Research Article

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The "sound of silence" in Granada during the COVID-19 lockdown

Abstract: Exceptional circumstances in the city of Granada due to the COVID-19 lockdown have provided the opportunity to characterise the impact of humans on its urban acoustic climate. Traditional environmental noise management and urban sound planning usually take into account noise sources in the city, such as industrial activities or road traffic noise, in model estimations, as well as in empirical research. But trying to isolate human impact by itself, human activity including social activity, walking, talking or just going around the city, has always been a difficult or even impossible task. The COVID-19 lockdown measures have provided the opportunity to study urban climate as never before, affected just by natural or animal noise sources. Previous soundscape research at some iconic sites in the city of Granada carried out in 2019 before the lockdown and a special measuring campaign carried out at the same locations during the lockdown in 2020 offered valuable information on sound levels and local characteristics in order to carry out this comparison. Results show a great change in environmental noise levels that is interesting not only because of its magnitude, but also for its implications, especially at those sites where social human activity was an identifying characteristic. Natural or animal sounds became surprisingly evident at some study sites, especially where road traffic noise dramatically decreased, leading to significantly lower background noise levels. Important spectral changes are observed before and during the lockdown, suggesting a shift from anthropic to animal sources in the acoustic environment.

Keywords: Lockdown; Environmental noise; Soundscapes; COVID-19; Cultural heritage

1 Introduction

When SARS-CoV-2, better known as Coronavirus, was recognized by the WHO as a pandemic on March 11th 2020, Spain was three days away from being subjected to the most rigorous containment the country has ever known (BOE, March 14) [1]. Strict containment measures were implemented in many countries around the world with so-called "lockdowns" leading to heavy limitations of movement for people and goods, bans of most domestic and international travels and social distancing and "stay-home" recommendations [2]. Changes of routines or forced lockdowns are attributes and corollaries of a new way of living a global pandemic. In this struggle of opposites, of contrasting experiences, cities have been left with soundscapes worthy of mention.

With most human activities in urban contexts severely limited because of lockdown policies, cities around the world have experienced unprecedented decreases of environmental noise levels: metropolis like New York, Paris, Rome, Barcelona, and many more, reported dramatic reductions of noise levels generated by road traffic and other transportation modes [3–6].

As a typical "non-essential" activity, tourism was one on which lockdown measures had the strongest impact. If the acoustic environments of bigger cities have received a lot of attention because of the reductions in road traffic noise, less is known about the effect that the COVID-related containment measures had on the soundscapes of smaller historical towns and cities. In this paper, some case studies are selected in the city of Granada (Spain), with a focus on iconic and monumental urban spaces, to investigate the effect that the stop of touristic activities had on the acoustic environments of those sites. The rationale for selecting those sites is investigating pedestrian areas, where road traffic noise (from distance) is expected

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to be a secondary sound source even in normal conditions (*i.e.*, without lockdown) and human sounds are likely to be more prominent, and considering what is the impact of the latter on the background noise levels of the sites using the "opportunity" offered by the lockdown.

Tourism research has investigated thoroughly how people experience iconic and monumental spaces (*e.g.*, [7]). It has been argued that the aesthetic appreciation of a touristic destination can be affected by its environmental qualities, like the scenery and the soundscape and these contribute to the overall tourist experience [8]. In general, soundscapes are gaining increasing attention in cultural heritage studies [9–11]; this trend is supported also by the framework provided by the UNESCO Convention on the Intangible Cultural Heritage [12] and one of its subsequent declarations [13, 14]. The soundscape approach plays also an important role in the tourism management of natural areas [15–19]. Yet, studies about the soundscape of touristic destinations in urban rather than natural contexts are still scarce [20, 21]. Liu *et al.* [22] studied the soundscapes of historical areas of Beijing, China. Puyana Romero *et al.* [23] noted significant differences in soundscape assessments between tourists and residents in their study on the soundscape of the city centre of Naples, Italy. A previous study in Naples by the same research group [24] focused on the changes in the sound environment in pedestrian areas of the historic centre experienced after the implementation of a Limited Traffic Zone (LTZ), which led to significant noise levels reductions from road traffic noise, even if in a less extreme situation as the one cities are experiencing due to the COVID-19 pandemic. In other studies in other regions of the world reporting about sound environment changes during the 2020 lockdown measures, attention is now being given not only to road traffic noise, but also human sound sources [3, 25].

This study highlights the exceptional state of silence that the city centre of Granada has experienced. The Alhambra, the most visited monument in Spain, can also be contemplated from historical viewpoints, that are sites of touristic interest themselves. Among them, there are the Paseo de Los Tristes, the Placeta de Los Carvajales and the Plaza de San Nicolás. Finally, the urban space of Bib-Rambla Square is an urban space for gathering and people flow, also typical of a tourist city like Granada.

In the Spring of 2019, as part of a different project, there was an opportunity to measure the sound pressure levels in these emblematic spaces. With the lockdown of mid-March 2020, it was possible to repeat measurements in the same places and points that had been already measured one year before, making it possible to carry out this comparison research work.

The aims of this study are: 1) quantifying in terms of sound pressure levels (SPL) the noise reduction induced by the lack of human activities at typical touristic destinations in Granada; 2) exploring possible changes in temporal and spectral patterns in the acoustic environments of the Granada sites between the normal situation and the lockdown situation.

2 Materials and methods

2.1 Case study sites

This work relies on four urban spaces in Granada that can be considered as iconic sites because of their touristic relevance, beauty and for being places where citizens and visitors gather to talk, walk, play or simply enjoy the environment. They are not the only places with such characteristics in Granada but sites where best coincidence measurements and recordings are available before and after COVID lockdown period. Figure 1 shows an overview image of the four selected locations in 2019 and Figure 2 shows the same locations in 2020. Main characteristics are summarized in Table 1 after a brief description of case study sites.

2.1.1 Placeta de los Carvajales viewpoint (CAR)

Placeta de Carvajales is a small square located in the lower *Albaycín* close to the bank of the river *Darro*; one of the less known viewpoints of the Alhambra. Since the 16th century, it has maintained the empty urban configuration. *Carvajales* is named in that way regarding to one of the most influential noble families of the 15th and 16th centuries, from the province of León, who accompanied the Catholic Monarchs in the Reconquest of Granada. Since the 1960s, when the last reforms were undertaken, the image of the viewpoint has not changed. It can only be reached on foot, through the centenary and narrow streets of the quarter, which eliminates at any time of the year, much of the noise of motor vehicles. On the other hand, the bustle of the people is constant. A frontal view of the Alhambra from the *Alcazaba* and from a lower point of view than San Nicolás, makes it a favourite place to visit for the locals and especially for young people.

Figure 1: From left to right and from top to bottom Placeta de Carvajales (CAR), Paseo de los Tristes (PLT), Plaza de Bib-Rambla (BIB) and Plaza de San Nicolás (SNC). Own resource (2019)

Figure 2: From left to right and from top to bottom Placeta de Carvajales (CAR), Paseo de los Tristes (PLT), Plaza de Bib-Rambla (BIB) and Plaza de San Nicolás (SNC). Own resource (2020)

Table 1: Main characteristics of selected case study sites

ID	LOCATION [LAT_N, LON_W]	GENERAL DESCRIPTION	TYPICAL SOUND ENVIRONMENT
CAR	Albaicín, old Moorish district [37,178946, −3,594216]	Viewpoint square of the Alhambra, isolated and away from traffic	No nearby traffic, sound from human voices and occasionally pets
PLT	Albaicín, old Moorish district [37,178794, −3,589437]	The lowest and longest viewpoint of the Alhambra, following river bed, full of restaurants and people	Traffic noise though limited circulation, sound from humans and nearby river
BIB	City centre [37.175395, −3.599808]	City centre square, no traffic but dense people walking concentration because of work in nearby buildings, including Town Hall, or leisure	No nearby traffic, sound from humans, hostel, and tourism activity
SNC	Albaicín, old Moorish district [37.181128, −3.592788]	Most important, direct view and emblematic Alhambra viewpoint, lots of people concentrates there, both locals and visitors	Some traffic noise and sounds from humans, including singing and music play

2.1.2 Paseo de los Tristes viewpoint (PLT)

The *Paseo de los Tristes*, meaning the path of the sad ones is an emblematic longitudinal square on the banks of the river *Darro* and at the foot of the Alhambra. It takes its name from the path that the relatives and friends of the deceased used to take from the Santa Ana's church (where the funeral was held) to the cemetery of San José, located on the same hill as the Alhambra and a few hundred metres away from it, up the slope of the *"Cuesta de los chinos"*.

Under normal circumstances it receives a large influx of people who walk from the *Carrera del Darro* towards the *Albaycín* or who rest in one of its terraces and bars, enjoying the views of the Nasrid monument.

The *Darro* River always has a significant flow of water, even in the summer season, but the murmur of the water is masked by the voices. Vehicle access to the area is also frequent but only allowed to local residents, especially by public transport and motorbikes, which use this route with one of the main accesses to the *Albaycín*.

2.1.3 Bib-Rambla square (BIB)

It was one of the squares within the walls of the Muslim city, which was colloquially called the Sandy Gate due to its configuration of alluvial deposits from the River *Darro*. On the plan of the of *Vico's Platform* from the end of the 16th century, the square can still be seen with the canvas of the wall on its south-west side, still intact. Since the Nasrid era, *Bib-Rambla* has always been a commercial epicentre

of the city. It has been a place for comedies, a bullring; but above all, a very important commercial space.

Bib-Rambla occupied a strategic place in the Nasrid city and, later, in Castilian. It was close to the silk market (*Alcaicería*), to the first University of Granada, to the main commercial axis that connected with Plaza Nueva (*Zacatín Street*), and also to the religious centres of the time (the Great Mosque and the Cathedral) that were so important in the active life of the city for centuries. All this has made it a neuralgic place of meeting for people, the main place of commerce, an area with a high density of people flows.

The noise of motor vehicles in this square is practically non-existent; there is only the noise heard from other adjacent streets. On the other hand, the bustle of the shops and the people who pass through make it a place subject to a high level of sound pressure.

2.1.4 San Nicolás viewpoint (SNC)

The origins of the Roman city of *Ilíberri*, or also known as *Florentia*, are very close to this beautiful *Albaycín* square. It seems that the location of the Roman Forum was in the *Placeta de las Minas* and therefore, from a very early age this square was an emblematic place of public attendance in the city. Iberians, Romans, Visigoths, Almoravids, Almohads, Nasrids, Castilians, Aragonese and Navarrese... were, among others, the different origins of these people from Granada who enjoyed the best views from this famous viewpoint named after Saint Nicholas.

Traffic noise in this area is moderate due to the influx of vehicles on its perimeter. The murmur of the people is always very high due to their unbeatable views of the Nasrid monument. Flamenco singers, laughter, children's games adorn the usual soundscape of this space.

2.2 Data acquisition

Audio samples were collected using a Brüel & Kjaer 4145 microphone mounted on a tripod, connected to its 2804 power supply. The signal is then fed into a Zoom F8 field recorder. The level was calibrated each time using a Brüel & Kjaer 4231 calibrator at 94 dB. Headroom is set depending on the conditions from 6 to 20 dB enabling the recording of 114 dB peaks. The signal is re-escalated using the calibration signal and then analysed using BK Connect software. This procedure complies with [26, 27]. In 2019 a large piece of foam that was originally suited for Brüel & Kjaer environmental microphones was used as windscreen (see photos) but in 2020 a RØDE spherical blimp was included in the setup.

Sound recordings were performed during March and May in 2019 at selected sites under normal human circumstances, which means quite a lot of people were around as well as some traffic, though limited because of traffic restrictions in these places. Same sound recordings were done at selected sites during lockdown period in April and May 2020 (see details in Table 2).

The same equipment, an omnidirectional microphone, used in 2019 was employed in 2020 measurements and the 2019 procedure and protocol was also repeated in 2020. A new Soundfield ambisonic microphone and 360-degree video camera were included in the 2020 campaign, though at present we are only considering the same type of recordings taken during 2019 and 2020 for evaluation purposes. Sound recordings available intervals vary from 10 to 15 minutes at each site. From these, we have selected six minutes interval recordings at each site in 2019 and 2020 trying to filter and, consequently, avoid the presence of anomalous events (ambulances, people shouting, talking too near to equipment, malfunctioning, etc.) while maintaining the same environmental circumstances and characteristic in 2019 and 2020 with the only difference of human presence. First data analysis and preview with BK Connect [28] converted each six minutes recording extract in a set of 3,600 individual 0.1 second sound level measurements from which we estimated acoustic parameters as shown below.

So, as far as this analysis is concerned, the database consists of a set of two 6 minutes sound recordings at each selected site, one during 2019 and a second one in 2020, under the same circumstances of recording place, date and period of the day with the only change being lockdown condition, as weather conditions were also quite similar from one year to another.

3 Results

3.1 Data post-processing

Acoustic parameters according to ISO 12913-3 [29] were estimated, including LAeq (dB(A)), LCeq (dB(C)), LAF5 and LAF95 (dB(A)), as well as other normal environmental indices including LAFmax, LAFmin, LAF10, LAF50, LAF90, LAE (all in dB(A)) and the standard deviation (SDEV) of data as shown in Table 3. As stated before and, again, according to ISO 12913-3 [29] psychoacoustic metrics were also computed using BK Connect including Loudness (N and N5, sone), Sharpness (S, acum), Tonality (T), Roughness (R, asper) and Fluctuation Strength (F, vacil) as shown in Table 4.

Loudness and its percentiles were calculated according to ISO 532-1 [30], Sharpness according to DIN 45692 [31] (Low-level compatibility was not used), Tonality according

Table 2: Sound recordings date, time and lockdown conditions

Site ID	Site short name	Date	Time	Lockdown
CAR	Placeta de los Carvajales viewpoint	20-03-19	~18.40h	NO
		01-05-20	~13.30h	**FULL**
PLT	Paseo de los Tristes viewpoint	20-03-19	~17.30h	NO
		27-04-20	~13.00h	**FULL**
BIB	Bib-Rambla square	15-05-19	~11.30h	NO
		01-05-20	~15.30h	**FULL**
SNC	San Nicolás viewpoint	17-05-19	~11.20h	NO
		01-05-20	~11.50h	**FULL**

Table 3: Summary environmental noise indices data in Granada, before (2019) and during lockdown (2020) at four selected sites

SITE	YEAR	LCeq	LAeq	LAF5	LAF10	LAF50	LAF90	LAF95	LAF10-LAF90	LAFmax	LAFmin	LAE	SDEV
CAR	2019	71.9	71.8	70.9	67.2	56.2	51.0	50.1	16.2	93.8	47.2	97.4	7.1
	2020	42.8	41.3	47.8	44.7	34.2	31.2	30.7	13.5	59.8	29.0	66.9	5.4
PLT	2019	63.9	57.5	61.8	59.1	53.6	50.9	50.5	8.2	76.6	49.3	83.0	3.8
	2020	52.8	44.3	46.6	45.8	43.4	42.5	42.4	3.2	54.3	41.9	69.8	1.5
BIB	2019	66.6	61.5	64.0	62.9	60.3	57.8	57.2	5.1	84.9	55.4	87.1	2.3
	2020	48.4	39.0	43.3	41.4	37.0	34.0	33.4	7.4	54.7	31.2	64.6	3.1
SNC	2019	67.3	62.0	65.9	64.2	60.1	56.7	55.9	7.5	78.2	52.0	87.6	3.1
	2020	50.0	42.2	47.4	45.7	39.5	35.5	34.7	10.2	53.8	32.5	67.8	3.9

Table 4: Summary psychoacoustic metric data in Granada, before (2019) and during lockdown (2020) at four selected sites

SITE	YEAR	N	N5	S	T	R	F
CAR	2019	23.9	20.8	1.4	0.09	1.55	1.24
	2020	3.7	3.8	2.9	0.06	1.60	0.97
PLT	2019	12.5	14.4	1.3	0.14	1.50	1.04
	2020	5.4	5.8	1.7	0.06	1.70	0.98
BIB	2019	17.0	16.4	1.8	0.15	1.38	1.21
	2020	3.2	3.9	1.2	0.13	1.26	0.70
SNC	2019	16.0	18.2	1.4	0.14	1.30	1.48
	2020	4.2	4.7	1.8	0.07	1.88	1.25

to ECMA-74 [32] (maximum of 5 tones, resolution of 2 Hz, a threshold of 1 dB and no lower threshold of hearing corrections), Roughness is calculated according to [30] with 70 Hz modulation frequency and 59.5 sone Loudness threshold, and Fluctuation Strength with 4 Hz modulation frequency and 116 sone Loudness threshold.

3.2 Overall effect of lockdown measures on broadband environmental noise

Noise reductions in terms of absolute 2019 vs 2020 measurements give us differences around 20 dB(A) in three sites and up to 30 dB(A) at Mirador de Carvajales (site no. 1-CAR). This is an impressive noise level reduction that would hardly take place in any city even if the strictest noise control and abatement proposals would ever be applied. In relative terms, the observed noise reduction reaches 40% at site no. 1, over 30% at sites no. 3 (Plaza Bib-Rambla-BIB) and no. 4 (Mirador San Nicolás-SNC) and

Table 5: Absolute and relative changes in sound levels before (2019) and during lockdown (2020); (*) LCeq dB(C)

SITE	Observed change (2019 vs 2020)	LCeq decrease	LAeq decrease	LAF10 decrease	LAFmax decrease	LAF90 decrease	LAFmin decrease	LAF10-LAF90 decrease	LAE decrease
CAR	Absolute dB(A)*	29.1	30.5	22.5	34.1	19.8	18.2	2.7	30.5
	Relative (%)	**40.5**	**42.5**	**33.4**	**36.3**	**38.8**	**38.6**	**16.5**	**31.3**
PLT	Absolute dB(A)*	11.1	13.3	13.3	22.2	8.4	7.4	4.9	13.2
	Relative (%)	**17.4**	**23.1**	**22.5**	**29.0**	**16.4**	**15.1**	**60.3**	**15.9**
BIB	Absolute dB(A)*	18.2	22.5	21.5	30.1	23.8	24.2	− 2.3	22.5
	Relative (%)	**27.3**	**36.6**	**34.2**	**35.5**	**41.2**	**43.7**	**−44.7**	**25.8**
SNC	Absolute dB(A)*	17.3	19.8	18.5	24.4	21.2	19.5	−2.8	19.8
	Relative (%)	**25.7**	**31.9**	**28.8**	**31.2**	**37.3**	**37.5**	**−35.3**	**22.6**

over 20% at site no. 2 (Paseo de Los Tristes-PLT) which, all together, describe a unique sound environment absolutely dominated by natural and animal sounds. To further investigate and understand these changes, absolute and relative differences have been computed, as shown in Table 5.

If we look at background noise as characterised by LAF90 together with the minimum noise level index, LAFmin, we observe an important decrease in sites no. 1 (CAR), no. 3 (BIB) and no. 4 (SNC) with similar absolute reductions in terms of LAF90 and LAFmin values and lower values in site no. 2 (PLT). As the nearby river in PLT is the main ambient difference, we may conclude water flowing explain these figures. Nevertheless, background noise experienced a very important reduction as shown in Figure 3 (a), in which we can see that human absence causes it to decrease by more than 40% in site no. 3 (BIB), where people moving around reach higher figures than in the rest of the places, where citizens and visitors mostly stand and gaze at views.

Greater changes are observed comparing higher noise levels before and during the lockdown, as shown in Figure 3. Maximum levels (LAFmax) experience more than 30% reduction in each site, being especially significant the shortening in the difference with LAF10 values during the lockdown. As high noise values are normally connected to human activity and machinery, lockdown measures not only have given more relevance to background noise but have also diminished maximum sound pressure levels to almost 40% in sites no. 1 (CAR) and no. 4 (SNC) and over 40% in site no. 3 (BIB), where humans moving around is a dominant characteristic of the site. Again, high levels reduction is not so big at site no. 2 (PLT), because of the river and limited road traffic to attend the residents' needs.

In environmental noise analysis, the difference (LAF10-LAF90) is normally used as an aid to identify low noise situations characterised by high equivalent levels because of occasional high noise episodes occasionally taking place. Site no. 1 (CAR) presents an impressive 16.2 dB(A) (LAF10-LAF90) difference in 2019, which best describes people around shouting and singing from time to time in an otherwise very quiet place. During the lockdown, this difference goes down but still remains at 13.5 dB(A) resulting in a 16.6 % difference (see Table 5). Site no. 2 (PLT) presents a 60.3% change as the difference (LAF10-LAF90) drops from 8.2 dB(A) to 3.2 dB(A) indicating a limited variety of sound sources at that site in the absence of human presence. This is something you can confirm by listening to the audios available at https://soundcloud.com/anecoica-ugr

Special attention must be given to sites no. 3 (BIB) and no. 4 (SNC) where the difference (LAF10-LAF90) does not
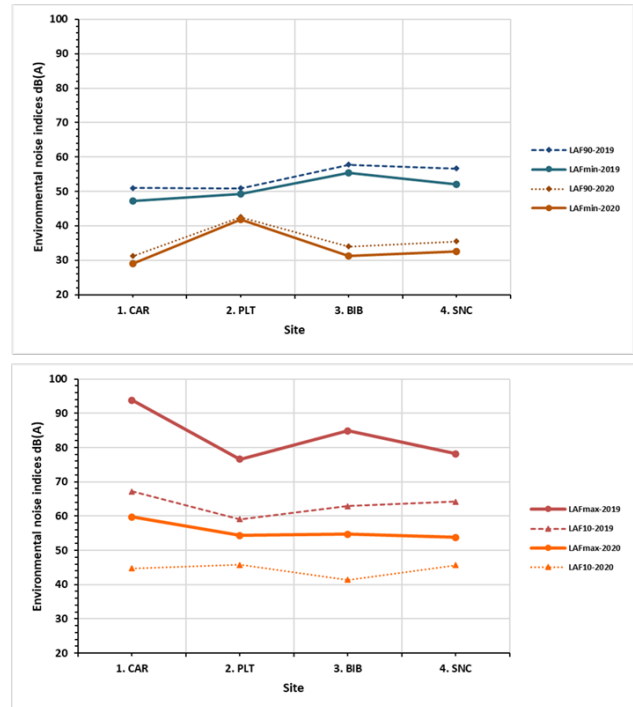

Figure 3: Environmental background and minimum noise indices (LAF90, LAFmin) (top) and environmental high and maximum noise indices (LAF10, LAFmax) comparison before (2019) and during lockdown period (2020) (bottom)

reduce but rather increases (negative numbers in Table 5), indicating a widening of the acoustic range for environmental sounds in these places, where natural and animal (mostly birds) sounds became evident in an extremely diminished background noise after lockdown. This is also observed in the standard deviation of the data, which increases in these two sites after lockdown.

Finally, sound exposure level LAE relative to one second (as usual in environmental studies) shows greater reduction at site no. 1 (CAR) during the lockdown, closely followed by site no. 3 (BIB) and 4 (SNC) and finally site no. 2 (PLT). These results are in accordance with the information coming from the rest of the noise indices, confirming that sites no. 1 (CAR) in Albaicín and no. 3 (BIB) in the town centre have benefited the most from lockdown measures, closely followed by normally crowded Mirador San Nicolás (site no. 4 – SNC) and site no. 2 (PLT) at the end of this comparison because of river proximity.

In order to provide further insights about the differences observed between 2019 and 2020, a more statistical approach was attempted. A direct comparison of the sound levels time series at the four selected sites should be interpreted with caution since we are dealing with asynchronous measurements. For this reason, a distributions
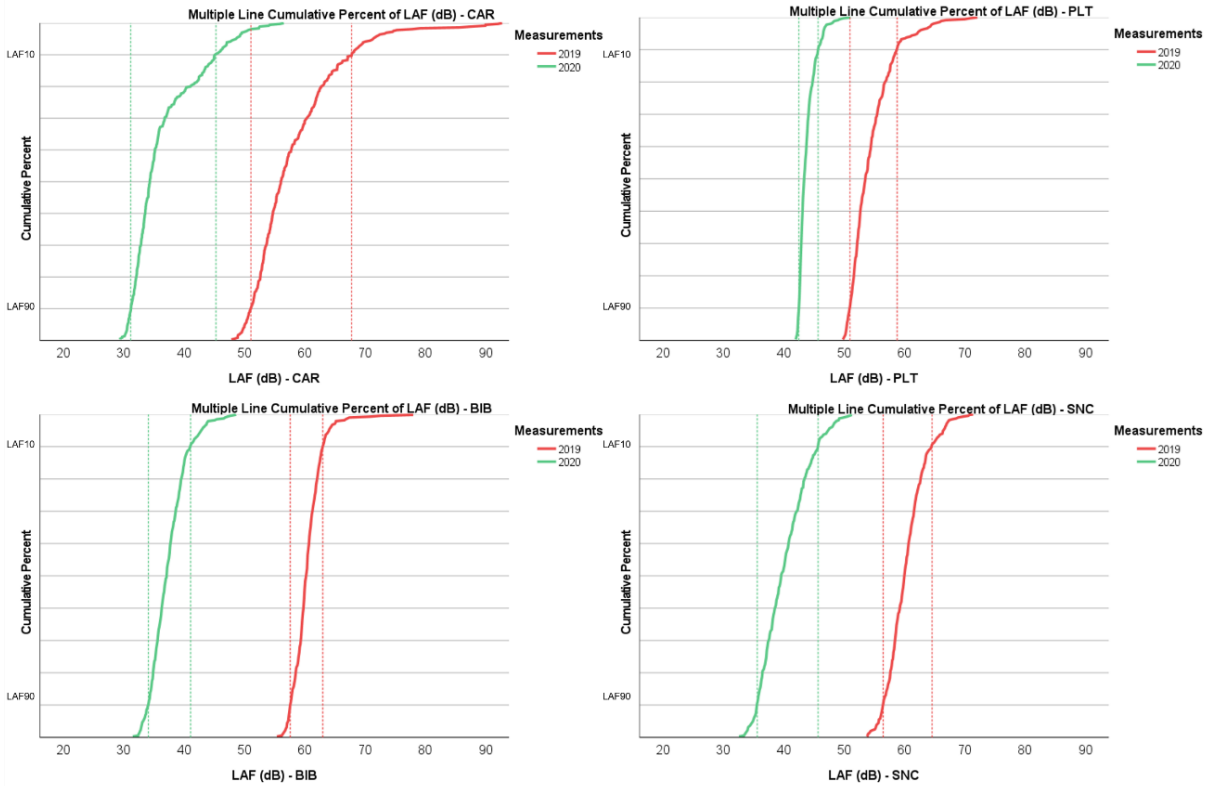
Figure 4: Cumulative distributions of LAF values for the four investigated sites, for the 2019 (red lines) and 2020 (green lines) measurements campaigns; for each series, the left dashed line represents LAF90, while the right dashed line represents LAF10
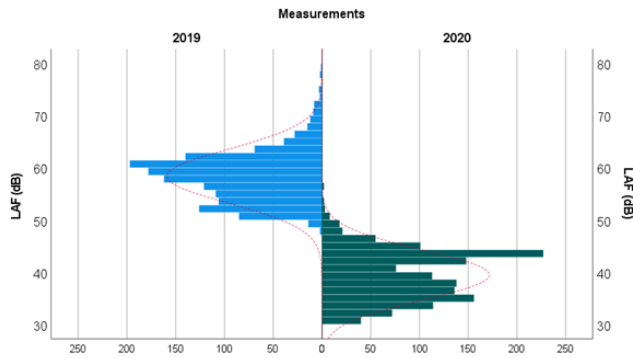

Figure 5: Aggregated (all four sites) LAF values distributions, split as per the 2019 and 2020 measurements campaigns

analysis was considered. Figure 4 shows the cumulative distributions of LAF values for each site, for the 2019 and 2020 measurements campaigns. The "offset" of the distributions is evident at all sites: the LAF10 values (*i.e.*, noisier events) of the 2020 datasets are always lower than the LAF90 values (*i.e.*, background noise) of the 2019 datasets, signifying a considerable drop in general environmental noise levels.

To test statistically the overall difference between the before- and during-lockdown measurement campaigns,

the LAF values for all the four sites were aggregated into a 2019 and 2020 dataset. A Mann-Whitney U test was run to determine if there were differences in LAF values between the 2019 and 2020 measurements data. Distributions of the LAF values for 2019 and 2020 were not similar, as assessed by visual inspection: the shift towards lower LAF values between 2019 and 2020 can also be observed in Figure 5. LAF values for 2020 (mean rank = 719.4) were statistically significantly lower than for 2019 (mean rank = 2149.6), $U = 2779.5$, $z = -46.25$, $p < .001$.

3.3 Overall spectral differences caused by lockdown measures on environmental noise

A-frequency weighting, dB(A), makes readings approximate the human hearing response, giving more weight to higher frequencies, especially from 0.8 kHz to 8 KHz, to which the human ear is more sensitive. On the contrary, C-frequency weighting, dB(C), acts almost equally on low and high frequencies, remaining essentially flat between 31.5 Hz and 8 kHz weighting. So, the difference between A and C weighted measurements indicates the presence
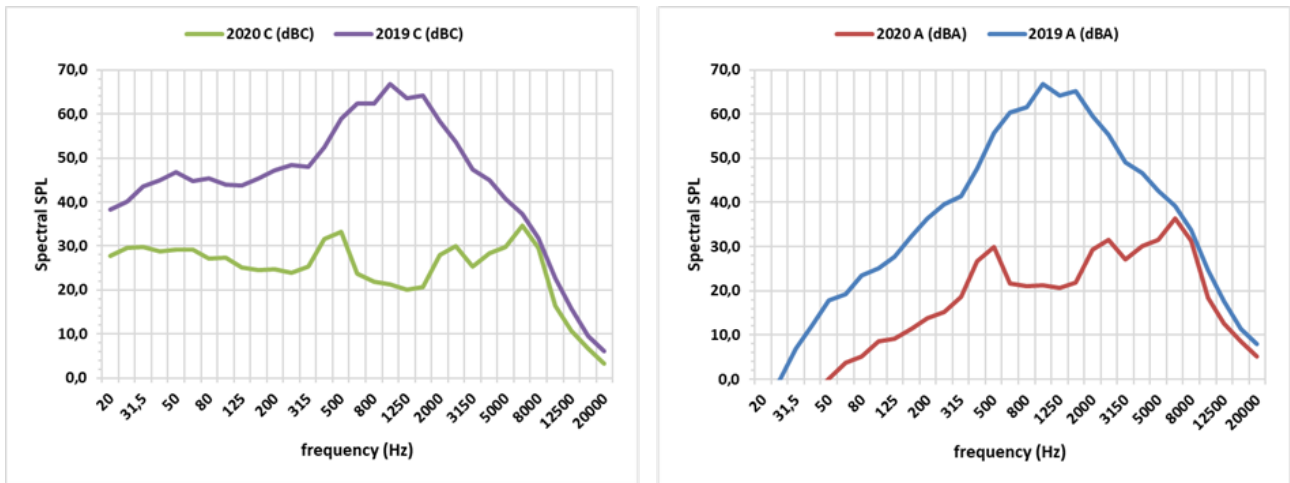
Figure 6: Overall C and A-weighted sound spectrum in 2019 vs 2020 at site no. 1 (CAR)
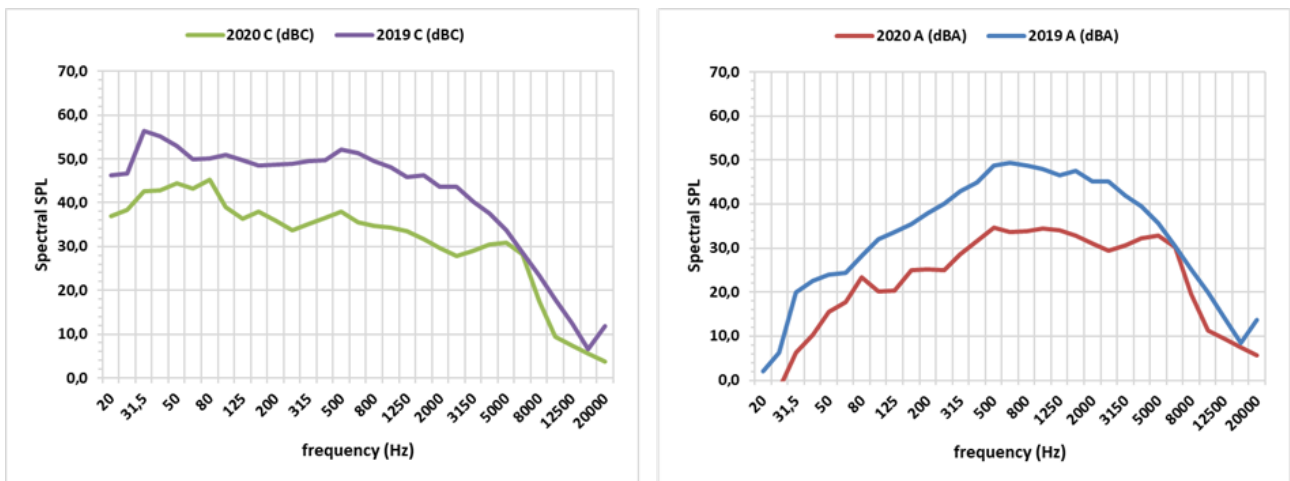

Figure 7: Overall C and A-weighted sound spectrum in 2019 vs 2020 at site no. 2 (PLT)
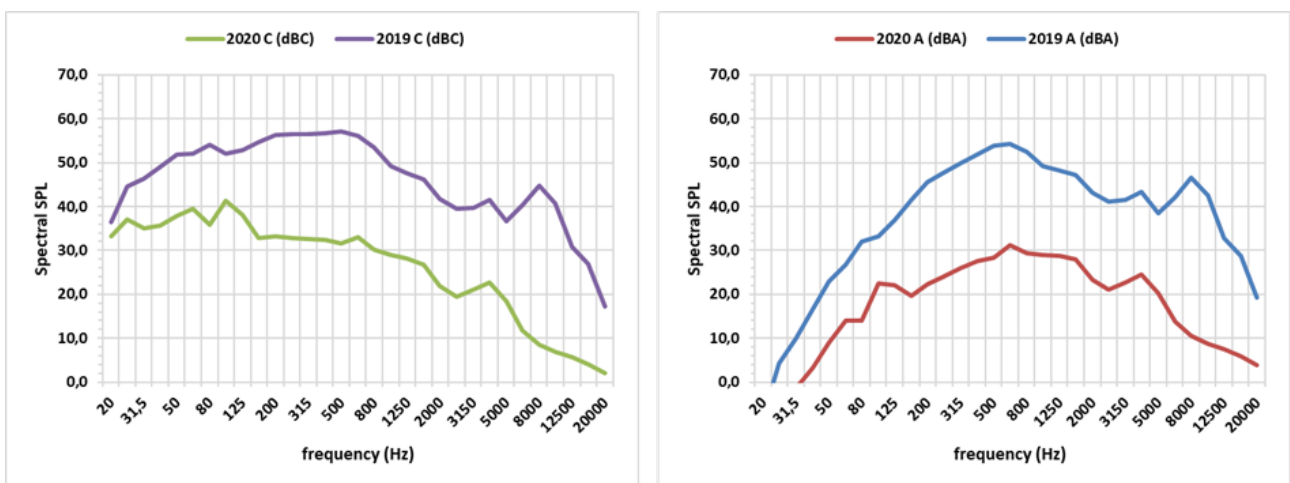

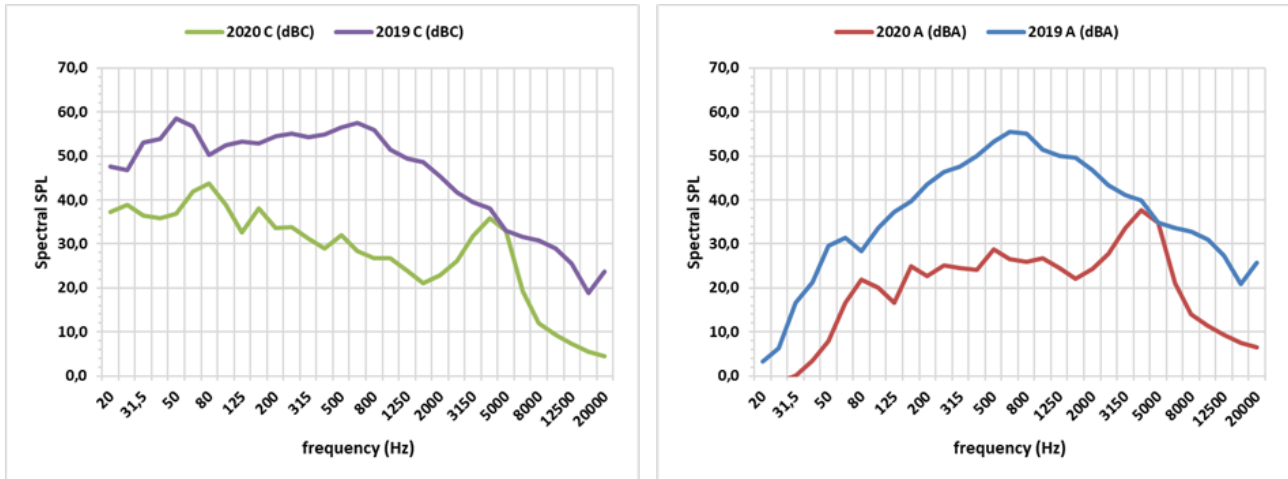**Figure 8:** Overall C and A-weighted sound spectrum in 2019 vs 2020 at site no. 3 (BIB)

Figure 9: Overall C and A-weighted sound spectrum in 2019 vs 2020 at site no. 4 (SNC)

of low-frequency sound which is typically associated with building and industrial machine noise, such as air handlers, or hum noise from small machines, like computers or televisions, normally annoying but not necessarily detected by human ear because of their low frequency [33]. So, having this in mind, we can see in Table 5 that greater relative LCeq vs LAeq differences around 10% take place in Bib-Rambla (BIB) and similar differences around 6% in Tristes (PLT) and San Nicolás (SNC) miradors, while quiet little difference is appreciated in Carvajales (CAR).

If we look at the noise spectra in 2019 and 2020 at each site (see: Figure 6, Figure 7, Figure 8, Figure 9), we find quite similar compositions and change in Carvajales (CAR), spectral peaks at 0.5 kHz, 2.5 kHz and 6 kHz during the lockdown in 2020 and 1 kHz in 2019 and no low frequencies peaks distinguished over the rest either during the lockdown or before, both in dB(C) and dB(A). On the contrary, significant dB(C) and dB(A) spectrum differences are found at the rest of sites, where low-frequency peaks are clearly present both during the lockdown and before, at frequencies ranging from 31.5 Hz to 100 Hz. As nearby heavy road traffic, mainly buses, or maintenance and air conditioning machinery are more likely to be detected in Bib-Rambla (BIB) than in Tristes (PLT) and San Nicolás (SNC), the differences dB(C) vs dB(A) are greater at BIB.

4 Discussion

The main effect of full-time (24h) citizens' lockdown is, obviously, urban noise reduction. But beyond the evident result that sound levels go down during the whole day pe-

riod, this study aimed to characterise the physical magnitude of this reduction and to investigate the new spectral composition of the urban soundscape. The acoustic environment is the result of combining all the sound sources within a given area, which includes human-caused sounds as well as natural or animal sounds. Low-frequency noise is common as background noise in urban environments as well as emission from artificial sources as stated before. But it also comes from natural air movement and turbulence and it is important and relevant in noise loudness judgement or noise annoyance estimation, greater for low-frequency for equal sound pressure level, or even protection against simultaneous higher frequency noise on hearing [34]. So, the decreased presence of low-frequency sound during the lockdown and, at the same time, selected low frequencies standing out in these places suggest that background noise has not only dramatically gone down but has also enhanced the audibility of specific local sounds in the environment.

Measured broadband and spectral noise levels data before and during COVID lockdown have highlighted important urban acoustics changes in Granada that can be solely attributed to human activity. Data analysis has also evidenced the great magnitude these changes can achieve and the notoriety of humans to substantially block natural or animal sound sources in the city.

Local authorities, urban managers and planners normally concentrate their work in controlling excess noise coming from industrial sources or road traffic rather than from social activity. In doing so, preferential attention is given to existing problems and, if considering future scenarios for urban planning, modelling tools are used to estimate environmental noise levels in which human activity

is never the main source, nor even one of the noise sources considered in the model [35].

The exceptional urban conditions after COVID lockdown have made it possible to investigate the human impact on environmental noise and evaluate to what extent human activity and, especially social activity, affects the acoustic climate in the city. Besides the inherent interest linked to a new, anomalous and exceptional situation characterization, results are also interesting for soundscape evaluations as pointed out by Aletta *et al.* [25] including citizens' perception assessment from environmental noise monitoring networks where auditions are necessary to evaluate and distinguish among city sound sources [36]. While gathering information on the perception of the acoustic environment during the lockdown was impossible because of the "stay-home" mandates, the recordings performed on site by the authors may certainly be used in future studies for laboratory experiments to get information on the comparison between the 2019 and 2020 conditions.

4.1 Noise reduction quantification

Environmental noise reduction is found to be greater in sites where human activity was predominant, either because people are normally around (CAR) or because they are normally moving around (like BIB). The reduction is not so significant in sites where natural or animal sounds are a normal characteristic of the place, such as PLT, in which higher differences between extreme sound levels lead to higher noticeability of such animal and/or natural sounds in the soundscape. In this respect, the sounds from River Darro acquire a special prominence in the soundscape of this particular place.

Special attention should be given to places like BIB and SNC, being both normally crowded places with very limited traffic noise, in which negative (LAF10-LAF90) differences during lockdown indicates the broadening of environmental limits in these places leading to a new situation in which you can even get to notice some natural and animal sounds never so clearly noticed there before or sounds coming from long distances in the city like bells sounds from churches far away from the site.

4.2 Changes in temporal and spectral patterns

Spectral change differences before and during COVID lockdown are less significant in places without traffic, indus-

trial or machine noise such as CAR. Spectral changes differences are greater in the rest of study case sites, especially those affected by some traffic noise (even though in a limited way), where some standing frequencies also appear and, consequently, discomfort and annoyance should also increase when accordingly evaluated.

Even though perception has not been assessed in this study, some information may be extracted from psychoacoustic metrics as shown in Table 4. Loudness reduction in CAR and BIB is over 80% during the lockdown, whereas it reaches 74% in SNC or limited to 57% at PLT. On the contrary, sharpness increases at every site except at BIB (−34,5%). Distortion increases sharpness as it does loudness, so why loudness and sharpness reduce at BIB but it doesn't at CAR, where only loudness reduces similarly (around 80%), should be further investigated. In any case, it is highlighting the importance of the observed spectral changes in soundscape evaluation. Finally, temporal patterns during COVID lockdown show fewer fluctuations and sound noise levels concentrating around instantaneous noise equivalent level except when local natural or animal sounds take place.

4.3 Effect of human activity on noise in the context of Strategic Noise Mapping (SNM)

The main effect of lockdown in the city of Granada is the almost total absence of motor vehicles circulating around. Few buses and taxis attend citizens' demands for minimum commuting resulting in a very low contribution of road traffic to environmental noise. As the Strategic Noise Map (SNM) [37] and the Local Noise Action Plan (LORCA) [38] pointed out, road traffic is the main source of noise in the city, so limited or totally restricted traffic around selected places during lockdown is significantly reflected in results, as shown in Table 3.

Environmental noise indices taken from 2016 SNM are shown in Table 6 together with LAeq levels from selected 6 minutes chunks used in this comparison. When attempting to compare SNM noise levels with other sound pressure levels from shorter recordings, it should be taken into consideration that SNM levels are computed on a long-time basis (yearly), average indices corresponding to day (Ld, 12h), evening (Le, 4h) and night (Ln, 8h) periods together with 24h indices (Lden). Long-time yearly averages are always lower than short-time average levels and they should only be considered as reference values for environmental conditions.

Table 6: Granada 2016 Strategic Noise Map yearly average noise indices values at selected sites together with LAeq from 2019 and 2020 short time measurements

Rate dB(A)	Ld	Le	Ln	Lden	LAeq 2019 chunk	LAeq 2020 chunk
CAR	47.3	46.6	42.1	50.2	71.8	41.3
PLT	56.0	55.5	50.3	58.7	57.5	44.3
BIB	56.7	52.3	50.0	58.2	61.5	39.0
SNC	53.3	52.9	47.8	56.2	62.0	42.2

Having this in mind and focusing on day time indices (Ld) coincident with our recordings, we see that site no. 3 (BIB) is the noisiest place of the four, as affected by heavy road traffic noise driving through the centre of the city. Next site no. 2 (PLT, with limited traffic for residents and tourist buses for visitors followed by site no. 4 (SNC) slightly affected by light road traffic noise from adjacent streets and site no. 1 (CAR) being the least affected by road traffic. This scenario differs from our recordings before lockdown because of human noise in sites no. 1 (CAR), 3 (BIB) and 4 (SNC) which is not considered by SNM. During the lockdown period (2020), the new scenario locates site no. 3 (BIB) as the quietest place without human presence and the other three in a much quieter situation as that described by SNM.

4.4 Effect of human noise on the selected sites' urbanscape

4.4.1 Carvajales viewpoint (CAR)

This beautiful mirador in Albaicin includes a long surface level fountain perpendicular to front line viewpoint. This fountain had water running in 2019 before lockdown as well as a lot of people around talking, singing or just peacefully enjoying the site. Some dogs were also present at the time the recordings took place. This was a normal situation at this viewpoint, where there is no traffic, and walking is the only way to get over there.

The low-risk context of this place makes it perfect for staying with children, altogether making it a quite vibrant but still peaceful place as noise mainly comes from people just present in that place. During the COVID-19 pandemic the situation completely changed because of the absence
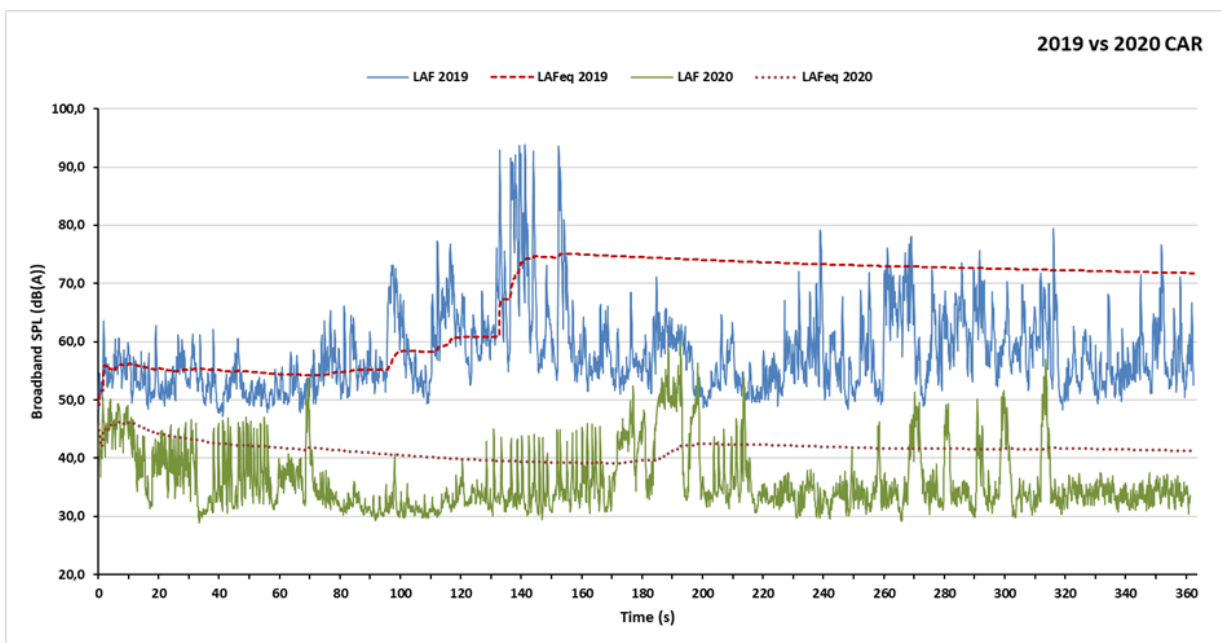

Figure 10: Broadband sound pressure levels in 2019 and during the lockdown in 2020 for the six minutes period recording together with the equivalent noise level at site no. 1 (CAR)

of human activity, giving place to a great decrease in noise levels as commented before.

If we look at the time series data during the six minutes recording before lockdown and during the lockdown, the absence of human noise and the increase of natural contribution on soundscape can be easily observed in lowered maxima and a lower standard deviation of the data around the average equivalent noise level in 2020 (Figure 10). The considerable drop in SPLs during the lockdown in 2020 evidences natural non-anthropic sounds, mainly birds. It is relevant that in this viewpoint, environmental levels are frequently below 40 dBA. It is a place protected by the adjacent buildings, making the sound of the wind passing through the treetops become insignificant. The most relevant anthropic sounds came from a nearby construction site, sporadically produced by building materials.

4.4.2 Paseo de Los Tristes viewpoint (PLT)

The "Paseo de Los Tristes" is a long street that used to be the only access to the ancient Arabic and Moorish quarter of Albayzin (sometimes written Albaicín) Road traffic is limited to taxis and tourist buses as well as resident and authorized vehicles. A lot of people get there by walking along the riverside (Darro river) and crowded bars and restaurants just before the high step drive towards Albaicín.

This scenario is perfectly captured by the sound recording in 2019 as shown in Figure 11, which contrasts with the lockdown scenario in which the total absence of people and traffic gives an almost linear evolution only disturbed by water flowing (river) and limited birds in a not so friendly environment under normal circumstances because of human activity. Water flowing is, in fact, a main contributor to SPL around 45 dBA in 2020, revealing its importance in this space. A police vehicle passing-by in near distance (more than 50 m away) from the recording site, as well as the sound of a digging machine working inside the Alhambra gardens in far distance (more than 200 m away) were the only minor human environmental disturbances. The murmur of water and birds were the protagonists in 2020, revealing the importance of non-anthropic sounds.

4.4.3 Bib-Rambla square (BIB)

Bib-Rambla square is one of the busiest and crowded spaces in Granada, located in the centre of the city and very near to Town Hall, bars, restaurants and shopping area. There is no road traffic around this square but heavy traffic with local buses, taxis and authorized vehicles drive through Reyes Católicos street, merely 100 metres from the centre of the square.

During the 2019 recording period it was full of people, the sun was shining in the sky and you could feel
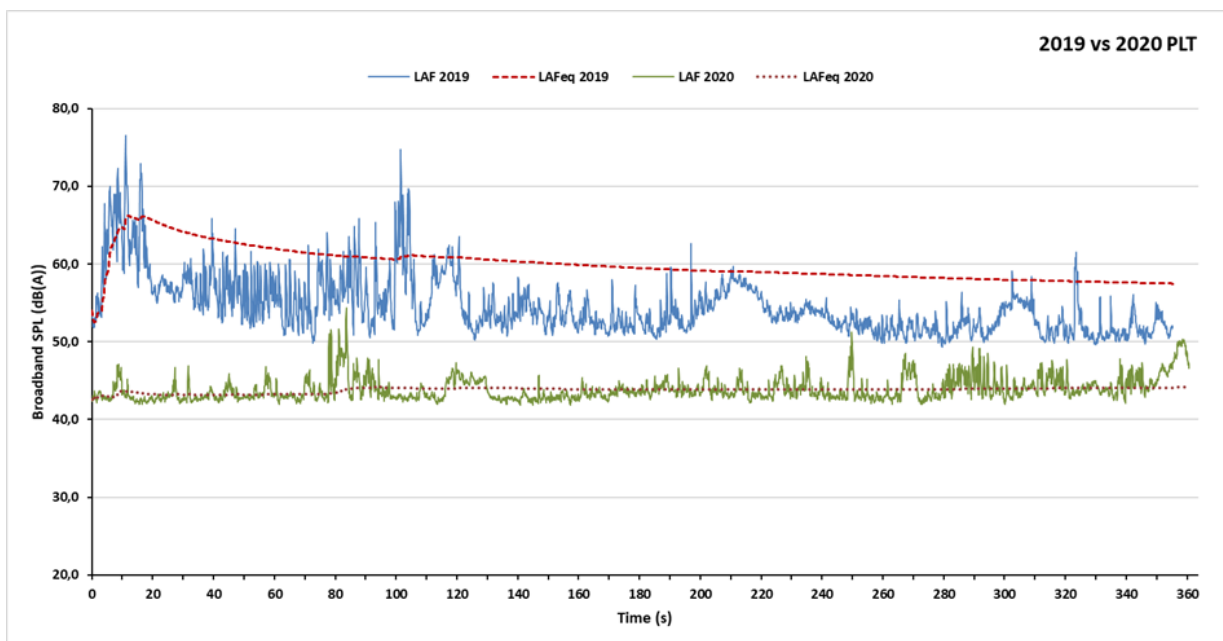

Figure 11: Broadband sound pressure levels in 2019 and during the lockdown in 2020 for the six minutes period recording together with the equivalent noise level at site no. 2 (PLT)
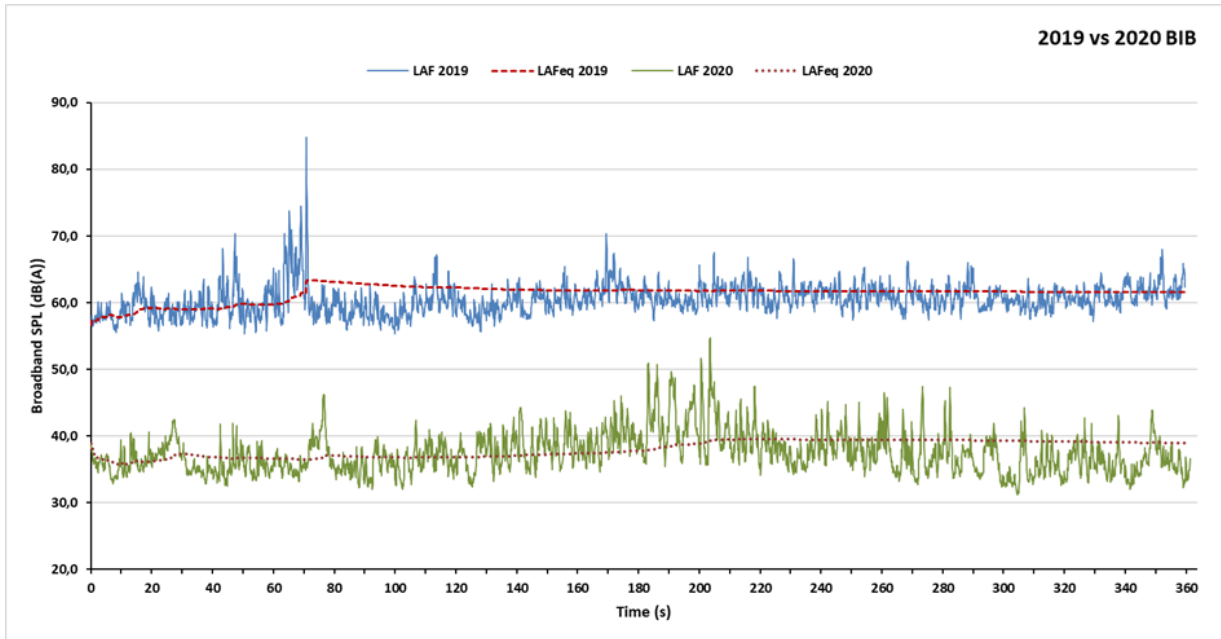
Figure 12: Broadband sound pressure levels in 2019 and during the lockdown in 2020 for the six minutes period recording together with the equivalent noise level at site no. 3 (BIB)

life around. Some pigeons were flying over tourists and citizens but were not the dominant sound source, mostly characterised by a vibrant environment with children playing, visitors having something to drink in nearby bars or sitting in public seats distributed all over the square.

During 2020, the total absence of people and few birds (mostly pigeons fed by people) made bells sound from the nearby cathedral and other churches the only soundmark in the area. Normally, the crowded square causes sound levels to stay high most of the time, with a low standard deviation around the mean value as shown in the 2019
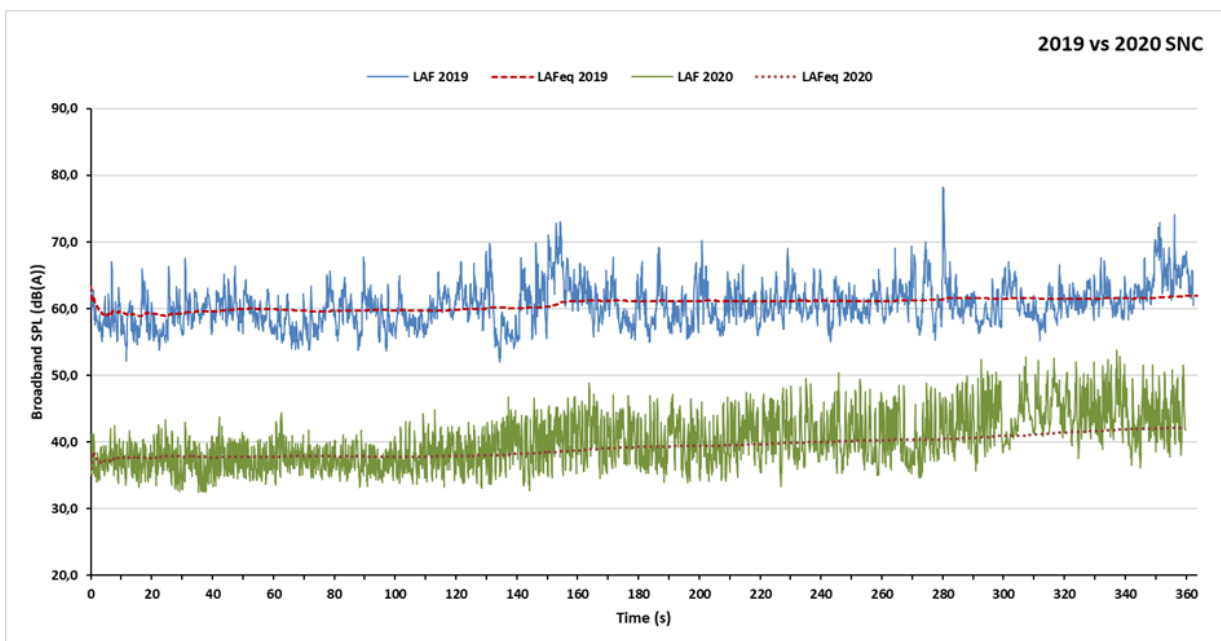

Figure 13: Broadband sound pressure levels in 2019 and during the lockdown in 2020 for the six minutes period recording together with the equivalent noise level at site no. 4 (SNC)

figure. On the contrary, the absence of human presence boosts natural, cultural and other city sounds from nearby streets increasing the standard deviation as well as the amplitude LF10 vs LF90 as commented before. Sound levels decreased considerably in this case too, as shown in Figure 12.

4.4.4 San Nicolás viewpoint (SNC)

San Nicolás is one of the most famous viewpoints in the city of Granada, located in Albaicín right in front of Alhambra over the opposite hill. It is always full of people, citizens and visitors, peddlers mixed with guitar played by local residents, just admiring the view or having something to drink in nearby bars and restaurants. Even though one can only get there by walking, some authorized vehicles drive through adjacent streets at low speeds. The ambient soundscape could be very well defined as vibrant because there is movement around and, normally, in comfort and peaceful acceptance of environmental noise. Altogether, you get quite high equivalent levels at mid-day and central hours of the afternoon and evening as shown in Figure 13

During the lockdown, the total absence of human activity and traffic around boosted birds, natural sounds and cultural sounds like bells from churches all over Granada or the Muslim call to prayer (*Adhan*) from a nearby mosque at certain times. Our recordings during COVID-19 captured birds and air movement and a light aeroplane flying in the distance which did not contribute much to the overall equivalent level.

5 Conclusions

The forced lockdown due to the COVID-19 pandemic in the Spring of 2020 has brought sudden and unexpected changes for the acoustic environments of cities. However, this situation also became a unique opportunity to experience how silent urban soundscapes can be. The main results of this case study show that:

- In terms of recorded sound pressure levels, the lack of human activities between the 2019 (pre-lockdown) and 2020 (during-lockdown) measurements campaigns at four typical touristic destinations in Granada accounted for reductions ranging between 13.3 and 30.5 dB(A).
- Considering the LAF datasets aggregated from the four sites in Granada, the LAF values distributions of the 2019 and 2020 measurements are different in

a statistically significant way, with 2020 values being considerably lower compared to 2019.
- Variations in the spectral content of the 2019 and 2020 measurements are smaller at locations less affected by road traffic noise, while they are greater at sites where traffic was a dominant source in the pre-lockdown scenario.

Sound recordings provide data that can be studied by other disciplines. Ornithologists, entomologists, sociologists, or psychologists are called to listen to the prevalence of non-anthropic noise and draw conclusions in their fields of knowledge. Further experiments with these recordings can provide information to plan, design, and restore built environments, detecting the needs for adequate acoustic environments that suit the landscape, history and architecture of a city. Not only to support the well-being and health of the local population, but also to enhance the visit of tourists meeting and exceeding their experiential expectations. Previous experiences show this is possible [39], and a holistic approach is desirable [35]. Some foundations on green areas have been explored [40] and citizens can be empowered to help research and improve on soundscapes [41].

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