Infrasonority

Exploration of Sound Energy below 20Hz in Music

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Declaration

I know that plagiarism is wrong. Plagiarism is to use another's work and to pretend that it is one's own.

I have used the author date convention for citation and referencing. Each significant contribution to and quotation in this dissertation from the work/s of other people has been acknowledged through citation and reference.

I declare that this dissertation is my own unaided work. It is submitted for the degree of Master of Music in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination in any other university.

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Abstract

This thesis investigates an underdeveloped and little explored area of music and the arts: the use of infrasound (frequencies below 20Hz) as musical material in creative composition. Discussions, research and experiments conducted toward the prospect of exposing infrasonic characteristics were fundamental to the composition and recital that informed the thesis. The infrasonic material from which the composition was created contained synthesized wave forms, recordings of elephant vocalisation and thunderstorms. The infrasonic reproduction for the concert required explicit attention and enquiry regarding physical properties of the sonic phenomenon, equipment infrastructure and limitations in human perception.

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Without the support of the Sound Corporation, none of the research experiments nor the recital would have been possible. The company staff engaged and assisted the experimentation process since the day they were approached. I am extremely grateful to have had access to this very high-end equipment which served the purpose of this unique artistic experimentation and incorporation of infrasound.

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To my supervisors Jonathan and Cameron, my gratitude for your empirical guidance with which I continue building my interest in writing. Your patience and enthusiasm has propelled this journey, resulting as growth in the expressions of my existential being.

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Chapter 1: Infrasound

1.1 Introduction and Rationale

Infrasound is described as sound energy oscillating or propagating through air as a pressure wave at a frequency lower than 20 cycles per second (Cowan 2016:74). It is observed in situations resulting from both natural events as well as man-made sound sources; for example, lightning storms, volcanic eruptions and earthquakes as well as large industrial motors or fans. Infrasound has also been discovered in the vocalised communication of animal species and specific to this research the African Elephant (*Loxodonta africana).* Thus, the study of infrasound has been conducted across a wide variety of reasons and from a variety of theoretical tenets.

It is incorrectly assumed that infrasound is inaudible to humans (Atkinson, Overton, and Cavagin 1995:18; Coon and Mitterer 2008:120; Leventhall 2009; Coon and Mitterer 2012:126). The mechanisms of the human ear are generally considered inadequate for acute infrasonic detection although the exact lower limit in regular human hearing is often contested. Infrasound along with sound above 20Hz is produced by vibrations transmitting through matter in a solid, liquid or gas state. Therefore, infrasound-waves travel through the air as well as the sub-surface of the earth, and in the same manner through the body of the listener. Humans detect and experience infrasound through resonances felt in other areas of the body, along with the simultaneous stimulation of the ear (Crawshaw 2014). With these properties considered, infrasound can be incorporated into musical composition, with the goal of stimulating the audience beyond the commonly understood thresholds of musical listening.

All Sound, be it from geophonic, biophonic or anthrophonic sources (Pijanowski et al. 2011), is vibration, each with a profile of simultaneously resonating higher frequencies (or upper partials). The harmonic series is a ratio of the harmonic activity which forms the quality of a particular sound (Roads 1989:14). The lowest of the multiple interacting harmonic partials is designated as the fundamental frequency (Farnell 2010:87). Many of my experiments in generating infrasound focused on production of fundamental frequencies below 20Hz. Ideally an infrasound composition primarily highlights the infrasonic frequencies. However, I recognise and embrace the possibility that during cochlear exposure[1] listeners could acknowledge stimulus from the relative resonance in the upper partials (Møller 2003:304).

[1]Cochlear exposure implies the acknowledgment of sound/music utilising only the mechanisms of the ear.

I acknowledge that recognising the impulses of slow pressure wave changes is a part of the experience of hearing infrasound (Cheveigne 2005:17). However, it is insufficient to monitor infrasound using ears exclusively since we are affected more significantly by a holistic (full range[2]) experience of audio. We are continually sensitized to the spectrum of our auditory capabilities and environment. One particular individual might not be consciously aware of infrasound while another who is frequently and consciously in such contact, might recognise infrasound more easily.

Plainly stated, infrasonic music is still rare and it is still unusual to use infrasonic material as the central feature for a musical composition. The lack of this particular musical usage is largely due to the misconceptions regarding the audibility of infrasound and/or the challenge of its manageable generation. The infrasonic wavelengths are larger and the vibrations slower than what is commonly considered audible so they potentially deter musicians and feature rarely in the arts (Crawshaw 2014:271).

Rare as infrasonic music is, it is not entirely absent and has of late become more discussed and available. Certain artists have contributed specific examples in which infrasound was used. Compositions for ‘Great’ organs explicitly like those with 32 foot (or larger) pipes were perhaps the first to include infrasound in music (Widor 1946:49). The futurist composer Luigi Russolo considered large explosions and mechanical devices in 1913, which presumably emitted infrasound, as musical (Russolo 1967:10). The serialist composer Karlheinz Stockhausen engaged with infrasonic composition with his piece Kontakte, which investigates the temporal structure of sound waves (Stockhausen and Barkin 1962:42). More recently at a concert in the Purcell Room, South London (Henderson 2003), it was discovered that an audience responds significantly to infrasound and since then artists have begun exploring infrasound in music. The most recent infrasound artists and researchers include Raviv Ganchrow, Sarah Angliss, Cat Hope, Alexis Crawshaw, dub king (Mark Henninger), Mario de Vega, Anne Sedes, Marta Olszewska and other electronic music composers that use Low Frequency Oscillators (e.g in Dubstep and Noise Music).

By the same token, composers have yet to explore the potential extent to which various types of infrasound can be incorporated into their composition and performance practices. We have yet to formalize ideal situations for when, where and how infrasound works in music, and in some cases we have yet to prove when infrasound is truly present. I critique artists who have intended to incorporate infrasonic materials in composition, largely on the validation methods they use to prove where frequencies occur below 20Hz in such compositions. Previous experiments were conducted without the adequate means to monitor specific fundamental frequencies in this desired range (Hope 2008). In order to provide

[2]This full range refers to the human hearing sensitivity range of all frequencies up to 20 000 Hz.

evidence of infrasound in my own compositions a variety of monitoring methods were researched. Additionally, customized technologies were implemented for identification during the recording and analysis of specific infrasound occurrences. Image processing such as an infrasound spectrograph, rather than common observable bodily traces of infrasound, allow the recognition of audible upper partials alongside the vibrotactile experience.

Composition in the case of infrasound provides direction for the discovery of aesthetic values within the unexplored territory. What makes my specific line of enquiry different from all the above predecessors is the incorporation of selected infrasonic field recordings. In addition to synthesizing infrasound, I have composed using infrasound captured from the vocalisations of African elephants and Highveld thunder.

My research contributes toward developing abilities in the perception of infrasound, as the listeners engage with sampled elephant, thunderstorm (Gray et al. 2001) and synthesized audio. Additionally, the Biophonic Soundscapes used for my compositions also carry the potential to increase the awareness surrounding the conservation of the African elephant.

This project therefore holds multiple values residing in both the opportunity to introduce and advance human recognition of infrasound in musical frameworks as well as contributing toward future developments in conservation techniques.

1.2 Research Aims

In conjunction with this thesis I have created a composition which acknowledges infrasound as musical events and exhibits my creative incorporation to an audience. This thesis and the combined composition intends to broaden the existing body of creative structures and theories surrounding the use of infrasound in music and other applicable research fields. Hence, the central question upon which I focused my research was:

> *Can validated infrasound be incorporated (or used exclusively) in a composition of music, and be acknowledged as musical material?*

This question delves into issues of perception with respect to sonic elements in music such as; rhythmic pulse, pitch, phasing, harmony and tuning temperament. Pertinent questions arose during the formulation of my theoretical framework and the consequent momentum of my investigation was based on supporting questions which have directed the research. These were:

a. *What does infrasound sound like?*

b. *Can we effectively record and monitor infrasound with conventional tools?*

c. *Is it possible to create infrasound with conventional musical equipment?*

d. *What are the circumstances in which this phenomenon can be perceived as musical material?*

e. *How is a standard western pitch perception model related to infrasonic exposure?*

f. *How does an infrasonic fundamental frequency affect a simultaneously resonating harmony?*

g. *Regarding rhythm; what are the inherent rhythmical properties of infrasound samples?*

h. *What are the behavioural traits of the multiple harmonic upper partials of an infrasonic sine wave?*

i. *What is the sonic profile of an infrasonic elephant call?*

j. *What are the particular characteristics regarding field recordings of this nature?*

All of the above queries are explored in this thesis and the resulting composition integrates electronically generated infrasonic discoveries, combined with infrasonic field recordings of the African elephant and Highveld thunderstorms. The above questions facilitated my aim to investigate the phenomenon, state the findings and continue to pursue the evolution of these technologies for further infrasonic application.

1.3 General Terminology

To address the wide range of terminology arising from both the scientific and musical fields, I have selected a set of terms specifically related to the concepts presented and discussed in this thesis. I have defined their functions and their classifications based upon the needs of this research and these definitions are provided in the table below (Table 1). The terms marked with the symbol * are of my own invention, and are helpful to the specific creative and scientific needs of the research project.

Table 1: List of terms and definitions occurring throughout the thesis

*Infrasonorities	Sonic activity (sonorities) emanating at frequencies below 20Hz.
SPL	Sound Pressure Level. A measurement of the amplitude of a sound wave (Møller 2003:76)
Acoustic Ecology	Awareness and monitoring of the acoustic environment at any given time (Wrightson 1999)
*Infra-mic	A name given to the modified infrasound microphone.
*Infra-spread	A document containing Infrasonic experiment data captured during my research (see section 4.6.1 and Appendix 2)
Biophony	Recordings of a particular environment for the purpose of obtaining sounds from non-human biological life (Gray et al. 2001)
Psychoacoustics	This term originates from a field in psychology and the concepts are generally concerned with actual and perceived stimulus in the body and the mind (Møller 2003:277)
Noise Music	Artistic audio that makes use of non-conventional instruments and extra musical sound sources (Kahn 2001:69)
Wavelength	The length between two respective corresponding positions that outline one complete wave oscillation (Farnell 2010:23)
Vibrotactile	A vibrotactile event refers to physical vibrations felt in the body (Crawshaw 2014)

Chapter 2: Producing and Incorporating Infrasound

As a principal part of this research it has been vital that the presence of infrasound can be shown to exist within the collected data and creative work output. For the purpose of better understanding infrasound, its propagation and its manipulation, I chose to acknowledge and consider elements regarding/relating to human stimulus and perception. These cornerstone considerations have directed my techniques in obtaining, producing and reproducing infrasound.

2.1 Perception of Infrasound

Apart from the expected perceptions of infrasound via the mechanisms of the ear, the entire body of a listener functions, to some extent, as a transducing membrane (Leeds 2010; Ihde 2012:231). Indeed for some, the physical stimulus in the body or ‘vibrotactile’ (Crawshaw 2014) experience can be an entirely sufficient method in the detection of a sound (Glennie 2015). As a deaf musician, Dame Evelyn Glennie advocates musical engagement in the deaf community. She speaks of sonic conduction through medium of the bones and flesh of our bodies, inspiring us to realise how sensitive these abilities can become. The deaf musician is not a central feature in this research but due to the nature of infrasonic stimulus, I include those with hearing disabilities as listeners. It is possible that an individual with severe hearing disability might engage with an infrasound concert to greater effect than a standard concert setting that has emphasis on frequencies above this range. Here arises, in my potential audience, an interesting overlap between the hearing and the deaf.

For all listeners it is important to include a considerable amount of evidence which proves that we can indeed safely perceive and experience infrasound (Altmann 2001:55; Leventhall, Pelmear, and Benton 2003; Crawshaw 2014). Experiments performed by scientists conclude that physiologically humans are susceptible to infrasound under favourable circumstances:

> Sounds at frequencies below 16Hz are clearly audible if the [sound pressure] level is high. The hearing threshold has been measured reliably down to 4Hz for listening in an acoustic chamber and down to 1.5 Hz for earphone listening. (Leventhall 2009)

In the case of exposure to infrasound at high Sound Pressure Levels (SPL), the listener does not purely rely on the hearing cortex (Auditory Cortex) but uses the Primary Somatosensory Cortex of the brain to detect occurrences. This is also known as non-cochlear membrane motion/vibrotactile stimulus (Kim-Cohen 2009:91) (Figure 1).

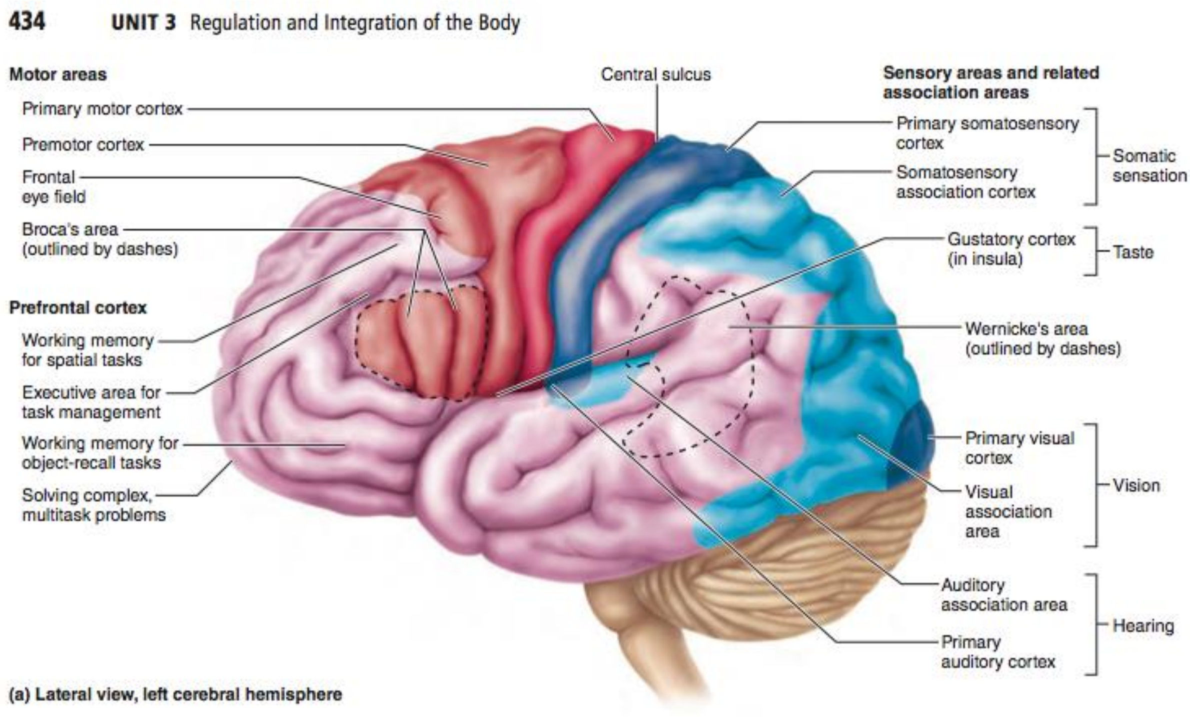

Figure 1: The two infrasonic detection areas in the brain are labeled as the Primary Somatosensory Cortex and the Auditory association area *(Marieb and Hoehn 2013:434)*.

The circumstances under which humans become acutely aware of infrasound require louder SPLs than for a higher frequency sound experience. Designs for equipment that could generate infrasound included rotary woofers and resonances of particular acoustic spaces, as well as the notorious non-lethal weapons (Vassilatos 1996:3). Vladimir Gavreau was a scientist known to have built infrasonic weapons during the Cold War. The Infrasound Whistle was one of the devices Gavreau developed for the application of non-lethal weaponry. The devices were specifically designed to cause sonic disturbance intended to harm the mechanisms of the human ear (Vinokur 2004). More recent experiments performed to test the viability of infrasonic weaponry concluded the following:

> The human auditory system seems to be relatively tolerant of low-frequency exposure, especially with infrasound where even at very high levels only some TTS (temporary threshold shift) and no PTS (permanent threshold shift)[3] occurs. Thirty seconds of exposure to 172 dB infrasound did not even produce reddening in a human eardrum. (Altmann 2001)

Optimal infrasound pressure levels for my intended purposes, being substantially lower in amplitude (75-110dB/SPL) and causing no threshold shift, can occur through various methods (Park, Garcés, and Thigpen 2009:). The physical requirement of continuously

[3]Terminology associated with resulting damage in a certain area in the hearing range of an individual, of which there can be a temporary or permanent implication.

producing atmospheric resonance is answered with a variety of sound generating devices. A membranous or rotary device could achieve this prospect with hand-power, or can be designed to operate electronically. A personal assessment of compatible infrasound equipment needs to occur for any infrasound composer, and in my case such propagation was most easily achieved by connecting amplifiers to multiple large diaphragm speakers.

The human brain operates via frequencies of electrical current flowing through its entire structure. These currents can be measured by an electroencephalograph (EEG) (Millett 2001). The theory of Auditory Beat Stimulation (ABS) embodies the use of rhythmic pulses and oscillations to promote a brain wave state. ABS and advanced sound production technology have largely increased the interests of sound stimulus in neurophysiology. Some of these wave states have properties akin to infrasound and correspond to similar rhythmic characters. Alpha brain waves commonly range between 8 and 13 cycles per second (Hz), and this wave stimulation has proven to have positive effects on the human body such as mood state stabilization, focus improvement and increased capacity for memory (Simmons 2016; Kraus and Porubanova 2015; Siever 2009:4). Converse to the military application of infrasound in non-lethal weaponry, composition containing infrasonic frequencies, administered at the correct amplitudes, can potentially promote positive psychological and physiological effects to the exposed individuals (Meade and Emch 2010:220; Cowan 2016:76; Takahashi et al. 1997:).

2.2 Theoretical Background

A lot of research has been performed regarding the discussed, structured and documented relationships between human understanding and the creation of music. What follows provides the reader with a selection of historic developments relating to my acknowledgement, comprehension and application of infrasound.

In western music history some of the first recorded theoretical discussions are the Pythagorean theorems regarding numerical values and musical tones. The examination of sound and its numeric quantification can be dated back to over 500 years B.C.E. (Johnston 2009), and these early experiments were conducted to formulate musical structures and devices in what was a previously unexplored field. Experiments by those who followed Pythagorean theories investigated variables of sonic objects, their vibrations and the consequential sounds. The results helped produce a foundation for a modern understanding of pitch and harmony (Radocy and Boyle 2012:293). Through observing the pitch change as a mathematical variable (string and pipe lengths, hammer weights etc.) the ancient Greeks began predicting sonic characteristics, thus opening up methods for the creation of music.

The theories of Pythagoras, through to those of Boethius (580-524 B.C.E), used mathematical investigation as a tool to help craft tonalities and scalar relationships appreciated by the audiences of their time (Collins and d' Escrivan 2007:9; Johnston 2009:16). With these tools they constructed, out of the seemingly infinite options of sounds, musical theories that allowed composers to locate and communicate methods of composition. The intervallic relationships between relating and desired pitch locations began with the diapason or octave, the dominant or perfect fifth and the major third (Johnston 2009). The developments that followed further divided the diapason to become the seven dedicated positions of western ecclesiastic modes, all of which are compatible devices for infrasound composition and experimentation.

The process of assigning exact frequencies to the notes of an instrument is done according to a tuning temperament. Temperament is the device which allows for a compatibility in tuning a wide variety of instruments to the same frequency. This allows for a composer to modulate the key of a composition, and distinguish the intervallic distances between musical notes. Various types of tuning temperaments were employed before the arrival of a compensating temperament similar to Equal Temperament (ET) exemplified by Johann Sebastian Bach's *The Well Tempered Clavier* of 1722 (Johnston 2009:74). From this evolved the interval structure of ET which today still is most widely used by western musicians. The modern day reference note or standard pitch to which temperament applies, is A at 440 Hz, and was standardized by the International Standards Association in 1939 (Johnston 2009:36). This standard frequency specification for A has varied over the years due to technological factors.

The temperament best used for a variety of musical genres is, to some degree, still contested. I will not be venturing an opinion on temperament uniformity because, personally, I experience flexibility on this topic. Being so early in the process of my theoretical nomenclature for a large portion of the infrasound range, I use various temperaments to explore and observe a variety of intervallic interactions. I am, as a trained musician, most familiar with an equal tempered approach, which can be applied just as easily below as above 20Hz providing me with an immediately useable classification method.

Table 2 below represents the Equal Tempered frequencies for low notes of a piano as well as the wavelengths at which they operate.

Table 2: Frequency and wavelength of specific notes *(Suits 1998)*.

Note	Frequency (Hz)	Wavelength (cm)
C_0	16.35	2109.89
$C^{\#}_0/D^{b}_0$	17.32	1991.47
D_0	18.35	1879.69
$D^{\#}_0/E^{b}_0$	19.45	1774.20
E_0	20.60	1674.62
F_0	21.83	1580.63
$F^{\#}_0/G^{b}_0$	23.12	1491.91
G_0	24.50	1408.18
$G^{\#}_0/A^{b}_0$	25.96	1329.14
A_0	27.50	1254.55
$A^{\#}_0/B^{b}_0$	29.14	1184.13
B_0	30.87	1117.67
C_1	32.70	1054.94
$C^{\#}_1/D^{b}_1$	34.65	995.73
D_1	36.71	939.85
$D^{\#}_1/E^{b}_1$	38.89	887.10
E_1	41.20	837.31
F_1	43.65	790.31
$F^{\#}_1/G^{b}_1$	46.25	745.96
G_1	49.00	704.09
$G^{\#}_1/A^{b}_1$	51.91	664.57
A_1	55.00	627.27
$A^{\#}_1/B^{b}_1$	58.27	592.07
B_1	61.74	558.84
C_2	65.41	527.47
$C^{\#}_2/D^{b}_2$	69.30	497.87
D_2	73.42	469.92
$D^{\#}_2/E^{b}_2$	77.78	443.55
E_2	82.41	418.65
F_2	87.31	395.16
$F^{\#}_2/G^{b}_2$	92.50	372.98
G_2	98.00	352.04
$G^{\#}_2/A^{b}_2$	103.83	332.29

Provided with the frequencies of musical notes presented on such a table, the directly relating infrasonic frequency specifications for “musical devices” can be conjectured. The location of envisioned infrasound notes allows for harmonic and melodic structure to be built in a conventional way, derived from equal temperament principals, yet with frequencies below 20 Hz. In order to be as accurate as possible the numeric values (frequency in Hz) of the infrasound notes are traced five positions into the decimal range. Through the application of a simple mathematical formula (illustrated in the equation below) a musical note, melody or harmony can be transposed into the infrasound range. For the purposes of generating and composing with infrasound waves I look at musical notes for their values in Hz to test the aesthetics of the relative infrasound. This allows me to transpose desired harmonic resonance or melodic phrasing into the infrasound range.

$$x = \frac{f}{2^y}$$

x= initial/desired musical note

f= frequency

y= integer value (1, 2, 3…) that diminishes the value below 20Hz

This equation calculates the relative numeric value of the frequency in the infrasound range. *x* represents the desired frequency or musical note and y represents the number of octaves diminishing the chosen note value (*f*) to below 20Hz.

Only as late as the 16th century did the appeal for consonance and harmony gradually increase. Marin Marsenne developed his measurements of audible pitch in equations that help design instruments and these equate fundamentally to our current understanding of harmonic resonance. The physics presented in his publications helps to locate the conditions under which acoustic dimensions of an instrument would provide a desired range of variable sounds. His arguments in *Harmonie Universelle* provide the knowledge which helped explain the series of frequencies at which instrumental sounds and notes resonate (Cohen 1981:23).

In 1807 the harmonic series was discovered and explained by a French theorist Jean-Baptiste-Joseph Fourier. It is suspected that the observation of this phenomenon was previously alluded to by musicians but never formulated in a specifically mathematical way. This series is applicable to modes of energy outside of my particular research field however its occurrence is presented as frequencies compatible with air pressure oscillations. The Fourier series categorizes the positions of sympathetic resonances related to a given sound. In music it is often referred to as the harmonic series. The fundamental frequency lies at the bottom of the spectrum and bears a heavy influence on the characteristic features of its harmonic partials. My research on infrasound incorporates the Fourier series to help locate and predict higher pitched (more easily recognised) activity congruent to any particular sound source (Table 3).

Table 3: Fundamental frequency and the ratios to its harmonic series after *(Johnston 2009:)*.

COMPONENT	FREQUENCY	RATIO	INTERVAL
Fundamental	f		
		2/1	octave
2nd harmonic	$2f$		
		3/2	perfect fifth
3rd harmonic	$3f$		
		4/3	perfect fourth
4th harmonic	$4f$		
		5/4	major third
5th harmonic	$5f$		
		6/5	minor third
6th harmonic	$6f$		
		7/6	(3– semitones)
7th harmonic	$7f$		
		8/7	(2+ semitones)
8th harmonic	$8f$		
		9/8	major tone
9th harmonic	$9f$		
		10/9	minor tone
10th harmonic	$10f$		
			etc…

The frequencies represented by these ratios in Table 3 above, correspond to transposable musical intervals and the presence of this phenomenon is a non-variable factor. Therefore, in the case of infrasonic field recording, the Fourier series serves as an initial indicator to infrasonic activity. During the propagation of an infrasound source the higher partial resonance, registered on conventional monitoring equipment, can help redirect the data, proving the occurrence of a particular frequency below 20Hz. If no limitations exist in the lower range of a monitoring device the fundamental frequency can be observed alongside its harmonic profile for more accurate analysis.

Herman Helmholtz was a definitive scientist in our understanding of human hearing capabilities. Whilst using a siren to determine the frequencies of audible tones, in the 1880s he discovered that the human ear can still experience sound energy as low as 16 Hz and attributed to this sensation a rhythmic effect (Helmholtz 1945:18). He did not sufficiently elaborate on desired aesthetics inside the lower range and we do not know if he had a particularly pleasant experience while listening to his mechanically generated sounds, but he formulated a new lower limit in human hearing. There was however another significant musical researcher that better investigated the aesthetics of mechanical sounds unrelated to existing pitch models.

When Luigi Russolo published his manifesto *The Art of Noises* in 1913 it set a precedent for a movement toward the acknowledgement and emancipation of noises in music. At the time industrial and mechanical innovations where highly admired by the public and Russolo listened to those resulting sounds with great musical admiration. He is considered the first musical futurist and viewed the confines of composition as limited and stifling; therefore he thought the inclusion of noise to be musically progressive and aesthetically obvious. For my research this is pertinent based on the forward-thinking approach of including what are traditionally accepted as non-musical elements into musical composition. In this research, I approach composition with similar sounds and noises in a more traditionally musical way, so perhaps not intrinsically related to the noise conceptions of the futurists. However, my ability to include infrasound would not have been as feasible without the impetus provided by Russolo. I share his enthusiasm too for extra-musical sounds, often unrelated to the conservative pitch relations prevalent in his time.

> To excite our sensibility, music has developed into a search for a more complex polyphony and a greater variety of instrumental tones and colouring. It has tried to obtain the most complex succession of dissonant chords, thus preparing the ground for Musical Noise. (Russolo 1967)

The creative apparatus which he crafted called *Intonarumori* consisted of many different sized motorized instruments. Crudely described as a hand powered rotary sound source in a box with a cone attached (Serafin 2005), the tones often displayed a shift in glissandi type fashion at which the lowest of his instrumental range could well have been frequencies below 20 Hz. The largest of the structures contained acoustic dimensions capable of infrasonic emission, although I have not come across documented evidence that Russolo ever focused on infrasonic generation as a goal. My approach is to isolate (to some extent) the infrasound range and compose exclusively with sound in this range as my primary musical material.

Another composer famously revered as both a musician and ornithologist was Olivier Messiaen (Dingle and Simeone 2007; Hill 2007). By incorporating and simulating bird song in his compositions, Messiaen proposed a musical unity between the music of nature and the music of man. His work is relevant to those desiring to incorporate biological sources within music. I draw on these principals to incorporate natural sound events, only in the infrasound range rather than with higher pitched frequencies. Melodies were extracted by Messiaen from bird song and used as aesthetically pleasing and instrumental devices. I too share an infatuation for the music of nature although I have chosen to focus on the sounds of the elephant as they occur in the infrasound range.[4]

[4] Considering the circumstantial propagation of this phenomenon, it is important to distinguish between sub-surface (seismic) and atmospheric infrasound. Both types occur in elephant vocalization (O'Connell-Rodwell 2007) and are equally interesting, however for the purpose of this circumscribed project I have chosen to focus only on atmospheric infrasound

South Africa it is not uncommon to encounter the African elephant (*Loxodonta africana*) in conservation parks and game farms and therefore elephant infrasound is easily accessible to me. This animal species is also known to be a social and vocal creature which assists the prospect of capturing sonic events for recording purposes.

Since the time of the aforementioned pre-electronic composers and their musical ideologies the technological world has found ways in which to quantify musical phenomena rendering it digitally compatible, malleable and available. With regard to more modern composition principles, the concept of scientific significance in music survived the transition (to some extent) from acoustic into electronic. Unlike the ancients (Pythagoreans) Edgar Varese and Iannis Xenakis are relatively recent links between mathematical methods and musical theories. Varese presented an ideology that all music is sound which is simply organized by the composer (Cox and Warner 2004:17). He lectured on the development and application of electronic music in the early 20th century. His students documented him stating the following:

> …this art is still in its infancy, and I hope and firmly believe, now that composers and physicists are at last working together and music is again linked with science as it was in the Middle Ages, that new and more musically efficient devices will be invented. (Cox and Warner 2004)

Xenakis too believed that there was an underlying unity between the sciences (Hermann, Hunt, and Neuhoff 2011:390) and music. Xenakis is largely associated with music composition (including electronic works) and architecture. His striking music made use of mathematics to incorporate elements of both acoustic space and chance or random frequency generation. Although I do not compose solely by generating such elements, infrasound can be dependent on production hardware and acoustic space and therefore produces random effects under varied circumstances. Often the foundation for an infrasonic composition comes in the form of numeric values that hold potential for existing or new notes, rhythms or musical effect. The structures revealed through mathematical equations provided Xenakis a scaffold with which to compose. In a similar manner, the potentially existing body of musical structures in the infrasound range remain largely unexplored.

Karlheinz Stockhausen as a composer is specifically relevant to both my research and creative work, most explicitly in his composition Kontakte (Stockhausen and Barkin 1962). In Kontakte he uses electronic methods to produce sounds in order to find the point at which a frequency is no longer heard as pitch but rhythm. The continuation of his work took him below 20 Hz where he still perceived pitch until 16 Hz. Stockhausen was revolutionary to the noise and infrasonic audience (Crawshaw 2014) particularly as he knowingly ventured into the infrasound range to find aesthetic and perceptive qualities. He draws attention to coloristic elements of sustained simple tones of infrasound. In his discussions he provides a definition of music with which he empowers work of this unusual nature.

> ...a musical composition is no more than a temporal ordering of sound events, just as each sound event in a composition is a temporal ordering of pulses. (Stockhausen and Barkin 1962)

As an artist, it is important for me to acknowledge, reflect on and where pertinent implement the relevant existing approaches as used by preceding composers. Writings pertinent to this field of research, from Stockhausen to Michael Nyman to Douglas Kahn, render it unnecessary for music to contain conventional harmony, rhythm or melody so as to be loved as music (Kahn 2001:68). Today broader classifications of musical movements, excerpts or genres are widely varied. The lines between noise, ambience and music are increasingly porous providing growth in musical complexity. The digital revolution has made it possible to create synthetic sound production of an individually tailored nature with virtually no boundaries. In the field of sonification we can listen to and analyse countless audio realisations of phenomena such as the sound of the sun, a black hole (Cutler 2012), the insides of a human body, sped up audio of plant growth (Mok 2014) and also the often overlooked frequencies in animal communication (Gray et al. 2001; Lopez 2006).

The inclusion of sonic elements that were previously not considered either musical or appealing has, therefore, expanded tremendously. The evolution of sound design and the conversion from acoustic to digital production within the studio environment has created opportunities which have proliferated possibilities exponentially, allowing composers to realise previously unimagined music. Today digital recording technologies provide a wide variety of software programs that are designed to facilitate the growing complexity of music. Manipulation of sonic parameters such as waveforms, frequency oscillation, compression, equalization (to name only a few) (Farnell 2010) allow us to craft music with increasing specificity and can help to better illustrate sonic phenomena.

These theoretical innovations offer methods with which to compose and harmonize in a previously unheard manner. The process of applying these types of intervallic harmonies and anomalies to infrasound “magnifies” the interactions of simple tones. By “magnify” I refer to the reduction at which a frequency oscillates across a similar timescale. If the relative infrasonic frequency intervals sound simultaneously to the listener then a familiar harmony is evoked in an unfamiliar way. The application of these musical theories provided interesting areas for my own creative conception (though my compositions are not exclusively bound to any particular theoretical position).

The composition created as the result of this research in combination with this thesis draws on many of the theorems and histories mentioned in this chapter and applied to frequencies below 20 Hz. The movements of my composition require mathematical equations and other scientific methods to amalgamate the desired features in an artistic endeavor with aesthetic impulses drawn from music and scientific history.

2.3 Validation of the Infrasound

Sound energy, in form, is acoustic air pressure propagating through our atmosphere as a longitudinal wave (Helmholtz 1945:9). The frequencies of a sound are defined by the number of pulsating compressions occurring per second. This value is measured in Hertz (Hz) and the amplitude in SPL. Comprehensively, human technology has advanced in the variety of hardware and software designs to produce, monitor and reproduce desired sounds (Baines, 1961; Farnell 2010).

Sonography is one of the many tools used for sonic analysis by means of generating a graphic image which displays various aspects of an audio file. The recorded audio (in this case) is digitally plotted on an X Y graph, where X represents time and Y the frequency. This type of image, being a direct representation of an acoustic recording, is called an audio spectrograph. Through spectrographic analysis I provide a means to better view the infrasonic properties in a recorded excerpt. As we all differ in our sensitivity to infrasound, this spectrographic monitoring system has proved relevant and useful. This approach provides data that is informative beyond the interpretation as well as memory of any specific listener and reveals unique characteristics within infrasonic occurrences such as those found in nature (i.e. elephant infrasound).

Knowing that elephants use infrasound to communicate I investigated existing methods of validating this claim within recorded data to incorporate information from biologists who work with spectrographic analysis. Biologists have been interested in infrasound to better interpret elephant behaviour since Katy Payne’s discovery of elephant infrasonic communication in 1986 (Payne, Langbauer, and Thomas 1986). African conservationists at the Rory Hensman Research Unit are seeking infrasonic recording technology which obtains detailed field recordings for elephant monitoring purposes. The modified technology used in my research possibly provides an affordable alternative method to monitoring herd movements. Aside from the affordability of the interface used, the entire recording station is relatively small and mobile. A considerable amount of infrasonic data can be collected for analysis with a modified dynamic microphone, entry-level soundcard, laptop and power source. Ultimately the understanding and implementation of this technology could serve the goal of reducing human elephant conflict.

The same elephant herd from which I extracted my data has also been researched by scientists in the field of geophysics. These scientists have been investigating the propagation of micro seismic activity from infrasonic vocalisations. With my data collection being focused purely on atmospheric infrasound from the same elephants, the spectrographs drew the attention of seismologists at the University of the Witwatersrand because these frequencies easily penetrate the ground surface. In the seismic field, the infrasound is referred to as a pressure wave (P-wave), due to its longitudinal propagation. Thus, geophysicists have an interest in this study, using it to make quantitative comparisons between the atmospheric and seismic bodies of data.

The physical, theoretical and scientific acknowledgements of the infrasound phenomenon provide me, as a composer, with a substantial fundament. The factual influence drawn from these varied fields support the development of creative application of the phenomenon itself, as well as broaden the contexts for thematic, conceptual and the artistic narrative.

Chapter 3: Literature Review

The body of literature selected here encompassing the infrasound phenomenon and pertaining directly to this project can be categorized as work on the following topics: the properties and perception of infrasound, historic reference, infrasonic music and acoustic ecology.

These topics are to be explored due to each having a unique significance in the structure of my research. The properties I discuss in the first part of this chapter are relevant due to their unusual conduct in the instances of infrasound. Thereafter I extrapolate historic references from which the phenomenon's' understanding originated as well as the term. In arguably rare examples musical context for infrasound has originated from certain artists which provides my research with useful information. Furthermore, acoustic ecology is reviewed in this chapter as animal sound sources are innately prominent in my composition.

3.1 The Properties and Perception of Infrasound

To experiment with infrasonic perception, the existing behaviour of sounds (also above 20Hz) was used to examine and test inherent qualities of infrasound samples in order to discover specific, and musical, characteristics. All music consists of sound, and sound possesses physical properties portraying a sonic source with an identifiable characteristic (Atkinson, Overton, and Cavagin 1995). As one might expect, the properties of infrasound differ from those found in sounds commonly associated with conventional music. It is therefore important to dissect the occurrence of this phenomenon and how infrasound propagates as a physical and psychological experience. The work of selected authors in this discussion will reveal the characteristics of infrasound, providing a basis of comprehension for the manipulation required in musical composition.

To understand how infrasonic-waves behave inside music, the properties considered in this part of the literature review will focus on Amplitude, Waveform, Wavelength and Transient value. It is also important to note that along with these properties, sound can be analysed by its fundamental qualities as well as the resulting upper partials. A partial (fundamental or overtone) of a sound, refers to a resonant frequency located within the sound's harmonic profile.

3.1.1 Amplitude

Among the many researchers who have published work on sound and its resulting stimulus the renowned scientist Herman Helmholtz is particularly significant. He wrote the book *On the Sensations of Tone* which was originally published in 1885. In chapter IX of this book, "Deep and deepest tones", he experiments with a siren and a number of different musical instruments to explore what he believed to be the lowest tones perceivable. It seems that, at the time, the lowest number of vibrations per second to produce a musical tone were considered between 8 and thirty Hertz. Early in this chapter he writes:

> It is necessary that the strength of the vibrations of the air for very deep tones should be extremely greater than for high tones, if they are to make as strong an impression on the ear. (Helmholtz 1945)

In summary, he attempts to locate the exact point at which an air wave oscillates slower than the human ear is best suited to detect. The instrument that he had used to achieve this was created to limit the variability of amplitude for a specific frequency or note. Upon experimenting with a sufficiently pressurized 16ft organ pipe, Helmholtz states that at 33 Hertz a sensation of tone is still perceivable, however, (in his own words):

> We almost begin to observe the separate pulses of air, notwithstanding the regular form of the motion. (Helmholtz 1945)

This suggests low frequency drones of this nature are unusual from a listener’s perspective, as the energy functions in-between the areas of rhythm and tone.

Spectral music, developed in the 1970s by Tristan Murail and Gerard Grisey, is formulated on sonographic and visual consideration of the audio spectrum occupied by a particular musical example. Generally these composers were interested in the representation of the sound events in the form of stave notation. Though relatively complex as an entire theoretical body, certain extrapolated principals translate compatibly to frequencies in the infrasound range. A spectral composition incorporates a form of visual analysis in the particularities of certain sounds.

> …a frequency-based conception of harmonic and timbral constructions allows composers to make use of much of the research in acoustics and psychoacoustics, which look into the structure and perception of natural (environmental) and instrumental sounds, providing models for the way in which various frequencies are created and interact to form our auditory impressions. (Fineberg 2000)

Amplitude is typically measured in either decibels or sound pressure level and it is the property of sound that holds potential risk for damage to the physical ear. The variable amplitudes that a frequency or frequencies may resonate at, and for that matter how the amplitude changes over time, are two qualities which allow for the analysis and identification of specific sound events.

Because register is of a large concern in my research, it must be remembered that the amplitude applied to music in the infrasound range can affect variable perceptive qualities of the same sound. The arrangement of a particular sound in a composition can depend on the amplitude at which it is diffused. The availability of a large dynamic range for infrasonic music will depend on mechanisms of the sound reproduction infrastructure. In the extreme cases where infrasound can reach SPL above 110 the composer and researcher will regulate appropriately to his or her desired effects.

Much of the available research on infrasound has looked into using the harmful effects of sonic weaponry as a non-lethal offensive. A report by Jurgen Altmann describes this type of sound use in the following way:

> Pressure variations mean deviations from the average air pressure toward higher and lower values, denoted by over- and under pressure. Usually these deviations are much smaller than the air pressure; they are called sound pressure. (Altmann 2001:9)

This over and under pressure is the amplitude at which the sound displaces the atmospheric pressure. Weapons that operate in the infrasound range are said to require less than one hour of exposure of between 90-120 SPL for effects such as an extreme distraction. The report contains evidence to propose that up to 175dB causes temporary threshold shift (TTS) but none to suggest permanent threshold shift, or deafness (Altmann 2001:17).

3.1.2 Waveform

The infrasonic waveform is important to consider since each individual wave period becomes gradually lengthier as we move lower down the frequency spectrum. Not only do waveforms contain unexplored aesthetically valuable assets to an infrasound composer, but they are to be carefully considered in accordance to the equipment which creates the acoustic energy.

Measured Tones, a book by Ian Johnston provides an understanding regarding the relationship and interconnected history of physics and music. In an introductory style, Johnston explains that acoustic sounds are all longitudinal pressure waves, travelling through the density of air in our atmosphere, although no two sounds are exactly the same. Acoustic vibrations, or compressions and refractions in the equilibrium of the atmosphere, have characteristic shapes that influence our identification of them and placement in the case of musical composition. Acoustic sound source material is classified as a complex waveform. It is complex due to the combination of variable qualities together formulating a more unpredictable pattern and unique sonic quality.

Basic synthesis of electronic sound originated from singular or multiple simple tone creations namely sine, square or saw tooth waveforms. They were given these names according to the gradient at which the amplitude of a continuous waveform begins and ends (Johnston 2009:93:306). These three waveforms each have a symbol that represents one wavelength (period of oscillation). This symbol is visually derived from the audio representation of an instrument called an oscilloscope. Upon discussing the physics behind an experiment with the oscilloscope, Ian Johnston describes that the device provides a visually bridging representation between acoustic vibration and musical timbre. My own infrasonic interest resides principally among the smoother options, isolating the sharper waveforms for very specific and sporadic use. The resulting effects provide a more comprehendible, rather than intrusive, experience from an interested listener seeking an unfamiliar aesthetic.

3.1.3 Wavelength

Andy Farnell's book, "Designing Sound", discusses the inner workings of audio from the modern production perspective. He reflects on wavelengths and their behaviour related to a source.

> Since waves take time to propagate some distance in space this introduces a delay between cycles of a wave measured at different locations in space...This is literally a measure of how long a wave is, in meters, and it's measured between the closest two points with the same displacement moving in the same direction. (Farnell 2010:23)

This is significant to my project because sonic wavelength increases with decreasing pitch or frequency. A severely high infrasound sine wave of 19.9 Hz propagates at a minimum wavelength of 17 m. This propagation sets infrasound apart from higher vibrations in that the audible reach is immediately of a larger radius. The wavelength is also an important factor in helping formulate an understanding regarding the disturbance of matter particles, not excluding the human body. Dealing with wavelengths that are so large presents challenges when considering an acoustic space in which to perform. A near-by chamber or duct made of any material holds the potential to resonate at a frequency which is directly proportional to its length or width. All types of matter have resonant frequencies but since infrasonic frequencies are so low and the wavelengths therefore so large they tend to travel through the nearest matter easily, rather than being diffused or dispersed (Farnell 2010:65).

The journal article "Tactical Infrasound" by Christopher Stubbs cautiously analyses wavelengths for infrasound from a military monitoring perspective and provides the following information.

> Infrasound's traditional use has been for monitoring of atmospheric explosions over large distances across the Earth's surface and it is under active development and use for CTBT monitoring at the present time. On

> these 1000-5000 km length scales, the dominant propagation effects are from the changing temperature profile in the atmosphere, and global winds.
>
> The frequencies that are typically of interest are in the range of 0.1 to 100 Hz (wavelengths of 3 km to 3 meters), and the propagation calculations are nearly always carried out by ray-tracing. Hence, the changes in all atmospheric quantities are assumed to occur over length scales much longer than a wavelength. (Stubbs et al. 2005:31)

3.1.4 Transient Value

The transient value translates as a stimulation which the listener experiences in the introductory phase when hearing a specific sound. Andy Farnell writes about the many facets of sonic production in his book *Sound Design*. Regarding transient particularities and how they affect our every sound, he wrote the following:

> A transient corresponds to the excitation stage. It is often considerably louder than the rest of the sound and is always short. It may contain sound from both the excited object and the exciter, for example a drum stick or bell hammer. (Farnell 2010:90)

The above-mentioned examples are sharp sounds, usually affiliated with a high SPL. In the case of infrasound caused by a lightning strike the transient is also identified as sharp, although the spectrum occupied is considerably larger than natural exclusively infrasonic sound. Conversely, the principal physical properties inherent in infrasonic waves tend not to have as sharp a transient. Instead some of the featured infrasound (generated and elephant samples) used in this research, typically, have slow rising transients operating at lower amplitudes. In synthesizing infrasound and seeking to use it as a musical device, it is important to understand that these transient values are not going to excite the same way as a snare drum, bell or string would. They may rather be associated with smoother and slower transients, generating a more gradual effect.

The Spectral composers Grisey and Murail were also interested in the transient values in their analyses of sound source sonic qualities intended for musical composition. The initial transient holds a considerable number of factors with regard to the profile and character of a sound. Joshua Fineberg, a researcher whose work focusses on Spectralist composers provides the following regarding their view on attack transients.

> …while many spectral composers have worked with the idea of attack transients and have sought to include and manipulate them in both electronic and instrumental synthesis, this modeling is rarely based on precise models emerging from analyses

and is, instead, more intuitively and metaphorically based on the concept. (Fineberg 2000:91)

3.2 History of Infrasound

A publication by the Royal Society in 1888 documents the aftermath of a volcanic eruption. *The eruption of Krakatoa and subsequent phenomena*[5] is one of the earliest documented sources recognizing infrasound. The report was a global co-operation with data captured by more than 50 stations. Scientists were able to measure the atmospheric displacement which caused observable changes on a metric scale. Barometers[6] and gasometers were among the first instruments to ever record infrasonic data. The authors did not refer to the phenomenon as infrasound in the report, and this data was not captured with any intent to reproduce the infrasound. The first recorded use of the term was only in 1927 (Definition of Infrasonic by Merriam-Webster' 2016) but could possibly have been implemented before since the term is naturally suitable with "infra" as the Latin prefix for the word "below" (a more familiar use of this is "infrared light"). The allocation of this term and the general social application began to grow immensely after the infrasonic studies of Vladimir Gavreaux during the 1960s (Vassilatos 1996:3).

A compilation of sketches, barometer readings and data sheets formed part two of the report. Lieutenant General R. Strachey, chairman of the meteorological office, wrote on both the air waves and the sounds recorded shortly after the Krakatoa eruption. He and his colleagues obtained widespread evidence that the pressure waves, as result of the explosive effect, were substantially further distributed than the epicentre of this outburst. He also mentions people local to New Guinea and in the affected radius, to have known this phenomenon from previous occurrences long before the cause of the sounds were identified (Strachey 1884:80).

In this early reference, investigators were already aware of both the atmospheric and seismic types of infrasound. This distinction is important in my work because the recording configuration relating to my research is built for the capturing of sound energy in the atmosphere. Investigating this phenomenon from both an atmospheric and sonic perspective, Strachey's contribution consists of two chapters, in the first his conclusions are

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[5]Along with the sonic and seismic phenomenon, volcanic, optical, magnetic and electrical reports are also included.

[6]Barometers and gasometers are both devises used to measure gaseous pressure. Barometric measurements are taken of the atmospheric pressure, and gasometers were industrial gas containers which corresponded to circumstantial atmospheric changes.

drawn from barometric measurements, and in the localities where they were not present other instruments provided the data:

> it appears that the atmospheric disturbance in question had very nearly the characteristic velocity of sound, and that its mode of propagation by an aerial oscillation, of comparatively short duration, was also closely analogous to that of sound. (Strachey 1884:72)

The second section takes into account the recollections of those who were within the area whom experienced strong pressure disturbances.

> The sounds were heard with great distinctness over the most distant parts of Java and Sumatra throughout the morning of Aug 27th, but it is remarkable that at many places in the more immediate neighbourhood of the volcano they ceased to be heard soon after 10 a.m., although it is known that the explosions continued with great intensity for some time longer. Very probably this peculiar phenomenon was caused by the large amount of solid matter which at about that time (10 a.m. local time) was ejected into the atmosphere by the volcano, and which formed in the lower strata of the air a screen of sufficient density to prevent the sound waves from penetrating to those places over which it was more immediately suspended. (Strachey 1884:79)

The shaded portion of the map in Figure 2 represents approximately the area over which the sounds were heard.

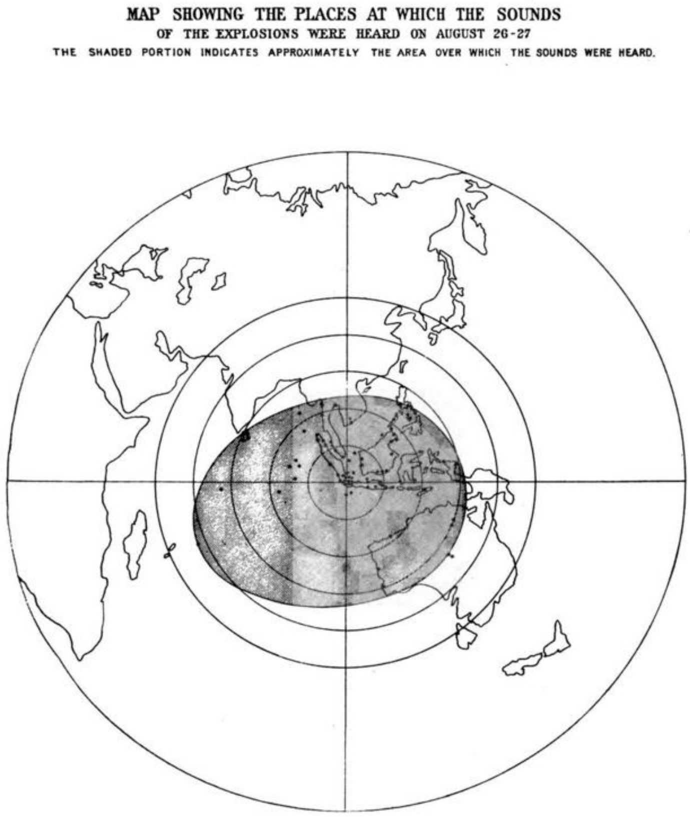

Figure 2: Area in which the eruption of Krakatoa was perceived. (Strachey 1884:153)

The study revealed that the waves travelled a recorded minimum of seven times around the globe, and that the data from various instrumentations concluded the source to be the same great explosion. These observations, made at these first stages of infrasonic research, were informative regarding the behaviour of infrasound and its powerful effect.

3.3 Tangibility of Infrasound (Helpful or Harmful?)

The broad definition of infrasound is stated as “the acoustic oscillations whose frequency is below the low frequency limit of audible sounds (IEC 1994)” (Leventhall 2009). The ambiguity arises in defining the lower limit of audible frequency (Cowan 2016:72). The lower limit is defined by the IEC as 16 Hz (Leventhall 2009), whereas 20 Hz is the more generally stated limit in the commonly accepted mechanical capabilities of human ears. In addition to the range of values stated by researchers, it must also be acknowledged that each individual will have their own lower limit of hearing.

An extremely common misconception is that infrasound is inherently harmful. There have been many claims surrounding dangers of the phenomenon, instilling a fear and often resulting in a one-dimensional view from society.

The inaudibility of infrasound is a misconception too as well as the misconceived physical dangers of infrasound. These dangers have been over exaggerated by various sources and media (Leventhall 2009:17). Regarding the propriety of infrasound, a difference of opinion occurs in the overlap of research done by Gerry Vassilatos and articles by G. Leventhall. In an article written by Gerry Vassilatos, he states the following:

> The most fundamental signals which permeate this world are inaudible. They not only surpass our hearing, but they undergird our being. Natural infrasounds rumble through experience daily. Their manifestations are fortunately infrequent and incoherent. Infrasound is inaudible to human hearing. The bottom human limit. The plynth. The foundation. Infrasound is not heard, it is felt and holds a terrible secret in its silent roar. (Vassilatos 1996:2)

Even though my position is to believe that this statement is not entirely true, particularly the alluded terror and undergirding, the article provides some information regarding the development of infrasound propagation. He explains how scientist Vladimir Gavreau and his team perceived an inaudible sound that disturbed various areas within their bodies. Other than the physiological effects they experienced, they additionally observed the changing surface of liquids in containers around their laboratory. In a pursuit to understand their various observations, Vassilatos notes:

> They could not pursue the “search” for long time periods. During the very course of tracking the sound down, an accidental direct exposure rendered them all extremely ill for hours. When finally measured, it was found that a low intensity pitch of a fundamental 7 cycles per second was being produced.
>
> Furthermore, this infrasonic pitch was not one of great intensity either. It became obvious that the slow vibrating motor was activating an infrasonic resonant mode in the large concrete duct. Operating as the vibrating “tongue” of an immense “organ pipe”, the rattling motor produced nauseating infrasound. Coupled with the rest of the concrete building, a cavernous industrial enclosure, the vibrating air column formed a bizarre infrasonic “amplifier”. (Vassilatos 1996:3)

This may seem distressing, but the team of scientists were experiencing, seemingly, unintentionally made infrasound under unusually uncontrolled and yet amplified conditions. To have disturbed the surface of liquid in the cup of a laboratory space I suspect that the levels must have been of severely high intensity, though the exact SPL is not specified. The prolonged exposure to this infrasound was unusual in that most infrasonic occurrences, such as thunderstorm and animal infrasound, are short lived as the wave is released into the atmosphere dispersing over distance in its volume and density (Farnell 2010:64).

Leventhall refers to the above proclamations in a later journal (Leventhall 2009:6), which was written in response to the complaints of the negative physical effects caused by wind turbine generated infrasound. He concludes in his revision that these complaints of infrasound are medically referred to as a type of somatization. To elaborate on this phenomenon, Tim Kenny writes the following:

> When mental factors such as stress cause physical symptoms the condition is known as somatisation. Somatoform disorders are a severe form of somatisation where physical symptoms can cause great distress, often long-term. However, people with somatoform disorders are usually convinced that their symptoms have a physical cause. (Kenny and Knott 2017)

Considering the studies undertaken by these various scientists pursuing an understanding and use for infrasound, we can safely implement boundaries where the exposure is harmless on human physiology and helpful to infrasonic composers. Anant Baijal's article discusses the prospect of including those who are hard of hearing into the experience of music. In this article's introduction, he explains that vibrotactility can provide a necessary multi-sensory experience to extend the musical audience into parts of the deaf community.

> …individuals in the hard of hearing and the deaf communities (HH/D) are at a considerable disadvantage and have been virtually excluded in discussion of the uses and importance of music in society.
>
> One less explored possibility for providing alternative access to music is the potential of the tactile system. The physiology and processing systems for hearing and tactile perception have many more similarities than the vision and hearing system. It may be possible to take advantage of the parallels for conveying music. (Baijal et al. 2012)

I am among those who argue that infrasound is not only audible but harmless to a human audience at the correct amplitudes. In my compositions, I chose to focus on subtle infrasonic effects which did not require significant amplitude (<90SPL). The physicality of the exposure challenges the very experience of listening and activates bodily segments into a vibratory state. In reconciling these positions through empirical observation, I deduce that infrasound potentially holds a range of inter-stimulatory occurrences, and contributes with this feature to the concept of music for audience members who are deaf or hard of hearing.

3.4 Infrasonic Music

Experiencing a very low frequency under the right circumstance may allow us to distinguish a pulsating effect as we are moved by the individual wavelengths (Helmholtz 1945:174), and therefore almost every infrasonic frequency's pulsation produces a noticeable rhythm at a constant speed or Beats Per Minute (BPM). This characteristic is shared, in theory, by all sound, but becomes more clearly distinguishable in this range (Helmholtz 1945:174).

In the infrasonic range it might not always be possible to systematically or artificially (in the case of equal temperament) distinguish the fixed pitch of a particular frequency or note. To answer questions regarding infrasonic pitch relations an audiological perspective[7] provides useful perusal. Alain de Cheveigné, a senior scientist at The National Center for Scientific Research (CNRS), explains what happens when we experience pitch.

> Pitch-evoking stimuli usually are periodic, and the pitch usually is related to the period. Accordingly, a pitch perception mechanism must estimate the period of the stimulus. (Cheveigne 2005)

The methods of musical listeners to estimate these periods are often not quantified numerically, but recognised as being melodic or harmonic according to the personal relevance and interpretation of a particular piece of music.

Because infrasonic situations are circumstantially experienced by humans as single cycles of the frequency rather than a pitch relating to the vibration, infrasonic sound character is perceptually principally rhythmical. Conversely the higher infrasonic frequencies function, arguably, in between the boundary areas of pitch and rhythm.

Lower infrasound frequencies display a harmonic ratio dispersed over a significantly larger spectrum than higher sound. The Fourier ratio of resonant frequencies naturally have only one (the fundamental) partial in the range from 10 – 20 Hz. Once the composer employs frequencies below 10 Hz there will feature and interact multiple harmonic partials inside the infrasonic spectrum producing a noticeable rhythm with simple sine waves. These sounds are primarily without distinguishable pitch, but still represent a richness in timbre.

> Contrary to the linear structure of notes and intervals, where distances are constant in all registers, the distances between the frequencies within the tempered scale and the potential for pitch discernment of the human perceptual apparatus is neither linear nor constant: it changes in a way that is completely dependent upon register. (Fineberg 2000:82)

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[7]Audiology is the branch of scientific and medical practice concerned with the ear and hearing disorders.

As the conventional use of melody in music does not necessarily include infrasound as a commonly used sonic feature, other umbrella terms for musical genre or style are considered in order to better frame/house the attributes of infrasonic music.

The Noise/Music boundary is an entry for absolutely any sound to feature in musical acknowledgement or context. When pitch no longer applies to an instrument or presented sonic anomaly, questions arise among some audiences regarding the musical category or genre of a particular song, movement or piece. Noise music has in itself become an overarching term for the incorporation of produced and recorded sounds, not found to be from those of conventional instruments. A noise music instrument can be found to operate in the entire audio spectrum and is not bound by any temperament or grid like note structure. Luigi Russolo (1885-1946), a pioneering member of noise music, argued in a manifesto written in 1913 (republished in 1967) that we encounter more noise than music in our daily lives and so we should strive towards comprehension and inclusion of noises in our immediate universe, just as we strive toward the mastery of sounds made by musical instruments.

> We must break at all cost from this restrictive circle of pure sounds and conquer the infinite variety of noise-sounds. (Russolo 1967)

In the very first conclusion of his manifesto *The Art of Noise*, he states that the domain of musical sounds must be expanded through the substitution of noise for conventional sounds made by known instruments. The eighth conclusion on the twelfth page of this document is as follows:

> We invite all the truly gifted and bold young musicians to analyze all noises so as to understand their different composing rhythms, their main and their secondary pitches. Comparing these noise sounds to other sounds they will realize how the latter are more varied than the former. Thus, the comprehension, the taste, and the passion for noises will be developed. Our expanded sensibility will gain futurist ears as it already has futurist eyes. (Russolo 1967)

My Infrasonoroties composition respond to Russolo's invitation to use specific examples within the Art of Noise's groupings (Table 4) 1 with roars and driving noises, 2 with snorts and 6 with animal voices. Because these sound categorizations identify certain infrasound examples their inclusion as a musical ideology serves as a principal to my composition methods.

Table 4: Noise groupings *(Russolo 1967)*.

1	2
roars	whistles
claps	snores
noises of falling water	snorts
driving noises	
bellows	
3	**4**
whispers	shrill sounds
mutterings	cracks
rustlings	buzzings
grumbles	jingles
grunts	shuffles
gurgles	
5	**6**
percussive noises using	animal and human voices:
metal, wood, skin,	shouts, moans, screams,
stone, baked earth, etc.	laughter, rattlings, sobs

By using the foundation of similar concepts put forward by Russolo, the intention of this thesis is to build on and broaden musical work by infusing infrasound (previously considered unmusical or extra-musical) into my compositions.

The scope with which the infrasound phenomenon (specifically) has been used in composition was rooted in the theoretical frames of various artists. A composition written to be presented as infrasonic music will require specific reproductive audio infrastructure. Without knowledge of when and where the infrasound might feature during playback, nor the intensity of the infrasound wave at hand, monitoring can be potentially problematic or cause damage to that particular infrastructure/speaker system. Therefore, in the search for musical infrasound examples it is important to regulate the monitoring devices with which to replay the infrasonic material.

Sarah Angliss is a British composer and instrument inventor with a particular interest in the haunted-like effects on an audience resulting from application of infrasound frequencies during performance (Henderson 2003). Using a pipe-like device in a concert setting to lace music with infrasound she helped discover the shiver-down-the-spine effects on an audience by means of surveying the attendees. The available audio sample of her infrasound composition seems to move systematically downward from sound above the infrasound range. Also included within her work to support the haunting effects are human voice recordings and Theremin type sonorities.

Concerned with the propagation of vast infrasonic wavelengths in the topography of a particular space, Raviv Ganchrow has previously facilitated infrasonic encounters with European audiences. The images available of his infrasonic infrastructure design seems to show the incorporation of an array of shipping containers each functioning as a resonating cavity. The enclosure opens to display two circular ports, one containing (at the centre) a four-bladed rotating fan structure. Another artist, Alexis Crawshaw, created an interactive sculpture with fluctuating textiles that visually responds when exposed to infrasound (Crawshaw 2014:5). This device was titled *Mirror Mirror* and used to find the particular infrasonic areas of resonance in an acoustic space. These are the concepts with which artists such as Ganchrow, Angliss and Crawshaw have begun to pragmatically incorporate infrasound in the disciplines of art and music.

In the 1950s Pierre Shaeffer sampled audio from his chosen sound sources (objet sonore) and alluded to the concept that musicality exists outside of the range or boundaries of conventional musical practices and design. *The Language of Electro Acoustic Music* edited by Simon Emmerson is attentive toward music where the pre-recorded material utilised in composition need not conform to exclusively musical or artistic organization principles (Emmerson 1986). Composing in this way is descended from the genre known as Musique Concretè. Another basis which made this movement possible, was that the technological ability to obtain, manipulate and exhibit such recordings had arrived.

The music composed by Schaeffer with sounds originating from non-conventional musical instruments evokes a different group of aesthetic experiences for the audience. Listening is an engagement between the transmitting sound and the receiving agent, and this activity varies in how it affects the listener. A member of the audience can greatly affect his/her own perception of the performance by listening in a particular way. He elaborated on this element of the musical experience, and suggested a categorization of four listening modes (quatre écoutes, Table 5). These translate (in numerical order) as: 1 casual/regular listening, 2 marginal listening, 3 reduced/profound listening and 4 semantic/comprehensive listening.

Table 5: Listening mode categorization (Vickers 2012).

	Abstract	**Concrete**
Objective	4. *Comprendre*	1. *Écouter*
Subjective	3. *Entendre*	2. *Ouïr*

The table (Table 5) maps the experience of a listener in reflection of various voluntary states. The objective row relates to situations where a listener is aware of the instrumentation or sound sources that create the audio experience, and engages with the object and resulting sound inseparably. The subjective category refers to a listener whom is circumstantially unaware or uninterested in the object or mechanics of the source. The modes falling within the Concrete column occur when a member of the audience experiences a particular sound event without the undergirding of external information or intended contextual meaning. Conversely the Abstract modes are preconceived analyses concerned with extracting from the audio comprehensible background information.

Michel Chion discusses in his article these modes in intensifying order of active engagement beginning with casual listening, a rather more instinctive activity, thereafter semantic listening, engaging with referenced or linguistic sounds, and then reduced listening. My interpretation is that whilst practicing this concept, a sound is reduced to its sonic properties alone and not the source from which it is made. Indeed, the awareness of the sound source is an important distinction for a listener. When a source is not objectified through visual representation the mind attenuates to comprehend the finer details in the sound.

> …the acousmatic situation could encourage reduced listening, in that it provokes one to separate oneself from causes or effects in favor of consciously attending to sonic textures, masses, and velocities. (Chion 1994:5)

Chion elaborates on the notion of acousmatic listening (a term coined by Schaeffer and borrowed from the classical art of declamation affiliated with reduced listening) with the following:

> Acousmatic sound draws our attention to sound traits normally hidden from us by the simultaneous sight of the causes-hidden because this sight reinforces the perception of certain elements of the sound and obscures others. The acousmatic truly allows sound to reveal itself in all its dimensions. (Chion 1994:5)

The general concept that all of these examples strongly promote is to listen in an “acousmatic” way (Emmerson 1986:40). An alternative approach to cognitive musical perception is proposed by writer Seth Kim-Cohen. His book named *In The Blink of An Ear* interprets a perceptive quality response to sound, yet does not assume a primary reliance on cochlear stimulation. When writing about the act of engaged listening, Kim-Cohen shares his comprehension through the words:

> Such a sound is not treated as a note with a pitch value, to be combined – in adherence to the edicts of either the tonal or atonal systems – with other notes to create harmonic relations. (Kim-Cohen 2009:9)

Certain artists are drawn to create music that stimulates the analyses of listening. William Duckworth compiles a number of interviews with these key figures into a publication named *Talking Music*. One particularly inspiring interview is the one held between Duckworth, La Monte Young and collaborator Marian Zazeela. During their discussions on rhythmical and tonal attributes, Young explains that his music investigates (among other concepts) the following:

> You know how frequency is rhythm? Well, I felt that my interest in pitch was an interest in vibration on a higher level. Most people are very involved with rhythmic elements in their music. But I was just interested in these long sustained tones and the pitch relationships between them. I felt that the rhythms, as we define them in normal music, tended to lead one back to a more "earthy" and earthly kind of existence and behaviour, whereas the long sustained tones tended to lead me toward a more spiritual path. They were a higher form of vibration. (Duckworth 1995)

In the context of my own research, the term "extra-musical" deriving from the German expression "Das Aussermusikalische" is said to incorporate that which is not traditionally musical. It is the passage for sounds and noises to receive the same attention as instrumental notes, melodies and harmony. Discussing the use of extra-musical samples, Goehr states:

> Historically, the extra musical seems to have accommodated precisely those properties of the musical world that are not specifically musical, yet have given to pure music its broader human and expressive significance. (Goehr 1998:10)

Mimesis is another feature of interest here because as a term it can link sound with text, idea and/or concept. The recorded elephant vocalisations might lend themselves to an extra-musical framework as well as mimesis. Another musician who has presented similar work is Amon Tobin. In a work called "Big Furry Head" from his 2007 album *Foley Room*, he uses low-frequency noise made by large cat species (Tobin 2007). This incorporation of animal sound provides the particularly useful agenda of Acoustic Ecology, since it brings to the listener sonic phenomena found in the natural world. This pertains to my research as I also use extra-musical sources, such as low-frequency elephant vocalisations.

3.5 Acoustic Ecology

> Your awareness of sound, specifically your level of awareness of the acoustic environment at any given time, is an issue central to the interconnected discipline of Acoustic Ecology (also known as Eco-acoustics). (Wrightson 1999)

This statement written by Kendall Wrightson explains how a number of activities can be related to this subject. Wrightson and many others consider the establishment of this field rooted in the concepts explored by R.Murray Schafer. Schafer's research provides us with ideals such as the following:

> New studies are needed in the curriculum and they will carry us far out into the shifting contours of interdisciplinary knowledge. The new student will have to be informed in areas as diverse as acoustics, psychoacoustics, electronics, games and information theory. (Schafer 1969:3)

Listening theory in modern practice exists in such a wide variety of possible experiences. A composer of music may take large influence from altering his/her listening mode during exposure to a sound. The works of sound artist/composer Francisco Lopez have included recordings of natural soundscapes and in doing so provide an overlap between the composition and admiration of a sonic environment. An article by Lopez entitled *Profound Listening and Environmental Sound Matter* considers an extended discussion on the act of listening to a type of wilderness.

> …a sound environment is the consequence not only of all its sound producing components, but also of all its sound-transmitting and sound-modifying elements. The birdsong we hear in the forest is as much a consequence of the trees or the forest floor as it is of the bird. If we listen attentively, the topography, the degree of humidity of the air or the type of materials in the topsoil become as essential and defining of the sonic environment as the sound-producing animals that inhabit a certain space. (Lopez 2006:83)

A pertinent aspect of Lopez's work lies in the recording approach, process and production. He refers to the reproduction of such audio to be a superimposition of the reality existing where the samples were extracted. Due to the mechanics of equipment and instrument design each sound environment, sample extraction and its reproduction is logically different.

> Since the advent of digital recording (with all its concomitant sound-quality improvements), it has become all the more evident, in our attempt at apprehending the sonic world around us, that the microphones we use are not only our basic interfaces, they are non-neutral interfaces. The way microphones "hear" varies so significantly that they can be considered as a first transformational step in the

> recording process. The consequences of the choices made regarding which microphones will be used are more dramatic than, for example, a further re-equalization of the recordings in the studio. (Lopez 2006:84)

Patricia Gray, a renowned musician and director of BioMusic research, believes that we naturally marvel at musical similarities in the communicative capacities common to both humans and animals (Gray et al. 2001). Due to the geographical environment of each individual human, they may or may not be exposed to the sounds of certain animals. As a South African one has the opportunity to be exposed to many different kinds of bird calls, and various wild animal noises. Music that incorporates samples from the natural world is also referred to as Biomusic. Donald A. Hodges provides a definition for BioMusic in saying:

> BioMusic is an interdisciplinary investigation of musical sounds in all species and the evolutionary basis for musicality. (Hodges 2009:64)

Henrik Brumm, a research group leader at the Max Planck Institute for Ornithology, discusses how this form of music (BioMusic) breaches the pop and experimental divide. This is achieved through applying the principals of BioMusic in the field of popular music, such as in the examples of The Beatles ("Black Bird").

> In BioMusic, composers use recorded sounds of animals (or even plants) as part of their music. BioMusic is a particular form of sampling, but in contrast to reusing a section or sample of a sound recording from another musical piece, samples from naturalistic recordings are used.
>
> From Vaillant and des Prez in the Middle Ages and Renaissance to Messiaen in the 20th century, composers have tried to reproduce birdsongs with musical instruments. (Brumm 2012)
>
> In popular music this technique has been regularly used since the 1950s (e.g., "Rockin' Robin" by Bobby Day, which peaked at Number 2 in the US Billboard charts in 1958). (Brumm 2012)

In creating BioMusic the composer sets out to, in part, engage with natural elements so that the listeners are either introduced, or sonically referenced to a particularly natural auditory atmosphere. In this manner the composer can draw on powerful extra-musical sources and weave them into another context, driving the conceptual component of the composition and contributing to the intent with which the musician performs.

3.6 The Biophony of Elephants

Katy Payne and Roger Payne are known for revealing important details surrounding sonic phenomena in animal communication. After publishing articles regarding her empirical research on African elephant vocalisations she inspired future bioacoustic researchers and is acknowledged as the founder of the Elephant Listening Project. Her research on elephant communication in 1985, and other publications, directed my research toward the use of elephant vocalisations for the purpose of composition. Though many ecologists have undertaken infrasonic studies on elephants, little has been done to incorporate such material into music.

Caitlin E. O'Connell-Rodwell is an expert on elephants and ecology. In one of her written articles she includes the following to be among many interesting facts regarding elephant behavior. (O'Connell-Rodwell 2007)

> Given the ability to detect subtle frequency differences in seismic cues, elephants most probably could also distinguish less subtle infrasonic seismic events, such as an approaching vehicle, helicopters, airplanes, weather (thunder storms), or earthquakes, providing the elephant with a sophisticated ability to exploit the seismic modality for many different purposes. (O'Connell-Rodwell 2007:292)

In providing information on the physical process of these sound emissions she states the following:

> Higher vertebrates have several types of cutaneous sensory organs that are thought to act as mechanoreceptors. Pacinian corpuscles, or pressure receptors, are the largest peripheral mechanoreceptors in mammals. Pacinian corpuscles are deeply placed, whereas the Meissner corpuscles or touch receptors are superficial. In humans, the peak sensitivity of the Pacinian corpuscles is around 250 Hz with a frequency range of as low as 20 Hz and as high as 1000 Hz and Meissners corpuscles being equally as sensitive between 10 and 65 Hz. (O'Connell-Rodwell 2007:290)

As part of this research I collected infrasound data in the field whilst the elephants were communicating. The elephants, residing at the Hensman research centre, are all of the African elephant species (*Loxodonta africana*). They are the largest of all the elephant species in body size (including voice box), and due to this they possess the ability to create the lowest elephant infrasound. From a mechanical perspective, the sound of an infrasonic elephant call is created by the pressurized air that is released through the vocal folds, producing an oscillation gradually ascending and descending in both frequency and amplitude. The visual representative profile of this is similar to that of a "bow" like figure (Figure 3).

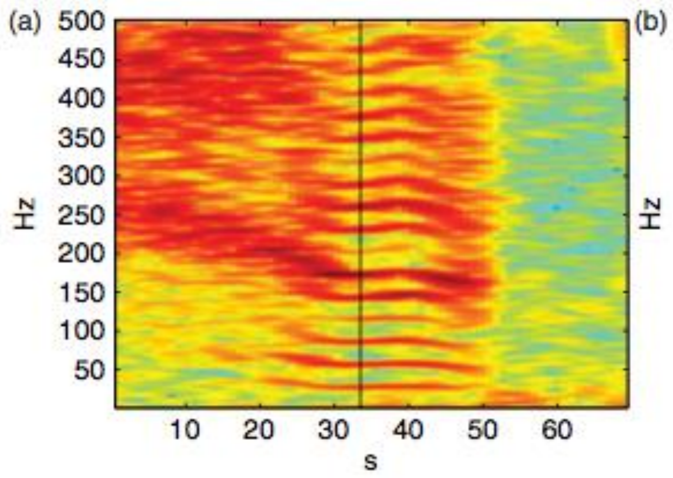


Figure 3: Bow like figure (Zeppelzauer, Hensman, and Stoeger 2014:15).

During any particular vocalisation, the profile of the sound is influenced by many variables. In some cases, a profile would have two apex points or would start higher and gradually move downward i.e. like a "half bow".

The saliency of any particular sound event recorded under field conditions can widely vary. The clarity of a spectrographic profile would depend largely on signal to noise ratio and interference such as wind noise. In addition to this, insurgent sounds often from mechanical motors can easily mask an elephant call due to similarities in spectrographic profile (Zeppelzauer, Hensman, and Stoeger 2014:13). Under the particular circumstances of my research those sounds most obtrusive and clouding to the distinguishability of the envisioned infrasound samples are aircrafts and off-road vehicles. Not only do these sound sources operate in a similar frequency band, they can also possess a similar "bow-like" profile, which potentially produces confusing data.

3.7 Chapter Overview

Historic work on infrasound and its incorporation into compositions, though not extensive, has been promising enough to encourage me as a young composer to further extend the field. Infrasound and its incorporation into musical composition is the central concept of my thesis. Music as a profession almost exclusively works within the range of 20 to 20 000 Hz. These limitations may be attributed to the outdated perception of human hearing thresholds together with the unviability to commercially manufacture equipment that can generate frequencies below 20 Hz.

Chapter 4: Research Methodology

This chapter contains the practical research I undertook in order to obtain a musical understanding of infrasound. Because there is no existing paradigm for successful infrasonic experimentation dedicated to my particular aim, this chapter therefore cannot draw on any existing mould for testing or procedure. The reasoning behind my chosen methods during this research was motivated by an evolution of infrasonic experiments and my resulting experience. The practice of infrasonic musical application was informed by my artistic approach to extract musical features from this uncharted territory.

Throughout the experimentation process, a suite of equipment was used to test various theories regarding the physical properties of infrasound. Additionally, this equipment was transported and tested in different locations to confirm its applicability in changing environments. The methodology outlines challenges and resolution in achieving the aim encountered from my cognitive (infrasonic comprehension) and material (equipment) departure points. To assist the creative process, I created a sound sample-bank of synthesized and recorded infrasound with which to experiment in composition.

The locations in Figure 4 referred to in this chapter correspond to the following:

1) My Home Studio

   Randburg - Johannesburg

2) The Sound Corporation

   Dunkeld - Johannesburg

3) Adventures with Elephants

   BelaBela

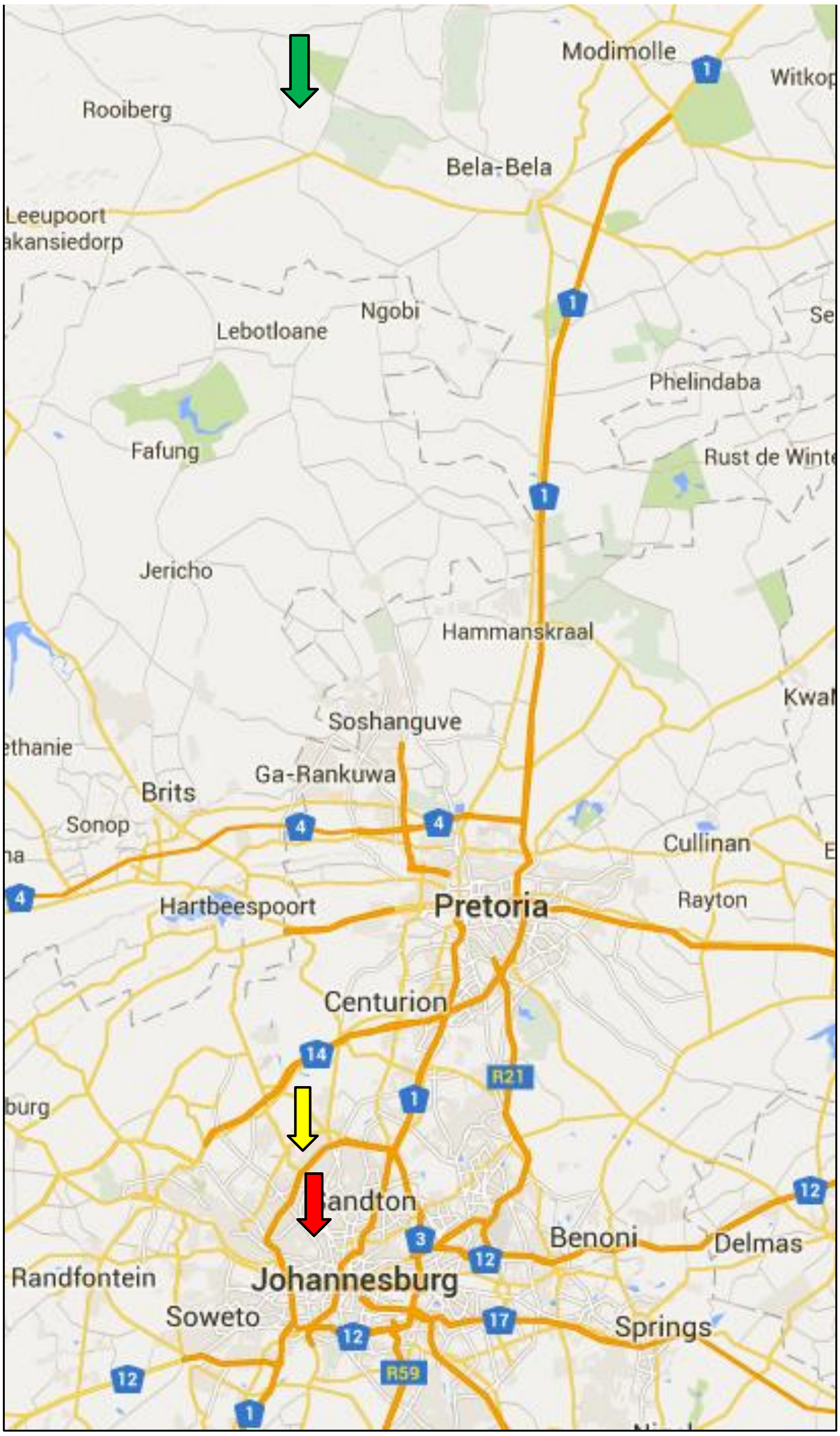


Figure 4: Map showing position of 3 locations.

The flow diagram below (Figure 5) is my representation of the aspects and challenges to be addressed for the successful production of an infrasound concert:

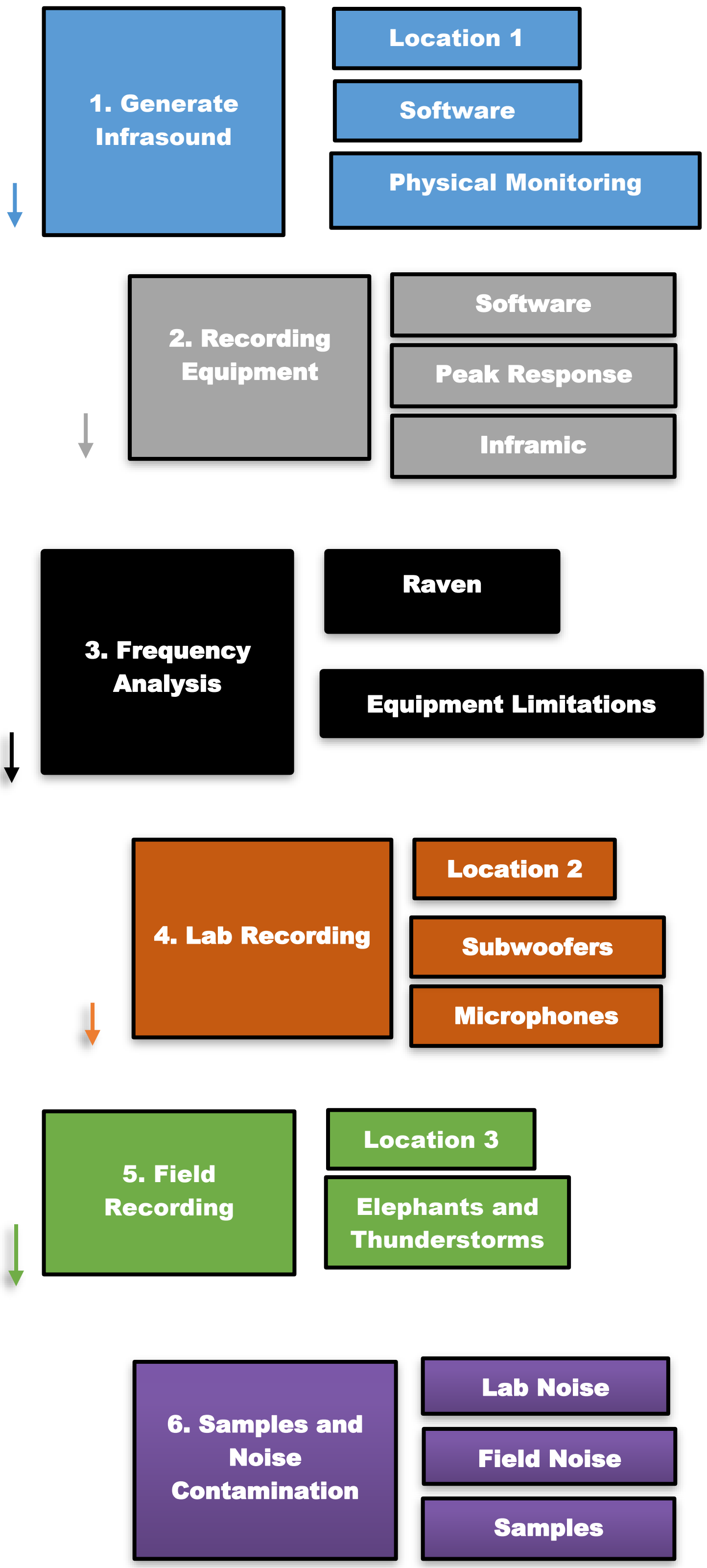


Figure 5: Methodology adopted to generate, identify and reproduce infrasound.

4.1 Generation and Detection of Infrasound

It is relatively common to experience low frequency vibrations (perhaps not infrasonic) in a conventional film/movie theatre. I therefore speculated that I already had the means to generate infrasound either digitally or acoustically. The challenge here was to isolate the phenomenon from the standard frequency spectrum in both analysis and reproduction, to consciously experience unaffected (by higher frequency sound) infrasonic occurrences.

Location 1: Home Studio in Johannesburg.

Two sound cards were linked up one at a time to my 2011 iMac computer, the first, a Focusrite Saffire Liquid 56 and the second a Presonus Audiobox-USB 2X2. The sound cards link to a stereo amplifier and this amplifier then powers two stereo monitors, a home theatre subwoofer and with a separate output, a 15inch driver connected to a 600-watt bass amplifier.

4.1.1 Digital Generation of Infrasound

A common way to create infrasonic effect is by using the synthesizer parameters known as Low Frequency Oscillators (LFOs). This was made famous by the Dub-Step music movement (Bradley 2013:12) and can sometimes affect an audio signal to seem near the bottom of the hearing range by use of intense rhythmical pulsation. I explored various synthesizers to generate an infrasonic sine wave with basic LFOs and found that these generally have movable parameters for lower frequency characteristics. These programs were rarely able to generate, in isolation, a waveform below 20 Hz. On my computer, I found a few of the default software programs used for sub-harmonic enhancement but this did not provide enough certainty to overtly examine specific infrasonic frequencies.

I experimented with enhancing the upper partials of predominantly low frequency active instruments, to try and emboss the audibility against higher pitched sound. The audio tool called SubBass (Logic 9 Plug in) synthesizes a low frequency tone and combines it with the user's data. Some digital audio devices are modelled to create the overtones from a 16 ft Organ Pipe, and fuse it with another sound. These enhancements overlap the infrasound border in order to add a vibrotactile experience akin to that found in high SPL infrasound exposure.

Although the software equalizers of most digital audio programs do not allow for tethering below 20 Hz, these equalizers were still useful when reducing the presence of frequencies between 20-20 000 Hz. The equalizing possibilities can allow subtle differences between one frequency and the next and for this reason they hold great appeal for me as a composer. I worked to eliminate most of the adjacent frequencies in such a way that infrasound would become more apparent.

Leventhall has concluded that, given the use of a capable system, infrasound is audible for humans down to 1.5 Hz (Leventhall 2007). The extended equal loudness curve of Leventhall (Figure 6) suggests that an infrasonic waveform must be at SPL of 80 and above for humans to become aware of it.

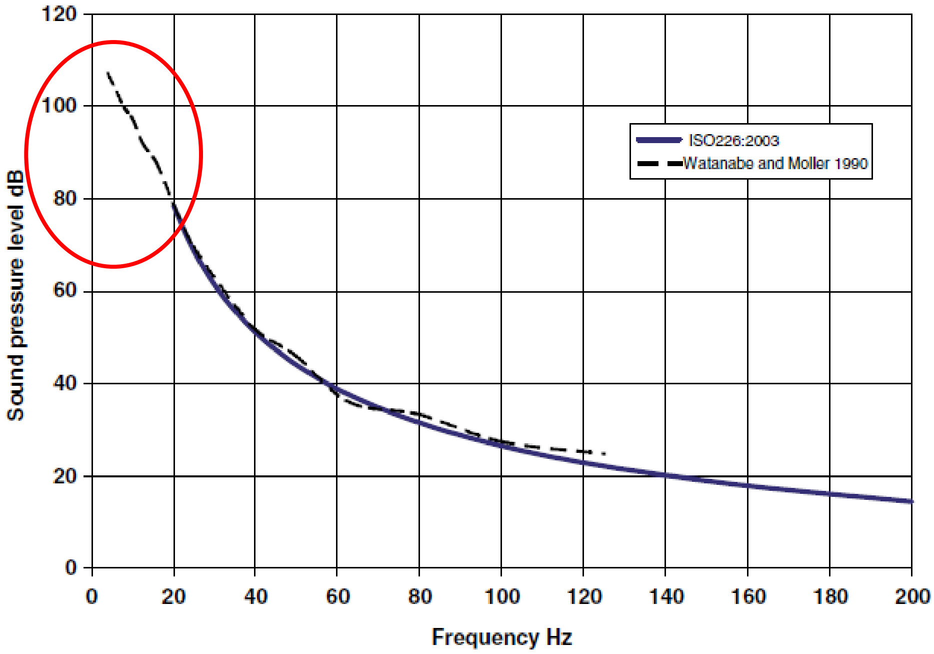


Figure 6: Extended equal loudness curve (Leventhall 2007).

During the process of testing the abilities of all the available speakers I began gravitating to the software program Audacity. In Audacity I discovered a simple tone generator that provided the ability to generate any waveform with a numeric value up to 5 decimals. Using Audacity I generated a test track of fundamental frequencies tailored for composition purposes.

The amplitudes of the frequencies in my created test track vary in accordance with the capabilities of the equipment in location one. Figure 7 shows the varying frequencies and their respective amplitudes.

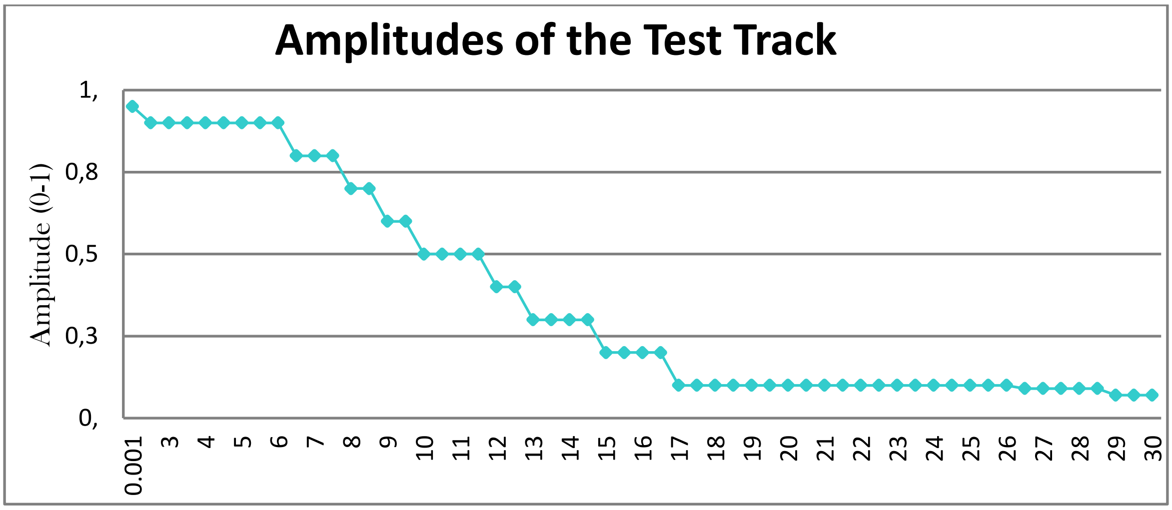


Figure 7: Graph of the inverse relationship between frequency and amplitude for the range 0.001 to 30 Hz.

From this test track graph, a suite of infrasonic samples (0.5 to 20 Hz) were generated in increments of 0.5 Hz for a period of one minute each. The maximum amplitude regarding clarity of the equipment (in location one) for each frequency was then plotted (Figure 7). Thereafter the frequencies were reproduced through the speakers in my home studio. The search for musical material within this realm began with physiological monitoring. I recorded my own experiences with the intention to establish a fundamental basis for creative comprehension. I did this through writing musical references for each frequency such as: “Cantering shuffle”, “Subtle Hip Hop” and “Tonish”. Table 6 is my categorization of specific infrasonic sine waves from personal exposure.

Table 6: Description table for various overt infrasonic frequencies.

Hz	Description	Hz	Description	Hz	Description
0.5	No Effect	8	Deceiving Pattern	15.5	Infrasoprano
1	Hazy Vibration	8.5	Impact Motor	16	Audible Pitch
1.5	Subtle Hip Hop Steady Groove	9	Motoric Sound	16.5	Purr
2	Anxious Heartbeat/Train	9.5	Tonish	17	Gentle Craft
2.5	Canter Shuffle	10	Overtonish	17.5	Hum
3	Swinging Double Tap	10.5	Vibration Foundation	18	Baritone
3.5	Reverse Double Tap	11	Pulsing Harmonics	18.5	In Face
4	Jackson Beat It	11.5	Driving Pulse	19	Very Nice Buzz
4.5	Hasty Beat	12	Harsh Infrasound	19.5	Flutter Sun
5	Empathetic Resonance	12.5	Pitched Tempo	20	Abrasive
5.5	Six Eight Feel	13	Ultra-Tonish	20.5	Drone
6	Nice Groove	13.5	Effective Vibration	21	Propeller
6.5	Mechanical Sound	14	Hypnotic	22	Sinus Sine Waves
7	Up Beat	14.5	Obscure	22.5	MechSpec
7.5	Pitch Smell	15	Mech Rumble		

Carefully fading in and out each sample allowed for sustained infrasonic oscillation without causing speaker damage. This created a formative idea of what the individual frequencies sounded like to me. The frequencies were first overtly observed as a digital waveform and manipulated to suit audible clarity according to my preference.

4.2 Electro Acoustic Generation of Infrasound

In order for infrasound to be perceptible, it is generally accepted that amplitude in the minimum region of 80 SPL is required (Leventhall 2009:3). This principle seems simple, however levels this high are often far beyond conventional home theatre speaker capacities. Testing the capabilities of infrasonic generation on an inadequate system can cause damage to the system due to the excessive amount of air which a device must move consistently. In the attempt to reach clearly audible infrasound, a diaphragm might cause distortion and rupture along the softer material of the cone where it meets the speaker coil.

Some lesser known inventions address this issue such as the rotary subwoofer (Figure 8). The device is designed to use controlled revolutions (per second) of a fan-like structure to oscillate the fundamental frequency in a contained closed space. Rather than rapidly moving a fixed diaphragm (conventional speaker coil) this type of subwoofer is a viable alternative to sustain a desired frequency. However, the capabilities of changing from one frequency to the next have a high probability of producing a lag in response. An air pressure escape port would be necessary to ensure that during the change between infrasonic frequencies no unwanted sound could interfere with the music. The enforced gap created between infrasonic notes would limit the variety of rhythmic subdivision.

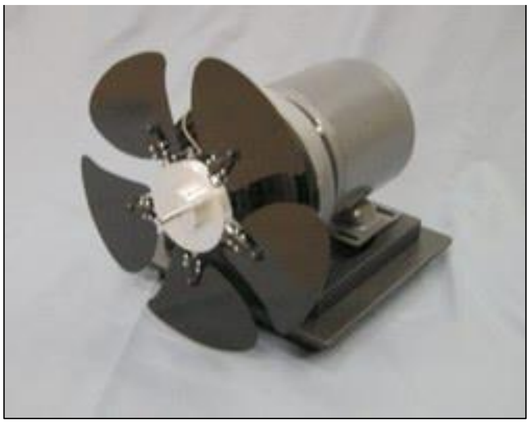


Figure 8: Rotary subwoofer.

Subsequently I considered and settled on the electro-dynamic subwoofer speaker systems, designed for outdoor use (Figure 9).

Figure 9: Electro-dynamic subwoofer.

The response from such a design delivers more accurate reproduction of field recordings and is able to cope with sudden changes between frequencies smoothly. I also understood that the moving diaphragm needed to be either A) large enough to comfortably produce infrasound, and/or B) it needed to be placed strategically within the housing structure to enhance low frequency replication. Some housing structures place the diaphragm behind a chamber or acoustic void in order to achieve high SPL resonance in the lower frequency range.

The Electro dynamic Speaker (EDS) is extremely common worldwide and through its technological evolution is available in a large variety of designs. By considering both diaphragm size and position a speaker system can be sensitized to a desired spectrum of frequencies. Since I initially needed to test the infrasound at home I obtained a small home theatre subwoofer and coupled it with my configuration. This provided enough SPL for me to work and compose with infrasound materials at home.

I speculated that an infrasonic musical performance, based purely on factors of reproduction (without acute monitoring), may falter as one might not necessarily be experiencing the fundamental frequency although a listener can have acknowledgement in perceiving the sine wave examples. Rather than directly responding to infrasound the cochlea is tracing the fundamental frequency using the multiple harmonic ratio occurring in that particular situation. I assert that the brain's sonic interpretation is accurate enough to locate the presence of a fundamental frequency as occurring outside the hearing range and that the human experience still responds in the higher range (>20 Hz) to detect the infrasound itself.

This rather obstructive possibility surfaced during experiments that produced Table 1. If it is true that we monitor infrasound by the respective upper partials in the harmonic series, then this truth may also cause plausible illusions of infrasound recognition.

4.3 Recording Equipment

Leventhal's' graph (Figure 6) shows that an infrasound source needs to be substantially louder than conventional bass frequencies, in order for the response to be physiologically detected. I realised that I would be under an inaccurate impression if a high pass filter (or any limitation affective from 20 Hz and downward) was installed on a piece of equipment used during an experiment. This could cut off a fundamental frequency at a linking point from the microphone, to the software, to the speaker coil and so these remaining upper partials might be all that is emitted. Therefore, the search for true infrasound began by investigating the spectral reach of different recording configurations optimized for digital audio production.

4.4 Conceptualizing the Infra-mic

In order to capture infrasound, audio needs to be converted to an electronic signal by means of a transducer. Infrasound occurs either seismically (below ground) or acoustically (above ground). The emphasis of this thesis is placed on recording and reproducing acoustic infrasound.

A large part of the research was inspired by infrasonic elephant field recordings. Work done by Roger and Katherine Payne (Payne, Langbauer, and Thomas 1986) provided an example for obtaining infrasound samples. I researched the microphone technology of their African elephant recordings obtained for analysis. From those sources I discovered that some microphone companies, such as Brüell & Kjær, provided products that can capture frequencies below 20 Hz in the field, but these are complex in design (Payne, Langbauer, and Thomas 1986) and expensive to obtain.

I considered building my own or modifying an existing microphone and investigated the possibility of transducing using a large speaker coil with electrical currents reversed. The reversal of the electric currents causes the diaphragm to act as a microphone rather than a speaker (Ballou 2012:20). This system is commonly used as a sub bass enhancing microphone, implemented by studio engineers for rock n roll kick drum recordings.

My process of understanding microphone designs began with learning the circuitry of basic homemade microphones. With time and experimentation my comprehension began to grow regarding the mechanisms of a conventional dynamic vocal microphone. Since I owned a number of these industry standard microphones I proceeded to take them apart and analyse their transducing elements. I consequently gained momentum when seeing that the Behringer super cardioid dynamic microphone contains an inflated plastic membrane fixed onto the transduction plate. I extrapolated and discussed the capabilities of using a relatively cavernous housing frame (having removed the standard mesh casing) and attaching it to this diaphragm for collecting infrasound.

Then, after viewing a video entitled Easy Infrasound acoustic source (k4nlz 2010), the host tightly fits a 50cc syringe barrel over a conventional dynamic microphone and reverses the (original) electrical current to create a small infrasound source. Noticing the diaphragm mechanism of my own dynamic microphone might fit into the same syringe size, it seemed logical to use the microphone with the syringe tip and cabling unchanged. I reassembled the dynamic microphone, obtained a syringe barrel and reattached the standard cabling positions. I concluded that leaving the transducer element of the microphone attached to its original steel cone frame would allow for conventional microphone boom-stand use. This was beneficial for positioning microphones during laboratory and field recordings.

The infra-mic was assembled by reconnecting the cabling of the transducing element, which was now situated at a distance behind the sound entry point of the syringe tip (Figure 10). The funnel attachment at the very end of the microphone was fitted with the intention to increase the peripheral scope of the microphone.

The data collected using the infra-mic manifested in the form of audio sample banks which were captured in a spreadsheet and later processed as spectrographic images.

Figure 10: The custom infra-mic.

4.5 Frequency Analysis

The intention was to capture audio from elephants as well as from thunderstorms and infuse these recordings into my own composition. In order to achieve this aim, I would need to generate and record infrasound at similar sound pressure levels to that of elephant communication and thunderstorm. These experiments would then serve as my field recording viability test to validate the presence of true infrasound in recorded audio samples.

The vast difference between various speaker designs in their abilities to replay my infrasound, produced different physiological effects. The challenge at this point was to provide evidence that these experiments involved true infrasound. The nature of the harmonic ratio means that some sinewaves (20-11 Hz) will have only the fundamental frequency in the desired range.

At the time of my first infrasonic recording it was unknown whether the data captured would contain true infrasound. I therefore needed empirical evidence to prove that my configuration was able to focus in the desired infrasonic range.

My experimentation began by investigating vibratory responses in paper sheets and inflated plastic bags placed directly in front of a speaker during low frequency generation. This is a method to visually promote the presence of infrasonic occurrence during experimentation (Smith 2010:1; Crawshaw 2014:5). Items were placed in front of the 15 inch Hartke bass amp during presumed infrasound exposure and the observations provided a reference for the infrasonic sensitivity of two different materials. I noticed that the movement of the plastic membrane was affected more than the paper sheet. This made me consider that rougher or less elastic materials could be too stubborn for optimized field recording sensitivity.

For the integrity of the research it was not substantial enough to observe my own human interpretations since human ears can be fooled by the apparent upper partials during the propagation of an infrasonic fundamental frequency. I investigated the possibilities of verifying that the fundamental frequencies were being generated below 20 Hz, since many of the software programs available to me contained a threshold of 20 – 20 000 Hz.

Specialized monitoring equipment used for outdoor sound events such as SMART contained this threshold as well, meaning the spectral capacity of the majority of manufactured equipment will only be effective above 20 Hz. The resulting challenge was to find a spectrum analyser[8] that could reveal an infrasonic fundamental frequency's' existence (<20 Hz). Upon investigating the monitoring methods of elephant communication I came across articles written by researchers in South Africa such as Sean Hensman. In some of those articles sound analysis software was used to illustrate infrasonic activity. The related software entities released a range of packages, one of which was a free version called Raven 1.0. This software was originally designed for eco-acoustic audio processing by the Cornell Lab of Ornithology. The most attractive characteristic of this software is that it possesses no cut off point in its lower register (no high pass filter). In some previous cases of infrasonic studies the harmonic series serves as proof of the infrasound phenomenon, however this program has the ability to plot within the infrasonic range making it my preferred software for visual representation.

I imported audio files into Raven and observed the resulting spectrograph. The software allows the user to tune in and adjust certain parameters linked to the imagery. The visuals

[8]A spectrum analyser measures the specific frequencies of audio activity in a particular sample (Kefauver 2001:40).

created helped illustrate various features relating to the recorded fundamental frequencies, upper partials and SPLs which formulated that sonic profile.

The first spectrographic images created were of the song “Something about You” (by Franx) exported using various software programs. The idea was to identify the software program that provided the most clarity in its lower frequency register.

The song contains baritone male voices, and multiple bass guitar parts. These instrumentations make the recording particularly dominant in the lower register of a conventional EQ spectrum. In theory, after the song is processed, the spectrographs should reveal a software program’s default capabilities in reproducing those frequencies after interpretive manipulation of the audio. The graphic representation indicates a sense of clarity or true sound related to the master file. The following image (Figure 11) displays the difference that each program has in relation to the original master file. This master file is a .wav audio file received from a professional mastering engineer. This file is imported into and exported out of each of the different digital audio programs, namely Audacity, Garage Band and Logic 9. Each of the resulting files is then processed through Raven to find the two spectrographs most similar.

The top two (master file and audacity export) have the most similarities whereas the bottom (Garage Band and Logic 9) are furthest from the original.

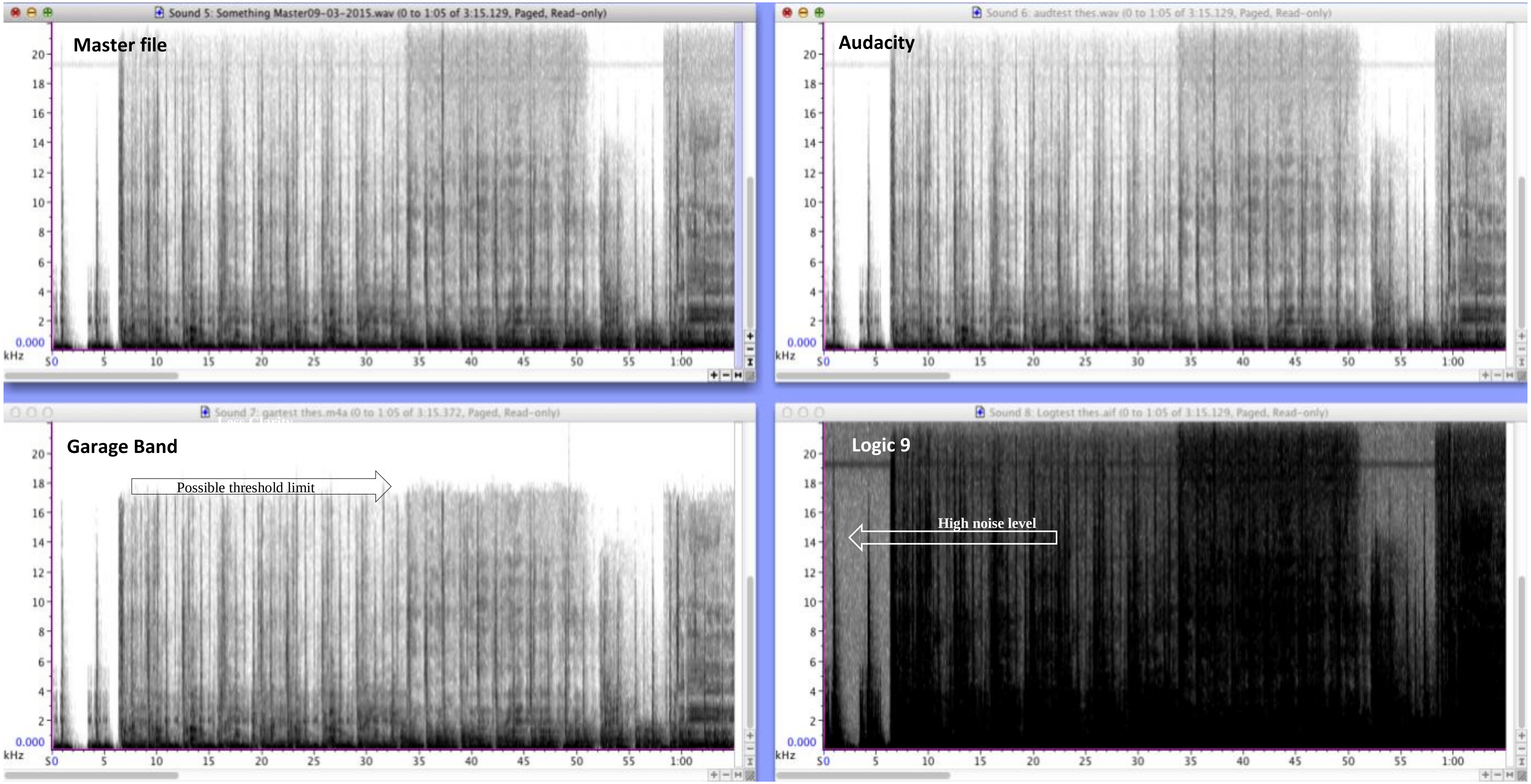


Figure 11: Visual outputs from various audio programs with default settings applied.

Upon analysing the outcome in Figure 11 I concluded that with default settings, Audacity reproduces the audio truest to the original file data. In order to effectively use Raven as a monitoring method, magnifications are needed to observe the activity in better view of the desired frequencies. When adjusting the parameters of a spectrograph, Raven allows the user to specify the frequency range. Each file is different and the manipulation of these parameters can vary for better illustration of either the environmental sound/background noise or a particular sound from a certain sound source. Most of the spectrographs taken during my research have the following settings, to visually enhance and identify infrasonic audio occurrences:1

- Spectrograph colour setting: 3
- Brightness: 77
- Contrast: 86
- Sharpness: 29564
- Horizontal zoom: zoom in (+), until view enhances infrasonic frequency range

Using an audio file containing a sine wave of 15 Hz I performed a test to confirm my results. The experiment was conducted again, but this time to observe the clarity of infrasound from an exported file (Figure 12).

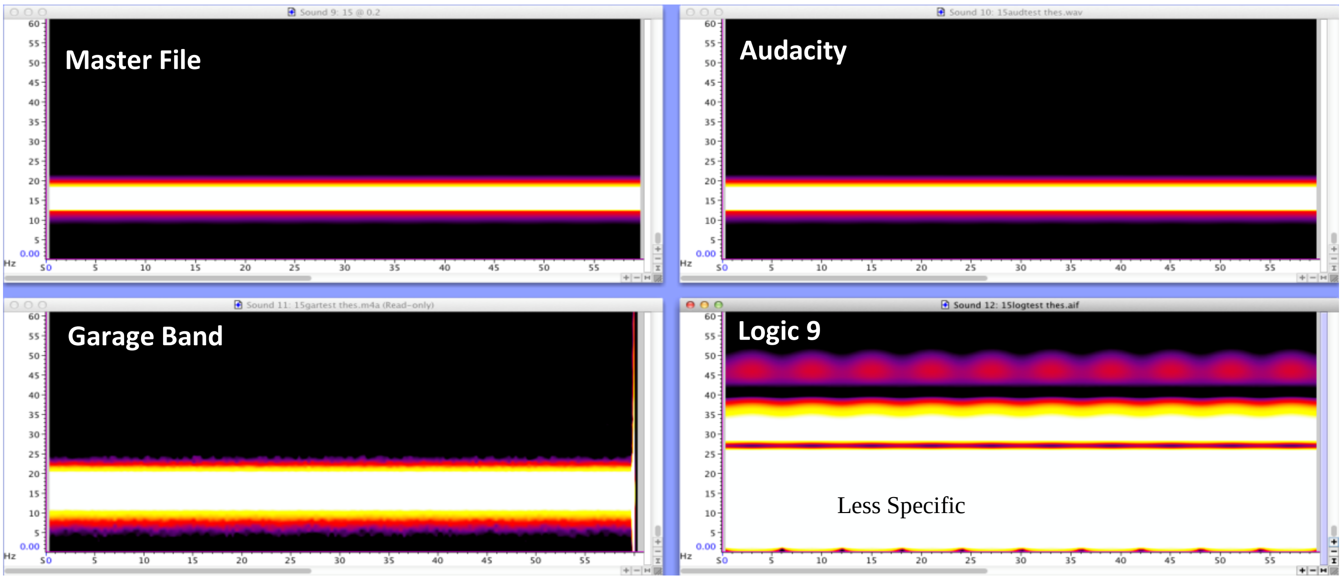


Figure 12: 15 Hz exported by digital audio programs with default settings.

Based upon these images I decided to proceed with Audacity as it provides the most consistency in reproducing the original recorded sound. This method effectively marks the beginning of true infrasound investigation and proves that experimentation can be monitored in the infrasonic range.

4.6 Experiments to Produce Infrasound

An appeal was submitted to a number of outdoor sound companies that could potentially host a temporary laboratory space and provide the necessary equipment to investigate infrasound production. The Sound Corporation quickly responded, granting me the opportunity to meet with them and discuss the purposes of my research. After meeting with the office staff on 18 February 2015, we came to the agreement that I could use their subwoofer systems and monitoring equipment for testing. While discussing the company's infrasonic capabilities the staff members and I proceeded to test various theories regarding the phenomenon.

Location 2: The Sound Corporation in Johannesburg.

The Sound Corporation have a warehouse in which is stored large outdoor PA systems. The Corporation's collaboration in this research allowed me access to a multitude of amplifiers and speaker systems designated for lower frequency response. The EAW subwoofer series in the warehouse includes models SB 1000z, SB 850 and SB 730. All of the speaker systems were amplified using the Lab Gruppen FP+ series. In addition, microphones responding within the infrasonic range such as the Earthworx M30 and Klark Teknik 6051 were also made available. They provided extra hardware and cabling as well as monitoring equipment which is predominantly used for outdoor events.

The corporation's variety of outdoor subwoofers were presented for testing in their warehouse which became the primary laboratory space. The performance of the custom infra-mic was then tested and compared with the microphone called the Earthworx M30 (a full spectrum microphone ranging down to 5 Hz provided by Sound Corporation).

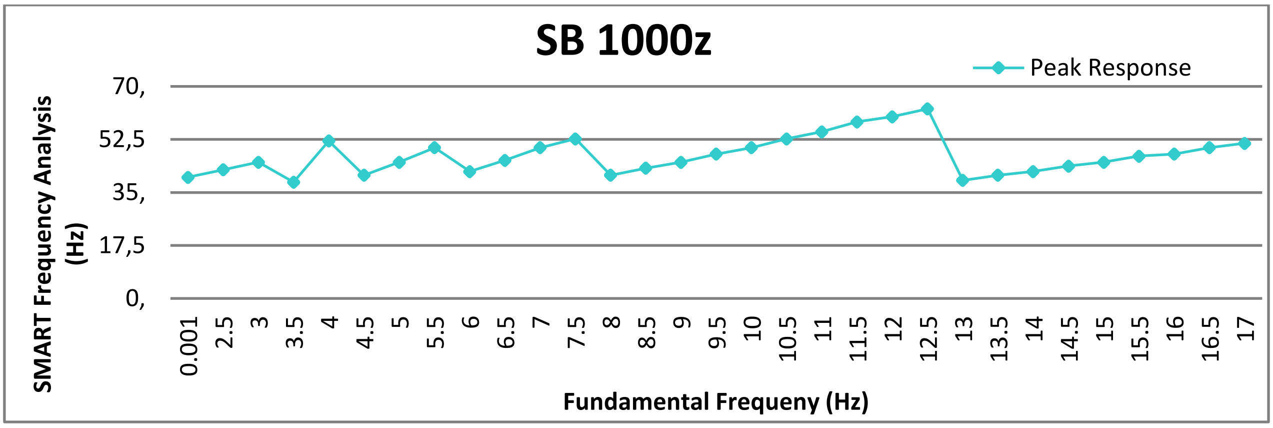
4.6.1 Three Important Sessions

In preparation for field recordings, three sessions were held at the warehouse in order to test the recording setup that would obtain infrasound. The first of the sessions was conducted before discovering Raven and spectrographic analysis, but infrasound production was confirmed with spectrographic analyses in the subsequent two sessions.

I. Session 1

Experimentation began immediately after the initial meeting with the Sound Corporation staff. The first experiment involved one SB 1000z subwoofer and the second involved two coupled together. In this collaboration we managed to collect the first body of data using the Earthworx microphone connected to the SMART frequency spectrum analyser. Peak frequency measurements within the threshold of the analysing software (SMART) were observed and noted during the initial reproduction of the infrasound test track.

The graphs below represent the peak frequency readings related to the intended fundamental frequencies. These values were collected during full spectrum measurements using SMART analyses (digital spectrum analyser) (Figure 13).



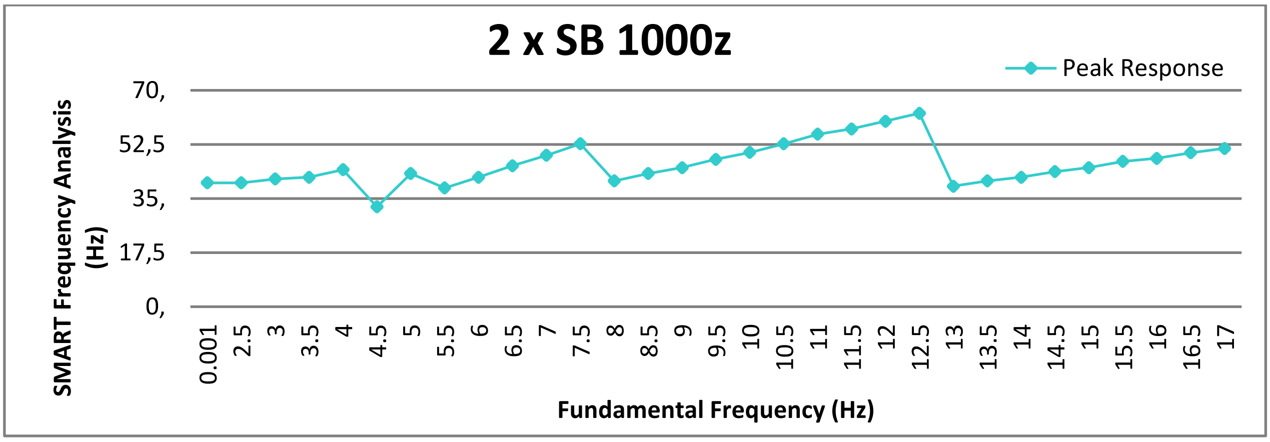


Figure 13: SMART frequency analyses response to the test track. X-axis represents the fundamental frequency and Y- axis represents the upper partial registered by SMART.

The Yamaha mixing desks were vital in the preservation of equipment during testing. If the signal was too strong then a red light would indicate clipping and the master faders were held back. It was also important to note that during a lot of the testing the available EQ settings were set to zero in the high and mid register.

During playback of the audio files, the test track had to be faded in louder and out softer from absolute zero. This was because a speaker diaphragm is unlikely to sustain abrupt frequency changes at such high levels of infrasound. With each playback session the system needed to be hand-regulated using the master faders in anticipation of possible audio irregularities or spikes.

The frequencies were played in ascending order and all people exposed to this session (myself included) did not enjoy the stimulation of the audio. The sounds were severely distorted and seemed to put an unnecessary strain on the movement capabilities of the speaker diaphragms. I noted an error in my process; by using Logic Pro 9 and the Focusrite Soundcard to replay the audio files the limits imposed on playback would have misrepresented the audio. In addition, some subwoofers were missing a coil and produced heavy rattling when active. These obstructions made me understand that there was more research to be done regarding infrasonic frequency generation and analysis.

II. Session 2

In the second session, recordings were made by placing microphones at various distances facing the speaker coil. The hypothesis was to see if perhaps the exact location of a frequency's wavelength provided the ideal microphone positioning for obtaining specific infrasonic frequencies. This was tested up to 25 metres which corresponds to the wavelength of 14 Hz (Holman 2012:5) (Cowan 1993:7). I concluded that though one exact wavelength is a reasonable position for some sustained frequencies, the recording quality was not diminished if the infra-mic was placed elsewhere. In addition, it would be considerably more difficult to adjust the microphone position according to an organic infrasound event. Therefore, it is unnecessary to consider the exact wavelength of a fundamental frequency for field recording purposes.

The data from this experiment was processed to make spectrographs of the various recorded frequencies. This was done to find out if the aim of specific fundamental frequency generation had been achieved. A spectrograph would reveal the activity and characteristics of the recorded material in the infrasound range.

I created an infrasound spread sheet document that captured various data values, providing me with the ability to view my progress. During an experiment where a sine wave was being played, I noted down various aspects resulting from the subwoofer designs and categorized these aspects in the following order:

- Gain Stability,
- Clarity,
- Pitch,
- Vibrotactile experience,

- Tone,
- SPL (this SPL is noted at the point where it becomes desirably audible).

This was a particularly fruitful session in determining factory specifications inherent in each of the amplifiers and the subwoofer systems.

III. Session 3

This session was aimed at finding the ideal method to replay infrasound and designate the subwoofer type which would be used for the recital. Among the low frequency speaker selection were three likely candidates which I concluded were most capable of infrasonic generation (Figure 14):

1. The EAW SB 730,
2. The EAW SB 850,
3. The EAW SB 1000z

An experiment was designed to distinguish which of these subwoofers would most clearly reproduce a range of infrasonic fundamental frequencies.

The different subwoofer models were connected to their amplifiers to generate synthesized infrasound sine waves, whilst I noted down the resulting sonic properties. The signal was automatically regulated by the test track's amplitudes as well as manually with mixing desk faders, using the clipping indicator to indicate and avoid any distortion.

Figure 14: SB 850 sub front loaded dual 18”.

The order in which the test track frequencies were played was from the highest to lowest since the previous session proved more difficult to monitor going the opposite way. I speculate that this is because the ear can be drawn into the infrasound range from above 20 Hz more easily than be initially stimulated by extreme infrasonic frequencies such as those below 10 Hz. In this order, recording of the various types of speaker systems was captured and, upon returning to location 1, the data was compiled with all the desired information. The following is an example of the data captured for the subwoofer type SB850 (Table 7).

Table 7: Section SB850 of Infraspread, where 0 is low and 10 is high.

	G Stability	Clarity	Pitch	Physical experience	Tone	Recording	Spectrogram	SPL
22 Hz	10	9	9	5	6	Y	Y	91
21 Hz	8	7	8	4	4	Y	Y	92
20 Hz	9	9	8	4	5	Y	Y	92
19 Hz	9	9	7	6	7	Y	Y	93
18 Hz	9	9	8	7	9	Y	Y	96
17 Hz	9	9	8	6	9	Y	Y	94
16 Hz	6	5	5	6	7	Y	Y	90
15 Hz	8	7	6	7	8	Y	Y	90
14 Hz	8	7	5	8	8	Y	Y	89
13 Hz	10	9	7	8	9	Y	Y	94
12 Hz	7	7	5	7	4	Y	Y	82
11 Hz	8	8	7	9	10	Y	Y	90
10 Hz	9	7	8	7	8	Y	Y	88
9 Hz	7	6	8	6	8	Y	Y	82
8 Hz	8	7	6	7	6	Y	Y	88
7 Hz	4	4	2	7	3	Y	Y	81
6 Hz	6	8	6	7	7	Y	Y	81
5 Hz	3	2	0	5	5	Y	Y	71
4 Hz	2	4	4	3	6	Y	Y	70
3 Hz	0	1	1	1	3	Y	Y	63
2.5Hz	2	2	1	3	5	Y	Y	69

Another required procedure was to compare the difference in recording quality between the two microphone types (infra-mic and Earthworx). The microphones where placed at the same distance from the subwoofers and recorded various samples.

The recordings were also processed using Raven to provide spectrographic representations for the subwoofer sound profiles, which also facilitated the comparison in frequency response between the two different microphones (Figure 15). In Figure 15 the top represents the custom infra-mic and the bottom represents the Earthworx M30. The three rows display the recorded spectrographs from the different types of subwoofer. The top displays the speaker model SB 750, the middle the SB 850 and the bottom the SB1000z.

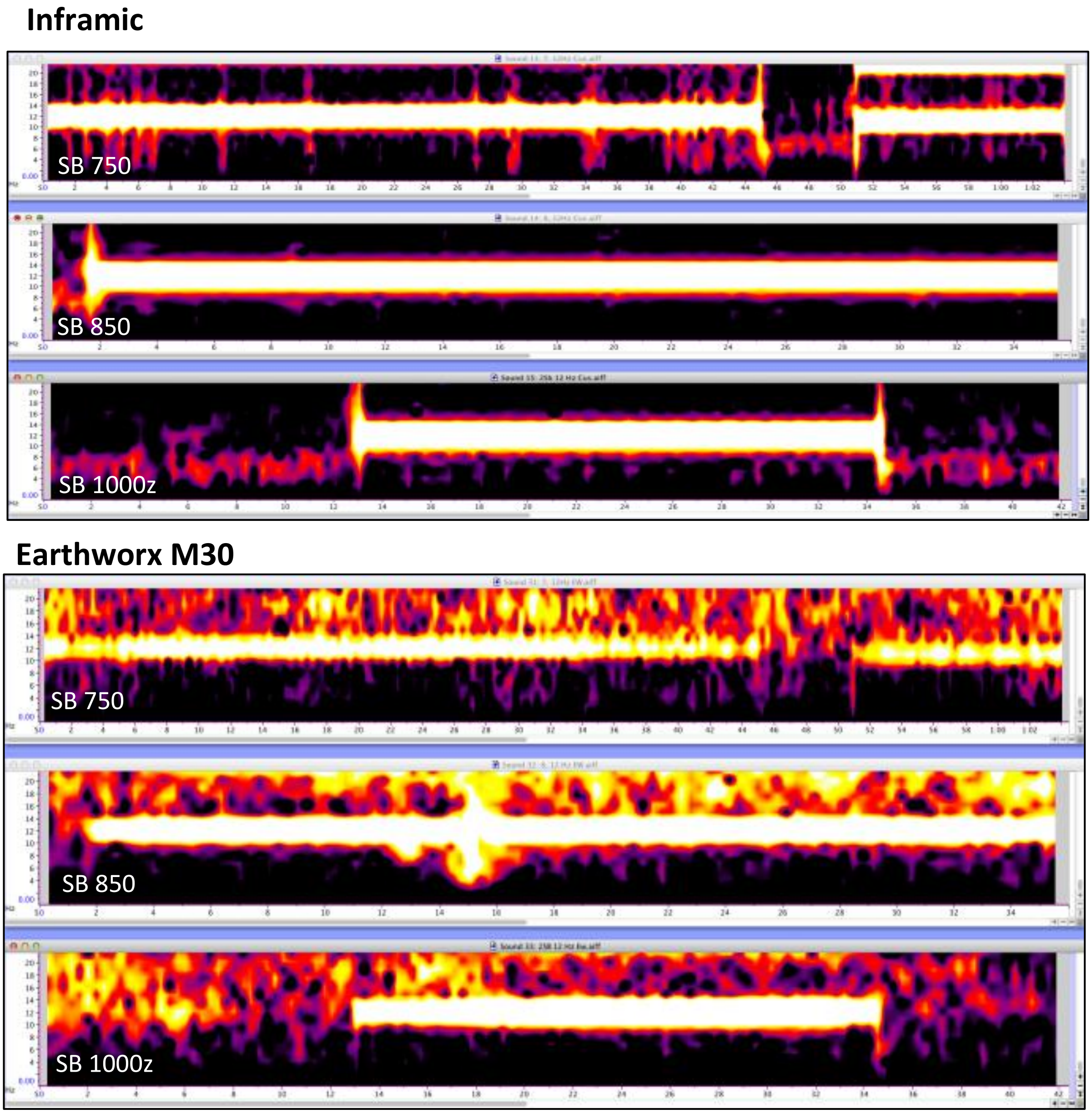


Figure 15: An example of the fundamental frequency 12 Hz.

Analysis of these spectrographs revealed that both the Earthworx and custom infra-mic were capable of obtaining infrasonic frequencies, with the infra-mic having a more isolated infrasonic response and less high frequency noise. The subwoofer profiles were varied and responded differently to different frequency ranges.

I concluded that the microphones would work best coupled together and subsequently split into separate files for spectrographic processing. By recording with both microphones their combined capabilities would be advantageous. Together the upper partials would be obtained by the Earthworx microphone, and the inframic would focus exclusively on the lower frequencies.

The spectrographic imagery, of reproduced and recorded sine waves, displayed a harmonic profile relating to the infrasonic fundamental frequency. This was to be expected, however it was the first time I had seen this phenomenon represented visually. In order to closely look at the infrasonic fundamental a spectrograph is magnified beyond the display of its harmonic series. However, when adapting the display parameters accordingly, one can see the fundamental frequency as well as the associated harmonic series. As seen in the following spectrograph (Figure 16), a harmonic series resonates in ratio to the fundamental.

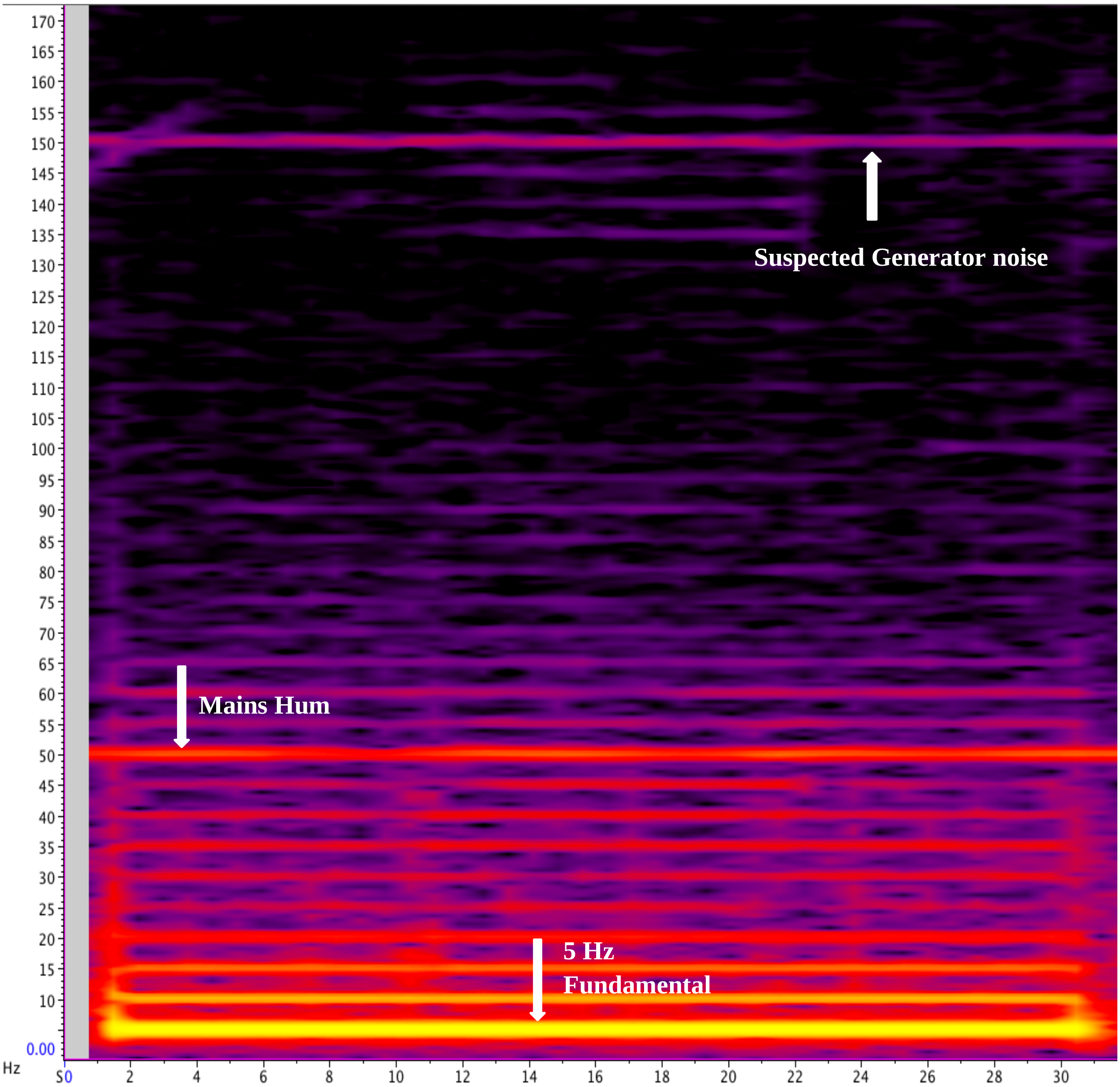


Figure 16: 5 Hz fundamental frequency with its harmonic series.

This same image (Figure 16) displays the constant occurrence of other prominent frequencies such as 50 Hz. This particular phenomenon has been identified as the mains hum: a sound emission caused by the flow in electrical current from an AC power source.

The strong presence of 150 Hz suggests electrical interference from a large industrial generator. This is confirmed because during the time of this recording the warehouse had no municipal electricity and was using such a generator.

As a result of the events captured in these images, I knew to expect some interference during the field recordings. This meant that selective and reductive equalization would be required to enhance the audibility of this data.

4.7 Field Recordings

Having been referred to Adventures with Elephants (AWE) I began to correspond with ecologist Sean Hensman and researchers under the collective of the Rory Hensman Conservation and Research Unit (RHCRU). Their continuing research is an inspiration to me and provides the prospect of merging resources for future interest aimed toward the eradication of human-elephant conflict. It is important for the RHCRU to use infrasonic monitoring techniques for the purpose of obtaining valuable information regarding the grazing and social behaviours of elephant herds.

Corresponding via email we discussed the process of making recordings with the Units's elephants. I enquired about particular details regarding the Unit's property, the elephants, the local weather and routines the handlers and herd live by. Among the enquiries was the request to split up and regroup the elephants as this was said to be a particularly vocal activity. Katy Payne makes multiple references to the joy elephants display when members regroup. My own research and data capture experience yielded the same outcome.

The feedback from the members of the research team was unanimously in favour of the experimentation to commence and in the correspondence I gathered information regarding elephant society and behaviour. Sean explained to me that the eldest (Chova) was nearing the end of his adolescent years at 25, but was suspected to grow larger by age 30. An adult may reach an age well over 60 and theory suggests that older elephants produce more infrasound as a result of larger adult vocal chords. This larger membrane is mechanically better equipped to produce lower frequencies.

<u>Location 3: Adventures with Elephants in Bela-Bela.</u>

A combination of the equipment used at Locations 1 and 2 as well as additional items were utilised to create four different field recording stations. Each station comprised a microphone mounted on conventional microphone boom stands, a sound card and a computer linked with XLR cabling. All of the computers used Audacity to capture and store the audio.

I arranged a recording session with the RHCRU at their centre on the morning of April the 13th 2015. In order to facilitate the process, I invited two friends to assist with setting up and running the equipment. One of them, a photographer and the other a musician.

Considering the dimensions of the recording field and the possible movements of the herd we brought equipment provision to cover distances of up to 125 m. The Sound Corporation provided the required equipment including the infrasonic microphone called the KlarkTeknik 6051 (better suited for field recording than the Earthworx), as well as conventional dynamic microphones. These microphones were used to record continuously at a sampling rate of 48 KHz.

Upon arrival it was a relief to see a manageable target area where the elephants were accustomed to interact with people and man-made objects. This target area is oval shaped, roughly 33 m in diameter and opposite their water hole from the resting area (Figure 17). The rectangular office and reception building has an equally long veranda with tables facing the target area along its length. We spread the four stations evenly along the target area on the veranda, each computer running its own microphones and sound card.

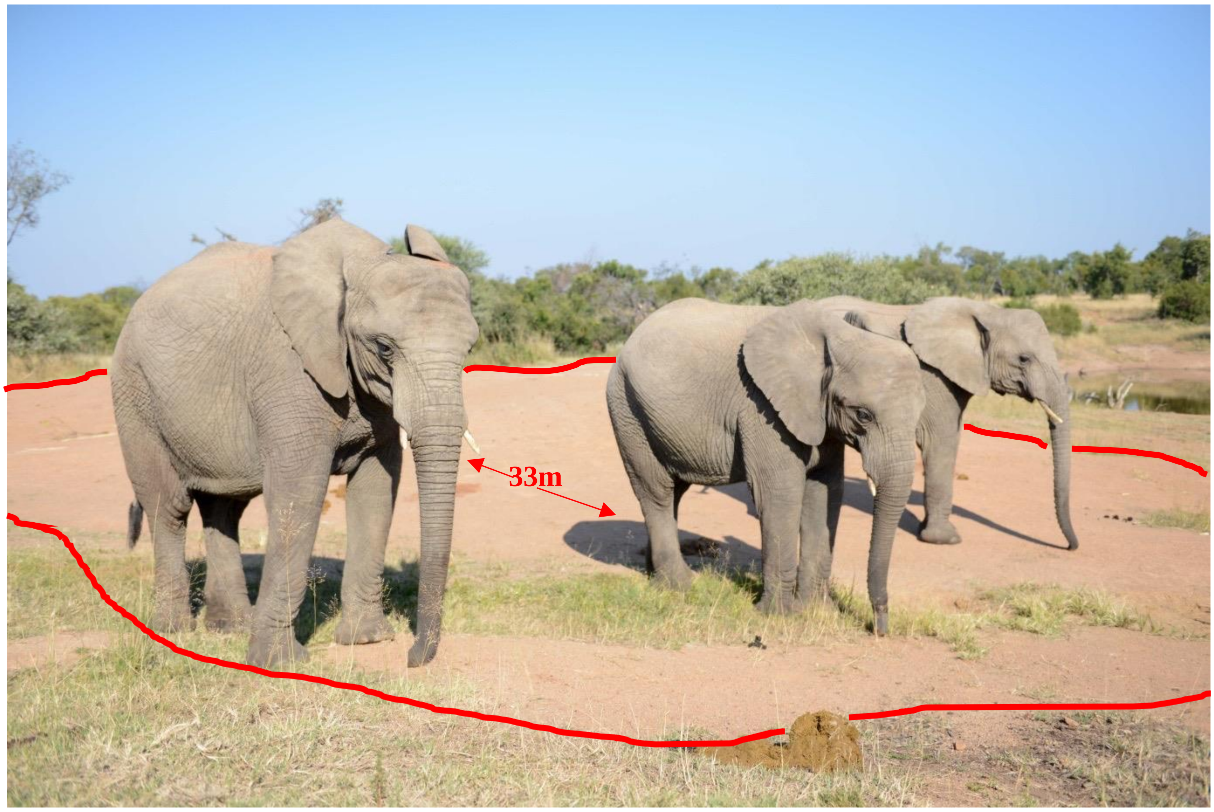


Figure 17: The oval shaped target area with three elephants.

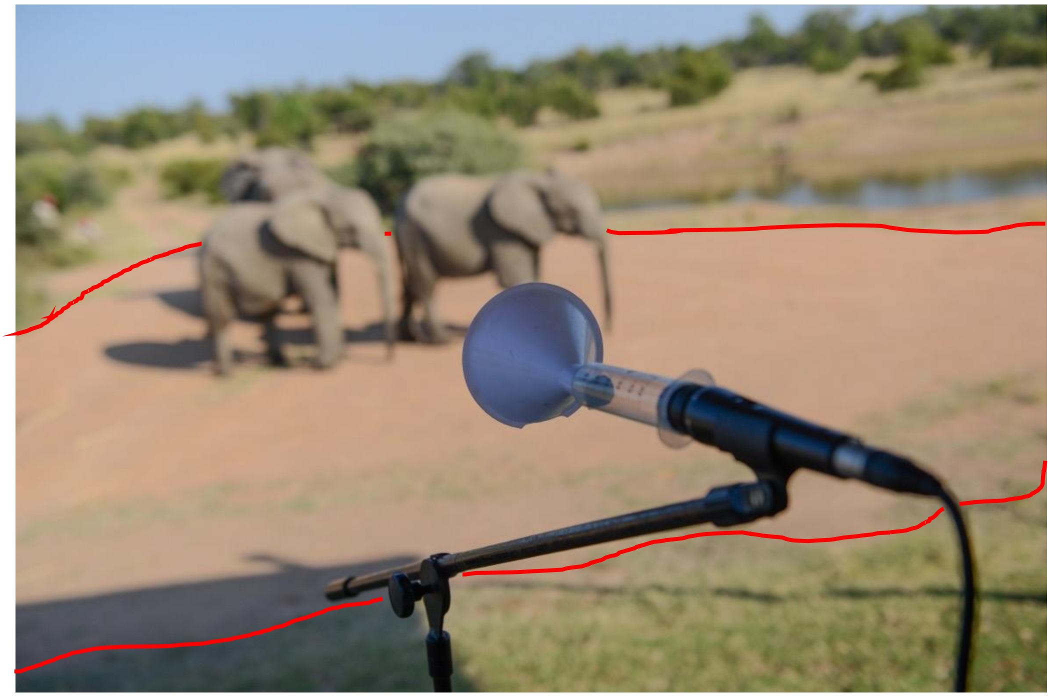


Figure 18: An infra-mic facing the target area.

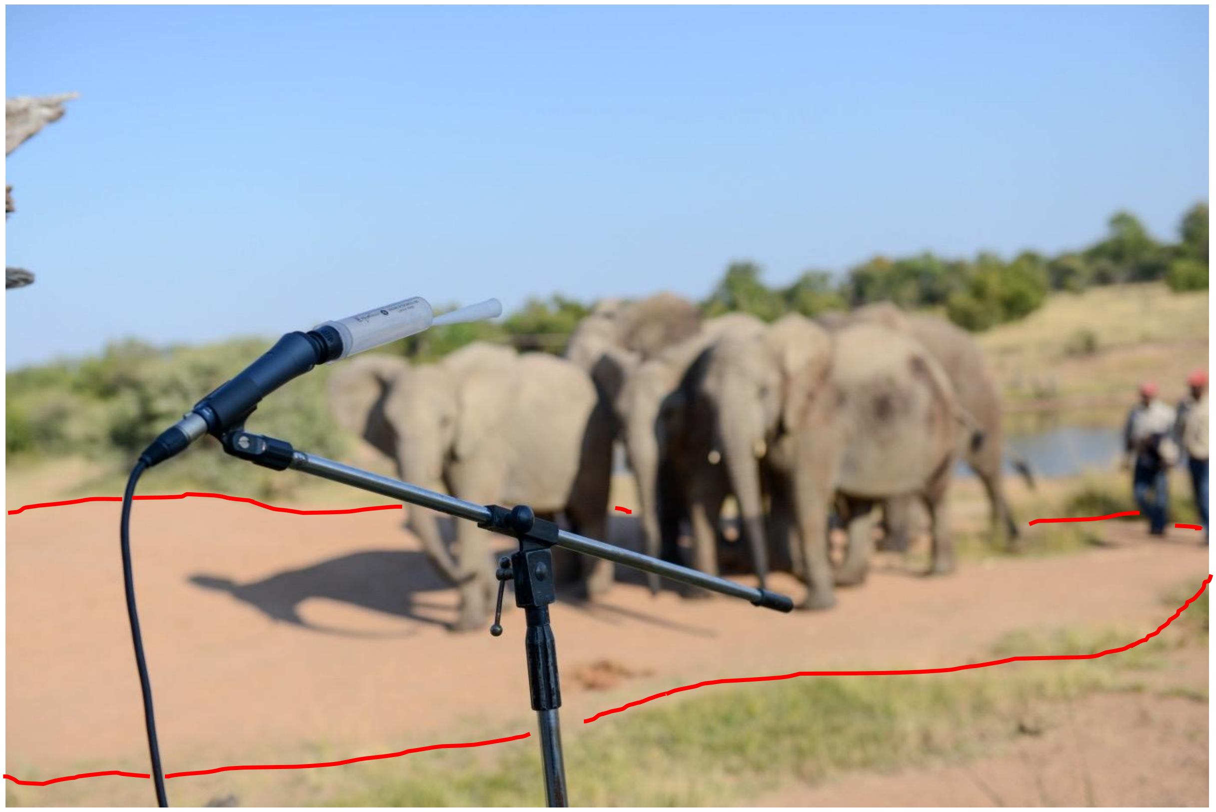


Figure 19: An infra-mic facing the target area with all five elephants.

Figure 20: C1 the main research computer and me.

At the time when the herd approached, as the elephants and their handlers moved toward the water hole, the stations were recording with both infrasonic and conventional microphones (Figure 17 - Figure 20). Though a few rumbles were noticed by others the infrasound was arguably unusual for me and therefore difficult to perceive. Sean Hensman and Micheal Hensman, both founding members of AWE (Adventures with Elephants) and RHCRU (Rory Hensman Conservation and Research Unit), asked whether the positioning of their herd was in accordance with the recording setup requirement. I replied in request for them to move as close as possible and they gently lured the five elephants closer to the microphones feeding them snack pellets to keep from wandering. The elephants investigated us and the equipment by smelling and touching the boom stands, cables and microphones. One of the female elephants called Messina proceeded to dismount and taste a microphone syringe barrel, only to spit it out again.

The herd was then split up and soon after rumbling followed. This result was consistent with the theories of their distant communication abilities. Content to keep grazing for a while, the elephants maintained a peaceful body language and some rumbled loud enough for me to clearly hear them. The staff members (Figure 21) then contacted one another via radio giving the signal to regroup the distant elephants with the rest of the herd. The stationary elephants began picking up their heads to look around, and we became aware of the more frequent rumbling under this circumstance. When an elephant is midway through a rumble and opens its mouth the rumble bursts into a roar which, in this case, was an exaltation of their exuberance. Intense nasal blows contribute to the biophony's sonic variety along with trumpeting and other vocal inflections such as quick roars called "barks".

We managed to arrange two sessions of regrouping within the target area on day one but due to the elephants' vast grazing habits more than one hour in the same place can be stressful for the herd. Because the configuration assembly took longer than expected we did not capture many recorded samples outside the target area identifiable as elephant infrasound. Thus we adjourned the recording to interpret the data with Raven, in search of viable examples of infrasound.

Figure 21: The AWE team.

I was surprised that the elephants were so interactive and spatially aware of foreign equipment in their surroundings. There were a few vocalisations captured by request (from a handler) for an elephant to speak. They would reward an elephant after obeying the command: "Talk".

In the field I scanned through the 63.3-minute recording with the iMac station after importing it into Raven. This imagery displayed a visible difference from the spectrographs analysed in the controlled environment of the warehouse (see section 4.6) largely due to the amount of infrasonic noise interference. This meant that the signal to noise ratio was lower and therefore less indicative of certain activity. In this uncontrolled environment I was monitoring audio with headphones (having no EQ settings), which made it hard to detect the infrasonic rumbles and anomalies. I realised that my re-equalization would have to be very specific in post recording production. After sorting through the raw recordings, I came across an elephant regrouping session where I found and amplified the image Figure 22 showing an elephant call with a fundamental frequency just below 20 Hz.

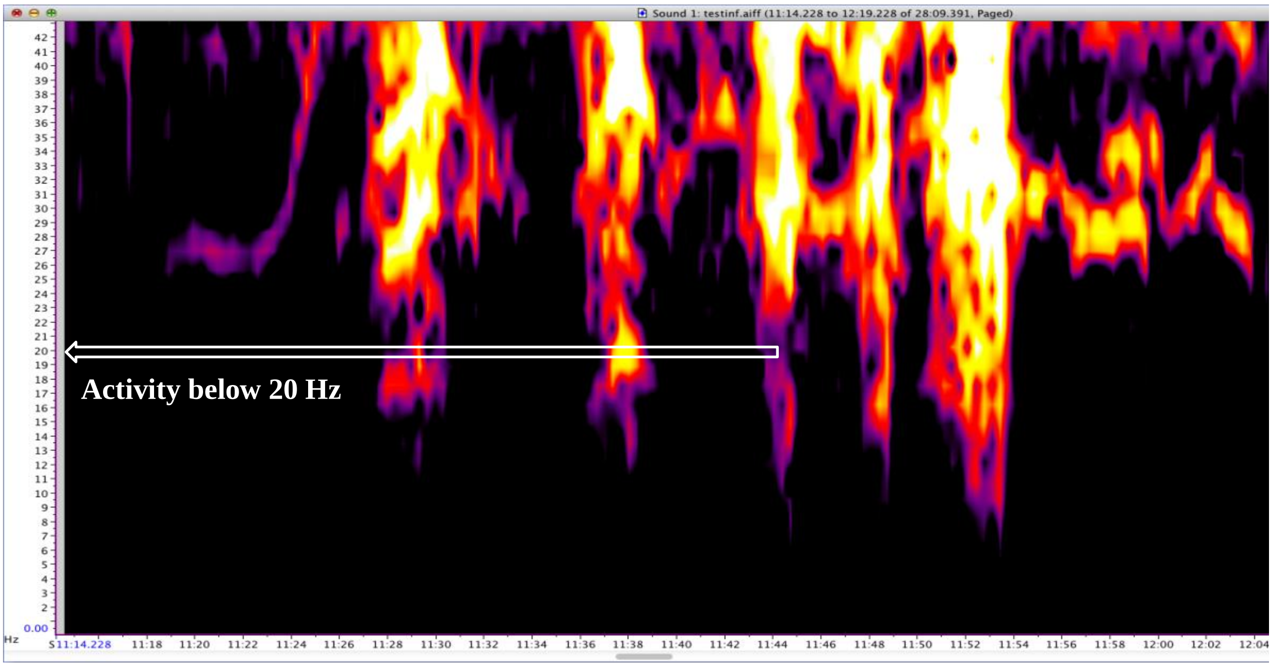


Figure 22: First sign of infrasonic field recording.

On day two the setup was adjusted for better positioning of the microphones. Initially they were placed across the width of the veranda, thereafter we dispersed them along the edge closest to the interaction area.

A portion of the noise was suspected to have been caused by the specific size of the syringe barrel cavity. This cavity would resonate in response to the passing wind and capture fluctuating low frequencies. As an improvised wind screen I crafted a dishwashing sponge into a triangular prism bulging slightly outward on the side facing the sound source. The sharp opposite end then fitted into the neck of the kitchen funnel connected at the syringe barrel tip.

In order to maximize vocalisation in the target area the herd members were brought there in two separate groups. The first group was heard rumbling at a distance of over 100 m by Michael Hensman and he commented that they were under the right social conditions for a substantial amount of vocalisation.

The increased amount of wind on day two was concerning but fortunately the elephants were louder than the wind. Minutes into the recording of the first group we captured rumbles among the females. Staff members prepared the target area with treats before the regrouping began, at which time the stationary elephants showed restlessness, moving about and flapping of the ears. Sharp, poignant blows and shuffling of their large feet appeared to me as a sense of incontrollable excitement. These ominous rumbles of reunion began to build in their anxiety to regroup. From the stationary group the elephant called Chova, whilst scuffing and spinning, picked up his head and projected a roar directly across the microphone line.

The final session on day two captured 58 minutes of data which needed processing to reveal whether true infrasound had been obtained. The samples were recorded as stereo recordings which were then split and exported out as one mono audio file per microphone. This allowed me to see and hear each individual microphone spectrum and mark reference points for certain sound events throughout the entire duration of the recordings.

I used a notebook to create a timeline of the raw data from each station, wrote down the times at which certain sonic artefacts occurred and allocated a short description such as “Epic Session”, “Voice Box Feel” or “Rumble in the Bundle”. A 16-page catalogue with these allocations became the reference list used in order to extract and store samples. In some cases, recorded excerpts were dismissed as sonic illusions.

4.7.1 Thunderstorm Field Recording

Since the above methodology was successfully implemented for the recording of biological infrasound, it logically follows that the same infrastructure could obtain thunderstorm infrasound from Johannesburg’s seasonal heavy weather. The intention of recording the thunderstorms was to combine an additional organic percussive dimension to the composition.

The thunderstorm audio was recorded throughout the storms that followed the 2015 drought, resulting in a number of recorded thunder samples. Similar to the elephant field recording procedure, the recorded thunderstorm samples were analysed for infrasonic activity to both confirm the presence of, and determine the range of, useful infrasound material. The range of infrasound obtained from the thunderstorm recordings is wide in frequency and extends across and beyond the infrasound spectrum (Figure 23).

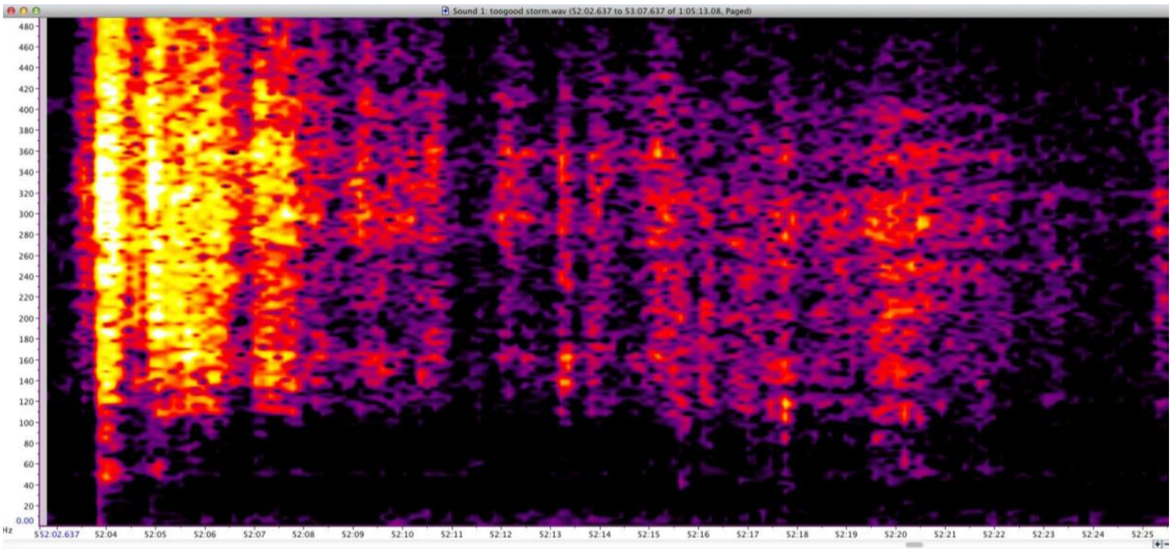


Figure 23: Spectrograph of a thunder sample.

4.8 Samples and Noise Contamination

The effects of noise contamination can be detrimental to successful field recordings. To prevent speech contamination the equipment operated for recording was optimized to the infrasonic range, however field recordings require certain devices to ensure that other unwanted noises do not irreversibly contaminate samples.

I took the following full spectrum readings (Table 8) on the dB meter to better describe the general soundscape noise levels.

Table 8: Soundscape features.

Feature	dB level
Without elephants	49
Elephants full group arrival	72
During grazing in target area	63 – 74
Separate group arrival	75
Loud rumbles	73
Roars	90

It is important to distinguish between the signal of the sound source and the background noise. Each microphone differs in design and therefore has a different spectral profile. The result of this is that the type of background noise differs for each microphone as they are overly sensitive to frequencies that resonate with their design framework. This is why the custom infra-mic has perhaps less contamination in the infrasound range, but also contains unwanted low frequency noise presence including footsteps and large motors.

Overall, the controlled environment of the warehouse allowed me to capture clearer signals than in the field. Noise contamination took different forms in the field (top) compared to the laboratory (bottom) (Figure 24). The following image distinguishes these different kinds of sound events in a captured sample. In addition, it is evident from the spectrograph that naturally created infrasound displays a more organic profile (animalistic/biological or wild/alive) than its synthesized counterpart.

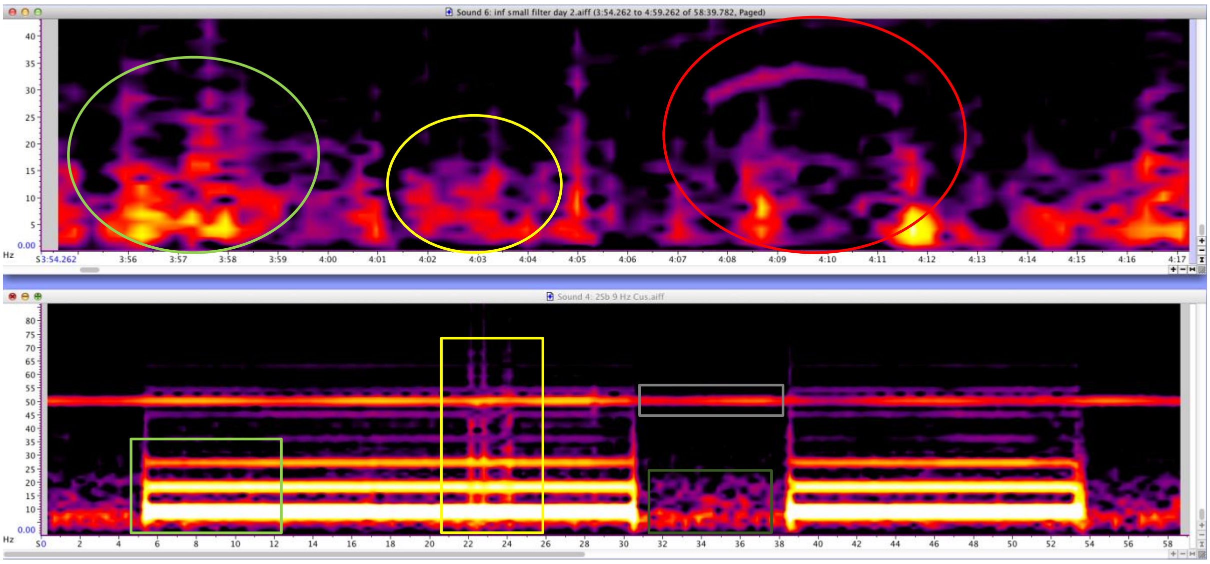


Figure 24: Typical noise profiles of locations two and three.

1. Footsteps
2. Wind noise
3. Elephant signal
4. Generated signal
5. Truck loading
6. Mains hum
7. Electrical interference/general noise

8. Off-road motor vehicle

Spectrographic images of field recordings illustrate the profile of natural infrasound and the variability of noise contamination. Figure 25 illustrates the difference in profile of a large motor vehicle and an elephant vocalisation.

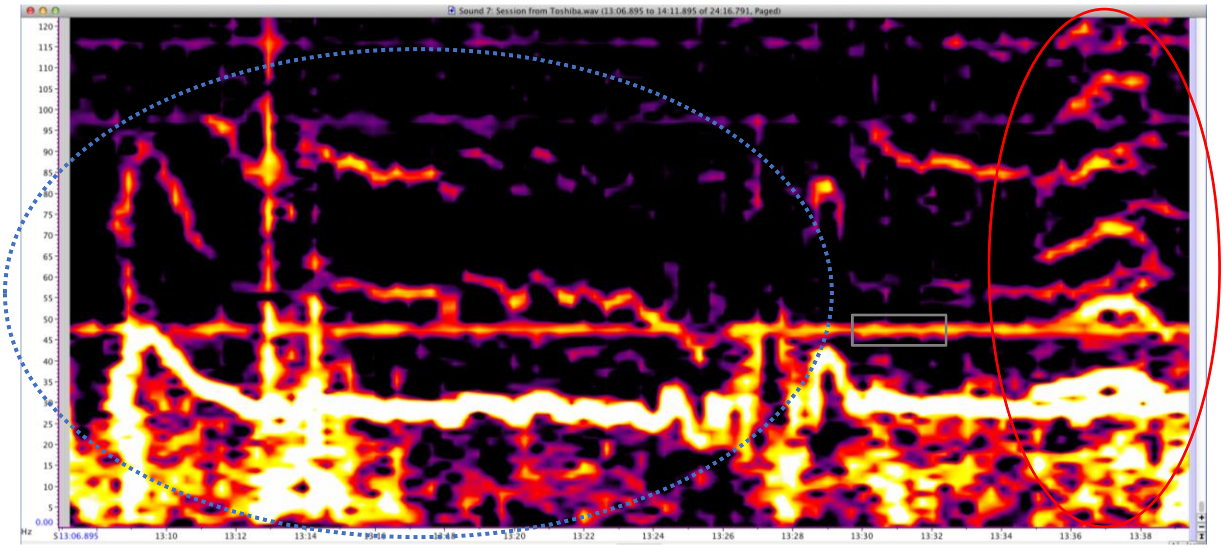


Figure 25: AWE Vehicle departure.

A spread sheet document was created to catalogue the data captured at AWE. This document was categorized in such a way that it helped create an identity for each sample. The unique ID was created with the following code structure:

- C1= Computer 1
- D1=Day 1
- S1=Session 1
- NM=Normal Mic
- IM=Infrasound Mic
- T=Microphones Together
- 1=Numeric value

The sample bank starts with C1_D1_S1_T.1, and ends with C4_D2_IM.10 (Day 2 contained 1 continuous session). Along with their unique IDs the samples also contain other entries that were labeled the following: Time-stamp, Alteration (such as equalization and compression), Spectrograph plotted (y/n), In Use (for composition), Comments and

SPL with SB1000z's. The last entry was added when the samples were taken to the Sound Corporation Warehouse and tested on my preferred system.

A spectrograph was plotted and analysed in order to confirm the presence of infrasound in the specific sample. Unfortunately, the data contains background noise from 6 Hz downward and consequently the fundamental frequencies could not always be clearly identified. The RHCRU researchers have confirmed that the elephants at AWE can produce vocalisations with infrasonic fundamental frequencies(Stoeger et al. 2012). Thus, the lowest frequency (above 6 Hz) observed in the spectrograph is treated as the fundamental (Figure 26). In the infrasound range, signals can overlap by one or two frequencies due to the air pressure being more unstable for larger wavelengths. The lowest frequencies captured in the sample contain fundamentals between 11 and 14 Hz. The arrows drawn on the following spectrographs (Figure 26 to Figure 30) indicate the highest and lowest points of the frequency during a particular vocalisation.

= Highest

= Lowest

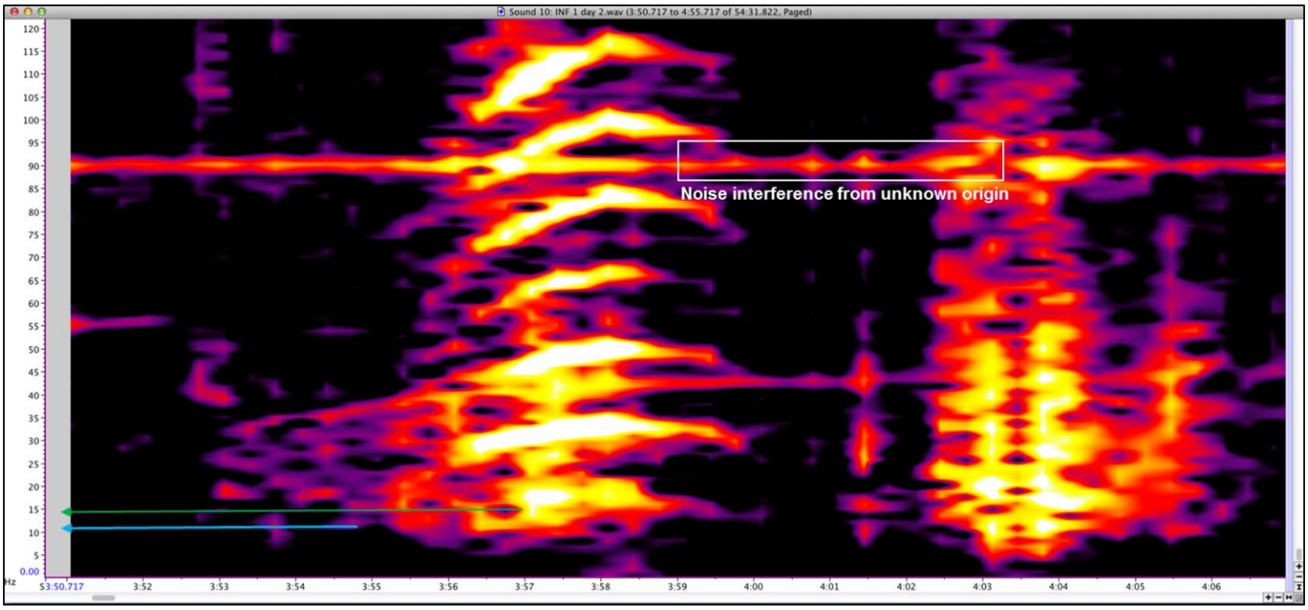


Figure 26: Approximately 18 Hz captured. Electrical interference occurs at 90 Hz from an unknown origin.

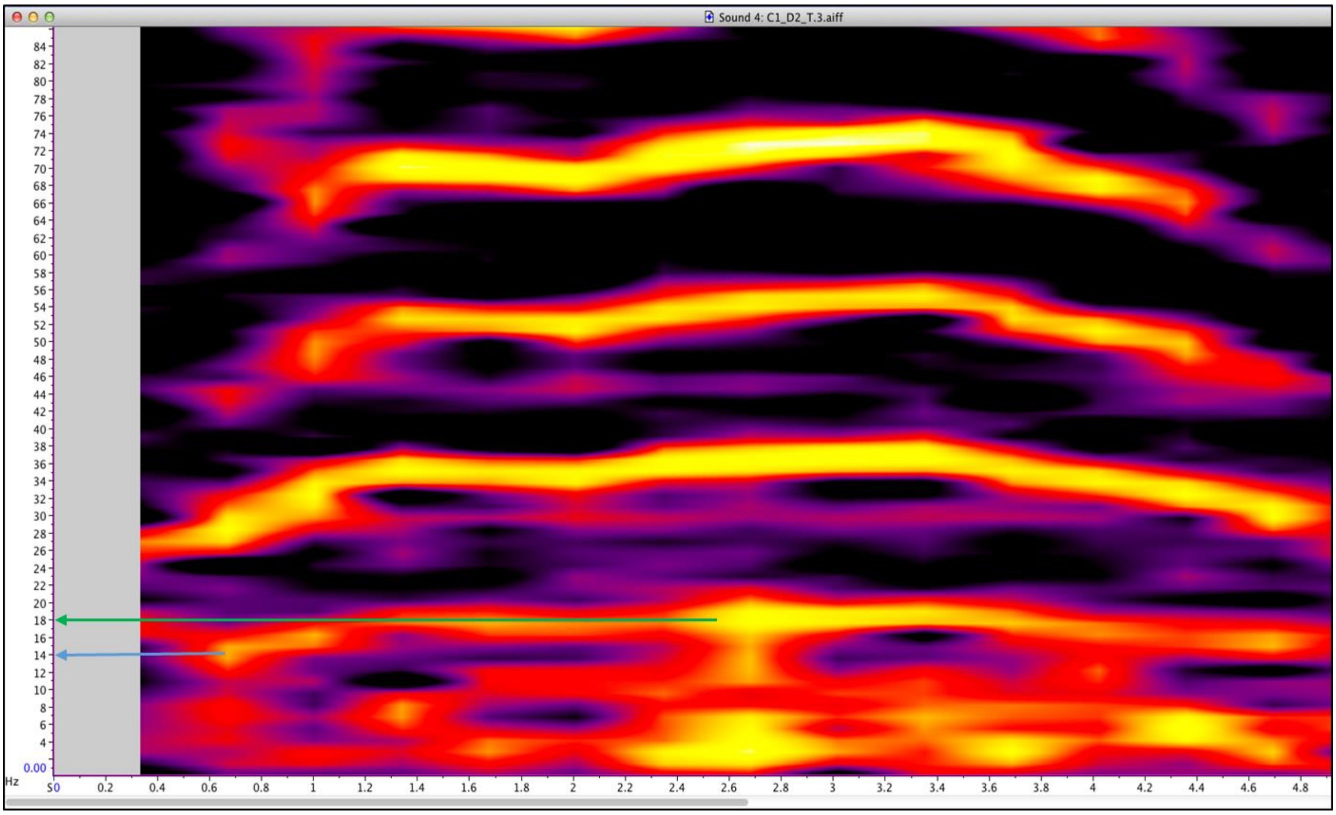


Figure 27: Infrasonic rumble 14-18 Hz.

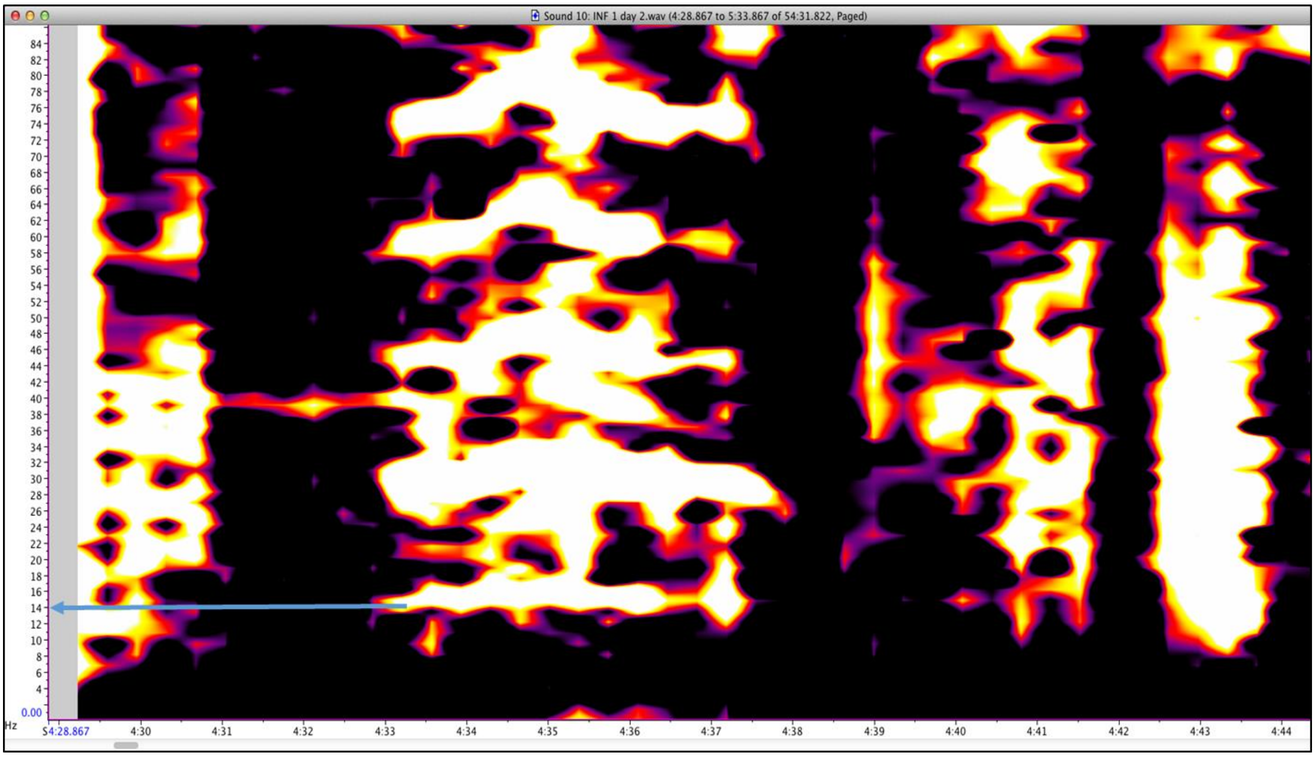


Figure 28: 14 Hz rumble.

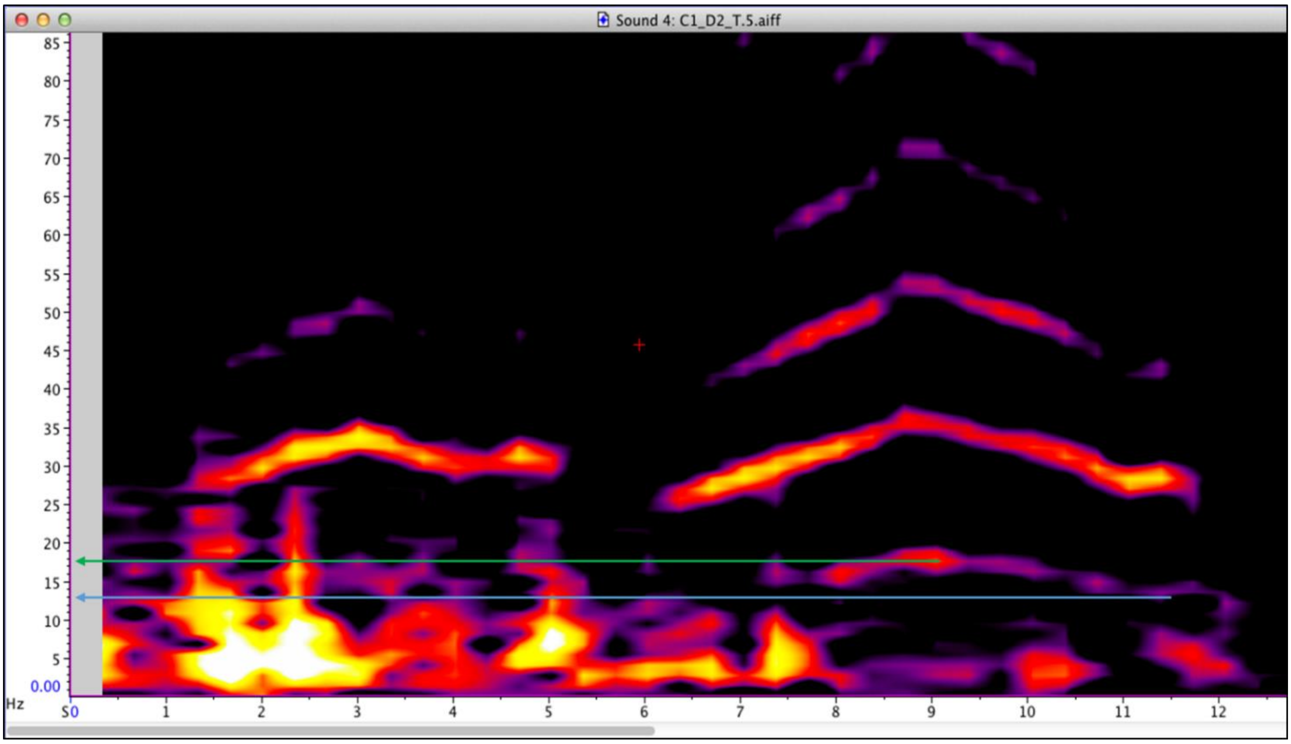


Figure 29: Rumbles reaching down to 13 Hz.

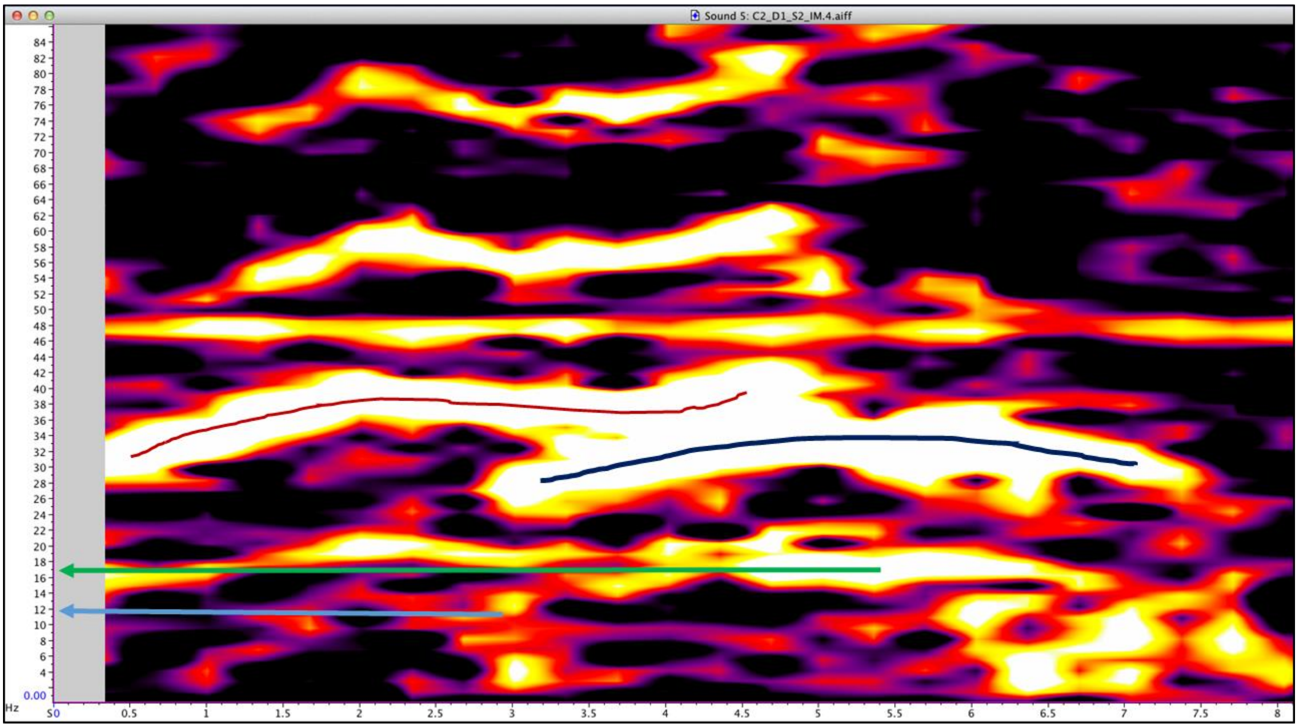
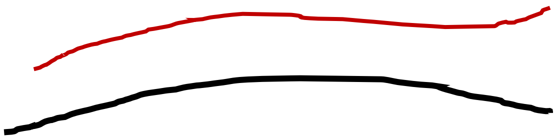


Figure 30: Two elephants vocalise at once, roughly 12 Hz fundamental frequency.

These graphic representations are drawn on the second partial of the sample's harmonic series.

Elephant 1 =

Elephant 2 =



4.9 Reflection on the Research Methodology.

The topics of this thesis drew on a wide range of research from various fields. Each aspect of the thesis relied on distinct musical interpretation as well as input from a respective or relevant field. The individual consideration of theories and technologies applied to each aspect of the methodology allowed me to successfully record infrasound. It has also allowed me to incorporate infrasound events into a composition which provides a true infrasonic musical experience.

In the future I hope to refine this technology and donate it to the ecological researchers and biologists at AWE towards developing an autonomous elephant monitoring system. This data is also currently being viewed by the WITS Department of Geophysics in order to do a comparison with seismographic data from the same elephants.

The research journey has been extremely inspiring to me as a musician. The success of generating and recording this particular infrasound resulted in the creation of a rare and unusual musical composition. The creation of my composition also promotes the awareness of infrasonic phenomena in the biophonies outside typical urban environments.

Chapter 5: Composition Methodology

The research and procedures of this thesis were ultimately structured by my artistic practice as a composer. The creative, mathematical and practical considerations provided the perspective with which I broadened my application for infrasonic musical placement and positioning. Consequently, the methodology and construction of the composition events are subject to me as the artist and researcher. The end result and musical concepts used in the recital did not solely conform to scientific or theoretical principals but provided a foundation from which my creative elements emerged.

Due to the relative lack of infrasonic music available thus far, either in the public domain or commercially, my compositions developed without significant influence from external examples (other infrasonic music). Instead, the exploration of the theoretical concepts, experiments and artistic interpretation later formulated musical character. In the infrasound laboratory (see section 4.6), musical pieces were inspired by the observation of theoretical experimentation and resulting acoustic interactivity. A broad area of the infrasound range was explored due to the specificity of each carefully calculated and generated sine wave. These generated waves are employed in conjunction with, as well as adjacent to, the field recordings of elephant and thunderstorm infrasound in the final composition.

5.1 Generated Infrasound

To aid the foundation of my understanding of this phenomenon, I first sought out the means to create infrasonic oscillation. Having experienced seemingly boundless low frequency vibrations on many occasions (in theatres, cinemas and festivals), I explored a variety of software programs in search for a simple wave-form oscillator. Ideally this software instrument would be without the 20 Hz limitations presumed to be in the threshold of human hearing. I found the least limited of these oscillators to be within Audacity, in which the exact frequency of the tone generator corresponds to a digital entry device.

Given this opportunity to manipulate such a device and the ability to create the infrasound, many questions such as the following arose:

A. In the infrasonic range which frequencies produce results of an audible, or for that matter a physical, nature?

B. How do we combine or infuse properties of existing temperament, and their inclusive theories, as well as higher pitched sound to enhance the listener's infrasonic hearing capabilities?

C. Does the experience of the audience coincide with my (the composer's) interpretations of the music?

D. When comparing recorded with synthesized infrasound, are there quality differences of digital, static or inorganic against biological, natural or animate attributes and does this pose challenges for the integration of this material? How can such challenges be overcome?

The answers to these questions are not the outcomes of hypotheses, but rather the promotion of a concept that an entire range of sonic frequencies are present in our world and should be included in the expression of creatives.

5.2 Theory and Experimentation

The procedures presented in this section are not a complete representation of available relevant theoretical perspectives, as some experiments were developed by personal interest and improvisation. Nevertheless, the general themes and common threads deployed in the writing process were captured during the use of the following concepts.

5.2.1 Simple Sine Wave Oscillation

Western music has a long history of performance techniques and composition devices. These include existing paradigms of melodic and harmonic structure. I chose to locate the majority of my composition within these existing theories as I found no reason to abandon the framework. I therefore made the personal choice to use, arguably conventional, music theory as well as representation.

Because the frequency variability of a synthesized musical note can extend into the decimal range it provides a large variety in quantifiable frequency destinations. I therefore felt it necessary to justify the use of a specific frequency, or infrasonic note, allocation to document and reflect on my infrasonic musical discovery and evolution. In the most dominant existing western music theories (such as the tonal system), a desired note can be chosen according to its relevance or intervallic distance to another or many other notes. Musical instrument design has had an intimate relationship with pitch, melody and harmony. This is why it is common to find a musical instrument presenting note locations inherently in a design such as a fretboard or keyboard. Without this visual framework, each frequency value chosen to be an infrasonic note equivalent required careful calculation for the same intervallic resonance and/or harmony to be tested accurately.

In my experience as a musician I have worked mostly with equal tempered tuning. It was important for me to see how a directly related temperament translates to frequencies in the infrasound range. For this reason, I used a simple mathematical formula $X=f/2^y$ to locate frequencies that could be considered of intervallic importance, presuming that equal temperament remains useful once induced into the infrasonic realm. Under certain circumstances a desired theory will require a frequency with more than five decimal variables, in which case the frequency is rounded off, or the temperament was considered flexible within the available range between neighbouring activity. This formula can be applied to a melody, harmony or any existing sonority of pitch (Figure 31).

a

=

b

Melody Notes	Original (Hz)	Infrasonic (Hz)
A	440	6.875
C	523.25	8.125
D	587.33	9.1775
E	659.25	10.30125

=

c

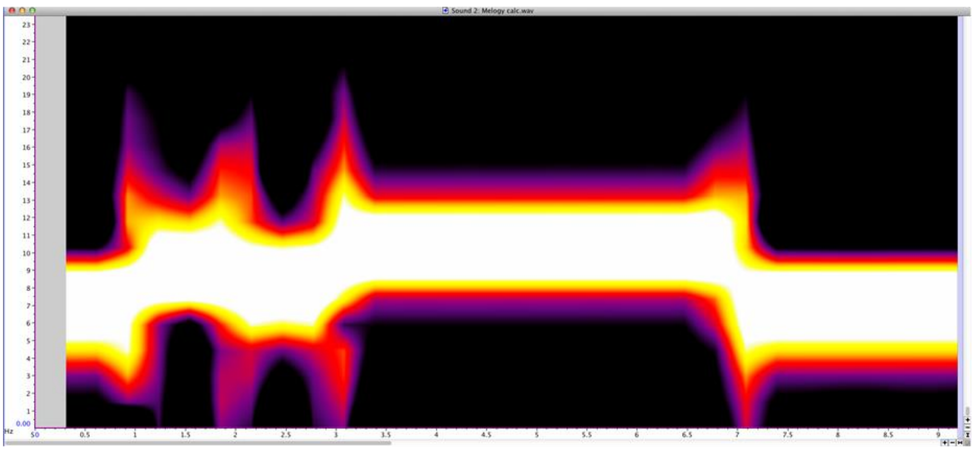


Figure 31: a) melody, b) frequency of a note and its transformation into infrasound, c) spectrograph of melody (a).

This spectrograph shows the linear representation in the time (y axis) duration of the frequency events. Notice that an infrasound wave of this type does not seem to function solely within the designated numeric frequency value, but rather occupies a range of adjacent frequencies. It is also important to note that the parameters of the visual representation can, to some degree, warp the bandwidth of the sonority, perceptibly expanding the areas of activity to seem broader than a particular frequency.

Infinite as the possibilities of generating infrasonic melody might seem, my musical goals required the inclusion and reflection upon a more complex and diverse theoretical background. Often, because the melodies produce little (if any) recognizable pitch, the infrasound can gain a sense of monotony and so came about the further experimentation of multiple infrasonic note interactions.

5.2.2 Combinations of Oscillations

An important concept to keep in mind is that once multiple frequencies begin oscillating through the same infrastructure (speaker system) some combinations of waves can cause an increase in resonating amplitude while others are being phased out or severely affected. This will produce a weakening and a strengthening of certain frequencies against others to noticeable and useful effect. Achieving the application of conventional harmonic structure in the infrasound range requires the most specificity in the calculation of each note frequency.

The process of producing a desired harmony/rhythm (since the oscillation is so low) began by identifying the frequencies of the desired musical theme. In the case of a conventional harmony, assuming A4 to be 440 Hz, a chord such as an F# minor triad (equal temperament) would have following values (Figure 32):

=

Note	Hz
C#	554.37
A	440
F#	369.99

Figure 32: a) notation (harmony), b) frequency.

Once these frequencies are identified each of the corresponding infrasonic values are determined by applying the formula $X=f/2^y$ (section 2.2). Thus, a harmony is processed in this way and provides values such as the following (Table 9):

Table 9: Infrasonic frequency of notation in Figure 32.

Note	Hz
C#	17.325
A	13.75
F#	11.5

As described in the methodology, one of the only true methods of monitoring the infrasonic activity is with a spectrographic program without limits in the lower register. Figure 33 shows a visual representation of the above harmony:

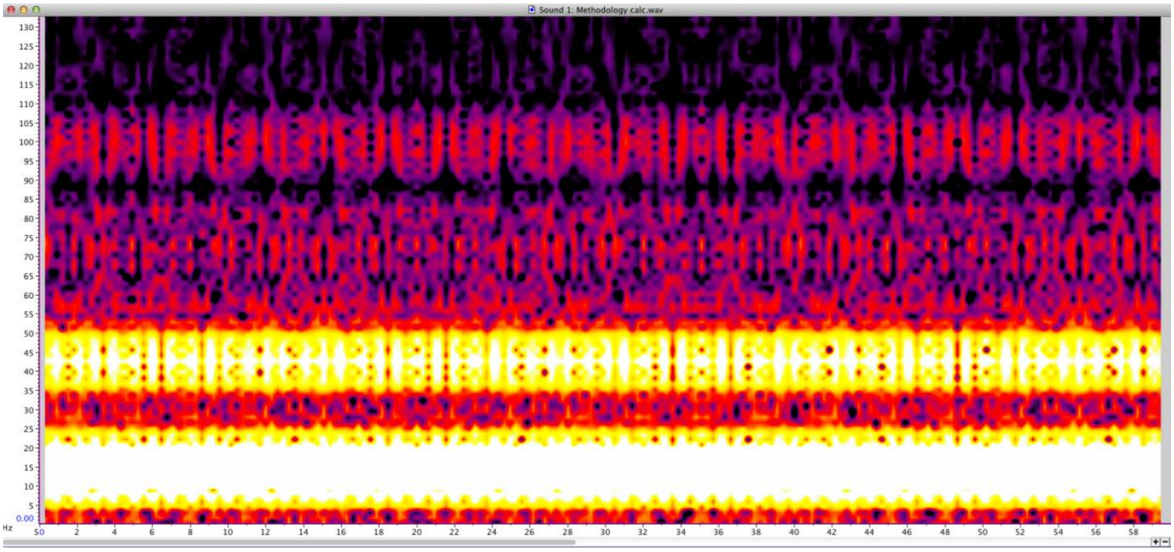


Figure 33: F# minor sub one.

The variety of combinations that was used for the culminating recital were not only restricted to singular or combinatory use of infrasonic frequencies. Additionally, certain atmospheric sounds (such as atmospheric “pads” and echoing droplets) compliment the infrasound register functioning as a supportive ambience. These ambient samples possess characteristics which create interesting phasing qualities when interacting with simultaneously resonating infrasound. The harmonic profile of the fundamental infrasound frequency interferes with the ambient audio, often by etching a perpetual rhythmic pattern from a continuously resonating sound.

5.3 Recorded Infrasound

I decided to capture, analyse and use infrasound occurring naturally to compose with a sense of organic sonic texture. My proposition is that naturally occurring infrasound will provide different characteristics from generated infrasound examples and that there exists value in the interplay between this duality.

It was necessary to isolate my composition within a small variety of infrasonic events due to the diversity of infrasound occurrences discovered thus far (Arora and Henme 2008). I therefore chose to focus on the capturing of two natural infrasound sources. The first, and most unfamiliar to me, is the infrasound of elephants. The second, infrasound from thunderstorms in Gauteng.

5.3.1 Elephant Infrasound

The discovery of elephant infrasound vocalisation by Katy Payne in the 1980's undoubtedly inspired many researchers to broaden the existing scope of knowledge (Payne, Langbauer, and Thomas 1986).

The elephant infrasound samples have certain characteristics that distinguish them as unique. The "bow-like" or "half-bow" profile (Section 4.6 The Biophony of Elephants) is one such feature as well as the soft and often unnoticed transients. When experiencing an infrasound vocalisation in the field, it is often only recognised mid-way or near the end of such a call. A more noticeable sonic trademark is that they occasionally change from a rumble to a more open mouthed sound such as a bark or roar. These changing spectral envelopes, and their spectromorphology[9], most certainly distinguish an elephant call from that of generated infrasound.

A number of useful and identifiable sounds were clearly recorded and translated particularly well on a speaker system. Other samples were only visible in a spectrograph at first. Certain extracted events were processed with attenuation to the higher frequencies, after which they became more apparent and equally desirable for my creative purposes. As mentioned in the methodology of my research (refer to Chapter 4) the wind noise in these particular types of field recordings can contaminate the audio and reduce the identifiability of a particular sound event.

5.3.2 Thunderstorm Infrasound

The second half of 2015 produced a drought for certain southern parts of Africa. The thundershowers that followed this dry season formed intense lightning strikes which generated infrasound in the resulting thunder. As I am situated near a cliff face I commonly experience the thunder sounds in a variety of echoing effects, which I hoped to capture and use in my compositions.

Using my infrasound recording equipment I captured raw sessions of thunderstorms during the circling of a storm around my location and again extracted the infrasonic events. Each thunderous sound event presented a spectrum of simultaneously excited higher frequencies depending on the distance between the lightning and the microphone. The closest lightning activity occupied the largest spectrum and loudest amplitude. Conversely the most distant strikes featured with less amplitude within a smaller

[9]Spectromorphology: the changing spectral envelope of a sound, also in relation to its Attack-Decay-Sustain-Release (ADSR) envelope.

spectrum. The small spectrum which the distant thunder occupied was most commonly found in the infrasound range and was therefore most useful to me.

The sound of a lightning strike presented many possibilities for my ideal composition aesthetic. Distant strikes provide a softer, more atmospheric, sound texture whereas a thunder crash recorded in close proximity possesses poignancy and sharpness which I incorporated to form rhythms. Reversing such a sample provided another, seemingly different, useful musical feature. The reverberated tail-end of infrasonic thunder often contained continuous rain ambience which became another instrumental sound quality.

Overall, the thunderstorm audio was used to create a larger biophonic space in which to place the audience. In the more up-tempo movements a strike might be used to slightly frighten or invigorate a listener. This particular effect requires regulation to stimulate the desired effect in a considerate manner.

5.4 Amalgamative Composition

For the purpose of arranging these sound events in a musical way, the instrumental sonorities were allocated a place in a composition according to their overt audibility. In my final experimentation at The Sound Corporation warehouse I coupled twelve SB1000z subwoofers together and this positioning provided my most perceivable, and therefore effective, results. This was also the session in which I made loudness measurements of various extracted samples (generated and recorded). The measurements were taken of the maximum (overall) SPL that was reached without any physical discomfort.

Figure 34 illustrates the chosen samples of elephant infrasound recorded by computer 1, with both microphones on field-recording day 2.

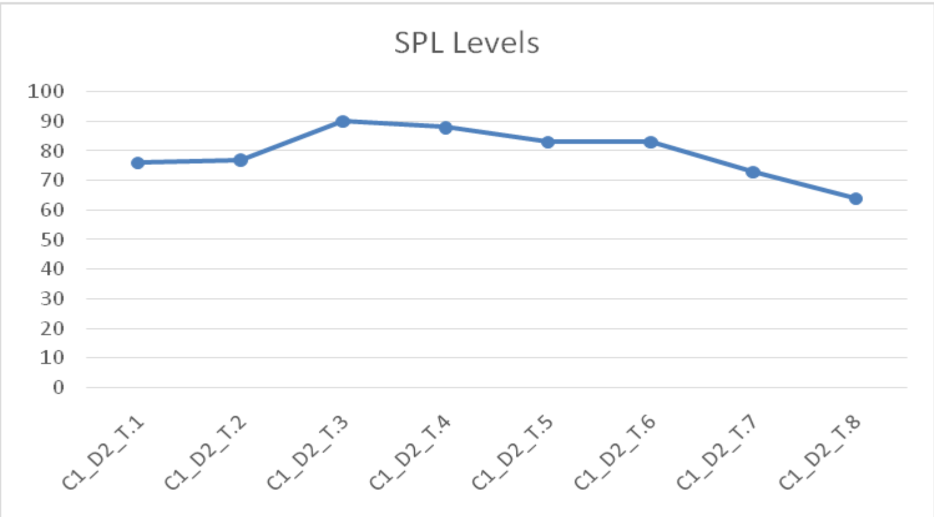


Figure 34: SPL levels of recorded samples.

The SPL values of the above samples indicate infrasound that is particularly audibly apparent, but not unpleasant or uncomfortable. It is somewhat of a limitation that the bandwidth of amplitude requires the specificity for sounds to be roughly between 80 and 100 SPL. In the process of amalgamating sound material into musical composition my creative efforts contributed to the dynamic gauge in positioning the samples, sine waves and accompaniment. The signal preparation sometimes included the process of normalizing a particular infrasound sample selectively equalized by a low-pass filter. Although equalization and compression can help to achieve this particular function, it was my intention to apply minimal audio manipulation and so arranged the components in relation to the loudness of each other.

5.5 The *Infrasonority* Notation

Since infrasound is somewhat of a new as well as niche entity in the musical framework, as of yet, no defined universal notation system illustrating methodic infrasound expression exists. In order to notate the infrasound components of each musical piece I chose to work with a graph and symbol system. A time-line is represented by the X axis of a graph and the Y axis represents the frequency spectrum in Hertz (similar to the spectrographs). To signify each of the featuring and supporting sonorities a symbol catalogue (Figure 35) was devised to function as a key for understanding the composition structure and instrumentation.

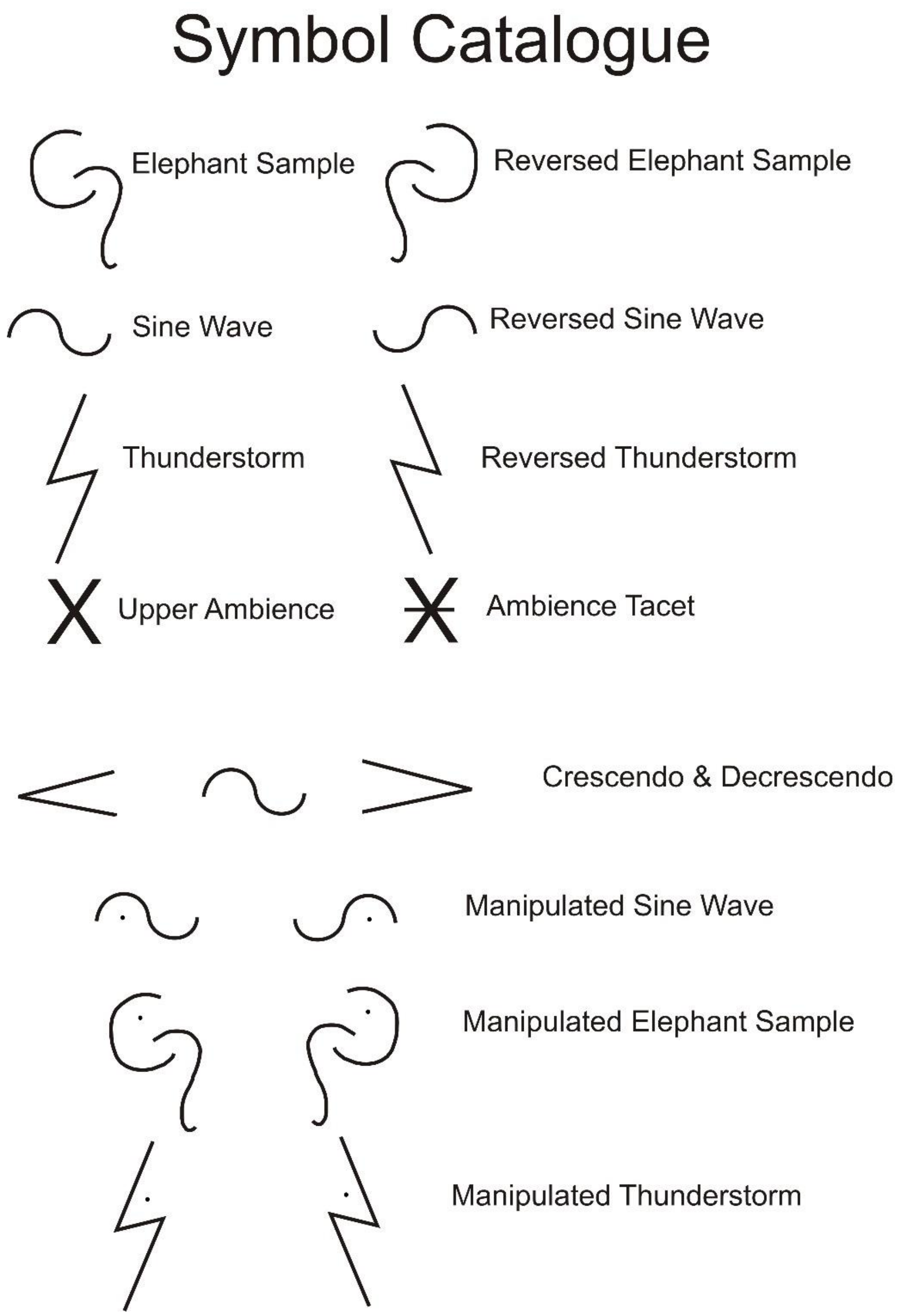


Figure 35: Notation key.

Each of the samples and their reversed option has specific envelope characteristics which creates additional variety within the recorded and generated catalogues. The retrograded crests and subsequent features of a particular audio sample can be perceived as indistinguishably different from its natural propagation. Reversed sine waves that do not possess particularly distinguishable linear features (a regular sine wave) also act upon accompanying sounds affecting the overall sonic properties.

A symbol is placed on the graph representing the cause of a musical characteristic or expression. In the case of an infrasound melody or harmony directly relating to conventional notation, a stave system with notation or chord symbol such as Cmin7 would be included in the graph. The graph, as well as the notation, makes it available for the reader to see exactly when the individual frequencies operate.

The indicated Ambience (refer to Symbol Catalogue, Figure 35) is placed as an accompaniment to the infrasonic activity in the foreground. Specified next to the ambience symbol is an indication such as an interval, harmony or soundscape and next to it a continuation line until tacet (Figure 36).

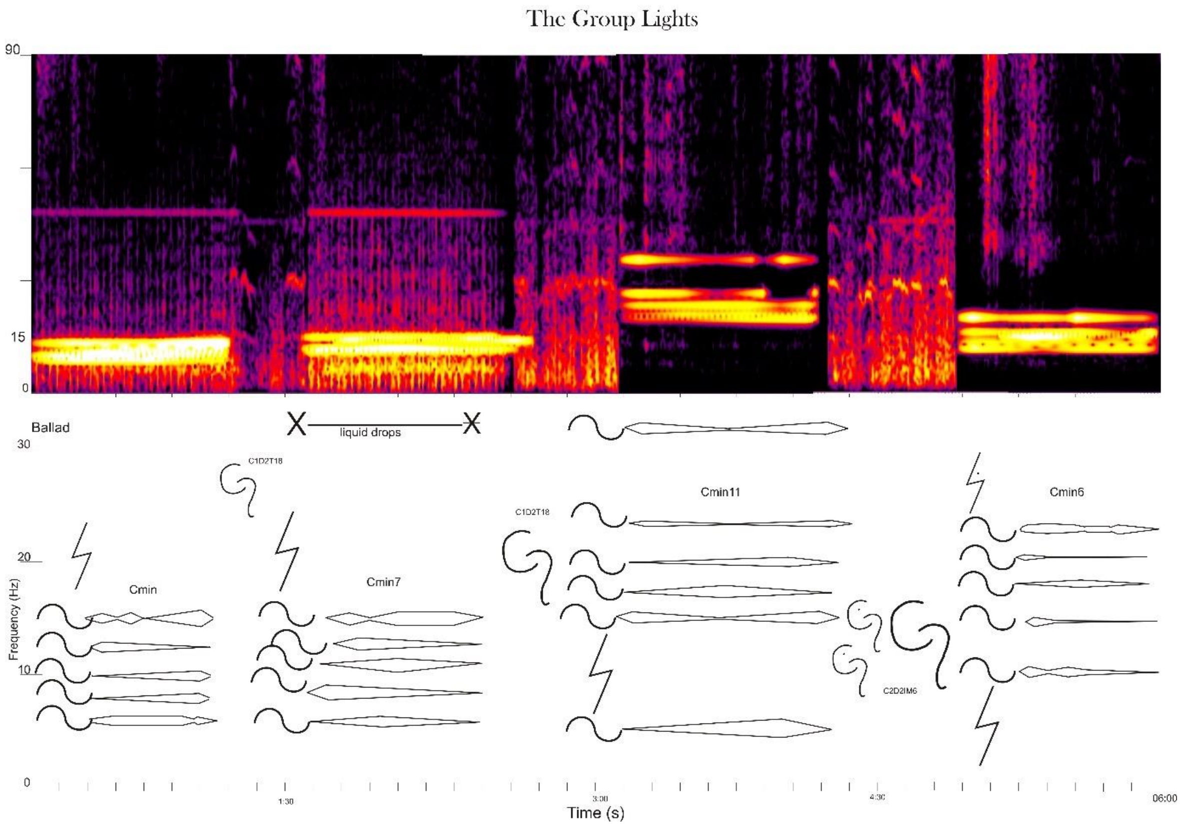


Figure 36: The group lights notation.

The use of crescendo and decrescendo are not separated in this form of notation. These symbols represent generated sine waves tapered to ideal amplitudes for the creation of varying effects derived from one particular infrasonic harmony.

Although the nature of this project is focused on frequencies below 20 Hz, for analytical purposes it was often my desire to allow higher activity in the spectrograph to expose intentional ambience or atmospheric accompaniment during interaction with the featured infrasound. Therefore, each of the compositions are assisted by a specially exported and aligned spectrograph varying slightly on the X and Y axis values (Figure 37). For a complete set of notations, refer to Appendix 2.

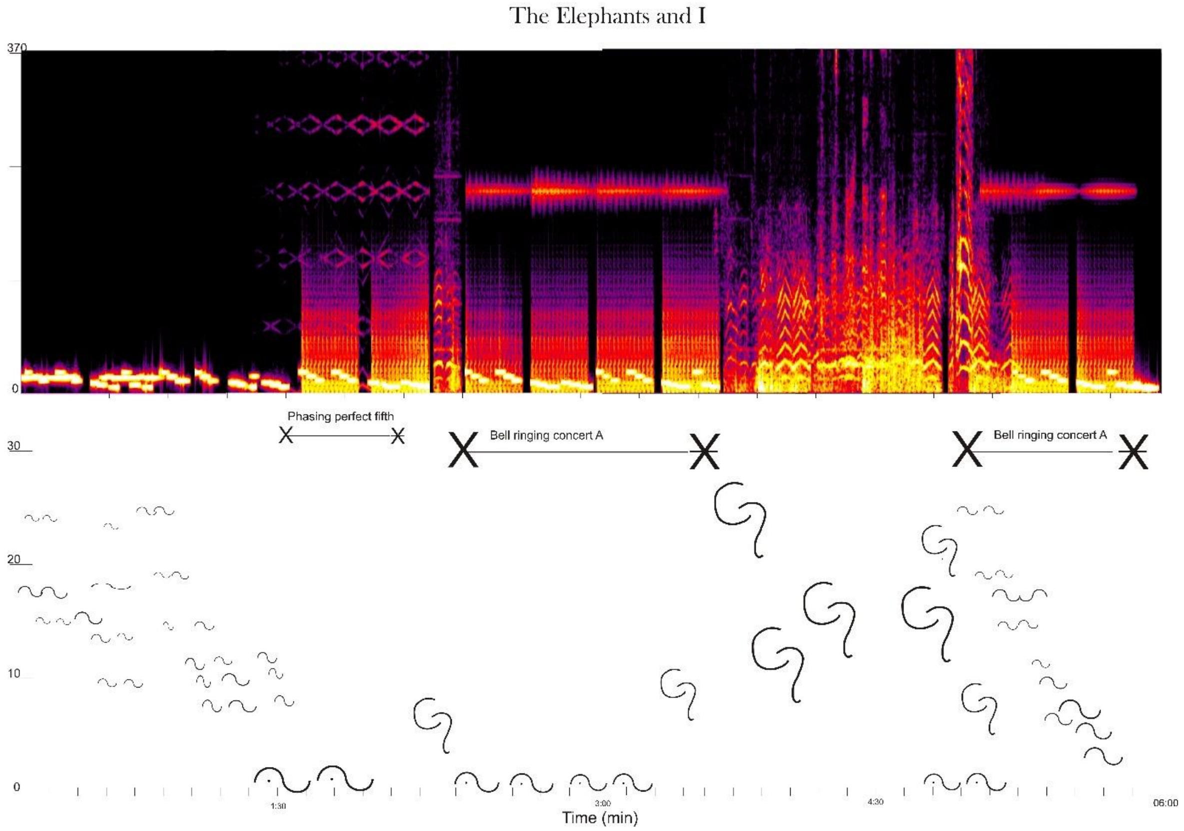


Figure 37: The elephants and I.

5.6 *Infrasonority* in Nine Movements

Containing the same title as the thesis, the research composition, which emerged from my use of the infrasound phenomenon, consists of nine movements. Each movement displays my expression of a concept inspired by particularly infrasonic audio qualities. The compositions flow from one to another in a way that pulls the ear down into the unusual/unfamiliar range of infrasound, descending from more familiar frequency stimulation. The features in each movement represent my musical expressions using digitally synthesized infrasound alongside elephant and thunderstorm infrasound.

In the first and last movements of the composition, I chose to amalgamate all of the three infrasound sources creating a full and active experience. In-between these two movements I explore the more exposed elements of infrasound through a reduction in accompanying ambience as well as varying the infrasonic instrumentation. Below are the nine movements with their titles in the ideal numeric sequence.

1 – Awaken 1

> A gradual unfolding of infrasonic events introducing listeners to a sonic palette found in my research. To awaken a new sense of hearing for a listener, I have synthesized

an infrasonic interval that produced a steady rhythm. A long intro serves as a build-up to the drum-like fill which is substituted/created with an elephant bark. This same feature then uses the phasing properties of a generated infrasound fundamental frequency, selectively slicing a reversed thunderstorm (in time) into a chorus. The majority of this movement shows thunderstorm strikes as percussive crashing as well as interplay between higher register infrasound (generated between 15-20 Hz) and elephant sounds.

2 – Awaken 2

In the second movement the texture is heavier with infrasonic sine waves. Sounding together at various and changing amplitudes sine waves below 20 Hz produce phasing effects to both fundamental and higher resonances.

3 – The group lights

An infrasonic duet – this ballade features the infrasound-based communication of Elephants interacting with an infrasonic harmony.

4 – Trobite

This tribute to Amon Tobin pays homage to his work by using the combination of animal sounds along with a deep slow groove figure. Rhythmically Tobin has a particularly energetic approach when using a slower (<120 bpm) tempo. He creates a mirage of steady yet eerie rhythmical atmospheres, with reversed and manipulated recorded samples.

5 –Levering

This movement centres around 10 Hz and the work exposes the listener to a sequence of events. These infrasonic expressions overlap one another in the arrangement creating diversified phasing effects.

6 – Staggered

A dark lullaby written to express the nostalgia of life near Highveld thunderstorms, contrasting the tension of the peaceful with the loud.

7 – Upon departure

This movement is inspired by the feeling of leaving a loved place or person. It was written in thought to the social bounds of elephants, and how they too grow attached to individuals and locations.

8 – Laluc

At the start of this movement the infrasound is extremely violent and as the section unfolds the music takes one from violence to an expression of love. There is a minimalist influence I drew, particularly from work by LaMonte Young which is perhaps not overtly apparent. The influence was particularly invoked for the sense of building a harmony in a drone like fashion. Young inspired me to look at beauty that can be created simply by sounding resonating elements together, long enough to entrance the listener.

9 – The elephants and I

This triumphant closing of the composition features synthetic infrasound paired with the joyous expressions made by elephants. This movement makes use of the absolute best elephant samples, and mid-way a regrouping session is additionally embellished further to simulate a larger herd. The finality of this piece is created in the hope to provide a memorable experience for the listener, with which he or she might attenuate themselves with to perceive future infrasound events.

5.7 The *Infrasonority* Recital

My recital took place on the 24th of July 2016 in the Wits Great Hall. This venue has a considerable amount of acoustic treatment including soft material covering most of the room surfaces as well as few rattling components and thus thought to be most appropriate. However, it was not infrasound-specific due to the rarity of such an event. My personal requirement was to find a decent concert venue with as few rattling components as possible. The isolation of the Wits Great Hall had good sound control to help prevent contamination of noises from exterior sound sources. These sound sources can possibly become amplified by particularly resonant cavities which cause potential interference during a recital. The infrasonic tone that occurs naturally in any space is difficult to predict accurately and for this reason a full day, prior to the recital, was necessary to tailor the movements according to the room's response.

Upon testing inside the venue with the full array of speakers I began to realise just how large an effect the acoustics have on infrasound specific music. The music required laborious retailoring mostly related to the equalization of the movements. This was done to highlight desired sonic features with attenuation for the substantial change in the acoustic dimensions. Mainly obfuscating the compositions from my original experience inside the warehouse was the specificity of a venue's reverberation. The interior of the room responded very unpredictably to the frequencies. Most notable was the continuous rattling of wall panels, lighting sockets and seating sections. Without a full monitoring infrastructure for room control I needed to adapt each movement, using my ears in various positions of the room, to accommodate conceptual and musical intentions.

5.7.1 The Experience

Typically, a modern-day film contains low frequency droning during selected narrative elements (Holman 2012:6). Infrasonic music is perceived with a similarity to more conventional theatrical droning qualities. However, the simultaneous use of all three components (generated, elephant and thunder infrasound) operated above and between such droning effects to articulate more noticeable sounds essentially functioning as melody, harmony and rhythm.

Various audience members shared their opinion on social media as well as on a radio interview by Radio Sonder Grense (RSG) (Fouché 2016). Some of the opinions are quoted here to provide the outsider's perspective alongside my own interpretations.

> Well, I think I can still feel it, like there is a pressure on certain bones in my brain, and I think those bones were vibrating during the performance. There were some moments where it was nauseating, and some moments where it was more peaceful. So I think he did well to take that range of emotion from such, kind of, limited material - Alex Parker. (Fouché 2016)

> This project challenges the boundaries of one's own perception. The music is infrasonic, existing in majority below the generally accepted limits of human hearing and activates emotive and physical responses in ways that one can only recognize as primal. On the last listening I found an amazing duality in my reaction, one where I had gooseflesh and a physical reaction reminiscent of fear, yet at the same time was safely enjoying the rendition in my active consciousness. Seems Franco has found a way to make my God given primal nature differ in its own musical experience to the perceptual reactions of my intellect - Jonathan Crossley. (Crossley 2016)

> The most euphoric sonic experience I've ever had. He's merged music and nature in a form which is experienced in a very primal way - Frederic Clarke. (Fouché 2016)

> It feels like an outer-body experience as you feel more than what you hear, and that is really amazing. Sound that utterly surrounds you inspires the imagination, almost like being in a desert or a forest of sound - Debbie Prinsloo (Translated from Afrikaans). (Fouché 2016)

My opinion regarding the various comments on the performance material is that these audience members had separated this particular experience from that of other musical performances. There are many writers who mention the concept of infrasound becoming easier to detect once a person is aware of its existence (Crawshaw 2014:274; Salt and Hullar 2010; Leventhall 2009:11). I find similar results in my own perception of infrasound and have come to believe that it is only after the recognition of infrasound that the individual's construction of infrasonic sensitivity and awareness begins to awaken. Ideally those individual infrasound listeners should be able to reference an example from the *Infrasonority* recital to continue stimulating their own hearing and detection abilities. My recital was such an opportunity created in the hope that with the help of this research we can generate more infrasonic interest assisting the formulation of concepts comparable to rhythm, groove, consonance, harmony and melody. The intention was to find communion with the listener using particularly interesting and stimulating effects in a demonstration of infrasonic discoveries.

Chapter 6: Conclusion

The research in this thesis was conducted to effectively embrace and enable the use of infrasound in my own musical composition. The music was composed, produced and then performed providing a unique and rare experience. Additionally I have certainly undergone a liberation, as a composer, with regards to source material and the overlap between acoustic awareness and digital expression.

6.1 Summary

By definition the word infrasound implies that the phenomenon is inaudible. I thus speculate that, in its linguistic meaning, the word infrasound itself has contributed to the common perception that these frequencies are beyond human hearing limitations. However, as previously noted some composers have applied similar sonorities, and refer to them with synonyms such as ultra-bass, sub-bass and Low Frequency Oscillations (LFO's). Because infrasound has already been given this name, and particularly for being closely related to the boundary of hearing and physical perception (circumstantially), I have asserted it to be contextually audible in the hope to ultimately broaden the rarity of its acknowledgement and musical use.

The chapters of this thesis illustrate the modus operandi I have applied for my artistic incorporation of infrasound sonorities, hence the title *Infrasonority*. In this project, the vastness of infrasonic occurrence is purposefully limited to digitally generated infrasound, recorded infrasonic elephant vocalisation and thunderstorm activity below 20 Hz. The infrasound was recorded with modified conventional equipment and reproduced on electro-dynamic sub-woofers. During the research undertaken to complete this document a sequence of scientific enquiries was pursued to provide greater creative insight supporting the expressions of the music.

In addressing the questions stemming from the aim, it was important to remember that the context and deductions of this research reside primarily in the realm of artistic research. I consider the practical achievement of this study to exist in the musically altering and recreating of infrasonic occurrences. The specific questions I have dealt with follow:

a. *What does infrasound sound like?*

   Moulding and adapting infrasonic audio to the ideals of the composer dictates the experiences of the audience. Naturally, my own specific conditioning and musical background gravitated the experimentation toward what I considered as most likely to be perceptible, stimulating or, ultimately, desirable. Once again the perceived lower limit in human hearing is based on contextual statistics, and therefore the audibility of infrasound is largely circumstantial. Under the conditions of my own infrasonic propagations the recognitions of the sound events are both audible and physically sensory. As a result of the smooth, rather than sharp, transient values of the generated infrasound, many of the sonorities are heard/felt as pulsation with dull attack. The discussions (between myself and audience members) relating to these sound experiences are often described in words such as internal or biological similar to hearing movements in one's jaw, a heart-beat or the inner audio rhythms of swallowing, breathing or bodily impact.

b. *Can we effectively record and monitor infrasound with conventional tools?*

Arguably, we can record infrasound with conventional tools. The dynamic microphone, sound card, computer software and their appropriate modifications are all easily attainable and achieved inside or near city environments. I was nevertheless fortunate enough to receive access to higher standard equipment, although the conventional devices functioned adequately in comparison.

Although the monitoring of infrasound as a process was not particularly difficult the required apparatuses were specific. Using conventional frequency analysis that includes a lower limitation at 20 Hz leaves the monitoring agent without precise information of the fundamental frequency. Therefore, he/she must make an imprecise judgment of the fundamental's frequency based upon higher partials registered in the spectrum analysis.

The spectrographic analysis used for this research was done with the freeware program Raven 1.0. Since it contains no lower limit threshold this program allowed for effective results in my research, and proved the existence of important elements of the infrasonic events captured, analysed and presented.

c. *Is it possible to create infrasound with conventional musical equipment?*

The need for expensive microphones is not a prerequisite for research such as this. However, the electro acoustic generation of infrasound does depend on the spectral specifications or aesthetic desires of the composer and in some cases may require innovative modifications. In order to continuously create large compressions of air, large subwoofer-like systems are required so that it will propagate without severely distorting. Amplifying the compositions particularly for the purpose of experiencing true infrasonic fundamental frequencies requires more specifically engineered equipment. More importantly the compatibility/relationship between the infrasound composition, the speaker capabilities and the acoustic dimensions of a hearing space can cause wildly varying effects. During my experimentations with this research I found that the interaction of these three elements can provide perceptibly different receptions of the same compositions all together. It is important for the composer to have a particular experience in mind which anchors the process from recording to concert presentation.

Similarly, a composition can seem different by positioning oneself (the listener) in a different position inside the hearing space. With more conventional equipment, such as the systems I used in my personal home studio, the infrasound tailoring procedure during composition potentially runs the risk of being monitored falsely. Presenting infrasound to an audience requires the sound reproduction system to be seen as an instrument in its own right, ideally available to the composer and functioning unreservedly. Without the continuous engagement of a particular sonic compatibility, between all three elements, the composer/producer/musician possibly works against their own intensions.

On the day of my recital the infrastructure consisted of an iMac home computer, PreSonus Soundcard, Yamaha MG16/4 mixing desk, Three Lab Gruppen FP10000q amplifiers, twelve EAW SB1000z subwoofers and four Yamaha R115 speakers. Four stacks of three subwoofers were placed one metre apart across the centre of the stage (stage back). The Yamaha speakers were placed two on the outside of the subwoofers along the same line, and one between the first and last subwoofer gaps to promote phasing effects between the high and low frequency range. This infrastructure is mostly designed for outdoor festival use and was powerful enough for the intensions of my composition. The potential energy of this system was chosen according to clarity in producing waves across the infrasound range rather than maximum SPL.

d. *What are the circumstances in which this phenomenon can be perceived as musical material?*

Recorded infrasound is explained in previous chapters, however sonically it can be dissected further. With the most rasping transient values among my sound samples, thunderstorm infrasound was used largely for rhythmical effect. As both the generated and elephant infrasound were often a gradual rise or fall in frequency the contrasting explosive character of a thunder strike proved highly perceivable and useful. The proximity difference between the microphone and sound source allowed the capture of a wide range in intensities that provided a percussive vocabulary. The nearest events being most demanding to the recording membrane or human ear and those further away contribute subtle and distant expressions.

The musicality of the recital experience conforms to subjective impression in the mind of the listener. Initially the listener is required to undertake a sensory calibration upon his or her first exposure. The receptive mechanism of the body can become sensitized during the attendance of an infrasonic movement or performance. Musically the composer can manifest desired intensions through infrasound expression and exposure in this way, and herein resides a sense of enthralling communion.

Musically the material conveys a relatively unfamiliar presentation differed from traditional concert hall practices and receptions, unless one is willing to look into the niche realms of noise music, soundscape ecology or vibrotactile stimulation. Infrasonic music can offer an interesting avenue to exploring physical perception and for this reason potentially provide a shared sense of musical communion with the deaf.

e. *How is a standard western pitch perception model related to infrasonic exposure?*

For the purposes of this research a considerable amount of infrasonic experimentation was done using western equal temperament. Structurally the equal tempered approach allowed for the testing of infrasonic compatibility with existing harmonic and melodic theory. The attempt to assimilate distinct pitch recognition in this project did not feature convincingly enough for such derivations to be established or disregarded. The overt use of infrasonic features in the composition largely produced rhythmical effects, however those were discovered due to the Equal Tempered approach.

Discussed in previous chapters are investigated properties of infrasonic melody (Section 4.4 Infrasonic Music) and with conclusion that we rarely experience pitch hearing frequencies within this range. The temperament was however not strict and to some degree a microtonal implementation assisted the tailoring for desired musical features in my composition. In the case of recorded samples, a primarily spectral approach broadens the diversity of available musical frequencies from particularly tuned notes.

> …the microtones in spectral music are simply approximations of a set of frequencies to the nearest available musical pitches…This approximation is

> often a last step, allowing the musical structure to be generated in its most precise form (frequencies), then approximated to the nearest available pitch depending on the instrumental abilities and context (Fineberg 2000:84).

Occasionally such a musical device as melody or harmony can be registered if the original reference is played in a higher register directly following or leading up to the infrasonic version. I do not know if any such pitch-based music is accurately perceived without priming a listener beforehand to listen for an infrasonic melody and distinctly recognise an intended consonance. As listeners differ in body and taste, and do not regularly experience such a sonic environment, I speculate that, regarding pitch perception of my infrasonic music, the experience for each individual was unique. For this reason, I chose not to elaborate on the use of melodic devices to the audience, before the performance, as each individual perception can then be interpreted uniquely. It is not entirely impossible to experience melodic and harmonic function in infrasonic music however I do not imagine a transcription or recollection to be accurately made on first account as the frequency identification and reverse calculation would require for extremely precise (better than human hearing) infrasonic monitoring.

f. How does an infrasonic fundamental frequency affect a simultaneously resonating harmony?

Infrasound can produce both enhancing and reductive characteristics affecting the higher frequency sounds it is presented with. However, for the composer to know which higher sounds to accompany (for various creative reasons) a recorded or generated infrasound sample, a spectrographic or highly sensitive monitoring assessment needs to occur.

During my experimentation I found that the dissonant and consonant relationship between infrasound and higher harmony was of particular relevance. By locating specific frequencies which are consonant to a simultaneously sounding higher harmony there seems to be a largely supportive effect, however, most strongly influential to the particular note quality inside the harmonic option.

When a particularly dissonant infrasonic fundamental sine wave sounds against a higher harmony noticeable phasing effects can be observed. This “etching” quality is seen in my research to reduce the over-all sound, forming a rhythmical quality instead of, but not without, a continuously sustaining harmony.

g. *Regarding rhythm; what are the inherent rhythmic properties of infrasound samples?*

Inherently in an infrasound wave, rhythmic patterns are recognizable. Below 20 cycles per second (<20 Hz) individual cycles can become perceivable as steady pulses or rhythm. It was found that by combining such an oscillation with another infrasonic frequency vastly increases the potential rhythmic variety. My personal approach was to investigate the infrasonic interactions of frequencies played in relation to familiar musical intervals and chords, and this provided largely rhythmical results.

It was interesting to me to observe how infrasonic frequencies relative to pitched notes and harmonies present rhythmical patterns and phenomena. This remains a fertile field of research as a multitude of musical effects were created from the experimentation with singular and combinatory oscillation theories. It is not unusual to find stimulating rhythmical properties when converting a familiar harmony into its infrasonic frequency representative. I intend to further explore and compose with groove figures[10] and percussive foundation found with systematic infrasound composition.

h. *What are the behavioural traits of the multiple harmonic upper partials of an infrasonic sine wave?*

The Fourier Series is easily observable in the spectrographic images of this research, although the particular profiles presented varying characteristics in the upper partials. As discussed in previous chapters, the three types of infrasound sources used were usually represented in the following two profiles. Synthesized sine waves have no noise and may show a clear Fourier series decreasing in SPL toward the higher harmonic partials. The recorded infrasound had differences in the upper partial profiles largely due to external interference such as electrical hum, room balance and surrounding soundscape.

i. *What is the sonic (and spectrographic) profile of an infrasonic elephant call?*

The infrasound of the elephant is both unique and identifiable. However, it can be difficult to isolate within raw data through audio monitoring alone. Using spectrographic imagery to recognise the visual profile of the sound improves the observation and comprehension of the recorded material. The sensitivity of human

[10]A groove figure is a sequence of rhythmic features which is recognised to be particularly musical.

infrasound perception is less acute than that of the elephant, and thus can be unrecognised if the acoustic SPL is too low. On the occasions where a lower SPL sample had been acquired the infrasonic activity was equalized and amplified to ensure better perceptibility for the human listener. Generally, these samples were replayed, unaccompanied, providing me with a clear impression of the sonic characteristics. The infrasound samples collected from the elephants in the field provide vibratory rumbling sound which begins around a certain frequency, increases in that frequency value (and often the SPL) and then decreased after reaching an apex, I refer to this as a bow-like profile (Figure 38).

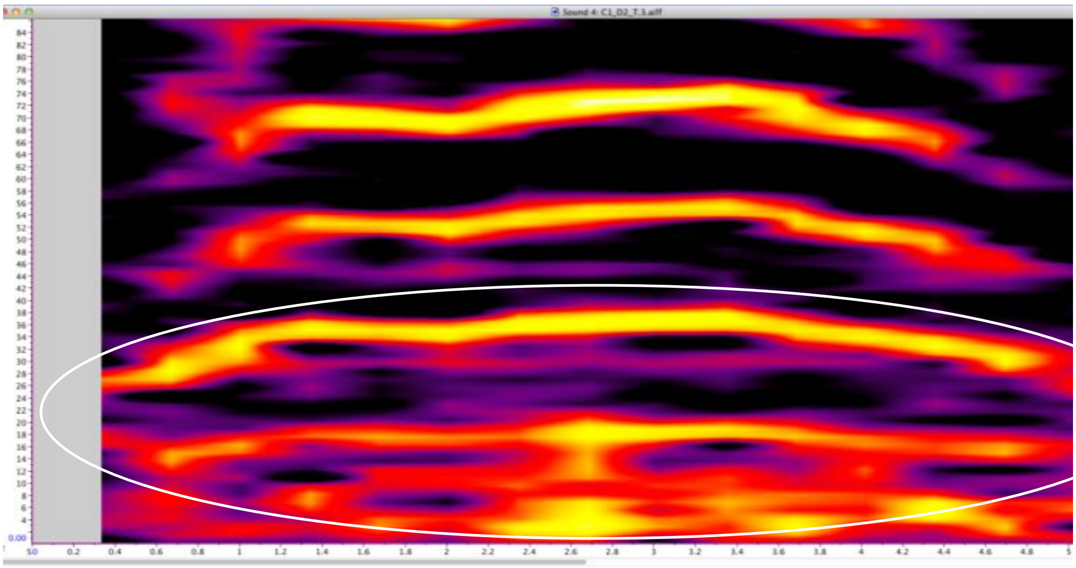


Figure 38: The bow like structure of an elephant vocalisation.

Depending on the amount of processing and amplification applied to the particular sample, the elephant infrasound could be made to sound gentle or aggressive. When a sample is heavily compressed and loudly mixed to feature among the accompaniment then a rumble can be heard more as a grandiose growling effect. Provided the speaker systems are adequately creating enough atmospheric pressure, and are not in a state of distortion, the diversity of elephant infrasound can be useful in a wide range of musical contexts.

j. *What are the particular characteristics regarding field recordings of this nature?*

Once infrasound researchers begin to focus on field recording, I believe they will encounter a variety infrasonic activity. There is a ubiquitous presence of infrasound in most field environments which requires the researcher to be specific in the particularly intended infrasonic sound subject. The diffusive nature of infrasound creates a wide propagation radius therefore the infrasound field recording can register unspecific activity from well beyond the targeted area.

6.2 Research Recommendations

A single composition cannot reflect the multitude of expressive possibilities that lie largely unexplored in the infrasound range. In addition to the minimal use arising from misconceptions of infrasound inaudibility by composers, infrasound compatible instruments and equipment are few and far between. If an increase in the knowledge and examples of infrasonic music is to be witnessed in the future, more musicians and researchers may be inclined to expand this particular field. For this reason, the following passage reflects on areas in the method and paradigms of my research that inspired recommendations aimed at interested individuals.

Overall, the controlled environment of the warehouse allowed me to capture a stronger signal than in the field (see section 4.7). The largest obstruction during this process was purifying the recorded audio of elements which obscured the audio. Because infrasound is emitted from wind, motor-vehicles and airplanes, their activity features across a large region of the infrasonic range. Due to the contaminating elements mentioned above, my captured audio samples required selective equalization. Provided that a recording program can recognise particular sound (versus noise) profiles according to desired research outcomes, selective equalization can be applied algorithmically as a plug-in device specifically tailored for work in the infrasound range. It is my recommendation that a researcher or innovator designs and produces such a software program which would greatly assist the recording and clarification process.

In addition to the inexpensive nature of the microphone modification it would be interesting to see paired with this research, a similar solution for the speaker system. This system could be useful to provide better clarity at the desired SPL upon playback of infrasound samples. During this particular research the electro-dynamic systems were made available and proved to be effective, however the equipment was not equally capable across the entire infrasound range. Upon reproducing very low frequencies (<5 Hz) as well as the layering of multiple infrasound samples the subwoofer systems used in this research leave room for improvement (recognizing that they were not designed for these intensions). This is why I believe the pursuit of innovative modifications, rather than more conventional equipment, should continue. Working within the capacity of non-specified equipment restricts the composer to some degree, and removing such limitations with more capable devices might result in more dynamic infrasonic composition. I would recommend that an infrasonic experiment be conducted with a movable and adjustable driver, rotary fan or membranous device without a fixed cabinet or resonating body. I suspect that temporarily installed in various architectural ducts, hallways and room spaces this device could facilitate an array of different infrasound samples to be analysed and collected.

The elephant herd which provided me with my samples consisted of members between 19 - 25 years of age. I suggest that subsequent data analysis could be performed over two more decades to investigate the continuity of voice quality belonging to an individual elephant throughout their lifespan. The results of such a study can keep the technology in a progressive state, which, if made available to ecological and biological researchers, can aid awareness and practicality for elephant conservation.

During the process of my research regarding vocalisations of the elephant I began to understand that other animals also produce infrasound. Among these included other land animals such as the Giraffe, Sumatran Rhino, Tiger (von Muggenthaler et al. 2001) and the Cassowary (Mack, Jones, and Nelson 2003). Perhaps the lowest of infrasonic vocalisations propagate in the oceans from whale song (Pulley Sayre 2006:25). It is a naturally following recommendation from the processes discussed in this thesis to be further applied in circumstances where other animal infrasound is present. Recording and analysis of these infrasonic occurrences would provide a composer with the adequate comprehension and source material to acknowledge and incorporate infrasound through music.

6.3 Reflection

The creative, musically theoretical and scientific linkages which guided the specific trajectory of this research expanded my comprehension of music as well as the infrasound phenomenon. During this project, elements and obstacles were identified and addressed, facilitating the practicality and prospect of creating and listening to infrasonic music. The sonic properties and musical characteristics of specific infrasound waves have been exposed, analysed and expressed/recreated in this research. Obstacles include misconceptions regarding the possibility of a purely musical application of infrasound, along with the feasibilities of infrasonic sound production.

With regard to the use of infrasound in music, the research and composition of this thesis addressed many uncovered and artistically unexplored curiosities which were expressed in the questions asked in the beginning of this document. Though musical infrasound can be interpreted innumerably, the malleability of infrasonic events will depend largely on the equipment capabilities and diligence regarding potential pitfalls such as high pass filters and lower limit thresholds in analogue or digital form.

Presenting three entirely different types of infrasonic sound sources promotes the ideology supporting musical recognition of sonic phenomena in general. More specifically this project carefully scrutinized selected sounds and noises below the perceived human hearing limit of 20 Hz. *Infrasonority* is a breach in the current boundaries limiting what is conventionally considered viable musical material, as well as an enquiry into the absence of infrasound in the arts. The resulting discoveries present a fissure in artistic limitation in aid of liberating the infrasonic composer.

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Appendix 1: Infraspread

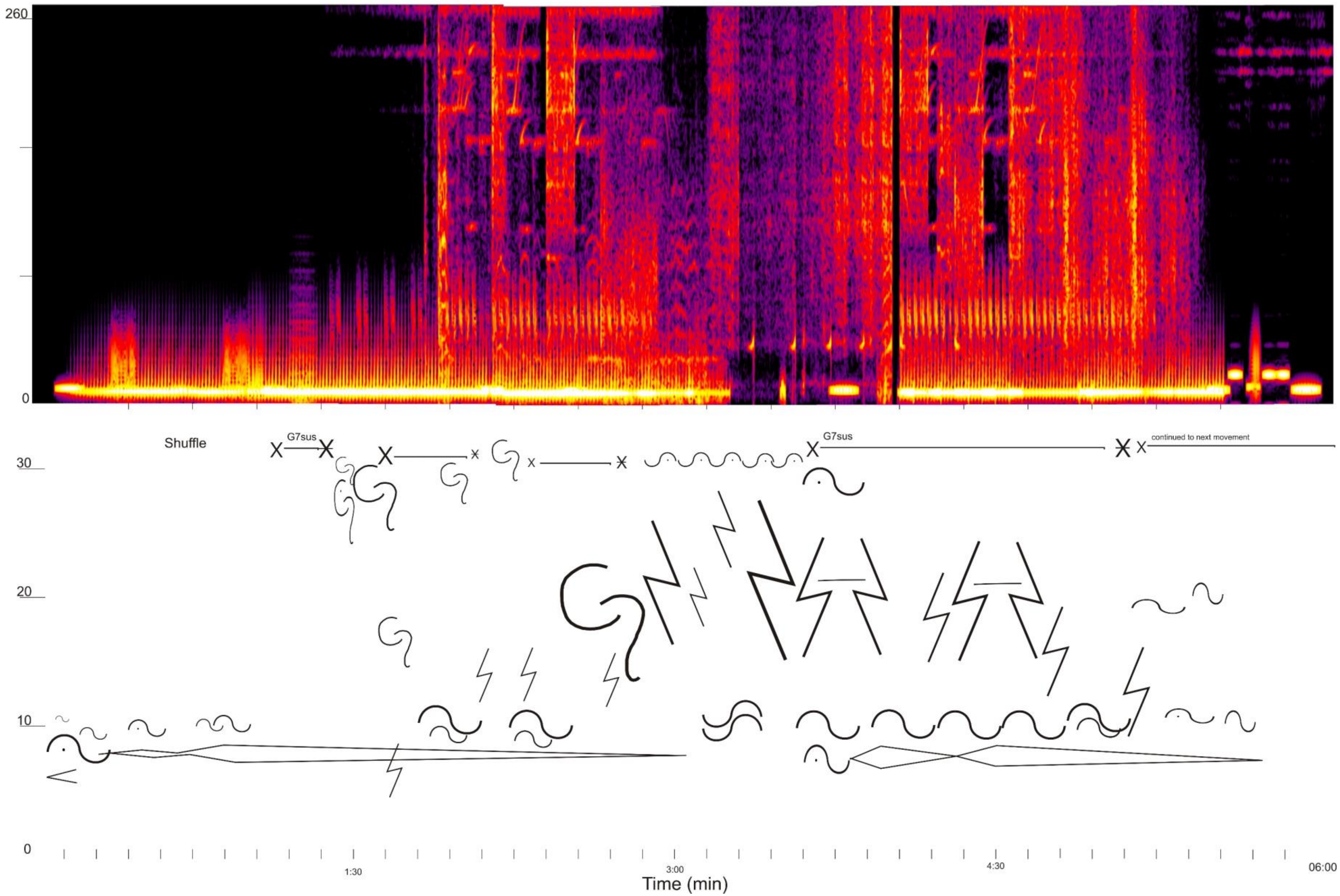
SB 850 Sub front loaded dual 18”						
Gain Stability	**Clarity**	**Pitch**	**Physical Experience**	**Tone**	**Recording**	**SPL**
10	9	9	5	6	y	91
8	7	8	4	4	Y	92
9	9	8	4	5	y	92
9	9	7	6	7	y	93
9	9	8	7	9	y	96
9	9	8	6	9	y	94
6	5	5	6	7	y	90
8	7	6	7	8	y	90
8	7	5	8	8	y	89
10	9	7	8	9	y	94
7	7	5	7	4	y	82
8	8	7	9	10	y	90
9	7	8	7	8	y	88
7	6	8	6	8	y	82
8	7	6	7	6	y	88
4	4	2	7	3	y	81
6	8	6	7	7	y	81
3	2	0	5	5	y	71
2	4	4	3	6	y	70
0	1	1	1	3	y	63

2	2	1	3	5	y	69
SB730 Sub Cone Mounted 15"						
Gain Stability	**Clarity**	**Pitch**	**Physical Experience**	**Tone**	**Recording**	**SPL**
10	10	8	2	8	y	96
10	9	8	2	6	y	93
9	10	9	4	7	y	92
10	8	7	3	7	y	92
8	7	8	4	6	y	95
10	8	7	5	8	y	90
4	7	4	4	7	y	85
9	8	4	7	8	y	91
8	10	6	6	9	y	92
7	9	6	7	9	y	92
6	7	6	6	4	y	86
9	6	7	7	8	y	93
7	5	4	8	7	y	83
8	7	8	8	8	y	89
7	7	8	7	6	y	87
5	5	6	8	6	y	80
6	6	6	8	7	y	85
4	5	2	5	4	y	86
3	1	1	4	2	y	66
1	1	4	2	3	y	67
	4	4	5	7	y	65
SB1000Z SUB Cone Mounted dual 18" with LGfp10 000Q @ 25 m						
Gain Stability	**Clarity**	**Pitch**	**Physical Experience**	**Tone**	**Recording**	**SPL**
7	5	6	2	4	y	93
7	6	4	3	6	y	90
9	7	4	5	5	y	88
8	5	2	7	7	y	92
7	6	4	5	8	y	88
7	7	7	6	8	y	86
6	3	4	5	2	y	82
9	6	6	7	7	y	86
7	7	5	8	8	y	95
7	8	5	9	8	y	97
8	9	4	10	9	y	94,5
9	8	4	8	7	y	91
8	7	5	10	8	y	90
8	6	5	6	8	y	89
8	6	3	9	9	y	85

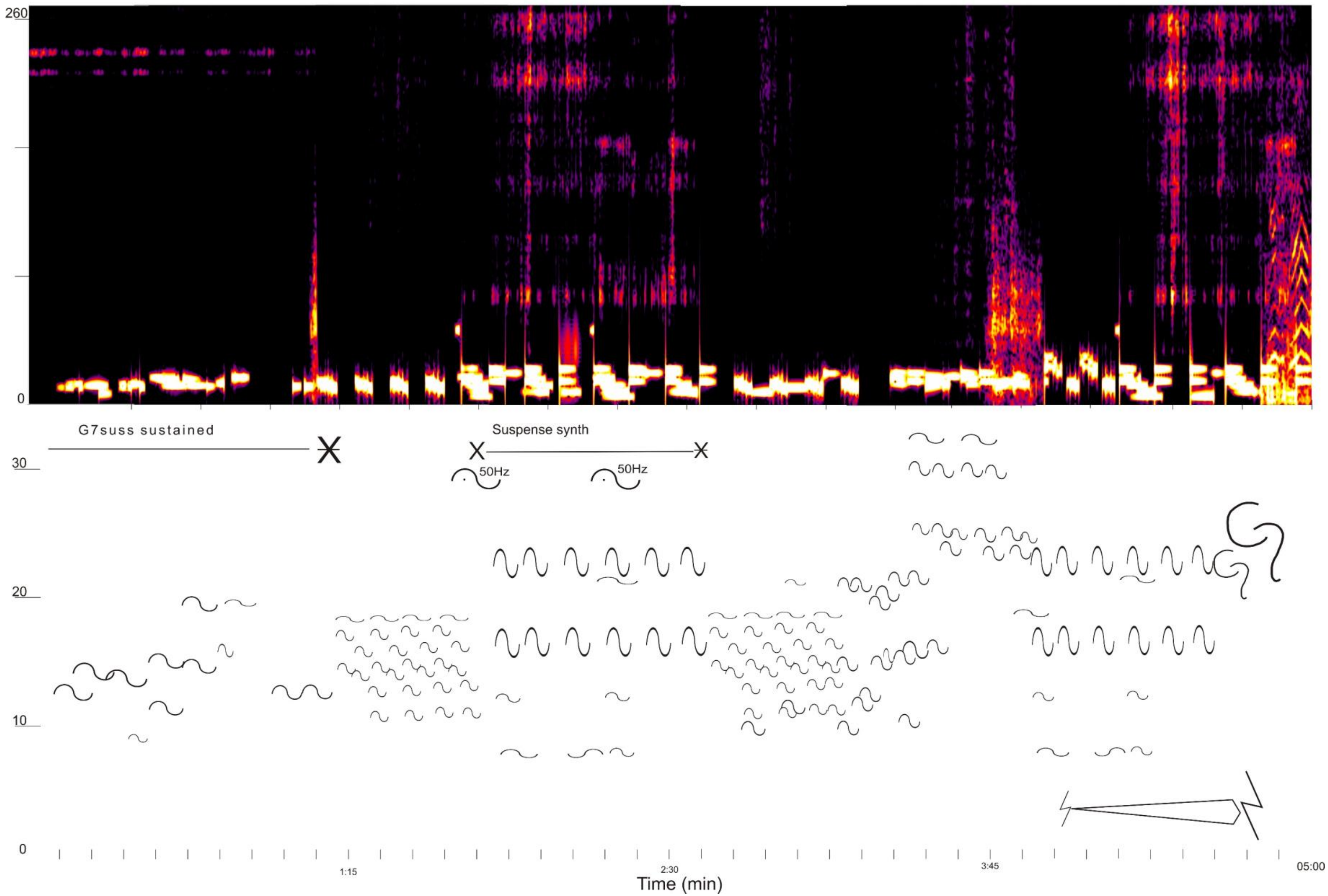
6	3	2	5	5	y	79
7	2	1	7	4	y	82
7	1	0	3	2	y	84 standing wave in warehouse
5	5	3	3	2	y	80
2	3	3	5	4	y	90 with feedback
2	4	3	4	5	y	96 with feedbaCK

Appendix 2: Notation

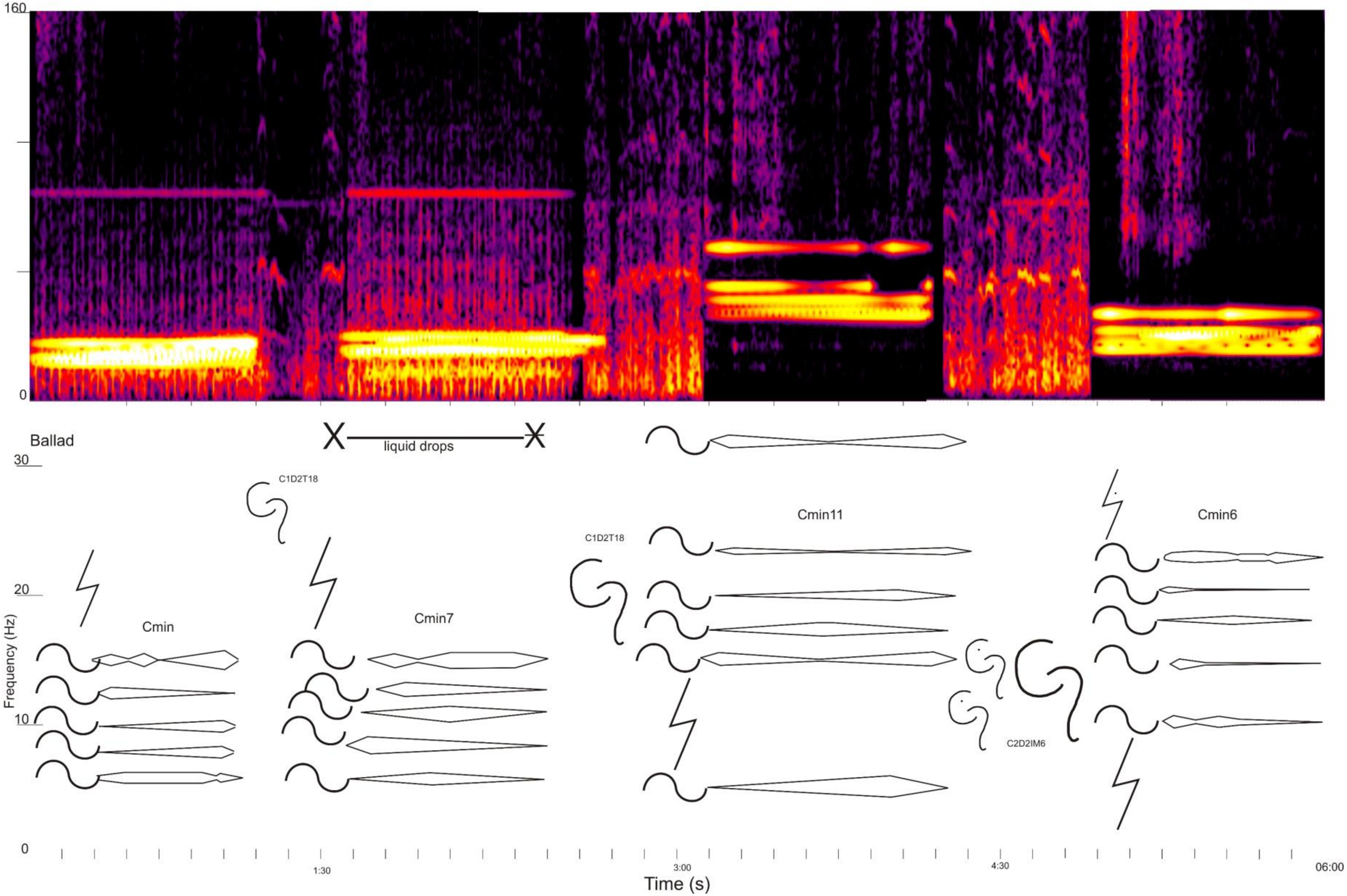
Awaken 1


260
0
Shuffle
G7sus
G7sus
continued to next movement
30
20
10
0
1:30
3:00
4:30
06:00
Time (min)

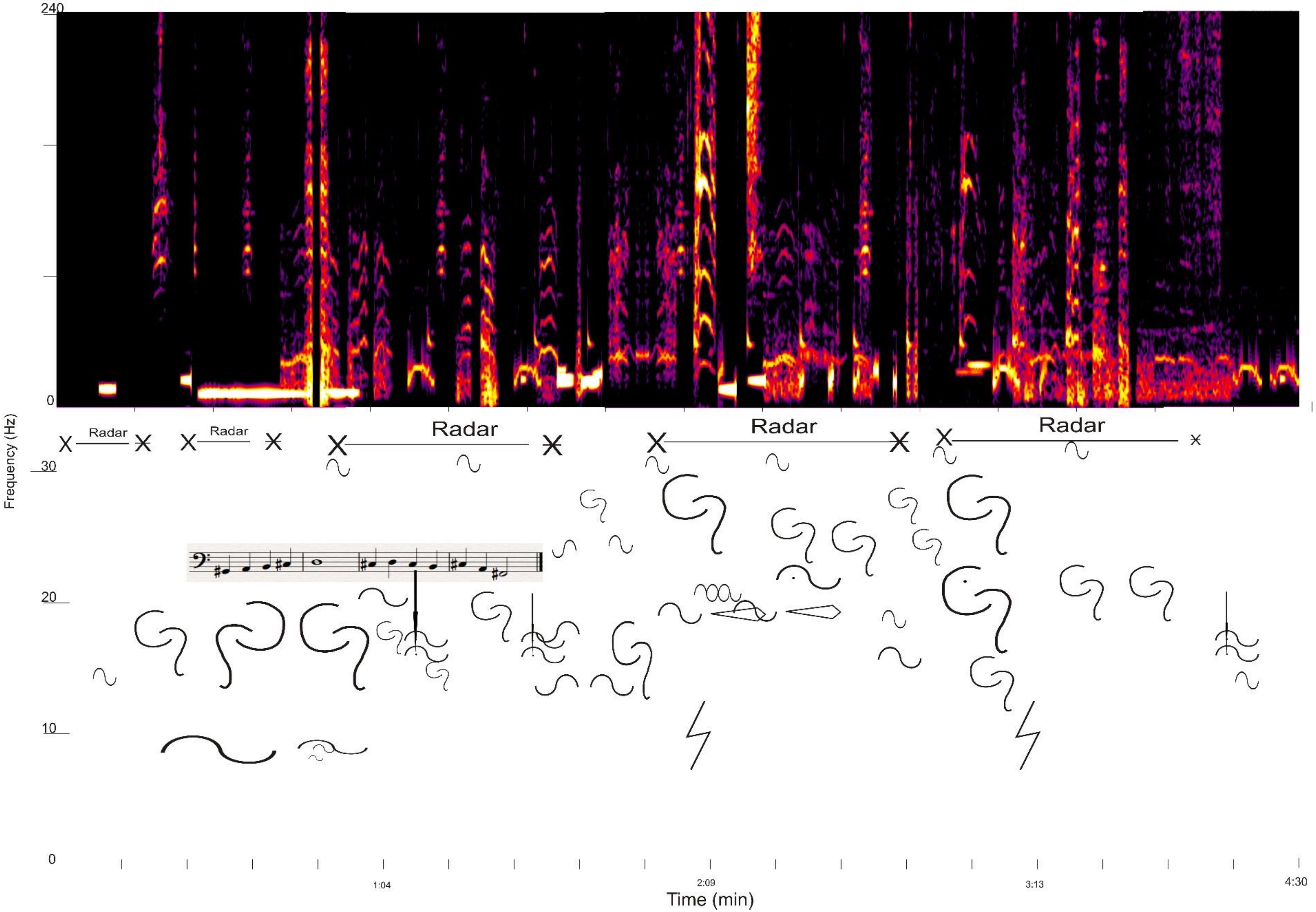
Awaken 2


260
0
G7suss sustained
Suspense synth
50Hz
50Hz
30
20
10
0
1:15
2:30
3:45
05:00
Time (min)

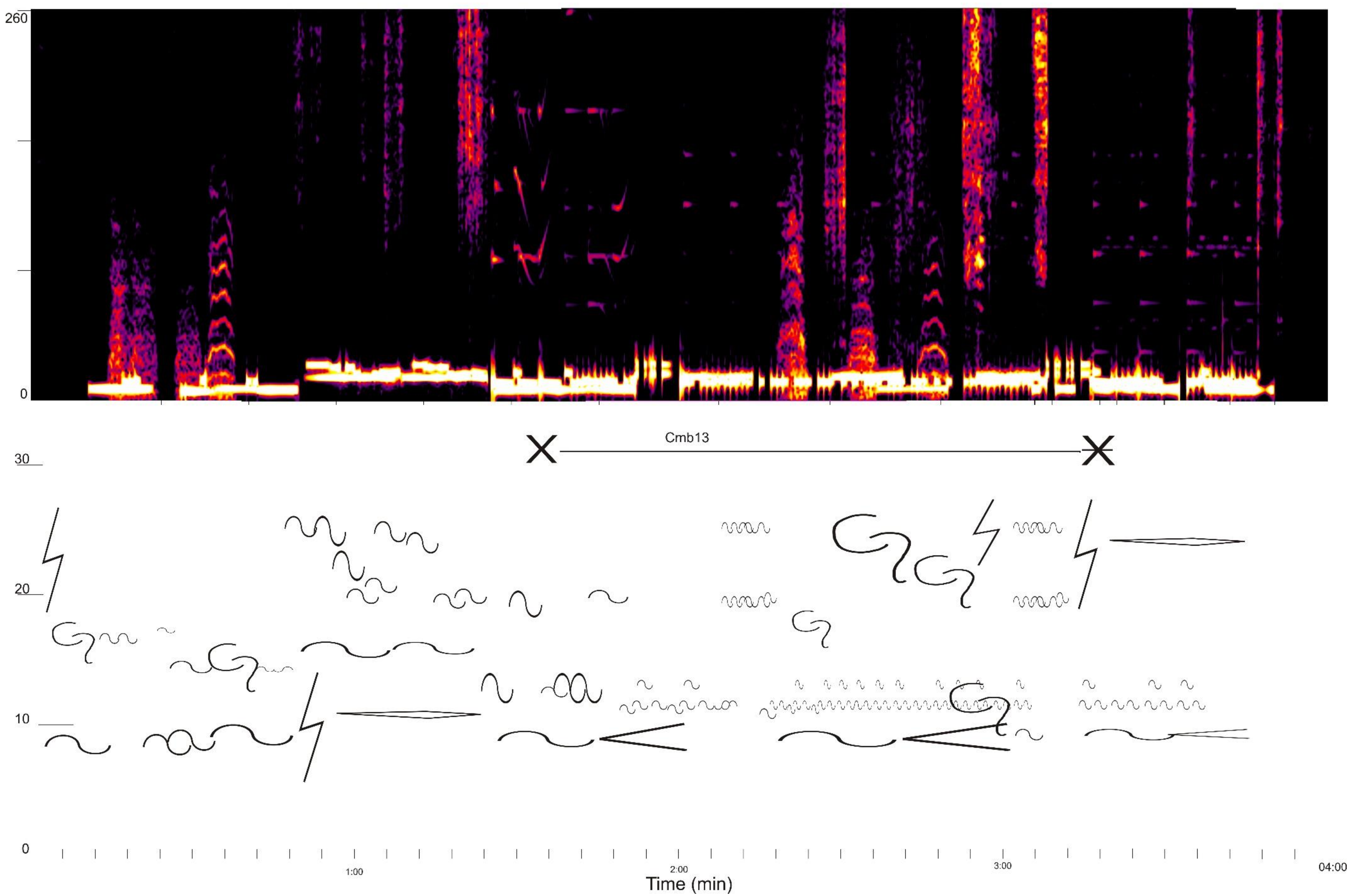
The Group Lights



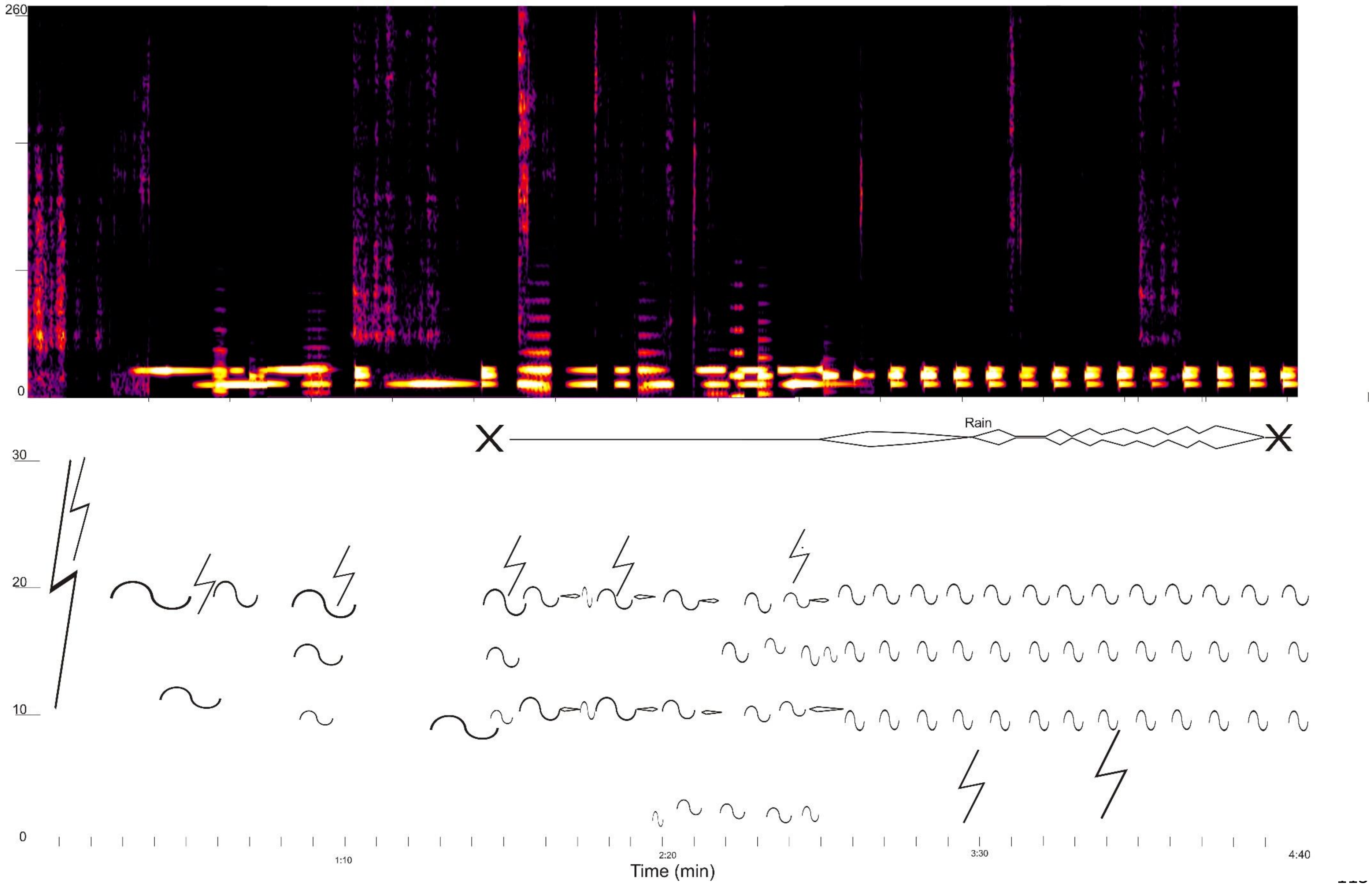
Trobite


240
0
Radar
Radar
Radar
Radar
Radar
Frequency (Hz)
30
20
10
0
1:04
2:09
3:13
4:30
Time (min)

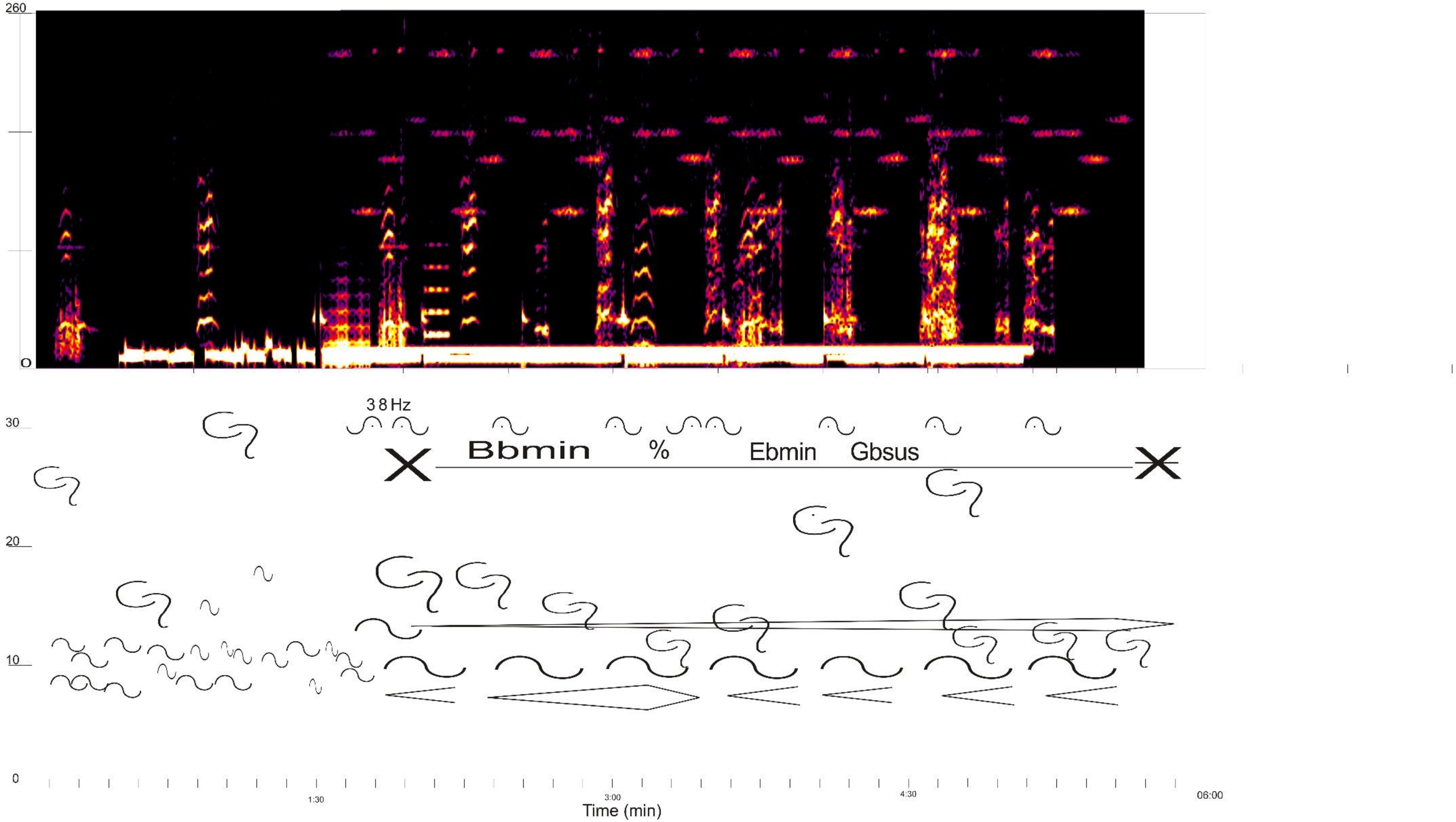
Levering



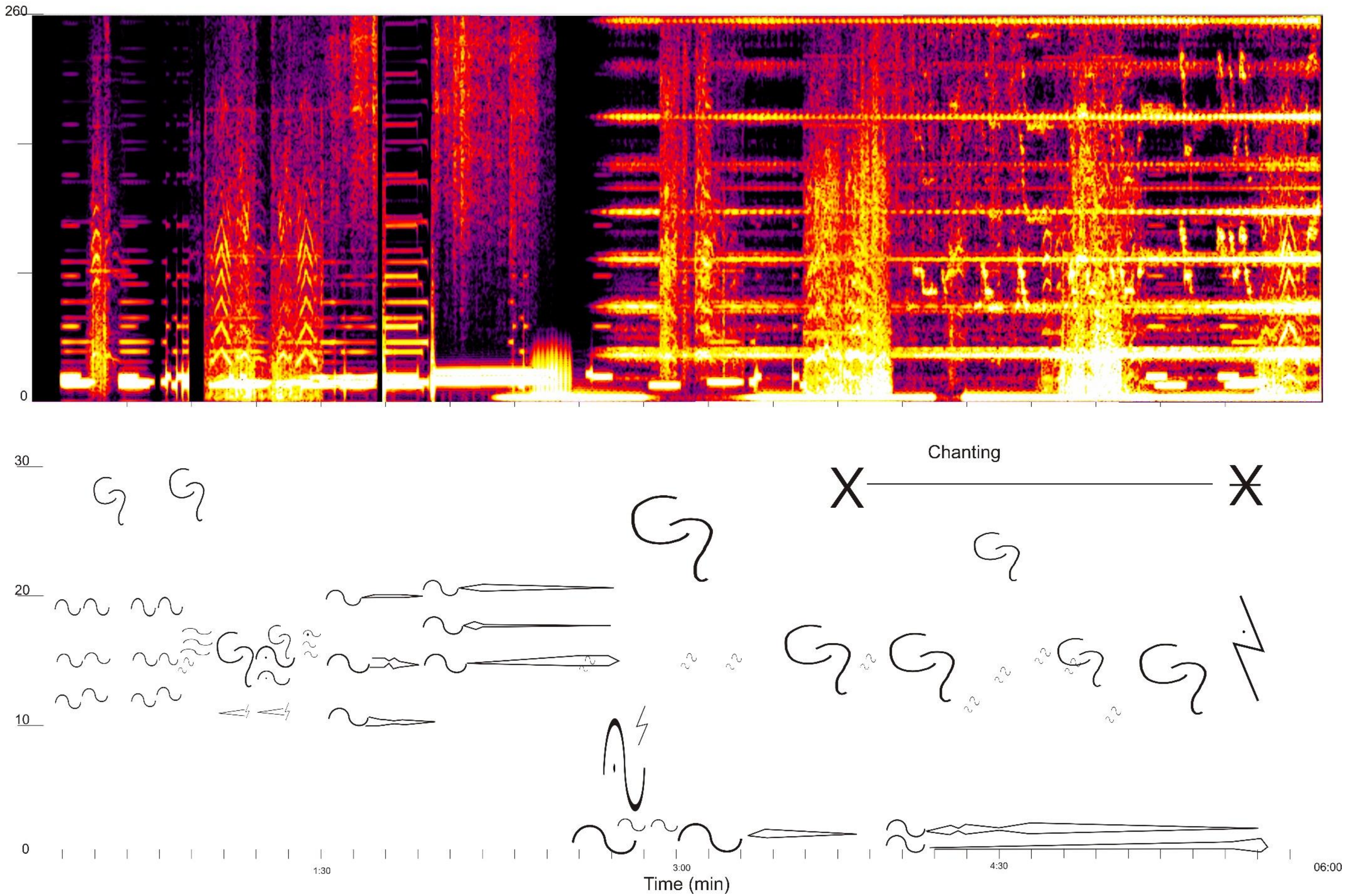
Staggerred



Upon Departure



LaLuc



The Elephants and I