Studying the dynamics of audio recordings at the Ticino River Park

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ABSTRACT

We present the results of a measurement campaign conducted in spring 2021 in the Ticino River Park, located near the urban area of Milan in Lombardy, Italy. Three sites were examined using two SET audio recorders, positioned along a transect at varying distances from a high-intensity traffic noise source. Recordings followed a pattern of 1-minute acquisition periods alternating with 5-minute pauses. Based on these data, we analyzed the dynamics of peaks in the Leq_{1s} *time evolution for each recording at each site. By grouping the recordings into one-hour intervals, we characterized the distribution and temporal delay of occurrences over a 24-hour period. The results offer valuable insights into the dynamics of acoustic activity across a gradient of anthropogenic disturbance.*

1. INTRODUCTION

The term soundscape has become widely used to describe the complex relationship between the landscape and the mixture of sounds characteristic of urban green areas. Soundscape analysis is typically based on the calculation of eco-acoustic indices, which can extract information about specific sound characteristics such as pitch, modulation, saturation, and amplitude. These indices, also referred to as eco-acoustic metrics, have gained popularity as proxies for species assemblage diversity and, consequently, for assessing environmental quality [1–3].

However, the complexity of sound mixtures often requires the implementation of more in-depth analysis. For example, in [4], the analysis of 60 hours of recordings enabled the identification of different biophonic activities throughout the day using unsupervised statistical techniques. Similarly, [5] analyzed autocorrelations of eco-acoustic indices time series recorded at two sites within the same park, uncovering an underlying structure of the environmental soundscape. This complex structure was found to be closely linked to the overall quality of the environmental sound (see [6, 7]).

In an effort to explore new approaches for investigating the complexity of soundscapes, this study focuses on a natural green area within the Ticino River Park, intersected by a highway. The proposed method is primarily based on analyzing the dynamics of peaks in the Leq_{1s} values calculated from recordings collected at each site.

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2. MATERIALS AND METHODS

2.1. Area of Study

The study was conducted in the Ticino River Park near Bernate Ticino, located in the western part of Lombardy, approximately 30 km west of Milan. This natural ecosystem is notably affected by several high-impact anthropogenic noise sources, including the A4 highway, a high-speed railway line to the north (see Fig. 1), and frequent overflights from the nearby Malpensa Airport.

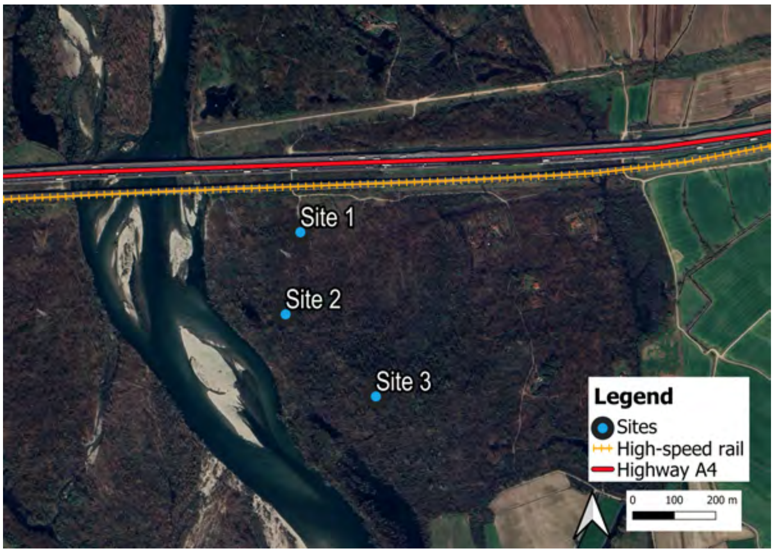

Figure 1: Area of study: Ticino River Park near Bernate Ticino with the indication of the three measuring sites.

2.2. Measurements

Recordings were collected between 26 May and 10 June 2021 using two SET (Soundscape Explorer – Terrestrial) devices. Each SET unit is equipped with environmental sensors (measuring humidity, temperature, light, and atmospheric pressure) and two microphones—one for low frequencies (up to 48 kHz) and another for higher frequencies (up to 192 kHz). The devices were mounted approximately 4 meters high on trees, along a transect perpendicular to the two main anthropogenic noise sources: the highway and the railway (Fig. 1).

Three sites were selected for this study, with a monitoring duration of approximately one week at each site. The recording devices were configured to follow a pattern of 1-minute recording followed by a 5-minute pause, using a sampling rate of 48 kHz and 16-bit WAV format. Since only two devices were available for monitoring three sites, the instrument initially deployed at Site 1 (Fig. 1) was relocated to Site 2 after the first week. As a result, the data collection was divided into two continuous periods of roughly one week each: the first period, from 26 May 2021 (starting at 13:00) to 2 June 2021 (ending at 23:54), covered Site 1 and Site 3; the second period, from 3 June 2021 (starting at 13:00) to 10 June 2021 (ending at 23:54), covered Site 2 and Site 3.

2.3. Data Analysis

From the entire recording period, we selected one representative day for each site, ensuring the absence of wind and rain. Due to the reasons mentioned above, the measurements were not conducted simultaneously. Specifically, 1 June 2021 was chosen for Site 1, while 8 June 2021 was selected for Site 2 and Site 3. In total, 240 one-minute recordings were analyzed. For each WAV file, we computed a Leq_{1s} time series. Using this basic indicator, we carried out two types of analysis:

- Search for Leq_{1s} peaks with different characteristics;
- Computation of delays between consecutive peaks of the hourly Leq_{1s} time-series.

The analysis was performed in R 4.3.3 [8] environment. In particular, the findpeaks() function from the *pracma* library was used for spotting the time-series Leq_{1s} peaks.

2.4. Aural Survey

For the validation of data analysis, we quantified the amount of bio-phonies, techno-phonies, and geo-phonies at each site by listening to all the recordings. Thus, for each one-minute recording of each selected day, we identified the "bird singing" activity expressed in terms of "none", "few", and "many" birds singing and the presence of anthropogenic noise expressed in terms of traffic noise characteristic such as "none", "continuous", and "intermittent".

3. RESULTS AND DISCUSSION

A spectrogram obtained from a recording at Site 3 at 06:00, and illustrated in Fig. 2, shows the presence of frequency peaks in the range 2-6 kHz which are typical of avian activity.

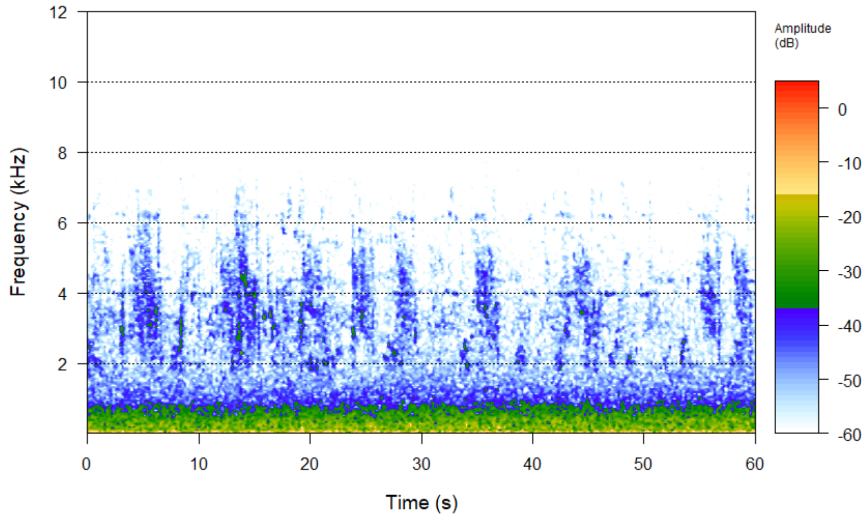

Figure 2: Typical spectrogram of a recording taken at 06:00 a.m. at Site 3. The time frame is one minute. The dB units shown are arbitrary.

By converting the frequency levels into Leq_{1s} (reference pressure = 2×10^{-5} Pa), and using the findpeaks() function, we identified a number of peaks in the corresponding Leq_{1s} time-series. To do this, we search for two types of peaks:

- (a) high-frequency peaks, where there is just a single decreasing step either before or after the peak, denoted as (1-1) mode;
- (b) low-frequency peaks, where there are two or more decreasing steps either before or after the peak, denoted as (2-2) mode;

Thus, the (1-1) mode accounts for all the Leq_{1s} peaks in the time-series, whereas the (2-2) mode acts as a kind of low-pass filter of Leq_{1s} fluctuations. Figure 3 shows the Leq_{1s} time evolution of a recording taken at 02:00 on Site 1. The red spots represent the peaks found according to the (1-1) mode, whereas the green spots those obtained according to the (2-2) mode.

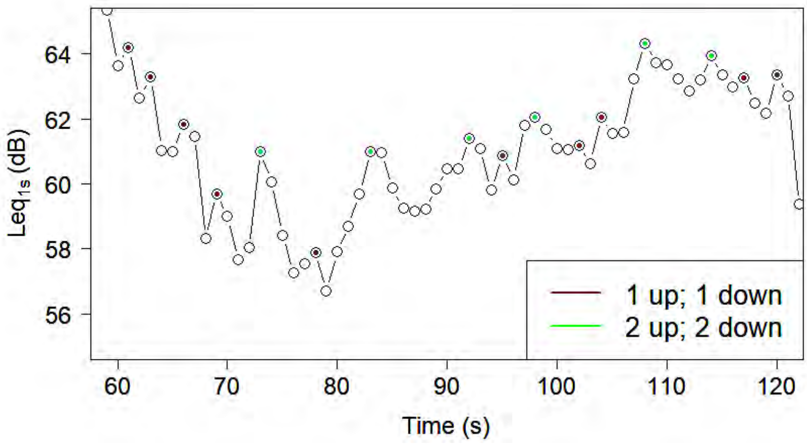

Figure 3: Leq_{1s} time evolution of a recording taken at 02:00 at Site 1. The red spots represents the peaks found according to the (1-1) mode, and the green spots according to the (2-2) mode.

Figure 4 illustrates the hourly peak frequency (i.e. the total number of peaks within an hour) for the three sites. Figure 4a refers to the (1-1) mode, while Figure 4b to the (2-2) mode. As expected, the peak frequency plunges when using the more restrictive filter in (2-2) mode. In the case of Fig. 4a, higher values are observed at 05:00 and at 17:00 for Site 3. Also, Site 2 presents peaks at 09:00, 12:00 and 17:00. In the case of Fig. 4b, higher values of Leq_{1s} peaks are observed at 04:00 for Site 2, and in the time interval 08:00-10:00 for Site 1 and 3. For the rest of the time, no significant differences are apparent.

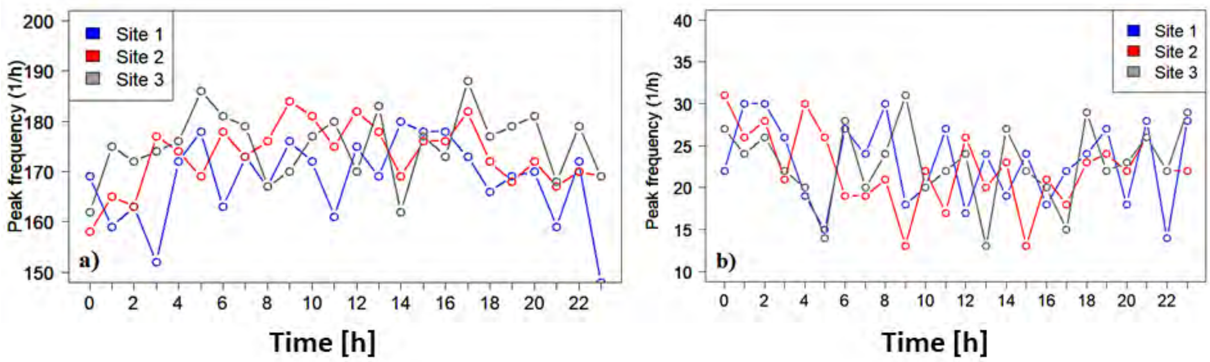

Figure 4: Hourly peak frequency calculated for the three sites along the day for: **a**) (1-1) mode, and **b**) (2-2) mode. Note the very different scales for the number of peaks used in a) and b).

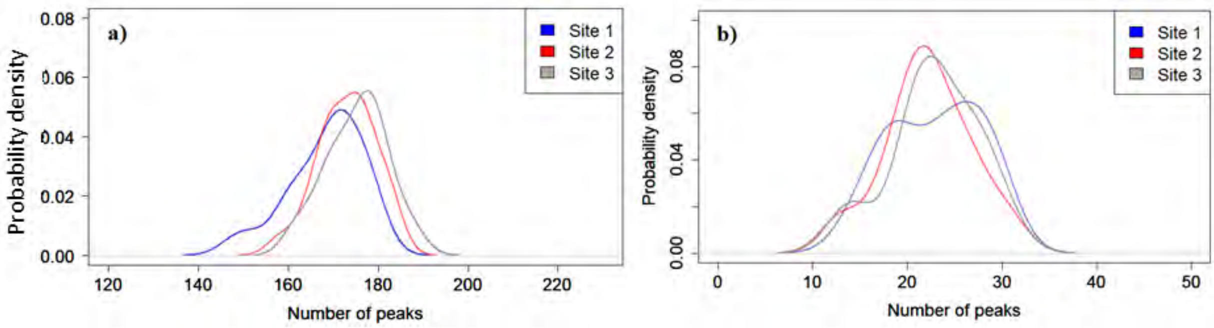

Figure 5: Probability density of peaks density at each site (see inset) obtained from the results shown in Fig. 4. **a**) refers to the (1-1) mode, and **b**) to the (2-2) mode.

The probability density of peaks is displayed in Fig. 5. As shown in Fig. 5a, Site 1 presents a lower maximum peak than Site 2 and Site 3, whereas in Fig. 5b, Site 2 and Site 3 display a similar distribution, while Site 1 presents a broader and a more pronounced double-peak distribution than for the other two sites.

Another interesting consideration emerges by computing the time delay between two successive peaks. This information can be regarded as the typical waiting time before another peak occurs. Results for the (2-2) mode are shown in Fig. 6, indicating that time delays behave similarly for the three sites along the day, except during the time intervals (09:00-10:00) and (14:00-17:00) which display significant differences between Site 1 and Site 2. In the first interval, Site 2 shows higher waiting times, whereas in the second interval, time delays alternate in duration between them. In contrast, for the (1-1) mode no significant delay variations are observed during the day.

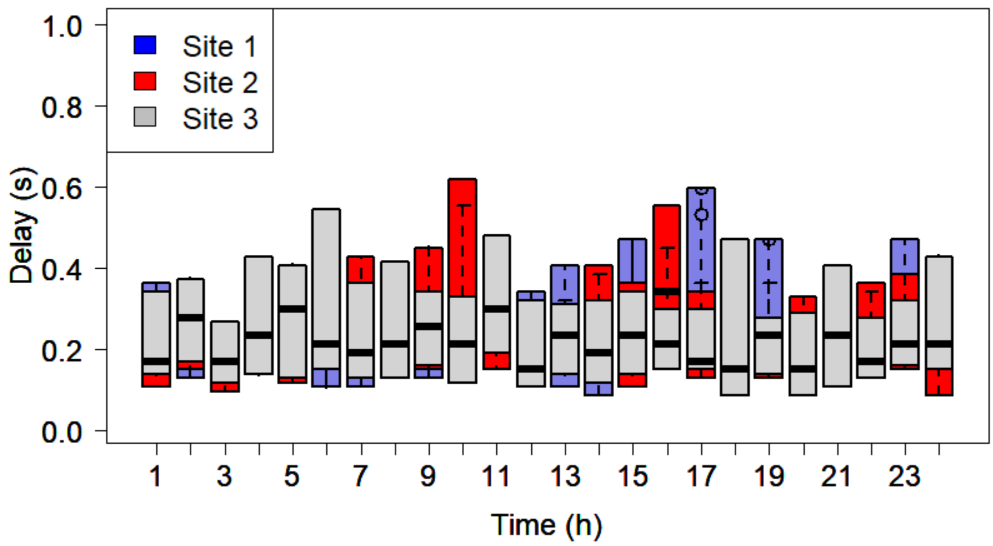

Figure 6: Boxplot of peak delays for the three sites along the day. (2-2) mode is shown.

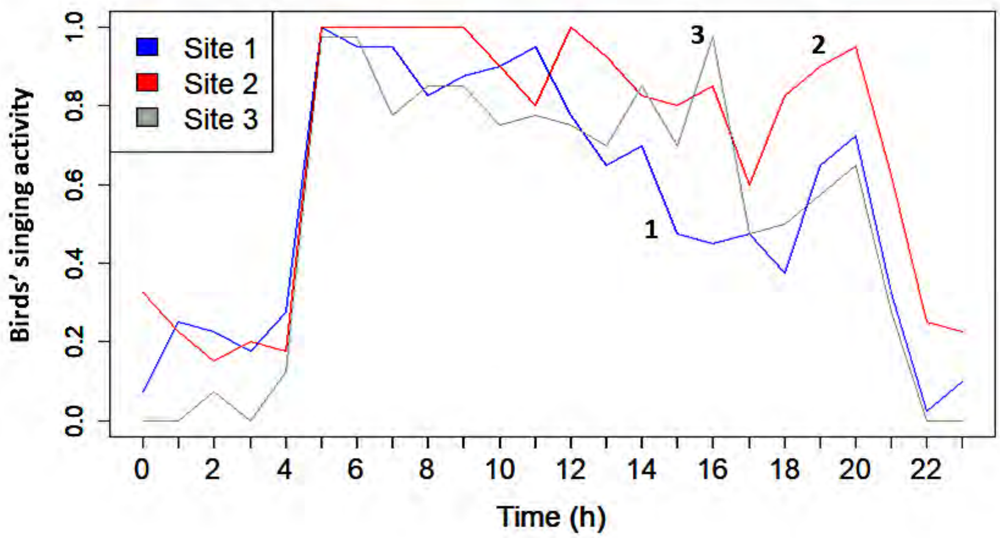

Figure 7: Birds' singing activity for the three sites during the day, normalized to 1.

In order to interpret these findings, we present the results obtained by listening to all the recordings to quantify the amount of bio-phonies, techno-phonies, and geo-phonies at each site. Figure 7 reports the results correlated to the "bird singing" activity expressed in terms of "none", "few", and "many" birds. These categories are converted into numerical figures by applying the following mapping: "none" = 0, "few" = 1, and "many" birds = 2; followed by a normalization of the results. As is apparent from Fig. 7, the three sites present very low level of singing activity during the night (00:00-04:00), while the one at Site 3 is the lowest. The highest activity is observed during the morning (05:00-11:00) for the three sites, while in the afternoon (12:00-17:00) Site 2 and Site 3 prevail over Site 1. Finally, singing activity at Site 2 dominates over the ones at the other two locations during the evening hours (17:00-23:00).

The same procedure is applied to the road traffic noise according to: "none", "continuous", and "intermittent", yielding, "none" = 0, "continuous" = 1, and "intermittent" traffic = 2. These results are illustrated in Fig. 8, where one can see that the traffic activity appears to be high (with a prevalence of intermittent traffic noise) for Site 1 and Site 2, and a prevalent continuous noise for Site 3 (due to its larger distance from the traffic noise source). From these observations, we can conclude that the higher peak density obtained using the (1-1) mode (Fig. 5a) can be associated with the intrinsic high-frequency of bird singing activity. In contrast, the presence of intermittent traffic noise favors the prevalence of the (2-2) mode type of data (Fig. 5b), yielding more profound peaks in the Leq_{1s} time-series (see Fig. 3). Regarding the low-frequency (2-2) mode activity, the waiting time among peaks seems to be larger for Site 2 and Site 3, especially in the early morning (see Fig. 6). In the latter, we also observe larger time delays during the period (16:00–19:00) for Site 1 and Site 2, in concomitance with the higher values of birds' activity.

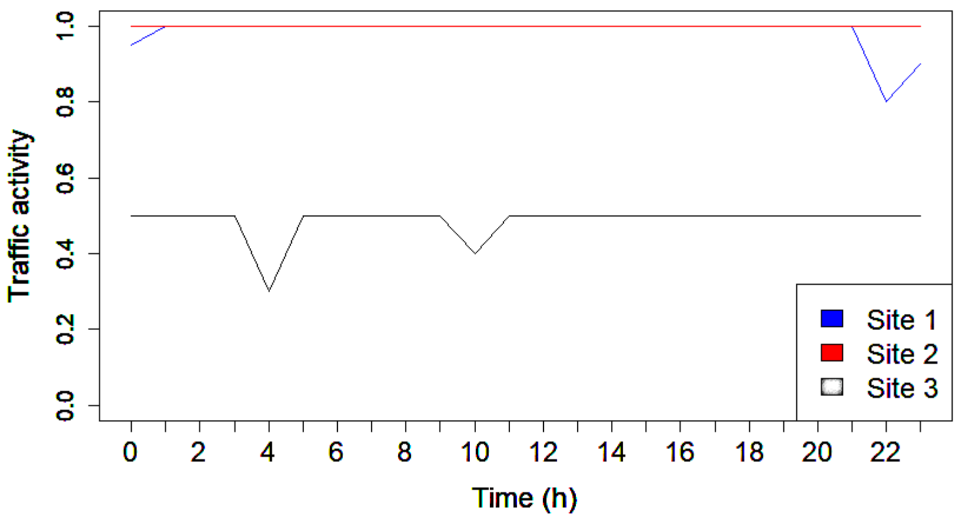

Figure 8: Traffic noise activity for the three sites along the day.

4. FINAL COMMENTS AND CONCLUSIONS

This preliminary analysis of simple indicators derived from a time-series, such as the peaks associated with the Leq_{1s} calculated from each recording at each site, provides interesting insights on specific dynamics occurring in local soundscapes.

By computing the probability distribution of peaks obtained in both (1-1) and (2-2) modes, that is high- and low-frequency modes, respectively, we have found a significant correlation between bird singing activity and the (1-1) probability distribution of peaks. In this case, Site 2 and Site 3 present higher high-frequency characteristics than Site 1 (close to the traffic noise source). On the contrary, the presence of intermittent traffic noise seems to be associated with the (2-2) probability distribution of peaks. In this case, Site 1 presents higher values for this low-frequency characteristics. Our findings suggest that the waiting time between peaks is longer at Site 2 and Site 3, particularly in the early morning, as shown in Fig. 6. In the same figure, we also observe a wider distribution of delays (see the coloured bands), which corresponds to periods of increased bird activity (see Fig. 7).

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