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Grimshaw-Aagaard, Mark Nicholas; Bemman, Brian

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An Exploratory Study on Ultrasound Presence in Urban Spaces

Mark Grimshaw-Aagaard
grimshaw@ikp.aau.dk
Aalborg University
Aalborg, Denmark

Brian Bemman
bb@create.aau.dk
Aalborg University
Aalborg, Denmark

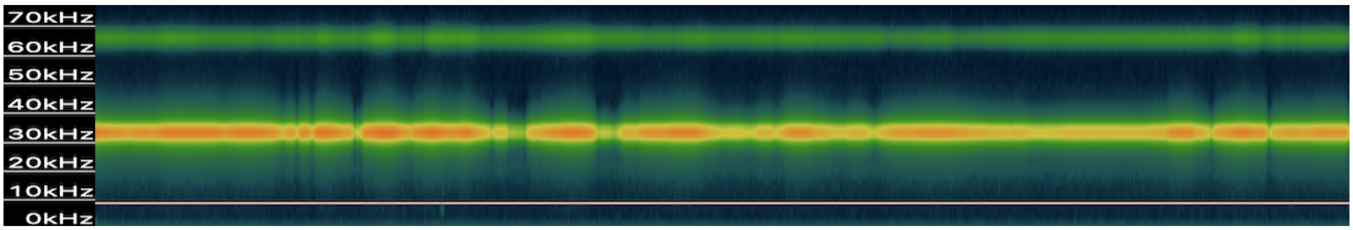

Figure 1: Ultrasonic signature of a motion detector.

ABSTRACT

Ultrasound is a frequently overlooked feature of our environment as it is not audible to humans and little is known of its health effects on humans. Presently, regulations governing noise pollution in urban areas concern only human-audible sound, and there are few regulations governing technologies that emit ultrasound as a by-product of their operation. Moreover, developing fields of research have highlighted the role of ultrasound in non-human species communication and the deleterious consequences for some species of human-produced ultrasound. If urban spaces are to become more sustainable through urban greening – capable of sustaining significant populations of non-human species – studies must be undertaken to begin investigating the presence of ultrasound in such areas. In this paper, we present an exploratory study of *urban ultrasoundscapes* aimed at measuring the presence and levels of ultrasound in a Danish city center. Our preliminary results show that there were significant increases in ultrasound at periods throughout the day with more or less a lower constant presence at locations that were furthest from major streets. In the urban recordings as well as one rural recording, however, the highest percentages of ultrasound occurred during the night and the lowest percentages were found during midday.

KEYWORDS

sustainability, biodiversity, ultrasound, urban spaces, recording, ultrasoundscape

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1 INTRODUCTION

The problem with sound is that its definitions, its measurements, and its uses are all too human centered. Consequently, this affects our relationship to the technologies that produce it – possibly biasing how we use such technologies as well as our understanding of their effect on the non-human world. In the case of ultrasound, this problem is even more apparent. We can take as an example, the American National Standards Institute (ANSI) Acoustics documentation which defines infrasound as "sound at frequencies less that 20 Hz" and ultrasound as "sound at frequencies greater than 20 kHz", with a further note that 20 Hz and 20 kHz mark the approximate lower and upper bounds of normal human hearing, respectively [3, p. 1]. In the document's definitions of sound, one definition states that sound is an "oscillation in pressure, stress, particle displacement, particle velocity etc., propagated in a medium with internal forces (e.g., elastic or viscous) or the superposition of such propagated oscillation," while another definition states that it is an "[a]uditory sensation" caused by the oscillation in a medium described by the former definition. Here, too, there is the suggestion that both ultrasound and infrasound are sounds that do not "evoke an auditory sensation" [3, p. 1]. With such definitions, quite interesting interpretations of what sound is are possible, such as the pataphysical statement that not all sounds evoke a sound [7]. Nonetheless, these observations illustrate that (1) our definitions of sound are (unsurprisingly) human-centered and (2) this human-centeredness in defining sound has possibly led to a significant gap in our understanding of the effects that sonic by-products of our technologies – particularly those outside the range of normal human hearing – might have on the environment and its non-human inhabitants.

It is quite surprising (and, indeed, alarming) to discover high levels of ultrasound from even the most mundane and pervasive of domestic and urban technologies, from vehicles to wireless communication devices. Take, for example, Figure 1 which shows the prominent ultrasonic signature of a motion detector, commonly found in various public urban spaces such as libraries, cafes, universities, and airports, that we are often in close proximity to in our daily lives (in this case, the device is situated approximately 1.5 meters directly above where one author stands during lectures). Measured at 1 meter distance, the mean sound pressure level for the 1/3 octave band centered on 32 kHz is 81.3 dB – such an SPL in the human-audible range is often compared to heavy traffic or a lawnmower.[1] As the importance of developing both 'green' and sustainable living spaces grows, we must be conscious of the possible effects that such technologies have on ourselves and our environment.

To this end, a 1982 publication by the World Health Organization (WHO) lists a number of potential adverse health effects on humans exposed to airborne ultrasound[2], including "temporary threshold shifts, altered blood sugar levels, electrolyte imbalance, fatigue, headaches, nausea, tinnitus, and irritability" [1, p. 15–16]. If unacceptable levels of ultrasound[3] are indeed present in urban environments – by definition, areas heavily populated by humans – then it might be the case, along with human-audible sound of course, that our interactions within such spaces will become negatively affected. The presence of such urban ultrasound must therefore be taken into account in current movements to 'green' our cities and make them more sustainable through the introduction of additional plant life and by encouraging animal species to better coexist in these spaces. Given that non-human species, plants, and animals, often have sensory thresholds above 20 kHz, and given that human-audible noise pollution (and, presumably, ultrasound pollution) increases as human presence increases, it is puzzling why there is not more data and knowledge about the presence and effects on urban life, of urban *ultrasoundscapes*.

In this paper, we present an exploratory study aimed at assessing the presence and amount of ultrasound at five urban locations (and one rural location) in and around the city center of a relatively small-sized city, Aalborg, located in northern Denmark. In section 2, we provide background information concerning ultrasound and sustainability from the perspective of acoustic ecology. Next, in section 3, we detail our procedure and the equipment used to carry out the recordings as well as the methods of analysis employed in quantifying the amount of ultrasound present. In section 4, we present our results and discuss our findings. Finally, in section 5, we conclude our findings and reflect on possible future work.

2 RELATED WORK

There exists a substantial body of knowledge regarding the ultrasound produced by specific human technologies in a number of different areas (e.g., medicine, communication, and industry). As far back as 1982, for example, the WHO identified a number of (then current) such consumer devices and industrial applications that produce airborne ultrasound, including cleansing, emulsifying, welding, flaw detection, dog whistles, pest controllers, alarms, and camera rangefinders, among others [1]. By 2007 (and later in 2016 – see below), [10, p. 65] argues that there had been no census regarding what exactly "ultrasound noise exposure" by these technologies means for humans, and, to the best of our knowledge, this is still the case. Leighton goes on to list three "categories of exposure of humans to ultrasound in air" [10, p. 64]:

(1) Exposure to ultrasound generated as a by-product of the operation of machinery (e.g., some dental tools);
(2) Exposure to ultrasound as a result of some machinery requiring the generation of ultrasound for its operation (e.g., diagnostic medical ultrasound);
(3) Deliberate exposure to ultrasound as a means of eliciting some response (e.g., pest control devices).

Leighton's first category above encompasses, for example, the ultrasonic noise pollution produced by wind turbines. Unfortunately, while there are current regulations governing the infrasound produced by these machines – regulations designed, in part, with the aim to manage the negative effects of infrasound on humans – there are few, if any, regulations on wind turbines regarding ultrasound [2]. There are, however, guidelines on curtailing the effects of wind turbine-generated ultrasound on non-human species, such as bats. Bats often die in collisions with wind-turbine blades, and there is some evidence to suggest that they are attracted to the ultrasonic signatures of the blades moving through the air [4, 6, 15]. Interestingly, one solution suggested to deter bats from the vicinity of wind farms is to in fact emit ultrasound designed to 'jam' the bats' echo-location abilities [6].

Leighton's second category describes the ultrasound produced, for example, by the diagnostic medical ultrasound machines now used widely in fetal scanning. The 1982 WHO document [1] expresses concern about the potential adverse health effects of medical ultrasound, decrying a lack of knowledge regarding this issue and calling for additional research [1]. Yet, as Leighton later observed in response to the medical profession's lack of concern over this warning and the minimal evidence supporting any *observed* adverse effects of medical ultrasound: "Foetal ultrasonic scanning is now so established in industrialized nations that it would now be difficult to find a control group for epidemiological studies" [10, p. 5].

Leighton's third category encompasses the ultrasound deliberately produced by technologies that serve most commonly as either weapons or deterrents whose intended targets can be human or non-human, such as with ultrasonic military weapons and pest control devices as well as those for warding off defensive dogs. A less overtly aggressive example is the increasing use of parabolic sonar in spaces such as museums. In all cases, however, humans are inadvertently (or not) often exposed to this ultrasound. Despite the proliferation of such technologies, Leighton notes that due to the potentially high intensity of ultrasound energy required for their operation along with "the paucity of information on the safe levels for human exposure to ultrasound in air…and the lack of traceability for the measurement of such fields…this could be a safety issue" [10, p. 30]. Unfortunately, the situation appears not to have changed much in the decade following this observation [11]. It would seem then that while there is an increasing amount of human-generated ultrasound in the environment, there is a lack of

[1] As noted elsewhere in this paper, there is little standardization of measurements for ultrasound and few regulations governing exposure; one must therefore be somewhat circumspect when comparing the effects of human-audible sound to those of ultrasound.
[2] While aquatic ultrasound is a related area of environmental concern, it is airborne ultrasound that is the focus of our research.
[3] What is an unacceptable level of ultrasound, for humans and non-humans alike, has yet to be defined.

consensus concerning the effects this ultrasound might have on the health and well-being of humans and non-human creatures alike. This is particularly problematic for our efforts towards sustainable biodiversity within our cities (see, e.g., http://naturkommunen.dk/) as there is increasing evidence that ultrasound plays a role in inter- and intra-species communication in insects and plants [8, 9].

Despite the importance of investigating ultrasound, most research with respect to sound in urban spaces has focused on human-audible sound, such as with the study of *urban soundscapes* [14] and the field of acoustic ecology [13]. More recent work includes citizen-science sonic surveys of large cities (e.g., SONYC: https://steinhardt.nyu.edu/marl/research/projects/sounds-new-york-city-sonyc) and the development of various methods within the domain of machine listening that have been applied to the tasks of detecting and classifying various sound events and human-audible pollution in such cities [5]. This emphasis on human-audible sound is further reflected in society at large with numerous regulations across the world governing noise pollution and acceptable sound levels within urban environments only within the human-audible range of 20 Hz to 20 kHz. Where there are regulations governing maximum permissible levels of ultrasound in the workplace, these tend to be set higher than for human-audible sound. For example, permissible levels up to 20 kHz range between 75–85 dB SPL while permissible levels above 20 kHz can be from 105 to 115 dB SPL depending on the country [12, p. 2532] – it might be that the higher level for ultrasound reflects the lack of audible annoyance (*viz.* awareness) for humans. Such regulations are not only human centered in the frequencies and intensities that they permit but are also human centered in other ways too e.g., regulations tend to be less strict when humans are expected to be active (but bats, for example, are sleeping). Unfortunately, to the best of our knowledge, none of these efforts concern themselves with urban ultrasound let alone any potential adverse health effects on humans and other species of ultrasoundscapes.

3 METHOD AND MATERIALS

In this section, we present our exploratory study with the aim of answering the following basic research question: *Is there a significant enough presence of ultrasound in the Aalborg city center to warrant further investigation?* We first explain the procedure and equipment used in making our ultrasound recordings and identify the recording locations in and around the Aalborg city center. We conclude with the basic signal processing methods used to measure the amount of ultrasound in these recordings. Should our initial findings prove promising, the long-term goals would be to expand the urban ultrasound survey across Aalborg and other locations in Denmark as well as make specific recordings of the possible sources of the ultrasound – both plant and animal species as well as technologies – that contribute to urban ultrasoundscapes.

3.1 Procedure

Six volunteer research assistants each made recordings at their personal residences over the course of approximately a week during the period between September 22nd and November 3rd, 2021[4]. Of these six recordings, five were made at locations in central Aalborg, Denmark – a relatively small-sized, former industrial city with an urban population of roughly 143, 000 inhabitants and urban density of 2, 400/km^2 (https://en.wikipedia.org/wiki/Aalborg). The sixth recording was made at two separate locations around a farm in the countryside outside of the city center. In all, 3.6 TB of data were recorded at 500 kHz sampling rates continuously through the day and night at each of the six locations. Figure 2 shows the five urban locations (A–E) in and around the Aalborg city center where the continuous ultrasound recordings were made over the course of about a week. Note that the rural location (latitude: 57.248886; longitude: 10.198458) is not shown but can be found approximately 35 km northeast of Aalborg.

As shown in Figure 2, locations A, B, D, and E all reside rather close to what might be considered a major road while location C resides in the heart of the city center along walking streets furthest from any major roadways. For these locations, research assistants were instructed to position the microphone outside their apartments placed either on a window or on a balcony pointing downwards toward the street as this was assumed to be the primary source of any ultrasound in urban environments. The height above street level for each microphone varied from approx. 4m on the 1st floor to approx. 10m on the 3rd floor. Upon returning the recording equipment, the research assistants provided the investigators with photographs of the area of focus for the microphones, GPS coordinates, and a description of the outside area including any notable potential sources of noise. As an example of the recordings made, Figure 3(a) shows a spectrogram of a short excerpt from an ultrasound recording made at location C (shown in Figure 2) in (b) where the placement of the microphone has been circled.

One will note in Figure 3(a) the presence of sound occurring both within normal range of human hearing (i.e., 20 Hz to 20 kHz) as well as seeming correlated ultrasound (i.e., above 20 kHz) in the signal. As the power spectral density indicates, the majority of the ultrasound power resides within the frequency band of 20 kHz to 75 kHz with little if any occurring above this threshold. However, the majority of the total sound power can be found in the audible range.

3.2 Recording Equipment

The Wildlife Acoustics SM4BAT-FS bioacoustics recorder and SMM-U2 ultrasonic microphone were used to make the six recordings. The SM4BAT-FS recorder is monophonic and capable of recording 16-bit PCM WAV files at sample rates of up to 500 kHz. Recordings can be triggered at certain frequency thresholds or can be continuous up to a 2GB WAV limit, at which point a new recording is automatically started. Two SD card slots support a total of 1TB memory meaning, theoretically, a total of 250 hours or so can be recorded at maximum settings with each 2GB file representing just over 30 minutes of recording time. In practice, however, the rechargeable batteries (4 x NiMH D size) hold enough charge to record roughly 6–7 days of material with reliability tailing off

[4]Average temperature in Aalborg during this time was 12 degrees celsius (high) and 8 degrees celsius (low) with an average pressure of 1013.1 (mb) and 78 percent air humidity.

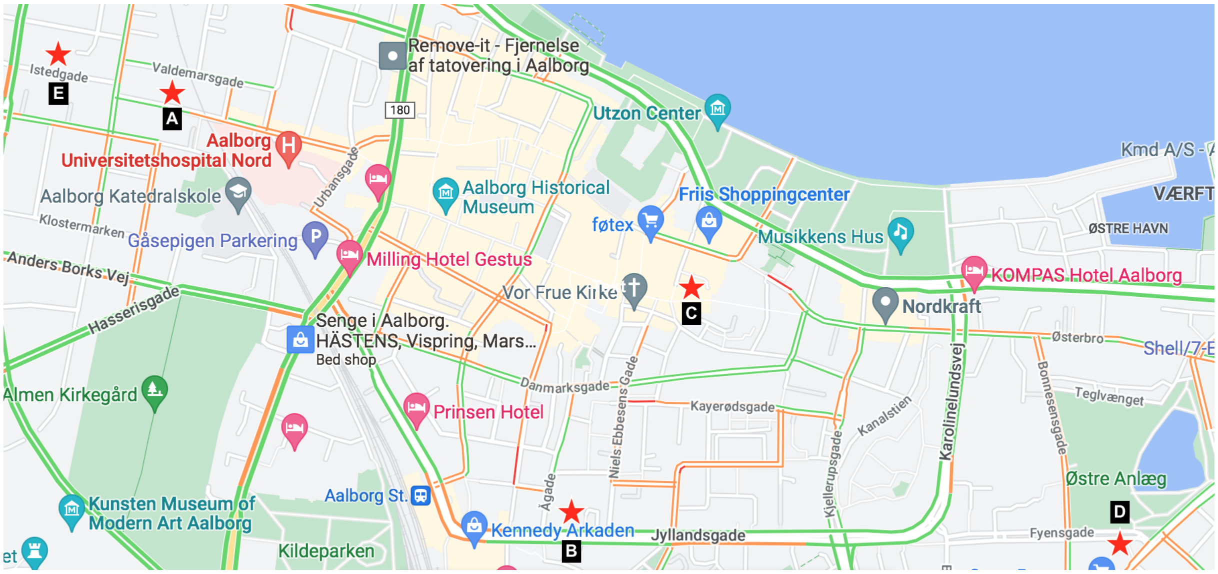


Figure 2: Five ultrasound recording locations (A–E) in and around the Aalborg, Denmark city center (Google Maps ©2022).

towards the end of this period. The SMM-U2 microphone has a cardioid pattern and can register frequencies up to approximately 240 kHz although its sensitivity falls 50–60 dBV/PA starting from about 100 kHz and above. Both the recorder and microphone are enclosed in rugged, waterproof polycarbonate suitable for outside use. Prior to recording, all equipment was checked and calibrated with the Wildlife Acoustics Ultrasonic Calibrator in both CAL and CHIRP modes and the correct date and time were set on each recorder. For each recording, the SM4BAT-FS recorder's 16 kHz hi-pass filter was disabled, the option for continuous recording at a 500 kHz sample rate was set, and the compression-less WAV recording format was chosen.

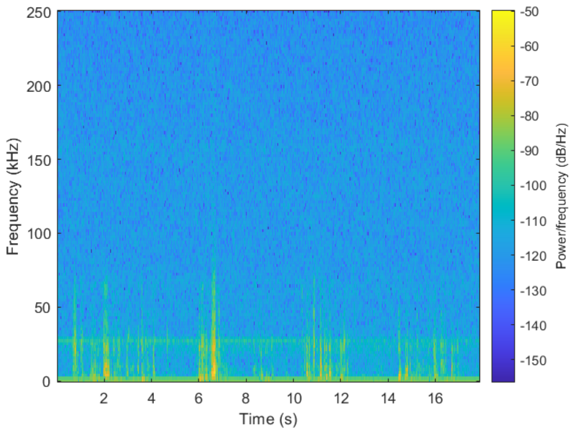
3.3 Analysis

In our analysis, we elected to use average band power in the frequency range 20 kHz to 200 kHz as a measure of the amount of ultrasound in each of the six locations (five urban and one rural) where recordings were made. Both the absolute average band power between 20 kHz and 200 kHz and the percentage of the average band power in this frequency range comprising the total average band power from 0 kHz to 200 kHz are reported. Because the absolute average band power for ultrasound is rather low in most natural environments (i.e., not technologically mediated ones such as when near an ultrasonic scanner, cf., Leighton [11] category 2), the percentage indicates how significant this amount is with respect to the total average band power recorded – this is particularly important at night, for example, where the absolute average band power in the ultrasonic range may remain low but nonetheless may make up a considerable amount of the overall sound present. For example, the absolute average power found in the evening recording of location C (shown in Figure 3) is extremely small at 1.04e-05W and the percentage of power in the ultrasonic range that makes up the total power of the signal is 1.48e-04. For comparison, the average band power of the motion detector (shown in Figure 1) in the range of 20 kHz to 50 kHz is considerably higher at 0.0259 Watts and the percentage of power in this range that makes up the total power of the signal is 99.955. It is important to note that when analyzing the recordings, we were unable to load each 2GB (approx. 32 minutes) recording in full due to insufficient computer memory, so we loaded $5,000,000$ samples randomly selected from each recording and computed our measurements from this subset. This approach further reduced the computation time needed.

4 RESULTS AND DISCUSSION

As a first step in our analysis, we looked at the amount of ultrasound present at each hour of the day over the course of a week at each of our five urban locations. Figure 4(a) shows the hourly average power of ultrasound averaged over the course of a week at five urban locations in Aalborg, Denmark while (b) shows this same average power as a percentage of the total average power. Note that while the average powers of locations are aligned by hour, the corresponding days over the week-long period might not be the same as the recordings were made during different weeks.

It is important to note that we should not expect to find high levels of power in the ultrasonic range under ordinary environmental conditions as natural airborne sources of ultrasound are generally low in intensity and such sound attenuates quickly in air, so the low power observed in Figure 4(a) is not surprising. What is interesting to note, however, are the relative contours of average power observed at each location. We can see, for example, that the contours for all locations remain relatively flat with each having only a few 'spikes' in power. Interestingly, these spikes are found at different times for each location with location B having a significant increase at 01:00 followed by fourteen hours of relatively flat activity while location C has a significant increase at 06:00 and 08:00 followed by twelve hours of relatively constant activity. Locations A and D are notable for having comparatively fewer periods of constant activity and location E is notable for having the highest increase



(a)

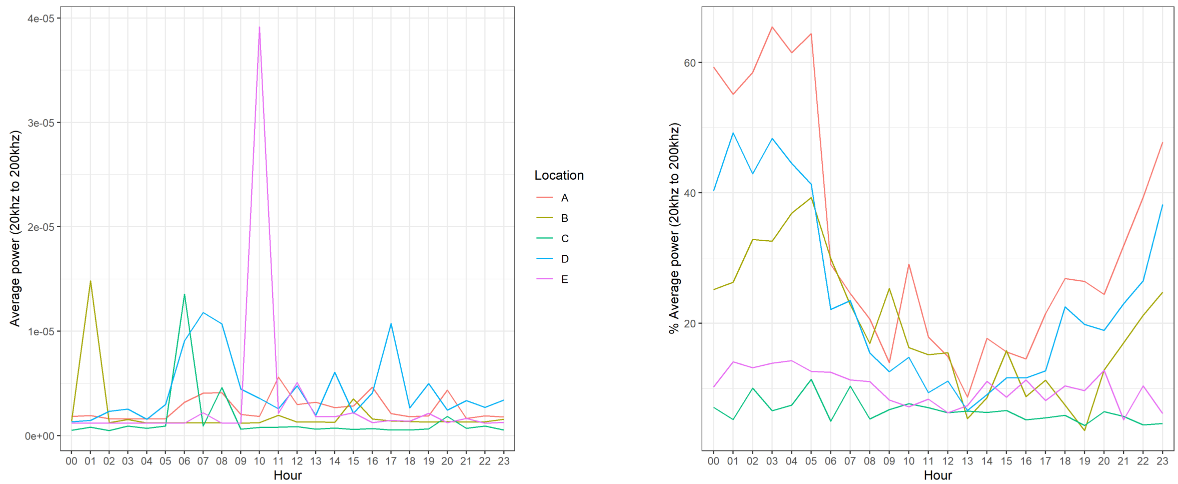
(b)

Figure 3: Spectrogram of an excerpt from the continuous ultrasound recording in (a) made at location C in (b).

in activity at 10:00. Moreover, if we look at Figure 4(b), we can see that as a percentage of the total average power in their recordings, locations A, B, and D have the highest overall contributions from ultrasound. Despite the sharp increase in absolute power observed in location E, as a percentage of the overall power, this location has one of the two lowest contributions of ultrasound along with location C – both of which remain rather steady in their activity. Under the assumption that traffic and human activity are the primary sources of urban ultrasound, this finding could be explained by the fact that both location C and E reside furthest away from any major roadways while locations A, B, and D all reside closest to such streets. Interestingly, we can see for all locations (but most notably for locations A, B, and D), that the greatest percentage of ultrasound was found in the middle of the night approximately between the hours of 20:00 and 06:00 with the most significant drop in percentage occurring at 13:00. This trend was consistent for all locations except C (and perhaps also E) which is in the heart of the pedestrian walking area of the city center and the furthest away from busy main streets.

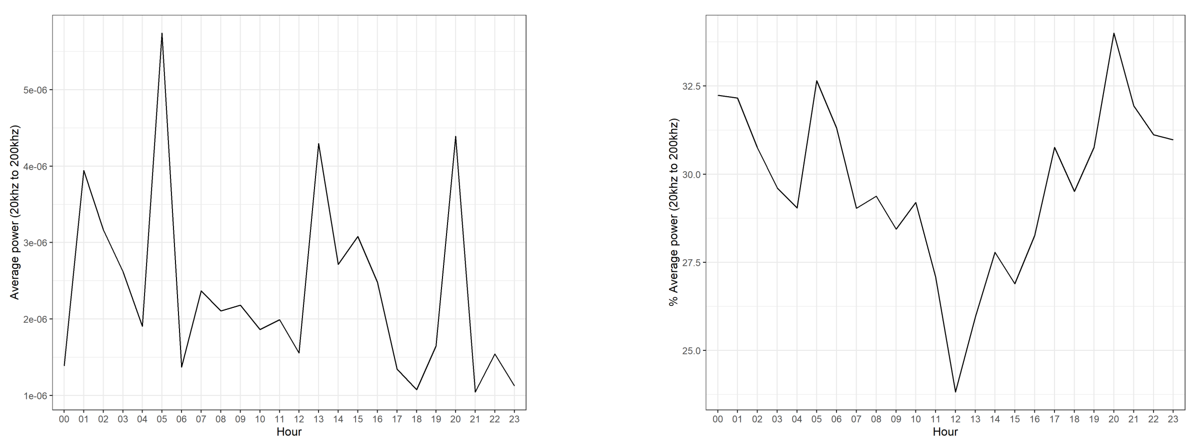
For comparison with our findings in urban spaces, we can look at the amount of ultrasound in our rural area outside of the Aalborg city center (latitude: 57.248886; longitude: 10.198458). Figure 5(a) shows the hourly average power of ultrasound averaged over the course of a week in a rural location outside of Aalborg, Denmark while (b) shows this same average power as a percentage of the total average power. We can see that the absolute average power at Figure 5(a) is on an order of magnitude lower than the average power found in the urban locations (shown in Figure 4) which suggests that the greatest sources of ultrasound in northern Denmark, as measured by power, may be those predominately found in urban environments. However, the absolute average power is considerably more varied than in many of the urban locations, with more frequent and sporadic increases in the detected ultrasound suggesting a less constant level of activity in this frequency range. If we look at Figure 5(b), we can see moreover that the percentage of average power comprising the total power present in the rural location is approximately equal to the average of percentages observed in the urban locations, relative to their different absolute average powers. We might expect to see these findings, however, given the differences in levels of human presence and activity between urban and rural locations.

As this was an exploratory study, we will conclude with a reflection on several aspects of our employed methodology, the nature of ultrasound, and the technical issues that may have arisen when recording such sound in urban spaces. Our original intention for disabling the 16 kHz hi-pass filter on the SM4BAT-FS recorder and electing to use continuous recordings rather than triggered recordings (that begin when sounds above a certain threshold are detected) was to also capture human-audible sound so that we could get a general idea of how much of the ultrasonic sound is a by-product of sources that also generate sound within the range of normal human hearing (e.g., cars) and how much of this sound exists entirely within the ultrasonic frequency range. Without a more thorough analysis, it would not be possible to draw any definitive conclusions, but in looking at Figure 3, for example, we can see that the ultrasound does indeed appear to be highly correlated with sources in the audible range. A possibly more significant issue concerns the approximately 50 dB sensitivity drop of the SMM-U2 microphone above approximately 100 kHz. Due to the relatively quick attenuation of ultrasonic frequencies and the recording height above street level at our locations, it may be that there is a considerably greater amount of ultrasound above (or indeed below) 100 kHz than was recorded with the SMM-U2.



(a) (b)

Figure 4: Hourly average power of ultrasound in (a) and percentage of average power of ultrasound (compared to total average power) in (b) averaged over the course of a week at five urban locations in Aalborg, Denmark.



(a) (b)

Figure 5: Hourly average power of ultrasound in (a) and percentage of average power of ultrasound (compared to total average power) in (b) averaged over the course of a week at a rural location outside of Aalborg, Denmark.

It is quite possible that more precise (i.e., flatter frequency response) results might have been obtained had we elected to use other available ultrasound recording technology. For example, Brüel & Kjær market systems capable of recording up to 140 kHz (see, e.g., https://www.bksv.com/en/instruments/daq-data-acquisition/lan-xi-daq-system/daq-modules/type-3052 and https://www.bksv.com/en/transducers/acoustic/microphones/microphone-set), but these are unfortunately prohibitively expensive for an exploratory study and are neither suitable for outdoor locations nor robust enough for extended use.

5 CONCLUSION AND FUTURE WORK

In this paper, we presented an exploratory study aimed at measuring the presence of often overlooked ultrasound in urban spaces. We collected continuous ultrasound recordings over the course of approximately a week at five urban locations in Aalborg and one rural location outside the city. Our results indicate that there is indeed ultrasound present in both urban and rural spaces that warrants further investigation. In most urban locations, there were significant increases in ultrasound, as measured by absolute average power, at certain times of the day with more or less a lower constant presence at locations that were furthest from major streets

– suggesting traffic as a possible source. As a percentage of the overall average power found in both the urban and rural recordings, however, the highest percentages of ultrasound were found during the night and the lowest percentages were found during midday. In future work, it would be interesting to investigate the actual sources of ultrasound – both plant and animal and technological – found in urban ultrasoundscapes. This would serve to lay the groundwork for the possible development of new datasets of urban ultrasonic sources with sustainable biodiversity in mind that could be used to, for example, train machine-listening algorithms to detect and classify these sources, as is already being done extensively with human-audible sound in large cities [5], or to correlate the human-audible sources of noise pollution in cities already well studied with the presence and intensity of ultrasonic sources.

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