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Noise levels evolution before, during and after the COVID19 Lockdown in Girona

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Abstract
The global COVID-19 pandemic has affected people's daily life. Health authorities all over the world have promoted restrictions on people and goods movement to reduce the pandemic effects. Moreover, in many countries Lockdown measures have been taken to stop the spread of the pandemic and prevent local health systems from collapsing. Lockdown measures have produced wide behavioural changes on the population, especially in cities. This fact has had a direct impact on the urban noise levels measured. Equivalent noise levels in Girona before, during and after the COVID- 19 Lockdown have been analysed to determine the variations due to pandemic restrictions. A wide time perspective is applied to the analysis and it is focused on citizens behaviour changes with the aim to discuss large variations on noise levels. Girona is placed in the North-East of Catalonia (Spain), and has a population of more than 100.000 citizens. In this paper we present on the one hand a day over day comparison of the mean value of four different sensors. On the other hand, an hour over hour comparison of the L_{Aeq} trend among same days of the week in the same sensor – focusing on traffic and leisure noise -, comparing before, during and after the lockdown. Data has been obtained from an acoustic sensor network deployed in the city. This analysis is part of the project "Sons al Balcó", which aims to draw the soundscape of Catalonia during the lockdown.

Keywords: COVID-19, Lockdown, Pre-Lockdown, Post-Lockdown, L_{Aeq}, noise, Girona.

1 Introduction

WHO declared the COVID-19 pandemic as an emergency on the 30^{th} of January of 2020 [1], and several European countries developed lockdown plans, based on restricting commercial activities and flights, decreasing the ground transportation [2], the schools were closed, and all companies promoted the teleworking, with the final goal of minimizing the interaction between people. In Spain a lockdown plan was also drawn, starting in March and finishing in June for the first part of the pandemic, with several different stages [3]. Nevertheless, after the first and hard lockdown, a second – and mostly softer –lockdown was installed after the second pandemic evolution after last summer.

This global social lockdown had a severe impact on the soundscape, especially of the urban environments [4]. Most of the noise [5] associated with everyday outdoor activities was severely decreased, and needed to be newly observed and integrated in an adhoc taxonomy. Noise ground transportation, mainly traffic noise [6, 7], but also changes in railway noise, and port noise, airport noise, industry noise and last, but not least, leisure-related noise [8] were clearly reduced in the analyzed cities, and even in quiet residential areas [9]. Perception changes were analyzed in different countries, e.g. Italy in [10], Granada (in Spain) by Vida *et al* [11] or even Montreal (in Canada) in [12], showing clear changes in measurements and perception before and during the lockdown.

In Catalonia, our project "Sons al Balcó" (the Catalan expression for *Sounds on the Balcony* [13] has studied the effects of the lockdown on people and the perception from home, as well as the changes in the L_{Aeq} values collected by sensors in cities like Girona or Barcelona [14, 15]. The work presented in this paper is an extension of [14] on quantitative data, which came out from four out of the eight calibrated sensors deployed in the streets of Girona (Spain), going further our first and preliminary analysis over the hard lockdown months, and widening the study to the second part of the pandemic soft lockdown.

This paper is structured as follows: Section 2 gives details about the wireless acoustic sensor network and the data collection, Section 3 plots the evolution of the L_{Aeq} during all 2020 and several comparisons between the Pre-lockdown levels, during the lockdown and Post-lockdown levels, and finally, Section 4 details some conclusions of this extended work.

2 Noise Monitoring Network and Data Collection

2.1. Details of the Wireless Acoustic Sensor Network

Sensors deployed in Girona are located in the city center, and constitute a network of up to eight sensors, as it can be observed on the map in Figure 1. The sensors locations are: 1) Rambla Xavier Cugat, 2) Ramon Folch, 3) C. Figuerola, 4) C. Güell, 5) Pg. d'Olot, 6) Pj. de Sant Feliu, 7) Plaça de Sant Feliu and 8) C. Joan Maragall w/ Bisbe Lorenzana. The sensors have been deployed by Urbiotica and the signal processing corresponding to the equivalent L_{Aeq} evaluation has been coded by Keacoustics. The sensors give a detail of L_{Aeq} with a maximum temporal resolution of 1 min. The sensors collect data all day and night and, besides several technical issues that occurred mainly after the 2020 Lockdown. The analyzed data is continuous 24 hours per day, throughout all analyzed weeks.

2.2. Data Collection during 2020

In a previous work done and published in JASA [16], data from February 2020 to the end of June 2020 was examined, sticking to the comparison between the Pre-lockdown, hard Lockdown, and the first weeks of Post-lockdown, when most of the activities were reopening. In this period, six different Lockdown stages were analyzed. The different stages were selected considering required degrees of restrictions:

- Stage 1: 12/03/2020–13/03/2020 School suspended and telework suggested.
- Stage 2: 14/03/2020–28/03/2020 School, non-essential shops, and any events closed, no walking outdoors, telework unless justified.
- Stage 3: 29/03/2020–12/04/2020 School, non-essential shops, and any events closed, no walking outdoors, telework unless justified. Non-essential movement banned.
- Stage 4 (similar to Stage 2): 13/04/2020–26/04/2020 School, non-essential shops, and any events closed, no walking outdoors, telework unless justified.
- Stage 5: 27/04/2020–24/05/2020 School and any events closed, telework unless justified. Walks allowed (major restrictions).
- Stage 6: 25/05/2020–07/06/2020 School and any events closed, telework.

In this work, data throughout a complete year has been considered. During the first period of pandemic, hard restrictions were implemented. After a de-escalation period, health indicators for COVID-19 worsened. This has led to continuous changes in restrictions, such as mobility or openness and capacity in bars and restaurants. Measures such as a curfew and capacity restrictions in bars and restaurants have been implemented to control the transmission of SARS-CoV-2.

Following dates define important changes in restrictions trough the analyzed period. This regulations have had a direct impact in daily life of population, as well as in economic activities.

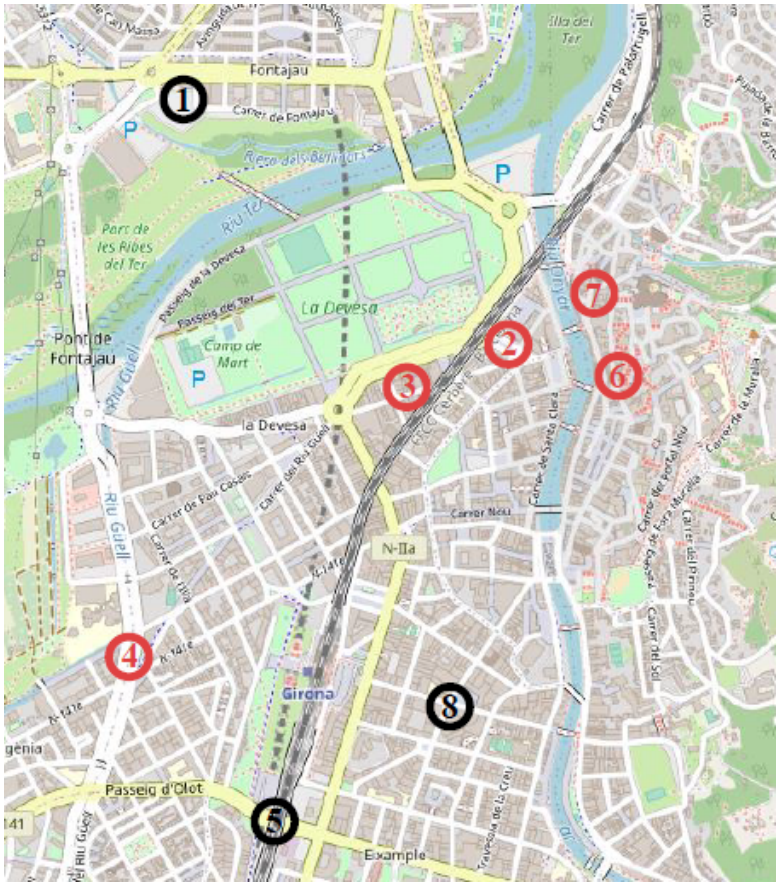

Figure 1: Map of the locations of the WASN sensors in Girona

– 08/06/2020 Cinemas, theaters and shopping centers can open with reduced capacity. Mobility to second residences is allowed, and night clubs can open with some restrictions.

– 01/08/20 50% capacity inside bars and restaurants. No limit in terraces. Harder restrictions in night clubs.

– 01/09/20 50% capacity inside and outside bars and restaurants. Furthermore, they must close at 1 a.m.

– 16/10/20 Bars and restaurant closed, except takeaway food. 50% capacity in cultural activities and they must close before 11 a.m. Universities classes online. Not allowed meetings of more than 6 people.

– 25/10/20 Curfew from 10 p.m. to 6 a.m. Cinemas and theaters closed. Mobility restrictions inside Catalonia and from Catalonia to other autonomous communities. Other restrictions implemented on 16/10/20 remain.

– 23/11/20 Bars and restaurants can open from 6 a.m. to 9:30 p.m. Others restrictions implemented on 25/10/20 remain.

– 19/12/20 New restrictions in bars and restaurants opening hours. It is only allowed from 7:30 a.m. to 9:30 a.m. and from 1 p.m to 15:30 p.m. The rest of the day only takeaway food permitted. There are three exceptions to the curfew hours. On 24/12/20 and 31/12/20, people must remain at home from 1:30 a.m. to 6 a.m.

Dates are displayed in chronological order and used to define possible changes on L_{Aeq} for the five sensors. It is important to assume that some changes in the restrictions may result in a slight and imperceptible variations in figures below (see Figure 2 and Figure 3).

After this review of stages throughout 2020, we would like to note that in this work we present a time extension of a previous work [3], which also processed L_{Aeq} values gathered in the nodes of Girona WASN. This previous work focused on the weeks previous to the Lockdown, during the lockdown and on some subsequent weeks. The current work analyzes the values of the L_{Aeq} of Girona noise sensors during all 2020, comparing the values of the previously described stages.

3 Results

This section focuses on describing the changes in noise levels due to COVID-19 restrictions throughout the year 2020. Two types of analysis are presented. On the one hand, subsection 3.2 presents the changes throughout the days of the year, with evaluations every 10 minutes ($L_{Aeq,10min}$). Moreover, different typologies of noise sources are considered depending on human activities predominance in sensors placement.

On the other hand, subsection 3.3 presents the $L_{Aeq,1hour}$ results of the analysis for the five most significant sensors, in terms of data availability. These outcomes are divided into week days and weekend days. In addition, three differentiated periods throughout 2020, with distinguishable pandemic restrictions are also taken into account for the analysis.

3.1. Analysis Details

Some data gathered from these sensors has already been analyzed in [16], however in this paper we show a wider analysis since we have increased the number of processed sensors as well as the time span. Due to issues that impact on the completeness of the data, only five sensors out of eight have been chosen for this study.

Sensors #2, #3, #4, #6 and #7 have been chosen to accomplish this analysis. Location of these sensors is shown as colored numbers in Figure 1. Locations can be classified in three main typologies of noise predominance, regarding the main activities in the sensor area: *i)* traffic noise, *ii)* leisure noise, *iii)* residential noise and *iv)* railway traffic noise.

We present the data gathered in Sensor #2 (Ramon Folch), which is placed in the city center and combines both traffic and leisure noise, as well as railway traffic. Sensor #3 (Figuerola) is placed in a narrow street with many restaurants, where leisure noise dominates. Sensor #4 (Güell) is located in a wide street with heavy traffic, which makes the place really noisy in terms of traffic. Sensor #6 (Pj. St Feliu) is located in a quiet touristic zone, in the old quartier. Finally, Sensor #7 (Pç. St Feliu) is also located in the old quartier, but in a touristic zone with several restaurants and with a combination of road and railway traffic during the day.

Data is gathered throughout the whole 2020 year, from 1^{st} of January to 31^{st} of December. The data collected from these five sensors is not complete and there are some gaps, scattered mainly in the second half of the year, except for Sensor #3, which did not gather data during almost all January. These gaps are marked in dark blue in all the plots drawn in Figure 2 .

As a first approach, the outcomes presented in Figure 2 shows the L_{Aeq} [dBA] sampled every 10 minutes for each of the five sensors, in the OZ axis. In each plot the OY axis represents the day (from 1^{st} of January to 31^{st} of December) and the OX axis the hour of the day (from 00h to 23h). We give more details in subsection 2.

The outcomes presented in Figure 3 are split in three groups: *i)* pre-lockdown period, which begins on the 1^{st} of January 2020 and ends on the 11^{th} of March 2020; lockdown period, which begins on the 12^{th} of March 2020 and ends on the 8^{th} of May 2020; and finally post-lockdown period, which begins on the 9^{th} of May 2020 and ends on the 31^{st} of December 2020. Figure 3 shows the L_{Aeq} [dBA] averaged in an hour for each of the five sensors and distinguishes week days and weekends, since the behavior is quite different. More details are given in subsection 3.

3.2. Daily Evaluation for $L_{Aeq,10min}$ during all 2020

Figure 2 shows the evolution of $L_{Aeq,10min}$ along a day for the five sensors analyzed.

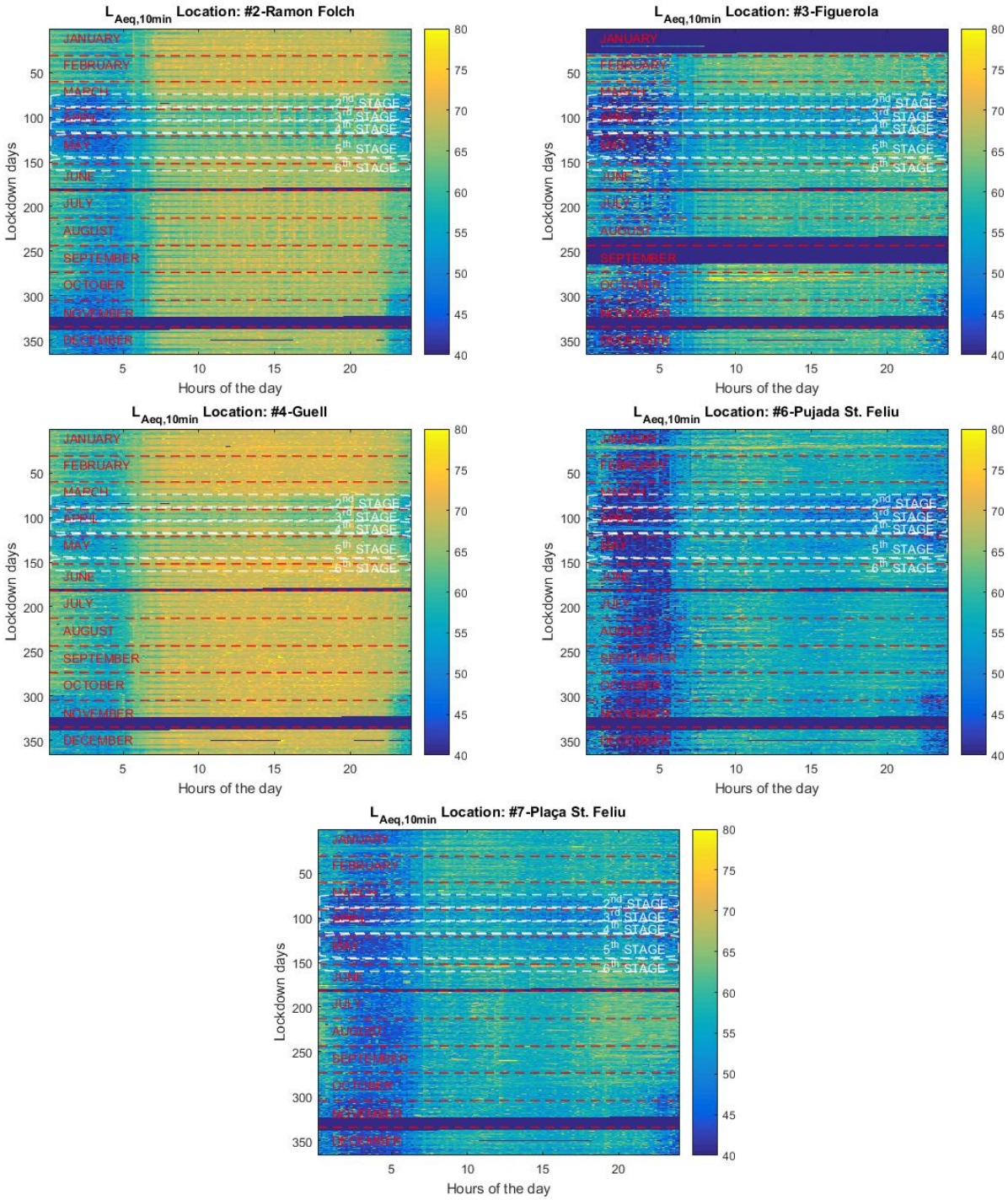

Figure 2: Daily evaluation of the $L_{Aeq,10min}$ values for 2020, from Jan 1^{st} to Dec 31^{st}. Missing data is represented by means of dark blue lines.

To start with the results of the analysis, all five sensors show a clear noise reduction at the end of October in night hours from 10 p.m. to 6 a.m. This behaviour continues until the end of the analyzed period. Noise reduction in these dates and noise reduction hours match with the curfew implemented on the 25^{th} of October,

which remains until the end of December. Night noise levels are comparable to those noise levels obtained from lockdown Stage 2 to Stage 5.

To follow with, Sensors #2 and #4 show the highest noise level among the five analyzed locations. This is due to traffic noise predominance in both of them, although there are some important differences. While noise typology in #2 comes from the traffic noise of neighbours mobility, leisure activities and railway (see [16] for more details), in Sensor #4 noise comes from a concurred crossroad with heavy traffic. This can explain why noise levels in Sensor #2 are lower than in Sensor #4, especially during nights but also during the day. In addition, differences in $L_{Aeq,10min}$ between week days and weekends are noticeable in Sensor #2, whereas in Sensor #4 these differences are slightly noticeable only from 7 a.m. to 10 a.m.

Values of the differences of $L_{Aeq,10min}$ among Pre-lockdown, Lockdown and Post-lockdown period are more relevant in Sensor #2. After an important decrease of noise levels from Stage 2 to Stage 5, in Stage 6 noise level increases not only during the day but also at night. After this change, noise levels remain stable until the end of October, which is due to de-escalation lockdown restrictions. However, $L_{Aeq,10min}$ during day hours are still lower than in pre-lockdown period. This can be caused by the fact that telework has been normalized in some companies, and the existence of several online classes in universities and educational centers, which minimize mobility. In addition, some of the restrictions applied to bars and restaurants can play a role in this values. From 25^{th} of October onwards, levels in Sensor #2 during day hours do not experiment relevant changes in comparison with the other months of post-lockdown period.

Sensor #4 also presents a decrease in $L_{Aeq,10min}$ from Stage 2 to Stage 5. Afterwards, the measured noise levels rise to nearly the same levels of Pre-lockdown period in day hours. For night hours, measured levels are slightly higher from June to October, in comparison with the Pre-lockdown period. This behavior can be explained by the summer period with more daylight, and because of the high temperatures that increase mobility to nearby beaches (which are only half an hour far, and are a real alternative to summer in the city).

In Sensor #3 noise performance and noise levels among the year are similar to Sensor #6 and #7. Is necessity to bear in mind that noise levels are dominated by leisure, bars and restaurants activities. Noise Levels during pre-lockdown period and the first months of post-lockdown are comparable. Besides, night levels during hard Lockdown stages are similar to those from 25^{th} of October and forward weeks. On the contrary, the day levels of pot-lockdown period do not decrease to those obtained during Stage 2 to 5.

Sensors #6 and #7 are located in the city old quarters. This is usually a quiet area, comparing its equivalent level values with other sensors, such as Sensor #2 and #4, where traffic noise predominates over other noise sources. In addition, Sensor #7 is located in an area with restaurants, bars and some terraces, quite active in summer. Noise level increased during both day and night period at the end of the 6^{th} stage due to de-escalation of lockdown restrictions in both sensors. Specially, night noise levels in Sensor #7 reached higher levels than in pre-Lockdown period and are higher than day hours as well. This can be explained by the noise coming from terraces caused by high summer temperatures, and the fact that local people use more terraces and restaurants since COVID-19 restrictions have reduced abroad travels during holidays. This trend continues until the end of September when the noise levels start to decrease due to colder temperatures, and a reduced use of outdoor spaces as well as the end of vacation period. Noise levels are stable until implementation of curfew when restrictions have a clear impact in noise levels. Even though curfew starts at 10 p.m. lower noise levels are gathered from 1 a.m. to 6 a.m. Despite the authors do not have available details to support this hypothesis, a possible explanation of this values could be because of garbage collector service, and the streets cleaning services.

3.3. Boxplots Evaluation

This section analyzes the aggregated values in 1 hour integration for the Pre-lockdown, Lockdown and Post-lockdown stages, for all the detailed sensors.

In Sensor #2, during the nights of both week days and weekends the median level of $L_{Aeq,1h}$ decreases almost 10 dBA. After the Lockdown it increases again but it not reaches those values registered before the Lockdown. During day hours the values of $L_{Aeq,1h}$ after lockdown reaches those values gathered before lockdown but only at week days, whereas at weekends noise measures are bounded 5 dBA below.

In Sensor #3, neither during weekends nor during week days the $L_{Aeq,1h}$ recovers those values registered before the Lockdown period. A high difference of $L_{Aeq,1h}$ exists between 1^{st} and 3^{rd} quartile during night hours, which may be given because it is an area with predominant leisure noise.

Due to the fact that Sensor #4 area is dominated by heavy traffic noise almost no reduction is observed during lockdown. Only during weekends a reduction of 5 dBA is noted. After the Lockdown the values of

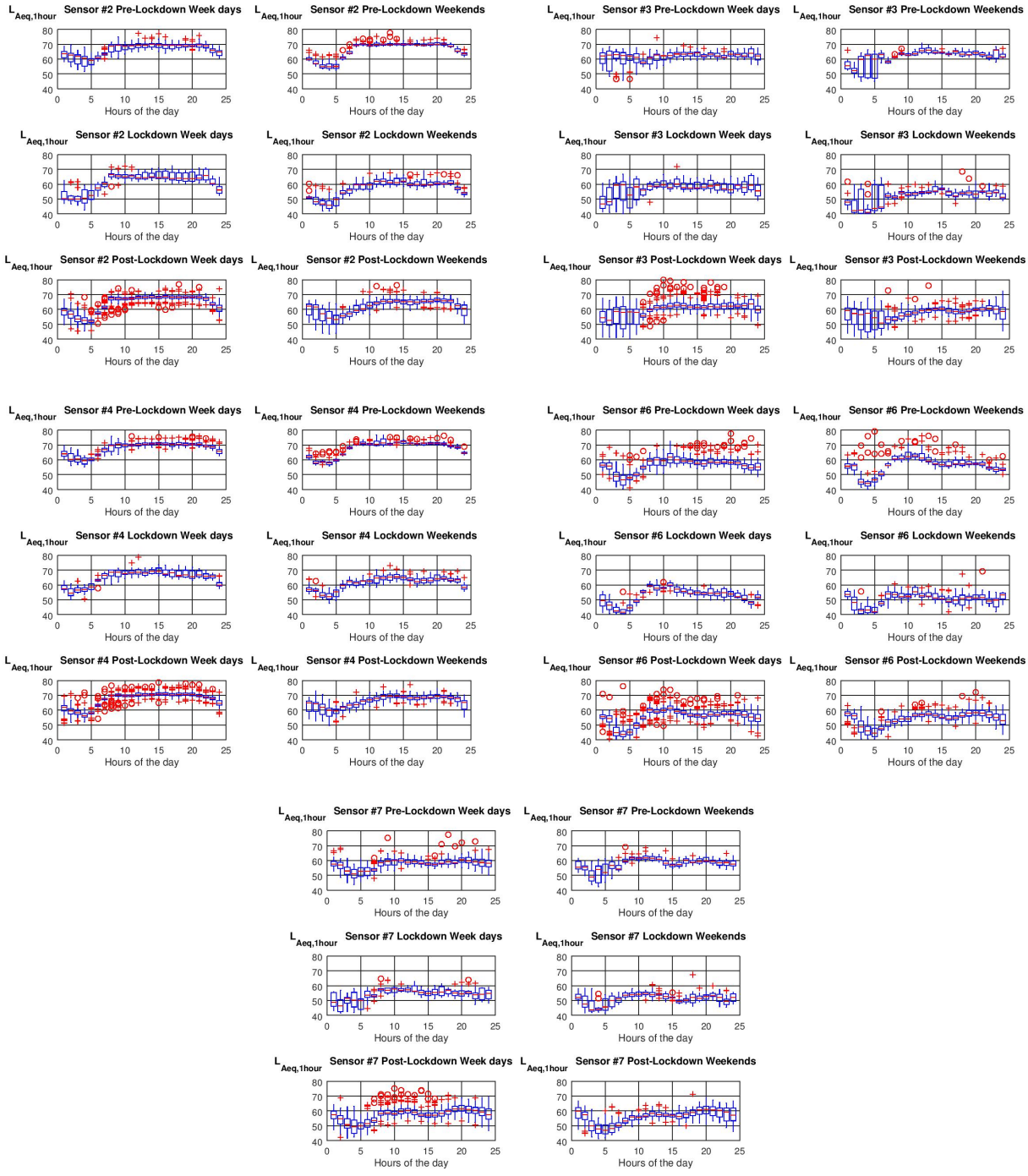

Figure 3: Boxplot values for $L_{Aeq,1hour}$ for *pre-lockdown*, *lockdown* and *post-lockdown* time windows, differentiating weekdays from weekends, for Sensors #2, #3, #4, #6 and #7.

$L_{Aeq,1h}$ are equal to those prior to lockdown, at week days and at weekends.

In Sensor #6 the post-lockdown values increase but they never reach the Pre-lockdown values, neither during week days nor during weekends of diurnal hours.

In Sensor #7 there is a high dispersion of values during night hours, maybe because it is a leisure area. The post-lockdown values reach the same values of $L_{Aeq,1h}$ of pre-lockdown period.

In all sensors placed on areas where leisure noise plays an important role (i.e., Sensor #2, #3 and #7), boxplots show a higher dispersion between 1^{st} and 3^{rd} quartiles during nocturnal hours rather than diurnal hours. This phenomena happens during week days, as well as during weekends, no mater being in a lockdown after or before.

A strange phenomena is observed after lockdown period, when a greater dispersion between maximum and minimum values, as well as the higher occurrence of outliers, is reported. This is observed in all sensors and only during week days. It may be due to continual changes in restrictions in addition to the implementation of the curfew. This has a clear impact on the behavior of obtained noise levels.

4 Conclusions

The conclusions reached in this work complement the conclusions of the former work in JASA [3]. The Lockdown stage led to a high decrease of noise levels measured in most of the sensors in Girona, except for the locations where traffic noise was totally predominant due to the fact that they are main connection roads.

The leisure noise source also deserves several conclusions, because it nearly disappears, especially during the lockdown and curfew period nights, mainly following the strict regulations set by the government. Subsequently, follows to current higher values than the usual ones just after the Lockdown. This behavior might be explained by the more relaxed restrictions, and because the citizens use the public space for their social relationships.

One of the points that the authors would like to underline, and raise awareness of the noise sources issue, is the fact that in some areas it has been really fast to recover the noise levels previous to the Lockdown, right after the restriction of activities have been relaxed. As we have referred in the literature, several studies point out that the decrease of noise in urban environments during the Lockdown has improved the perception of soundscape for citizens, especially when talking about traffic and leisure noise. It is something that the pandemic taught all of us, as citizens, and we should work to preserve it, balancing it with city life.

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References

[1] Youngmee Jee. WHO International Health Regulations Emergency Committee for the COVID-19 outbreak. *Epidemiology and health*, 42, 2020.

[2] Francesco Aletta and Dan Osborn. The COVID-19 global challenge and its implications for the environment–what we are learning. *UCL Open Environment*, 2020.

[3] Rosa Ma Alsina-Pages and Pau Bergadà. Evaluation of the L_{Aeq} levels during the COVID-19 lockdown period using a static wireless acoustic sensor network in the city of Girona. 2021.

[4] Francesco Aletta, Tin Oberman, Andrew Mitchell, Huan Tong, and Jian Kang. Assessing the changing urban sound environment during the COVID-19 lockdown period using short-term acoustic measurements. *Noise Mapping*, 7(1):123–134, 2020.

[5] César Asensio, Pierre Aumond, Arnaud Can, Luis Gascó, Peter Lercher, Jean-Marc Wunderli, Catherine Lavandier, Guillermo de Arcas, Carlos Ribeiro, Patricio Muñoz, et al. A taxonomy proposal for the assessment of the changes in soundscape resulting from the covid-19 lockdown. *IJERPH*, 17(12):4205, 2020.

[6] Francesco Aletta, Stefano Brinchi, Stefano Carrese, Andrea Gemma, Claudia Guattari, Livia Mannini, and Sergio Maria Patella. Analysing urban traffic volumes and mapping noise emissions in Rome (Italy) in the context of containment measures for the COVID-19 disease. *Noise Mapping*, 7(1):114–122, 2020.

[7] Rosa Ma Alsina-Pagès, Francesc Alías, Patrizia Bellucci, Pier Paolo Cartolano, Ilaria Coppa, Laura Peruzzi, Alessandro Bisceglie, and Giovanni Zambon. Noise at the time of COVID 19: The impact in some areas in Rome and Milan, Italy. *Noise Mapping*, 7(1):248–264, 2020.

[8] Enza De Lauro, Mariarosaria Falanga, and Laura Tedeschini Lalli. The soundscape of the Trevi fountain in Covid-19 silence. *Noise Mapping*, 7(1):212–222, 2020.

[9] Kimihiro Sakagami. A note on the acoustic environment in a usually quiet residential area after the 'state of emergency'declaration due to COVID-19 pandemic in Japan was lifted: supplementary survey results in post-emergency situations. *Noise Mapping*, 7(1):192–198, 2020.

[10] Chiara Bartalucci, Raffaella Bellomini, Sergio Luzzi, Paola Pulella, and Giulia Torelli. A survey on the soundscape perception before and during the COVID-19 pandemic in Italy. *Noise Mapping*, 8(1):65–88, 2021.

[11] Jerónimo Vida Manzano, José Antonio Almagro Pastor, Rafael García Quesada, Francesco Aletta, Tin Oberman, Andrew Mitchell, and Jian et al. Kang. The sound of silence in Granada during the COVID-19 lockdown. 2021.

[12] Daniel Steele and Catherine Guastavino. Quieted city sounds during the covid-19 pandemic in montreal. *International Journal of Environmental Research and Public Health*, 18(11):5877, 2021.

[13] Rosa Ma Alsina-Pagès, Ferran Orga, Roger Mallol, Marc Freixes, Xavier Baño, and Maria Foraster. Sons al balcó: Soundscape Map of the Confinement in Catalonia. In *Engineering Proceedings*, volume 2, page 77. MDPI, 2020.

[14] Rosa Ma Alsina-Pagès, Ferran Orga, Roger Mallol, Marc Freixes, Xavier Baño, and Maria Foraster. Soundscape of Catalonia during the first COVID-19 lockdown: Preliminary results from the Sons al Balcó project. 2021.

[15] Daniel Bonet-Solà, Carme Martínez-Suquía, Rosa Ma Alsina-Pagès, and Pau Bergadà. The soundscape of the covid-19 lockdown: Barcelona noise monitoring network case study. *International Journal of Environmental Research and Public Health*, 18(11):5799, 2021.

[16] Rosa Ma Alsina-Pagès, Pau Bergadà, and Carme Martínez-Suquía. Changes in the soundscape of Girona during the COVID lockdown. *The Journal of the Acoustical Society of America*, 149(5):3416–3423, 2021.