

METHODOLOGIES FOR ENVIRONMENTAL SOUND ASSESSMENT: CHARACTERIZATION AND MEASUREMENT APPROACHES AT SIX ES SITES IN PORTUGAL

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ABSTRACT (ORAL)

Environmental sound assessment can be carried out in different ways, depending on the measurement goals, the sampling techniques used (both spatial and temporal), and the effort required to obtain representative results. The purpose of the measurement may be to characterize the overall sound levels at a given time, without distinguishing between their sources or whether they are considered pleasant or unpleasant. Alternatively, it may aim to characterize sound levels associated with specific human activities, including noise from road, rail, and air traffic, as well as industrial operations. A major challenge, however, is the development of sound assessment methods that go beyond traditional “noise mapping” to capture the complexity of acoustic environments, which include both natural and anthropogenic sounds. This is particularly relevant in the context of environmental sustainability and biodiversity conservation, where sound plays a crucial role in ecological processes and human well-being.

The NATURELAB project addresses this challenge by creating an integrated framework for classifying different natural spaces (such as forests, urban parks, and gardens) based on their potential to promote health. Within this framework, the present study contributes by collecting and analyzing acoustic data from six Experimental Sites (ES) in Portugal. These data, along with on-site visits and short-term measurements, provide the foundation for defining robust measurement strategies in the next phase of the project. This study presents information collected on the acoustic environment of six Experimental Sites (ES) in Portugal. This information, combined with on-site visits and short-duration measurements, has supported the identification of appropriate measurement types to be implemented in the following project phase.

Keywords: Environmental sound; noise; monitoring methodologies

1. Introduction

1.1. Environmental sound assessment: From regulatory frameworks to perceptual approaches

Environmental noise represents a major public health concern and is recognized among the top environmental risks to human health. Its adverse effects on health and well-being have raised increasing concern among the general population as well as European policymakers. In response, the European Union issued the Directive 2002/49/EC (EU, 2002), to establish a common framework for the assessment and management of environmental noise. This directive, known as the Environmental Noise Directive (END), mandates that all Member States develop strategic noise

maps for major transport infrastructure—namely roads, railways, airports—as well for agglomerations. Following the development of these maps, Member States are also required to prepare action plans aimed at mitigating noise exposure and its associated effects. Furthermore, national legislations have been established to define limit values for the noise indicators L_{den} (day-evening-night noise indicator) and L_n (night noise indicator). Standardized methodologies for assessing urban environmental sound predominantly rely on quantitative measures based on long-term A-weighted equivalent sound pressure levels, typically expressed for daytime (L_{day}), evening ($L_{evening}$), and nighttime (L_{night}) periods, in accordance with ISO 1996-2 guidelines (ISO, 2017).

In parallel, the World Health Organization (WHO) Regional Office for Europe has issued guidelines to protect public health from exposure to environmental noise from various sources (WHO, 2018). These guidelines detail the health impacts of noise exposure, including noise-induced hearing loss, sleep disturbance, cardiovascular and psychophysiological effects, as well as impacts on cognitive performance, speech intelligibility, and social behaviour. Recommended threshold values for L_{den} are 53 dB for road traffic noise, 54 dB for railways, 45 dB for aircraft, and 45 dB for wind turbines. Exposure above these thresholds is associated with well-documented negative health outcomes (WHO, 2018).

Traditional approaches to environmental noise control have predominantly focused on minimizing undesirable sounds, with limited attention given to the potential health and psychological benefits of positively perceived sounds. However, empirical studies conducted in urban open spaces suggest that when sound levels remain below 65–70 dBA, individuals' assessments of acoustic comfort are influenced not only by sound intensity but also by the nature of the sound, user characteristics, and contextual factors (Yang & Kang, 2005). Consequently, there has been a paradigm shift from a purely quantitative noise assessment to a more holistic and perceptual-based framework.

1.2. Objectives

A detailed description of the methodology employed in this project is available in NATURELAB D1.1 (Fernandes et al., 2025). This study presents the basic level methodology applied for characterizing the sound environment of ES in Portugal, acknowledging the dual nature of sound sources—ranging from anthropogenic noise with the potential to cause annoyance to natural sounds which can have positive health effects.

2. Methods and Results

2.1. ES monitoring methodologies

Within the scope of the NATURELAB project, and to characterize environmental sound in both quantitative and qualitative terms, three monitoring strategies will be employed: basic, intermediate, and high. Each strategy is aligned with specific objectives and indicators.

The basic-level monitoring strategy involves collecting all available information on the characteristics of sound sources associated with human activities at each Experimental Site (ES)—for example, train schedules, noise maps, or noise action plans. This level is more closely related to the characterization of the potential adverse effects of noise (or its absence). The data gathered during this phase will support the optimization of the design and implementation of more advanced monitoring strategies, following preliminary measurements. Intermediate-level monitoring will be conducted over a one-year period, when necessary, and will consider different source emission and sound propagation characteristics. The high-level monitoring strategy, which is more closely related

to the assessment of sound perception, complements the previous strategies. It involves the measurement of more complex indicators in addition to sound levels (e.g., Loudness), as well as binaural audio recordings and soundscape characterization along the therapeutic pathways (see Fernandes et al., 2024, for more details).

2.2. Results from basic level monitoring methodology strategy in Portuguese ES

At this level, all available acoustic data were gathered. This included municipal noise maps (*Sintra*, *Esposende*, and *Viana do Castelo*), major road noise maps (A28), and railway noise maps (*Linha de Sintra/Lisboa* and *Linha do Oeste*). This information was complemented by site visits to each experimental location and very short-term measurements (5 minutes each). The information collected during the basic monitoring phase for the Portuguese ES is presented in Table 1 (further details are available in Barbosa et al., 2025).

Table 1. Basic level monitoring for the Portuguese ES

Experimental Site	Main anthropogenic sound source	Available Information	Observations
ES1- National Park Sintra Cascais	Local road (N 375) and car park at the entrance	No more information available. Sound levels below 50 dB(A)	Due to the local topography, the sound of road traffic is not perceptible inside the park. In this ES, natural sound sources are dominant.
ES2 -Ribafria Farm	Local road (<i>Estrada da Varzea</i>)	Noise map of the municipality of Sintra (July 2020)	Indicator (L_{den}) range between 50 and 55 dB(A). Depending on the distance to the road and terrain elevation, road traffic noise can be noticeable.
ES3 - Horticulture Allotment in Mira Sintra	Railway traffic derived from trains of <i>Linha do Oeste</i>	<i>Linha do Oeste</i> noise map (Bifurcation of <i>Meleças and Mira Sintra</i>), published in 2017.	Indicator (L_{den}) range between 45 and 55 dB(A). Due to local topography, noise from trains <i>Linha de Sintra/Lisboa</i> are also perceived and road traffic noise from nearby roads. In this ES traffic noise is dominant.
ES4 - Rinchoa Eco Park Sintra	Railway traffic from trains of <i>Linha do Oeste</i>	<i>Linha do Oeste</i> noise map (Bifurcation of <i>Meleças and Mira Sintra</i>), published in 2017.	Indicator (L_{den}) range between 50 and 65 dB(A) throughout the park depending on the location. Natural sound sources are dominant, except when a train passes on <i>Linha do Oeste</i>
ES5 - Foz do Neiva	Road traffic noise from local road (<i>Foz do Neiva</i> street)	Noise map of the municipality of Esposende (January 2008)	Indicator (L_{den}) range between 50 and 55 dB(A), depending on the distance to the local road. Nearby the riverside natural sources are dominant.
ES6 - Esposende Municipality	Road traffic noise from A28 motorway	A28 noise map (February 2025)	Indicator (L_{den}) range between 50 and 60 dB(A),

3. Preliminary findings and next steps

The acoustic environment of Ribafria Farm, Rinchoa Eco-Park Sintra, Horticulture Allotment in Mira Sintra, and Esposende Municipality is influenced by anthropogenic noise sources, primarily from road traffic (in the case of Ribafria Farm and Esposende Municipality) and railway traffic (impacting Rinchoa Eco-Park Sintra and Horticulture Allotment in Mira Sintra). Preliminary noise measurements

(based on very short sampling periods) revealed variations in sound levels: 44–47 dB(A) at Ribafria Farm, 40–47 dB(A) at Rinchoa Eco-Park Sintra, and 54 dB(A) at Horticulture Allotment in Mira Sintra (only one location was selected for this site, as this ES is still under construction). These initial values should be regarded as indicative, serving to guide the selection of measurement locations for future monitoring campaigns.

In terms of noise source assessment, and based on the data collected during the basic level monitoring phase, three measurement locations were selected within Ribafria Farm for approximately 90 minutes of data collection. For Rinchoa Eco-Park Sintra, five measurement locations were identified, with each location being monitored for approximately one hour. These monitoring campaigns will be repeated in both the Autumn/Winter and Spring/Summer seasons. For Esposende Municipality, the strategy involved measuring at a location close to the motorway throughout the entire day, while simultaneously conducting brief measurements at four additional locations within the ES area.

However, the evaluation of the acoustic environment at these sites extends beyond mere sound level assessments. Other factors, such as the qualitative assessment of the sound environment, the types of activities conducted at each site, and the proximity to residential areas (particularly relevant for Rinchoa Eco-Park Sintra), must also be considered.

Furthermore, audio recordings of the sites will be analyzed to differentiate the natural sounds present, using physical descriptors. This dual approach is essential for environmental sound assessment, as many naturally occurring sound sources can have beneficial effects on human health.

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