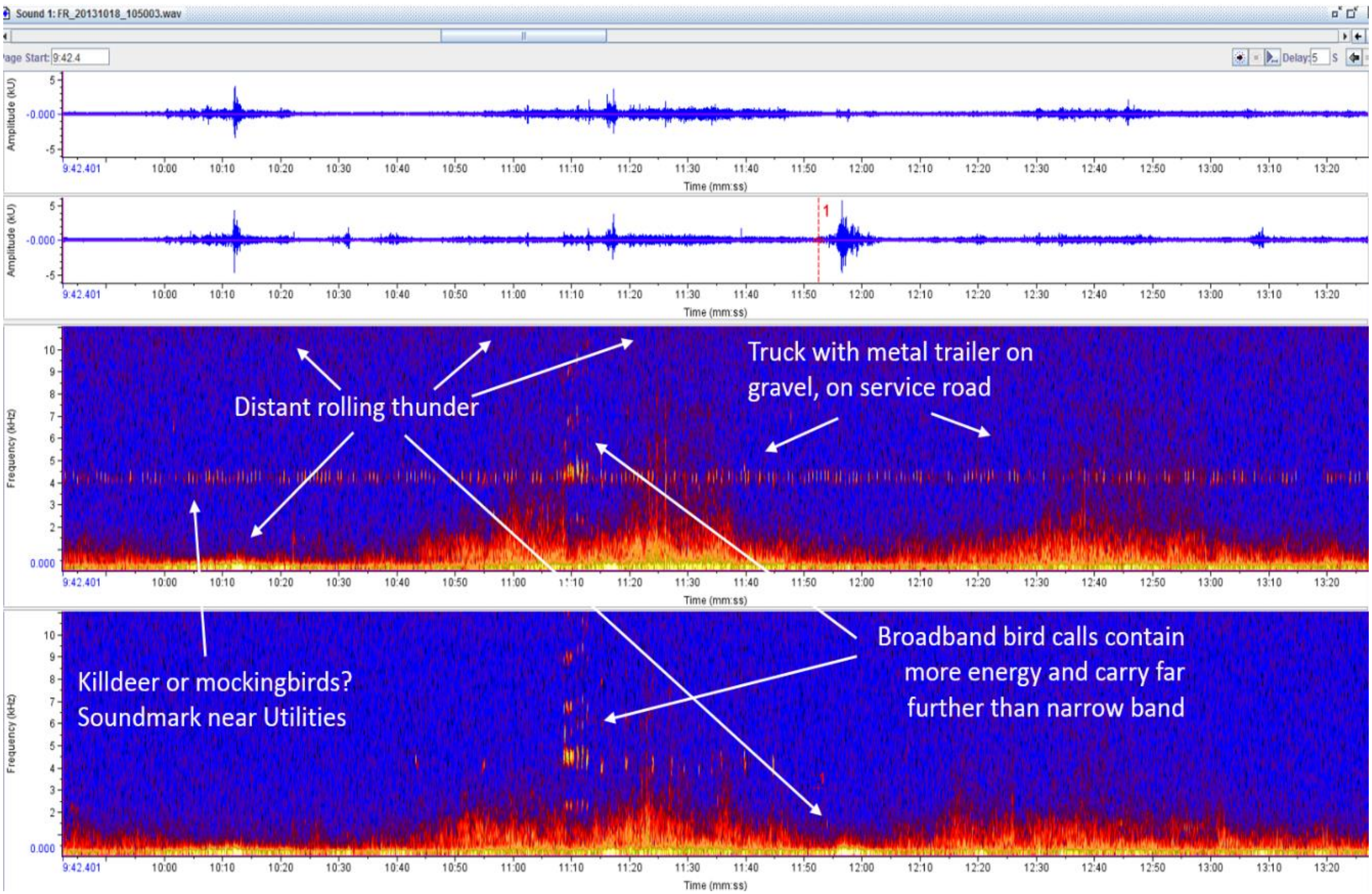
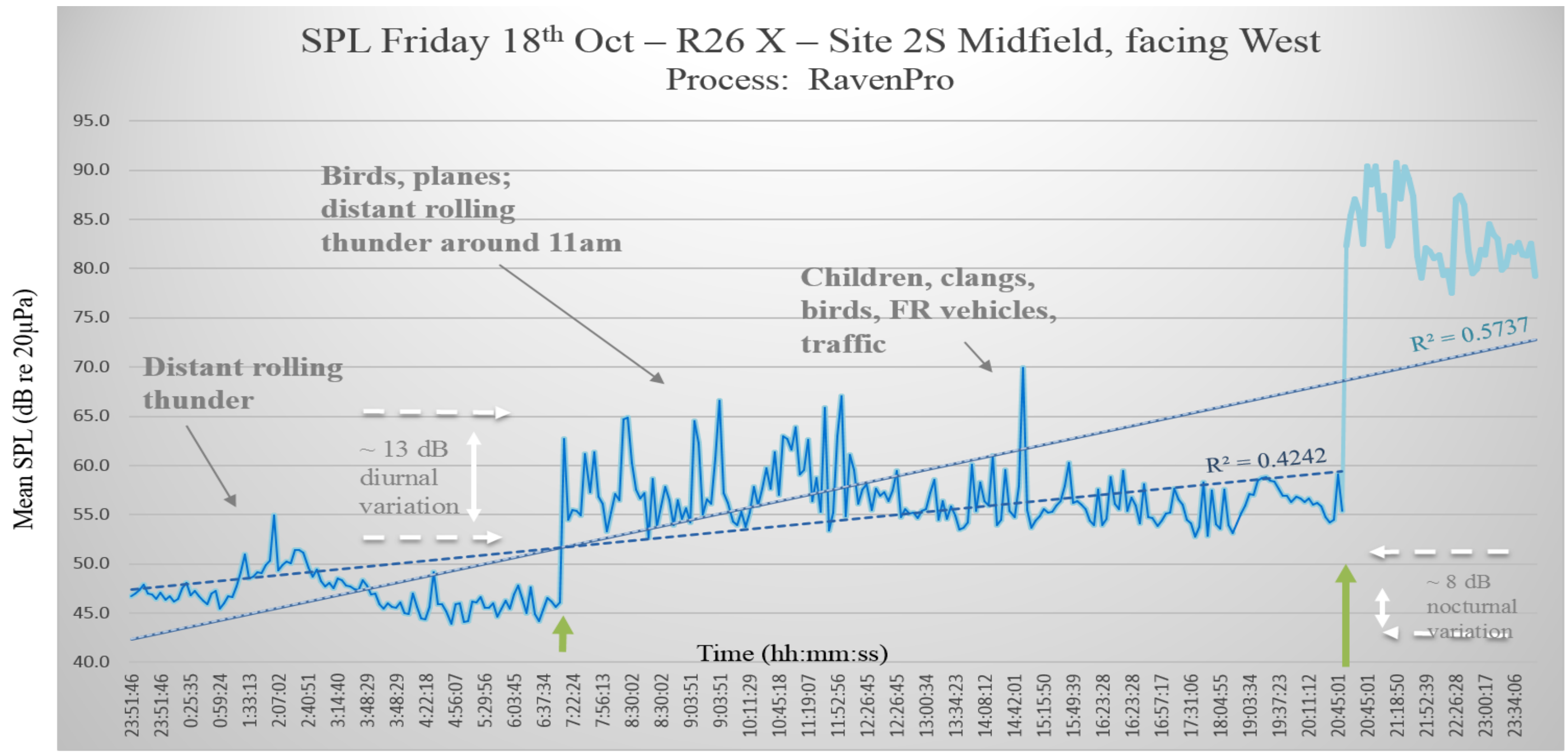


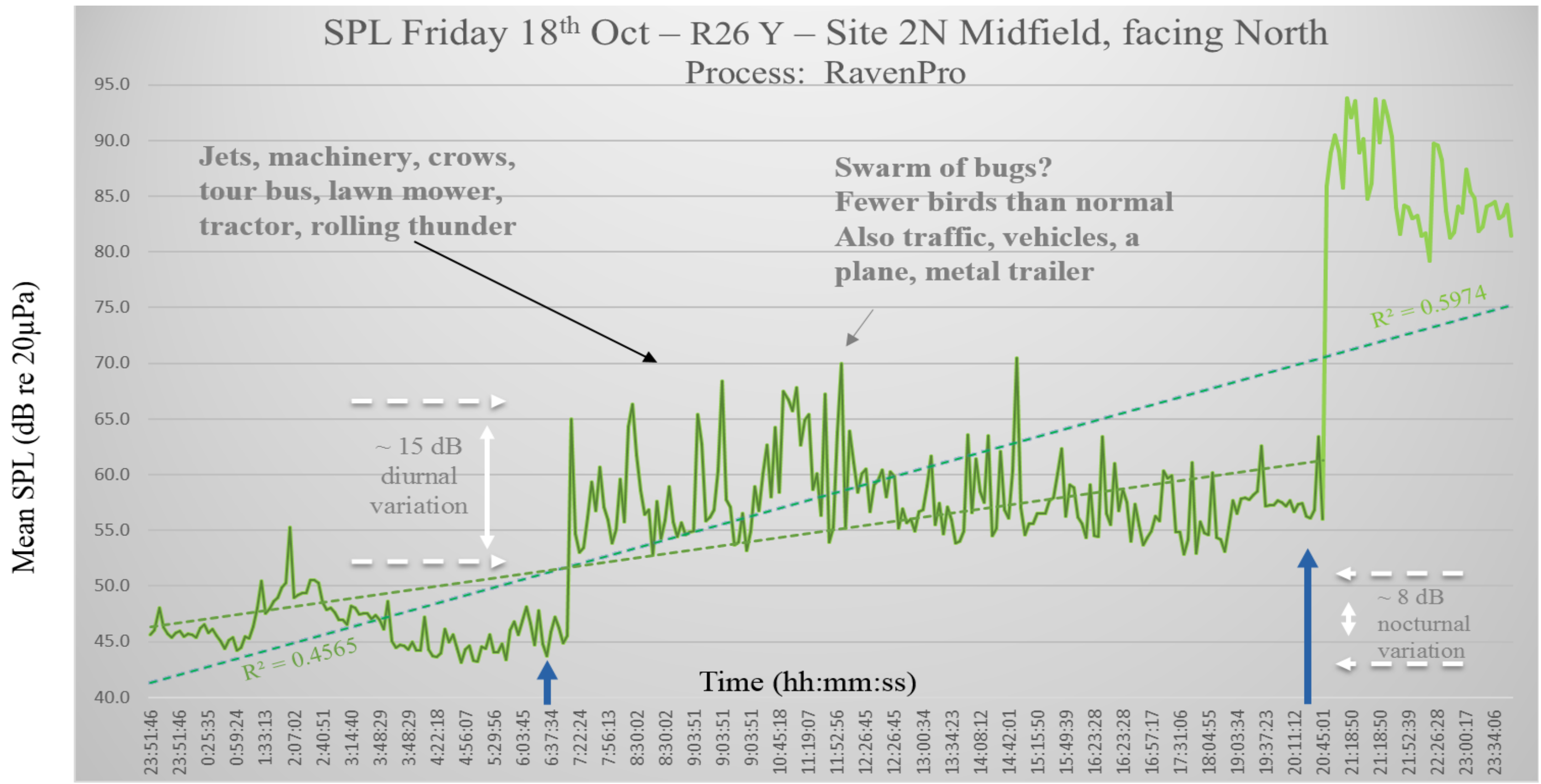
Figure 46. **Thunder semi-masked by truck noise.** These roughly three minute spectrograms starting at 11:00 depict the intensity of even brief distant thunder for those sensitive to these low frequencies, despite the sound events appearing masked by typical sound events of the utilities soundscape. These spectrograms show typical daytime characteristics of the soundscape at the SM2.1 sites.



Diurnal Trend: ~ 6:40 – 20:45 (dawn chorus till storm)

	Mean SPL Interval	Trendline	Minimum	Maximum	24 Hour Variation	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
Incl Storm	4m14sec	$R^2 = 0.5737$	43.9 dB at 4:56	90.8 dB at 21:18	46.9 dB	~ 13 dB		57.6 dB	11.6
Before Storm		$R^2 = 0.4242$		69.9 dB at 14.42	26.0 dB		~ 8 dB	53.4 dB	5.4

Figure 47. **Friday as heard from midfield, at site 2 South.**



Diurnal Trend: ~ 6:40 – 20:45 (dawn chorus till storm)
Note 34.5 dB increase within 20 minutes from 56.0 dB at 20:50

	Mean SPL Interval	Trendline	Minimum	Maximum	24 Hour Variation	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
Incl Storm	4m14sec	$R^2 = 0.5974$	43.1 dB at 4:56	93.8 dB at 21:15	50.7 dB	~ 15 dB		58.3 dB	12.7
Before Storm		$R^2 = 0.4565$		70.5 dB at 14.42			~ 8 dB	53.8 dB	6.4

Figure 48. **From site 2 North.**

microphone is too similar for this (Figures 49, 50, 51, 52). While the timing seems the same, the amplitudes vary on some. They are greater from the south. Only the extremely sensitive Earthworks measurement microphones indicated some amplitudes greater to the north. These microphones were omni directional and only about ten meters apart, but each may have been shadowed by trees nearer the edge of the clearing on their side away from the Roland. Thus the northern Earthworks may have had greater exposure to sounds from the south, toward the utilities area. Although the images do not show this, two pulses, at 27m55secs and 28m11secs, were clipped on the Y microphone facing west, but not on any other microphones. The vertical pulses in the spectrograms do not match those in the waveforms, but show relative power below 4 kHz and more below 3 kHz. Some stretch from extremely low frequency to at least the 22,050 kHz that was the upper sampling setting for these recordings. The red energy from 27m10secs to 27m42secs is first a staff vehicle then an additional car, on the country road. A little while later, a distant or possibly high-flying plane passed by. There are a number of faint frequency bands that showed more clearly on the southern mics – at 11, 14, 16.5, and 20 kHz. The 11 kHz band appeared most strongly however on the directional Y microphone that faced north, towards the bush nearby where the fenceline turned an obtuse corner from running roughly northeast to northwest, and was characteristic of midfield during most days. Further investigation into the source of these frequency bands and the unusual amplitude patterns will be required to even determine whether they are biophonic or anthrophonic - perhaps electrical or machine noise.

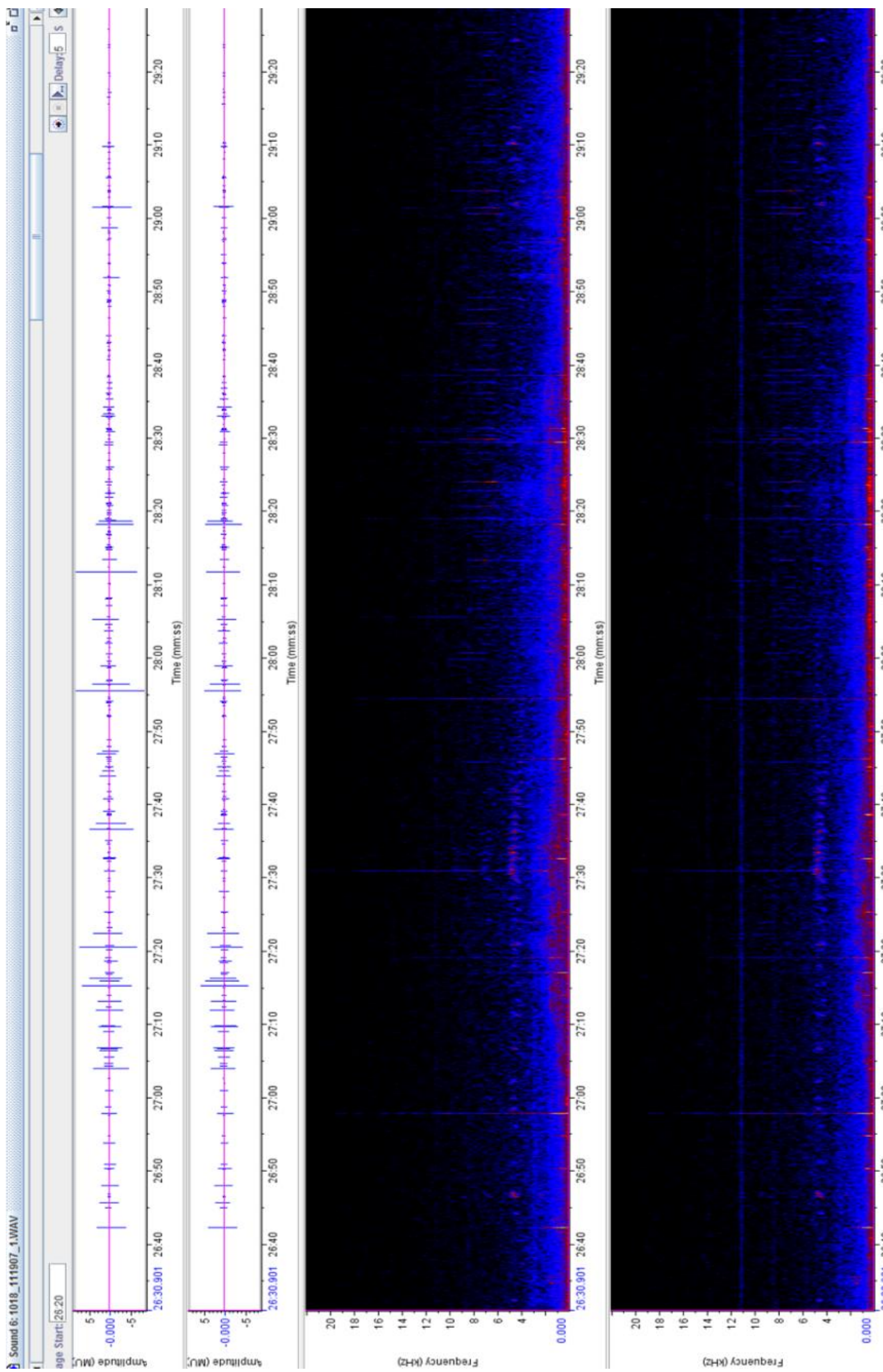


Figure 49. **An unrecognized sound event from the R-26 XY microphones.**

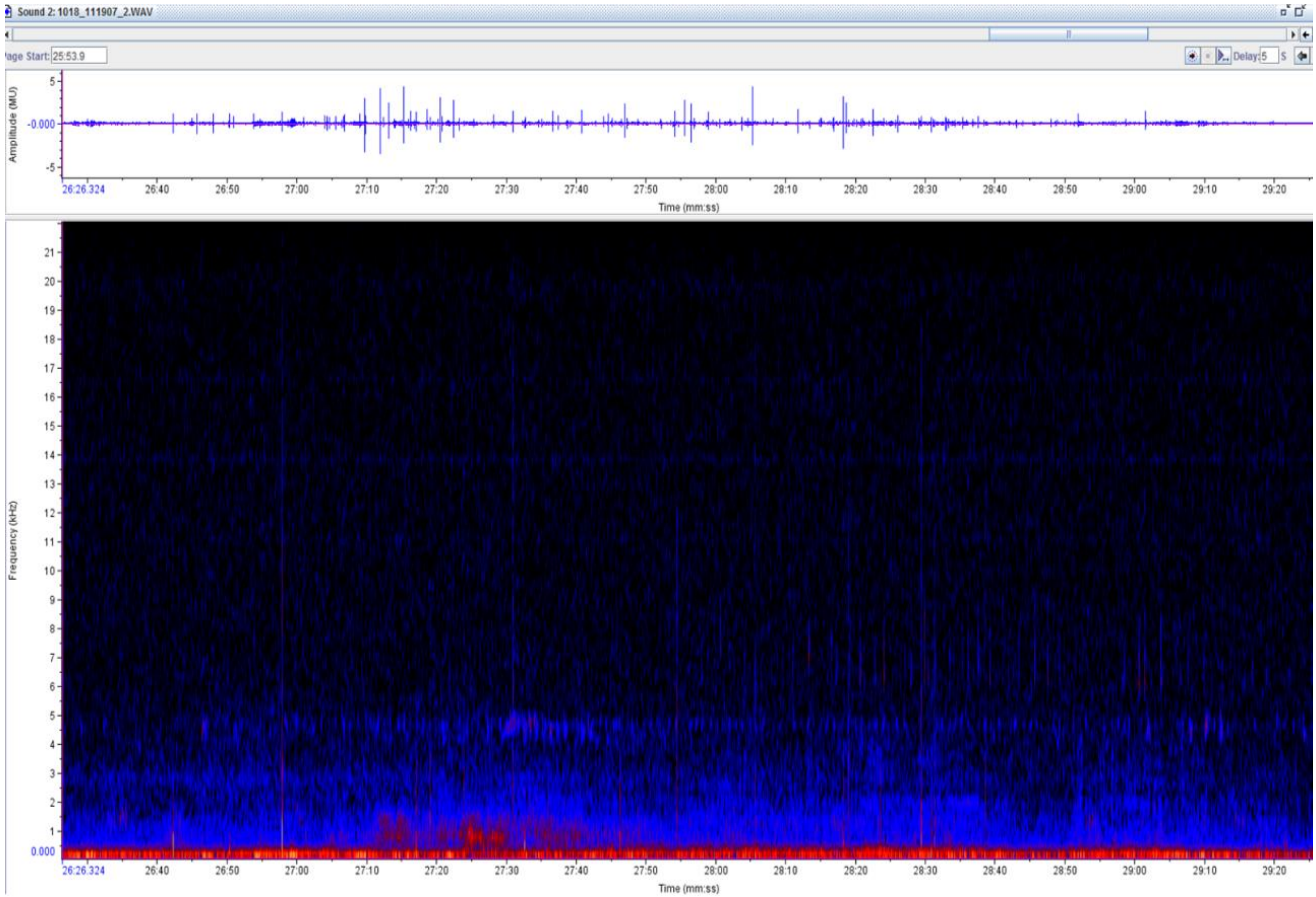


Figure50. **The same event from the R-26 omini microphones.**

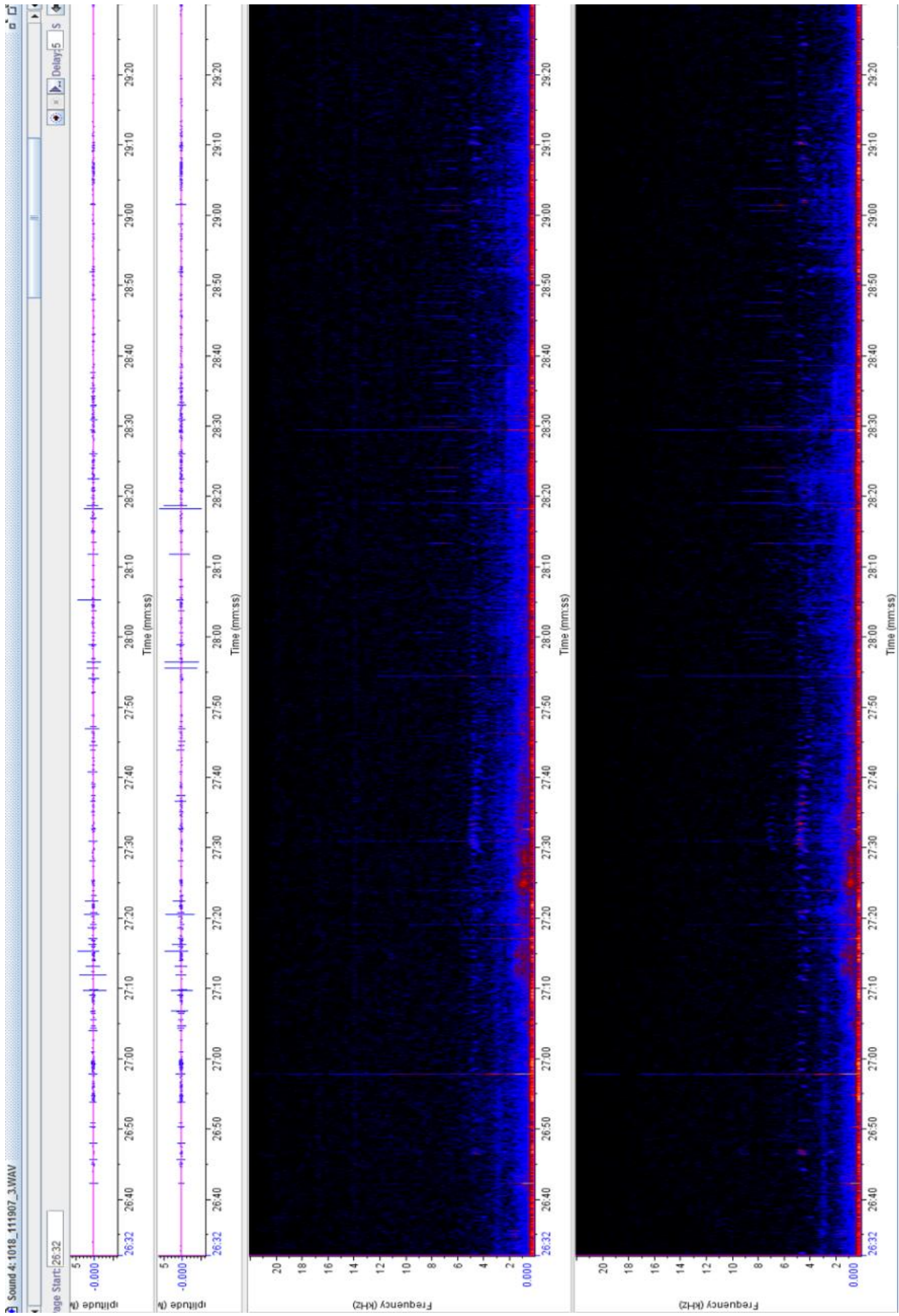


Figure 51. **The same event from the Earthworks M23 microphones.**

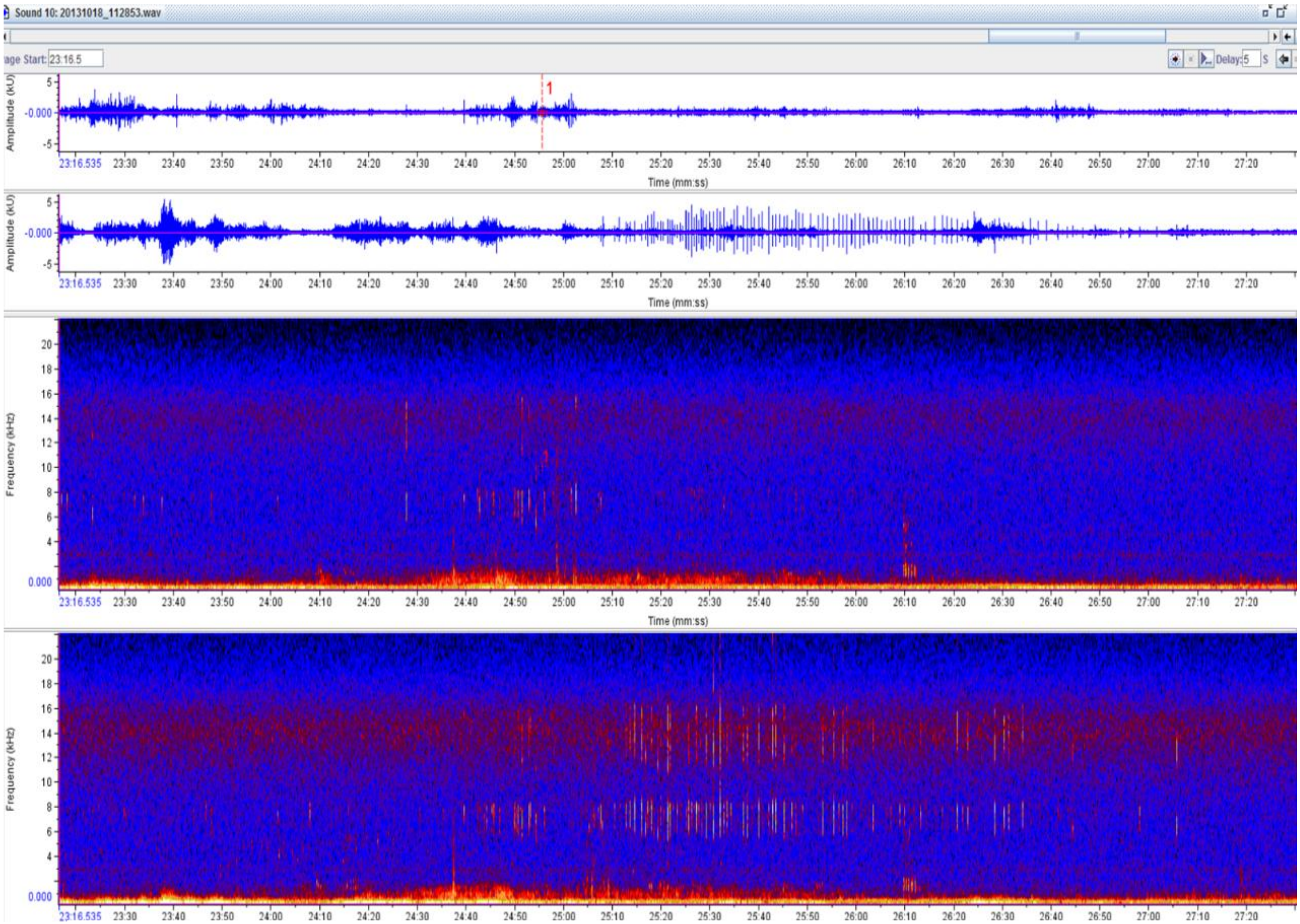


Figure 52. **The same event from SM2.3**

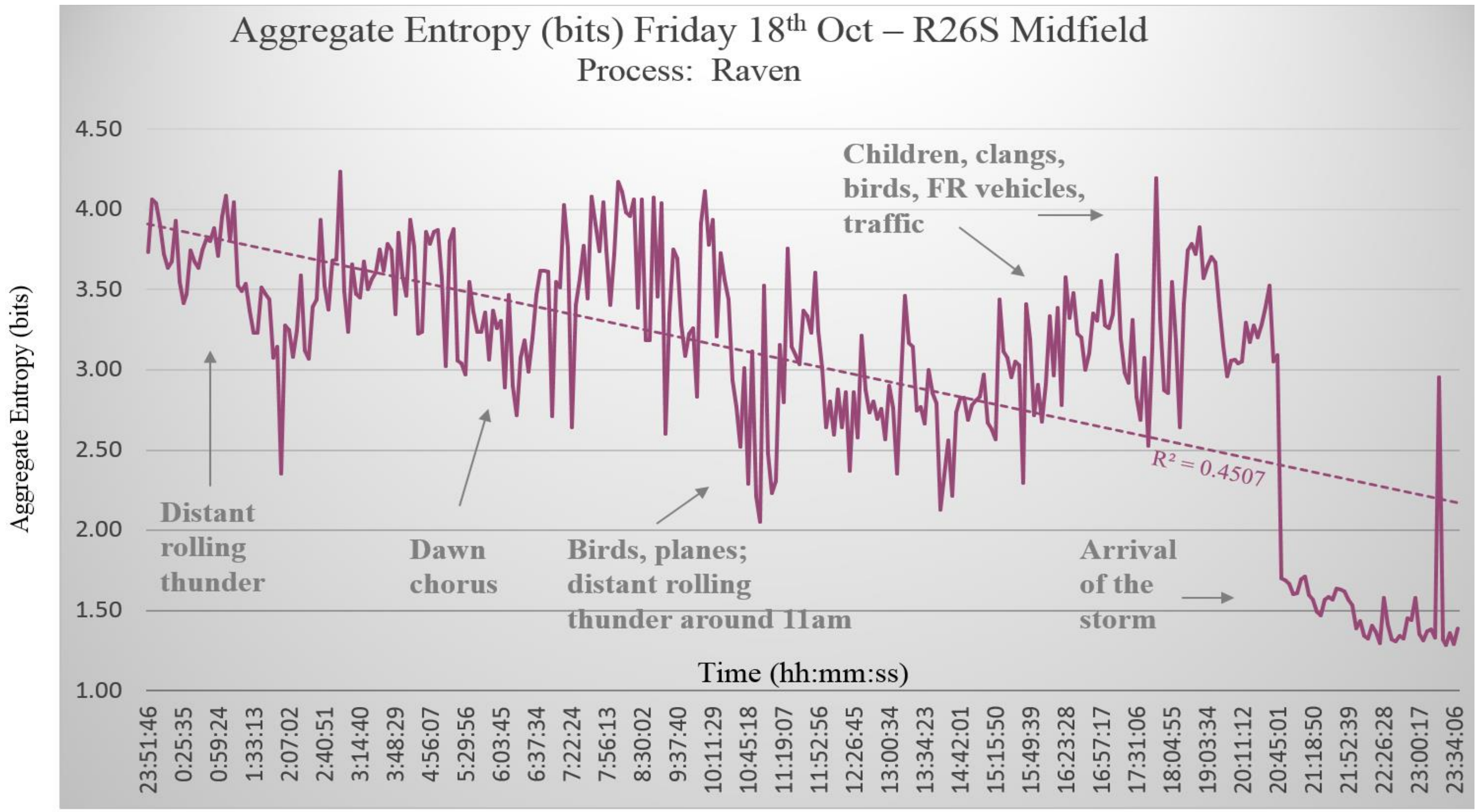
By contrast, no such pattern was recorded by the SM2 nearest the utilities buildings, but the SM2.3 did record it, mainly from SM2.3N. The vertical frequency bands that it registered mainly stretched from about 6 to 9 kHz, then again from 11 to 15 kHz, although some were as low as 3 and one was still visible at 19 kHz.

Other Sound Parameters

Just as the SPL can be calculated from Raven's RMS measurements and then tabulated and graphed, so too can be the other parameters measured within Raven. Entropy is presented as an example.

The concept of entropy as it might relate to sound is new to many experienced acousticians since it is not required for measurements of the vocalizations of a species. It is defined as the degree of disorder in a section of sound. It is known that humans respond negatively in physiological terms to fluctuating or impulse sound, and other mammals may potentially as well, thus this was measured so that in future studies at other locations, their entropy can be compared and correlations to health explored (Figure 53).

Entropy may be just as low (or high) during periods of great amplitude as it may be during quiet periods, since disorder can occur anywhere on the continuum. The lowest entropy on Friday was during the high winds of the storm and to a lesser extent during the lawn mowing and the multiple sound events that accompanied it, when all other sounds were masked. High entropy occurred during the calmest time of the night, when a single bird call or rhino snort contrasted starkly against the ambient peace, during the



	Mean SPL Interval	Trendline	Minimum	Maximum	Average	Standard Deviation
Incl Storm	4m14sec Raven	$R^2 = 0.0035$	1.29 bits at 23:34	4.24 bits at 3:14	3.04 bits	0.75

Figure 53. **Aggregate entropy, or disorder in Friday's soundscape.**

build-up of the dawn chorus, perhaps as birds spontaneously added their songs, and as staff progressively arrived and began their preparations for the day.

While entropy may seem undesirable from the perspective that humans respond poorly to fluctuating noise, it can be important for communication. Birds and animals call between loud noises, so quiet lapses are vital in an otherwise loud environment. Humans generally require at least a 10 dBA signal-to-noise ratio in order to discriminate a sound signal. This ratio increases as one ages or if hearing becomes impaired, which is why some people have trouble discerning words when two conversations run concurrently or when music is playing in the background. We do not know the ratio that might be required for rhinos or other animals.

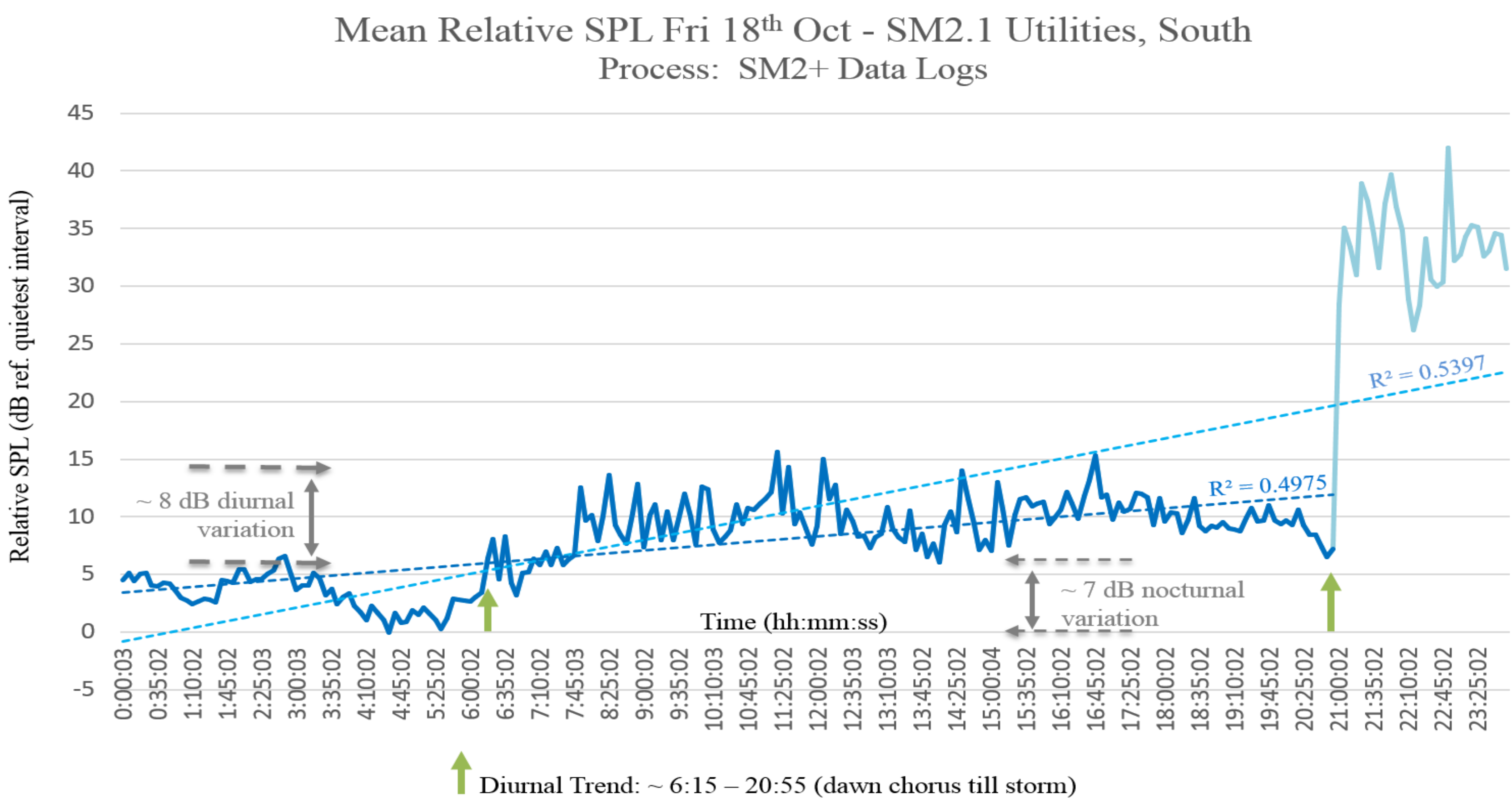
SongMeter SM2+ Data Log Processing

As an example of how the activities at two sites can be meaningfully, but simply, compared in another manner, the soundscapes at SM2.1 and SM2.3 are compared to illustrate a second method of analysis, using the SongMeter's data logging system that provides dB(V_{RMS}) figures from which relative SPL can be calculated (Figures 54, 55, 56, 57). Such analysis cannot be accurately compared with data processed in Raven since the method of calculating the SongMeter data log dB(V_{RMS}) involves a different measurement and averaging system than Raven uses. The SM2+ Data Log system is extremely fast in comparison with the Raven system of analysis as each five-minute section does not need to be treated as it is in Raven: separately opened, analyzed, named, saved, the data imported from a text file into an excel file, those files combined into a single spreadsheet, then calibrated, and the SPL levels calculated. While this system is *far* more convenient, it lacks the detail and additional sound metrics of the Raven system.

While the SM2+ Data Log analysis cannot be directly compared with recordings from other data acquisition systems, it can be compared with that of other SongMeters, and thus of site 3 near the main entrance to FRWC. (Figures 56 and 57 show site 3's relative SPL for Friday, site 1's is shown in Figures 54 and 55).

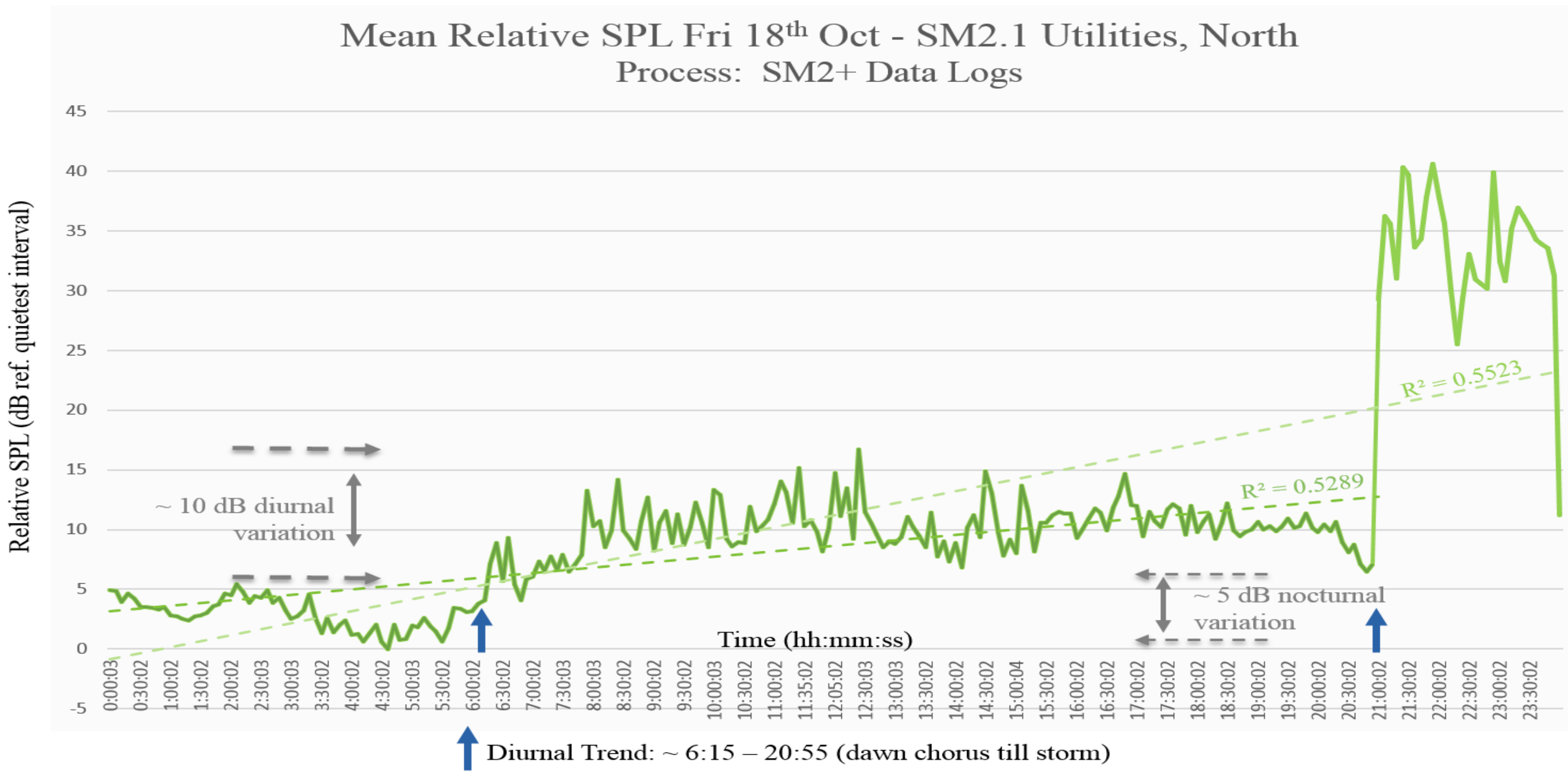
The sonograms show that both the diurnal and the nocturnal soundscapes at site 3 experienced higher SPLs and higher variation than at site 1. The loudest pre-storm peak at SM2.1N was 16.7 relative dB, while it was 37.6 dB at SM2.3N. This is a huge difference when it is remembered that just a 3 dB increase is a doubling of power. The significance of such increases in sound is still to be discovered as rhinos' perception of sound and their sensitivities to various frequencies are unknowns.

Part of the late morning increase on the northern-most microphone, SM2.3N was IWN, however the wind speed was about 7 kph lower than around 9am, for example, so that does not explain the high peak. There was distant rolling thunder, but that impacted all the microphones. The key factor was that while vehicles, trucks, traffic, machinery, and the thunder were contributing their noises, a lawn mower and a weed trimmer were steadily working their way closer, eventually moving up and down the fence line to a location immediately northwest of the microphones. Three minutes of that peak time shows the greater activity on the second channel (SM2.3N) (Figure 58). The penetrating broadband vocalizations towards the center of the spectrogram were from a crow that took the opportunity of a brief lull in the noise, further adding to the SPL.



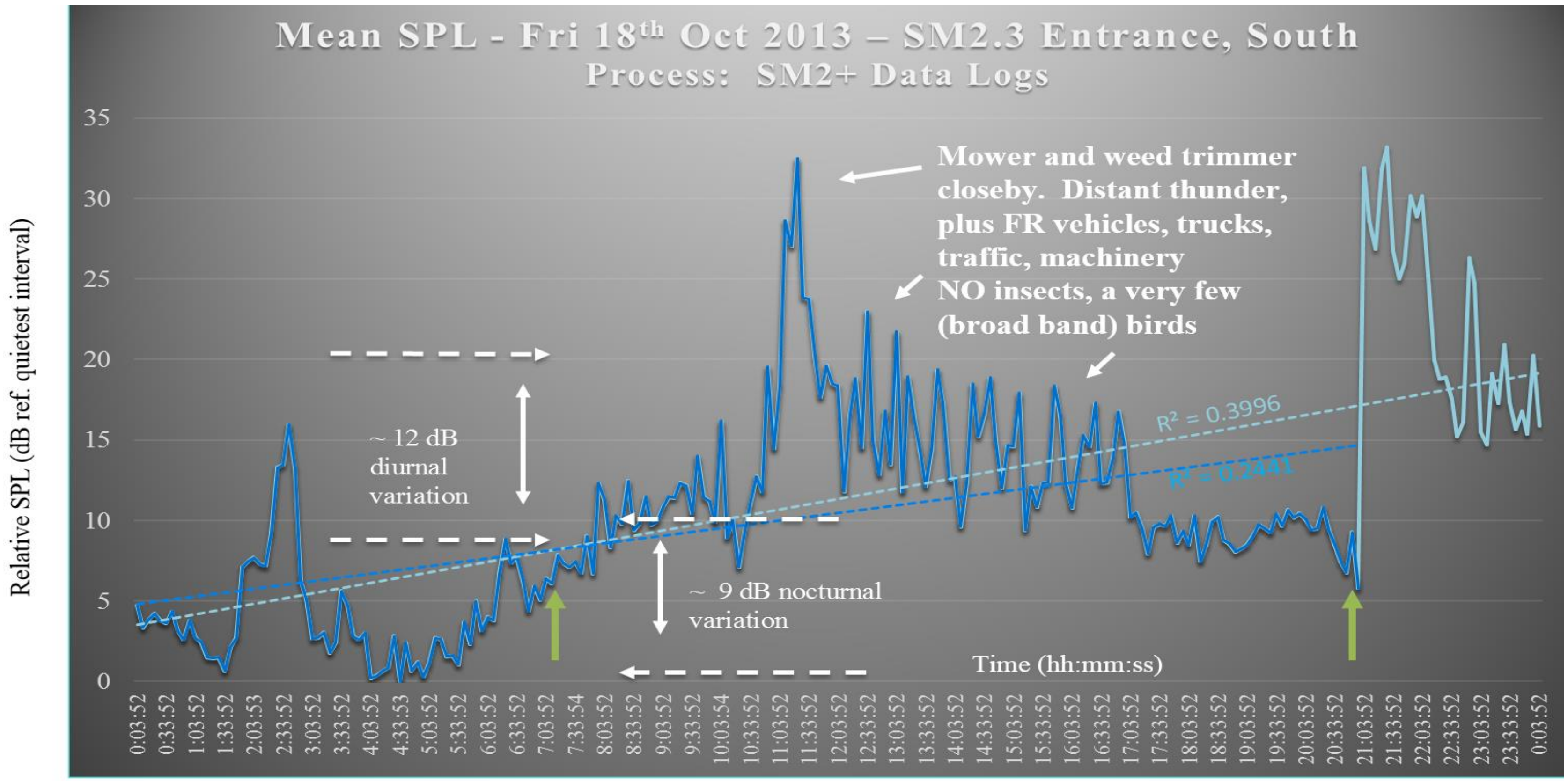
	Mean SPL Interval	Trendline	Minimum	Maximum	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
Incl Storm	5 minutes SM2+data log	$R^2 = 0.5397$	0 dB at 4:35	42.0 dB at 22:55	~ 8 dB		10.9 dB	9.23
Before Storm		$R^2 = 0.4975$		15.6 dB at 11:15		~ 7 dB	7.7dB	3.5

Figure 54. **Re-analysis of the soundscape at SM2.1S, using the SM2+ Data Logs.** The sound curve is very similar to that in Figure 44. Events can still be clearly identified, but the data have been smoothed so the height of many peaks and troughs diminished, and some peaks were absorbed into neighboring sections of the curve, which thus lacks a considerable degree of detail.



	Mean SPL Interval	Trendline	Minimum	Maximum	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
Incl Storm	5 minutes SM2+data log	$R^2 = 0.5523$	0 dB at 4:35	40.6 dB at 21:55	~ 10 dB		11.2 dB	9.4
Before Storm		$R^2 = 0.5289$		16.7 dB at 12:30		~ 5 dB	7.9 dB	3.8

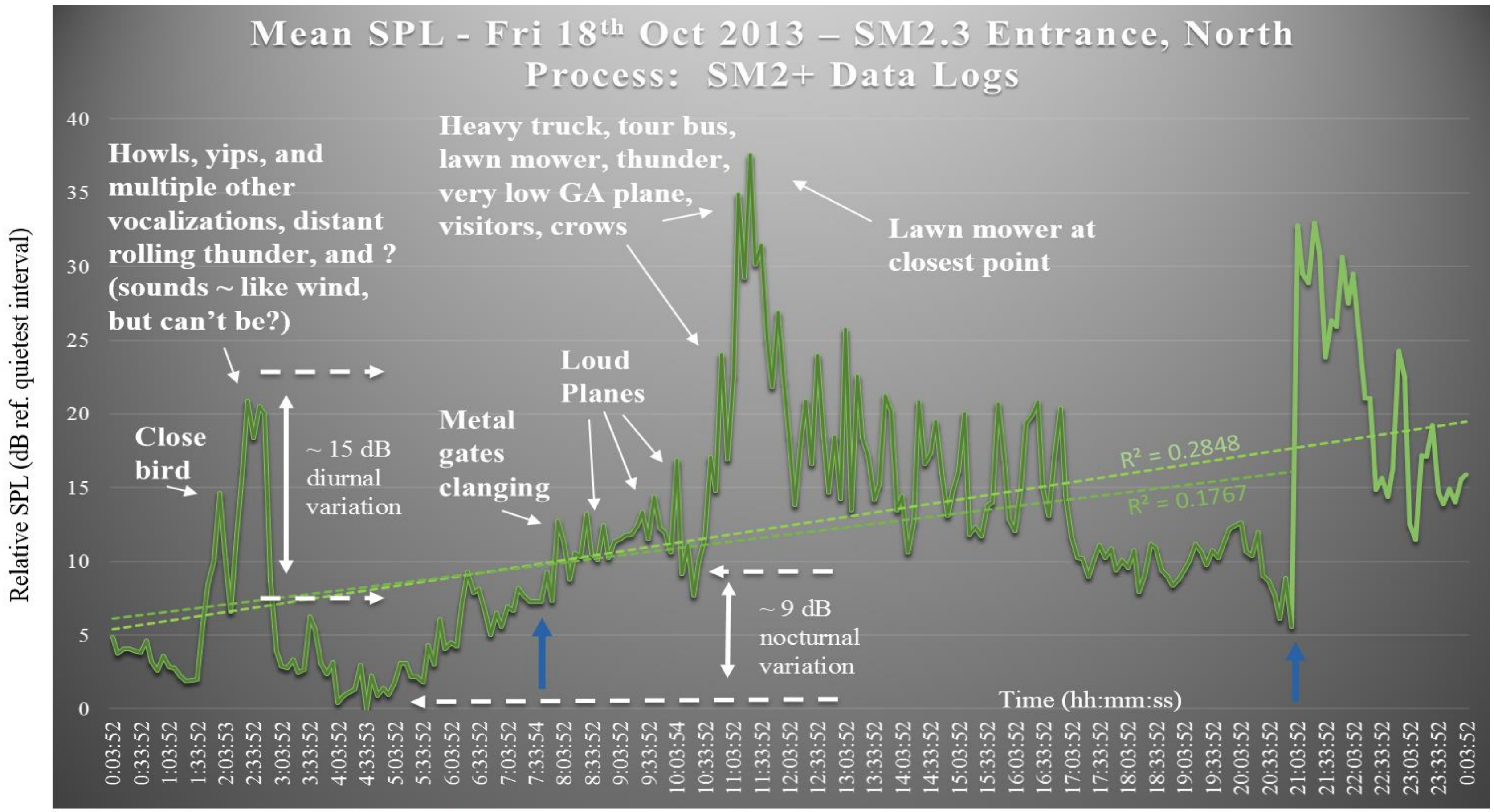
Figure 55. **Re-analysis of the soundscape at SM2.1N.**



Diurnal Trend: ~ 7:15 – 20:53 (dawn chorus till storm)
Note 26 dB increase within 10 minutes from 41.3 dB at 20:53

	Mean SPL Interval	Trendline	Minimum	Maximum	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
Incl Storm	5 minutes SM2+data log	$R^2 = 0.3996$	0 dB at 4:33	33.2 dB at 21:23	~ 12 dB		46.9 dB	12.7
Before Storm		$R^2 = 0.2441$		32.5 dB at 11.18		~ 9 dB	45.3 dB	6.4

Figure 56. **The soundscape at SM2.3S.** The northern end of the rhino enclosure was considerably louder than the southern end on Friday.



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
Before Storm		$R^2 = 0.1767$		37.6 dB at 11:18		~ 9 dB	11.1 dB	6.9

Figure 57. **The soundscape at SM2.3N.** The site of the northernmost microphone was the loudest of all on Friday,apart from at the peak of the storm

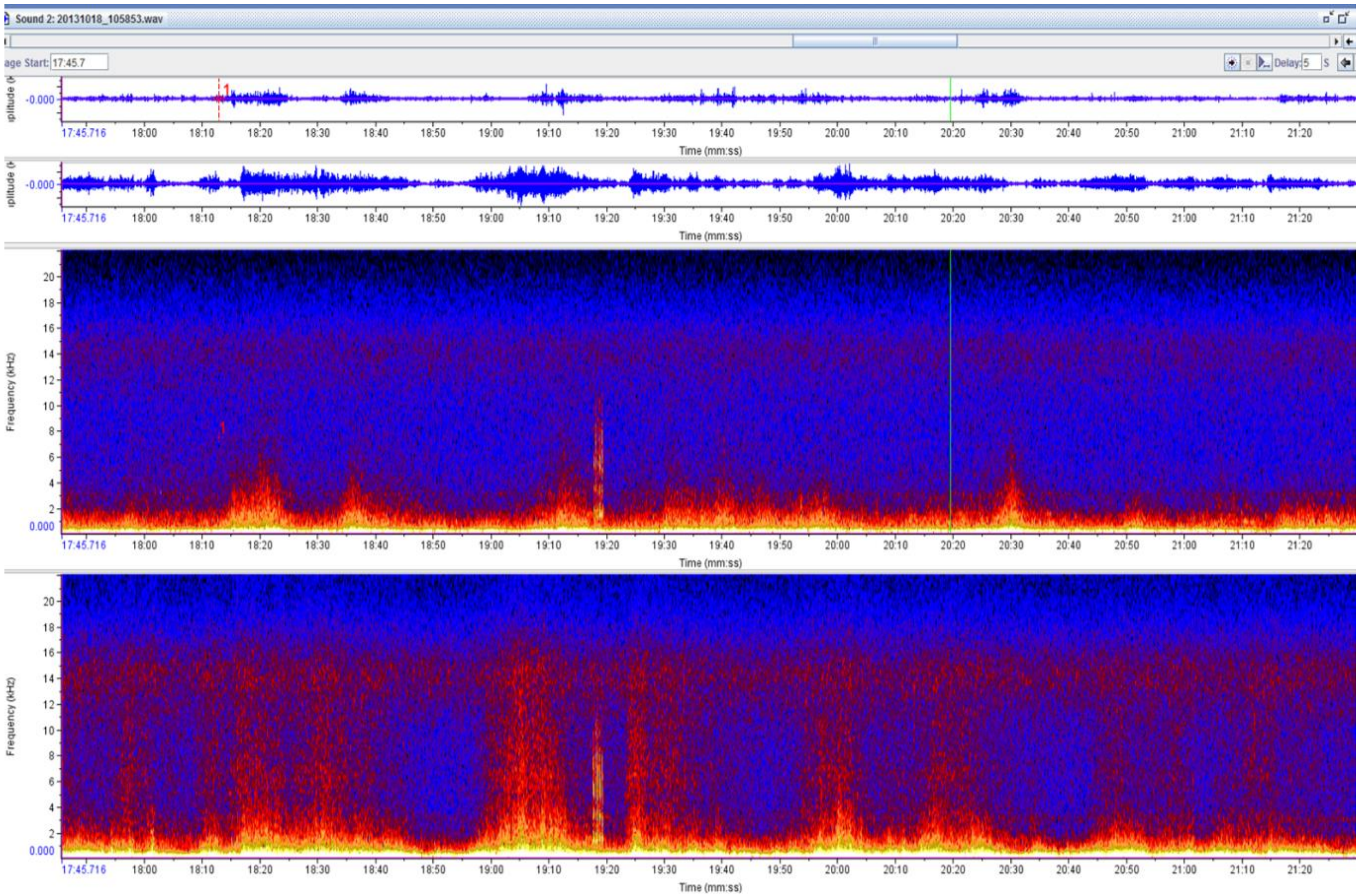
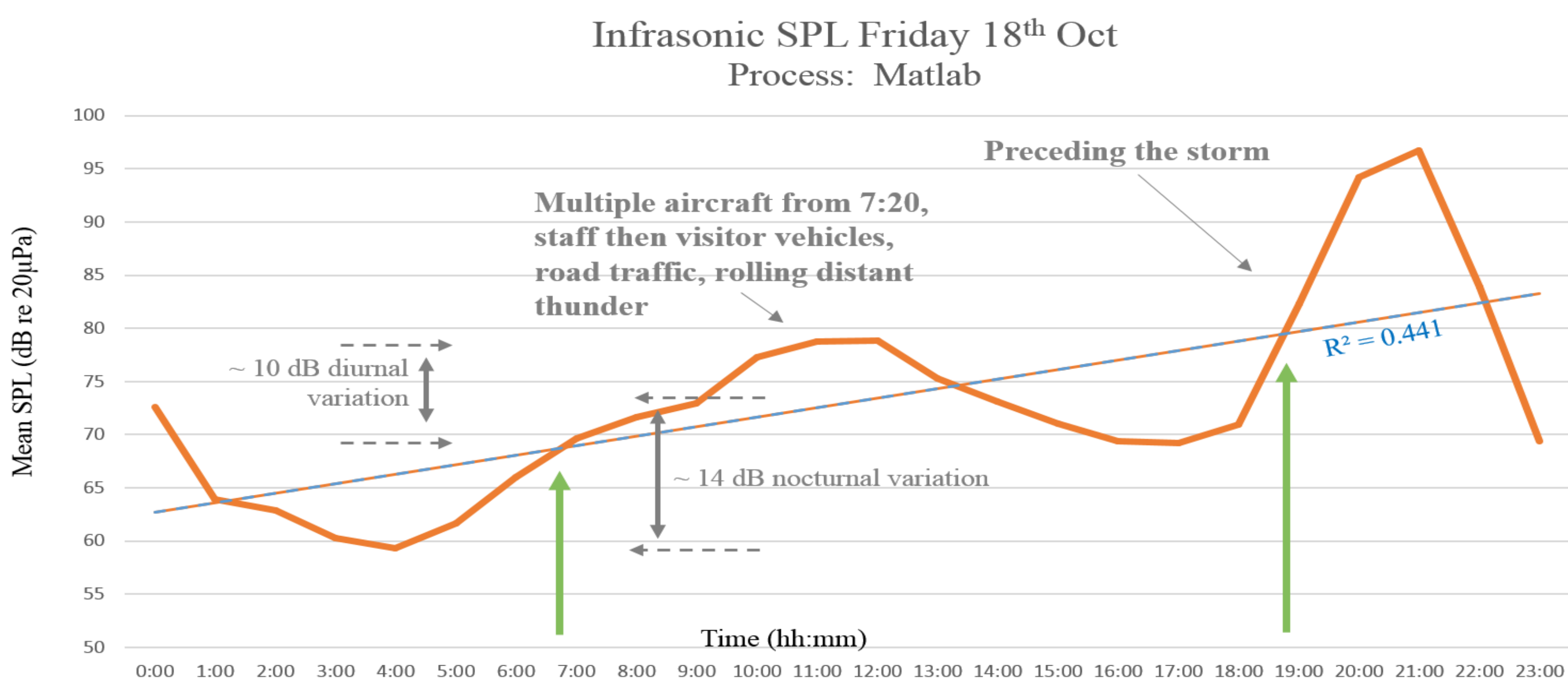


Figure 58. **A period of intense noise at site 3 due to lawn mowing and multiple other sources.** The sound events included distant rolling thunder, lawn mowing, heavy machinery, vehicles on the road and entering the car park, a tour bus, and crows – together creating even more noise than the weather front that night.

The Infrasonic and Seismic Soundscapes

In addition to the sonic soundscape, infrasonic and seismic influences were documented. In the same way that SPLs were calculated and graphed, the infrasonic RMSs were extracted (via Matlab), amalgamated, and then graphed for the day (Figure 59). The infrasonic readings were high during the periods of high wind shortly after midnight, and again during the storm. These readings were averaged over all six channels rather than three, but even then they are not as accurate as if ten or more sensors had been used. They still provide an overview of the activity of the day, however. The diurnal and nocturnal variations are in a similar range as the sonic variations, as is the diurnal trend in terms of both time and trendline. A major difference between the infrasonic and sonic pattern of the day however is the build-up prior to the evening storm. In the case of the sonic reports, all ten channels indicated a lull and then an enormous and very sudden increase within a matter of just a few minutes. The infrasonic increase on the other hand began about four hours before the weather front actually arrived in meteorological terms, and began declining almost immediately. These infrasonic data were averaged over one-hour periods, whereas the sonic data were averaged over five minutes or less, so they exhibit a large degree of smoothing, but even then the trends remain apparent. Future analysis will investigate all of the data within Raven on a one minute or less basis, so exact comparisons and correlations can be made.

Appendix D shows the hourly mean variation for Friday 18th for one of the six infrasonic channels as extracted in Matlab when the RefTek files were converted to .wav files in preparation for processing them in Raven. Some hours of channel two are included to illustrate that their locations and orientations provide slightly different



Diurnal Trend: 7:00 – 19:00 (dawn chorus till storm)

Storm cannot be ignored since the build-up of low frequency background noise begins 3 hours before the weather change arrives

	Mean SPL Interval	Trendline	Minimum	Maximum	24 Hour Variation	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
Including Storm	I hour	$R^2 = 0.441$	59.3 dB at 4:00	96.8 dB at 21:00	37.5 dB	~ 10 dB	~14 dB	73.0 dB	9.32
Before Storm				78.9 dB at noon					

Figure 59. **Infrasonic mean SPL for Friday 18th October**

sound metrics. The times in their file names are Julian dates, so 2013291050000000 refers to 2013 October 18 00:00:00.000. As with the sonic data, it is important to regard the changing scales in these images as the windows have been reduced to reveal maximum detail. When there is a single spike, however, the window has been expanded to show that spike in its entirety. Appendix E contains examples of comparable seismic data for channel 1 (North-South), channel 2 (East-West) and channel 3 (the vertical axis). Infrasonic sensors are very prone to wind noise, especially below 2 Hz. While every attempt was made to stamp down the grass around the sensors before they were activated, wind in nearby grass and trees does influence readings and needs to be averaged out. Protocol normally requires a minimum pattern of at least ten infrasonic sensors to average out wind noise sufficiently, and the ducommun website (http://www.ducommun.com/ducommunmiltec/InfrasoundSensors.aspx? last accessed 5 November 2014) highlights an infrasound signal in the 1-4Hz range that was only detected after averaging the data of 25 sensors. Only six sensors were used for this project. The data for some days must still be processed, amalgamated and averaged. The unaveraged degree of activity on channel 1 during the quietest and the loudest sonic periods of Friday 18th October at site SM2.3N reveals far greater infrasonic activity during the loudest sonic period (Figures 60 and 61). Infrasonic channels 2 and 3 reveal a similar pattern (Appendices D and E).

While infrasonic energy appears to have been greater during periods of high sonic activity, and this has been observed on many occasions, further study will be needed to determine the sonic parameters that are required before this relationship no longer exists. Almost all the Fossil Rim recordings demonstrate strong to intense low frequency

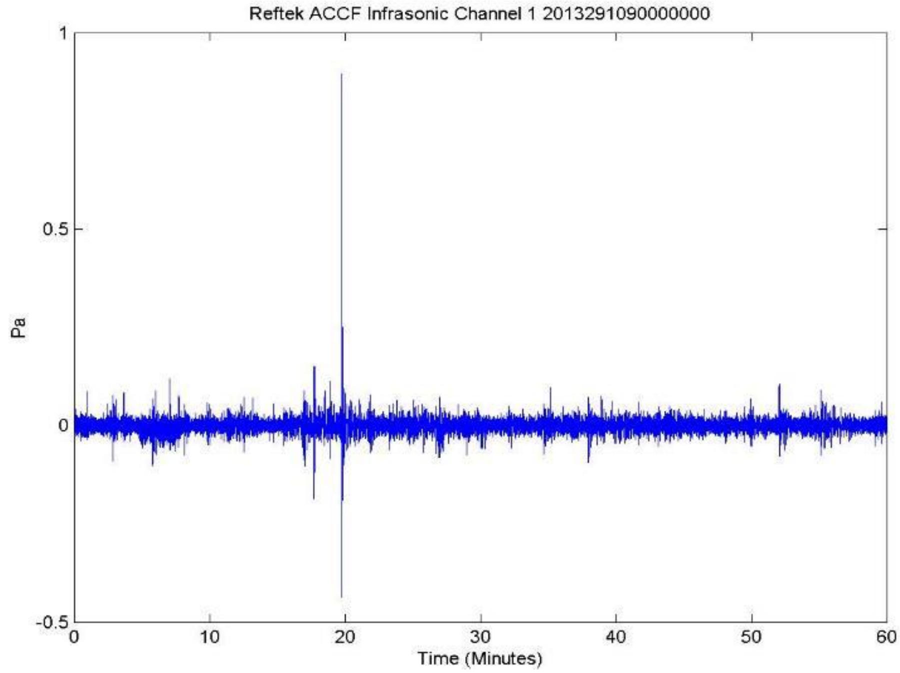


Figure 60. **Unaveraged infrasonic activity 4:00 to 5:00**. The quietest time on Friday 18th at SM2.3N was 4:53, which also appears to be the quietest period of infrasonic activity in this sonogram. There was a very brief but far stronger burst of infrasonic activity at about 4:19, although that was not large by the standard of other periods of that 24 hours.

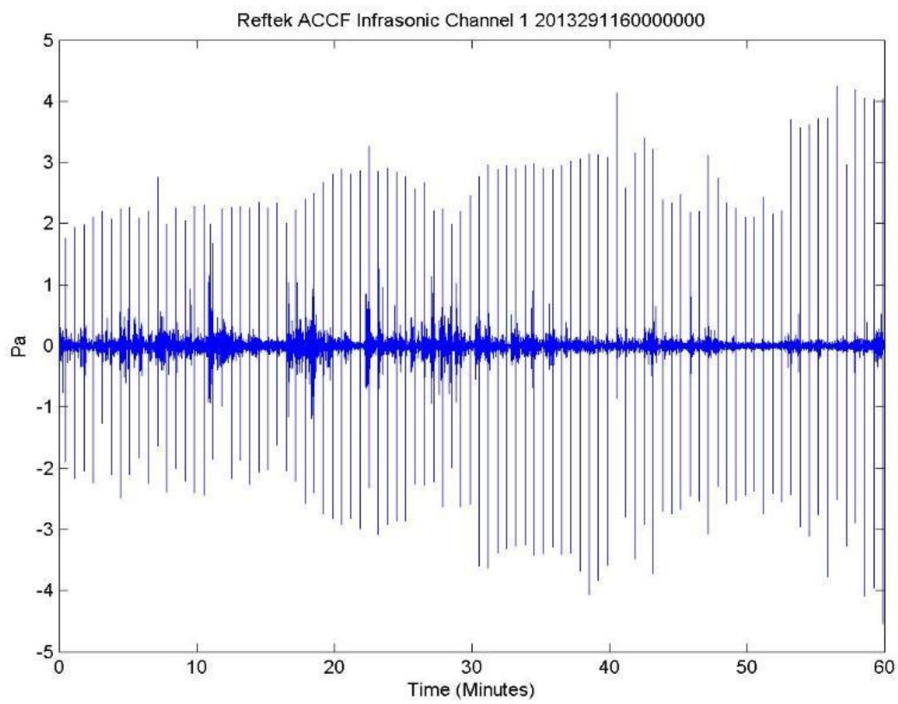


Figure 61. **Unaveraged infrasonic activity 11:00 to 12:00**. During the loudest period of the day at SM2.3N, channel 1 demonstrated far greater infrasonic activity than during the night.

activity, so at this site during this period it may be that infrasonic activity ran relatively parallel with the sonic activity.

The seismic data behave a differently from the sonic and infrasonic, measuring velocity and direction of ground movement rather than SPL. After processing these data in Matlab to convert them from the RefTek file format, they do not reveal an obvious relationship to the sonic or infrasonic data in the way discussed above. Energy can and does transfer between the ground's surface and the air, but it is beyond the scope of both this project and the equipment that was available, to determine the way any infrasonic energy transfer may have occurred or even whether more low frequency energy emanated from the Earth or the air. In this case, the pre-dawn seismic activity for all three channels was generally a little below 1.5 V (uncalibrated) (Figure 62). However while North-South channel 1 remained about the same from 11:00 to 12:00 (when SM2.3N had exhibited its highest SPL) (Figure 63), East-West channel 2 and Vertical channel 3 were both far slower, at less than 0.2 V (Figures 64 and 65).

At about 11:11 a strong pulse was recorded in all three seismic directions, with another at about 11:59. This time the strength and also the relationship varied on each channel. At first inspection these strong pulses do not appear correlated to any particular activity that was recorded by the sonic equipment, but deeper investigation will explore this. It is known however that seismic and infrasonic waves travel enormous distances, and at varying rates according to the media through which they pass, so the source of these pulses are unlikely to be discovered. Future efforts will be undertaken to correlate the sonic, infrasonic, and seismic data across the time-scale to identify meaningful correlations and/or trends.

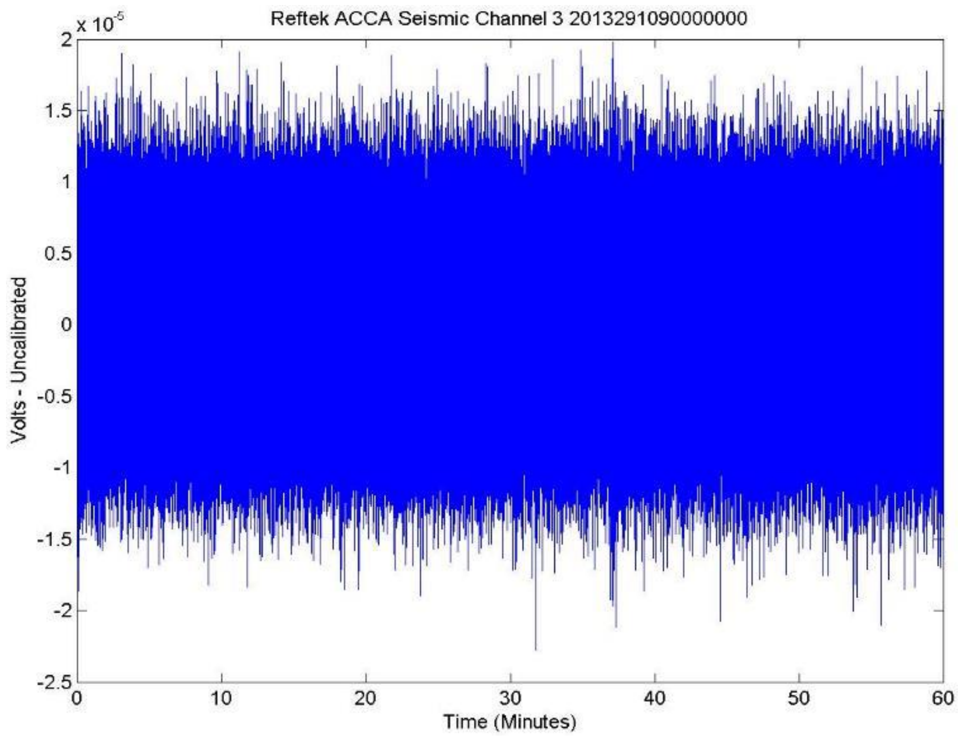


Figure 62. **Uncalibrated seismic activity 4:00 to 5:00**. The sonograms for channels 1, 2, and 3 appear to be similar, mainly registering below 1.5 V.

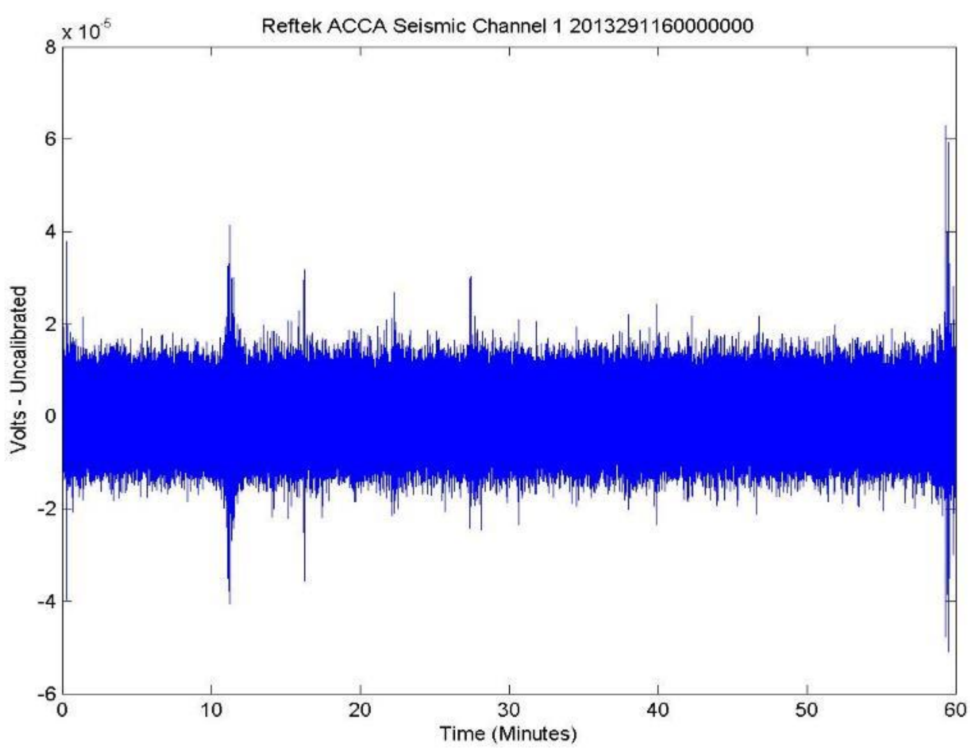


Figure 63. **Channel 1 uncalibrated seismic activity 11:00 to 12:00**. Channel 1 (North-South) exhibited a considerably stronger waveform than channels 2 and 3.

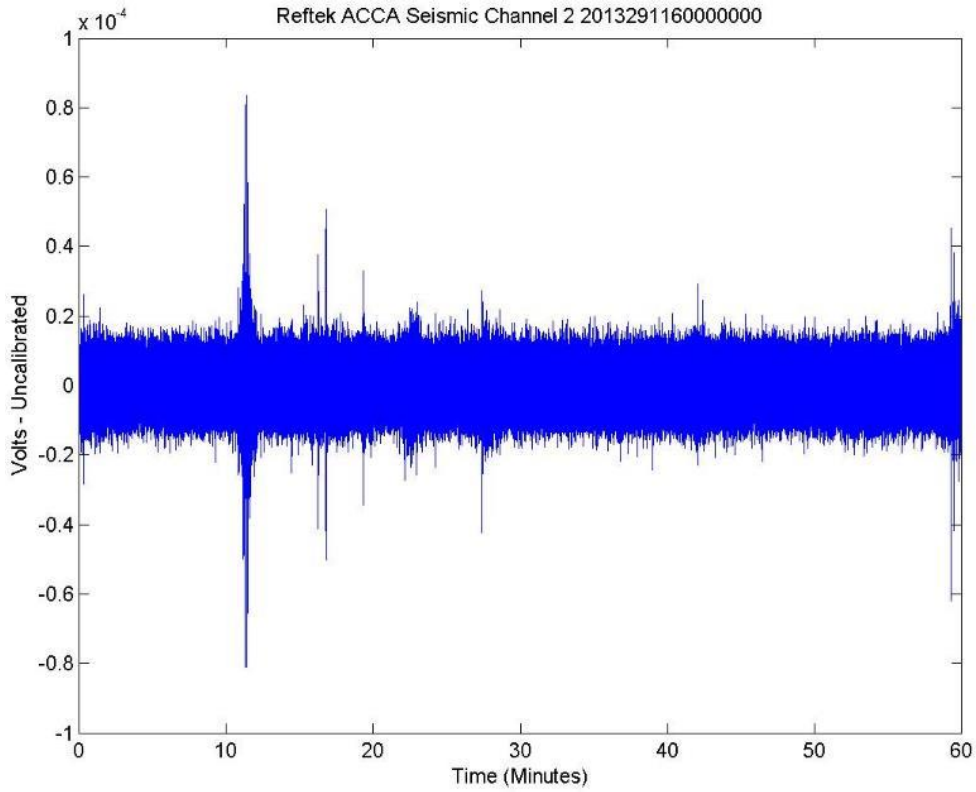


Figure 64. **Channel 2 uncalibrated seismic activity 11:00 to 12:00**.

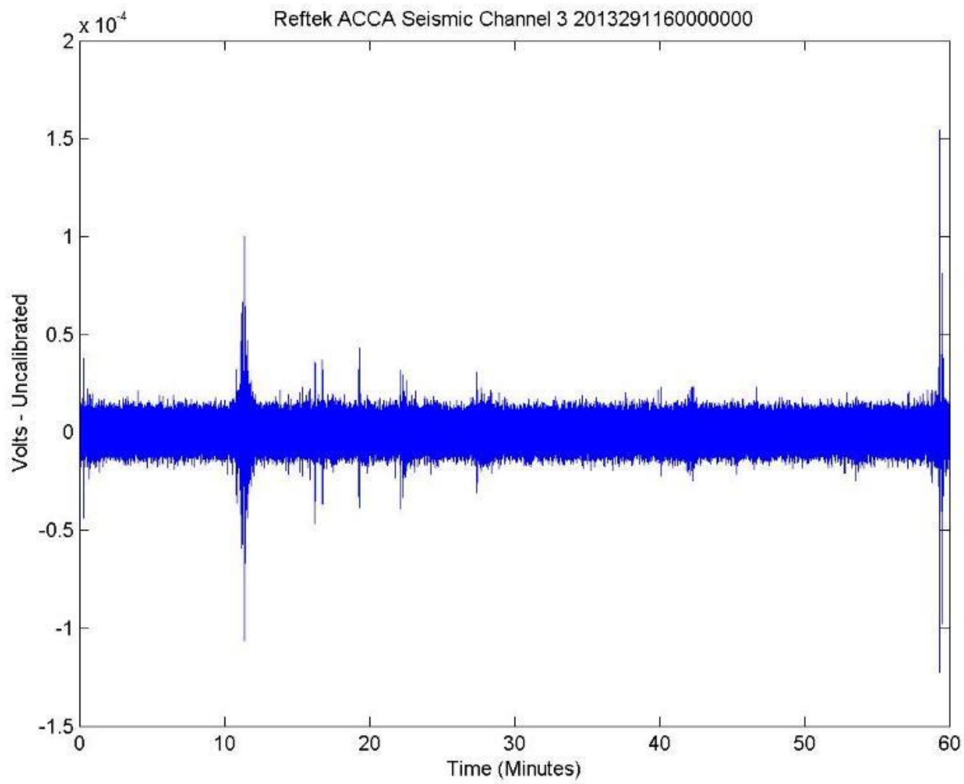


Figure 65. **Channel 3 uncalibrated seismic activity 11:00 to 12:00**.

Monday 21^{st} October

In order to place Friday 18th October in some perspective, I will present a summary of Monday 21st October. Monday 21st was selected for the comparison since it was the loudest day documented because of repair and grading of roads to the west of the rhino enclosure following the storms of the week before. Monday also included a storm, but it occurred at the beginning of the day. Just after midnight winds reached 42 kph at The Overlook and by 0:30 gusted at 55 kph (Figure 66). The winds emanated from the south so much of the valley was protected by the Rim. The ProWeather station near the utilities buildings indicated 21 kph and 28 kph at those times, respectively. From 6:30 to 8:00, The Overlook winds were calm, albeit with fairly gentle gusts and veering from due south to due north. By 9:00, they were primarily from the south again, but they returned to northerly winds by mid-afternoon. In the valley, the ProWeather station indicated that the winds followed roughly similar patterns of both direction and speed. Site 3 was far less protected from the south but no weather data was available there.

On Monday 21^{st}, using Raven's more comprehensive measurement system, the Roland R-26's XY directional microphones at site 2 reported that 3:24 was the quietest time of day (Figures 67 and 68). Most insects had fallen still, the birds had not started their dawn chorus, and few travelers were on either the county road or the state highway. The mean SPL could be roughly correlated with the wind speed during the night, until staff started to arrive and the SPL increased independently of the wind. Shortly after 8:00 staff began preparing vehicles for their day's work repairing the roads to the west of the rhino enclosure; the first tractor headed out of the utilities area at 9:20 according to the investigator's log. As well as tracing the overall SPL for the day, the data depict the

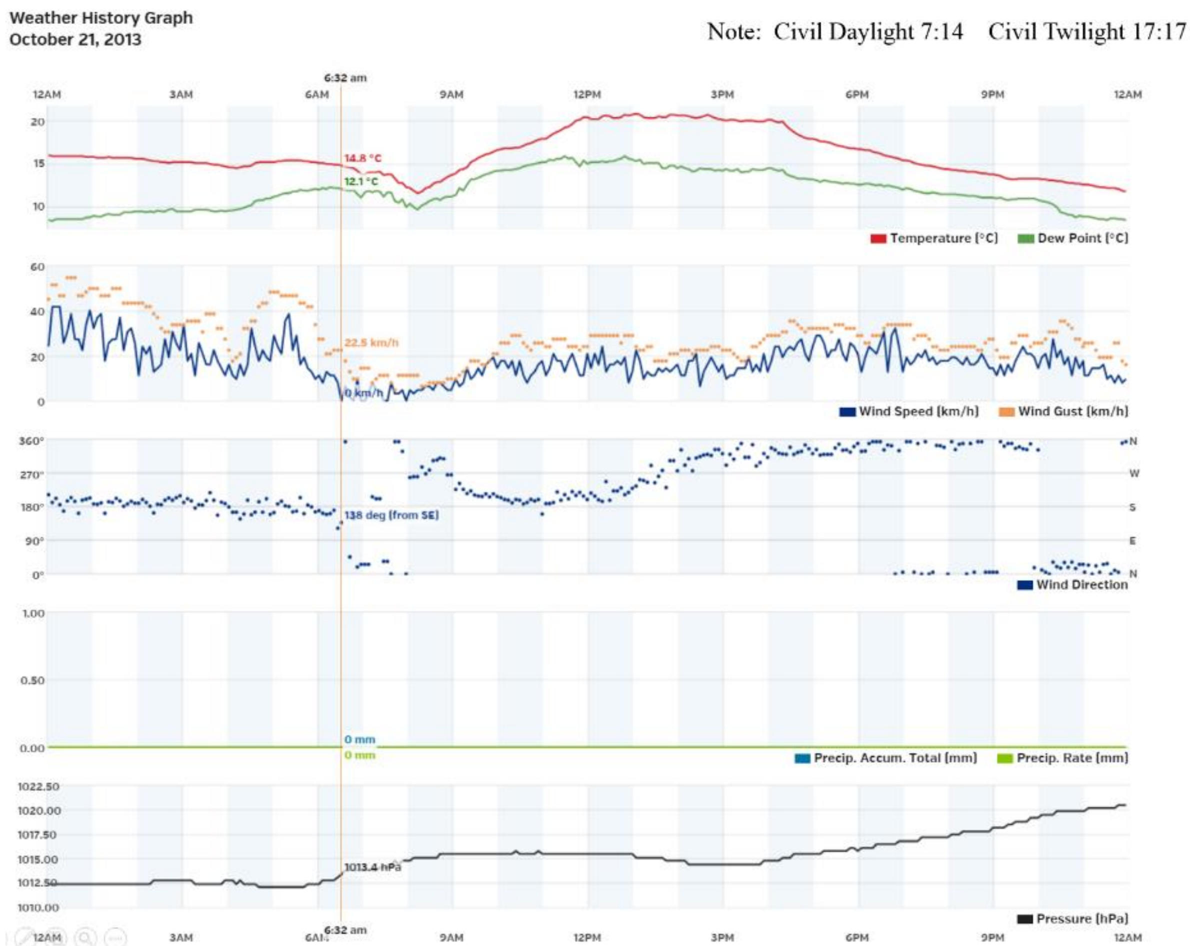
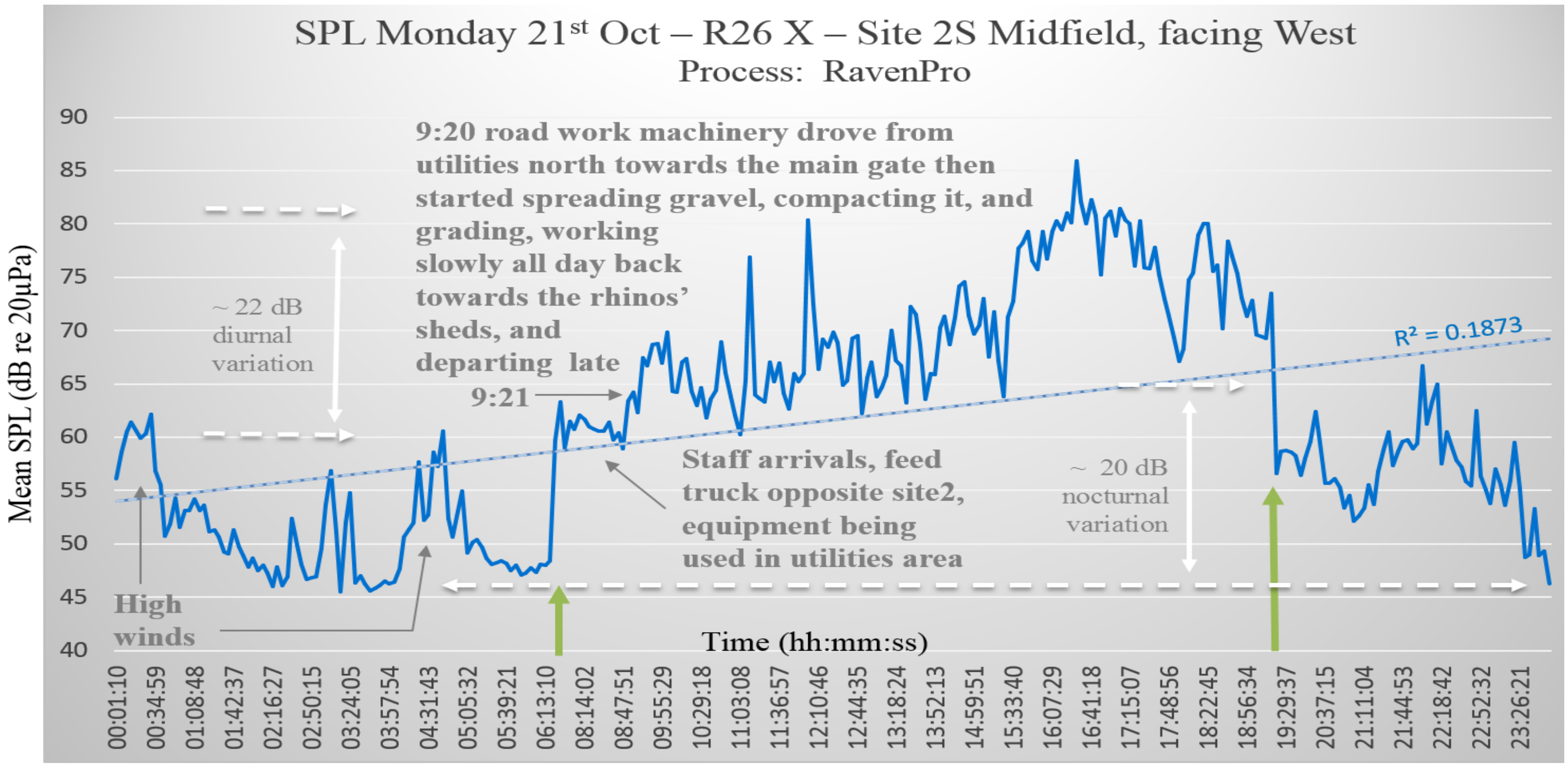


Figure 66. **The 24 hour report from The Overlook**. Station KTXGLENR3 (http://www.wunderground.com/personal-weather-station/dashboard?ID=KTXGLENR3#history/s2041/e2041/mdaily last accessed 5 November 2014) shows that the temperature and dew point gradually dropped overnight until a little after 8:00 (shown by the red and top green lines respectively), and at 6:32 (the vertical orange line) the previously high wind from the south dropped to 0 and the gusts from 55 kph at 0:30 to 22.5 kph, and shortly thereafter also to 0 (the blue line and yellow dashes respectively). In the calm, the wind swung 180^{o} from south to north (navy dotted line), gradually returning to the south by late morning and then progressively swinging back to the north through the afternoon. No precipitation was recorded (flat green line), and the atmospheric pressure rose gradually throughout the day (black line).

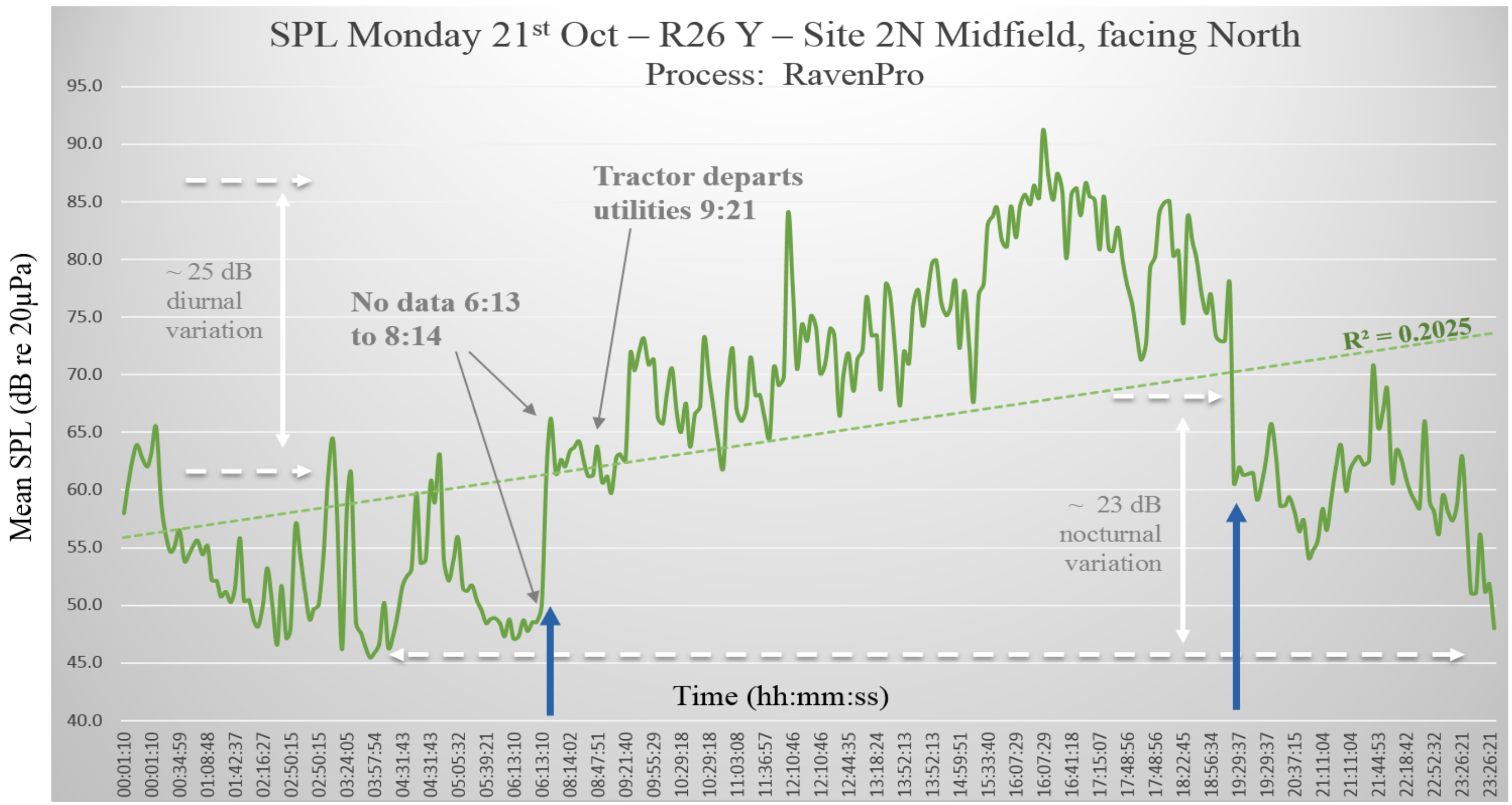
progress of the road crews as the tractors and trucks left the utilities buildings around 9:30am, headed along the western side of the rhino enclosure towards the trail exit, then proceeded to work back from the north, filling and grading ruts beside the paved trail and then filling and grading the unpaved staff access road bounding the rhino enclosure. According to the Roland, the SPL quickly dropped more than 16 dB at about 19:00 after



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	24 Hour Variation	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
4m14sec	$R^2 = 0.1873$	45.5 dB at 3:24	85.9 dB at 16:07	40.4 dB	~ 22 dB	~20 dB	61.6 dB	10.2

Figure 67. **Monday as registered midfield by the Roland R-26 X microphone, facing west.**



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

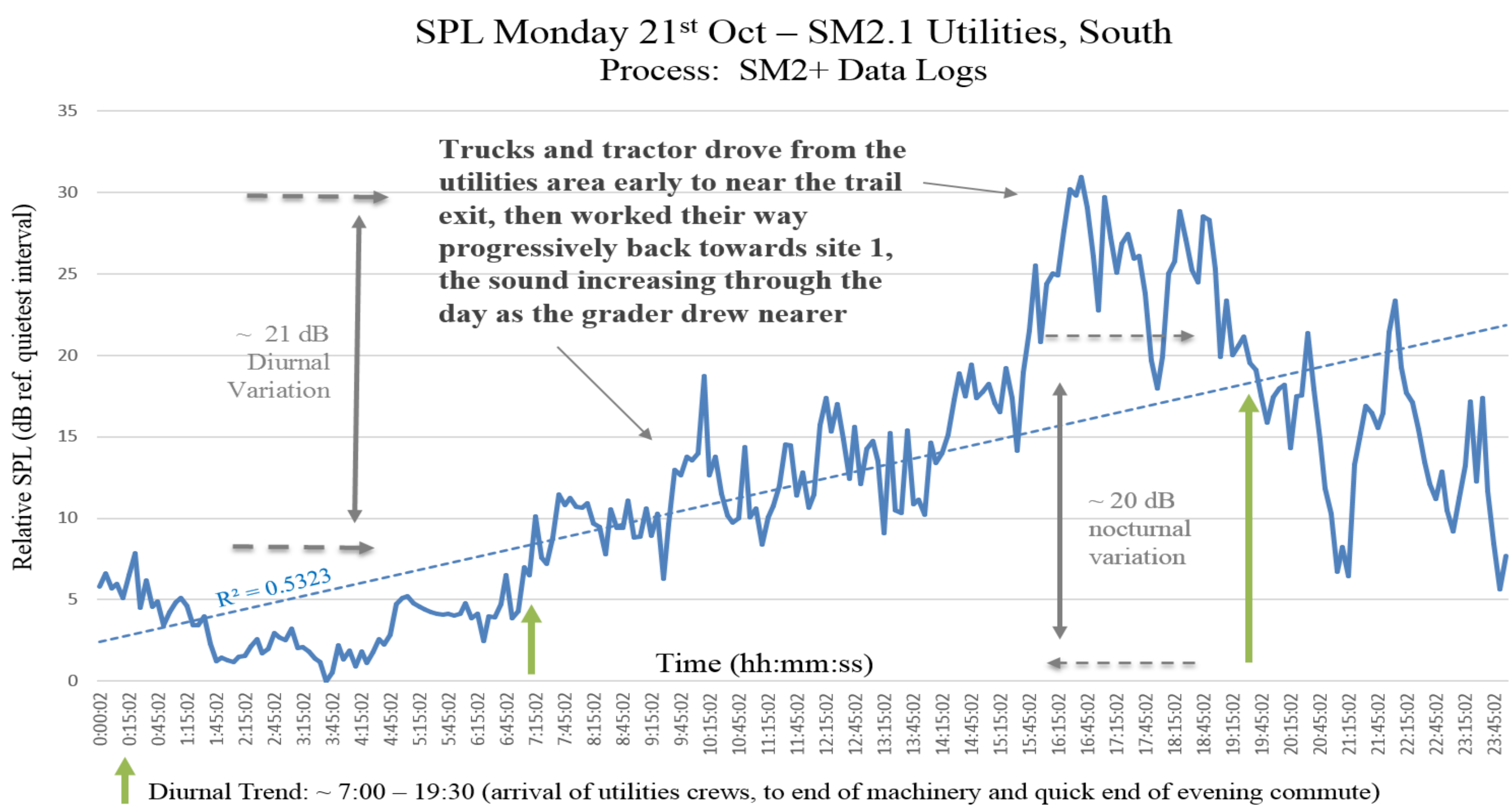
Mean SPL Interval	Trendline	Minimum	Maximum	24 Hour Variation	Diurnal Variability	Nocturnal Variability	Average	Standard Deviation
4m14sec	$R^2 = 0.2025$	45.5 dB at 3:57	91.2 dB at 16:07	45.7 dB	~ 25 dB	~23 dB	64.7 dB	11.4

Figure 68. **Monday from the perspective of the Roland R-26 Y Microphone.** This faced north but was partially protected from the south by trees

the staff returned the vehicles to the utilities area, and headed home. Little traffic remained on the roads. The wind was either gentle or calm, but it generally subsided as the evening progressed. By midnight all was calm. It was interesting that although the wind was lower around 21:30 than at 22:30, the SPL levels were higher. This was due to a prolonged series of mass vocalizations through the evening peaking around 21:45, as if the animals that had appeared absent from the recordings in the presence of so much ambient noise during the day, had now found their voices. It should be noted that the Roland ran out of memory and recording ceased at 6:13 and did not recommence until 8:14. This caused an apparent sudden rise in SPL, which actually occurred more 8:14. This caused an apparent sudden rise in SPL, which actually occurred more gradually throughout those two hours as indicated by the SM2 recordings.

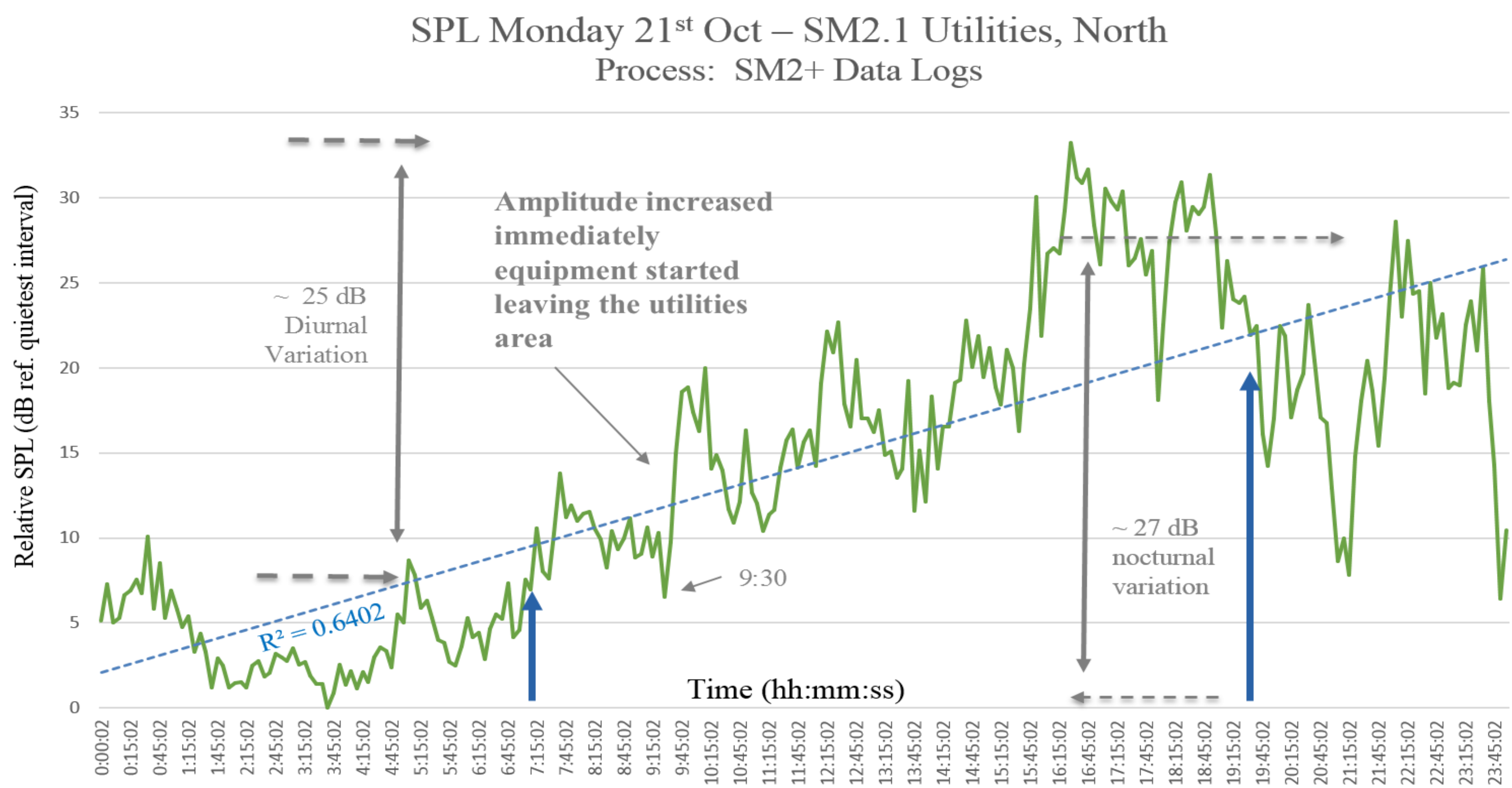
Not only is the daytime maximum SPL greatly increased, from 70.5 dB to 91.2 dB in the case of site 2N, the variability of the noise, the diurnal and nocturnal and24 hour variations changed from 15, 8 (not including the evening storm) and 50.7 dB respectively on Friday (the latter number being so high due to the sudden evening storm) to 25, 23 and 46 dB at the same site on Monday (compare Figures 47, 48 to Figures 67, 68). An increase of 3 dB is actually a doubling of amplitude; therefore these increases are especially noteworthy. While humans do not normally perceive 3 dB as doubling, just as a substantial increase, it is unclear how rhinos and other animals may perceive it. It could be assumed, however, that an increase of 25 dB throughout the day is particularly significant. A table comparing the parameters for each day can be found in Appendix F.

A comparison is also presented using the SongMeter Data Log system to calculate the relative SPL for Friday (Figures 54, 55) and Monday (Figures 69, 70) at site 1.



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

Figure 69. **Monday from Site 1S.** The SongMeter sensors nearest the utilities buildings show increasing noise as the road crews worked steadily towards them throughout the day.



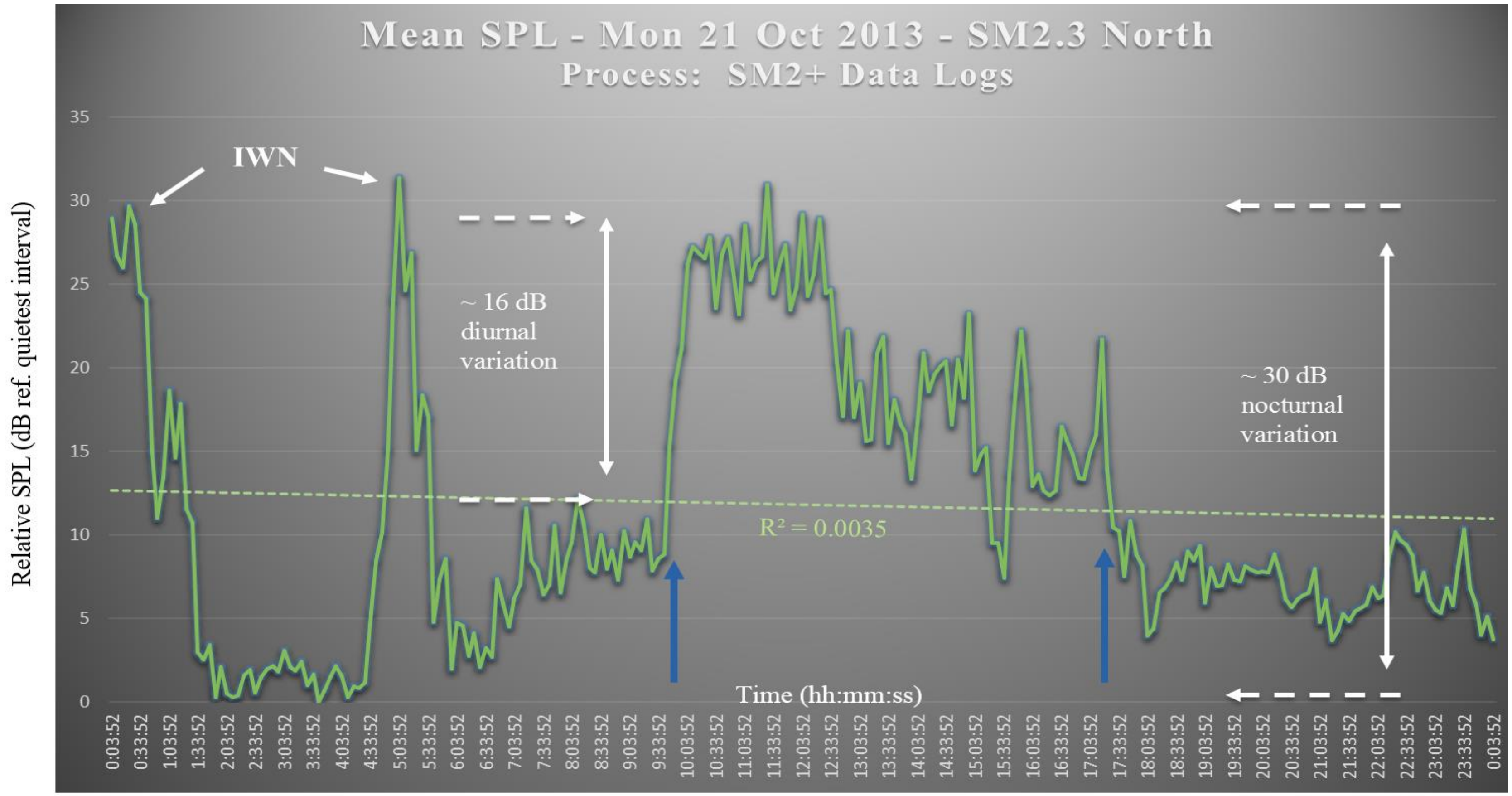
Diurnal Trend: ~ 7:15 – 19:40 (arrival of utilities crews, to end of machinery and quick end of evening commute)

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	33.35 dB at 16:30	~ 25 dB	~ 27 dB	14.2 dB	2.7

Figure 70. **Monday from Site 1N.** Just 21 meters to the north but less sheltered from the south, amplitudes and the daily variations were considerably higher during the early morning wind storms, during much of the roadwork, and during the animals' evening discussions

Although the sensors at site 1 were close to the utilities area, they were partially in the sound shadow of the buildings so did not start registering high SPL on Monday until the tractor and trucks were passing on the service road. They were well protected by trees from the strong southerly winds around 0:30 and 5:00, especially SM2.1S. Despite using a different measurement system, this SongMeter data can still be compared to that from the Roland in general terms using graphs. The Raven data have been calibrated, enabling the report of actual decibel levels, while the SM2+ Data Log data remain in relative terms; the resolution is less fine, so the general curves should be observed rather than detailed evaluation of the measurements on the axes. However, both systems' graphs from sites 1 and 2 reflect the slow progress of the machinery up the service road then back along the enclosure's boundary. Their stories read similarly because the road workers simply drove past the southern end of the service road and began their noisy grading and compacting at some distance from each of those recorders, then progressively worked back towards them, causing their SPL to gradually rise. The highest amplitude for the R26 occurred around 16:00 while the workers were midfield, and over half an hour later for SM2.1, by the time work was opposite that site. Both systems documented the high amplitude caused by the communal evening chatter.

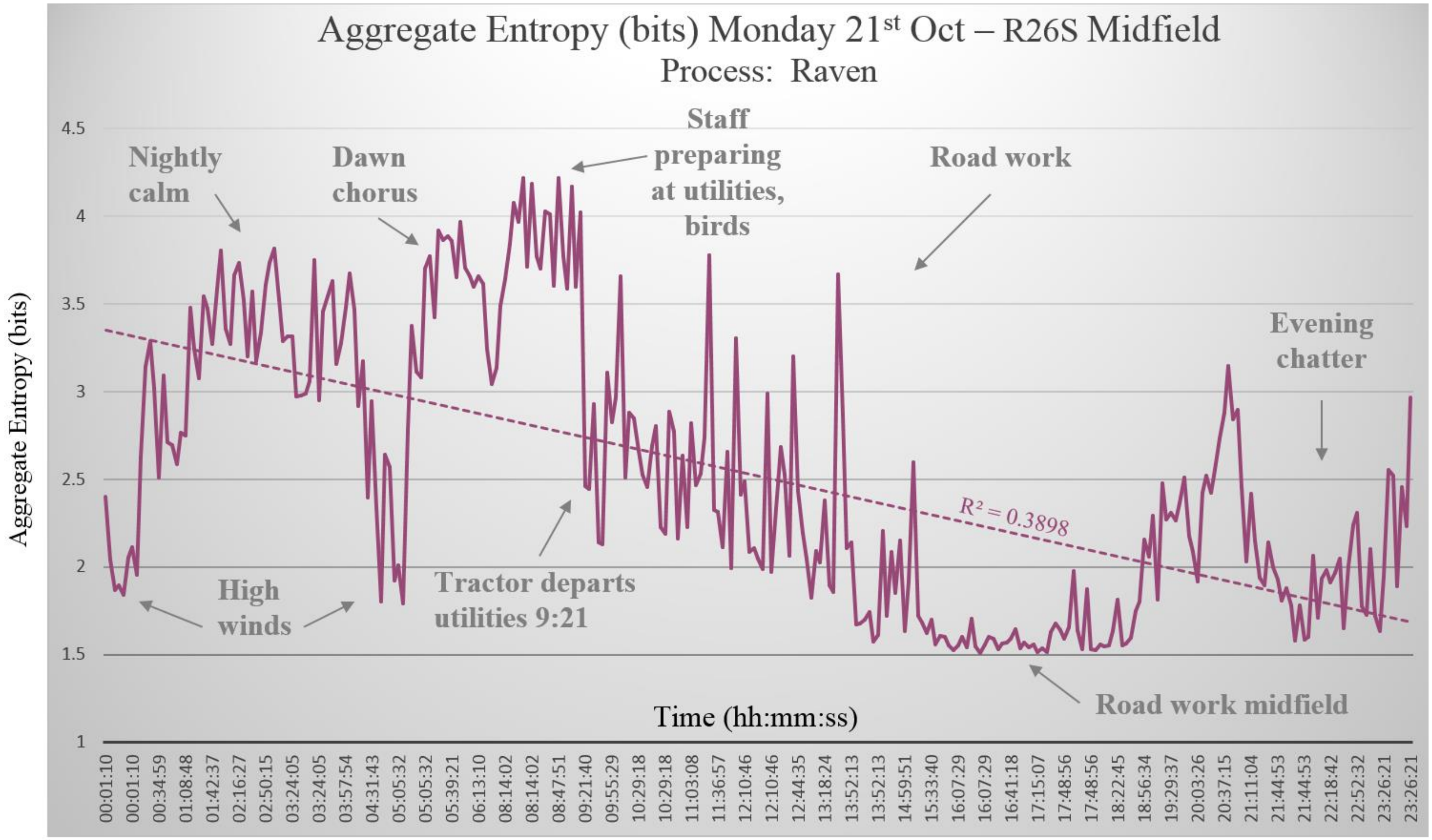
The SM2.3 microphones were vulnerable to the high overnight winds because they pointed to the southwest and were further from the protective Rim. The winds swung to south-southwest and gusted at 55 kph around 00:30 and 47 kph around 5:30, the times that indicated two of the three highest amplitudes of the day (Figures 71, 72). This was due to direct buffeting by gusts, and the recordings suffered IWN in the same way as the R-26 microphones which had been exposed to the north-northwesterly winds on



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 71. **Site 3 mean SPL.** Strong winds caused IWN and extreme amplitudes very early Monday**.** The northernmost sensor did not collect as much biophonic activity as other microphones during the chatter shortly after dark, perhaps because it was the closest to the road and to generally open ground and may have harbored different species



	Mean SPL Interval	Trendline	Minimum	Maximum	Average	Standard Deviation
Incl Winds	4m15secs Raven	$R^2 = 0.3898$	1.51 bits at 16:07	4.22 bits at 5:03	2.5 bits	0.8

Figure 72. Again, much of the entropy mirrored the SPL.

Friday night. These gust speeds were as high as or even higher than Friday. In each case however, the IWN was only during the gusts, and useful data were collected between these as the microphone windscreens were able to manage the sustained winds. Since the SM2.1 and the R-26 microphones faced northwest (apart from the Roland R-26's internal X microphone that pointed west southwest), they were not as vulnerable on Monday. The SM2 recorders at both sites 1 and 3 reported the gradual build-up of biophonic activity after the winds had settled, leading to the dawn chorus that continued well after staff arrived for the day. The biophonic component subsided as the machine noise increased.

Entropy

As on Friday, Monday's entropy curve for the Roland site midfield trended the opposite direction of its SPL for much of the time (Figure 72). It was low during the highest winds, when all other sounds were masked, and also when the roadwork was loudest, when the workers were on the service road opposite site 2. Another period of low entropy occurred during the nocturnal "chorus" when birds, insects, and a variety of animals combined voices to provide almost continuous activity. High entropy occurred during the calmest time of the night, when a single bird call or rhino snort contrasted starkly with ambient peace. The dawn chorus was another such period, particularly as birds seemed to be awakening and contributing their songs on an *ad hoc* basis at first. Once the full chorus was formed, the SPL rose, but the entropy reduced. A similar situation occurred regarding the workmen arriving at the utilities area, banging a car door and dropping heavy equipment into a trailer.

It can be seen from these reports that even a soundscape considered by many to be calm, peaceful, and natural, actually contains an infinite number of elements (such as sound sources, geographic situation, and environmental factors), and that these sometimes work together (for example to increase SPL), sometimes against each other (for example by masking) to create the totality of the sounds we perceive at any place and time. The following chapter discusses how these preliminary findings met the four goals of the project, improvements that could be implemented in future, and particular challenges and observations.

8. DISCUSSION

The Results

This project commenced with four goals, which are addressed in turn below.

Goal 1

To develop a method to comprehensively record, measure, analyze, and characterize the broadband soundscape of the captive white rhino, and from the possible perspective of rhinos residing in the enclosure at FRWC over a one-week period of normal activities.

Fossil Rim's white rhino soundscape was successfully recorded throughout a week of normal park activities by five separate acoustic, infrasonic and seismic data acquisition systems and by a total of ten sonic, six infrasonic, and three seismic sensors to capture frequencies from 0.1 Hz to 22,020 kHz, and an analysis method was developed to study the resultant broadband sound metrics. While each of the sonic, and both cameras, had to pause during SD card and/or battery maintenance, and the Roland and the Drift ran out of data storage occasionally, the inbuilt redundancy in the project design resulted in the other recorders continuing to record the environment without a break. At no time was more than one recorder out of operation. Considerable work remains to analyze and correlate the data, and thus to complete the characterization of the soundscape at the enclosure, but the method has proven its efficacy.

Goal 2

To note the vocalizations of the southern white rhinoceros, and to roughly estimate the bandwidth used by these particular animals.

It was observed that, as had previously been hypothesized (Davies, Krebs, and West 2012), the rhinos' vocalizations with repetitions of short syllables across a range of frequencies does enable them to communicate in the face of ambient noise. In addition, although a relatively small portion of the data has been processed and visualized to date, it is apparent that a number of the vocalizations of the white rhinos of FRWC involve very low fundamental frequencies with harmonics that rise to over 15 kHz, some to 18 kHz with possible higher vestiges. Since the rhinos were not visually observed during this time, it was not known which one/s of the females made these calls nor their distance from the recorder. The stronger vocalizations studied to date have been against a background of considerable noise so it has been difficult to identify the full size of the bandwidth involved, but the investigator will continue to seek further examples and believes there is sufficient evidence to warrant a formal, focused study. It would be interesting to determine whether these higher frequency and more powerful vocalizations only occur against a loud ambient background, and/or if they occur in nature when communication over greater distances is required – in the way that humans may raise or intensify their voices in similar circumstances. Long-term recordings could be made when all the rhinos are together, in their yards or in the nighthouse, to determine whether such calls are made in those situations. Recordings when the rhinos are separated, particularly the mother and calf perhaps, may provide a different set of acoustic signatures. The rhino vocalization studies in the literature to date appear to have all been as the result of recordings at close range within a zoo environment and do not appear to have documented such broadband vocalizations. A future effort in this research is to explore not only the vocalizations, but their apparent purpose, to continue the work begun by Policht et al. (2008).

Goal 3

To demonstrate that techniques and language not normally used in the discipline of Geography could broaden its scope and expand the tools available to those investigating their environment.

Like most people who have grown up in urban or noisy environments, many geographers are more aware of things they learn visually rather than aurally. That may be due to the city soundscape lacking meaningful content for them due to an overabundance of noise. However those who rely on hearing more than on sight due to physical limitations or confinement are aware of and dependent on their soundscape as much or often far more than on what they see. Their world is still rich in information. So it can be invaluable to consider, explore, and mine the acoustic aspects of any environment. Probably the most recognized geographer to do this, and the most widely published in a field associated with acoustics is Reginald Golledge, who pioneered analytical approaches to behavioral geography in the 1970s before becoming blind in the mid-1980s, after which he turned his attention to how the visually impaired could navigate the world with acoustic and haptic GPS-based technology.

Just as some things need to be seen to be appreciated, others must be heard to be discovered. This project revealed the presence of wildlife such as coyotes, possibly bats and mice and other species that were unlikely to be seen from the rhino enclosure. It revealed an active nightlife, and abundant biophonic, geophonic and anthrophonic influences. We learned something about local culture from road and air traffic flow at different times of the day and night. Perhaps more importantly, we learned how to not only document sound events but to actually measure the rhythm of a time and place demonstrated in terms of sound pressure levels and entropy but available for a variety of other acoustic parameters. This process can be applied to virtually any chosen location.

Even those geographers who do not become adept in geographic information systems and remote sensing, both based on images, should understand their potential. They should be able to identify when those resources could be used to advantage, and to confer productively with experts in those fields. Merely by listening to an environment and documenting it perceptually, perhaps just by creating a simple hand-written sound event log and possibly mapping its variation over a region, much can be learned about the character of a place that may not be discernable from a purely visual perspective. However measuring and quantifying the soundscape provides far greater knowledge. It is hoped that this project will create awareness among geographers of the potential of these techniques, and that soundscapes will be respected for the information they can impart, for the way they can be managed to the benefit of humans and non-humans, and like landscapes, also for their potential beauty.

To date few acousticians appear to be geographers, and even fewer who might measure and quantify soundscapes. Yet many of their questions overlap with topics in which geographers have expertise, or could contribute a different perspective. Schulte-Fortkamp (2014 a, 2014b) stressed the importance of interdisciplinarity to appreciate the broad roles of soundscapes and the need for a common language to discuss, as well as measure, varying soundscape techniques. Geographers are appropriately skilled to help draw together and cohesively build on concepts from these fields. Scientists in North America, Europe and Australia have been collaborating to develop ISO international standards relating to soundscape research. Among their recommendations are that soundscape ecology should emphasize the ecological characteristics of sounds including the effects of elevation, latitude, and edge-core situation on acoustical processes, spatio-temporal dynamics, soundscape linkage to environmental covariates, human impacts on the soundscape, soundscape impacts on people, and soundscape impacts on ecosystems (Pijanowski and Farina 2011). Geographers are indeed well placed to collaborate in such research.

Goal 4

To demonstrate how the processing and analysis of the data collected at FRWC can be formulated to characterize the soundscape that their rhinos experience.

The simple sound log provides a good foundation for determining where FRWC lies on the continuum of anthrophonic to natural soundscapes. Katydids, crickets, killdeer, and the mixed voices of more distant animals provided the keynotes, but when they suddenly ceased they became sound signals, warning others that something unusual had occurred. Other keynotes were anthrophonic, for example vehicles on the country road, the distant hum from the highway, barks from neighboring dogs, aircraft, the clang of metal trailers, the sound of tires on gravel, the voices of excited children, or of tour guides in the zoo safari buses. Keepers' and staff voices along the rhinos' fence however were sound signals and attractive, as the rhinos frequently wandered across to them and often received a rub.

Just by listing and categorizing sound events, it was learned that on Friday 18th October the rhinos could be heard near site 1 in 53 percent of the sections throughout the day. Anthrophonic events occurred in 67 percent, other biophonic in 86 percent, and geophonic in 16 percent of the sections. At one end of the continuum, in high traffic urban locations, 100 percent of the acoustic environment may be genuinely anthrophonic, or may sound that way if all other categories are masked. In the few truly natural environments that still exist, 100 percent of the soundscape is created by biophonic and/or geophonic sources. At times this was the case at Fossil Rim, when strong winds masked any vestige of anthrophonic sound, but when all was quiet there seemed to be a distant dull hum of road or other anthrophonic noise, particularly from site 3. If this very dull background hum is ignored, as is the case when one is on-site as it must be carefully listened for, then for much of the time Fossil Rim exhibits a strong trend towards being a natural environment.

By mathematically measuring the recordings, diurnal and nocturnal patters can be observed, or any other period of interest, and for a variety of acoustic parameters. The examples presented were patterns of SPL and entropy, but other factors can be studied similarly and to greater depth, such as the overall energy in a sequence, or the frequencies at which most power is generated. Individual frequency bands can be isolated and searched and measured, according to the suspected acoustic sensitivity of the rhinos or of other animals in the vicinity such as the blackbuck, blesbok, or ostriches. Once all the data have been processed for all sensors and their results correlated, it will be possible to observe daily rhythms and whether they demonstrate any regularity. It will also be possible to divide the data into any time lengths to observe the characteristics of periods of day such as post-midnight, the dawn chorus, early morning, feeding times, work hours, visitation periods, evening, or night. The impact of varying weather patterns can be studied by comparing the weather data from The Overlook and from the ProWeather stations with the data from each of the six sonic sites and the infrasonic sensors.

Not only IWN could be removed from the recordings, but also sections of anthrophonic noise if desired, to create a baseline of the ambient soundscape without intrusive transient events. The time ratio of this background ambient soundscape to periods when there are transient events, during different times of the day or night, or on weekends as compared with workdays, would also be worthy of study. Another goal of later data mining will be to categorize the various types of transient events such as feeding, exhibit cleaning and maintenance, workshop activities, zoo tours of various types compared with individual visitors using their own vehicles, “loud” events such as lawn mowing and road repairs, and events off-site such as transportation, the monthly siren test, nearby shooting, or other activities.

No two microphone sites provided the same results. Each site was protected from and vulnerable to different types and different levels of sound from each category of sources. Site 1 for example, although close to the utilities buildings and very vulnerable to activities behind those buildings, was protected by them from the sound of the workshops and from the loading of heavy equipment in front of them. Each site was impacted by winds or rain from a different direction, and even though thunder impacts massive areas, it turns out the impact is not equal as the intensity of thunder varied from site to site. Sites were probably most unique according to their biophonic contents. Even the shrill yaps and howls of the coyotes were heard more clearly from sites 2 and 3 at times than from the presumably closer site 1, sheltered by its closer proximity to The Rim perhaps. The soft vocalizations of the semi-free roaming residents of Fossil Rim were also far clearer at some sites than others. The insects and killdeer seemed pervasive, although the levels of reception for even those varied from place to place. However the most distinguishing group were often small creatures that could be heard, or possibly visualized, from a single microphone – possibly field mice, frogs, and bats.

There are many instances of animal vocalizations that will require confirmation by the staff or experienced volunteers at FRWC. Identification will assist in determining their likely relative locations and distances from the microphones. Certain calls, particularly those of higher frequencies, were received at one or two sensors but not at others, or transitioned from one sensor to another. Exploring this may lead to not only more knowledge about a species and its activities (particularly their nocturnal habits), but might aid in developing alternative remote animal tracking techniques. Analysis of the contents of the sound files is a major project in itself, but identification of and selection of clear calls could be the foundation of a separate publication in collaboration with Fossil Rim staff, and the basis for a Fossil Rim sound library, with key examples also being sent to the national archives of the Macaulay Library at the Cornell Lab of Ornithology.

Insects and birds were prolific and highly audible at various stages of day and night. The soundscape was dominated by insects during late afternoons and evenings and by birds during the dawn chorus and into the day, but they diminished as the day wore on and both insects and birds seemed to cease vocalizing, or were masked by loud sound events. This biophonic reduction in the face of high amplitude noise was notable whether, as the recordings showed, the source was geophonic (for example the wind storms) or anthrophonic (trucks and machinery). At these times, only the birds with loud shrill calls could be heard, such as crows, but even they took advantage of gaps in the ambient noise.

Improvements

Fossil Rim's white rhino soundscape was measured continuously throughout a week of normal park activities by five separate acoustic, infrasonic and seismic data acquisition systems and by a total of ten sonic, six infrasonic, and three seismic sensors to capture frequencies from 0.1 Hz to 22,020 kHz, and an analysis method was developed to study the resultant broadband sound metrics. In addition, the data every five minutes from two weather stations and photos every minute from two video cameras await to be correlated. Much was learned, and many improvements will be implemented to streamline future exercises ranging from a final full length pilot study to permit any problems to develop over time, to the refinement and better management of some of the equipment such as a later model GoPro camera and the addition of a third camera so the entire study site could be observed throughout daylight hours. On-site recordings would be analyzed in more detail at an early stage and all the equipment would be calibrated as much as possible before the pilot studies, including a range of dry, damp, wet and soaking windscreens to determine which work best in varying weather conditions. Calibrations would be rechecked immediately before and after the official recording period to ensure no problems had developed, such as the questionable wide band of noise around 15 kHz in both SongMeters. It would be valuable to determine whether that was machine noise, environmental noise or some other factor. Further investigation may make this apparent. Such calibration was attempted for this project, but due to complications was not yet successfully achieved.

Now that a data analysis protocol has been established, some of the measurements that became redundant (such as clock time) could be removed, making the process faster. While some other measurements may not seem important yet, it may not be until they are correlated with recordings at other facilities that their significance becomes apparent. Still other measurements, such as the power functions, are known to be important and have been tabulated but are awaiting proper calibration and their patterns are still to be investigated. They could be graphed in relative terms like the SM2+ Data Log dB(V_{RMS}), but need calibration to have real meaning. Filenames and section lengths would be better coordinated across all the equipment. The investigator would have her own latest edition of Matlab and a better working knowledge of it (she promises), although Raven Pro Interactive Software would remain the processing method of choice in part because the measurements made at Fossil Rim would remain a more accurate baseline, but also because it provides the most accurate, comprehensive and also user-friendly visualization and analysis available at an economic price. It may well be that over time more efficient programs become available, but any change of system would require the ability to accurately calibrate it with Raven's analysis in order to compare it with Fossil Rim's 2013 data. That being said however, by actually recording the soundscape at Fossil Rim, this project's entire raw database could be re-processed in any new system so direct comparisons with future recordings could still be made. It would just take time.

Challenges and Observations during Recording

The location and the need to mount equipment high out of reach of ostriches and other animals was fully appreciated but added to the challenge of this recording project. It was difficult not to adulterate the soundscape when walking on the gravel to approach the sensors, or as occasionally occurred, when placing a ladder against unstable fence wire, although one became adept at walking quietly from stable rock to rock where possible. It was difficult to monitor battery levels, data storage capacity, and equipment status more than two or three times a day between returning to a mains power computer to download the data and to recharge the GoPro camera. Since the recordings were as broadband and as high resolution as possible, it took significant time simply to download the SD cards onto an external hard drive between maintenance runs. It was necessary to carefully judge when it would be necessary to replace the next card or battery and to be in the right place/s at the right time, since the area could not be accessed after dark. Very high capacity SDHC cards are now available, but even the newly purchased Roland R-26 was not designed to take advantage of them. Data storage was never a problem for the SongMeters since they were developed to be left in the field for months at a time. Monitoring the equipment was even more challenging in wet weather. One could not guarantee keeping the equipment dry when reaching high above one's head to remove the weatherproofing to access a recorder. Three days were interspersed with heavy rain and high winds, which made it impossible to change the Roland's and the Drift's SD cards safely, so there were some extended periods when they could no longer record due to full memory. The inbuilt redundancy of multiple recording systems reduced the significance of this, but also reduced the observation of the individual character of the midfield recording site.

Equally concerning was estimating the wind speeds and direction (or more significantly, the gust speeds, since they were not predicted) in time to add additional foam windscreens. Weather Underground does not offer predictions since individuals simply offer a recording service. Weather forecasts for Glen Rose were gleaned night and morning from weather.com, and during daytime data downloads. Data and phone access were both difficult behind the recording fenceline.

Fossil Rim is prone to strong winds that can arise or change direction quickly. In calm periods heavy windscreens are undesirable as they reduce the microphone sensitivity. However without screens, IWN can cause the total masking of sought-after sounds. It was decided early in the project that since it would be impossible to change windscreens at night or even quickly during the day, it would be necessary to compromise with a standard windscreen at all times, and to only add heavier screens to one of each pair of sonic microphones after strong winds were predicted, noting when they were added so those recordings could be calibrated accordingly. One of each pair of sonic microphones 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 reducing the IWN on the other sensor so it could report during the wind noise. Even with the additional windscreen however, the microphones were still susceptible to IWN. 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. Their main impact was masking low frequency sounds, and adding considerably to amplitudes. Since the project seeks to eventually examine the infrasonic soundscape as much as the sonic, the low frequency wind data remain valuable when the wind did not cause mechanical buffeting of the microphones. Such segments can be manually removed from the recordings later as necessary. Due to the different orientation of the microphones at each site, analysis to date has not discovered a time when more than two sensors were simultaneously impacted by IWN, and often only one was, so viable comparable metrics were accrued throughout the recording period. Clipping was rare, occurring on one or possibly two microphones during IWN but mainly when it sounded like insects striking the screened microphones directly – or was it perhaps electrical noise? That requires further analysis and investigation.

It was notable how much the soundscape changed according to wind speed and direction. Some sounds from distant upwind were only audible during steady winds. 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. It should be noted that during and soon after 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 some accounting for these effects could be achieved in more detailed analysis. The two days reported in this dissertation experienced minimal (0.5 mm on Friday 18th) or no precipitation (Monday 21st).

Inaccessibility was an issue for the GoPro camera in particular as even on its slowest setting of one frame per minute, its battery lasted less than three hours and only one spare battery was available. The batteries could only be recharged in the camera so merely six hours could be recorded at a time. For a future project the latest model cameras could be used as they are less likely to suffer these limitations, or a spare camera could be included so one could act as a charger while the other actually photographed. It is possible that in a zoo environment, security cameras may already monitor enclosures from a good vantage point and their footage may be made available.

Long periods of inaccessibility might not be an issue if recording in a zoo. It would probably be smaller and require fewer sensors, and it would not take long to move between them to provide appropriate windscreens and maintenance. In inclement weather it may be possible to dismount them and move them to a sheltered area in order to open them safely. Microphone positions may be more sheltered and so avoid IWN. Mains power would be available and if a secure area were provided, downloads could continue on-site while the investigator monitored the equipment and kept a running log of activities. (Due to the need to return to the far side of FRWC to download data and to recharge batteries, there were extended periods during which an event log could not be diarized.) Night access may be granted as most zoos have night security staff who are frequently interested in new projects and who may agree to accompany the researcher to the site 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 any more than necessary.

While the pilot studies proved very helpful and a steep learning curve, a longer and more comprehensive pilot would have revealed issues that proved difficult to resolve in the field during the final pilot because it continued straight into the week of formal recording. Equipment could not be replaced or readily altered. Issues which did not become apparent prior to the extended final pilot included:

- certain brands of large SDHC cards proving incompatible with the Drift camera
- the need for far more batteries for the GoPro camera, and a second GoPro so the batteries could be re-charged in one while the fence-mounted unit could continue recording
- the ProWeather station appeared to operate without problems in the city, mounted as designed on and in a building, but onsite at FRWC its hygrometer started to fail on a semi-regular basis during the heat of the day. This could have been returned to the manufacturer for investigation if the problem had been recognized in time. The differences in the wind and at times a small rain squall at one end of the enclosure and not the other, suggests that in an ideal world it would have been advantageous to have had another small weather station near SM2.3. This would have also acted as a back-up if one had experienced a major failure.

- considering the wind variability and how difficult it was to quickly change windscreens back and forth at appropriate times, it may have been better to leave one microphone of each pair in a standard cover all the time (as was done), while the other could have been in a heavy duty windscreen each night and during any day when winds were expected to change. This would have effectively halved the number of useful sensors at any one time, but may have ensured that one of each pair was sufficiently protected to avoid IWN, thus conserving a record of the soundscape at each site no matter the weather.

Obtaining low-frequency calibration of the acoustic recorders is difficult. Most manufacturers do not guarantee or therefore disclose frequency responses below 20 Hz. The calibration facility at UT Austin is only capable of testing down to 200 Hz, so the Earthworks mics, which bear a factory calibration down to 9 Hz, were very helpful.

Unfortunately the Roland R-26 and the SongMeter SM2+s did not end one recording and commence the next file in a synchronized manner. For a future project, it would be useful to program all the recording systems, including the infrasonic and seismic ones, to restart at precisely 30 minute intervals if that were possible. This would greatly aid later synchronization of sound events, photographs, weather data and other reports. It may however mean that up to 30 minutes may be lost if the system was powered down for maintenance and had to wait for the pre-set time before it would recommence a scheduled recording.

Similarly, it would be extremely helpful to process all formats and lengths of recordings in the same page size. To date, long files have been divided into eight sections for comparison and statistical analysis. If all sections were of precisely the same length, comparison would be more efficient. However that would either require all the original files to be the same length, or the last page in a file to be an odd size, which could complicate analysis and documentation.

By far the greatest challenge turned out to be developing an efficient and reliable protocol to mine the almost 1.5 TB of data. Even the support staff and developers at Raven, and the teaching staff at the two Cornell summer schools had not realized how difficult this was to prove, since they have little experience in analyzing such a copious broadband dataset. Idea after idea was tested, often taking weeks to work through how it could be implemented, only to eventually discover that promising advances did not prove any more workable in the long run.

With regard to how the rhinos may perceive their acoustic environment, this may be the focus of a later study. It will be necessary to calibrate and properly identify the lower limit of their vocalizations on the assumption that their hearing is sensitive to at least that limit, but probably lower still. Sounds they are exposed to within that range could played to them and their movements filmed – whether they are attracted to, deterred by, or choose to ignore such sounds. The sounds would need to have acoustic significance since this has been shown to be equally as important as the frequencies, power, structure, and context of a sound. If a range of facilities that hold white rhinos are recorded and analyzed, and their metrics correlated with the health and well-being of their rhinos and it is suspected that certain acoustic parameters may cause stress, these soundscapes could be played to rhinos at other facilities for short periods to see whether they respond behaviorally or physiologically. It would be ideal to provide a soundproof area where the animals could avoid such noise if they choose.

Having discussed the project, I report my conclusions in the following, final chapter.

9. CONCLUSIONS

The research project began with and addressed four goals as a means to start to answer three broad questions: How can a soundscape be comprehensively measured and characterized for the captive southern white rhinoceros *(Ceratotherium simum simum)*? What does doing so tell us about their environment of captivity? How can this method be employed to understand the contrasts of the soundscapes of captivity and natural habitats?

The project undoubtedly developed an effective standard for recording, measuring, and characterizing such a soundscape, however various aspects can and will be progressively refined ranging from recording methods such as the use of windscreens and if available, a more comprehensive infrasonic data acquisition system so wind noise can be better accounted for and even the lowest frequencies reliably identified, to improving the speed and efficiency of analysis, the latter being most important before similar soundscape analysis is likely to be widely adopted. Future analyses could draw on this dataset to seek particular parameters known to be injurious to humans such as fluctuating or impulse noises, as well as those characteristics already known to invoke responses in other animals, such as those regarding the durations and structures of sounds.

While much of the analysis remains to be completed, it is obvious that this soundscape contains almost continuous artifacts of the rhinos' captivity, especially during work hours when the maintenance and animal-care staff are carrying out their duties. Most notable are the sliding and banging of metal gates and doors, the use of machinery and equipment, the transportation of these and of food and other supplies by trucks and trailers, visitors' vehicles and voices, zoo safari tour commentaries over a megaphone - all are elements of the captive soundscape. Even some sounds made by the rhinos themselves are not as they would be in their natural environment where they would be likely to saw their horns against sound absorbing tree trunks or rocks rather than against metal rails, the sound of which permeates great distances. Even the mix of biophony is different from that of natural rhino environments across southern portions of Africa. The species of birds, insects, and frogs would differ, as well as the voices of and constancy of the other captive species within the rhinos' range of hearing, many of which would naturally inhabit other parts of the globe and therefore never come within the hearing range of a wild rhino. There would be an intense vocal repertoire around many a natural watering hole, but not this particular mix, and not with this constancy because in the wild animals tend to remain quieter while they are dispersed, hunting, or vulnerable to predation. Outside the perimeter of FRWC the sounds of road and air transportation, agricultural animals and activities on neighboring ranches, and almost constant but unidentified and intense low frequency noise sources are constant reminders that this environment is enveloped within an anthrophonic soundscape.

From the evidence presented here, Fossil Rim proved relatively characteristic of a natural soundscape as opposed to an anthrophonic one, particularly during the absence of visitors and staff, in terms of being comprised of a high ratio of biophonic and geophonic noise for the majority of the time, particularly at night. Biophonic content included bird calls, insects, and the vocalizations of a wide variety of animals, all of which are known to provide security for the myopic rhinoceros. Their absence is as informative as their presence since regular sound patterns indicate that nothing out of the ordinary is occurring, but if they should suddenly either fall silent or give alarm calls, surrounding animals including the rhinos would be alerted.

The major geophonic contributor was wind, which could suddenly change direction and strength, and accordingly bring with it a range of different sound events from the rustle of leaves through the bush beside the enclosure, to clearer awareness of maintenance activities, of zoo tours or visitors' voices and vehicles, or from further afield the sound of traffic, or perhaps the sound of agricultural animals, of animals within FRWC, or of those roaming wild.

This tendency towards being a natural soundscape was despite some form of anthrophonic noise being audible almost all day and night, even if the source was dogs barking in the distance or the almost ever-present road hum. The two days reported did include a great deal of machine and engine noise, but most loud maintenance equipment was moved from area to area (like the lawn mower and accompanying weed trimmer) and most animals were semi-free roaming over large areas so none were impacted at high intensity or for long periods. Some tasks occurred infrequently (such as the road work). Vegetation and soil likely attenuated much of the noise, which is another characteristic of a natural soundscape, as is the high ratio of biophony and/or geophony that frequently accompanies or even masks some of the less intrusive anthrophonic noise.

Judging from FRWC's world renowned record in conservation, this level of anthrophony balanced by considerable biophony and geophony is a healthy soundscape for its rare and endangered species, including the southern white rhinoceros. Following similar analysis of a wide range of environments in which the white rhinoceros is held, future research may seek to determine whether there is a point on the natural/anthrophonic continuum where the well-being of individual animals or of a species appears to decline, or whether specific acoustic parameters such as the ratio of noise at frequencies above the auditory thresholds of specific species plays a greater or lesser role, if any.

This research provides a standard against which the soundscapes of other captive environments can be compared, and eventually correlations and contrasts can be sought between varying sound metrics and the health, well-being, longevity, and reproductive success of the white rhinos at each facility. If relationships are discovered, ameliorations could be sought. Noise management is an important aspect of city planning in many parts of the world and very effective controls can be implemented, many of which would blend appropriately into a zoo or wildlife park environment. Examples are strategically placed earth banks planted with attractive but dense vegetation, where the soil as much as the plants absorb sound. In urban areas, cities often seek places to dump earth and rubble following road or construction developments, so may supply such earth banks free of charge to the animal-care facilities. They can be readily landscaped to add to the sustainability and aesthetic beauty of a region. They can also be planted with vegetation that may improve the variety and freshness of animals' diets. Even in a small urban zoo, sound absorbing walls can be constructed with such compact and simple materials as besa blocks which can be filled with soil and planted, so that the concrete is hidden and the animals within the enclosures can graze without stomping down the fresh plants.

This research provides a standard against which the soundscapes of other facilities can be compared. Once it has been refined and proven by analysis of the soundscapes of a wide variety of institutions housing white rhinos, and if relationships are discovered between certain sound parameters and their health and well-being, it could be employed for any other species, endangered or not, captive or wild, agricultural or even domestic such as in animal shelters, and aspects of their soundscapes that are correlated to behavioral or physiological issues could be addressed.

Identifying and understanding the soundscapes within which we hold animals captive may teach us to think anew about their management. Since the auditory sensitivities of species differ widely, it would benefit animal-care administrators to recognize any undue noise within their facilities, and then to identify the animals within their care that are likely to be most sensitive to the bandwidths concerned. Certain soundscapes are more appropriate for specific species, but many aspects of soundscapes can be modified or tailored for the animals held within them, just as substrates and other aspects of zoo facilities have been tailored in recent decades.

While the soundscape that is the focus of this project may mean *nature* to visitors, and *habitat* to animal care workers, it still also represents *artifact* and *place*. Hearing the soundmarks and keynotes and seeing the sonograms of the highly visible and persistent bands of insect, bird, and varied animal vocalizations combined with the sound signals of rhinos grazing, locomoting, and vocalizing, stamps the identity of this soundscape: *"Fossil Rim."*

APPENDIX SECTION

Appendix A. Equipment Layout – Locations from Google Earth

ProWeather Station
32°10'29.21"N, 97°47'42.33"W elevation 290 m

GoPro Camera
32°10'29.66"N, 97°47'42.35"W elevation 290 m

SongMeter site 1 – microphones ~ 21 m apart
SM2.1 South
32°10'31.29"N, 97°47'42.00"W elevation 287 m

SM2.1 North
32°10'31.86"N, 97°47'41.60"W elevation 287 m

Roland R-26 site 2 – Earthworks microphones ~ 5 m each side of the main unit
Roland R-26 Earthworks South
32°10'36.32"N, 97°47'38.57"W elevation 287 m

Roland R-26 – internal XY and Omni microphones
32°10'36.47"N, 97°47'38.46"W elevation 287 m

Roland R-26 Earthworks North
32°10'36.61"N, 97°47'38.36"W elevation 287 m

SM2.3 microphones ~ 29 m apart
SongMeter3, mic 3-North
32°10'40.98"N, 97°47'40.32"W elevation 280 m

SongMeter3, mic 3-South
32°10'40.18"N, 97°47'39.72"W elevation 281 m

Refteks + 10 sensors, geophone
32°10'39.76"N, 97°47'37.89"W elevation 284 m

Drift camera
32°10'41.05"N, 97°47'40.37"W elevation 280 m

Appendix B(i). **Weather Underground KTXGLENR3 Data**

1	Time	TemperatureC	DewpointC	PressurehPa	WindDirection	WindDirectionDegrees	WindSpeedKMH	WindSpeedGustKMH	Humidity	HourlyPrecipMM	Conditions	Clouds	dailyrainMM	SoftwareType	DateUTC
247	10/21/2013 20:29	14.1	11.3	1017.8	North	350	16.1	24.1	83	0			0	meteohub	10/22/2013 1:29
248	10/21/2013 20:34	14.1	11.3	1017.8	North	5	16.1	24.1	83	0			0	meteohub	10/22/2013 1:34
249	10/21/2013 20:39	14	11.2	1017.8	North	355	17.7	22.5	83	0			0	meteohub	10/22/2013 1:39
250	10/21/2013 20:44	13.9	11.1	1017.8	North	355	20.9	22.5	83	0			0	meteohub	10/22/2013 1:44
251	10/21/2013 20:49	13.9	11.1	1017.8	North	5	17.7	25.7	83	0			0	meteohub	10/22/2013 1:49
252	10/21/2013 20:54	13.8	11.1	1017.8	North	5	14.5	27.4	84	0			0	meteohub	10/22/2013 1:54
253	10/21/2013 20:59	13.8	11.1	1018.2	North	5	14.5	27.4	84	0			0	meteohub	10/22/2013 1:59
254	10/21/2013 21:04	13.7	11	1018.2	North	5	11.3	22.5	84	0			0	meteohub	10/22/2013 2:04
255	10/21/2013 21:09	13.6	11.1	1018.2	North	355	16.1	19.3	85	0			0	meteohub	10/22/2013 2:09
256	10/21/2013 21:14	13.4	10.9	1018.2	NNW	343	11.3	19.3	85	0			0	meteohub	10/22/2013 2:14
257	10/21/2013 21:19	13.3	10.8	1018.5	North	350	16.1	19.3	85	0			0	meteohub	10/22/2013 2:19
258	10/21/2013 21:24	13.2	10.9	1018.5	North	350	12.9	25.7	86	0			0	meteohub	10/22/2013 2:24
259	10/21/2013 21:29	13.2	10.9	1018.8	NNW	337	17.7	25.7	86	0			0	meteohub	10/22/2013 2:29
260	10/21/2013 21:34	13.3	11	1018.8	NNW	341	20.9	29	86	0			0	meteohub	10/22/2013 2:34
261	10/21/2013 21:39	13.3	11	1018.8	NNW	336	24.1	29	86	0			0	meteohub	10/22/2013 2:39
262	10/21/2013 21:44	13.3	11	1018.8	NNW	334	20.9	29	86	0			0	meteohub	10/22/2013 2:44
263	10/21/2013 21:49	13.3	11	1019.2	North	349	20.9	24.1	86	0			0	meteohub	10/22/2013 2:49
264	10/21/2013 21:54	13.3	11	1019.2	NNE	17	19.3	25.7	86	0			0	meteohub	10/22/2013 2:54
265	10/21/2013 21:59	13.3	10.8	1019.2	NNW	333	14.5	25.7	85	0			0	meteohub	10/22/2013 2:59
266	10/21/2013 22:04	13.2	10.7	1019.5	North	11	19.3	25.7	85	0			0	meteohub	10/22/2013 3:04
267	10/21/2013 22:09	13.2	10.6	1019.5	North	5	20.9	27.4	84	0			0	meteohub	10/22/2013 3:09
268	10/21/2013 22:14	13.1	10.5	1019.5	North	0	14.5	30.6	84	0			0	meteohub	10/22/2013 3:14
269	10/21/2013 22:19	13.1	10.3	1019.5	NNE	32	27.4	30.6	83	0			0	meteohub	10/22/2013 3:19
270	10/21/2013 22:24	13	10	1019.9	NNE	20	19.3	30.6	82	0			0	meteohub	10/22/2013 3:24
271	10/21/2013 22:29	13	9.4	1019.9	NNE	16	22.5	35.4	79	0			0	meteohub	10/22/2013 3:29
272	10/21/2013 22:34	12.9	9.3	1019.9	NNE	31	16.1	35.4	79	0			0	meteohub	10/22/2013 3:34
273	10/21/2013 22:39	12.8	9.1	1019.9	NNE	18	19.3	33.8	78	0			0	meteohub	10/22/2013 3:39
274	10/21/2013 22:44	12.8	9.1	1019.9	NNE	32	11.3	32.2	78	0			0	meteohub	10/22/2013 3:44
275	10/21/2013 22:49	12.7	8.8	1019.9	NNE	15	19.3	27.4	77	0			0	meteohub	10/22/2013 3:49
276	10/21/2013 22:54	12.7	9	1019.9	NNE	26	14.5	27.4	78	0			0	meteohub	10/22/2013 3:54
277	10/21/2013 22:59	12.6	8.9	1019.9	NNE	26	17.7	24.1	78	0			0	meteohub	10/22/2013 3:59
278	10/21/2013 23:01	12.6	8.9	1019.9	North	5	11.3	25.7	78	0			0	meteohub	10/22/2013 4:01
279	10/21/2013 23:06	12.6	8.9	1020.2	NNE	24	11.3	25.7	78	0			0	meteohub	10/22/2013 4:06
280	10/21/2013 23:11	12.5	8.8	1020.2	North	0	14.5	25.7	78	0			0	meteohub	10/22/2013 4:11
281	10/21/2013 23:16	12.4	8.7	1020.2	NNE	22	14.5	22.5	78	0			0	meteohub	10/22/2013 4:16
282	10/21/2013 23:21	12.3	8.6	1020.2	North	5	14.5	19.3	78	0			0	meteohub	10/22/2013 4:21
283	10/21/2013 23:26	12.3	8.6	1020.2	NNE	26	16.1	19.3	78	0			0	meteohub	10/22/2013 4:26
284	10/21/2013 23:31	12.2	8.5	1020.2	NNE	28	9.7	19.3	78	0			0	meteohub	10/22/2013 4:31
285	10/21/2013 23:36	12.2	8.7	1020.2	North	0	11.3	19.3	79	0			0	meteohub	10/22/2013 4:36
286	10/21/2013 23:41	12.2	8.7	1020.2	North	10	8	25.7	79	0			0	meteohub	10/22/2013 4:41
287	10/21/2013 23:46	12.1	8.6	1020.5	North	5	11.3	25.7	79	0			0	meteohub	10/22/2013 4:46
288	10/21/2013 23:51	11.9	8.6	1020.5	North	351	8	17.7	80	0			0	meteohub	10/22/2013 4:51
289	10/21/2013 23:56	11.8	8.5	1020.5	North	355	9.7	16.1	80	0			0	meteohub	10/22/2013 4:56
290	**MAX**	**20.8**	**15.9**	**1020.5**			**41.8**	**54.7**	**90**	**0**			**0**		
291	**MIN**	**11.6**	**8.4**	**1012.1**			**0**	**4.8**	**61**	**0**			**0**		

Appendix B(ii). **ProWeather Data**

Time	Interval(m	Indoor Humidity(	Indoor Tempe	Outdoor Humidity	Outdoor Tempe	Absolute Pressure(i	Wind(m/h	Gust(m/h	Gusts KPH	Directio	Relative Pressure(	Dewpoint	Windchill(	Hour Rain(	24 hour Rain(	Week Rain(	Month Rain	Total Rain(	Wind Level(bft)	Gust Level(bft)
20-10-2013 23:57	5	46	61.3	53	58.5	28.89	4.5	10.7	17.22	SW	29.92	41.4	56.8	0	0	1.67	1.69	1.69	2	3
21-10-2013 00:02	5	46	61.2	52	58.6	28.89	1.6	3.8	6.12	SW	29.92	41.2	58.6	0	0	1.67	1.69	1.69	1	2
21-10-2013 00:07	5	46	61.2	52	58.6	28.89	1.6	3.8	6.12	SW	29.92	41.2	58.6	0	0	1.67	1.69	1.69	1	2
21-10-2013 00:12	5	46	61.2	51	59	28.89	1.6	4.5	7.24	N	29.92	41	59	0	0	1.67	1.69	1.69	1	2
21-10-2013 00:17	5	46	61.2	51	59.2	28.89	4.5	9.8	15.77	S	29.92	41.2	57.6	0	0	1.67	1.69	1.69	2	3
21-10-2013 00:22	5	46	61.2	50	59.4	28.9	1.6	3.1	4.99	SW	29.93	40.8	59.4	0	0	1.67	1.69	1.69	1	1
21-10-2013 00:27	5	46	61.2	50	59.4	28.89	1.6	5.4	8.69	SSE	29.92	40.8	59.4	0	0	1.67	1.69	1.69	1	2
21-10-2013 00:32	5	46	61	49	59.5	28.88	3.8	5.4	8.69	SW	29.92	40.5	59.5	0	0	1.67	1.69	1.69	2	2
21-10-2013 00:37	5	46	61	49	59.5	28.89	3.8	8.3	13.36	SSW	29.92	40.5	59.5	0	0	1.67	1.69	1.69	2	3
21-10-2013 00:42	5	46	61	49	59.5	28.89	1.6	4.5	7.24	SWW	29.92	40.5	59.5	0	0	1.67	1.69	1.69	1	2
21-10-2013 00:47	5	46	61	49	59.5	28.89	0.7	3.8	6.12	SW	29.93	40.5	59.5	0	0	1.67	1.69	1.69	1	2
21-10-2013 00:52	5	46	61	49	59.5	28.89	1.6	4.5	7.24	SSW	29.92	40.5	59.5	0	0	1.67	1.69	1.69	1	2
21-10-2013 00:57	5	46	61	49	59.4	28.89	0.7	3.1	4.99	W	29.92	40.3	59.4	0	0	1.67	1.69	1.69	1	1
21-10-2013 01:02	5	46	61	49	59.4	28.89	0.7	5.4	8.69	SW	29.92	40.3	59.4	0	0	1.67	1.69	1.69	1	2
21-10-2013 01:07	5	46	61	49	59.4	28.89	0.7	5.4	8.69	SW	29.92	40.3	59.4	0	0	1.67	1.69	1.69	1	2
21-10-2013 01:12	5	46	60.8	50	59.2	28.89	1.6	3.1	4.99	NW	29.92	40.6	59.2	0	0	1.67	1.69	1.69	1	1
21-10-2013 01:17	5	46	60.8	50	59.2	28.89	0.7	2.2	3.54	NNW	29.92	40.6	59.2	0	0	1.67	1.69	1.69	1	1
21-10-2013 01:22	5	46	60.8	49	59.2	28.89	1.6	3.8	6.12	E	29.92	40.1	59.2	0	0	1.67	1.69	1.69	1	2
21-10-2013 01:27	5	46	60.8	49	59.2	28.88	2.2	4.5	7.24	SW	29.92	40.1	59.2	0	0	1.67	1.69	1.69	1	2
21-10-2013 01:32	5	46	60.8	49	59.2	28.89	3.8	9.2	14.81	SSW	29.92	40.1	59.2	0	0	1.67	1.69	1.69	2	3
21-10-2013 01:37	5	46	60.8	49	59	28.89	0	3.8	6.12	SW	29.92	39.9	59	0	0	1.67	1.69	1.69	0	2
21-10-2013 01:42	5	46	60.6	49	59	28.89	2.2	4.5	7.24	S	29.92	39.9	59	0	0	1.67	1.69	1.69	1	2
21-10-2013 01:47	5	46	60.6	49	58.8	28.89	0	0	0.00	E	29.92	39.7	58.8	0	0	0.9	1.69	1.69	0	0
21-10-2013 01:52	5	46	60.6	49	58.6	28.89	1.6	6	9.66	SE	29.92	39.6	58.6	0	0	0.9	1.69	1.69	1	2
21-10-2013 01:57	5	46	60.6	49	58.6	28.89	0	0.7	1.13	SE	29.92	39.6	58.6	0	0	0.9	1.69	1.69	0	1
21-10-2013 02:02	5	46	60.4	49	58.5	28.89	0.7	1.6	2.57	SEE	29.93	39.4	58.5	0	0	0.89	1.69	1.69	1	1
21-10-2013 02:07	5	46	60.4	49	58.5	28.89	0.7	1.6	2.57	SEE	29.93	39.4	58.5	0	0	0.89	1.69	1.69	1	1
21-10-2013 02:12	5	46	60.6	49	58.3	28.89	1.6	3.1	4.99	E	29.93	39.2	58.3	0	0	0.87	1.69	1.69	1	1
21-10-2013 02:17	5	46	60.4	48	58.1	28.89	0	0	0.00	E	29.93	38.5	58.1	0	0	0.87	1.69	1.69	0	0
21-10-2013 02:22	5	46	60.4	48	57.7	28.9	1.6	3.1	4.99	E	29.93	38.3	57.7	0	0	0.86	1.69	1.69	1	1
21-10-2013 02:27	5	46	60.3	48	57.4	28.89	0	1.6	2.57	SEE	29.93	37.9	57.4	0	0	0.86	1.69	1.69	0	1
21-10-2013 02:32	5	46	60.3	48	56.8	28.89	0.7	2.2	3.54	E	29.93	37.4	56.8	0	0	0.85	1.69	1.69	1	1
21-10-2013 02:37	5	46	60.3	48	56.5	28.9	0.7	3.1	4.99	E	29.93	37	56.5	0	0	0.85	1.69	1.69	1	1
21-10-2013 02:42	5	46	60.1	49	56.3	28.9	0	1.6	2.57	E	29.93	37.4	56.3	0	0	0.85	1.69	1.69	0	1
21-10-2013 02:47	5	46	60.1	49	55.9	28.9	0	0	0.00	E	29.93	37	55.9	0	0	0.84	1.69	1.69	0	0
21-10-2013 02:52	5	46	59.9	48	55.6	28.9	0	0	0.00	E	29.93	36.3	55.6	0	0	0.83	1.69	1.69	0	0
21-10-2013 02:57	5	46	59.9	49	55.4	28.9	0	2.2	3.54	E	29.93	36.7	55.4	0	0	0.83	1.69	1.69	0	1
21-10-2013 03:02	5	46	59.7	49	55.2	28.9	0	0.7	1.13	SEE	29.93	36.5	55.2	0	0	0.8	1.69	1.69	0	1
21-10-2013 03:07	5	46	59.5	49	55.2	28.9	0	0.7	1.13	SEE	29.93	36.5	55.2	0	0	0.8	1.69	1.69	0	1
21-10-2013 03:12	5	46	59.5	49	54.9	28.9	0	2.2	3.54	SE	29.93	36.1	54.9	0	0	0.73	1.69	1.69	0	1
21-10-2013 03:17	5	46	59.4	49	54.7	28.9	0	0.7	1.13	SE	29.93	36	54.7	0	0	0.72	1.69	1.69	0	1
21-10-2013 03:22	5	46	59.4	49	54.7	28.89	0.7	2.2	3.54	E	29.93	36	54.7	0	0	0.67	1.69	1.69	1	1
21-10-2013 03:27	5	46	59.2	48	54.7	28.89	2.2	3.8	6.12	E	29.93	35.4	54.7	0	0	0.65	1.69	1.69	1	2
21-10-2013 03:32	5	46	59.2	48	54.7	28.89	0.7	2.2	3.54	E	29.92	35.4	54.7	0	0	0.64	1.69	1.69	1	1
21-10-2013 03:37	5	46	59	47	54.5	28.89	0	0.7	1.13	SE	29.92	34.7	54.5	0	0	0.63	1.69	1.69	0	1
21-10-2013 03:42	5	46	59	47	54.5	28.89	1.6	2.2	3.54	SE	29.93	34.7	54.5	0	0	0.61	1.69	1.69	1	1
21-10-2013 03:47	5	46	58.8	46	54.3	28.89	0	3.1	4.99	SE	29.92	34	54.3	0	0	0.61	1.69	1.69	0	1
21-10-2013 03:52	5	46	58.8	47	54.3	28.89	1.6	3.1	4.99	SEE	29.92	34.5	54.3	0	0	0.6	1.69	1.69	1	1
21-10-2013 03:57	5	46	58.6	46	54.5	28.88	0	1.6	2.57	SE	29.92	34.2	54.5	0	0	0.6	1.69	1.69	0	1
21-10-2013 04:02	5	46	58.6	45	54.5	28.89	0	1.6	2.57	SE	29.92	33.6	54.5	0	0	0.59	1.69	1.69	0	1
21-10-2013 04:07	5	46	58.5	45	54.5	28.89	0	1.6	2.57	SE	29.92	33.6	54.5	0	0	0.59	1.69	1.69	0	1
21-10-2013 04:12	5	46	58.5	45	54.3	28.89	0	1.6	2.57	SE	29.92	33.4	54.3	0	0	0.59	1.69	1.69	0	1
21-10-2013 04:17	5	46	58.5	45	54.1	28.89	0	0	0.00	SE	29.92	33.3	54.1	0	0	0.59	1.69	1.69	0	0
21-10-2013 04:22	5	46	58.3	44	54.1	28.89	0	0.7	1.13	SE	29.92	32.7	54.1	0	0	0.59	1.69	1.69	0	1
21-10-2013 04:27	5	46	58.3	45	54	28.89	0	1.6	2.57	SE	29.92	33.1	54	0	0	0.59	1.69	1.69	0	1
21-10-2013 04:32	5	46	58.3	45	54	28.89	0	0	0.00	SE	29.92	33.1	54	0	0	0.58	1.69	1.69	0	0
21-10-2013 04:37	5	46	58.1	45	54.1	28.89	2.2	6	9.66	NE	29.92	33.3	54.1	0	0	0.57	1.69	1.69	1	2
21-10-2013 04:42	5	46	58.1	46	54.5	28.88	0.7	2.2	3.54	SE	29.92	34.2	54.5	0	0	0.57	1.69	1.69	1	1
21-10-2013 04:47	5	46	58.1	45	55	28.88	2.2	8.3	13.36	SE	29.91	34.2	55	0	0	0.57	1.69	1.69	1	3
21-10-2013 04:52	5	46	58.1	44	55.8	28.88	2.2	4.5	7.24	SW	29.91	34.2	55.8	0	0	0.56	1.69	1.69	1	2
21-10-2013 04:57	5	46	58.1	43	56.1	28.88	3.1	10.7	17.22	SW	29.91	34	56.1	0	0	0.54	1.69	1.69	1	3
21-10-2013 05:02	5	47	58.1	40	56.7	28.88	5.4	9.2	14.81	SSW	29.92	32.7	53.6	0	0	0.54	1.69	1.69	2	3
21-10-2013 05:07	5	46	58.1	40	56.7	28.88	5.4	9.2	14.81	SSW	29.91	32.7	53.6	0	0	0.54	1.69	1.69	2	3
21-10-2013 05:12	5	46	58.3	38	57.4	28.88	1.6	3.8	6.12	NW	29.91	32	57.4	0	0	0.54	1.69	1.69	1	2
21-10-2013 05:17	5	47	58.3	37	57.6	28.88	0.7	2.2	3.54	NW	29.91	31.5	57.6	0	0	0.54	1.69	1.69	1	1

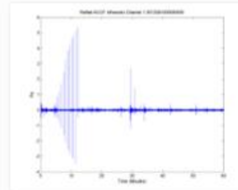
Appendix C. **Sound Event Log**

L14 =COUNTIF(C6:C445,"*insects*")

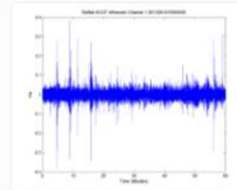
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	20131018	Friday		Rhino	Anthro	Biophi	Geopl	Comment	Weather	COUNTS	29 minute	58 second	recording
2											Anthro	138	
3	FR_201+3:6331017_23:	a	a.birds.insect.rhino.coyote.otheranimals.ALL	1		1						85	
4	FR_20131017_235004	b	b.insects.birds.Rvoc Rmovement.frog?.ALL	1		1						41	
5	FR_20131017_235004	c	c.birds.insects.Rvoc.barks.Rmovement.Rheavybreathing.ALL	1	1	1						37	
6	FR_20131017_235004	d	d.birds.Rmotion.Rvoc.car.birdsBB.otheranimals.fenceclang.ALL	1	1	1						35	
7	FR_20131017_235004	e	e.Rvoc.insects.birdsBB.ALL	1		1						13	
8	FR_20131017_235004	f	f.Rvoc.insects.birds.ALL	1		1						10	
9	FR_20131017_235004	g	g.birdsBB.insects.Rvoc.barks.ALL	1	1	1						13	
10	FR_20131017_235004	h	h.insects.barks.Rvoc.birds.ALL	1	1	1						0	
11												39	
12	FR_20131018_002003	a	a.insects.Rvoc.Rmotion.birdsBB.barks.ALL	1	1	1							
13	FR_20131018_002003	b	b.insects.birds.barks.Rvoc.ALL	1	1	1							
14	FR_20131018_002003	c	c.insects.birds.Rvoc.ALL	1		1						134	
15	FR_20131018_002003	d	d.Rvoc.insects.Rgas.ALL	1		1					Bio	312	
16	FR_20131018_002003	e	e.Rvoc.insects.fewbirds.ALL	1		1						53	
17	FR_20131018_002003	f	f.birds.insects.barks.ALL	1	1	1						79	
18	FR_20131018_002003	g	g.barks.insects.Rvoc.critters.few.birds.Rheavybreathing.ALL	1	1	1							
19	FR_20131018_002003	h	h.barks.insects.Rvoc.fewbirds.Rmotion.Rgas.critters.ALL	1	1	1							
20													
21	FR_20131018_005003	a	a.coyotes.insects.Rvoc.barks.fewbirds.ALL	1	1	1							
22	FR_20131018_005003	b	b.barks.coyotes.insects.Rvoc.critters.fewbirds.ALL	1	1	1					Geo	62	
23	FR_20131018_005003	c	c.barks.birds.insects.critters.Rvoc.ALL	1	1	1						3	
24	FR_20131018_005003	d	d.Rvoc.insects.birdsBB.Rmotion.barks.ALL	1	1	1						5	
25	FR_20131018_005003	e	e.birds.insects.Rvoc.Rhuffing.ALL	1		1						5	
26	FR_20131018_005003	f	f.insects.Rhuffing.birds.Rvoc.Rgas.Rmotion.ALL	1		1						0	
27	FR_20131018_005003	g	g.Rmotion.birds.insects.ALL	1		1							
28	FR_20131018_005003	h	h.birdsBB.insects.Rmotion.barks.Rvoc.ALL	1	1	1							
29													
30	FR_20131018_012003	a	a.birdsBB Rvoc.insects.Rgrazing.critters.distantbarks.ALL	1	1	1						0	
31	FR_20131018_012003	b	b.Rvoc.Rgrazing.birdsBB.Rgasinsects.ALL	1		1							
32	FR_20131018_012003	c	c.birds.Rvoc.Rgrazing.insects.ALL	1		1					104 rhino pre civil daylight		
33	FR_20131018_012003	d	d.insects.birds.Rvoc.Rgas.ALL	1		1					14 rhino post civil twilight		
34	FR_20131018_012003	e	e.birds.insects.Rmovement.maybewolves.barks.ALL	1	1	1							
35	FR_20131018_012003	f	f.insects.barks.Rvoc.birds.ALL	1	1	1							
36	FR_20131018_012003	g	g.barks.Rvoc.insects.birdsBB.car.ALL	1	1	1							
37	FR_20131018_012003	h	h.cars.birds.insects.distantbarks.birdsBB.ALL		1	1							
38													
39	FR_20131018_015003	a	a.insects.birds.Rvoc.distantbarks.ALL	1	1	1							
40	FR_20131018_015003	b	b.insects.birds.Rvoc.ALL	1		1							
41	FR_20131018_015003	c	c.insects.birds.Rhuffing.Rvoc.ALL	1		1							
42	FR_20131018_015003	d	d.insects.Rhuffing.birds.ALL	1		1							
43	FR_20131018_015003	e	e.insects.birds.Rmotion.Rgas.ALL	1		1							
44	FR_20131018_015003	f	f.insects.Rmotion.fewbirds.Rvoc.ALL	1		1							
45	FR_20131018_015003	g	g.insects.birds.Rvoc.Rgas.barks.ALL	1	1	1							
46	FR_20131018_015003	h	h.insects.fewbirds.critters.ALL	1		1							

APPENDIX D

Hourly mean variation in the INFRASONIC data for Friday 18th Oct



20131018_291_InfACCF_Infrasonic_Channel_1_20 13291000000000



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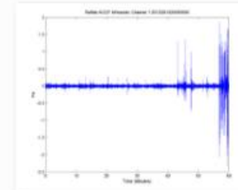

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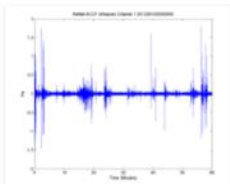

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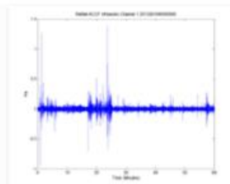

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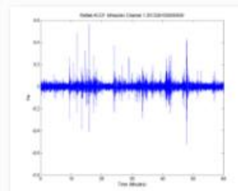

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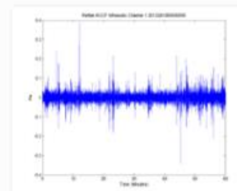

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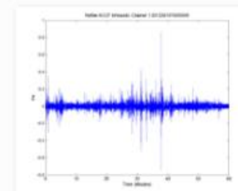

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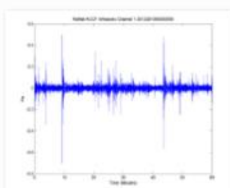

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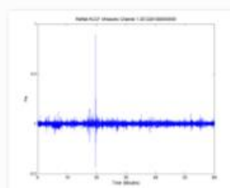

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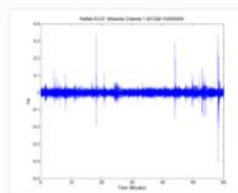

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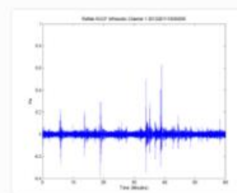

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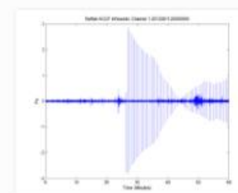

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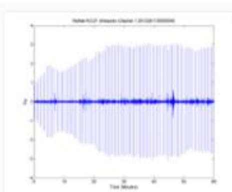

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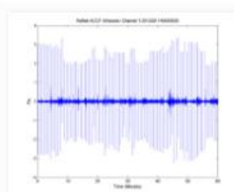

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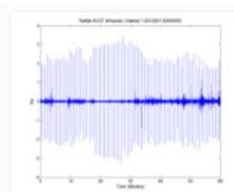

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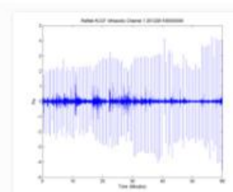

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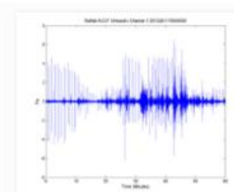

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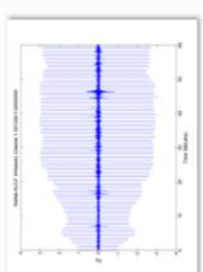

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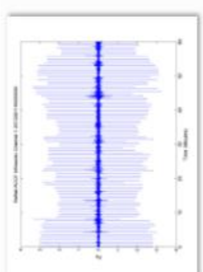

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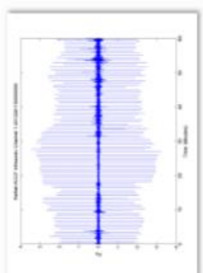

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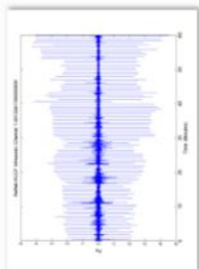

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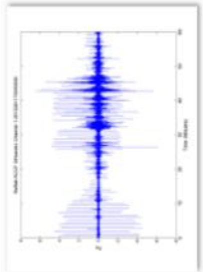

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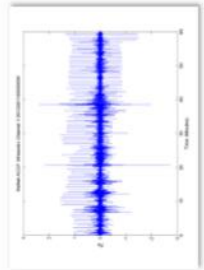

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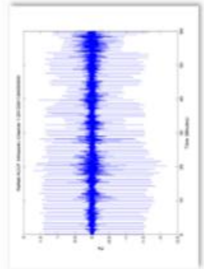

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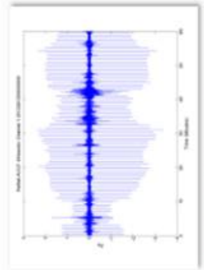

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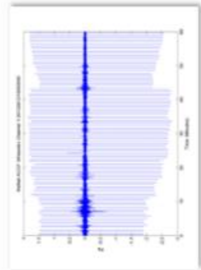

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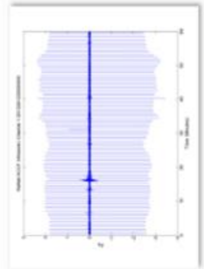

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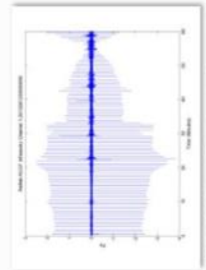

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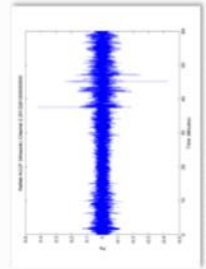

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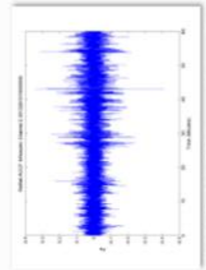

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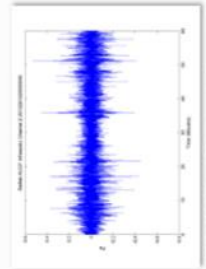

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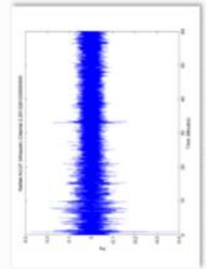

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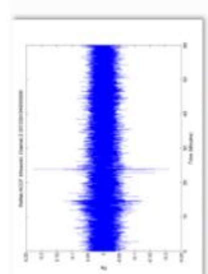

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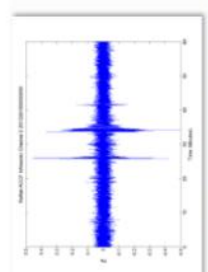

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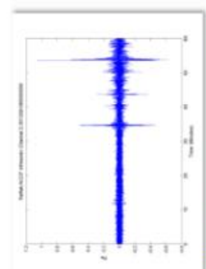

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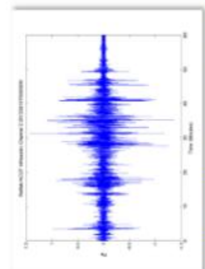

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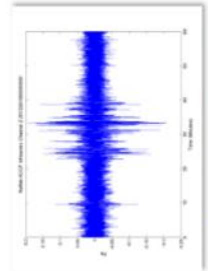

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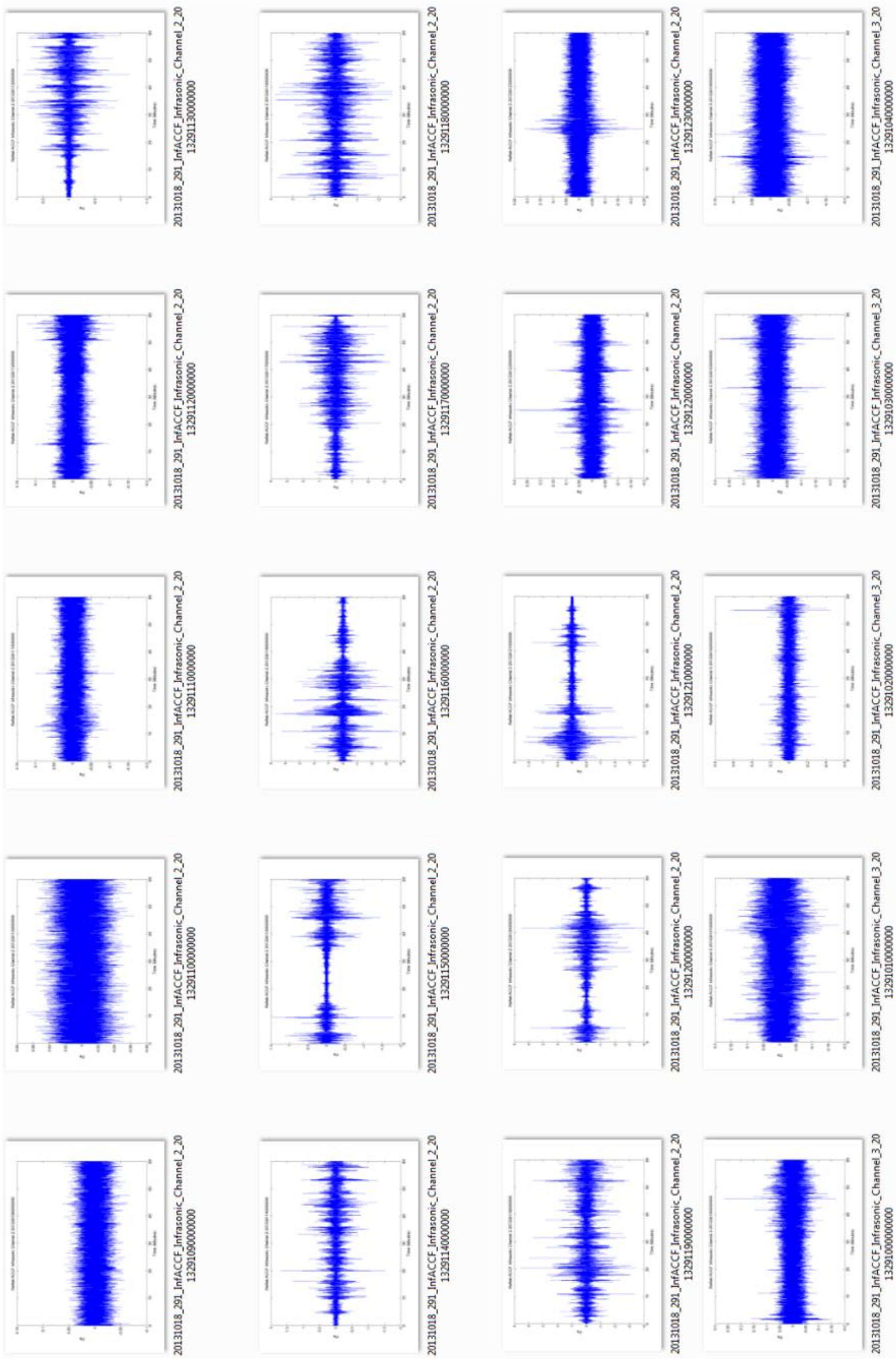
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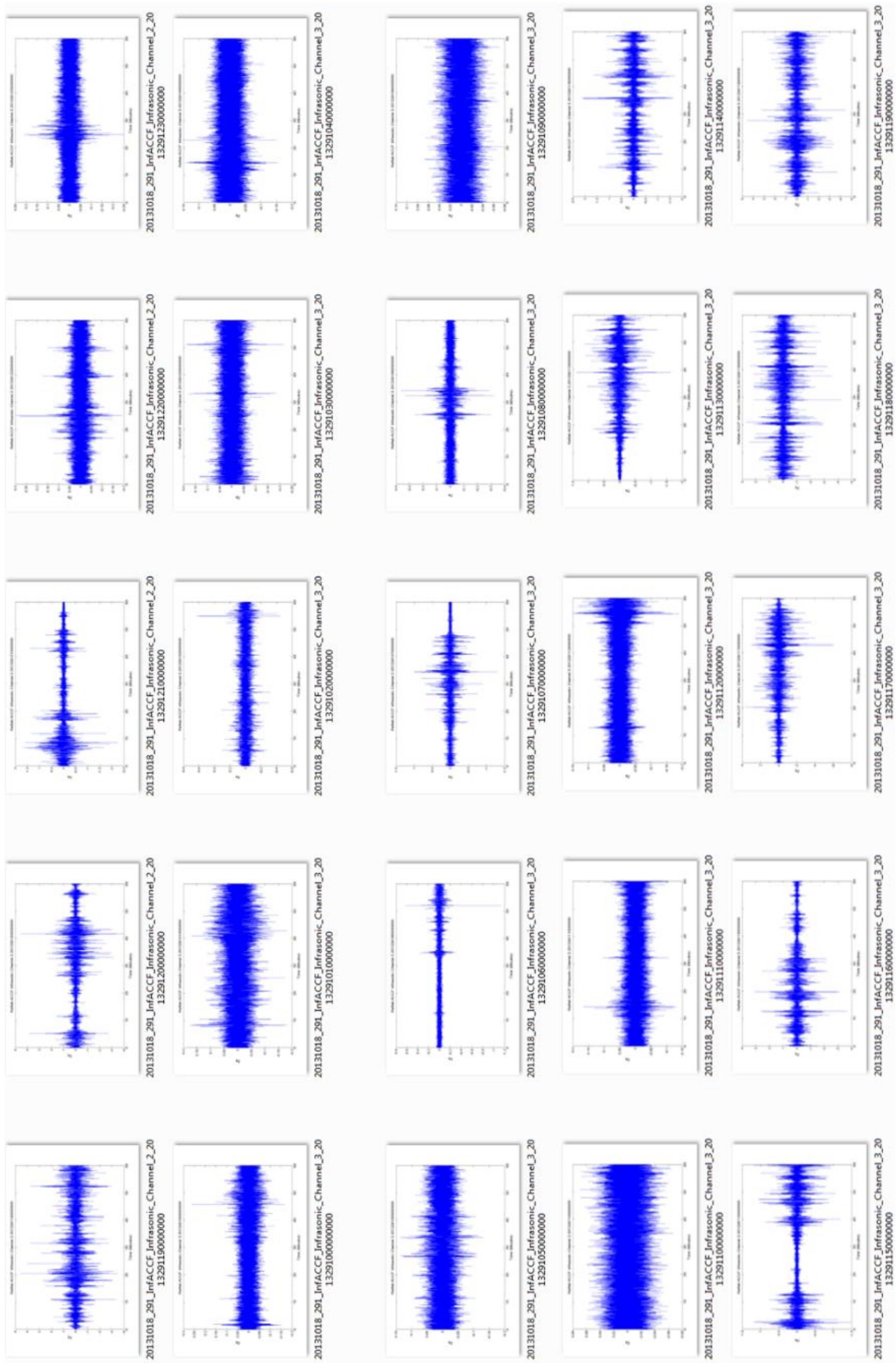
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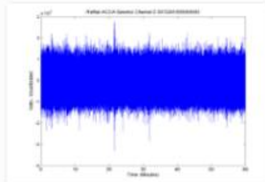
APPENDIX E

Hourly mean variation in the SEISMIC data for Friday 18th Oct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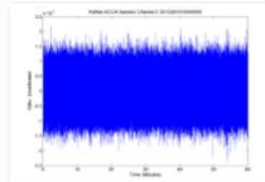
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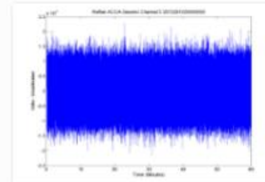
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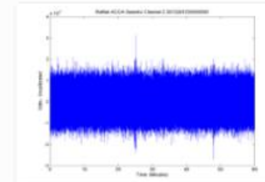
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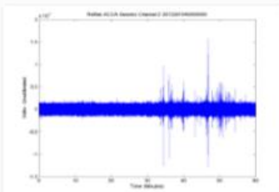
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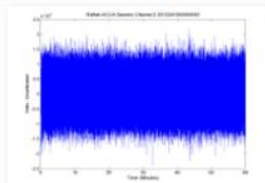
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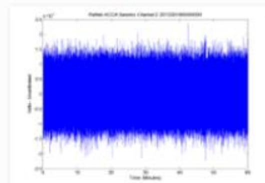
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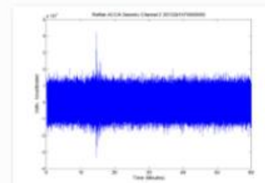
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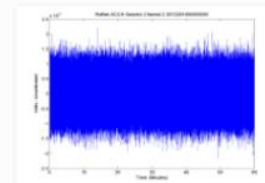
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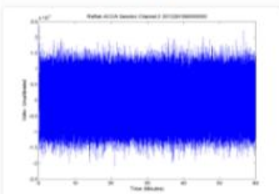
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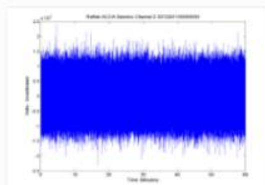
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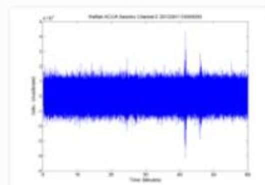
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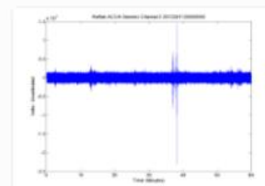
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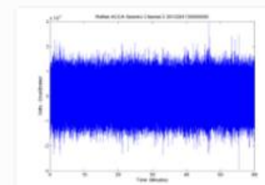
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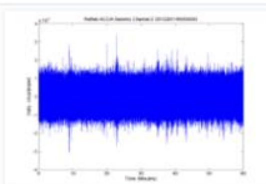
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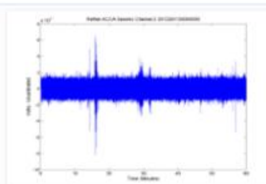
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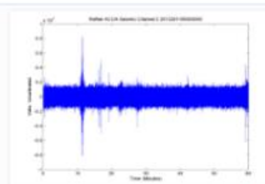
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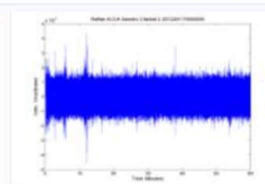
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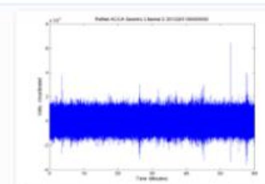
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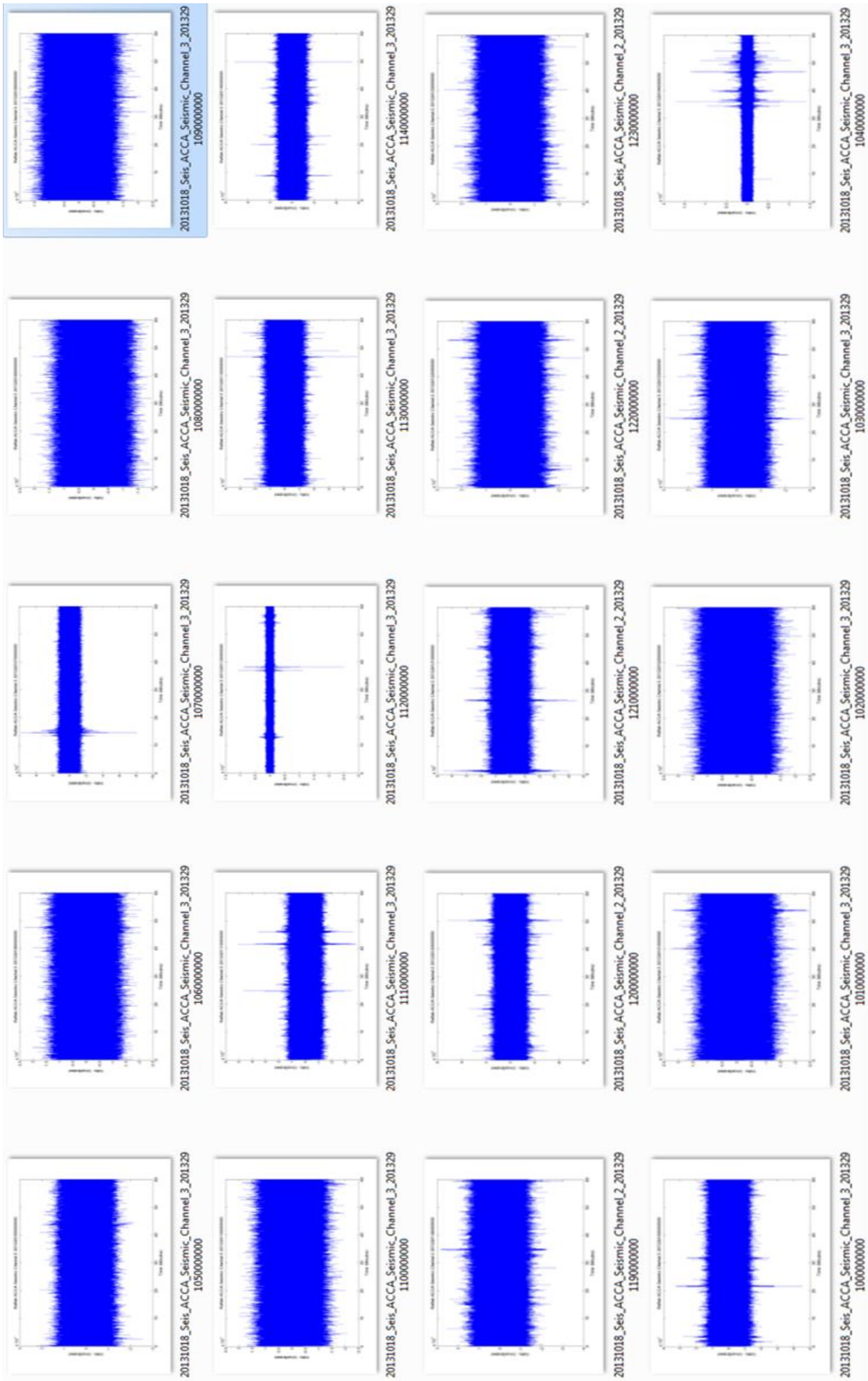
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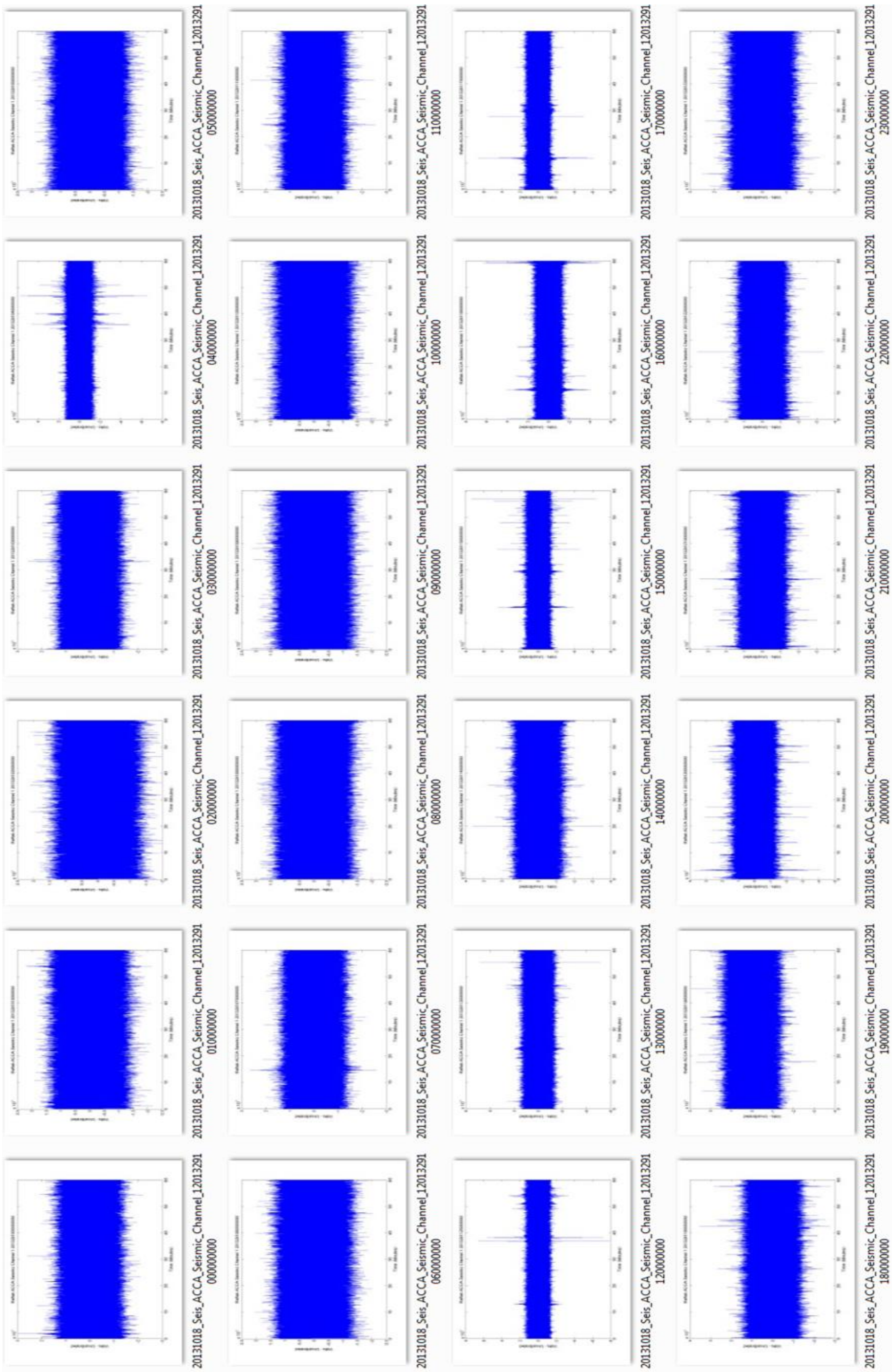
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Appendix F(i). **Mean SPL Statistics for two Days**

Processed in Raven – Friday 18th Oct										
Site		**Mean SPL Interval**	**Trendline**	**Minimum**	**Maximum**	**24 Hour Variation**	**Diurnal Variability**	**Nocturnal Variability**	**Average**	**Standard Deviation**
SM2.1S Utilities		4m14sec	$R^2 = 0.5737$	37.8 dB at 4:31	83.4 dB at 21:53	45.6 dB	~ 13 dB		50.8 dB	11.4 dB
	Pre Storm		R2 = 0.4242		69.1 dB at 11:08	31.3 dB		~ 7 dB	46.5 dB	4.6 dB
SM2.1N Utilities		4m14sec	$R^2 = 0.5346$	37.8 dB at 4:31	83.4 dB at 21:53	45.6 dB	~ 13 dB		50.8 dB	11.4 dB
	Pre Storm		$R^2 = 0.3517$		69.1 dB at 11:08	31.3 dB		~ 7 dB	46.5 dB	4.6 dB
R-26 S		4m14sec	$R^2 = 0.5737$	43.9 dB at 4:56	90.8 dB at 21:18	46.9 dB	~ 13 dB		57.6 dB	11.6 dB
	Pre Storm		$R^2 = 0.4242$		69.9 dB at 14.42	26.0 dB		~ 8 dB	53.4 dB	5.4 dB
R-26 N		4m14sec	$R^2 = 0.5974$	43.1 dB at 4:56	93.8 dB at 21:15	50.7 dB	~ 15 dB		58.3 dB	12.7 dB
	Pre Storm		$R^2 = 0.4565$		70.5 dB at 14.42			~ 8 dB	53.8 dB	6.4 dB
Infrasonic SPL – processed in Matlab - Friday 18th Oct										
RefTek Infrasonic		1 hour	$R^2 = 0.441$	59.3 dB at 4:00	96.8 dB at 21:00	37.5 dB	~ 10 dB	~14 dB	73.0 dB	9.32 dB
	Pre Storm				78.9 dB at noon					
Processed in Raven – Monday 21st Oct										
R-26 S		4m14sec	$R^2 = 0.1873$	45.5 dB at 3:24	85.9 dB at 16:07	40.4 dB	~ 22 dB	~20 dB	61.6 dB	10.2 dB
R-26 N		4m14sec	$R^2 = 0.2025$	45.5 dB at 3:57	91.2 dB at 16:07	45.7 dB	~ 25 dB	~23 dB	64.7 dB	11.4 dB

Appendix F(ii). **Relative SPL Statistics from Processing with SM2+ Data Logs for two Days**

Friday 18th Oct									
Site		**Mean SPL Interval**	**Trendline**	**Minimum**	**Maximum**	**Diurnal Variability**	**Nocturnal Variability**	**Average**	**Standard Deviation**
SM2.1S Utilities		5 min	$R^2 = 0.5397$	0 dB at 4:35	42.0 dB at 22:55	~ 8 dB		10.9 dB	9.23 dB
	Pre Storm		$R^2 = 0.4975$		15.6 dB at 11:15		~ 7 dB	7.7dB	3.5 dB
SM2.1N Utilities		5 min	$R^2 = 0.5523$	0 dB at 4:35	40.6 dB at 21:55	~ 10 dB		11.2 dB	9.4 dB
	Pre Storm		$R^2 = 0.5289$		16.7 dB at 12:30		~ 5 dB	7.9 dB	3.8 dB
SM2.3S Utilities		5 min	$R^2 = 0.3996$	0 dB at 4:33	33.2 dB at 21:23	~ 12 dB		46.9 dB	12.7 dB
	Pre Storm		$R^2 = 0.2441$		32.5 dB at 11.18		~ 9 dB	45.3 dB	6.4 dB
SM2.3N Utilities		5 min	$R^2 = 0.2848$	0 dB at 4:53		~ 15 dB		12.4 dB	7.6 dB
	Pre Storm		$R^2 = 0.1767$		37.6 dB at 11:18		~ 9 dB	11.1 dB	6.9 dB
Monday 21st Oct									
SM2.1S Utilities		5 min	$R^2 = 0.5323$	0 dB at 3:40	31 dB at 16:40	~ 21 dB	~ 20 dB	12.1 dB	0.9 dB
SM2.1N Utilities		5 min	$R^2 = 0.5323$	0 dB at 3:40	33.35 dB at 16:30	~ 25 dB	~ 27 dB	14.2 dB	2.7 dB
SM2.1S Utilities		5 min	$R^2 = 0.0148$	0 dB at 3:38	24.3 dB at 10.:8	~ 14 dB	~ 15 dB	10.5 dB	6.2 dB
SM2.1N Utilities		5 min	$R^2 = 0.0035$	0 dB at 3:38	31.4 dB at 5:03	~ 16 dB	~ 30 dB	11.8 dB	8.2 dB

AUTHOR’S PERMISSION STATEMENT

Figures 1 and 2 are used with the permission of Dr Bryan Pijanowski, as per his email of 6 October 2014:

On Mon, Oct 6, 2014 at 6:52 PM, Pijanowski, Bryan C <bpijanow@purdue.edu> wrote:

Hi Susan,

I am happy to provide you with the following:

As first author on the papers that contain the requested figures, I provide you with the permission to use this in your dissertation and any follow up publications so long as the source of the figure (give full citation) is fully acknowledged in said publications.

All the best to what appears to be a very fruitful career!

Bryan Pijanowski
Professor and University Faculty Scholar
Director, Discovery Park Center for Global Soundscapes
305 FORS Building and
B066 Mann Hall
Department of Forestry and Natural Resources
Purdue University
West Lafayette, Indiana 47907
(765) 496-2215 (office)
(765) 496-2422 (fax)

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