The Perceived Quality of Soundscape in the Archaeological Area of “Foro Romano” in Rome

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The paper describes the study carried out in the area of Colosseum, Roman Forum and Palatine Hill in Rome, selected for its unique characteristics and importance, being the Italian most visited touristic site. Data on the sonic environment and appraisal of some environmental features, including a few non acoustic ones (like landscape and smell), have been collected in 8 sites selected to cover different characteristics. The acoustic data have been determined from binaural recordings taken at the above sites simultaneously with subjective ratings collected by a structured questionnaire filled in by 212 interviewees. Statistical analyses have been applied to extract main features and to classify the sites by the unsupervised learning algorithm of k-means clustering. Among the various solutions, the one that groups the data into two categories looked the most appropriate: in one the sonic environment is dominated by technological sources, whereas in the other one anthropic sources are predominant.
Key words: Soundscape, Perception, Classification

1. INTRODUCTION

The UNESCO Convention for the safeguarding of the Intangible Cultural Heritage [1] has recognized the close connection between tangible and intangible cultural heritage and the concept of cultural heritage has been enlarged. The archaeological areas have the peculiar feature to include both tangible and intangible cultural heritage to create a unique cultural identity which can be attractive for the tourists and important for the local and global community. These areas are also interesting because their acoustic environment, often formed by many sounds from tourists, outside recreational and commercial activities and surrounding road traffic, can greatly influence the tourists' enjoyment of the area itself.

The concept of soundscape, introduced in the early 1970s by the Canadian composer R. M. Schafer [2], has attracted interest from both applied and social sciences, as well as arts and humanities, due to its strong interdisciplinary appeal. Notwithstanding that over the recent years an increasing number of studies have been published on soundscape, proposing models for its characterization, classification and practical approaches for its improvement [3], only a few dealt with archeological areas, like that performed in the excavations of Pompeii in Italy [4].

Regarding the perception of sound, Schubert stated that “identification of sound sources and the behaviour of those sources is the primary task of the auditory system” [5]. Further studies have confirmed that categorization of everyday sounds operates mainly on the basis of source identification [6].

Ecological psychology recently drew attention to urban soundscapes, in which noise is emitted simultaneously by a wide variety of sources, to better understand how people sort out mixtures of sounds into discrete categories in their everyday lives [7]. Results converge to highlight a distinction between three categories, namely natural sounds, anthropic sounds and technological or mechanical sounds, the first two rising to positive reactions, whereas the last are associated to negative responses [8].

In urban soundscape a distinction can be made between sound events, attributed to clearly identified sources, and ambient noise, in which sounds blur together into collective background noise. Sound events are spontaneously described with reference to specific sources, by nouns referring to them or part of them generating the noise. On the contrary, in the descriptions of ambient noise, there are few references to the sound source and a majority of simple adjectives referring to the physical features of the acoustic signal (namely, temporal structure and timbre), suggesting a more abstracted conceptualization of a sound in itself [9].

For a proper assessment of the soundscape, the first step should be to identify and categorize different soundscapes. This categorization should be focused on learning about the main acoustical characteristics of the sonic environment, as well as to ascertain how this is perceived by the population exposed to it.

The present paper deals with the above objective and describes the study carried out within the SONORUS project, a Marie Curie Initial Training Network under the FP7 People Programme, aimed to plan the acoustic environment of cities in a holistic way supporting wellbeing and health of inhabitants. In particular, Rome was one of the four cities selected as test cases to apply the approach of urban sound planning. The area of Colosseum, Roman Forum and Palatine Hill was selected for its unique characteristics and importance, being the Italian most visited tourist site in 2016 [10].

Data on the sonic environment have been taken in 8 sites at the same time of collection of subjective appraisals of some environmental features, including a few non acoustic ones (like landscape and smell), given by 212 respondents via a structured questionnaire. Statistical analyses, performed with the "R" software [11], have been applied to describe the main features of the environment in each site and to group and classify them accordingly. The output of cluster validation suggested to apply the unsupervised learning algorithm of k-means clustering. Among the various solutions, the one that groups the data into two categories (one where the sonic environment is dominated by technological sources and the other one where anthropic sources are predominant) appeared the most appropriate considering the characteristics of the sites.

2. EXPERIMENTAL AND DATA PROCESSING

2.1 The area of the study

The area of the study included the Flavian Amphitheatre (Colosseum), the Palatine Hill and the Roman Forum (see Fig. 1). This area, well known worldwide as slightly over 6,4 million of visitors were registered in 2016, is 0.015 km^2 and it is surrounded by very busy roads, frequent traffic jams and intense anthropic activities. According to the noise zoning approved by the Rome's Municipality the area is included in class 1 (area most sensitive to noise), for which the noise limits in terms of L_{Aeq} are fixed to 50 and 40 dB(A) for the day- (06-22 h) and night-time (22-06 h) respectively. Unfortunately these limits are exceeded very often

Fig. 1. The area under study inside the red line (www.google.it/maps)

Fig. 2. The pedestrian area (in green) around part of the Colosseum

and the noise outside the area deteriorates the soundscape in the area and the enjoyment of visitors.

For instance, the Colosseum was a roundabout until early 1980s and only afterwards various road traffic restrictions have been implemented, like the pedestrian area reported in green in Fig. 2.

2.2 Measurement of the sonic environment

Acoustic data of the sonic environment were collected by a sound level meter (Brüel & Kjær 2250) and binaural recordings (lasting 15 minutes each) during day-time in 8 selected sites, 3 inside the area (red circles in Fig. 3) and 5 just outside (green circles in Fig. 3). All the measurements were attended by operators. In the post processing phase spurious sound events were eliminated, hence reducing the duration of measurements, and for each site the acoustic and psychoacoustic parameters reported in Table 1 were determined by the software ArtemiS Suite. In particular, roughness was calculated on the basis of the hearing model according to Sottek [12], and fluctuation strength was computed similarly to roughness, adapted in a way that the maximum of the fluctuation strength is obtained at 4 Hz instead of 70 Hz as for the roughness.

Table 1. Acoustic and psychoacoustic parameters determined at each site

Continuous equivalent level Leq dB and dBA	Sharpness S_{avg} acum (according to standard DIN 4569)
Percentile levels L_{A5}, L_{A10}, L_{A50}, L_{A90}, L_{A95}	Roughness R_{avg} asper
$L_{eq} - L_{Aeq}$, $L_{A10} - L_{A90}$	Fluctuation strength F_{avg} vacil
Loudness N_5, N_{50}, $N_5 - N_{50}$ sone (according to standard DIN 45631/A1)	

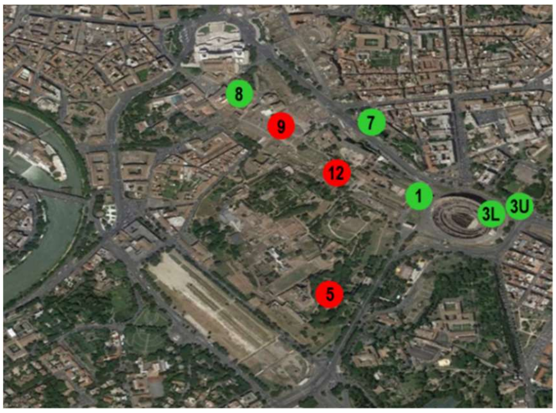

Fig. 3. The 8 selected sites for the survey and sound measurements; sites just outside (green circles) and inside the area (red circles)

2.3 Subjective evaluation of the area

To collect subjective appraisal on perceived quality of some features of the area, a questionnaire, modified from ones applied in previous studies [13, 14], was set up and structured to gather the following information:

- personal data (age, gender, occupation, country);
- motivation to stay in the area;
- -perceived quality of security, maintenance, cleanliness, environment, soundscape, landscape and smell, each rated on a 7-point scale from 1 (very bad) to 7 (excellent);
- sounds (chosen among 13 preselected categories) expected to hear, sounds actually heard and those making the area pleasant;
- soundscape attributes (unpleasant vs. pleasant, uneventful vs. eventful, depressing vs. exciting, chaotic vs. calm), each rated on a 7-point scale from 1 (clearly negative) to 7 (clearly positive) with center value (4) as neutral rating [15];
- predominant nature of soundscape, to be chosen among technological, anthropic and natural;
- indication of visual elements (chosen among 12 preselected categories) expected to watch, elements actually seen and those making the area pleasant;
- landscape attributes, equal to those used for rating the soundscape;
- predominat nature of landscape, to be chosen among built, anthropic and natural;
- overall enjoyment of the area given on a 7-point scale from 1 (a little) to 7 (a lot).

The questionnaire, in English, was distributed among 212 subjects around the selected 8 sites, simultaneously with the sound measurements and binaural recordings, in order to match, as close as possible, the acoustic data with the actual sound exposure of interviewees. Table 2 reports the number of interviews at each site.

Table 2. Number of interviews at each site

	Site	Number of interviews
1	Entrance to Colosseum	24
3L	“Fori Imperiali” St. – “Labicana” St. level of Colosseum Square	24
3U	“Fori Imperiali” St. – “Labicana” St. level	32
5	“Foro Palatino” entrance. “San Gregorio” St.	23
7	Tourist information point	33
8	Terrace. Sight of “Foro Romano”	27
9	“Curia”, Temple of “Antonio and Faustina”	24
12	Entrance to “Via Sacra”. Arch of Tito	25

2.4 Statistical analysis

The acoustic and subjective data have been analyzed by the “R” software [11], a free open-source software environment for statistical computing and graphics, together with RStudio, an integrated development environment (IDE) for R [16].

Among all the collected data, a subset was chosen forming a matrix, with no missing values, including 212 observations (rows) and 28 variables (columns). The selected variables were 15 continuous, the acoustic parameters, and 13 ordinal, the subjective responses on the following items of the questionnaire: security (SEC), maintenance (MAN), cleanliness (CLN), environment (ENVQ), soundscape (SQ), landscape (VQ), smell (SMQ), soundscape pleasantness (SQ_PL), soundscape eventfulness (SQ_EV), soundscape excitingness (SQ_EX), soundscape calmness (SQ_CA), soundscape type (Sclass) and overall enjoyment of the area (GLIKE).

Multicollinearity analysis between the variables has been performed applying the Spearman’s rank correlation coefficient r. Afterwards, cluster analysis has been applied in order to identify structures within the data. Clustering is one of the most widespread descriptive methods of data analysis and data mining. It is a data segmentation technique that divides a large dataset into different homogenous groups on the basis of similarity in the data. Three data sets were considered, each one with standardized values (mean = 0 and unitary standard deviation), formed by the ordinal variables only, the continuous variables only and, finally, the complete data set (28 variables). The R-package “optCluster” [17] was applied to determine the optimal clustering algorithm, chosen among: AGglomerative NESting hierarchical clustering (AGNES), Clustering LARge Applications (CLARA), DIvisive ANAlysis clustering (DIANA), hierarchical Ward clustering, kmeans, model and Partition Around Medoids (PAM). The optimal number of clusters was determined considering the solutions between 2 and 5 groups and calculating the Euclidean distance between observations.

3. RESULTS AND DISCUSSION

Table 3 reports gender and age of the interviewees (percentage) at each site and overall values; considering the logistic constraints, the sample looks balanced across these variables at least for the overall values. As expected, tourism was the predominant motivation of being in the area (90%).

Regarding multicollinearity, the correlogram of the ordinal variables is given in Fig. 4. All the Spearman’s rank correlation coefficients are positive; the highest value (r=0.67) is observed between cleanliness (CLN) and perceived environmental quality (ENVQ), as well as perceived soundscape quality (SQ) and its pleasantness (SQ_PL).

Rather different is the correlogram of the continuous variables (acoustic and psychoacoustic parameters) given in Fig. 5. Fluctuation strength (F) is negatively correlated with most of the other parameters; the highest positive Spearman’s rank correlation coefficient ((r=0.99) is observed between sound level percentile L_{A50} and loudness percentile N_{50} (N50_DIN). Good positive correlation is shown by many parameters with the exception of fluctuation strength (F), sharpness (S), $L_{eq} – L_{Aeq}$ (Leq.LAeq) and $L_{A10} – L_{A90}$ (LA10.LA90).

The correlogram of all the 28 variables, given in Fig. 6, clearly shows that acoustic and psychoacoustic parameters are either negative or poorly correlated with the subjective ratings.

Table 3. Gender and age of the interviewees (percentage values)

Site	Gender		Age (years old)				
	Male	Female	18-24	25-29	30-39	40-49	≥ 50
1	41.7	58.3	25.0	20.8	20.8	20.8	12.5
3L	50.0	50.0	33.3	37.5	8.3	20.8	0
3U	53.1	46.9	28.1	28.1	12.5	21.9	9.4
5	41.7	58.3	20.9	37.5	20.8	0	20.9
7	54.5	45.5	24.3	24.2	27.3	15.2	9.1
8	57.1	42.9	10.7	14.3	3.6	14.3	28.5
9	44.0	56.0	16.0	24.0	16.0	24.0	0
12	44.0	56.0	16.0	8.0	12.0	16.0	12.0
Total	49.0	51.0	24.1	24.1	23.6	16.5	11.8

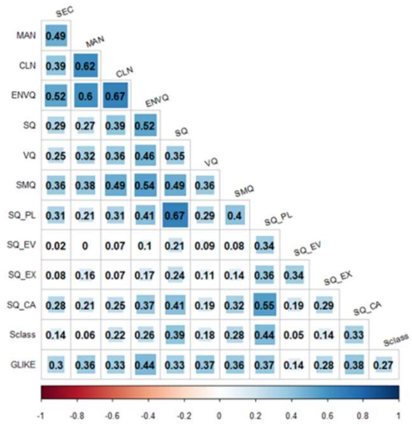

Fig. 4. Correlogram of the 13 ordinal variables (subjective responses)

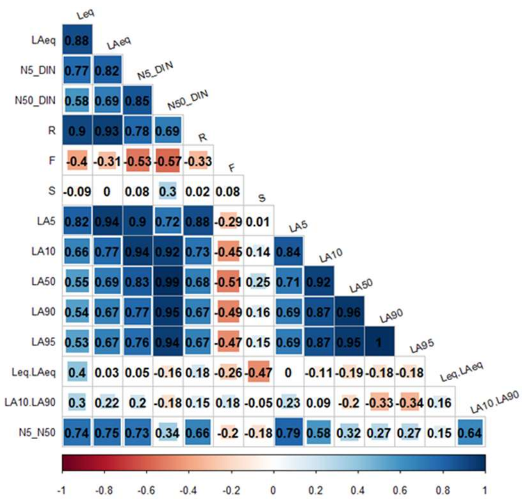

Fig. 5. Correlogram of the 15 continuous variables (acoustic and psychoacoustic parameters)

For instance, the perceived soundscape quality (SQ) shows the highest negative Spearman's rank correlation coefficient (r = - 0.37) with L_{A10} and the highest positive value (r = 0.26) with fluctuation strength (F).

Excepting the predominant nature of soundscape, all the remaining 12 features of the area have been rated on a 7-point scale which is symmetrical to the center value 4, that is negative responses are associated to scores from 1 to 3 and positive ones to scores from 5 to 7. Fig. 7 shows the diverging stacked bar plot of subjective appraisals at each site

A more synthetic report of the above data is obtained pooling together the scores of negative and those of positive responses for all the features and computing the corresponding percentage of subjects for each site. The results are summarized in Table 4, where between ( ) are indicated the corresponding percentages for the perceived quality of soundscape only. Considering all the 12 features, site 12 has obtained the highest percentage of positive values, followed by sites 8 and 9. The highest percentage of negative values is observed at site 3U followed by sites 1 and 3L. As far as soundscape quality concerns, the sites 12, 8 and 9 are ranked as all the 12 features for positive values, whereas for negative scores site 5 shows the highest percentage followed by sites 1 and 3U. The last column in Table 4 reports also the LAeq values measured at each site.

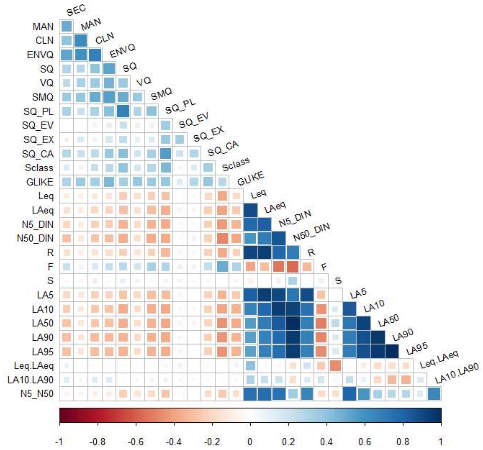

Fig. 6. Correlogram of all the 28 variables

The Spearman's rank correlation coefficient between L_{Aeq} and positive scores (> 4) of perceived soundscape quality is, as expected, negative (r = - 0.53), that is increasing L_{Aeq} reduces the perceived quality of soundscape, and the value is lower than that obtained considering all the 12 features, including the non-acoustic ones (r = - 0.74).

This confirms the need of a holistic approach in the sonic environment evaluation, which should take into account all the factors influencing the subjective appraisal.

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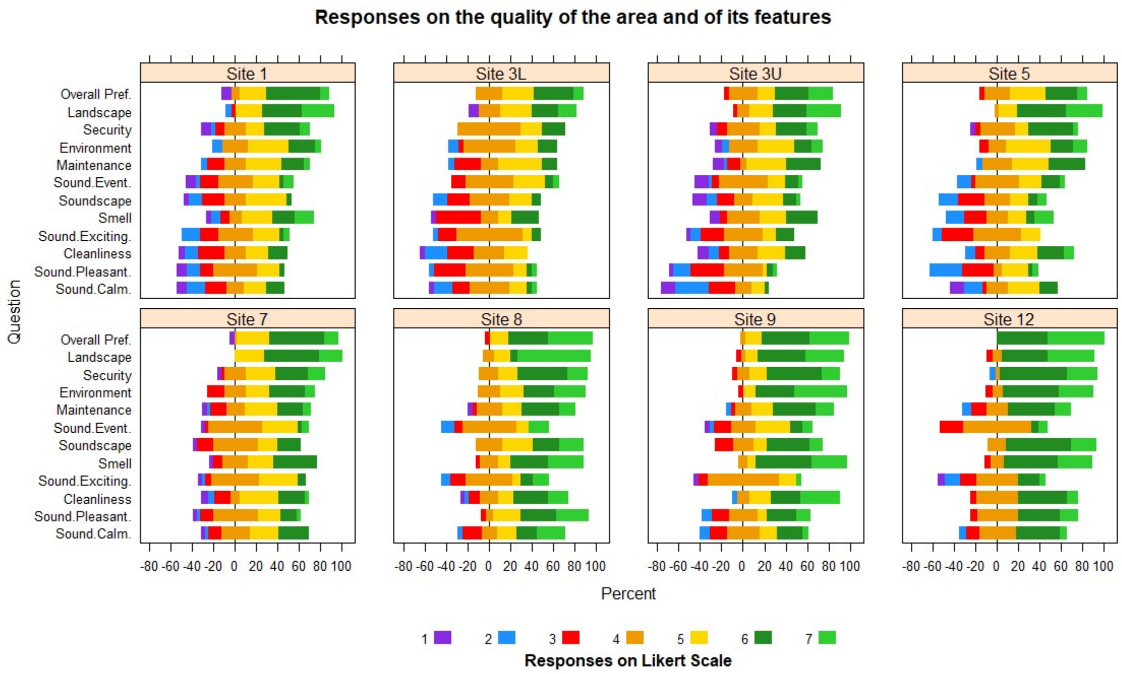

Fig. 7. Diverging stacked bar plot of subjective appraisals at each site

Table 4. Percentage of the interviewees giving the score for all the 12 features of the area; soundscape quality data between ( )

Site	Score

	< 4	4	> 4	L_{Aeq} dB(A)
1	25.7 (37.5)	21.2 (20.8)	53.1 (41.7)	64
3L	23.6 (33.3)	37.2 (37.5)	39.2 (29.2)	62
3U	26.3 (37.5)	26.8 (18.7)	46.9 (43.8)	64
5	22.2 (41.7)	24.7 (25.0)	53.1 (33.3)	63
7	13.1 (18.2)	25.5 (42.4)	61.4 (39.4)	61
8	8.3 (0)	21.5 (25.0)	71.8 (75.0)	54
9	10.0 (16.0)	19.0 (20.0)	71.0 (64.0)	57
12	7.3 (0)	17.3 (12.0)	75.3 (88.0)	60

Table 5. Classification of sites obtained by k-means applied to the 13 ordinal variables (observation percentages)

Site	Cluster	
	1 (123 obs.)	2 (89 obs.)
1	45.8	54.2
3L	25.0	75.0
3U	28.1	71.9
5	26.1	73.9
7	66.7	33.3
8	88.9	11.1
9	91.7	8.3
12	92.0	8.0

Table 6. Classification of sites obtained by DIANA applied to the 15 acoustic parameters (observation percentages)

Site	Cluster			
	1 (81 obs.)	2 (121 obs.)	3 (9 obs.)	4 (1 obs.)
1	---	100	---	---
3L	---	100	---	---
3U	21.9	78.1	---	---
5	---	100	---	---
7	24.3	75.7	---	---
8	100	---	---	---
9	100	---	---	---
12	60.0	---	36.0	4.0

Table 7. Percentage of agreement between subjective and acoustic classification (percentage values)

Site	Cluster	
	1	2
1	---	54.2
3L	---	75.0
3U	9.4	50.0
5	---	73.9
7	15.1	21.2
8	85.2	---
9	91.7	---
12	56.0	---

The above positive rating outcome is somehow reflected in the results obtained by the cluster analysis performed on the 13 ordinal variables. The optimal solution computed by the R-package "optCluster" corresponds to the unsupervised learning algorithm of k-means (Hartigan-Wong method of agglomeration) and two clusters, as reported in Table 5, each including a portion of the data set.

Considering the majority of observations (rows in the data matrix), sites 7, 8, 9 and 12 belongs to cluster 1, formed by 123 observations out of the total of 212 ones (58%), whereas the remaining sites are associated to cluster 2 (89 observations, 42% of the entire set).

The optimal solution computed by the R-package "optCluster" applied to the dataset formed by the 15 acoustic parameters was the DIvisive ANAlysis clustering (DIANA) algorithm and 4 clusters, as reported in Table 6, each including a portion of the data set.

Considering the majority of observations (rows in the data matrix), sites 8, 9 and 12 belongs to cluster 1, whereas the remaining sites are associated to cluster 2. Site 12 is split into cluster 1, 3 and 4, the last formed by 1 observation at site 12 only. The clustering is more robust than that obtained by the subjective ratings as 5 sites (1, 3L, 5, 8 and 9) are completely (100%) associated to a single cluster.

The percentage of agreement between subjective and acoustic classification, excluding clusters 3 and 4 of the latter, is reported in Table 7, showing an unsatisfactory overlap each other. This is a further confirmation that the soundscape, as perceptual construct, depends on several variables, not only the acoustic ones.

Finally, the R-package "optCluster" has been applied to the entire data set formed by the 28 variables and the optimal solution corresponds to k-means method and two clusters, as reported in Table 8. Cluster 1 is formed by 93 observations (43.9%) and cluster 2 by 119 observations (56.1%).

Considering the majority of observations (rows in the data matrix), sites 8, 9 and 12 belongs to cluster 1, whereas the remaining sites are associated to cluster 2. It has to be pointed out that in sites belonging to cluster 1 the predominant nature of soundscape is anthropic, whereas in those associated to cluster 2 the soundscape is dominated by technological sound sources.

Table 8. Classification of sites obtained by k-means applied to the 28 variables (observation percentages)

Site	Cluster	
	1 (93 obs.)	2 (119 obs.)
1	---	100
3L	8.3	91.7
3U	21.9	78.1
5	---	100
7	27.3	72.7
8	100	---
9	100	---
12	96.0	4.0

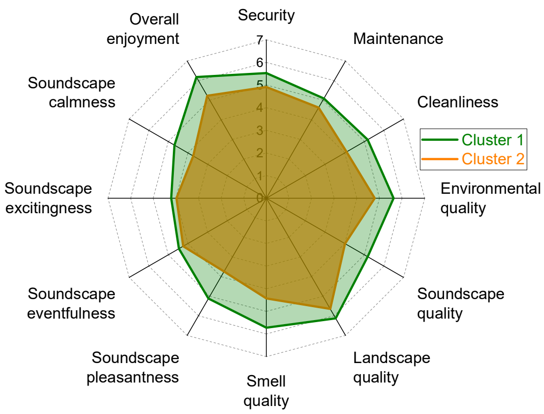

Fig. 8. Average scores of the area features vs. cluster membership

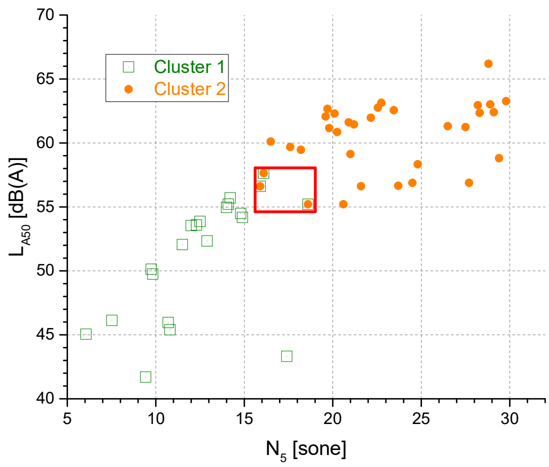

Fig. 9. Percentile loudness N_5 and sound level L_{A50} vs. cluster membership

The radar plot in Fig. 8 shows that cluster 1 includes areas having features rated by subjects with average scores higher than those obtained for areas belongings to cluster 2. In particular, the highest differences in decreasing order are observed for soundscape pleasantness, smell and soundscape perceived quality.

Dealing with acoustic parameters, the scatter plot in Fig. 9 shows that percentile loudness N_5 and percentile sound level L_{A50} are suitable to discriminate the areas according to the two clusters. The area of confusion for correct classification is shown by the red rectangle, delimited by 16-19 sone for N_5 and 55-58 dB(A) for L_{A50}. Outside this area, lower values for both the parameters are observed for areas included in cluster 1 and, on the contrary, higher values correspond to areas associated to cluster 2.

4. CONCLUSIONS

Cluster analysis applied to the data collected in the study area has shown that the classification of the 8 sites based on subjective appraisal of the features of the area itself (including the non-acoustic ones) does not match satisfactorily that obtained by the acoustic parameters. This confirms the need of an holistic approach in evaluating the sonic environment which should take into account all the factors influencing the subjective appraisal.

Considering subjective ratings and acoustic parameters, the unsupervised learning algorithm of k-means grouped the 8 sites into two clusters, one formed by sites where the soundscape was dominated by anthropic sound sources (cluster 1) and the other by technological sources (cluster 2). The percentile loudness N_5 and percentile sound level L_{A50} resulted to be suitable to discriminate the sites according to the above two clusters.

Further analyses are planned on developing classification models, like discriminant analysis and binomial logistic regression.

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