Towards an environmental sound map at Parco Nord of Milan, Italy

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ABSTRACT

Green areas suffer the growing influence of urbanization and may benefit from the use of passive acoustic monitoring (PAM) which can provide biodiversity estimation and conservation especially in fragile environments such as urban parks and protected areas. A network of low-cost sensors has been distributed over an area of approximately 20 hectares at the Parco Nord of Milan, Italy, to highlight areas with different acoustic characteristics. The audio files analysed in this study were recorded at 16 sites on four sessions between May 25th and May 29th 2015 from 06:30 a.m. to 10:00 a.m.. Seven eco-acoustic indices have been computed and analysed. A map of eco-acoustic indices has been built and validated by comparing the results with an aural survey aimed at determining the sound components at each of the sixteen sites (biophonies, technophonies and geophonies). This approach may represent a useful tool for an integrated approach aimed at conservation planning and development decisions.

1. INTRODUCTION

Sound is an everywhere component in the environment with potential negative effects on human health as proved by a number of studies [1, 2]. The noise effect on wildlife is a branch of acoustics called soundscape ecology. The term "soundscape" is generally referred to as the relationship between the landscape and the mixture of sounds that characterize it. Sounds at a location include bio-phony (animal vocalization) [3], anthrophony (mechanical sounds) and geophony (wind or rain) [4]. Studying the soundscape may help determine to what extent anthropogenic noise, while being part of the soundscape itself, plays a role in disturbing terrestrial and marine habitats, altering intra and inter-species communications. Soundscape is investigated through passive acoustic monitoring

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which consists of recording devices placed in the studied area to extract information on the abundance of species and the ecosystem condition [5-7]. The audio recordings are then analysed using eco-acoustic indices, which capture different sound characteristics, such as frequency modulation and distribution, wave amplitude and compare spectral and temporal trends.

Recently, cost-effective soundscape assessment tools have been successfully applied to traffic noise mapping in urban areas as for instance in Madrid [8], Rome [9], Paris [10], Milan [11] and Rotterdam [12], but it is now becoming a strong requisite across all fields of eco-acoustics and bioacoustics.

In this paper, we present the results of a measuring campaign performed at Parco Nord of Milan, Italy using eco-acoustic indices aimed at the realization of spatial maps of environmental sound characteristics.

2. MATERIAL AND METHODS

The area of study extends over 20 hectares of wooded parcel at the outskirt of the city of Milan, and surrounded by a congested road network and a near light aircraft airport. Measurements were taken in May 2015 using 16 low-cost recording devices positioned on a regular grid as shown in Fig. 1.

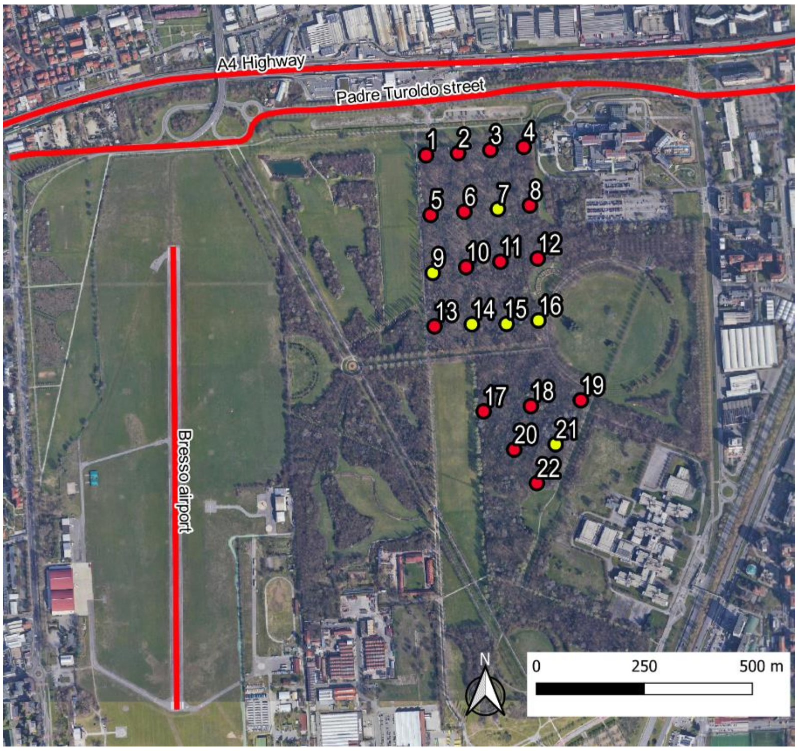


Figure 1: Measurement sites. Red circles represent the effective measuring sites (16). Yellow circles represent sites (6) where sensors had a glitch.

For each site and day of monitoring (four in total), 3.5 h were recorded (from 6.30 am to 10.00 am).

Seven eco-acoustic indices have been employed: the Acoustic Complexity Index (ACI) [12], the Acoustic Diversity Index (ADI) [13], the Acoustic Evenness Index (AEI) [14], the Bio-acoustic Index (BI) [15], the Normalized Difference Soundscape Index (NDSI) [16], the Dynamic Spectral Centroid (DSC) [17] and the Acoustic Entropy (H) [18].

The eco-acoustic indices have been computed according two different patterns in order to extract different characteristics of the time series.

1. **Global information**: for each site, computation of seven eco-acoustic indices at 1 s integration time. The distribution of the values of each index has been described using the most representative statistical metrics. For this purpose, seven descriptors were considered:

the mean value, median, mode, standard deviation (SD), interquartile range (IQR), skewness, and kurtosis.

2. **Dynamic information**: for each site, computation of seven eco-acoustic indices integrated over 30 minutes.

An aural survey, aimed at determining the sound components, such as biophonies, technophonies and geophonies at each site, has been performed as cross-validation of the eco-acoustic indices analysis.

3. RESULTS

The choice of the eco-acoustic indices and their settings for the analysis requested an initial tuning due to the specific environment under investigation. We started with the seven eco-acoustic indices as also employed in previous works [19, 20]. For NDSI the threshold between human-generated and biological sounds is generally set at 2 kHz, whereas for BI, the area under the mean frequency spectrum describing the biophonic activity is limited within 2 kHz and 8 kHz. These settings have been successfully used in other contexts [21], but in the specific case they proved to be inappropriate because of the presence of bird species such as the carrion crow (*Corvus cornix*), the wood pigeon (*Columba palumbus*) and the cuckoo (*Cuculus canorus*) which produce sounds in the interval considered to be restricted to technophonies. For this reason, we limited our analysis to five eco-acoustic indices, namely ACI, ADI, AEI, H and DSC.

3.1 Results for procedure 1) Global information

For each eco-acoustic time series (time resolution 1 s) the corresponding distribution of values has been described using the most representative statistical metrics: the mean value, median, mode, standard deviation (SD), interquartile range (IQR), skewness, and kurtosis. This implicates the use of 5 x 7 (n° of indices times n° of statistical descriptors) parameters. Such parameters were reduced using a principal components analysis (PCA). Dimension 1 of the PCA, describing 54.1% of the data variability, is mostly associated with the statistical descriptors of ADI (29.8%), AEI (30.0%) and H (27.4%); DSC contributes to dimension 2 with 57.8%, and dimension 3 has a prevalence of ACI (41.5%). The resulting significant components (3 components accounting for about 80% of the total variance) have been used in a cluster analysis to investigate the similarity of the measurement sites. For a detailed description of the statistical procedure, see reference [22, 23]. In Fig. 2, the distribution over the area of study of a representative index for each dimension is illustrated. The reported values refer to mean values of the distribution of (a) ADI index, (b) DSC index and (c) ACI index.

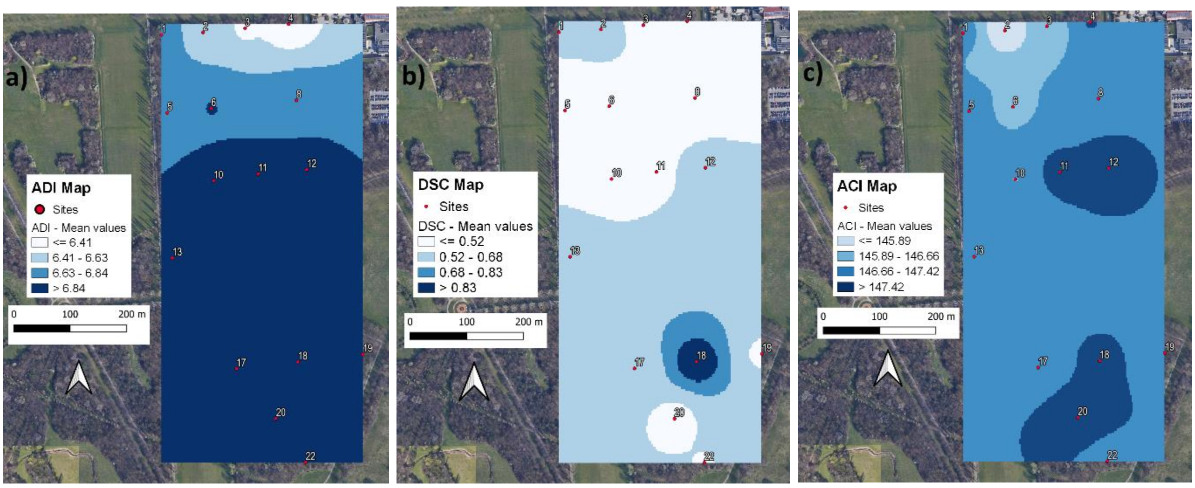


Figure 2: Spatial maps of the mean values of the distribution of (a) ADI index, (b) DSC index and (c) ACI index.

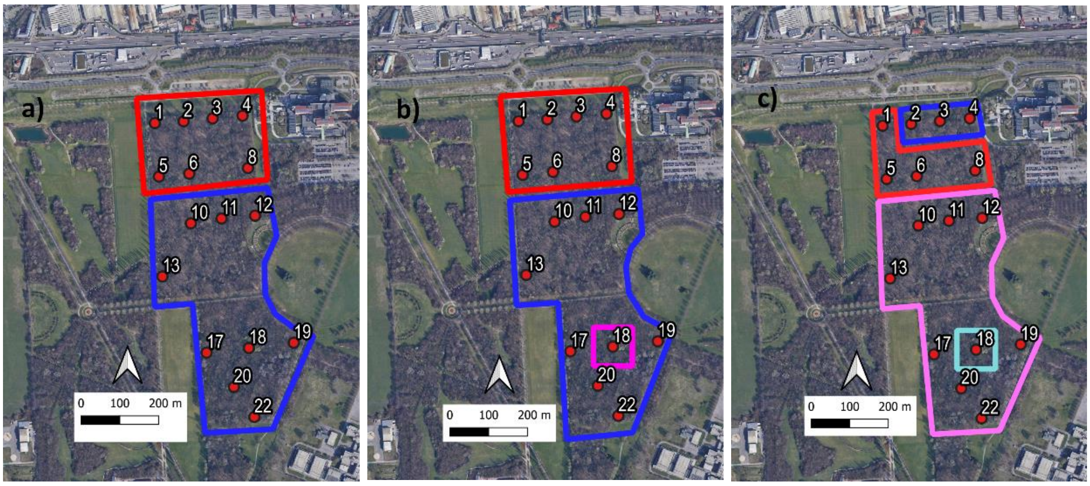


Figure 3: Areas corresponding to two, three and four-cluster solutions using the global information procedure. The colour contours are drawn as a help for the eyes with the following correspondence: red = cluster 1; blue = cluster 2; pink = cluster 3; light blue = cluster 4. The reported sites represent the effective measuring sites.

Figure 3 shows the results of the cluster analysis at two (a), three (b) and four (c) solutions using k-means algorithm. We can clearly observe how the spatial distribution of ADI in Fig. 3(a) (with a significant presence in dimension 1) is well described by the cluster analysis results at two clusters. This solution shows that sites are gathered depending on the distance from the main traffic noise sources. The three-cluster solution matches the information brought by ADI and DSC (representative of dimension 2) and highlighting site 18 , whereas the four-cluster solution splits cluster 1 (red colour in Fig. 3) and still presents site 18 as one-cluster element.

3.2 Results for procedure 2) Dynamic information

For this analysis an integration time of 30 min. has been adopted. This means that each 3.5h audio recording has been transformed into seven-value indices, thus ending up with a 5 x 7 matrix (five indices each one described by seven values) for each site. Following the same procedure described above, we reduced the dimensionality of to three components describing about 79% of the original variance.

In this case, Dimension 1 of the PCA, describing 37.6% of the data variability, is mostly associated with the statistical descriptors of ADI (26.3%), AEI (27.7%) and DSC (34.0%); ACI and H contribute to dimension 2 with 27.0% and 57.1%, respectively and dimension 3 has a prevalence of ACI (37.9%). For this second procedure, the cluster analysis was less satisfactory. As it can be observed in Fig. 4, the grouping provided either a one-site cluster or a fragmented subdivision. Both solutions cannot be accepted, in principle, as environmental noise is not likely to manifest such a behaviour especially in presence of specific noise sources (traffic noise from a highway).

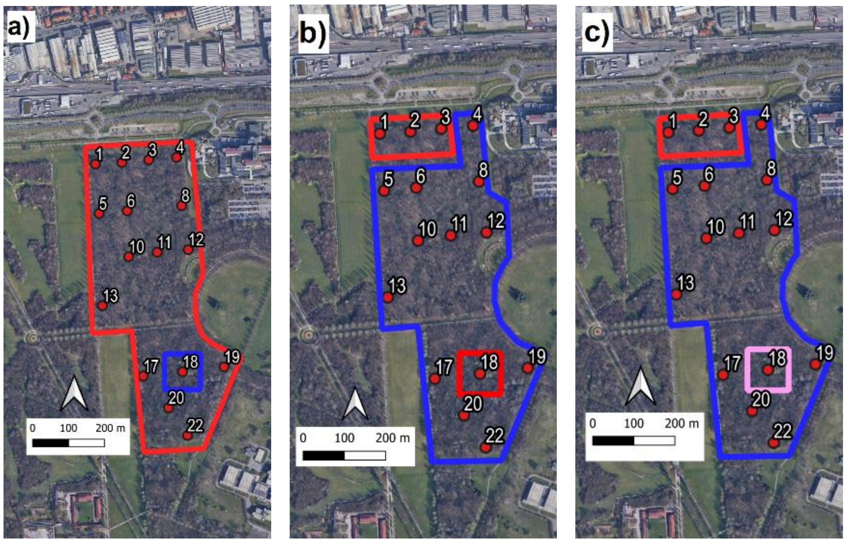
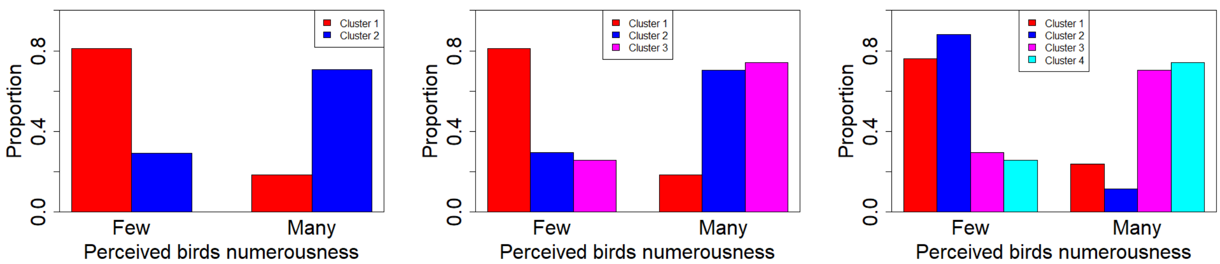


Figure 4: Areas corresponding to two and three-cluster solutions using the dynamic information procedure due cluster. The colour contours are drawn as a help for the eyes with the following correspondence: red = cluster 1; blue = cluster 2; pink = cluster 3. The reported sites represent the effective measuring sites. (a) DIANA and k-means algorithms; b) PAM algorithm; c) DIANA, k-means and PAM algorithms.

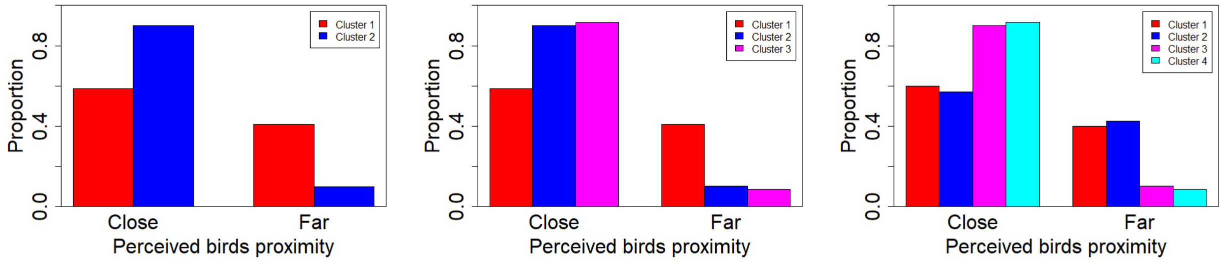
4. DISCUSSION

In order to validate the results of the statistical analysis, we focused on the procedure described in Sect. 3.1. This because for the procedure described in Sect. 3.2, the outcome scenarios of the cluster analysis performed on the two-day campaign and within the single day (see Fig. 4) were fragmented and not univocal. This result is due to the short recording time (3.5 h) which did not allow to record a significant variation of avian vocalizations and, thus capture the typical dynamics associated with the periodicity of sound sources (birds' choruses and traffic noise).

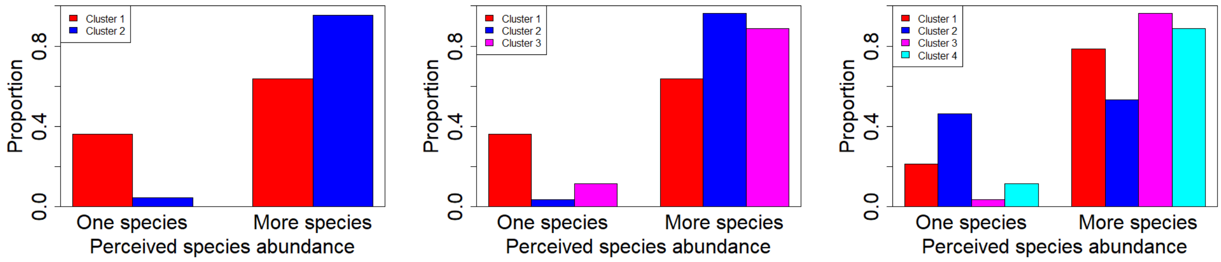
The validation of the results is based on a sound-truth comparison. An aural survey of the audio records belonging to the first day of campaign was done. For all the monitoring sites, an expert operator carefully listened to the recordings according to the following scheme: one minute of listening every two minutes. During the listening 13 avian species were identified. Each recording was labelled with one or more of the following sound characteristic: birds' numerousness, their proximity to the recording devices, proportion of time occupied by avian singing activity in each time slot, traffic intensity, traffic characteristic and presence of other noise sources.



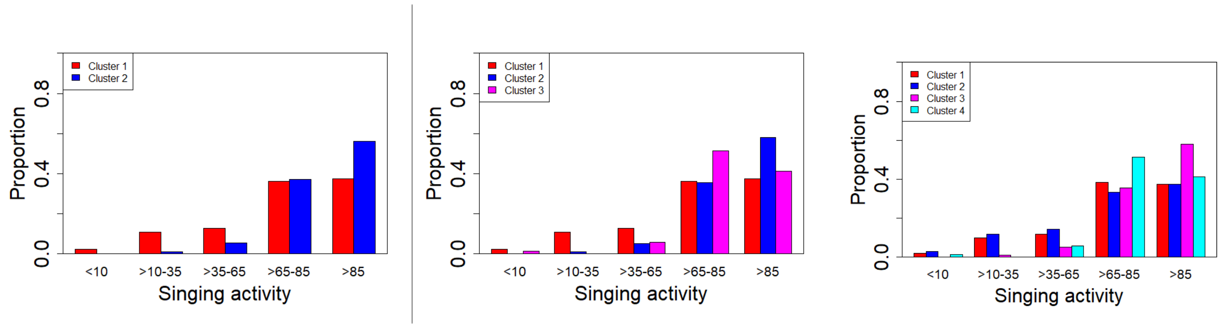
a)


Proportion
0.0
0.4
0.8
Cluster 1
Cluster 2
Cluster 3
Cluster 4
Close
Far
Perceived birds proximity

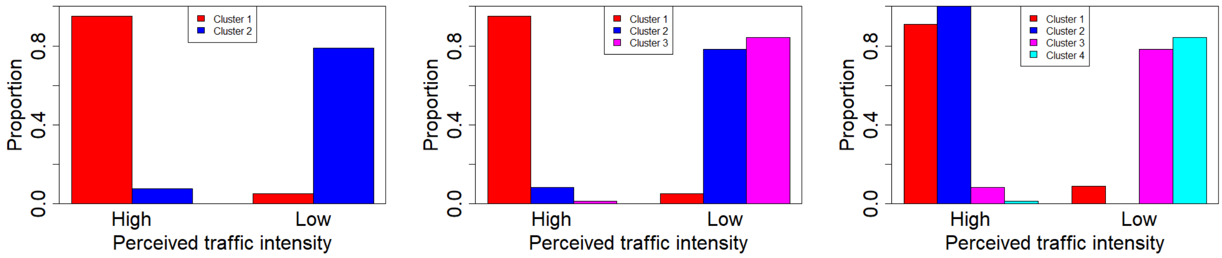
b)


Proportion
0.0
0.4
0.8
Cluster 1
Cluster 2
Cluster 3
Cluster 4
One species
More species
Perceived species abundance

c)


Proportion
0.0
0.4
0.8
Cluster 1
Cluster 2
Cluster 3
Cluster 4
<10
>10-35
>35-65
>65-85
>85
Singing activity

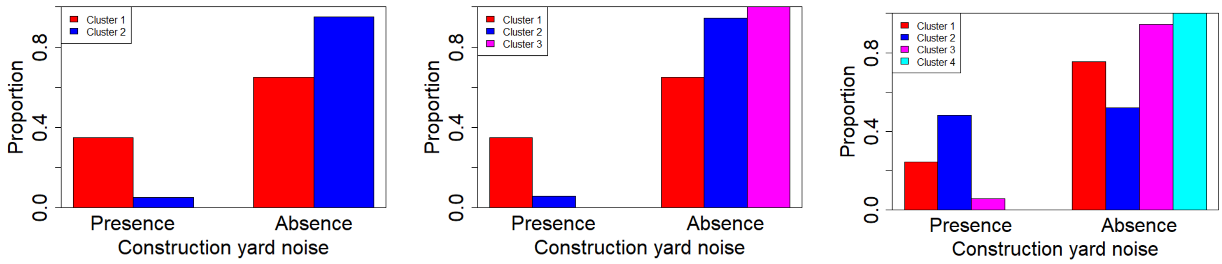
d)


Proportion
0.0
0.4
0.8
Cluster 1
Cluster 2
Cluster 3
Cluster 4
High
Low
Perceived traffic intensity

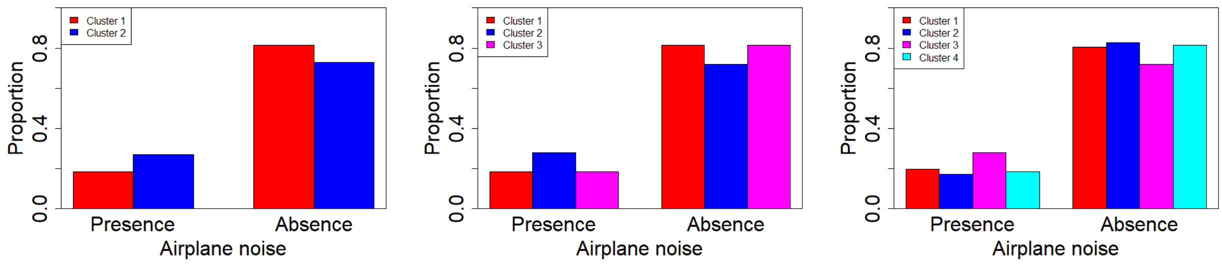
e)


Proportion
0.0
0.4
0.8
Cluster 1
Cluster 2
Cluster 3
Cluster 4
Continuous
Irregular
Perceived traffic characteristics

f)



g)



h)

Figure 5: Distribution of the aural characteristics in the two, three and four-cluster solution as obtained by k-means algorithm.

The graphs of Fig. 5 show the distribution of the aural characteristics in the two, three and four-cluster solution. As is apparent, just the two-group solution allows separating effectively the clusters. For the three and four clusters, we can observe similar values, thus not easily distinguishable.

In particular for the birds ’numerousness (Fig. 5a), the sites belonging to cluster 1 are characterized by the presence of few bird individuals (< 4 individuals) for about 80% of cases whereas cluster 2 is characterized by a majority of recordings (≈ 70%) where the perceived birds ’numerousness is greater than 4 individuals.

As for the perceived singing proximity (Fig. 5b), both clusters’ composition is made of audio recordings containing close and far singing activity but with different proportions. Cluster 1 contains a proportion of close perceived singing activity of about 60% and 40% of far perceived singing activity, whereas in cluster 2, we find ≈90% and ≈10%, respectively.

The perceived singing abundance (Fig. 5c) gives few singing activity for the majority of recordings in cluster 1 (≈80%) and many bird singings for the majority of cluster 2 (≈70%).

The previous results are confirmed looking at the singing activity quantified as the percentage of singing presence in the audio recording time (see Fig. 5d). In cluster 1, we have the presence of a significant proportion (26%) of recordings with low/moderate bird’s activity (<65%), an interval of activity between 65% and 85%, with 36% of proportion equally distributed in the two clusters and a prevalence of recordings with singing activity above 85% of 56% for cluster 2 against 37% for cluster 1.

Figures 5(e) and 15(f) report the proportion of audio recordings in the two clusters versus the presence of traffic perceived in terms of two categories: intensity and dynamic characteristics. The results seem to indicate that cluster 1 presents the majority of audio recordings characterized by a high perceived intensity whereas for cluster 2 the perception is of a low intensity traffic noise (distant traffic noise). For both clusters, the traffic noise is however perceived as continuous.

Figure 5(g) illustrates the presence of acoustic sources from a construction site characterized by moving-vehicle-alarm beeps and impact noises. In this case, cluster 2 shows the majority of recordings without such kind of disturbance (95%) against cluster 1 (65%).

Figure 5(h) shows how the airplane noise generated during takeoff is almost equally perceived in both clusters.

5. CONCLUSIONS

This study proposes a methodology for analysing the soundscape of an urban park by analysing the time series of five eco-acoustic indices with an integration time of 1 second and the implementation of different statistical descriptors. The obtained results using the "global information" pattern, provide spatial maps well correlated with the results of an aural survey. The results obtained using a 30-minute integration time were not satisfactory ("dynamic information").

The implemented procedure is able to distinguish areas characterized by a different soundscape composition: presence of different biophonic and anthrophonic sources. However, more studies are needed to confirm the applicability of the methodology to habitats characterized by different soundscape distribution and dynamics.

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