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The Quiet Rural Soundscape and How to Characterize it

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Summary
Inhabitants of densely populated cities may benefit from the occasional visit to a restorative environment. The soundscape of this environment may add to the restorative and appealing power of the area. In European directives and policy intentions of many countries, the preservation and management of quiet areas has been subscribed. Nevertheless there is little scientific knowledge on how to characterize such areas and possibly grant quality labels. In this manuscript the quiet rural soundscape is studied within its specific context: non-acoustical environment, use… Several indicators for its characterization are derived from a theoretical point of view. These indicators are tested on usability in a particular case study. This leads us to proposing a multi-criteria assessment of quality labels for the quiet rural soundscape.

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1. Introduction

The concept of quiet area (QA) has been introduced in many countries' legislation and is more recently mentioned explicitly in the European Environmental Noise Directive [1]. This document defines: *"Quiet area in an agglomeration" shall mean an area, delimited by the competent authority, for instance which is not exposed to a value of* L_{den} *or of another appropriate noise indicator greater than a certain value set by the Member State, from any noise source.* Similarly: *"Quiet area in open country" shall mean an area, delimited by the competent authority, that is undisturbed by noise from traffic, industry or recreational activities.* These definitions leave room for interpretation and critical reflection. The aim of this paper is to provide a starting point for this.

Since quiet areas are nothing but soundscapes which have the particular quality of quietness, it is worthwhile to bring the discussion on quiet area characterization, categorization, and quality labeling to the broader perspective of soundscape research. This work nevertheless focuses on the very particular context sketched in section 2.1: the quiet area in open country.

The study of soundscapes in general and quiet areas in particular can serve different purposes. Many of the papers in this special issue of Acta Acustica united with Acustica aim at scientific *understanding* from a psychological or sociological point of view. In policy planning, policy support, monitoring, and environmental impact assessment, indicators are commonly used. This paper looks in particular at indicators for characterizing the quiet rural soundscape. Deriving such indicators involves a delicate balance between scientific accuracy and practical applicability. Indicators should fulfil the general requirements for a good indicator (as proposed e.g. by the OECD): there should be a scientifically proven link between the effect one wants to quantify and the indicator; the indicator should be measurable at reasonable cost and preferably calculation models should be available; the indicator must be understandable by policy makers and the population at large. In addition, indicator-sets should highlight non-overlapping dimensions of the problem.

In section 2 we try to fulfil the first requirement: scientifically proven link between effect and indicator, mainly on the basis of an extended literature study. This literature study mainly focuses on soundscape research but also (mental) health related aspects are discussed. In section 3 the shortlist of possibly useful indicators is concretized, taking into account measurability, predictability and understandability for a broad public. The indicators are tested on a typical quiet rural soundscape and for comparison also on an urban area with particular focus on the non-overlap requirement. This section thus aims at proving that the selected indicator-set fulfils the additional requirements outlined in the previous paragraph. Section 4 discusses our findings and proposes a multi-criteria assessment of quiet rural soundscape quality.

2. Quiet areas from soundscape perspective

2.1. Defining the context

The soundscape concept has been introduced into the research of urban acoustic environments a few decades ago

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from an artistic angle [2, 3]. Since then, several authors have used the concept – but unfortunately also sometimes misused it – in their research on urban and rural sound fields, its perception and its effect on quality of life, well-being, and health. A comprehensive literature overview can be found in [4, 5]. As the name suggests, soundscapes have much in common with landscapes. Both combine physical characteristics with perception in a particular context and from a particular point of view. Studying them can lead to preservation of unique specimens or to the design of pleasing new ones. A quiet area can be regarded as a particular type of soundscape that is worth preserving because of a unique feature: *quietness*. Preserving a QA is as such not necessarily different from preserving other (typical) soundscapes. Hence we will from this point on refer to the quiet rural soundscape as the object of this study.

It has been stressed by many that a soundscape is always assessed within a context and that non-acoustical factors play an important role [6, 7]. These non-acoustical factors can be related to the physical environment (called the "enviroscape"), such as the visual setting or the presence of air pollution, or to personal factors (called the "psychscape"), such as noise sensitivity and attitude toward the noise source [8]. The term "psychscape" is used here in a slightly generalized form including the instantaneous state of mind. In this paper, the context is well-defined:

- The "enviroscape" is a rural one: combined agriculture and woodland, bushes, scattered farms and an occasional village, a small stream or other water features, low level roads and paths without or with very limited motorized traffic. Occasionally some infrastructure for quiet recreation such as horseback riding, cycling, sailing…
- The "psychscape" is the state of mind of people looking for quiet recreation, relaxation, quality time and mental restoration. In a small survey with visitors to a typical quiet rural area, enjoying landscape and nature, walking and cycling (physical exercise), enjoying the silence, relaxing, and studying plants and animals, were mentioned as important reasons for being in this area.

This context may look very limited in scope but it is of importance for many European city dwellers because it is *within reach* for "a day at the countryside" in most places. The great outdoors and large natural reserves are not reachable without travelling the better part of a day and thus have to be left for holiday periods.

2.2. Verbal descriptors

Reported work related to finding verbal descriptors for categorizing soundscapes differs strongly between holistic evaluations or event oriented evaluation. In [9] Raimbault *et al.* analyse lexical categories of wording used by both city planners and city-users in open interviews. They come to the conclusion that city-users tend to use most often "vocabulary of comparison" (noises, "noise of source" object, subject pronouns, assessment), "generic expressions" (noise, descriptions of spaciousness, descriptions of duration), and "human noises descriptions" (human voices, subject pronouns, assessment), in that order. This confirms the finding from earlier work that description of a soundscape includes components related to sounds or noises that are mainly linked to sources and components related to ambient or background sound [10]. In the quiet rural soundscape, the ambient or background noise becomes more important for several reasons. Long periods filled with a mixture of sounds will separate noises that can clearly be linked to specific sources. We have previously [11] put forward the hypothesis that *a feeling of quietness is determined by intervals of silence where silence itself is defined as the ambiance of a soundscape, the gap or distance, the auditory space between sound events.*

For an assessment of soundscapes, most researchers use a semantic differential (SD) [12, 13, 14, 15, 16, 17, 18, 19, 20]. As an indicator, the SD has properties that are of particular interest: measurability at reasonable cost, transparency for policy makers and the public at large. Moreover, it allows to force those questioned to assess the soundscape in a more holistic way and to go beyond the identification and description of sound sources. The words used often involve emotional reaction and feeling related to the acoustic field. As a scientific tool, open questionnaires yield much more valuable information. The analysis of the above mentioned field studies revealed principle components in the assessment of soundscapes. Although there are discrepancies between studies, Table I shows that at least some broad lines emerge. Discrepancies are not only attributable to the different use of wording but also to the range of soundscapes considered. A first factor, which seems to arise as the most important factor in all studies considered, is related to the pleasantness or loudness of the soundscape. A second factor is related to the temporal structure, the eventfulness or the activity of the soundscape. Next to these, a factor related to the familiarity with or the auditory expectation of the soundscape is often encountered [13, 14, 15], as well as a factor related to the spatial characteristics of the soundscape [12, 16] and a factor related to the spectrum or timbre of the soundscape [17].

2.3. Physical indicators

Based on the research results summarized in Table I, the sound strength is recognized as an important factor. A classical noise level indicator seems well suited to describe this first factor in the soundscape. However, this does not imply that the indicator should be L_{Aeq}. Statistical levels such as L_{A10} or N_{10}, the 10-percentile loudness level, may be more suitable [12]. Often, when a SD scale is used for validating a strength indicator, *quiet* is contrasted to *loud*, thus not leaving much room for an interpretation of *quiet* other than *not-loud*. In [21], the evaluation of many quiet and not-so-quiet rural areas by a single observer was compared to different level indicators. It was found that statistical levels between L_{A50} and L_{A95} were better predictors for quietness than L_{Aeq} or L_{A10}. In [22] a similar conclusion is drawn on the basis of the evaluation of the perception of quietness-loudness on 14 open urban spaces across Europe with about 500 participants per site. It is concluded

Table I. Factors emerging in analyses of soundscapes based on semantic differentials. *: Instead of using a fixed set of semantic differentials, the subjects had to give their own terms.

Research	Factor	Expl. variance	Description
Raimbault *et al.* [12]	1	67.0 %	Assessment (*pleasant* vs. *unpleasant*) linked to strength (*quiet* vs. *loud*)
	2	15.0 %	Sound dynamics: temporal balance (*steady* vs. *unsteady*), spatial arrangement (*organized* vs. *disorganized*)
	3	8.0 %	Spatial dimension (*little attending* vs. *very attending*, *far* vs. *nearby*) and clarity (*distinct* vs. *hubbub*)
Axelsson *et al.* [13]	1	49.0 %	Pleasantness (pleasant, appealing)
	2	19.0 %	Eventfulness (eventful, lively)
	3	6.0 %	Familiarity (ordinary, common, familiar)
Viollon *et al.* [14]	1	46.6 %	Affective impressions, preferences (pleasant, comfortable, rural, friendly, silent . . .)
	2	18.0 %	Activity due to sound presence of human beings (bustling, marked by living creatures. . .)
	3	11.6 %	Auditory expectations (unexpected, impression of falsehood)
	4	9.6 %	Quality of auditory information (informative, clear)
Kawai *et al.* [15]*	1	25.0 %	Preference (*irritating* vs. *relieving*, *unpleasant* vs. *pleasant*, *artificial* vs. *natural*)
	2	16.8 %	Activity (*lively* vs. *deserted*, *joyful* vs. *empty*, *exciting* vs. *gloomy*)
	3	9.2 %	Daily life (*common* vs. *strange*, *usual* vs. *special*, *daily* vs. *unusual*)
Västfjäll *et al.* [16]	1	-	(Un)pleasantness (annoying, dangerous, intrusive, hectic, loud, sharp)
	2	-	(Un)natural (surprising, traffic sound, single sources. . .)
	3	-	Time variation (rhythmic, reverberant, pulsating)
	4	-	Spatial impression (open, closed)
	5	-	Mechanical (mechanical, artificial)
	6	-	Time stability (continuous)
Zeitler *et al.* [17]	1	29.0 %	Evaluation (*ugly* vs. *beautiful*, *unpleasant* vs. *pleasant*, *calming* vs. *agitating*, *boring* vs. *exciting*, *gentle* vs. *harsh*, *pure* vs. *impure*, *soft* vs. *hard*)
	2	17.0 %	Timbre (*dark* vs. *light*, *low* vs. *high*, *muffled* vs. *shrill*, *dull* vs. *sharp*, *light* vs. *heavy*)
	3	16.0 %	Power (*weak* vs. *strong*, *soft* vs. *loud*, *flat* vs. *rumbling*)
	4	8.0 %	Temporal change (*unsteady* vs. *steady*, *smooth* vs. *rough*)

in this study that *the background sound level (L_{A90}) has been found to be an important index in evaluating soundscape in urban open public spaces – a lower background sound level can make people feel quieter.*

A second family of physical indicators could refer to the spectral content of the sound. Based on the analysis of timbre in music, the centre of gravity of the spectrum is proposed in [12]. Purely on the basis of knowledge on outdoor sound propagation, it can be assumed that this parameter relates to distance perception [23]. But it could also be a suitable indicator to distinguish between high fidelity and low fidelity soundscapes [24].

A third factor, emerging in almost all studies, is related to the temporal structure of the soundscape. An indicator for soundscape dynamics has already been proposed based on early music research [25, 26, 27]. Basically, the spectrum of the temporal envelope (loudness, short term L_{Aeq}) of the sound field is calculated. In [25], it was shown that in music, often a linear spectrum emerges on a log-log plot with a slope of about -1. Artificial music produced with this property also was perceived as the most appealing, compared to music which had a steeper (-2) or a flatter slope (0). This so called $1/f$ noise is ubiquitous in nature. Recently it was also found in the rural and urban soundscape [26], where this slope was linked to the complexity encountered in natural soundscapes. A direct link with the fractal dimension of the temporal envelope of the soundscape was also given. It has been suggested that music actually imitates the dynamics of natural soundscapes. Comparison of the slope and the deviation from a straight line found in music with those found in rural and urban soundscapes on a fuzzy basis, resulted in the formulation of a music-likeness indicator ML1[27]. This indicator represents the degree to which the temporal structure of the soundscape is "like the typical temporal structure of music".

A link with landscape preference gives some confidence that the fractal dimension of the temporal structure in rural soundscapes may be a good preference indicator. In [28], the landscape silhouette outline or horizon was studied, which can be considered as the landscape analogue to the temporal envelope of sound events in the soundscape. It was found that the fractal dimension of this silhouette outline serves well as a predictor of landscape aesthetic preference, because it is strongly related to naturalness.

Additional confidence in the choice of this indicator was found in recent neurophysiological work. In [29], the authors investigated the response of the primary auditory cortex (A1) to tonal complexes of different temporal characteristic. Random amplitude walks with power spectrum slope $1/f^{\gamma}$ with γ between 1 and 1.5 seemed to trigger a stronger overall firing rate, indicating that the primary auditory cortex is tuned to this type of temporal dynamic behaviour, commonly found in natural soundscapes [26]. The effect was most pronounced for the steady state response and for the onset. Offset response (one second after the stimulus) was strongest for lower powers, γ. The latter are indicative for more random, unpredictable amplitude variations. In [30] the authors analysed the response of millions of neuron firings using electroencephalograms (EEG) when a listener was exposed to sound with music-like dynamics. Using analysis of the EEG based on chaos theory, they conclude that in a first phase of listening to music-like sound the brain dynamics is *complex and chaotic*. After this first phase, which they call a learning phase, *the subjects exhibited more synchronous activities of fewer (brain)cell assemblies when listening to* $1/f$ *sound.* This more regular pattern of brain activity was also observed for other familiar sensory inputs. An additional result – of particular interest for us – was that amplitude variation resulted in stronger effects than pitch variation.

2.4. The quiet rural soundscape and human health

Mental health is recognized as a major problem for the health care systems in today's society and depression will become the second most costly illness after cardiovascular diseases by the year 2020 [31]. Stress induced by the work situation and by a disturbed person-environment relationship alike, could be relieved by accessing psychologically restorative environments. There is a growing body of evidence that a natural environment is preferred over an urban one for psychological restoration [32, 33, 34]. The difference between an urban and a natural environment is more specifically due to a difference in: presence of people, sound level, and aesthetic quality [34]. Although sound is mentioned here, it is rarely part of the laboratory experiments that often rely on visual material only to evoke a particular environment. In [35] video material is used, including an audio track containing sounds of birds and other animals to evoke the natural setting. Positive correlation between the video shown (after inducing stress and anxiety) and profile of mood states was observed. This study showed a significant advantage of natural environment on restoration from anxiety based stress and mental fatigue.

Although a direct relationship between natural soundscapes and psychological restoration has to our knowledge not been proven scientifically till today, the body of indirect evidence of its importance is strong. In experiments using visual material, the perceived restorative potential seems to play an important role in stating a preference [36]. It is safe to assume that the participants in a study that are shown a photograph of a natural scene, will mentally add a suitable soundscape during their evaluation, so a disturbed soundscape may lead to disappointment and a lesser restorative potential. In [37], the author concludes that *attentional capacity can be renewed in natural environments because natural environments are innately fascinating, they evoke a type of effect-less attention, a fascination that allows directed attention to rest and restore.* This indicates why perfect silence is not the preferred restoring soundscape. The presence of stimuli with natural spectral and dynamic characteristics is advantageous.

2.5. Indicator set for quality assessment of the quiet rural soundscape

Based on the discussion above, an indicator set for assessing the quality of quiet rural soundscapes is derived. The selected set contains:

1. holistic evaluation of the sound environment by visitors based on SD;
2. evaluation of presence and disturbing character of specific sounds (cars, agriculture…);
3. physical background level measured as a statistical level in the range L_{A90} to L_{A50};
4. physical measure for the naturalness or pleasing character of the temporal structure of the soundscape: slope of envelope power spectrum, or music-likeness;
5. physical measure of spectral content: centre of gravity of spectrum;
6. noise event counts, either manned or based on number of emergences over background;
7. non-acoustic factors such as the biological and scenic value or the congruence of the area.

Within this set, a possibly important dimension is missing: a physical indicator for the enveloping character of the soundscape, which involves binaural hearing. Such an indicator was not included because there was insufficient evidence of its applicability found in literature.

3. Comparing an urban area to a quiet rural area

In this section, the shortlist of indicators presented in the previous paragraph will be made more concrete and tested for applicability. Its use will be illustrated with results of a case study comparing a typical quiet rural area to an urban area. Aerial photographs of both study areas are shown in Figure 1. The quiet rural area considered, called the Dender-Mark quiet area, is situated in the southern part of Flanders. Extensive sound measurements in the past indicated a high quality soundscape. Because of the absence of traffic noise, exceptional low background noise levels can be measured during the day and night. The area is rather hilly, with heights above sea level varying from 15 m to 100 m, which results in a number of places with panoramic views. Several visible and less visible cultural relics are scattered through the area; several woodlands are present. Activities are mostly related to agriculture and leisure, although the area also has a residential character. The urban area considered is the city of Ghent. For surveys, points of interest scattered all over the city are used. For mapping purposes, part of Gentbrugge, a town in the agglomeration of Ghent, was chosen. This area contains local streets with

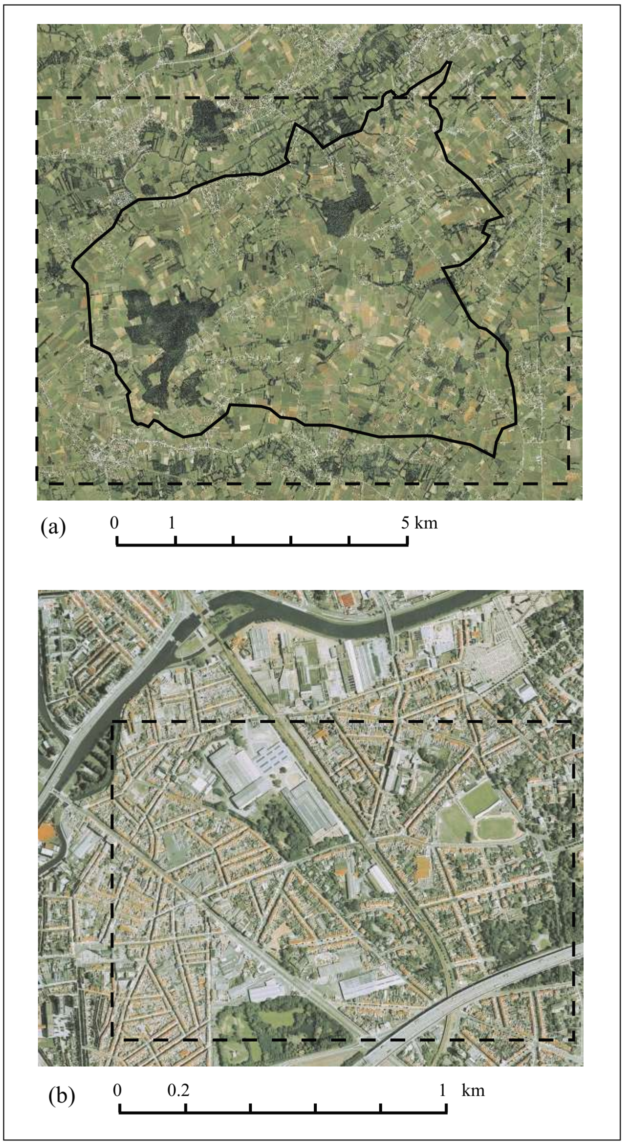

Figure 1. Aerial photographs of the study areas: (a) the quiet rural area Dender-Mark (outline of the area is shown in solid lines) and (b) the urban area Gentbrugge. The dashed lines delimit the area considered for the maps in Figures 4 and 6.

low and medium amounts of traffic and a district road. The E17 highway is crossing the area in the south east, and is situated on a viaduct about 20 m high, with noise barriers on both sides. A railroad is also crossing the area from the south to the north. The area has a mainly residential character; road traffic and daily life of the inhabitants are the main sources of noise.

3.1. Holistic evaluation of the sound environment by visitors based on SD

A 9-item SD questionnaire presented to 200 visitors at several locations in both study areas was used to query the holistic experience of the sound environment. A PCA analysis on all data revealed that two factors explain 68 % of variance. The first factor explains 52 % of variance and contains *silent* vs. *loud*, *natural* vs. *unnatural*, *relaxing* vs. *stressing*, *soft* vs. *rough*, *exciting* vs. *boring* and *open* vs. *enveloping*. The second factor explains 16 % of variance and focuses on *not sharp* vs. *sharp* and *complex* vs. *simple* but contains a mix of other dimensions as well. In Figure 2 the observations are plotted on these two dimensions. The first factor seems to be the most important one to distinguish the quiet rural soundscape. It fits most closely to the first factor found in the studies discussed in section 2.2, related to the pleasantness of the soundscape; high values of factor 1 indicate a more pleasant soundscape. The second factor could be linked to the eventfulness (complexity) of the soundscape, usually the second factor distinguished in the discussed literature. A low value for the second factor, indicating more simple (or clear) composition of the soundscape and more high frequency components, could be associated to high fidelity [3], and could help to assess the soundscape quality in more critical cases.

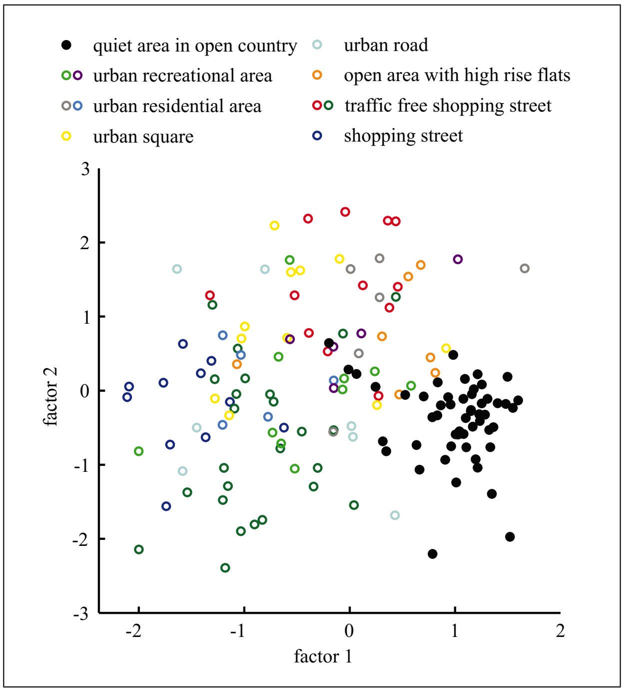

Figure 2. Factors extracted from a SD analysis of urban (10 locations) and quiet rural soundscapes.

The multidimensional assessment outperforms direct questioning on the quality of the quiet soundscape. A direct question (taken from [38]): “When thinking about the area where you have been walking/cycling, how would you describe the soundscape?” with an 11-point answering scale between “not at all silent” and “very silent” was also included in the survey in the quiet rural area. The Dutch word “stil” used in the questionnaire was translated to “silence” rather than to “quietness” because it is closer in meaning. It turned out that several participants had difficulties rating the sound field for silence when e.g. loud bird singing was heard. This observation contrasts to some extent with the analysis of the questions in the next sections, which clearly shows that bird song is evaluated as fitting very well in this environment.

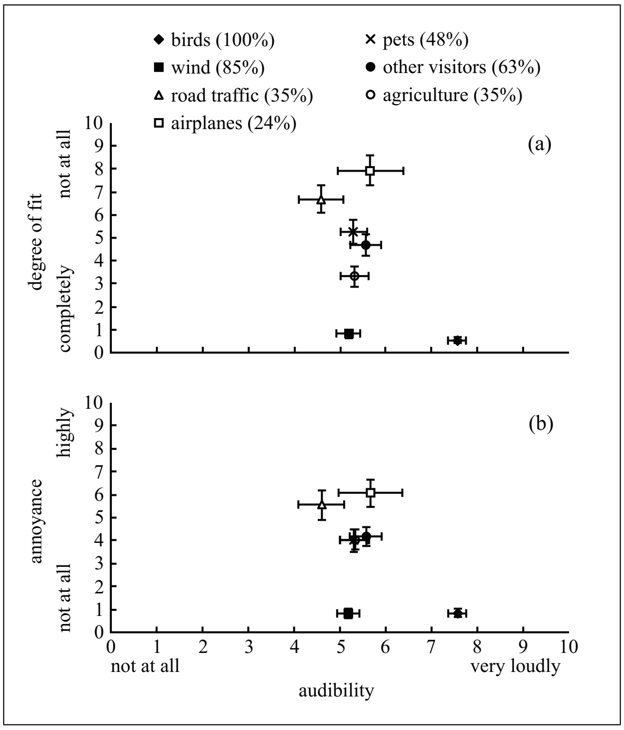

Figure 3. Audibility of various sounds, compared to (a) their degree of fit to the quiet rural environment and (b) the annoyance they cause. The percentage of the visitors that actually heard these sounds is given between brackets.

3.2. Evaluation of presence and disturbing character of specific sounds

The quiet rural soundscape is *not* silent. Visitors will hear a multitude of sounds that help to shape their overall appreciation. Some of these sounds may be experienced as completely compatible with the specific context of a quiet rural soundscape or they may even underline the quiet character of it. As part of the questionnaire discussed in the previous paragraph, visitors of the rural study area were (during their visit) asked about a set of sounds whether they heard them loudly while they were walking or cycling in this area. They were also asked whether these sounds fitted well in this area or not and whether they found these sounds annoying. An 11-point scale was used for formulating their answers. Figure 3 summarizes the results. Bird sounds and wind, although heard by many and rather loud, were rated in harmony with the environment. Road traffic noise and noise caused by airplanes do not fit well. Sounds produced by pets, agricultural activities, and other visitors are rated between fitting and not fitting. For annoyance, the trend is similar.

These results indicate the need for this indicator to be included in the proposed multi-criteria analysis. Loudness seems unimportant in the evaluation of the degree of fit and annoyance. This is in line with one of the main conclusions of [9] that meaning is of utmost importance. In contrast to the evaluation of urban soundscapes [39], the sound of human voices is judged on average somewhat unfitting and annoying in this quiet rural setting.

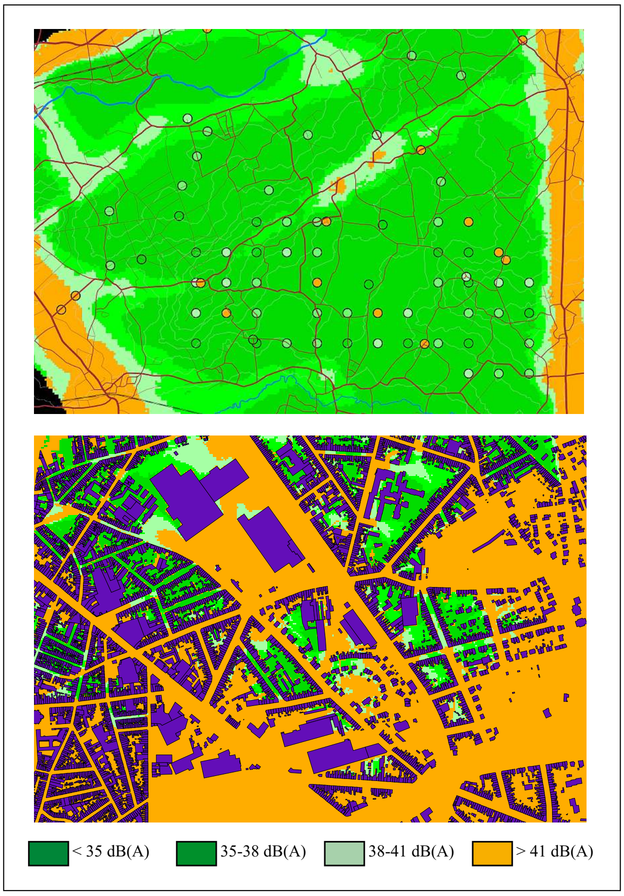

Figure 4. Road traffic L_{A50} maps of (a: top) the quiet rural area (measured values in circles) and (b: bottom) the urban area.

3.3. Physical background level measured as a statistical level in the range L_{A90} to L_{A50}

Based on the discussion above, a high-index statistical noise level was chosen as one of the physical indicators to quantify the quality of the quiet rural soundscape. In previous work [21] an L_{A50} of around 38 dB(A) was found to be suitable to predict the categorization in quiet and non-quiet areas by a noise expert. Thus we chose 35, 38, and 41 dB(A) as critical values. To investigate how this indicator works in practice, a road traffic L_{A50} map of the rural area and part of the urban area under study was calculated using the model based on traffic microsimulation introduced in [40] (Figure 4). In the rural area, the undulating terrain was taken into account for the sound propagation simulations. The main roads at the edges of the map remove quietness over an extent of about 500 m, but in the central area, traffic is not dense enough to influence L_{A50}. This picture is totally different from the more conventional L_{Aeq} maps. In the urban area, the background level is only low enough for the area to be a candidate quiet soundscape in a few secluded backyards. Note however that the map does not include other sound sources that might be present in these backyards.

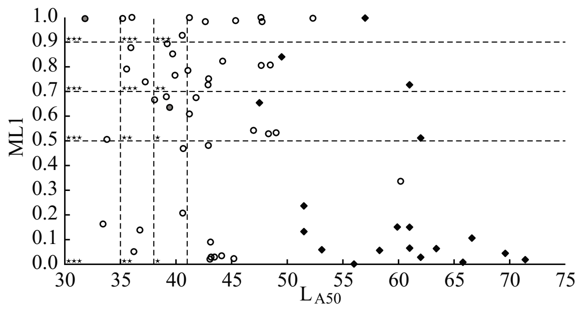

Figure 5. Music-likeness of the soundscape temporal structure versus L_{A50} for (♦) the urban area and (○) the rural quiet area. The gray circles are at the location of the survey; the dashed lines outline areas where a different quality label (stars) could be assigned.

3.4. Physical measure for the naturalness of the temporal structure of the soundscape

Based on the discussion in section 2, the second most important physical indicator for a quiet rural soundscape could be the slope of the power spectrum in the envelope of instantaneous noise levels. This indicator unravels into several conditions: linearity on a log-log scale of the power versus frequency plot; value of the slope of this linear fit. In addition the frequency interval over which the characteristic behaviour is checked is important. Since the typical envelope power spectrum is also observed in music, we defined the music-likeness of the soundscape in [27]. This quantity measures the resemblance of the soundscape dynamics to music dynamics. In particular, the frequency interval [0.002 Hz, 0.2 Hz] is selected and this is referred to as ML1 (see Appendix A1).

This indicator was measured in the urban and rural soundscape under study. The result of these measurements is shown in Figure 5. It is seen that the music-likeness is orthogonal to L_{A50}, indicating that quiet soundscapes do not necessarily have pleasing dynamics and vice versa. Nevertheless, there is a trend of finding more music-like soundscapes in the rural area. To categorize soundscapes, thresholds for ML1 are fixed at 0.5, 0.7 and 0.9 in a somewhat heuristic way.

In order to establish the possibility to predict music-likeness of soundscapes, road traffic noise levels were calculated on a per second basis for the rural area. This fluctuating level was mixed with the recorded noise level produced by birds singing in the countryside. The resemblance to music of the dynamics that was obtained is mapped in Figure 6(a). It becomes clear that only at very long distances to roads, the soundscape is music-like. Closer to the roads, the evolution of sound levels becomes too predictable. Near more busy roads there is some increase in ML1, but this can not be seen with the scales used in Figure 6. Measured sound level envelopes show slightly more music-like dynamics. This could be explained by the prevalence of natural sounds, which are not included in the map, and by complex dynamics of long distance sound propagation [26] not included in the noise propagation model used to produce the map.

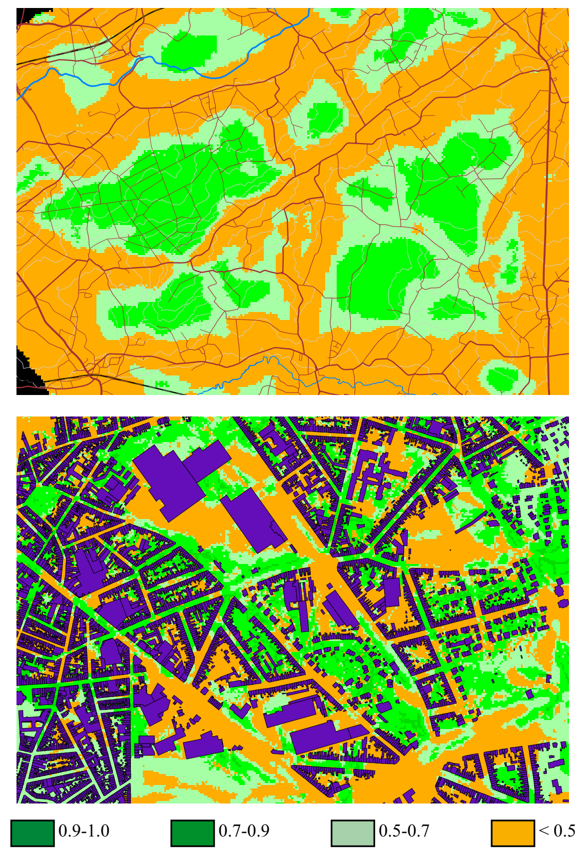

Figure 6. Music-like temporal structure ML1 in the soundscape of (a) the rural (road traffic noise + birds) and (b) the urban (road traffic noise) areas under consideration. Dark green values represent a high degree of music-likeness.

In the urban setting it is much more difficult to map the multitude of sound sources that make up the overall soundscape. Using road traffic noise alone, the map showing resemblence to music dynamics in Figure 6(b) is obtained. Even with only this single source, the picture already looks quite complicated. The main reason for this is that traffic dynamics may become complex, with a traffic intensity versus frequency characteristic that causes noise levels to fluctuate in a music-like way in the frequency range envisaged. This situation is found at densities close to road saturation.

3.5. Physical measure of spectral content: centre of gravity of spectrum

The unweighted spectrum *centre of gravity* or *centroïd* was proposed in [12] as an acoustic measure of the spectral content or timbre of the soundscape. It is calculated according to the following formula:

$$G = \frac{\sum_i \left[10^{L_i/10} \times B_i\right]}{\sum_i \left[10^{L_i/10}\right]}, \tag{1}$$

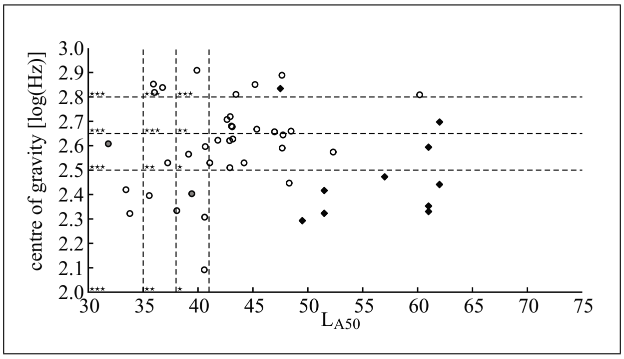

Figure 7. Centre of gravity of the spectrum of the soundscape versus L_{A50} for (♦) the urban area and (∘) the rural quiet area. The gray circles are at the location of the survey; the dashed lines outline areas where a different quality label (stars) could be assigned.

where L_i is the unweighted sound level in dB, measured for each third octave band, with centre frequency B_i ranging from 80 Hz to 8 kHz. The frequencies below 80 Hz were left out in [12] because outside acoustic measurements in urban environment were not consistent in this frequency range. To compensate for this, the spectrum was not weighted for the calculation of G. This indicator was calculated for various recordings made in the urban and rural soundscape under study. The results are contrasted to L_{A50} in Figure 7. It can be seen that also the centre of gravity of the spectrum is orthogonal to L_{A50}. There is a small trend of finding sound fields with higher timbre in the rural area. The rural measurements with $\log_{10} G < 2.5$ were mostly made near the roadside; the lowest rural dot corresponds to a recording where heavy agricultural vehicles could be heard. The 3 urban measurements with highest timbre were made in shopping streets without road traffic. The centre of gravity G therefore is a good measure for the degree of pollution of the soundscape with traffic noise.

3.6. Noise event count, manned or based on number of emergences over background

Noise events disrupt long periods of silence. However, they may or may not disturb the typical, natural quiet rural soundscape depending on their origin. Note that we consider disturbance of the soundscape to be a different experience, a different factor than the basic quality assessment. This view is inspired by the observation that most indicators for quietness are very little influenced by the presence and strength of noise events. Nevertheless, too many disturbances will harm the soundscape and thus an indicator should be included in the quality evaluation. To measure disturbance by noise events, usually it is suggested to count the number of noise events that do not fit into the soundscape (cf. Figure 3). Alternatively, the overall time that non-fitting sound events can be heard could be measured, or the mean duration of uninterrupted quietness.

To be able to count the number of non-fitting sound events automatically, a threshold value of e.g. 50 dB(A) could be set [41]. Alternatively, it could be assumed that once the sound level of a noise event decreases to more than 3 dB(A) below the background noise level, the noise event can not be heard. This is however only a first approximation of the binaural masking effect.

Due to the lack of accurate signal processing methods for the recognition of non-fitting sounds, especially if they are only marginally emerging from the background, an indicator based on such automatic recognition is not advisable. The sound field in natural environment will be composed of slowly varying background noise: wind, water and a multitude of rather short animal vocalisations. Intruding sounds (from cars, airplanes, etc.) will often consist of longer events. Thus a very transparent and easy recognition would consist of identifying disturbing noise events as events that emerge for at least 3 seconds from the instantaneous (30 second) background. Based on this assumption, a number of physical indicators were investigated in this study. The number of noise events N_{cn} is defined as the number of times the sound pressure level exceeds a threshold level; the total duration of the exceeding of this threshold is noted as T_{cn}. The threshold is set relative to the background (statistical) noise level. In several sound recordings in the quiet rural area under study, noise events of several origins were identified by a focused listener. For more continuous disturbances such as the murmur of distant traffic, each 30 seconds, the noises heard were noted down. Finally, the total time of the presence of non-fitting sound was summed. A linear regression analysis was done between the observations by the focused listener, and the sound pressure level based indicators. Results are summarized in Table II.

The number of vehicles heard at close distance correlates best with the number of sound events that exceed L_{A50} with 3 dB(A). Also, a calculation on the basis of exceeding L_{A95} with 10 dB(A) gives a good correlation. None of the indicators correlates with the duration traffic can be heard at larger distance during the measurement. The total duration that non-fitting sound events can be heard correlates somewhat with the number of times L_{A95} is exceeded by at least 3 dB(A), but no simple linear relation was found. From this analysis it can be concluded that the detection of the disturbance of a soundscape by non fitting sounds can only be done by a human observer or a more sophisticated source identification mechanism. If the scope is narrowed however to sporadic road traffic noise at short distance, counting the number of times the instantaneous background level measured as L_{A50} is exceeded during at least 3 seconds is the best alternative. Note that for noise mapping purposes, the problem of source identification is obsolete but knowing the overall (natural) background level is not trivial.

4. Discussion — Multi-criteria assessment

Based on the views condensed from literature in soundscape research and related fields, and based on the application in a case study, conclusions can be drawn concerning the categorization and quality labeling of the quiet ru-

Table II. Pearson correlation between results from a focused listener, and calculations based on the sound pressure level time series. The relative threshold is shown between brackets.

Indicator		Number of noise events caused by vehicles	Duration presence of noise of traffic at large distance	Duration presence of non-fitting sound
L_{A50}		0.36	0.05	0.01
L_{A10}		0.35	0.08	0.01
N_{cn}	(10 dB(A) above L_{A95})	0.53	0.07	0.09
N_{cn}	(3 dB(A) above L_{A95})	0.10	0.09	0.32
T_{cn}	(10 dB(A) above L_{A95})	0.28	0.03	0.07
T_{cn}	(3 dB(A) above L_{A95})	0.32	0.08	0.12
N_{cn}	(10 dB(A) above L_{A50})	0.20	0.02	0.12
N_{cn}	(3 dB(A) above L_{A50})	0.74	0.06	0.19
T_{cn}	(10 dB(A) above L_{A50})	0.05	0.03	0.07
T_{cn}	(3 dB(A) above L_{A50})	0.26	0.02	0.12

ral soundscape. In this work a very particular context was considered (section 2.1); however, we have the impression that the proposed set of indicators could also be used for assessing the quality of the acoustic environment in urban parks and other quieter areas. Proposed limit values will need to be adapted however.

The quiet rural soundscape finds its main societal value in its use for quiet recreation, it may benefit the general mental health of the population through its potential for psychological restoration, and it may help to reduce mental fatigue. These functions require this environment to be *within reach* of the city dweller. This leads us to propose a quality scale rather than to impose strict limits. It allows conserving or creating somewhat lesser quality quiet rural soundscapes that are more within reach and better ones that may be further away from densely populated living areas. In particular, if this policy were adopted at a European level, it would allow also to distinguish between member states with vast amounts of open area and smaller overpopulated ones.

A first set of criteria are the perception based criteria. They have the huge advantage that they sample the opinion of those visiting the area. A possible disadvantage is their limited spatial resolution, which makes them less useful for drawing detailed maps. The absence of calculation models jeopardises their use in impact assessment and policy action planning. The first proposed indicator in this category is based on a SD questionnaire. A factor related to the pleasantness, naturalness or quietness of the soundscape, derived by summing scores on SD's given in section 3.1, should score at least positive for minimal quality. It could be quite useful to add a second factor measuring the eventfulness or high fidelity of the soundscape, but this could not be established in the case study. Within the set of perception based criteria, it seems very useful to add a second criterion based on perception of non-fitting sounds. The most versatile way of including the degree-of-fit between sounds heard and the enviroscape/soundscape is to ask the users for it during the survey, at the same time that they are asked about the sounds they heard and how loud they were. The degree-of-fit question could then serve as a filter for the hearing/loudness question. If both are assessed using an 11-point scale, the simplest operation leading to such filtering would be to take the minimum of the degree-of-non-fitting and the overall loudness. A conceptually easier approach consists of the researcher deciding beforehand which sounds do not fit the soundscape. Whatever the method used, the average over all visitors of the overall loudness of any non-fitting sound should be below 1 if an 11-point answering scale is labeled 0 to 10 for minimal quality (single ⋆). Even stricter requirements need to be imposed for higher quality ranking.

A second class of indicators have a physical origin. These indicators have the advantage of easy measurability and predictability. Thus they can be used to clearly define the borders of the quiet rural area and to predict the impact of policy action plans. Nevertheless these indicators go beyond the classical L_{Aeq} and therefore require more extensive modeling. The case study however clearly showed that this modeling is feasible. In order of importance, we propose to include L_{A50} as a measure for the basic requirement that the background or ambient sound should have a low level; ML1 as an indicator for the dynamics of the soundscape linked to pleasing character and mental restorative potential; G for frequency content quantifying low frequency mechanical noise; and N_{cn}, the number of clearly noticeable non-fitting events, as a proxy for manned identification of sources. A first proposal for limit values for different quality categorization is given in Table III. For several of the criteria there are little studies to back up a solid proposal for these limits and more extensive research is required. These cases are clearly indicated.

A final category of indicators is related to non-acoustical factors. They are important to guarantee optimal use of the quiet rural soundscape. Firstly, the region must be sufficiently large without any disrupting infrastructure dividing it. This criterion is related to the recreational use. The proposed surface is based on a rough estimate of cycling/walking speed and required duration of a visit needed to experience the beneficial effect of the environment. The final criterion introduces biological, natural, and landscape value in the multi-criteria assessment. This is

Table III. Proposed criteria for assessing the quality of the quiet rural soundscape and proposed limit values. It is indicated (+) where more extensive research is required to refine the limits.

Indicator	Quality indication ⋆	⋆⋆	⋆⋆⋆	Importance
SD — pleasantness	to be investigated			high
non-fitting sounds	<1	<1+	<1+	medium
L_{A50}	<41 dB(A)	<38 dB(A)	<35 dB(A)	high
ML1	>0.5	>0.7	>0.9	medium
$\log_{10}(G)$	>2.5+	>2.65+	>2.8+	low
N_{cn} (during 15 minutes)	<20+	<10+	<5+	medium
congruent area	>10km²	>10km²+	>10km²+	low
biological/nature/landscape value	low	medium	high	medium

required, both because of well known inter-sensory effects and because a complete restorative environment is aimed for.

The multi-criteria quality assessment methodology proposed above and the selection of a complete set of indicators for this purpose is to our knowledge the first of its kind. It is derived for a particular context but could probably be extended to other context easily.

Appendix

A1. Calculation of music-likeness ML1

The calculation procedure starts from a time series of $L_{Aeq,1s}$ levels as the temporal envelope of the soundscape. The power spectrum S_L^2 of this series is then calculated using an FFT, applying a rectangular window with the same size as the time series, and removing the DC term. The total length of the time series determines the lower frequency bound of the resulting spectrum. As we are also interested in correlations between the sound events over longer timescales (several minutes), noise levels should be measured during a sufficiently long period. A minimum of 15 minutes is proposed, which will result in a lower bound of at least $2/(15 \cdot 60) = 0.002$ Hz.

Subsequently, the spectrum is smoothed to 12 data points per octave band. For this, the frequency axis is subdivided in 1/12th octave intervals, and the average power level in each interval is calculated (or interpolated if necessary). This will result in an equidistant spacing of the data points, when the spectrum is plotted on a log-log scale, which is necessary to make a correct linear regression (see Figure A1). A straight line is fitted through the resulting data points in the interval [0.002 Hz, 0.2 Hz] on a log-log scale, and the slope α and the rms value ϵ of the fitting error are calculated. Finally, the fuzzy correspondence of the parameters α and ϵ to typical values found in music [27] is calculated using the following formula:

$$\text{ML1} = f(\alpha, \sigma_{\alpha 1}, \rho_{\alpha 1}, \sigma_{\alpha 2}, \rho_{\alpha 2}) \cdot f(\epsilon, \sigma_{\epsilon 1}, \rho_{\epsilon 1}, \sigma_{\epsilon 2}, \rho_{\epsilon 2}) \quad \text{(A1)}$$

with

$$f(x, \sigma_1, \rho_1, \sigma_2, \rho_2) = g(x, \sigma_1, \rho_1, \vartheta_1) \cdot g(x, \sigma_2, \rho_2, \vartheta_2)$$

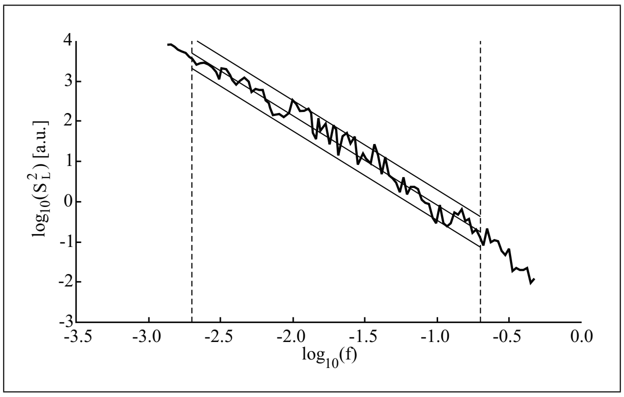

Figure A1. Example of the calculation of a linear fit of S_L^2 in the interval [0.002 Hz, 0.2 Hz].

$$\vartheta_1 = \begin{cases} 0 & \text{if } x > \rho_1 \\ 1 & \text{if } x \le \rho_1 \end{cases} \qquad \vartheta_2 = \begin{cases} 0 & \text{if } x < \rho_2 \\ 1 & \text{if } x \ge \rho_2 \end{cases}$$

$$g(x, \sigma, \rho, \vartheta) = \exp\left[-\frac{(x-\rho)^2}{2\sigma^2}\right] \cdot \vartheta + (1 - \vartheta)$$

and the distributions extracted from analysing several music fragments in [27]:

$$\sigma_{\alpha 1} = 0.488 \quad \sigma_{\alpha 2} = 0.305 \quad \rho_{\alpha 1} = \rho_{\alpha 2} = -0.931$$
$$\sigma_{\epsilon 1} = 10.000 \quad \sigma_{\epsilon 2} = 0.069 \quad \rho_{\epsilon 1} = \rho_{\epsilon 2} = 0.437$$

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