Using soundscape assessment tools to determine the impact of industrial noise in quiet areas

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ABSTRACT

This paper reports an attempt to use soundscape assessment tools to investigate the impact of industrial noise in a quiet area. The conservation of quiet areas is encouraged due to their positive effects on health. However, typically the assessment of industrial noise neither promotes the conservation of quiet areas nor quantifies the impact on the restorative qualities of natural soundscapes. Assessing industrial noise with soundscape tools could allow for the consideration of context and the impact on restorative qualities.

Soundwalks were conducted in accordance with ISO 12913-2 with eleven participants in a remote part of Scotland both with and without an industrial source present. The effects of context are found to be key to the impact of industrial noise and, contrary to guidance, intrusiveness is no less relevant in low background sound level environments. Naturalness was the most important perceptual rating scale, accounting for 29% of the total variance, despite not being recommended in ISO 12913-2. However, the spectral centroid and music-likeness, objective metrics that could allow for simplified identification of natural soundscapes, are not found to be reliable indicators.

INTRODUCTION

Recent EU [1] and UK [2] policy, as well as recommendations by the World Health Organisation (WHO) [3], promotes the preservation of areas unspoilt by anthropogenic noise. However, there is no commonly adopted definition of these areas, nor any guidelines on how to implement or regulate any protection.

Conversely, the assessment of industrial noise in the UK suggests that absolute levels might be a better indicator of impact in low background sound level environments than its relationship with background, the recommended assessment method in normal conditions [4]. The use of an absolute threshold in low background sound level environments could lead to high levels of industrial noise relative to background sound levels and be audible at significant distances. This method of assessment conflicts with recommendations to promote and preserve areas unspoilt by anthropogenic noise.

The field of soundscapes offers a novel opportunity to assess the aural environment and its perceptual value. Assessing the acoustics of an environment through soundscapes allows for full consideration of the context and can provide information on the perceived value of the soundscape influencing any decisions on its protection.

NATURAL SOUNDSCAPES AND QUIET AREAS IN OPEN COUNTRY

Losses in the perceived quality of an area due to degradation of soundscapes is often not considered, or is at least secondary to the more researched area of the impact on health of exposure to high levels of noise [5], despite the fact that positive soundscapes have been shown to result in beneficial health outcomes.

In particular, natural soundscapes have been found to result in alleviation of stress, better self-reported health [6], increased recovery speeds [7] and an improvement in well-being [8]. Positive soundscapes have been found to increase calmness and relaxation, irrespective of continuous equivalent sound pressure level [9]. Naturalness, pleasantness and calmness have been shown to be key restorative elements of soundscapes [10]. It is therefore of interest to preserve positive soundscapes where possible, or design them where feasible. There is significant value in access to natural or pleasing soundscapes, both in subjective preference, with a high proportion of the population wanting their protection [11], and also in monetary value [12]. Degradation of the natural soundscape has been linked to declining inclinations to preserve rural or wild areas [13] and reduced enjoyment of these areas [14] while the presence of anthropogenic noise can detract from the visual perception of scenic areas [15].

The European Noise Directive (END) [1] necessitates the protection of quiet areas in open country, defined as:

> *"A quiet area in open country shall mean an area, delimited by the competent authority, that is undisturbed by noise from traffic, industry or recreation."*

This definition is fundamentally different to that of quiet areas in urban areas, which is dependent on an absolute noise level. The definition of quiet areas in open country suggests that the acoustic environment should be dominated by natural sounds [16]. The relationship between the two concepts of quiet areas in open country and natural soundscapes in general suggests that the former might be identified by using soundscape tools [17].

The lack of rigid definition of quiet areas in open country allows for member states to consider what is appropriate for them. Some member states have advocated identifying quiet areas in open country through acoustic metrics [7]. While this technique is relatively simple [18], there are drawbacks in that only major noise sources are considered, noise propagation models are less accurate at larger distances, the integration of industrial noise in the models is limited, and there is limited consideration of context or prevailing background conditions.

Sweden and the Dender-Mark area of Belgium propose identifying quiet areas in open country through the assessment of soundscapes. This provides a framework in which the value of the environment can be considered, enabling a prioritisation of resources [19], while also considering prevailing background sound levels and context.

Hybrid methods have also been proposed, such as that by De Coensel and Botteldooren [20], which considers a holistic evaluation of the environment, the presence of disturbing sounds, background sound levels ($L_{A90,T}$), a measure of pleasingness (music-likeness), the spectral

centroid, noise event counts and the biological and scenic value of the area. The spectral centroid is suggested as a possible metric to report in ISO 12913-2 [21].

A particular type of quiet area in open country is one with particularly low background sound levels, typically remote and barren areas with low density of wildlife [22]. These soundscapes are typically perceived as being uncomfortable. In these environments, anthropogenic sources can still be audible with an associated impact, even if their sound pressure level is extremely low [23]. Low background soundscapes therefore form a particular type of quiet area in open country or natural soundscapes where normal assumptions about appropriate sound pressure levels from anthropogenic sources might not be valid.

INDUSTRIAL NOISE

The END necessitates the inclusion of industrial sources in noise mapping and is reported with the same criteria as transportation noise. However, the perception and impact of industrial noise should not be rated against the same criteria as transportation noise [3].

The nature of industrial activities means that their auditory perception is inherently varied and related to the specific works being carried out. As a result, industrial noise does not lend itself to reliable noise annoyance curves. This increased sensitivity is due to the character of industrial noise [24], with residents becoming highly attuned to sources perceived as the most annoying, even at low levels [8].

The intrusiveness of a source (the difference in the source level over background sound level) has been found to be a more stable indicator of annoyance than its absolute level. The correlation between intrusiveness and annoyance can be enhanced through the use of character correction penalties [25]. However, intrusiveness models generally do not account for whether the spectrum of the background sound masks that of the industrial noise, often leading to misleading conclusions [26].

In the UK, the assessment of industrial noise is based on its intrusiveness accounting for character corrections [4]. However, it is recommended that where background sound levels and rating levels are low it might be more appropriate to determine the impact based on the absolute levels rather than the exceedance of rating sound level over background sound level. This is at odds with the END and the Noise Policy Statement for England, both of which promote the preservation of quiet areas, and is not consistent with the perceived annoyance of industrial noise.

While there is a limited body of research into the potential impacts of low levels of industrial noise in areas of low background sound [27], implications can be inferred. Low level sources can be found to be disproportionately annoying [28] and the character of a sound is of increasing importance in determining annoyance at lower levels [29]. Areas of low background sound are likely to be in rural or natural areas where an industrial activity is more likely to be incongruent with the landscape, which can lead to reduced acceptability of [30] or increased disappointment in [20] the perceived soundscape. The introduction of a subjectively dominant source is likely to alter the perception of a natural soundscape [31], particularly given that the type of background, and therefore its context, affects the relationship between intrusiveness and annoyance [28]. There is evidence to suggest that annoying sounds can lead to a loss of ability to relax and a resultant delayed sleep onset [32], which can lead to chronic sleep disturbance [33], irrespective of absolute sound pressure level.

As industrial noise is perceived to be more annoying in isolation than alongside natural sounds [28], in areas of particularly low background sound levels, it is possible that impacts are understated, particularly given that sound level meters are typically only valid for levels above approximately 25 dB(A). While concerns regarding how to assess industrial noise in low background sound environments in the UK were raised prior to the revision of PPG24 [34], no justified guidance has been drafted that addresses this. It has been suggested that assessment methods, other than those derived from noise annoyance curves might be appropriate [34]. Soundscape studies could provide a holistic framework through which the impact of low level industrial noise in low background sound environments could be assessed considering context, while also avoiding the innate difficulties in accurately measuring low sound pressure levels with readily available sound level meters [14].

EXPERIMENTAL DESIGN

An experiment was designed to test the following hypotheses:

- Soundscape assessment provides useful tools for determining the impact of industrial noise in quiet areas of open country, by considering context and alleviating the difficulties of measuring low sound pressure levels.
- The assessment of quiet areas in open country and natural soundscapes requires a different set of rating scales to those identified for urban soundscapes or those recommended by ISO 12913-2.
- The perception of industrial noise does not justify different assessment methods for low and normal background sound level environments.
- The spectral centroid and music-likeness provide an indication of the quietness of an area of open country or the naturalness of a soundscape.

Selection of appropriate location

A site was identified based on previous experience of industrial operations in quiet areas. The industrial source is an electricity substation, which was considered suitable due to its continuous operation with consistent noise levels.

The natural soundscape location is dominated by forestry, streams and unkept land. While the presence of commercial forestry could technically constitute an industrial location, its visual perception was noted to be faux-natural, with no forestry works going on during the survey period. The industrial soundscape was identified as being similarly located in an area surrounded by commercial forestry, with streams and unkept land. The primary difference in the landscape was noted to be the presence of the substation and surrounding pylons.

Soundwalks

The assessment of soundscapes was conducted in accordance with the principles of ISO 12913-2. The assessment method of soundwalks was considered to be appropriate due to the full consideration of context within the natural environment.

The first soundwalk method of ISO 12913-2 was used due to the increased focus on understanding the reasoning behind the rating of soundscapes. As soundscape descriptors vary between settings, particularly with regard to rural or urban settings [35], a number of additional metrics to those recommended in ISO 12913-2, as shown in Table 1 [36], were

identified as valuable and collected. A number of questions identified within the literature [19] [37] [38] were posed to the participants to understand their experience with similar soundscapes, their perception of the land use or to identify reasons behind any trends in the data. General questions regarding the participants and their perception of the area were asked before each survey, with the soundwalk responses completed following each soundwalk. In all cases the participants conducted the natural soundwalk at approximately 21:00 followed by the industrial soundwalk at approximately 21:30.

Table 1: Collected Metrics

Perceptual Scales		**Objective Scales**	
Quality and context	Quality	Sound pressure metrics	$L_{Aeq,T}$
	Appropriateness		$L_{Ceq,T}$
	Acceptability		$L_{Af5,T}$
Perceived affective quality	Pleasant		$L_{Af10,T}$
	Chaotic		$L_{Af90,T}$
	Vibrant		$L_{Af95,T}$
	Uneventful	Psychoacoustic loudness models	N_{rmc}
	Calm		N_5
	Annoying		N_{90}
	Eventful		N_{95}
	Monotonous	Psychoacoustic qualities	Tonal audibility
	Comfortable		Sharpness
	Natural	Natural soundscape indicators	Spectral centroid
	Boring		Music-likeness
	Meaningful		
	Calming		
	Varied		
	Far		
	Directional		
	Spacious		
	Dynamic		
	Familiar		

The soundwalk routes are shown in Figure 1. The acoustic environments were noted to be largely similar with the exception of noise from the substation, with slightly more running water audible in the industrial soundscape.

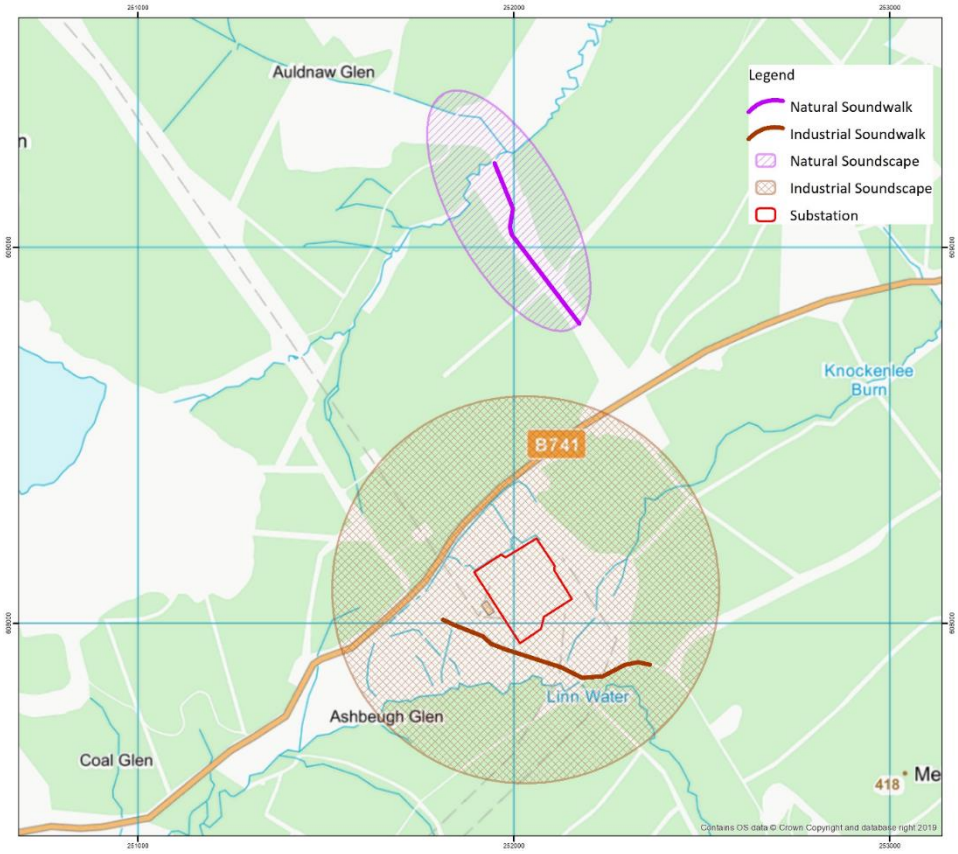

Figure 1: Study soundscapes and soundwalk routes

Eleven participants carried out the soundwalk in groups of no larger than four. The age of participants ranged from 28 to 66, with six men and five women. Weather conditions were variable, with soundwalks conducted in both dry and wet conditions.

Data Processing

Calibrated audio recordings were carried out with a Type 1 sound level meter at a bit depth of 24-bits and a 48 kHz sampling resolution. From these, the acoustic and psychoacoustic metrics recommended in ISO 12913-2 were calculated in MATLAB alongside the spectral centroid and music-likeness. All collected objective metrics are presented in Table 1. Tonality was assessed using the tonal audibility metric detailed in BS 4142:2014 to allow for a comparison with a typical assessment for industrial noise.

As the collected participant response data was ordinal rather than linear, non-parametric statistical analyses methods are used to process the results. Significantly different results are found using the Mann-Whitney U Test. A significance level, alpha, of 5% is considered in line with best practice. However, a Bonferroni procedure is applied to control experiment-wise errors due to the number of variables. Acoustic metrics were tested for normal distribution using a chi-squared test to ensure the validity of a parametric two-sided test of significance.

RESULTS

No significant differences were found for the responses due to age, rural or urban residence, professional experience in acoustics or due to rainfall. In investigating the effect of rainfall on acoustic and psychoacoustic parameters, only in the natural soundscape were any significantly different results found between dry and wet conditions, with the $L_{Af10,T}$, $L_{Af90,T}$ and $L_{Af95,T}$ found to be lower in dry conditions, although trends identified higher sound levels and loudness in wet conditions.

Other noise, which includes industrial noise, was perceived to be significantly more perceptible in the industrial soundscape, while none of the other sources varied significantly, suggesting that the soundscapes were perceived similarly with the exception of the industrial noise. While not significant, there was a small decrease in natural sounds perceived in the industrial soundscape which was not noted by the surveyor, suggesting informational masking due to the industrial noise.

The introduction of the industrial noise into the natural soundscape resulted in a significantly worse soundscape, which was significantly less appropriate and less acceptable than that of the natural soundscape. These results were reflected in perceived uses of the space, with the majority stating they would use the natural soundscape for recreational purposes and the majority suggested they would avoid the industrial soundscape. Almost all participants stated that the natural landscape looked positive, while the majority described the landscape with industrial uses as being either bad or ruined by the industry. While both landscapes showed similar evidence of being used for commercial forestry, the participants overwhelmingly described the primary use of the industrial landscape as being for the electrical industry as opposed to forestry.

Analysis of the perceived affective quality found that the industrial soundscape was significantly less pleasant, calm, comfortable, natural and calming. The industrial soundscape was also found to be significantly more annoying and monotonous. Open questioning found the participants to feel calm, content, curious and relaxed in the natural soundscape, while unwelcome and unsettled in the industrial soundscape.

Principal component analysis found that over 60% of variance in the description of the soundscapes was attributable to natural (29%), pleasant (18%) and calming (14%). The inclusion of annoying (11%) and monotonous (9%) brings the total variance to over 80%.

While the differences were not significant, the sound pressure level and loudness were generally higher in the industrial soundscape than in the natural soundscape. Participants noted the natural soundscape to be as quiet or less quiet than expected, while there was a larger disparity in the perceived loudness of the industrial soundscape, with none finding it to meet expectations.

The psychoacoustic metrics found higher tonal audibility and lower sharpness in the industrial soundscape than the natural soundscape, as expected due to the low frequency tonal noise of electrical substations, although not significantly so.

While the results of the soundscape indicators were not significant, trends were identified. The spectral centroid was found to be lower in the industrial soundscape than the natural soundscape and the music-likeness was higher in the industrial soundscape.

While it was not the purpose of the soundwalks to conduct an assessment in accordance with BS 4142, some commentary on how the results differ from the outcomes of an assessment of this type is useful. Measurements to determine the specific sound level were not conducted

according to the principles of BS 4142. However, as noise from supergrid transformers is known to be at 100 Hz and harmonics thereof, an approximation of specific sound level has been determined by summing all energy at harmonics of 100 Hz ±5 Hz. The rating level has been calculated by applying a tonal penalty derived from the calculated tonal audibility. The rating level is compared against the background sound level collected on the natural soundwalk, which is considered as a surrogate location. A range of excesses were measured with a mean of -6 dB, indicating a low likelihood of adverse impact.

DISCUSSION

The consideration of context in the assessment of industrial noise is encouraged in the UK, however with limited guidance on how to do so. The use of soundscape assessment tools allows for the consideration of context, through visual aspects, perceived land use and effects of informational masking. While an assessment of industrial noise in line with BS 4142 suggests a low likelihood of adverse impact, 40% of the participants found the industrial soundscape to be annoying, suggesting a likely adverse impact.

Using soundscape assessment tools, the impact of industrial noise on quiet areas can be quantified. While currently this doesn't provide a means to predict the impact on quiet areas, therefore promoting their conservation in line with guidelines, this does encourage research into predictive tools, such as auralisations.

The key descriptors used to quantify the natural soundscape were natural, pleasant and calming. These descriptors have been identified [10] as being key restorative elements of natural soundscapes, suggesting that assessing these descriptors could allow for a quantification of the impact of industrial noise on the positive effects of natural soundscapes.

Principal component analysis identified the key perceived affective quality to be natural, which is not included as a recommended scale in ISO 12913-2. Metrics proposed by De Coensel and Botteldooren to indicate the naturalness of a soundscape were not found to be reliable indicators due to the frequency spectrum and temporally consistent nature of the industrial source in question.

In BS 4142 there is a suggestion that in areas of low background sound levels, or for sources with low specific levels, the intrusiveness of the sound might not be important. However, the results of the investigation did not find any correlation between perceived annoyance and background levels, which varied from 28 to 41 dB $L_{A90,T}$, indicating that the impact of industrial noise is not greater in higher background sound environments for quiet areas in open country. Further, there was no significant correlation between perceived annoyance and the excess calculated in accordance with BS 4142.

CONCLUSIONS AND FURTHER WORK

The responses of the soundscape assessment indicated an adverse impact due to the industrial source, while the results of a BS 4142 assessment indicated a low likelihood of adverse impact. This shows a clear disparity between the outcomes of assessment methods. BS 4142 recommends considering the context of the environment when determining the impact, but does not provide clear recommendations on how to do this. Analysis of the

perceived affective quality of the industrial soundscape found a significant reduction in the key descriptors relating to the restorative qualities of natural soundscapes. This highlights the importance of the context being a natural soundscape to the perceived impact of the industrial noise. The findings suggest that using soundscape assessment methods to determine the impact of industrial noise in natural soundscapes or quiet areas in open country inherently considers the context.

None of the perceived attributes collected in this study, including annoyance, were related to any of the acoustic or psychoacoustic metrics collected. While BS 4142 suggests that in areas of low background sound, the absolute level of the industrial noise might be more appropriate than the margin by which it exceeds background, this statement was not confirmed by the present findings.

Principal component analysis identified the key perceived affective quality in the assessment to be naturalness, which is not recommended in ISO 12913-2, suggesting that the assessment method for natural or rural soundscapes might require additional rating scales.

The spectral centroid and music-likeness were not significantly different between the soundscapes, despite the soundscapes being perceived differently. Contrary to its proposed use, music-likeness was in fact found to be higher in the industrial soundscape than in the natural soundscape.

Access to quiet areas is important to the wellbeing of many people. The presence of even very low levels of industrial noise can significantly affect how people perceive an otherwise quiet area. However, the experiment described here has shown that this effect is not well understood. Further work should be carried out to explore the use of soundscape assessment tools in determining the impact of industrial noise in quiet areas. The study should be expanded to include a higher number of participants and the findings should be validated either through listening tests or interviews. The annoyance of industrial noise should also be validated using the methodology of ISO/TS 15666. The assessment should be repeated for different sources of industrial noise, which would verify the findings and also provide more information on the reliability of the spectral centroid and music-likeness.

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