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# ACOUSTICS - SCIENCE, ENGINEERING AND APPLICATIONS

*Research Based Book Chapter*  
**NOISE CHARACTERISTICS IN MEDITERRANEAN COASTAL  
TOURIST CITIES**

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**RESEARCH BASED BOOK CHAPTER****NOISE CHARACTERISTICS IN MEDITERRANEAN COASTAL TOURIST CITIES**

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**Abstract**

Coastal tourist cities are subject to considerable population fluctuations between the winter and the summer season, as well as between workdays, holidays or weekends. Through the analysis of the data obtained by noise monitoring/samplings, or modelling using prediction software, for winter and summer seasons it is demonstrated that the environmental noise is directly related to the population behaviour, being the main noise sources the road traffic on roads with the highest vehicle capacity.

The analysis and comparison of the sound evolution along both workday and holidays showed very typical patterns, which can be used as keys for the forensic acoustics. By analysing these patterns, this method can be applied to determine whether a certain noise corresponds to a working day or to a holiday or weekend.

The conclusions of this chapter, with the specific characteristics of each coastal tourist city, can support the development of smart and sustainable urban environments. Understanding how these characteristics influence the city's soundscape is crucial for its effective prediction and management. The aim is to assist decision-makers in formulating urban design criteria that foster the sustainability of the tourism industry while enhancing the quality of life for residents.

**Keywords**

Coastal Tourist Cities, Noise Pollution, Urban Noise, Traffic Noise, Weekend Effect, Noise Characterization, Natural Reserve

**1. Background**

The primary attraction of Mediterranean coastal tourist cities, and the main foundation of their economy, is sun, beach, and nature tourism. Most of these cities are in the subtropical zone of the planet, characterized by the typical Mediterranean climate, with warm summers where temperatures range from 14°C to 35°C, and mild winters between 4°C and 16°C. This temperature variation causes the population of these cities

to increase tenfold, or even fifteenfold, during the summer season compared to winter, along with a corresponding rise in economic activity and, indirectly, noise levels. Paradoxically, this increase in noise contrasts with the tranquility, rest, and calm sought by tourists during their summer holidays [1, 2]. Various studies, such as the report [3], have already noted that promoting tourism activities necessarily generates a certain degree of conflict and displacement, with noise pollution being one of the factors driving this. Recreational zones within protected natural environments also present significant management challenges for those responsible for their oversight [4].

Several sociological studies published [5-7], conducted across various Greek islands such as Rhodes, Mykonos, Santorini, Crete, etc., conclude that excessive noise generated by the urgent needs of tourism leads to a degradation of the quality of life for residents who remain throughout the year, as well as for visitors to these coastal tourist cities.

Additionally, in [8], the author analyses the acoustic situation of the tourist city of Castro (Chile), reaching several conclusions, including: 1) that the time period between 03:00 and 07:00 hours shows the greatest difference in LAeq between the high and low tourist seasons, with a variation of 3.8 dBA; 2) that Sunday is the quietest day of the week; and 3) that the average difference in the equivalent level LAeq of daytime noise between the high and low tourist seasons in the city is 2.4 dBA, with the maximum difference observed in the city centre.

## **2. Materials and Methods**

To analyse the acoustic situation of this type of city, an urban centre on the Atlantic coast of the province of Huelva (Spain) was selected.

### **2.1. Study Area**

The coastal tourist city chosen as an example is the urban centre of El Portil, located in the south-west of the Iberian Peninsula, within the municipality of Punta Umbria (Huelva). See Figure 1.

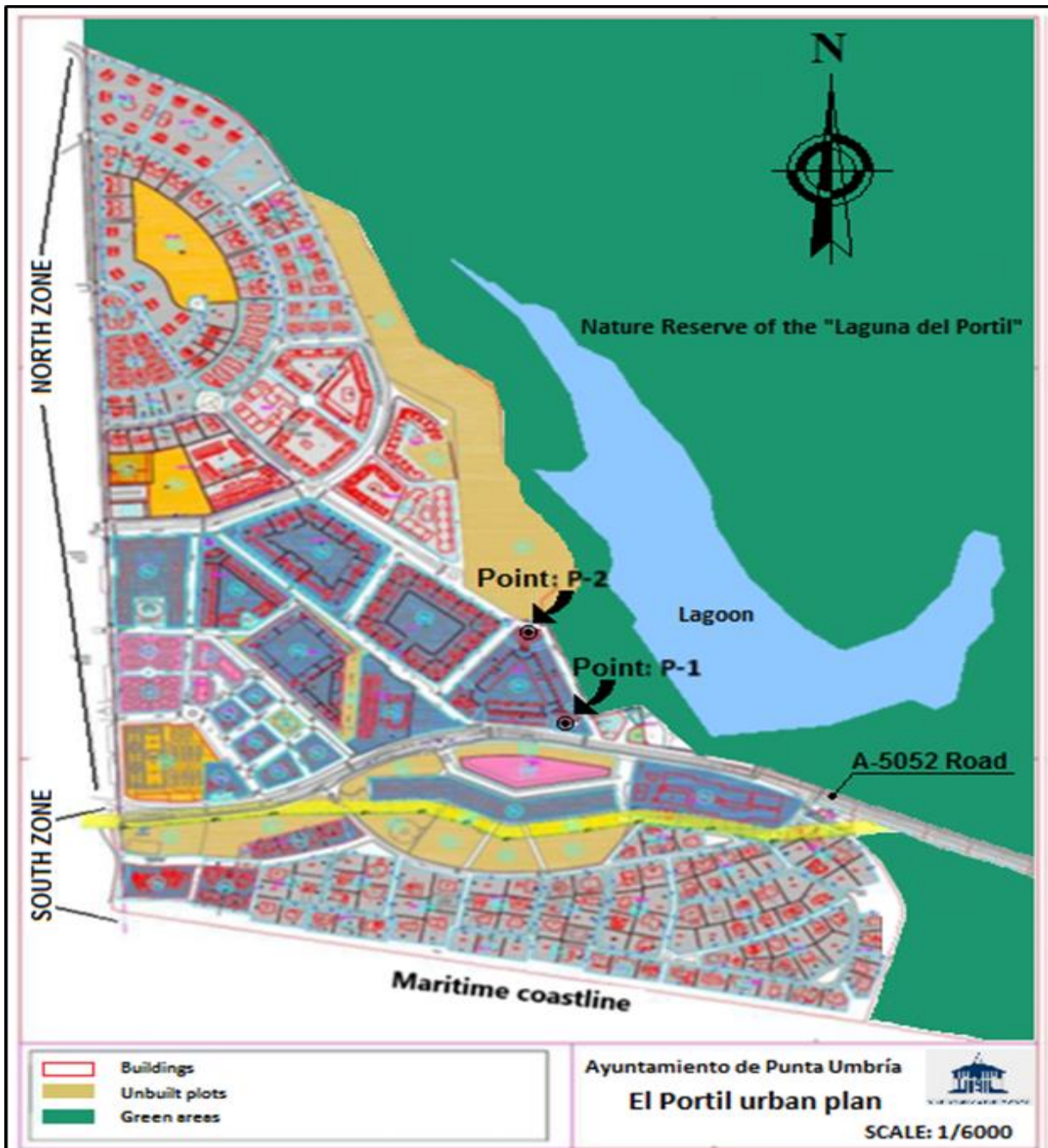


**Figure1.** Location of the study area

It is situated along the so-called Costa de la Luz. Due to its characteristics, it can be considered an example of a small coastal tourist city. Its sole economic activity is tourism, which is also the reason for its existence, with over 3 km of shoreline featuring calm waters and fine, golden sands. Its population is highly seasonal, estimated at around 1,200 inhabitants during winter and approximately 15,000 during the summer season, most of whom are tourists from the province of Huelva, as well as from Seville, Badajoz, Madrid, and even international visitors [9].

The urban centre of El Portil is primarily traversed by the regional road A-5052, which runs east to west. This road also acts as a physical barrier, dividing the population into two clearly differentiated zones: the northern zone (between the A-5052 and the pines of the Natural Reserve), which is larger and characterised by taller buildings; and the southern zone (between the A-5052 and the shoreline), which has a lower population density and consists mainly of dispersed single-family homes of up to two storeys.

This urban distribution can be observed in more detail in the following Figure 2.



The regional road A-5052, which traverses the entire centre as well as the Laguna del Portil Natural Reserve (LPNR), an invaluable ecological natural area that surrounds this urban centre from the west to the east and includes a coastal lagoon, and on the other side, the maritime-coastal shoreline.

## **2.2. General Methodology**

To address the objectives of this chapter, four techniques or methodologies were followed. These have also allowed for comparison and contrast of the results obtained through each of them.

**2.2.1. Weekly continuous monitoring** with 5-minute recordings at two points within the urban centre. One point is closer to the A-5052 road, and the other is farther away. Point P-1 (the closest to the A-5052) and P-2 on Avoceta Street. The distance between these two points is 133 metres in a straight line, and their locations can be seen in the previous Figure 2.

**2.2.2. 24-hour monitoring** with 1-second recordings. These measurements were carried out only at point P-1, the closest to the A-5052 road.

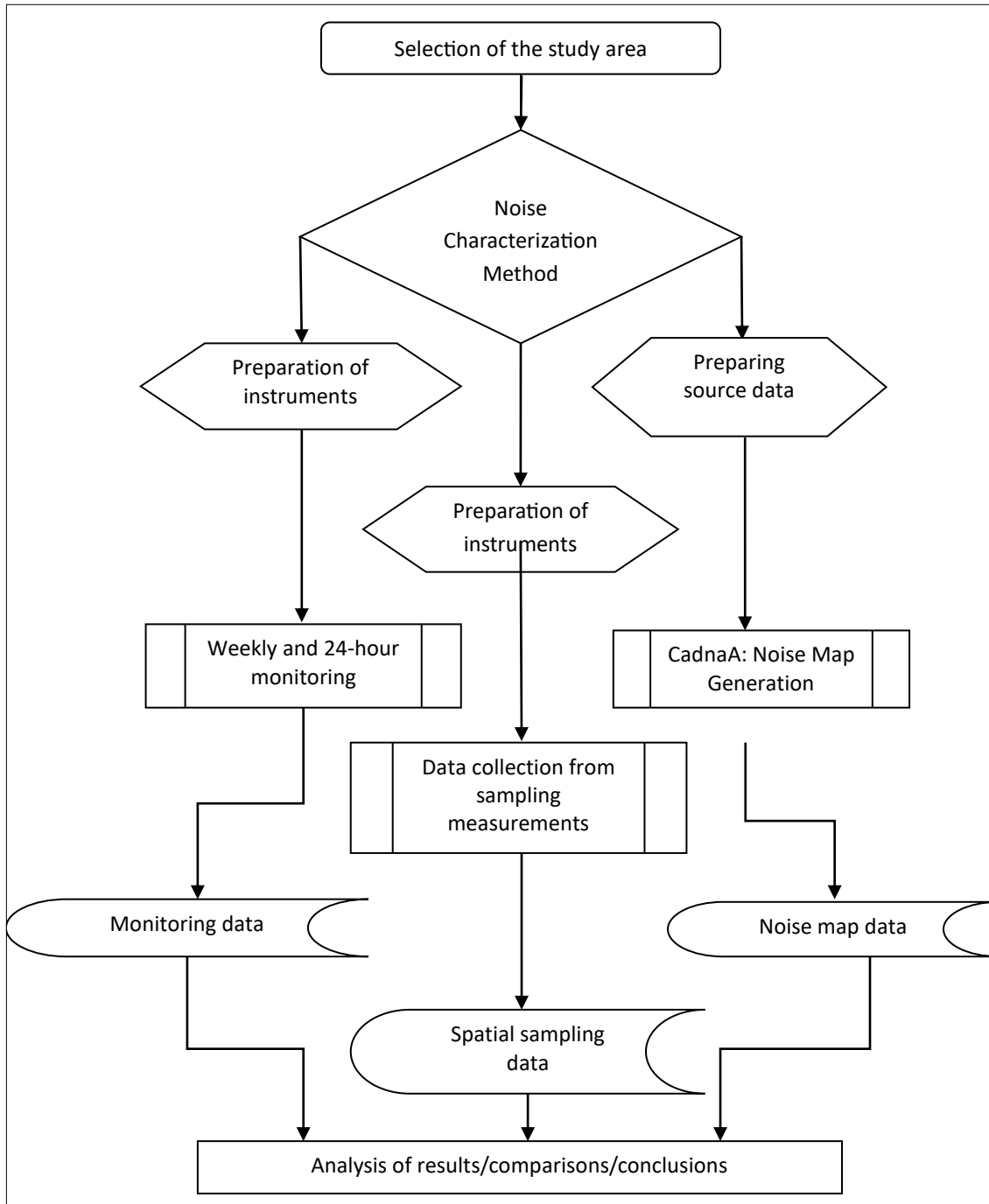
**2.2.3. Spatial sampling measurements** at 43 widely distributed points within the LPNR. To plan and prepare the spot measurements, both in winter and summer, the "grid" technique was used. A grid of 40 x 40 metres was overlaid on the sampling area (LPNR) using an aerial photograph of the zone obtained from Google Earth. This approach helped distribute the measurement points as evenly as possible across the sampling area [10].

**2.2.4. Modelling** using the CadnaA prediction software for the entire study area and generating noise maps. For this modelling, vehicle counts on the main roads within the urban centre were used, reflecting these counts through their ADT (Average Daily Traffic in vehicles per day), as shown in Table 1.

**Table 1.** Capacity expressed in ADT (v/day) of the main streets of El Portil

| <b>Road</b> | <b>Season</b> | <b>Day (D)</b> | <b>Evening (T)</b> | <b>Night (N)</b> | <b>Total</b> |
|-------------|---------------|----------------|--------------------|------------------|--------------|
| A-5052      | Winter        | 2887           | 998                | 302              | 4188 [11]    |
| A-5052      | Summer        | 7151           | 3011               | 2066             | 12228 [11]   |
| Avoceta St. | Winter        | 37             | 20                 | 3                | 60           |
| Avoceta St. | Summer        | 1043           | 523                | 165              | 1731         |

Once the data were obtained through these four research methodologies, it was possible to compare the results and draw conclusions about the evolution of noise across the entire area. The entire methodological process is better understood through the diagram in Figure 3.



**Figure 3.** Outline of the methodologies followed in the research work

### 2.3. Instrumentation

The main devices used in this study were:

- **For weekly monitoring:** Class 1 precision integrating sound level meter, brand RION, and model NL-31.
- **For 24-hour monitoring and spatial sampling:** Class 1 integrating-averaging sound level meter, brand CESVA, model SC-20c.
- **For noise mapping:** Prediction software version 4.3 of CadnaA.

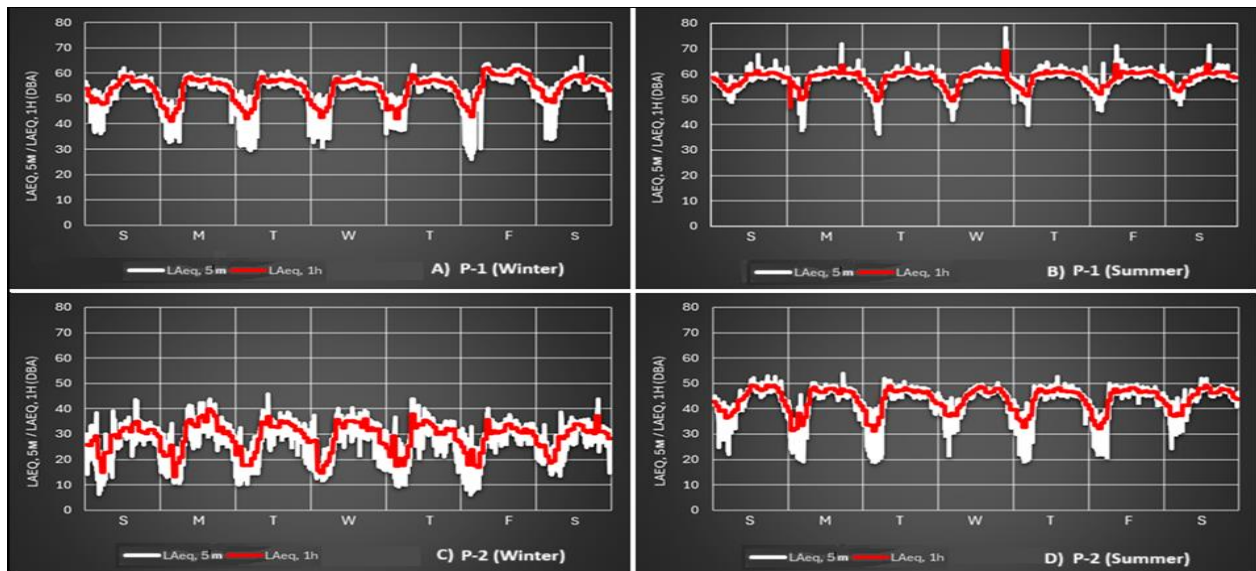
### 3. Results and Discussion

#### 3.1. Weekly Monitoring

Figure 4 below presents four graphs corresponding to measurements taken over a one-week period at points P-1 and P-2, during winter and summer:

- A) Point P-1 in winter
- B) Point P-1 in summer
- C) Point P-2 in winter
- D) Point P-2 in summer

In each of the four graphs, the 2016 records of 5-minute intervals (LAeq, 5m) are shown in white. The red line added represents the evolution of the LAeq, 1-hour index throughout each week, highlighting the weekly sound footprints and smoothing out fluctuations in the LAeq, 5m records.



**Figure 4.** Sound footprints of weekly recordings. LAeq, 5m / LAeq, 1-h indices, in dBA

While the summary of statistical data, indices, and percentiles for the four samples is provided in the following Table 2, the same statistical data have been added for each of the periods into which a day is subdivided according to [12] Directive 2002/49/EC: daytime period; evening period; and night period.

**Table 2.** Summary of weekly monitoring values, indices and percentiles, in dBA

|        |     | LAeqT                | LA1  | LA5  | LA8  | LA10 | LA40 | LA50 | LA60 | LA90 | LA95 | LA99 |      |
|--------|-----|----------------------|------|------|------|------|------|------|------|------|------|------|------|
| Winter | P-1 | Weekly Global        | 56.0 | 62.2 | 60.0 | 59.2 | 58.9 | 56.3 | 55.6 | 54.3 | 44.6 | 39.0 | 31.7 |
|        |     | Week: daytime period | 57.7 | 63.0 | 61.0 | 60.0 | 59.6 | 57.4 | 57.0 | 56.6 | 54.6 | 53.4 | 50.1 |
|        |     | Week: evening period | 56.2 | 62.2 | 60.0 | 59.2 | 58.9 | 56.3 | 55.6 | 54.3 | 44.6 | 39.0 | 31.7 |
|        |     | Week: night period   | 49.3 | 56.6 | 54.2 | 53.2 | 52.9 | 48.7 | 47.5 | 46.0 | 35.8 | 33.2 | 29.7 |
|        | P-2 | Weekly Global        | 31.6 | 40.8 | 36.7 | 35.4 | 34.9 | 30.6 | 29.4 | 27.4 | 15.1 | 12.6 | 9.4  |
|        |     | Week: daytime period | 33.6 | 42.1 | 38.4 | 37.1 | 36.6 | 32.6 | 31.6 | 30.7 | 25.7 | 23.0 | 17.2 |
|        |     | Week: evening period | 31.4 | 38.8 | 34.4 | 34.0 | 33.7 | 31.2 | 30.6 | 30.0 | 26.3 | 22.8 | 18.3 |
|        |     | Week: night period   | 24.1 | 33.4 | 30.2 | 29.1 | 28.5 | 20.4 | 18.3 | 16.6 | 11.5 | 10.3 | 7.8  |
| Summer | P-1 | Weekly Global        | 59.4 | 64.0 | 61.7 | 61.3 | 61.1 | 59.6 | 59.2 | 58.5 | 53.2 | 51.2 | 47.3 |
|        |     | Week: daytime period | 60.2 | 64.0 | 62.0 | 61.5 | 61.3 | 60.2 | 59.9 | 59.5 | 57.6 | 56.6 | 54.7 |
|        |     | Week: evening period | 61.1 | 65.4 | 62.0 | 61.7 | 61.4 | 60.1 | 59.8 | 59.6 | 58.7 | 58.3 | 57.5 |
|        |     | Week: night period   | 55.8 | 60.5 | 58.9 | 58.5 | 58.3 | 56.0 | 55.2 | 54.1 | 50.1 | 48.5 | 41.3 |
|        | P-2 | Weekly Global        | 45.5 | 50.1 | 48.8 | 48.4 | 48.2 | 46.3 | 45.5 | 44.0 | 34.6 | 30.3 | 20.6 |
|        |     | Week: daytime period | 47.1 | 50.9 | 49.1 | 48.8 | 48.7 | 47.3 | 46.9 | 46.6 | 44.4 | 42.9 | 39.0 |
|        |     | Week: evening period | 46.1 | 50.6 | 48.2 | 48.0 | 47.8 | 46.4 | 45.9 | 45.4 | 42.6 | 41.3 | 38.6 |
|        |     | Week: night period   | 39.4 | 46.1 | 43.6 | 43.1 | 42.8 | 38.9 | 37.6 | 36.2 | 24.3 | 21.7 | 19.6 |

From the analysis of Figure 4 and Table 2, it can be deduced that P-2 is generally subjected to lower sound pressure levels than P-1, both in winter and summer. This is justified by the fact that P-2 is located further away from the A-5052 road compared to P-1. These differences for each of the indices can be observed in Table 3.

Likewise, from that analysis, it can be inferred that the indices in the winter season are lower than those in the summer season, regardless of the monitoring point. This can be justified because the ADTs in summer, depending on the time of day, are between 7 and 70 times higher than those in winter. Additionally, the number of inhabitants is also 12 times higher. In Table 4, these differences for each of the indices can be observed.

**Table 3.** Differences in index values between monitoring points P-1 and P-2 at each season, in dBA

|               |                                       |                             | LAeqT | LA1  | LA5  | LA8  | LA10 | LA40 | LA50 | LA60 | LA90 | LA95 | LA99 |
|---------------|---------------------------------------|-----------------------------|-------|------|------|------|------|------|------|------|------|------|------|
| <b>Winter</b> | <b>Difference between P-1 and P-2</b> | <b>Weekly Global</b>        | 24.4  | 21.4 | 23.3 | 23.8 | 24   | 25.7 | 26.2 | 26.9 | 29.5 | 26.4 | 22.3 |
|               |                                       | <b>Week: daytime period</b> | 24.1  | 20.9 | 22.6 | 22.9 | 23   | 24.8 | 25.4 | 25.9 | 28.9 | 30.4 | 32.9 |
|               |                                       | <b>Week: evening period</b> | 24.8  | 23.4 | 25.6 | 25.2 | 25.2 | 25.1 | 25   | 24.3 | 18.3 | 16.2 | 13.4 |
|               |                                       | <b>Week: night period</b>   | 25.2  | 23.2 | 24   | 24.1 | 24.4 | 28.3 | 29.2 | 29.4 | 24.3 | 22.9 | 21.9 |
| <b>Summer</b> | <b>Difference between P-1 and P-2</b> | <b>Weekly Global</b>        | 13.9  | 13.9 | 12.9 | 12.9 | 12.9 | 13.3 | 13.7 | 14.5 | 18.6 | 20.9 | 26.7 |
|               |                                       | <b>Week: daytime period</b> | 13.1  | 13.1 | 12.9 | 12.7 | 12.6 | 12.9 | 13   | 12.9 | 13.2 | 13.7 | 15.7 |
|               |                                       | <b>Week: evening period</b> | 15.0  | 14.8 | 13.8 | 13.7 | 13.6 | 13.7 | 13.9 | 14.2 | 16.1 | 17   | 18.9 |
|               |                                       | <b>Week: night period</b>   | 16.4  | 14.4 | 15.3 | 15.4 | 15.5 | 17.1 | 17.6 | 17.9 | 25.8 | 26.8 | 21.7 |

**Table 4.** Differences in index values between winter and summer at each monitoring point, in dBA

|                                             |            |                             | LAeqT | LA1  | LA5  | LA8  | LA10 | LA40 | LA50 | LA60 | LA90 | LA95 | LA99 |
|---------------------------------------------|------------|-----------------------------|-------|------|------|------|------|------|------|------|------|------|------|
| <b>Difference between Summer and Winter</b> | <b>P-1</b> | <b>Weekly Global</b>        | 3.4   | 1.8  | 1.7  | 2.1  | 2.2  | 3.3  | 3.6  | 4.2  | 8.6  | 12.2 | 15.6 |
|                                             |            | <b>Week: daytime period</b> | 2.5   | 1.0  | 1.0  | 1.5  | 1.7  | 2.8  | 2.9  | 2.9  | 3.0  | 3.2  | 4.6  |
|                                             |            | <b>Week: evening period</b> | 4.9   | 3.2  | 2.0  | 2.5  | 2.5  | 3.8  | 4.2  | 5.3  | 14.1 | 19.3 | 25.8 |
|                                             |            | <b>Week: night period</b>   | 6.5   | 3.9  | 4.7  | 5.3  | 5.4  | 7.3  | 7.7  | 8.1  | 14.3 | 15.3 | 11.6 |
|                                             | <b>P-2</b> | <b>Weekly Global</b>        | 13.9  | 9.3  | 12.1 | 13.0 | 13.3 | 15.7 | 16.1 | 16.6 | 19.5 | 17.7 | 11.2 |
|                                             |            | <b>Week: daytime period</b> | 13.5  | 8.8  | 10.7 | 11.7 | 12.1 | 14.7 | 15.3 | 15.9 | 18.7 | 19.9 | 21.8 |
|                                             |            | <b>Week: evening period</b> | 14.7  | 11.8 | 13.8 | 14.0 | 14.1 | 15.2 | 15.3 | 15.4 | 16.3 | 18.5 | 20.3 |
|                                             |            | <b>Week: night period</b>   | 15.3  | 12.7 | 13.4 | 14.0 | 14.3 | 18.5 | 19.3 | 19.6 | 12.8 | 11.4 | 11.8 |

A global examination of Figure 4 reveals a clear similarity in the shapes of all the daily sound footprints on workdays (WD), and another distinct similarity for holidays (HD), irrespective of whether they occur during the winter or summer monitoring periods. In general, WDs are defined as Monday through Friday, while HDs correspond to Saturdays and Sundays. However, it should be noted that during the summer monitoring week at point P-1, Friday fell on August 3rd, a local holiday, and at point P-2, Wednesday fell on August 15th, a national holiday.

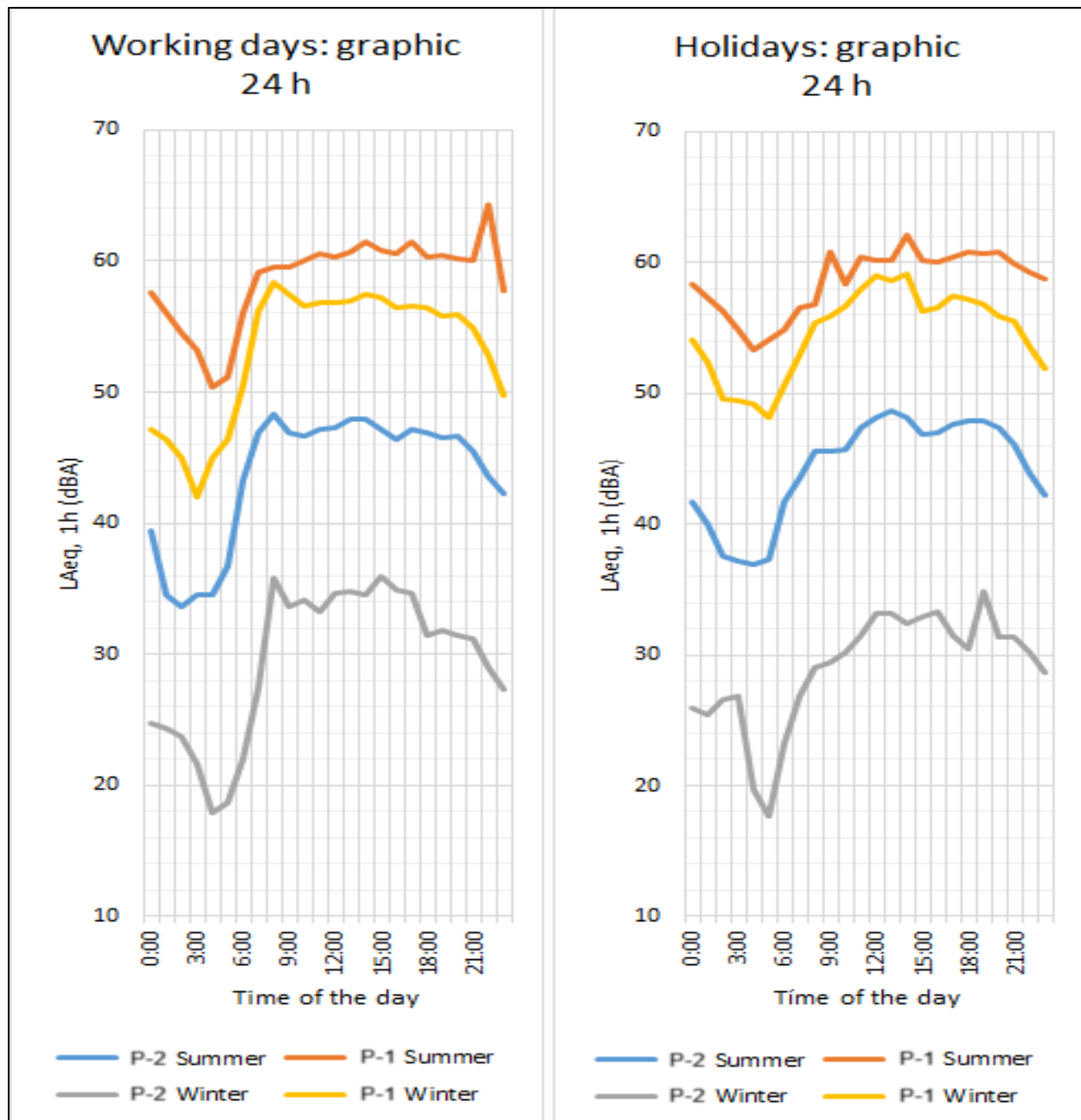
Further analysis of Figure 4 indicates that at both monitoring locations and across both seasons, the minimum hourly equivalent continuous sound levels (LAeq,1h) for all days consistently occur during the night-time period, as expected. On WDs, the lowest levels typically occur at 04:00, whereas on HDs, the minimum is generally observed at 05:00. Moreover, in all four graphs, the minimum LAeq,1h values recorded on HD nights are

higher than those on WD nights, with an average difference of 4.1 dBA between Friday and Saturday night-time minima. The Friday of P-1 in summer has been excluded from this comparison due to its classification as a local holiday.

Focusing now on the diurnal profiles, it is evident that they follow an inverted U-shape. However, while the WD profiles exhibit steeper gradients, particularly on the ascending (morning) side, the HD profiles are characterised by more gradual, curved slopes on both sides. To examine this phenomenon in greater detail, the overall LAeq,1h levels for WDs and HDs were calculated for each season and monitoring location. These values are presented in Table 5 and illustrated graphically in Figure 5.

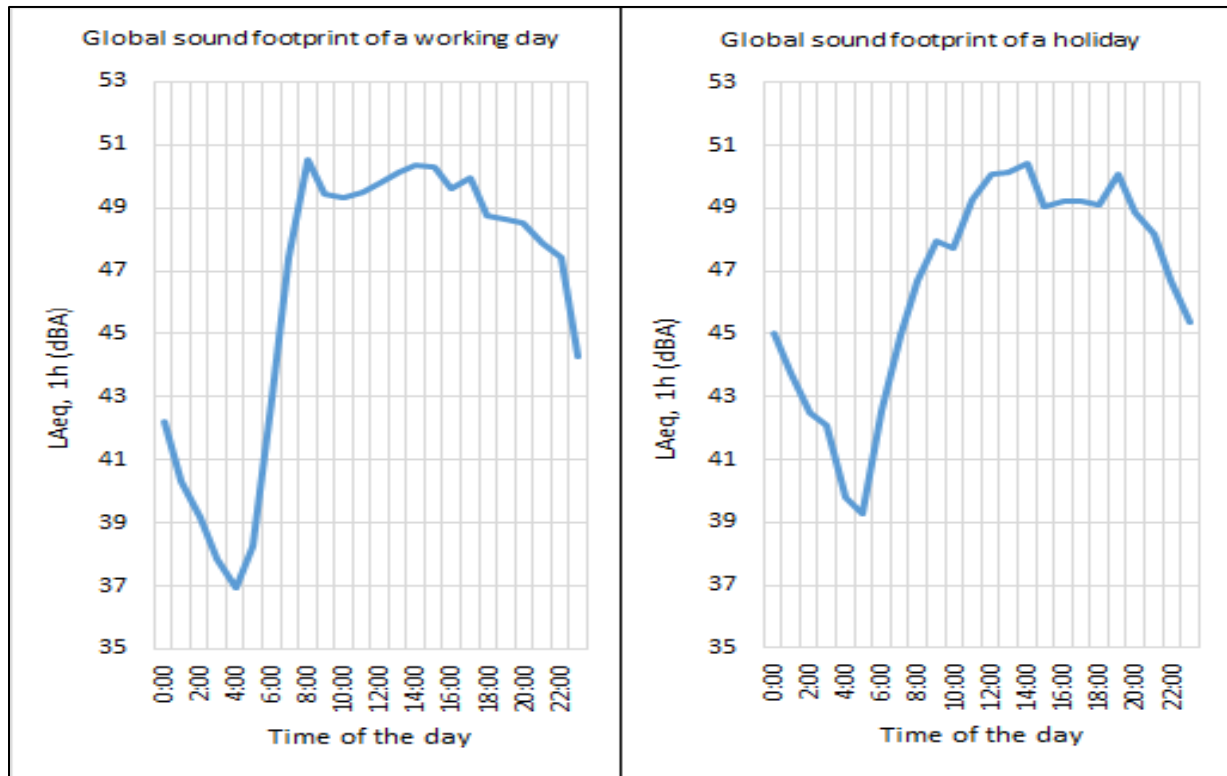
**Table 5.** LAeq,1h global levels of the WD and the HD in each season and measurement point in dBA

| TYPE OF DAY | WD    | WD    | WD    | WD    | HD    | HD    | HD    | HD    |
|-------------|-------|-------|-------|-------|-------|-------|-------|-------|
| POINT       | P-1   | P-1   | P-2   | P-2   | P-1   | P-1   | P-2   | P-2   |
| SEASON      | W     | S     | W     | S     | W     | S     | W     | S     |
| 0:00        | 47.10 | 57.63 | 24.71 | 39.42 | 54.11 | 58.32 | 26.00 | 41.72 |
| 1:00        | 46.43 | 56.07 | 24.31 | 34.53 | 52.43 | 57.35 | 25.36 | 39.99 |
| 2:00        | 44.95 | 54.52 | 23.69 | 33.66 | 49.54 | 56.30 | 26.55 | 37.54 |
| 3:00        | 41.97 | 53.21 | 21.64 | 34.52 | 49.49 | 54.89 | 26.85 | 37.15 |
| 4:00        | 44.98 | 50.35 | 17.85 | 34.48 | 49.18 | 53.31 | 19.76 | 36.87 |
| 5:00        | 46.43 | 51.12 | 18.68 | 36.71 | 48.14 | 54.06 | 17.67 | 37.33 |
| 6:00        | 50.52 | 56.08 | 22.01 | 43.31 | 50.54 | 54.81 | 23.25 | 41.63 |
| 7:00        | 56.21 | 59.19 | 27.44 | 46.92 | 52.96 | 56.57 | 26.85 | 43.53 |
| 8:00        | 58.43 | 59.49 | 35.83 | 48.28 | 55.41 | 56.76 | 29.03 | 45.58 |
| 9:00        | 57.49 | 59.55 | 33.66 | 46.95 | 55.91 | 60.82 | 29.46 | 45.62 |
| 10:00       | 56.54 | 60.07 | 34.09 | 46.60 | 56.73 | 58.38 | 30.16 | 45.71 |
| 11:00       | 56.88 | 60.60 | 33.26 | 47.12 | 57.94 | 60.39 | 31.51 | 47.34 |
| 12:00       | 56.83 | 60.34 | 34.64 | 47.25 | 58.96 | 60.11 | 33.15 | 48.11 |
| 13:00       | 57.00 | 60.66 | 34.76 | 47.97 | 58.59 | 60.21 | 33.18 | 48.70 |
| 14:00       | 57.48 | 61.47 | 34.49 | 47.91 | 59.12 | 62.13 | 32.45 | 48.09 |
| 15:00       | 57.24 | 60.81 | 35.93 | 47.19 | 56.31 | 60.20 | 32.92 | 46.86 |
| 16:00       | 56.44 | 60.61 | 34.86 | 46.44 | 56.52 | 60.02 | 33.32 | 47.00 |
| 17:00       | 56.56 | 61.45 | 34.60 | 47.16 | 57.44 | 60.35 | 31.44 | 47.65 |
| 18:00       | 56.41 | 60.26 | 31.46 | 46.85 | 57.23 | 60.75 | 30.51 | 47.84 |
| 19:00       | 55.77 | 60.43 | 31.88 | 46.49 | 56.82 | 60.73 | 34.88 | 47.89 |
| 20:00       | 55.93 | 60.20 | 31.42 | 46.61 | 55.93 | 60.76 | 31.42 | 47.35 |
| 21:00       | 54.86 | 60.05 | 31.18 | 45.44 | 55.45 | 59.89 | 31.40 | 46.03 |
| 22:00       | 52.87 | 64.36 | 28.96 | 43.49 | 53.53 | 59.22 | 30.22 | 43.84 |
| 23:00       | 49.78 | 57.75 | 27.36 | 42.23 | 51.87 | 58.67 | 28.62 | 42.25 |



**Figure 5.** Comparison of sound footprint between a working day and a holiday [9]

By integrating the hourly  $LA_{eq,1h}$  values from the four monitoring campaigns for both workdays (WD) and holidays (HD), composite graphs were obtained for each type of day. These represent the overall sound footprints of WDs and HDs, respectively, as shown in Figure 6.



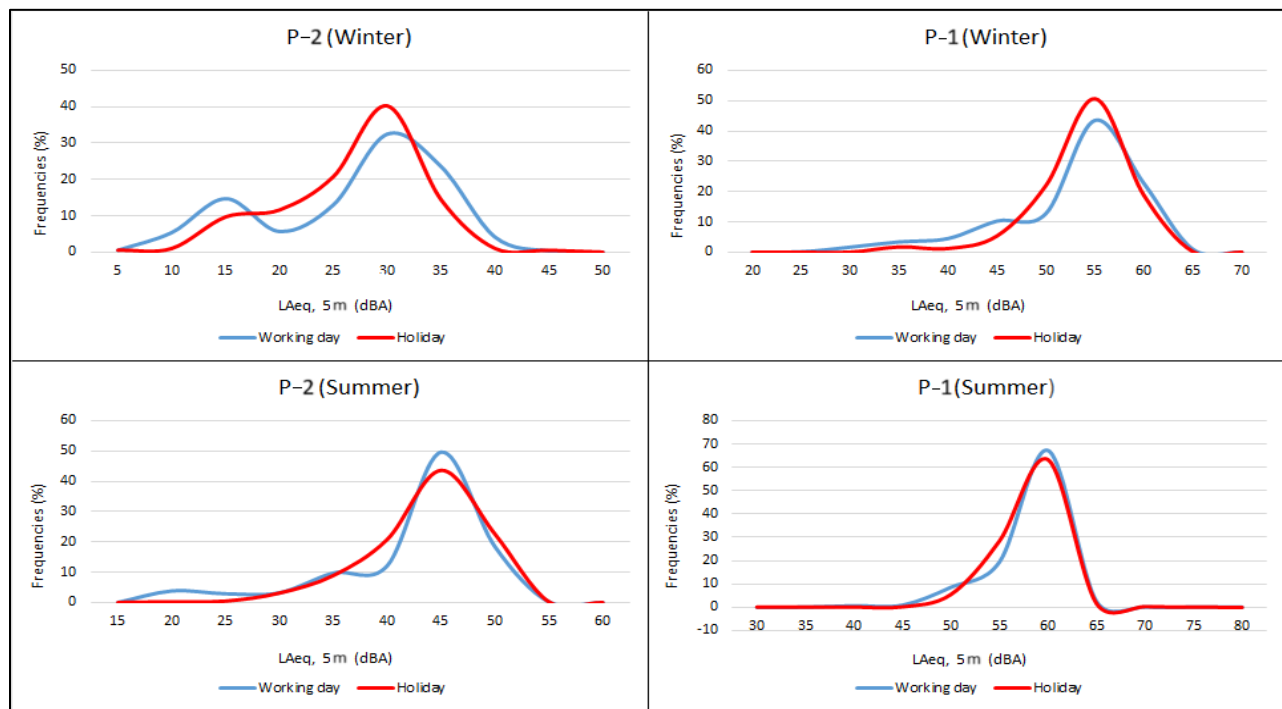
**Figure 6:** Comparison of sound footprint generic between a) workday b) holiday [9]

By comparing the generic temporal patterns of the sound footprints for workdays (WD) and holidays (HD) shown in Figure 6, the following conclusions can be drawn:

1. The absolute maximum level (50.6 dBA) on a WD occurs at 08:00 and becomes a much lower relative maximum (48 dBA) on an HD.
2. The peak level at 14:00 (50.5 dBA) on a WD also occurs on an HD; however, in this case, it represents the absolute maximum for HDs.
3. The relative maximum level (50 dBA) at 17:00 on a WD is observed at 19:00 on an HD.
4. The absolute minimum level on a WD occurs at 04:00, with a value of 37 dBA, whereas on an HD, it occurs at 05:00, with a value of 39 dBA. It can also be observed that the decline in noise levels at the end of the day begins at 17:00 on WDs, while on HDs, this decline starts later, at 19:00.

5. Regarding the shape of the sound footprints in Figure 6 during the period between 04:00 and 08:00, it is evident that both WD and HD profiles follow an approximately linear trend. This behaviour is also present in the individual sound profiles in Figure 4, although there are notable differences in the slopes of these linear segments between WDs and HDs. Calculating the slopes for Figure 6 yields global values of 3.40 dBA/h for WDs and 1.73 dBA/h for HDs, indicating that the slope for HDs is approximately half that of WDs. This represents a significant difference that enables a clear distinction between the two types of days.

The frequency distributions of the LAeq,5m time series from the four monitoring campaigns, separately analysed for WDs and HDs, were also examined. These distributions are presented graphically in Figure 7.



**Figure 7.** Diagrams distribution of frequencies of the LAeq. 5m; WD vs. HD [9]

For each season and monitoring point, the distribution function of LAeq,5m shows the relative maximum at the same noise level, regardless of the type of day (e.g., point P-1 in summer peaks at 59 dBA). This confirms that the main noise source—road traffic—remains consistent across both types of days. The frequency distribution peaks are listed in Table 6.

**Table 6.** Situation of the peaks of the main source of noise

| Point | Season | Level    | Peak |
|-------|--------|----------|------|
| P-2   | Winter | LAeq, 5m | 31   |
| P-1   | Winter | LAeq, 5m | 55   |
| P-2   | Summer | LAeq, 5m | 45   |
| P-1   | Summer | LAeq, 5m | 59   |

From Table 6, it can be observed that at point P-2, the peak increases by approximately 14 dBA in summer compared to winter, whereas at point P-1 the increase is only 4 dBA. Furthermore, Figure 6 shows that in winter, at both P-1 and P-2, the peaks corresponding to the main noise source (road traffic on the A-5052) are higher on HDs than on WDs. In contrast, in summer, the opposite occurs: peak values on WDs exceed those on HDs. This indicates that in winter, the primary noise source (A-5052) has a greater impact on overall noise levels during HDs, whereas in summer, this influence shifts to WDs.

Figure 7 also reveals that, for any season and monitoring location, the peaks related to the secondary source (background noise) are consistently higher on WDs than on HDs. These five-minute equivalent level frequency distributions suggest that, in summer, there is no significant difference in the distribution of acoustic events (i.e., human activities) between WDs and HDs, as the majority of the population is on holiday. However, clear differences are observed in winter, due to a significant increase in population during weekends. This is attributed to a rise in weekend tourism in winter, while weekday population levels remain low (weekend effect). In contrast, during summer, the tourist population increases by 1,150% and remains stable throughout the entire week (seasonal effect), with only daily behavioral patterns varying. This explains the temporal displacement of the background noise peaks.

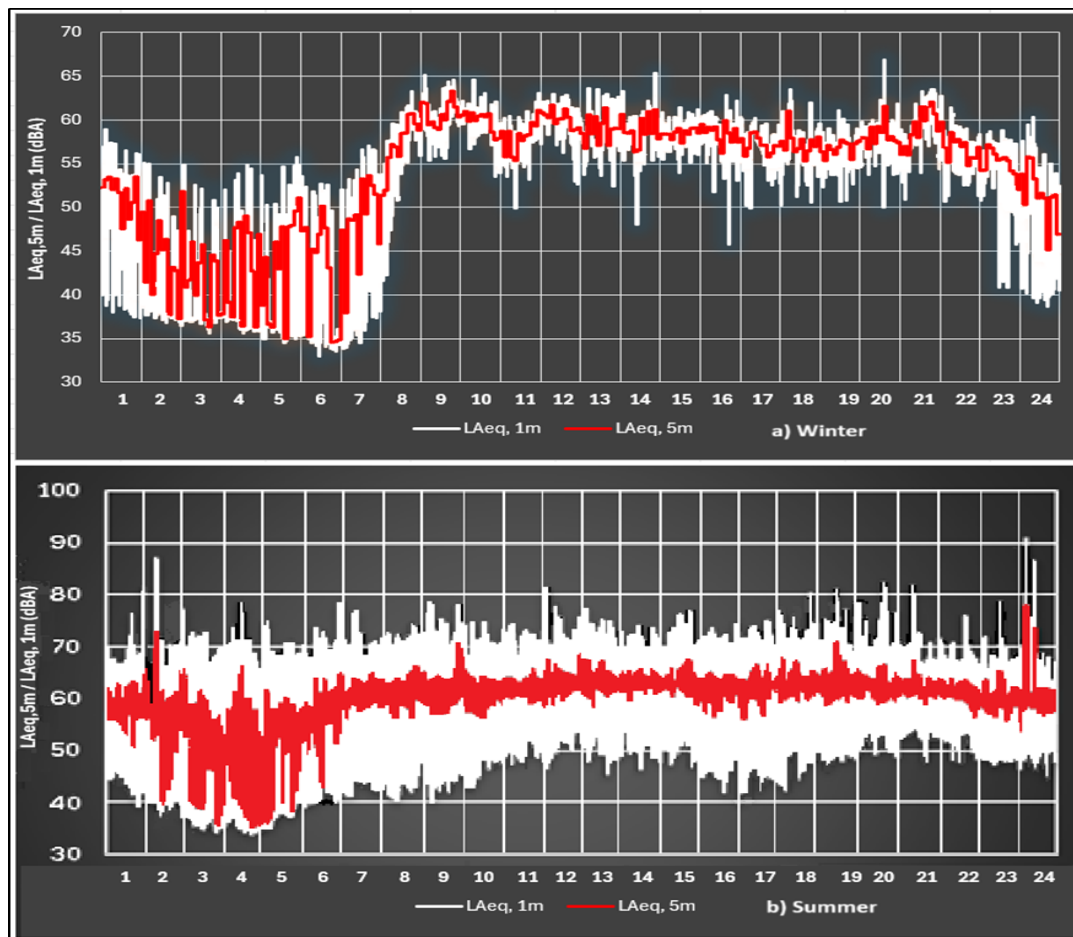
### **3.1. 24-Hour Monitoring**

In addition to the weekly monitoring campaigns conducted using five-minute intervals, a full 24-hour monitoring session was carried out for a single WD in both winter and summer. In this case, data were recorded at one-second intervals, yielding 86,400 data points per seasonal sample. This allowed for a much higher temporal resolution in noise

analysis around monitoring point P-1, enabling the identification of further details and conclusions. Point P-1 is the most affected by traffic from the A-5052 road.

Figure 8 presents two graphs corresponding to the 24-hour monitoring results for winter and summer WDs at point P-1. To prevent overcrowding of the graphs,  $L_{Aeq,1s}$  values were not plotted directly. Instead,  $L_{Aeq,5min}$  values are shown (in white), along with a red line representing the evolution of the  $L_{Aeq,1min}$  index over the course of the day. This red line helps highlight the 24-hour acoustic footprint and smooths out the fluctuations of the five-minute measurements.

A summary of statistical data, acoustic indices, and percentiles for both samples is provided in Table 7. This table also includes the same statistical parameters calculated for each of the time periods defined by [12]: Daytime period, Evening period, and Night period.



**Figure 8.** Sound footprints from 24-hour records of a WD, with  $L_{Aeq, 1m}$  /  $L_{Aeq, 5m}$  indices, in dBA: a) winter, b) summer

**Table 7.** Summary of 24-hour monitoring values, indices and percentiles, in dBA

|               |                            | <b>LAeq</b> | <b>LAm<sub>ax</sub></b> | <b>LAm<sub>in</sub></b> | <b>LA1</b> | <b>LA5</b> | <b>LA08</b> | <b>LA10</b> | <b>LA40</b> | <b>LA50</b> | <b>LA60</b> | <b>LA90</b> | <b>LA95</b> | <b>LA99</b> |
|---------------|----------------------------|-------------|-------------------------|-------------------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| <b>Winter</b> | <b>Global 24h</b>          | 57.1        | 83.8                    | 31.1                    | 66.9       | 63.6       | 62.3        | 61.6        | 52.8        | 49.7        | 46.2        | 36.2        | 35.0        | 33.5        |
|               | <b>24h: daytime period</b> | 58.9        | 77.6                    | 34.5                    | 67.9       | 64.5       | 63.5        | 62.9        | 56.8        | 54.9        | 53.0        | 45.7        | 43.4        | 34.9        |
|               | <b>24h: evening period</b> | 57.9        | 83.8                    | 35.2                    | 67.1       | 64.1       | 63.0        | 62.3        | 54.1        | 51.8        | 49.3        | 42.2        | 40.9        | 39.0        |
|               | <b>24h: night period</b>   | 48.8        | 73.5                    | 31.1                    | 62.8       | 53.6       | 49.5        | 47.0        | 38.4        | 37.6        | 37.0        | 34.8        | 34.3        | 33.5        |
| <b>Summer</b> | <b>Global 24h</b>          | 61.7        | 90.7                    | 33.9                    | 69.5       | 66.4       | 65.5        | 65.0        | 60.7        | 59.1        | 57.2        | 44.6        | 40.4        | 36.6        |
|               | <b>24h: daytime period</b> | 62.6        | 81.1                    | 40.3                    | 70.4       | 67.2       | 66.4        | 65.9        | 62.0        | 60.8        | 59.3        | 51.9        | 48.9        | 44.4        |
|               | <b>24h: evening period</b> | 62.4        | 82.3                    | 46.3                    | 68.8       | 66.1       | 65.4        | 65.0        | 61.9        | 61.1        | 60.2        | 55.6        | 54.0        | 50.8        |
|               | <b>24h: night period</b>   | 56.3        | 90.7                    | 45.5                    | 67.0       | 63.9       | 62.9        | 62.4        | 55.7        | 53.2        | 50.1        | 39.4        | 37.9        | 36.6        |

From the analysis of the acoustic footprints in Figure 8, the most immediate observation is that noise levels during the summer are higher than those recorded in winter. The differences across various indices and time periods are summarized in Table 8.

**Table 8.** Differences in dBA between summer and winter, based on 24-hour monitoring values, indices, and percentiles.

|                                             |                            | <b>LAeq</b> | <b>LAm<sub>ax</sub></b> | <b>LAm<sub>in</sub></b> | <b>LA1</b> | <b>LA5</b> | <b>LA08</b> | <b>LA10</b> | <b>LA40</b> | <b>LA50</b> | <b>LA60</b> | <b>LA90</b> | <b>LA95</b> | <b>LA99</b> |
|---------------------------------------------|----------------------------|-------------|-------------------------|-------------------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| <b>Difference between summer and winter</b> | <b>Global 24h</b>          | 4.6         | 6.9                     | 2.8                     | 2.6        | 2.8        | 3.2         | 3.4         | 7.9         | 9.4         | 11.0        | 8.4         | 5.4         | 3.1         |
|                                             | <b>24h: daytime period</b> | 3.7         | 3.5                     | 5.8                     | 2.5        | 2.7        | 2.9         | 3.0         | 5.2         | 5.9         | 6.3         | 6.2         | 5.5         | 9.5         |
|                                             | <b>24h: evening period</b> | 4.5         | -1.5                    | 11.1                    | 1.7        | 2.0        | 2.4         | 2.7         | 7.8         | 9.3         | 10.9        | 13.4        | 13.1        | 11.8        |
|                                             | <b>24h: night period</b>   | 7.5         | 17.2                    | 14.4                    | 4.2        | 10.3       | 13.4        | 15.4        | 17.3        | 15.6        | 13.1        | 4.6         | 3.6         | 3.1         |

Another notable aspect is that in the winter footprint, the oscillation band of LAeq,1min values between 08:00 and 22:00 is narrower (approximately 10 dBA) compared to that of summer (approximately 25 dBA). This is attributable to the proximity of point P-1 to the A-5052 road, meaning its acoustic environment is heavily influenced by traffic flow. This suggests that the hourly traffic volume (ADT) at this location is lower in winter than in summer.

By comparing the LAeq,5min plots (in red), it is evident that throughout the day, the winter graph is less densely populated than that of summer. This again reflects the lower vehicle flow rate per unit of time in winter.

Moreover, in summer, the band representing LAm<sub>ax</sub> values remains relatively uniform throughout the day—ranging approximately between 68 and 78 dBA—indicating that

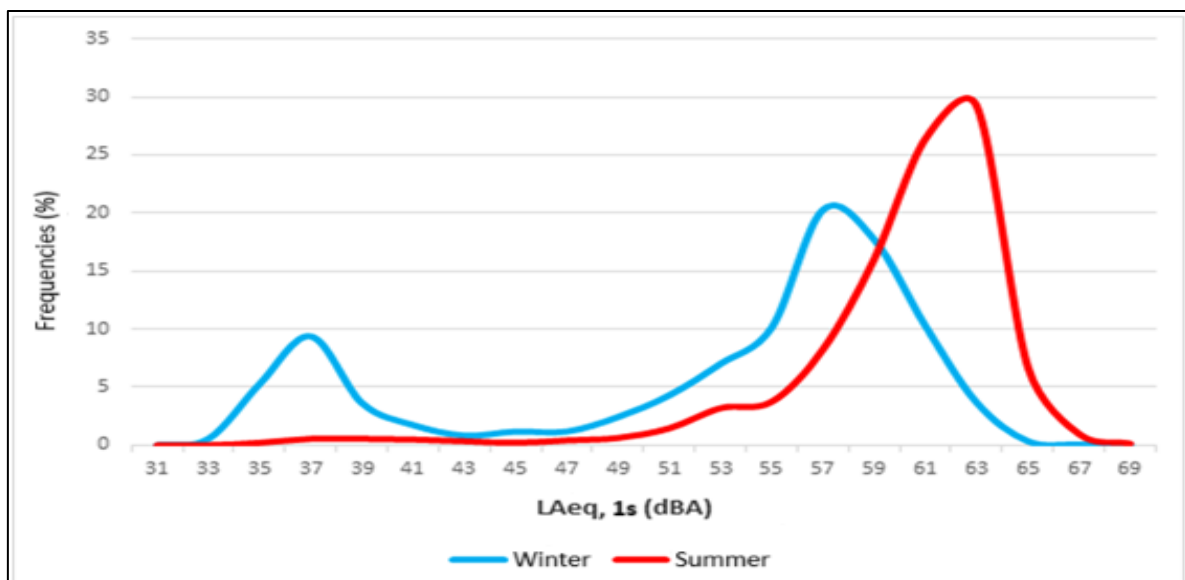
the recorded noise primarily originates from road traffic. In contrast,  $L_{Amin}$  values show much greater variation across the day (roughly from 34 to 50 dBA), suggesting that these lower levels are less influenced by traffic and more affected by background noise stemming from other sonic events related to resident activities.

Another striking feature appears in Figure 8 (winter): during night-time hours (01:00 to 07:00), the  $L_{Aeq,1min}$  values form a plateau, with minimum values fluctuating between 34 and 38 dBA.

Conversely, in Figure 8 (summer), this period is characterized by a V-shaped dip, with minimum values of 35 dBA occurring only between 03:00 and 04:00. This pattern indicates a more pronounced decline in nocturnal activity during winter nights compared to summer, suggesting that in summer, residents both stay up later and rise earlier.

Figure 8 also reveals, particularly through the  $L_{Aeq,5min}$  graphs, that in winter, rest hours on WDs begin around 22:00, followed by a drop of approximately 10 dBA between 22:00 and 00:00. In summer, this decrease is much smaller—only around 3 dBA.

Finally, the frequency distributions of the data series from both 24-hour monitoring campaigns (winter and summer) were also analysed. These are graphically represented in Figure 9.



**Figure 9.** Diagrams distribution of frequencies of the  $L_{Aeq, 5m}$ ; winter and summer [1]

Upon analysis of this figure, the most significant observation is that the frequency distribution diagram for winter displays two relative maxima. This suggests the existence of two distinct frequency distribution functions of acoustic events, each associated with a different primary noise source. In contrast, the summer distribution shows only one prominent peak, indicating the dominance of a single primary noise source.

The first peak in the winter data appears around 37 dBA and corresponds to nocturnal acoustic events unrelated to road traffic—in other words, background night-time noise. The second peak, centred around 58 dBA, is primarily attributable to road traffic from the A-5052.

In contrast, the summer frequency distribution presents a single absolute maximum, associated with road traffic noise from the A-5052. This peak is located around 63 dBA and encompasses approximately 98% of all measurements, which fall within the range of 45 to 68 dBA. As expected, due to higher traffic volumes in summer, this maximum is shifted approximately 5 dBA to the right compared to the winter season. Additionally, a slight bulge can be observed in the lower-level range (around 38 dBA), which accounts for only 2% of the one-second measurements. This minor secondary peak is likely attributable to the same background night-time noise source identified in winter.

Therefore, it can be concluded that in summer, there is effectively only one frequency distribution in the one-second measurements, corresponding to noise from the A-5052. This dominant source (98% of the measurements falling between 45 and 68 dBA) effectively masks any other, less intense background noise sources.

### **3.2. Spatial Sampling Measurements in the LPNR**

Following the spatial sampling methodology described in the General Methodology section, data were collected in winter from the 43 selected points, the locations of which are shown in Figure 10.



**Figure 10.** "Grill" with the location of sampling points in the LPNR area [1]

And whose results for both winter and summer are shown in Tables 9 and 10, respectively.

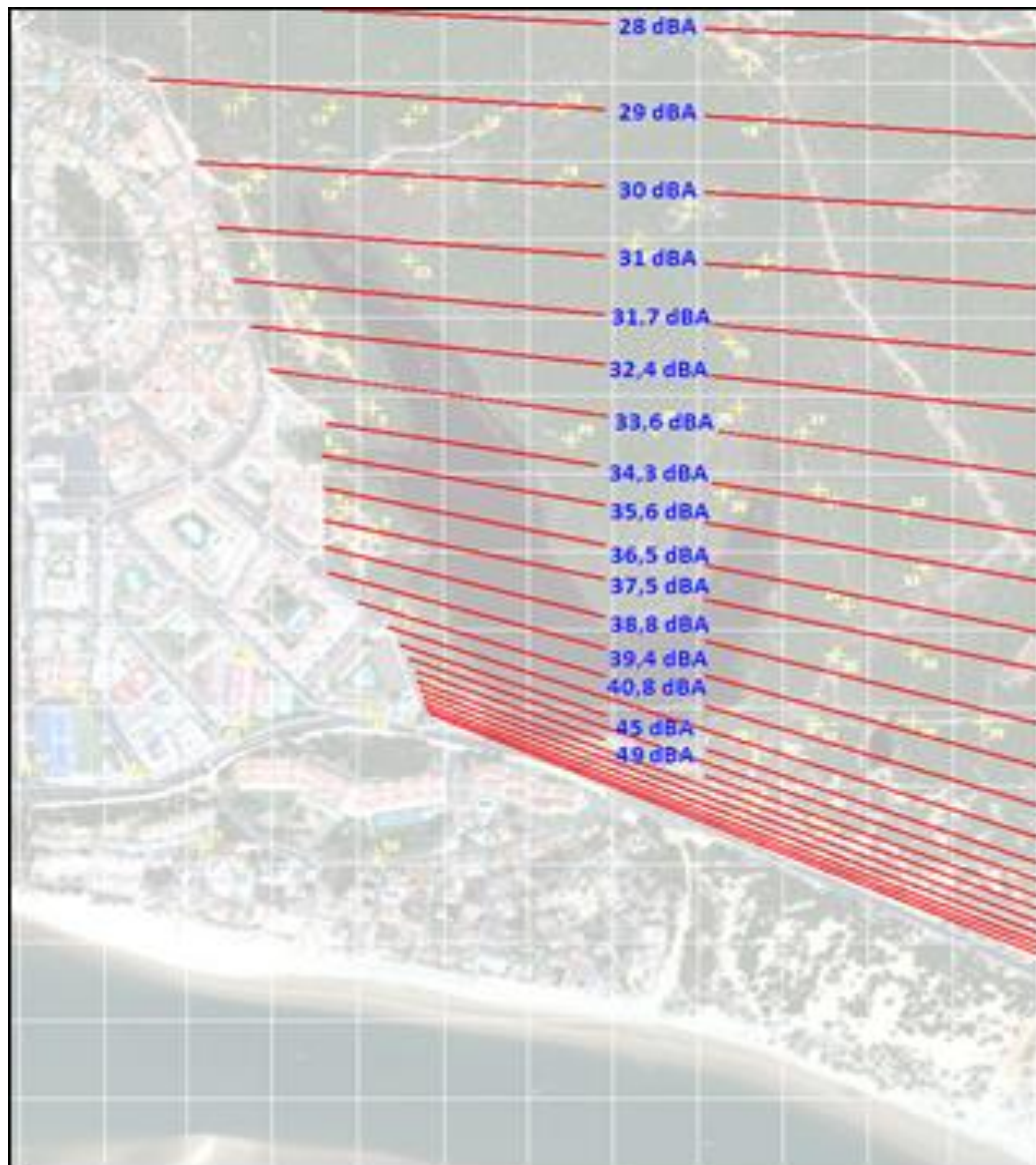
**Table 9.** Spatial sampling results in the LPNR in winter (dBA)

| Sampling points | LAeq, 5m | Leq1s max. | Sampling points | LAeq, 5m | Leq1s max. | Sampling points | LAeq, 5m | Leq1s max. |
|-----------------|----------|------------|-----------------|----------|------------|-----------------|----------|------------|
| WINTER          |          |            | WINTER          |          |            | WINTER          |          |            |
| 1               | 46.3     | 55.4       | 16              | 29.1     | 34.4       | 31              | 44.7     | 50.0       |
| 2               | 41.0     | 51.2       | 17              | 28.9     | 31.0       | 32              | 45.2     | 51.1       |
| 3               | 37.5     | 48.5       | 18              | 28.7     | 31.1       | 33              | 45.9     | 51.5       |
| 4               | 33.6     | 35.9       | 19              | 30.5     | 35.4       | 34              | 49.2     | 56.1       |
| 5               | 36.1     | 36.1       | 20              | 31.6     | 34.8       | 35              | 47.7     | 52.8       |
| 6               | 32.9     | 36.9       | 21              | 31.2     | 36.7       | 36              | 47.3     | 53.8       |
| 7               | 31.8     | 36.8       | 22              | 31.5     | 37.1       | 37              | 48.8     | 54.2       |
| 8               | 32.5     | 35.2       | 23              | 31.8     | 38.3       | 38              | 49.8     | 54.1       |
| 9               | 37.9     | 48.8       | 24              | 33.1     | 37.7       | 39              | 50.3     | 55.3       |
| 10              | 29.7     | 33.6       | 25              | 34.6     | 39.5       | 40              | 51.4     | 57.8       |
| 11              | 29.6     | 32.6       | 26              | 35.1     | 43.1       | 41              | 59.6     | 62.2       |
| 12              | 42.4     | 51.9       | 27              | 34.6     | 41.7       | 42              | 62.7     | 65.4       |
| 13              | 30.3     | 36.6       | 28              | 33.6     | 37.9       | 43              | 63.9     | 64.8       |
| 14              | 30.7     | 37.8       | 29              | 34.9     | 39.8       |                 |          |            |
| 15              | 29.3     | 33.7       | 30              | 35.1     | 37.7       |                 |          |            |

**Table 10.** Spatial sampling results in the LPNR in summer(dBA)

| Sampling points | LAeq, 5m | Leq1s max. | Sampling points | LAeq, 5m | Leq1s max. | Sampling points | LAeq, 5m | Leq1s max. |
|-----------------|----------|------------|-----------------|----------|------------|-----------------|----------|------------|
| SUMMER          |          |            | SUMMER          |          |            | SUMMER          |          |            |
| 1               | 51.1     | 59.9       | 16              | 34.1     | 39.9       | 31              | 44.7     | 50.0       |
| 2               | 49.2     | 57.6       | 17              | 34.4     | 40.3       | 32              | 45.2     | 51.1       |
| 3               | 44.6     | 52.2       | 18              | 33.9     | 39.7       | 33              | 45.9     | 51.5       |
| 4               | 41.7     | 48.8       | 19              | 34.9     | 40.2       | 34              | 49.2     | 56.1       |
| 5               | 42.2     | 49.4       | 20              | 35.7     | 40.6       | 35              | 47.7     | 52.8       |
| 6               | 37.3     | 43.7       | 21              | 38.0     | 43.3       | 36              | 47.3     | 53.8       |
| 7               | 36.4     | 42.6       | 22              | 36.8     | 43.1       | 37              | 48.8     | 54.2       |
| 8               | 35.9     | 42.0       | 23              | 37.5     | 42.8       | 38              | 49.8     | 54.1       |
| 9               | 38.7     | 46.3       | 24              | 38.4     | 43.8       | 39              | 50.3     | 55.3       |
| 10              | 35.2     | 40.1       | 25              | 39.8     | 44.3       | 40              | 53.4     | 57.8       |
| 11              | 34.8     | 39.6       | 26              | 40.4     | 45.0       | 41              | 61.6     | 62.2       |
| 12              | 36.4     | 42.6       | 27              | 44.5     | 49.3       | 42              | 65.9     | 66.4       |
| 13              | 34.1     | 39.9       | 28              | 41.8     | 45.4       | 43              | 63.9     | 64.8       |
| 14              | 34.3     | 40.2       | 29              | 42.7     | 46.7       |                 |          |            |
| 15              | 34.6     | 40.5       | 30              | 43.8     | 50.1       |                 |          |            |

From the analysis of the data in Table 9, the remarkably high values observed at measurement points 09 and 12 stand out in comparison to their adjacent points. These elevated values are justified by the presence of swallows and swifts vocalising during the nesting period at point 09, and croaking frogs during mating season at point 12. Consequently, these measurements are significantly different from the rest. Applying the Grubbs test [13] to these two points, in relation to their closest neighbouring values, confirmed that they are outliers. This justified their exclusion from the interpolation process used to generate the winter isoline maps of the LPNR, as illustrated in Figure 11.



**Figure 11.** Map of the LPNR isolines. in winter (LAeq, T in dBA) [1]

When analysing the data from the 43 spatial sampling points for the summer season in Table 10, no similarly extreme values were identified. This is mainly due to the different environmental conditions at the time of measurement, particularly the reduced acoustic activity of animals, as the measurements did not coincide with nesting or mating periods, unlike during the winter campaign.

As was done for the winter data, and after correcting the measurements at points 09, 12, 27, and 34, a summer-season isoline map of the LPNR was produced, as shown in Figure 12.



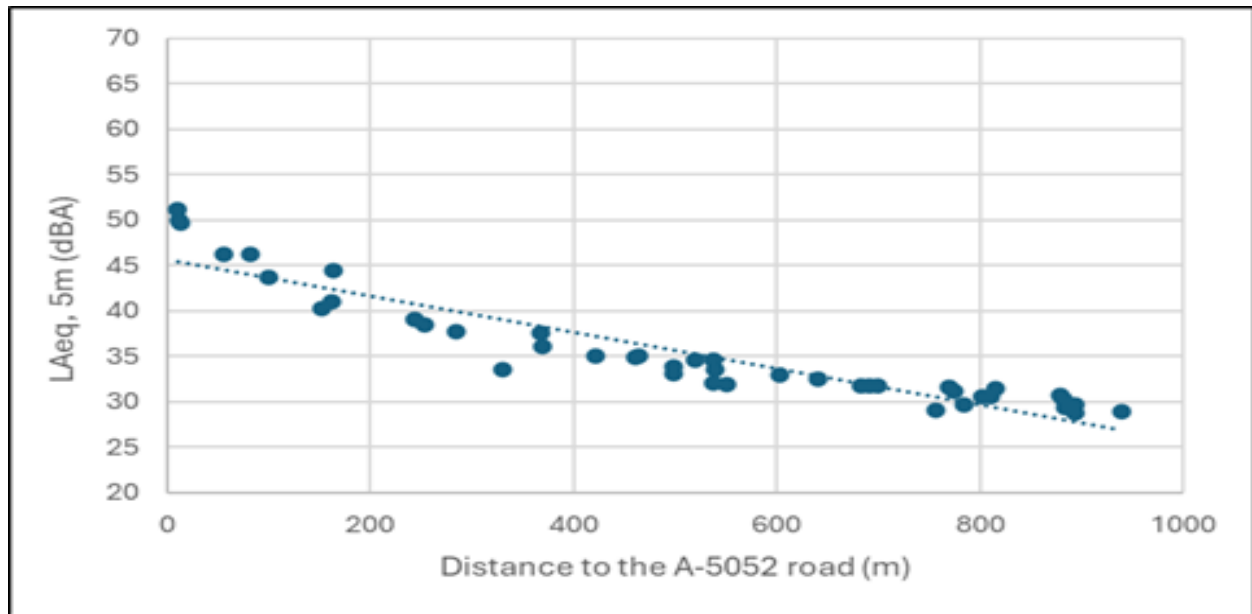
**Figure 12.** Map of the LPNR isolines. in summer ( $LA_{eq, T}$  in dBA) [1]

To examine how noise levels vary within the LPNR as a function of distance from the A-5052 road, the distances from each of the 43 sampling points to the A-5052 were calculated, and each was associated with its corresponding  $LA_{eq,5m}$  value for both the winter and summer seasons. This information is summarised in Table 11.

**Table 11.** Distance to the A-5052 road (m) and LAeq,5m (dBA) values in winter and summer

| Sampling point | Distance | LAeq. 5m (w) | LAeq. 5m (s) | Sampling point | Distance | LAeq. 5m (w) | LAeq. 5m (s) | Sampling point | Distance | LAeq. 5m (w) | LAeq. 5m (s) |
|----------------|----------|--------------|--------------|----------------|----------|--------------|--------------|----------------|----------|--------------|--------------|
| 1              | 54.7     | 46.3         | 51.1         | 16             | 756.8    | 29.1         | 34.1         | 31             | 537.2    | 32.1         | 44.7         |
| 2              | 161.5    | 41.0         | 49.2         | 17             | 939.3    | 28.9         | 34.4         | 32             | 550.0    | 31.9         | 45.2         |
| 3              | 368.2    | 37.5         | 44.6         | 18             | 893.5    | 28.7         | 33.9         | 33             | 498.7    | 33.8         | 45.9         |
| 4              | 329.9    | 33.6         | 41.7         | 19             | 809.7    | 30.5         | 34.9         | 34             | 283.5    | 37.7         | 46.2         |
| 5              | 368.8    | 36.1         | 42.2         | 20             | 770.2    | 31.6         | 35.7         | 35             | 252.5    | 38.5         | 47.7         |
| 6              | 602.3    | 32.9         | 37.3         | 21             | 774.9    | 31.2         | 38.0         | 36             | 242.6    | 39.1         | 47.3         |
| 7              | 683.4    | 31.8         | 36.4         | 22             | 814.9    | 31.5         | 36.8         | 37             | 151.6    | 40.2         | 48.8         |
| 8              | 639.7    | 32.5         | 35.9         | 23             | 700.0    | 31.8         | 37.5         | 38             | 99.0     | 43.7         | 49.8         |
| 9              | 691.5    | 31.7         | 35.5         | 24             | 497.9    | 33.1         | 38.4         | 39             | 162.9    | 44.5         | 50.3         |
| 10             | 783.5    | 29.7         | 35.2         | 25             | 537.7    | 34.6         | 39.8         | 40             | 82.2     | 46.2         | 51.4         |
| 11             | 893.6    | 29.6         | 34.8         | 26             | 420.7    | 35.1         | 40.4         | 41             | 13.1     | 49.7         | 59.6         |
| 12             | 801.9    | 30.6         | 35.2         | 27             | 519.2    | 34.6         | 40.5         | 42             | 11.2     | 49.9         | 62.7         |
| 13             | 883.0    | 30.3         | 34.1         | 28             | 538.6    | 33.6         | 41.8         | 43             | 10.5     | 51.1         | 63.9         |
| 14             | 879.0    | 30.7         | 34.3         | 29             | 460.5    | 34.9         | 42.7         |                |          |              |              |
| 15             | 883.1    | 29.3         | 34.6         | 30             | 464.4    | 35.1         | 43.8         |                |          |              |              |

By plotting the LAeq,5m values against distance to the A-5052 for both the winter and summer periods, Figures 13 and 14 were obtained, respectively. These figures also include the linear regression lines.



**Figure 13.** LPNR noise level variation with distance from the A-5052 (winter)

Examining Figure 13, which shows the linear variation of  $L_{Aeq,5m}$  during winter in relation to the distance ( $d$ ) in metres to the A-5052, the trend line reveals that as  $L_{Aeq,5m}$  increases, distance from the A-5052 decreases. The linear regression equation, fitted at a 95% confidence level, is:

$$L_{eqT} = (45.6 \pm 0.7) - (0.0199 \pm 0.0012) \cdot d$$

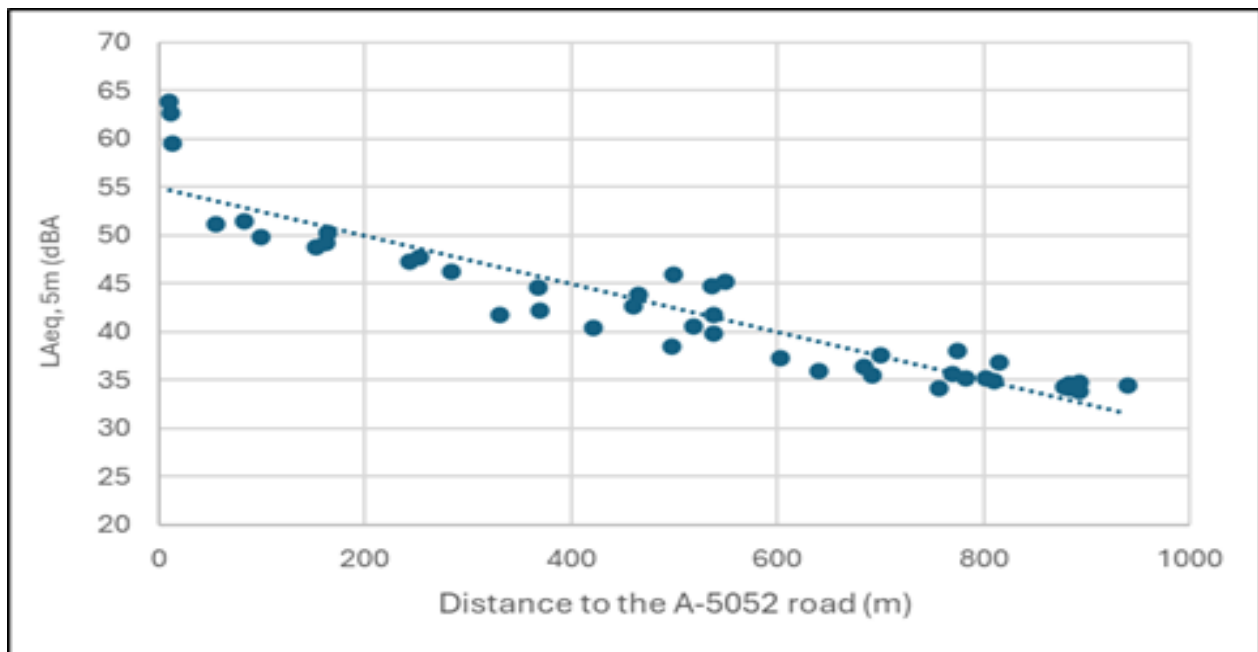
Determination Coefficient:  $R^2 = 0.869$

Standard error of the estimate:  $SE(\bar{y}) = \frac{S_y}{\sqrt{n}} = \frac{6.1036}{\sqrt{43}} = 0.9$

From the above equation, it can be deduced that for every metre away from the A-5052, there is an average decrease of  $(0.0199 \pm 0.0012)$  dBA in noise level during the winter period.

Furthermore, in Figure 12, only points 11, 17, and 18 (among the furthest from the A-5052), and points 41, 42, and 43 (among the closest), deviate from the overall linear trend. The latter may be due to the breakdown of the linear source model at such close distances, potentially related to geometric divergence and ground effect, as proposed by [14].

Figure 13, by contrast, presents the linear variation of  $L_{Aeq, 5m}$  during the summer period in relation to distance from the A-5052.



**Figure 14.** PNR noise level variation with distance from the A-5052 (summer)

**Analysing its trend line**, it is observed that, as in winter, when the LAeq, 5m increases, the distance to the A-5052 road decreases. The regression line, adjusted at the 95% confidence level, is defined by the following equation:

$$L_{eqT} = (54.9 \pm 0.9) - (0.0249 \pm 0.0016) \cdot d$$

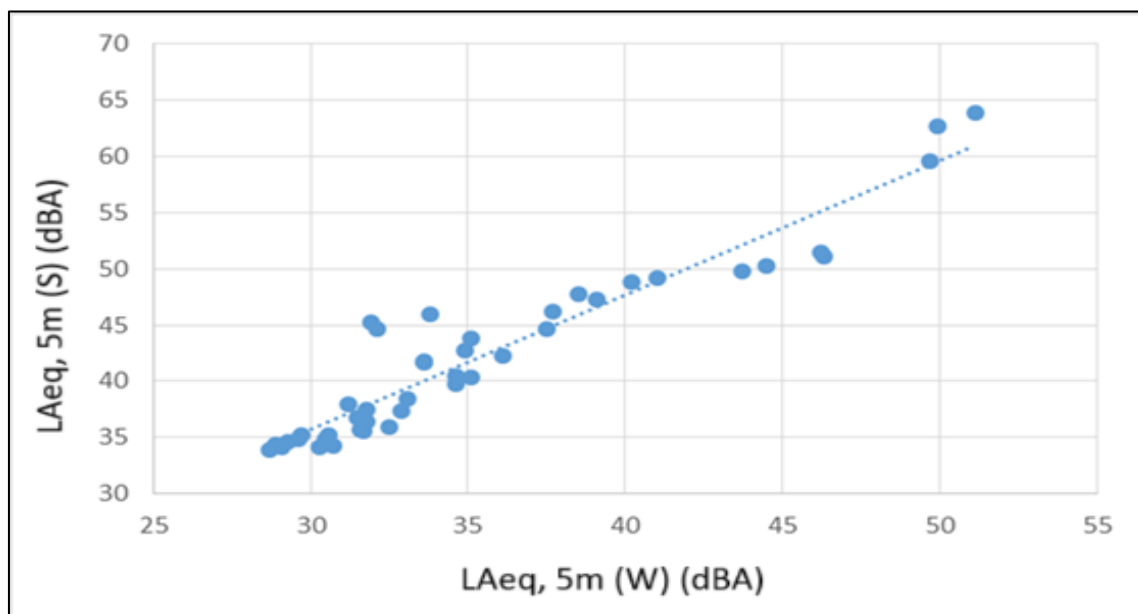
With a coefficient of determination:  $R^2 = 0.851$

And a standard error of the estimate:  $SE(\bar{y}) = \frac{S_y}{\sqrt{n}} = \frac{7.7014}{\sqrt{43}} = 1.2$

This regression equation describes the linear variation of the LAeq, 5m noise level during the summer period as a function of the distance (d) in metres to the A-5052 road. It indicates that for every meter one moves away from the A-5052, there is an average decrease of  $(0.0249 \pm 0.0016)$  dBA in noise level during the summer.

In Figure 14, the same outliers are detected as in the winter analysis, specifically, points 11, 17, and 18, which are the furthest from the A-5052, and particularly points 41, 42, and 43, which are the closest. Again, it is assumed that the linear noise source model becomes invalid at such short distances from the road, because of geometrical divergence and ground effect, as proposed by [14].

Next, when plotting LAeq, 5m winter values on the x-axis against the corresponding LAeq, 5m summer values on the y-axis for each of the 43 spatial sampling points within the LPNR, Figure 15 is obtained.



**Figure 15.** LAeq, 5m (w) vs LAeq, 5m (s) at the 43 sampling points of the LPNR

The regression line has been added to this graph fit, with a confidence level of 95%, and whose equation responds to:

$$L_{eqT}(s) = (1.20 \pm 0.06) \cdot L_{eqT}(w) - (0.26 \pm 2.22)$$

With a coefficient of determination:  $R^2 = 0.902$

And a standard error of the estimate:  $SE(\bar{y}) = \frac{S_y}{\sqrt{n}} = 7.7014 / \sqrt{43} = 1.2$

This equation implies that for every 1 dBA increase in the winter equivalent noise level, there is a corresponding  $(1.20 \pm 0.06)$  dBA increase in summer. As the intercept is virtually compatible with zero, the two variables are strongly correlated, suggesting that for a given point (x), the noise level in one season (summer) is proportional to that of winter, taken as the reference.

Furthermore, the  $R^2$  and  $SE$  values indicate that the fit is very satisfactory. This confirms that the behaviour pattern of the main noise source — road traffic along the A-5052 corridor — is almost identical in both seasons, with the only difference being the intensity of the traffic.

### **3.3. Modelling Using CadnaA Prediction Software**

By modelling the entire study area with CadnaA, general noise maps were generated. From these, predicted noise level data were extracted for the monitoring points P-1 and P-2, as well as for the same 43 locations used in the spatial sampling within the LPNR. A thorough comparison was then carried out between these predicted values and the results obtained from the weekly monitoring campaigns, the 24-hour monitoring, and the spatial sampling conducted in the LPNR. This comparison aimed to validate and cross-check the results derived from the acoustic modelling noise maps generated with CadnaA.

For this modelling process, it was first necessary to gather all the relevant data and parameters required to feed the model and accurately define the scenarios used for the acoustic simulation. Among these were the vehicle speed on the A-5052 road—set at  $40 \text{ km} \cdot \text{h}^{-1}$ , which is the maximum speed limit established for this section of the road through El Portil by the Directorate-General for Traffic—as well as the subsequent definition of the calculation grid ( $40 \times 40 \text{ m}$ ), etc. Based on this input, general noise maps for the entire study area were produced for both seasonal periods (winter and

summer), and within each, for the day, evening, and night periods. Point receptors were also placed on the façades of buildings at monitoring locations P-1 and P-2 to estimate façade noise levels for each period.

This modelling process resulted in the following noise maps:

- WINTER daytime noise map
- WINTER evening noise map
- WINTER nighttime noise map
- SUMMER daytime noise map
- SUMMER evening noise map
- SUMMER nighttime noise map.

These are shown in Figures 16 to 21, respectively.

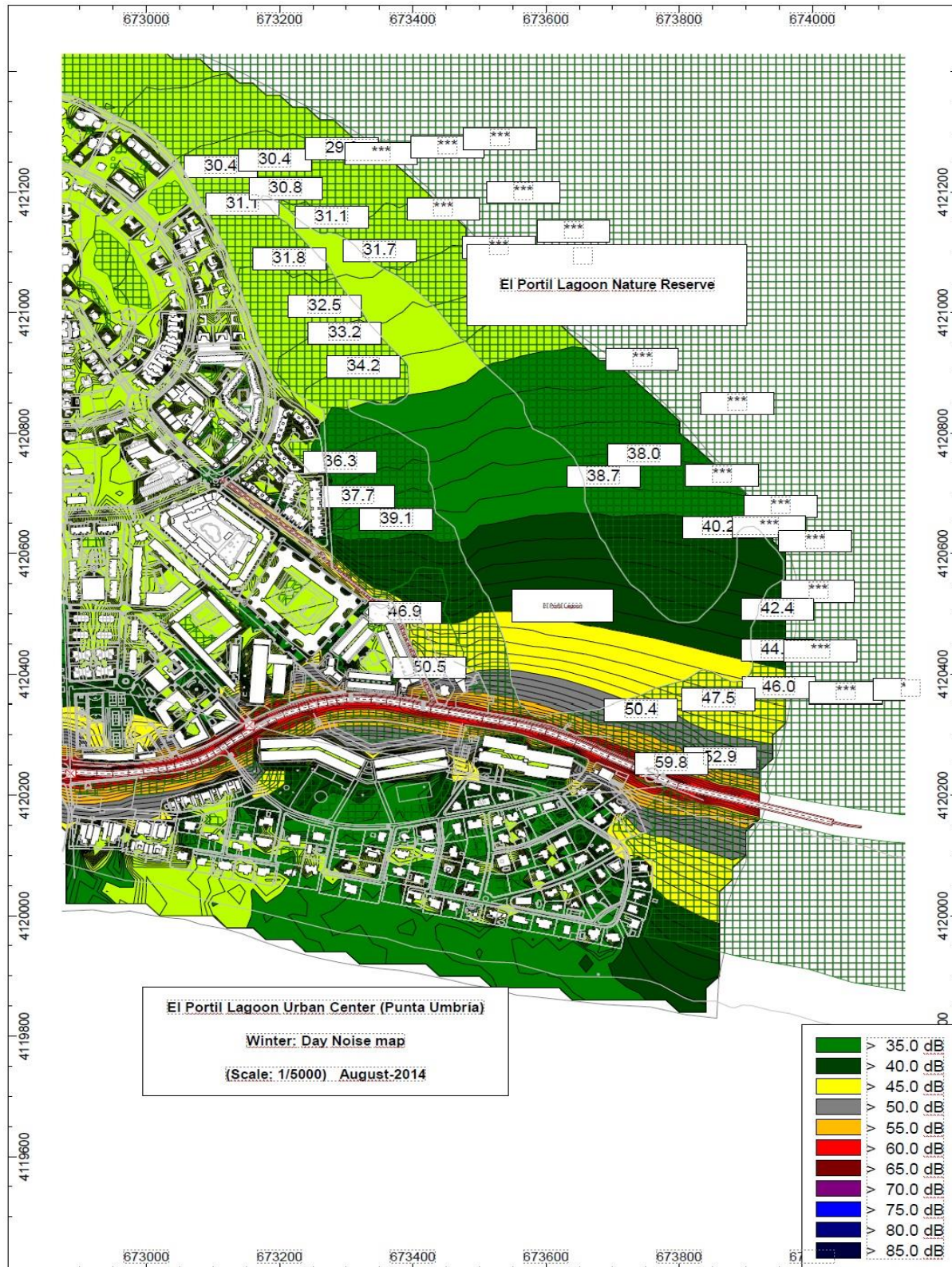


Figure 16. Winter daytime noise map, with levels

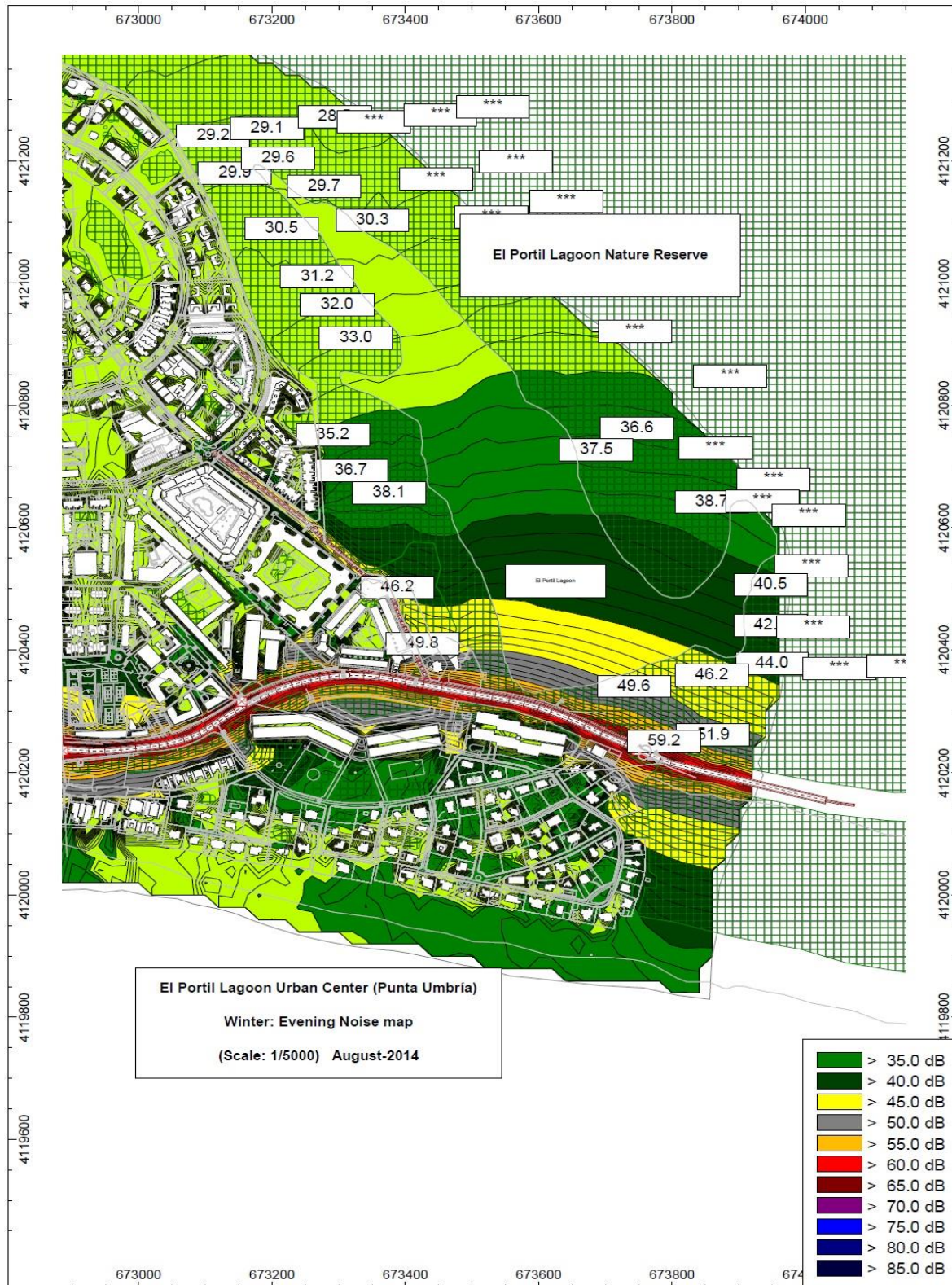


Figure 17. Winter evening noise map, with levels

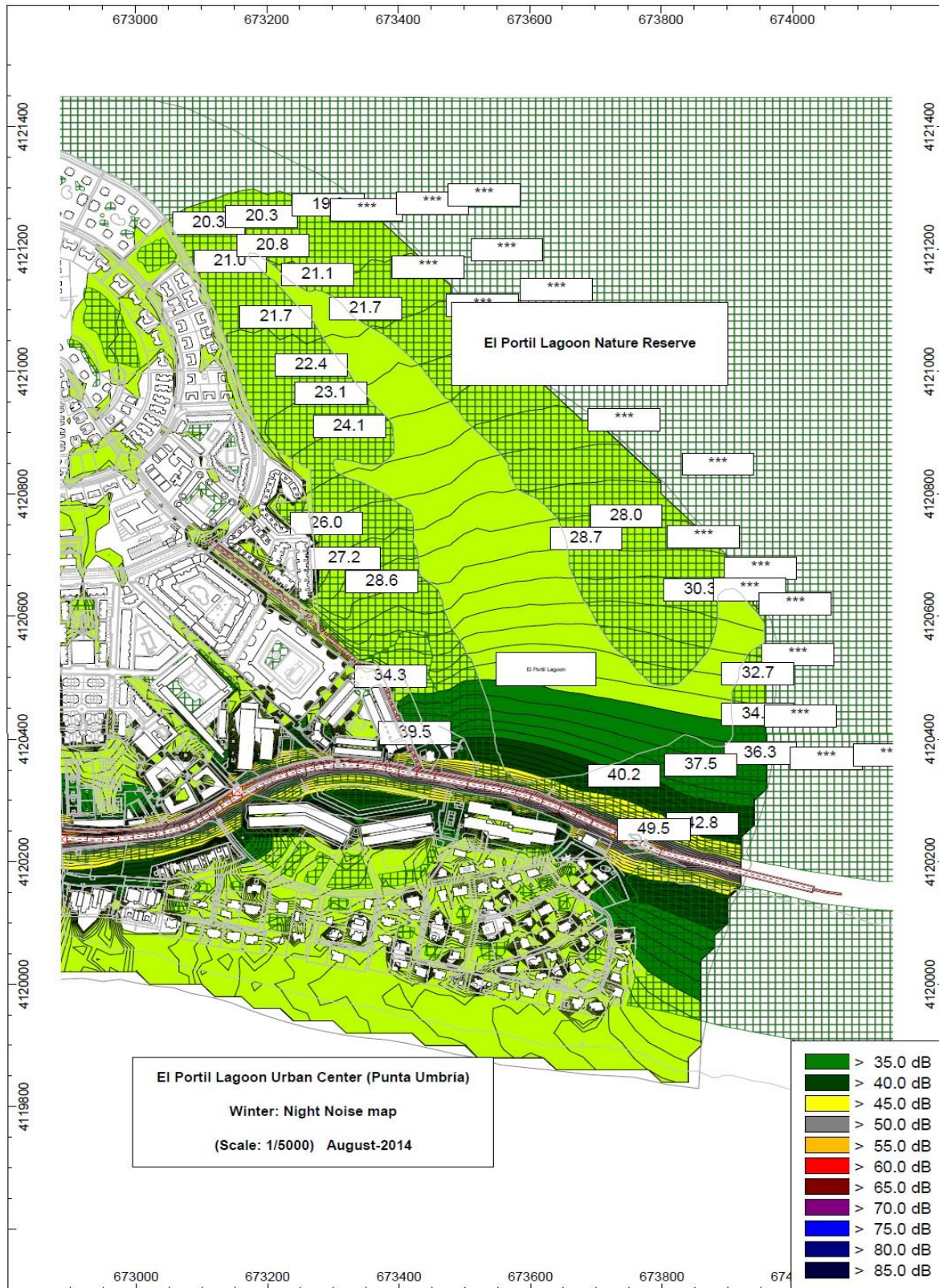


Figure 18. Winter nighttime noise map, with levels

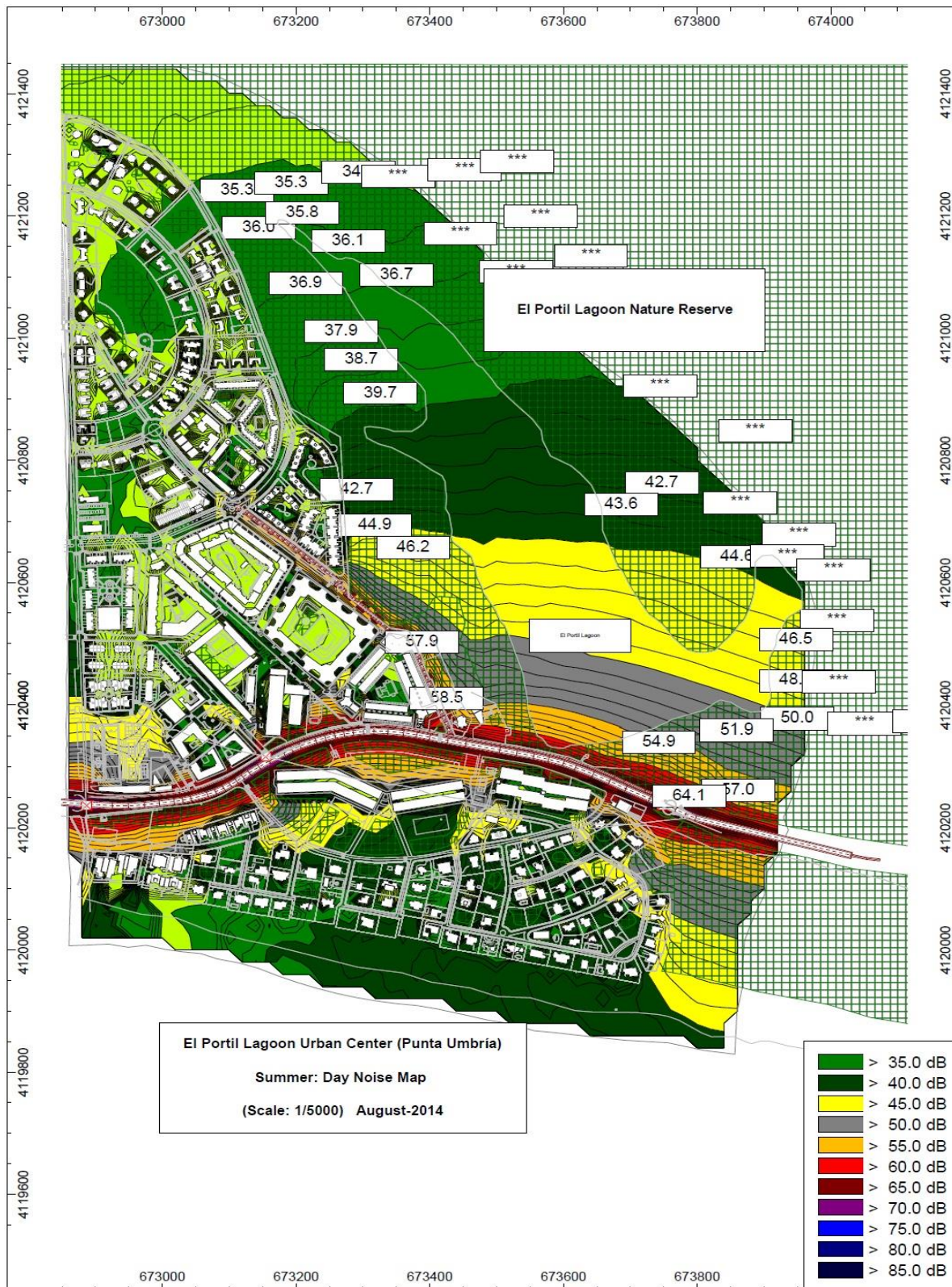


Figure 19. Summer daytime noise map, with levels

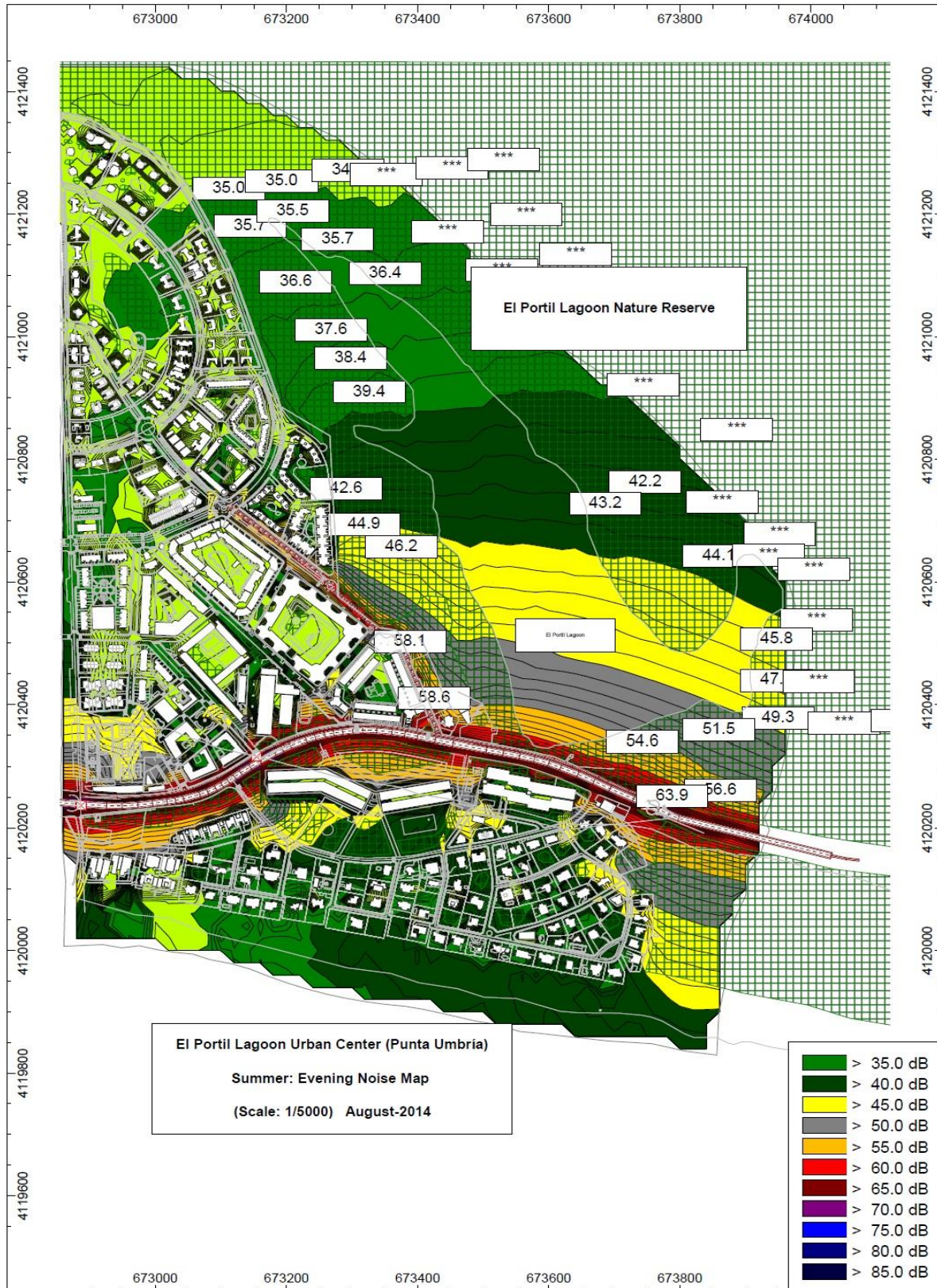


Figure 20. Summer evening noise map, with levels

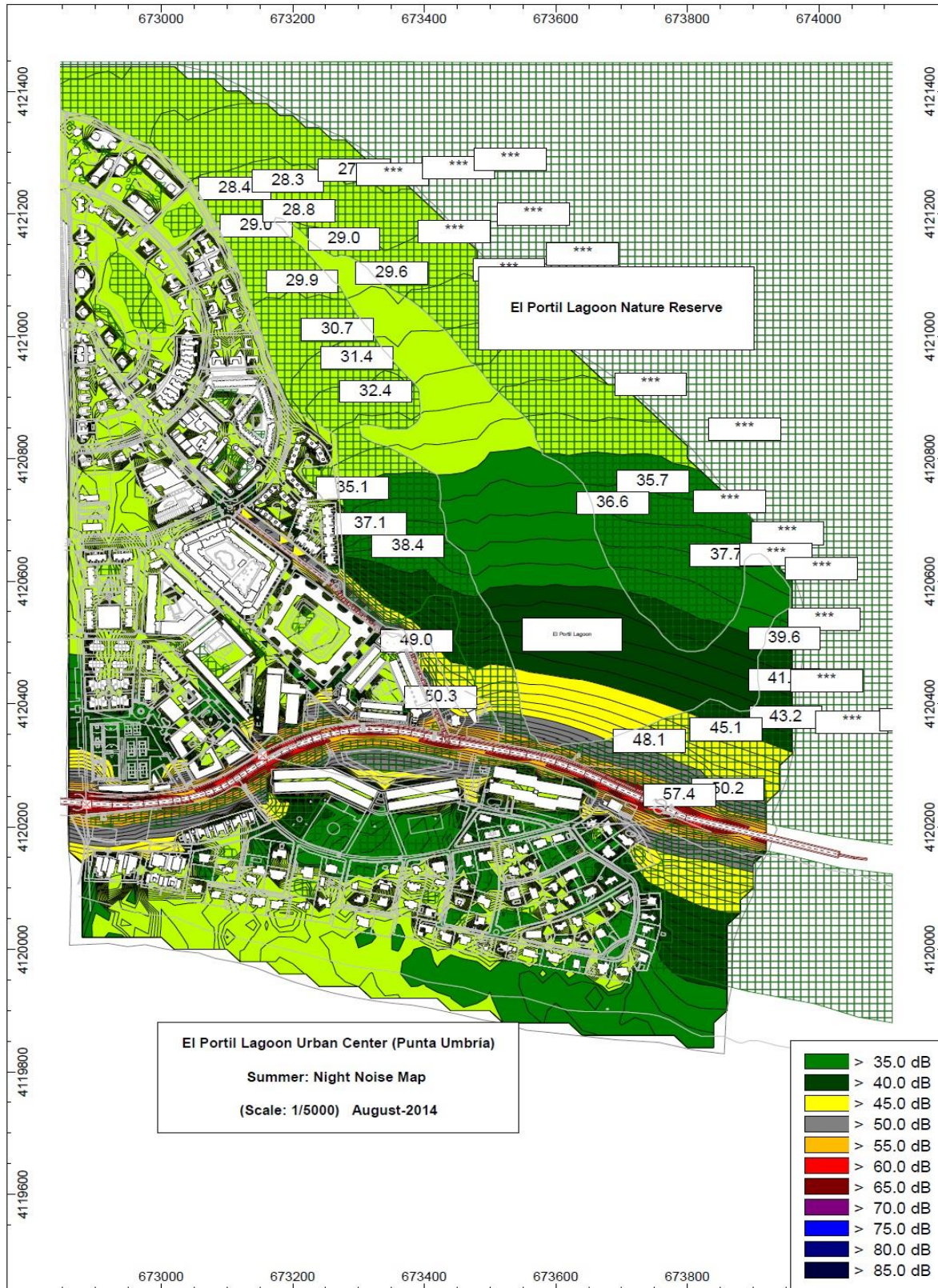


Figure 21. Summer nighttime noise map, with levels

Each of the noise maps includes sound level labels at the 43 locations corresponding to the spatial sampling points in the LPNR, enabling direct comparison between modelled results and actual measured values.

From observing the above maps, the most notable findings are:

1. That the most intense colours appear near the A-5052 road corridor—these correspond to the highest noise levels—while moving away from the road, they gradually shift to paler colours, representing more moderate noise levels. This indicates that traffic on the A-5052 is the primary source of noise within the urban area.
2. In both winter and summer, noise levels during the daytime period are significantly higher than during the night-time period. This was expected, as the CadnaA model only included the A-5052 and Avoceta Street as noise sources, with the traffic flow (ADT) being the parameter that changes between seasons. This parameter is substantially higher during the day than at night, as shown in the traffic count data in Table 1.
3. Noise levels in summer are approximately 4.6 dBA higher than in winter at locations nearest to the A-5052, regardless of the time of day. At points farthest from the road, the increase reaches about 6.0 dBA. This can again be explained by the model, which only includes the A-5052 and Avoceta Street as linear sources of noise, and where traffic volumes are significantly greater in summer. Furthermore, these results align with those described by [14], who states that the noise level from a road can be expressed as:

$$L_{eq} = L_o + 10 \cdot \log Q$$

where  $Q$  is the traffic flow (vehicles $\cdot$ h $^{-1}$ ), and  $L_o$  is the reference level for  $Q = 1$  vehicle $\cdot$ h $^{-1}$ . Therefore, the difference in noise levels between summer and winter is given by:

$$L_{eq}(s) - L_{eq}(w) = 10 \cdot \log(Q_s/Q_w) = 10 \cdot \log(509.7/174.4) = 4.65 \text{ dBA}$$

a value that closely matches the model's output.

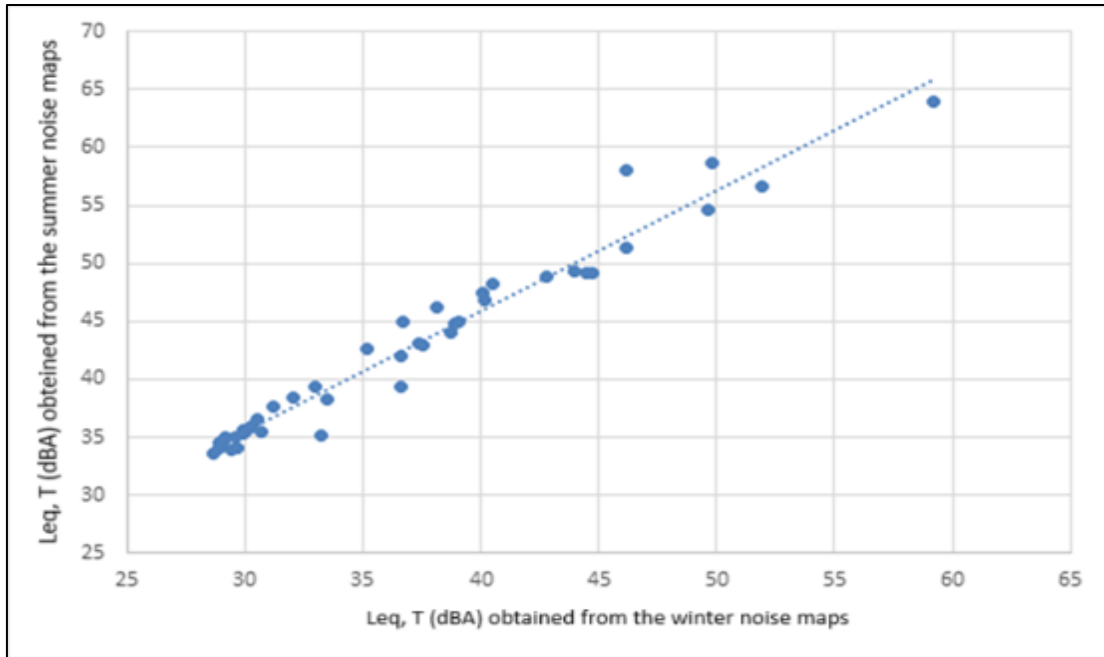
4. The forested areas included in the model provide minimal acoustic attenuation, particularly at low and mid-low frequencies, as supported by findings in [1, 15, 16], and [17].

To conduct a more in-depth analysis of the modelling results within the LPNR, see Table 12.

**Table 12.** Results extracted with CADNA-A from the evening noise maps at the 43 points receivers of the LPNR

| Sampling point | L <sub>AeqT</sub> maps |        | Sampling point | L <sub>AeqT</sub> maps |        | Sampling point | L <sub>AeqT</sub> maps |        |
|----------------|------------------------|--------|----------------|------------------------|--------|----------------|------------------------|--------|
|                | WINTER                 | SUMMER |                | WINTER                 | SUMMER |                | WINTER                 | SUMMER |
| 1              | 49.8                   | 58.6   | 16             | 28.9                   | 34.1   | 31             | 38.9                   | 44.8   |
| 2              | 46.2                   | 58.1   | 17             | 28.7                   | 33.6   | 32             | 39.1                   | 44.9   |
| 3              | 38.1                   | 46.2   | 18             | 29.4                   | 33.9   | 33             | 40.2                   | 46.8   |
| 4              | 36.7                   | 44.9   | 19             | 29.7                   | 34.0   | 34             | 40.1                   | 47.5   |
| 5              | 35.2                   | 42.6   | 20             | 29.9                   | 35.3   | 35             | 40.5                   | 48.3   |
| 6              | 33.0                   | 39.4   | 21             | 30.7                   | 35.5   | 36             | 42.8                   | 48.8   |
| 7              | 32.0                   | 38.4   | 22             | 33.2                   | 35.1   | 37             | 44.0                   | 49.3   |
| 8              | 31.2                   | 37.6   | 23             | 30.3                   | 35.9   | 38             | 44.7                   | 49.2   |
| 9              | 30.5                   | 36.6   | 24             | 30.1                   | 35.7   | 39             | 44.5                   | 49.1   |
| 10             | 29.9                   | 35.7   | 25             | 33.5                   | 38.2   | 40             | 46.2                   | 51.4   |
| 11             | 29.2                   | 35.0   | 26             | 36.6                   | 39.3   | 41             | 49.6                   | 54.6   |
| 12             | 29.6                   | 35.0   | 27             | 37.4                   | 43.1   | 42             | 51.9                   | 56.6   |
| 13             | 29.1                   | 34.7   | 28             | 36.6                   | 42.0   | 43             | 59.2                   | 63.9   |
| 14             | 28.9                   | 34.5   | 29             | 37.5                   | 43.0   |                |                        |        |
| 15             | 29.0                   | 34.3   | 30             | 38.7                   | 44.0   |                |                        |        |

When the data from the previous table are transferred to a comparative graph showing the winter measurements against the summer measurements, at the same 43 points of the spatial sampling, the result is shown in Figure 22.



**Figure 22.** Winter-summer comparison of noise levels obtained from noise maps at the sampling measurement points in the LPNR

This figure reveals a very clear linear correlation between the noise levels recorded in winter and those obtained in summer. Whose least squares fit is given by the equation:

$$L_{eq}(w) = (4.3 \pm 1.2) + (1.04 \pm 0.03)$$

With a coefficient of determination of:  $R^2 = 0.961$

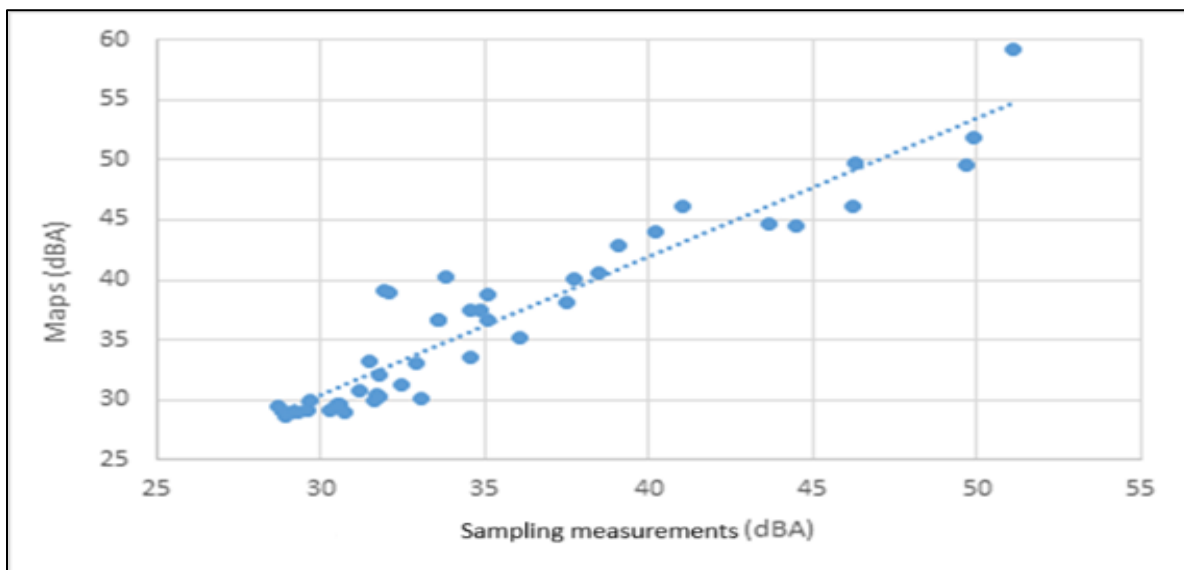
And a standard error of the estimate:  $SE(\bar{y}) = 1.6$

As expected, the slope of the linear fit is compatible with unity, and the intercept is around 4.3 dBA. This latter value represents the increase in noise level during summer compared to winter, assuming a slope equal to one.

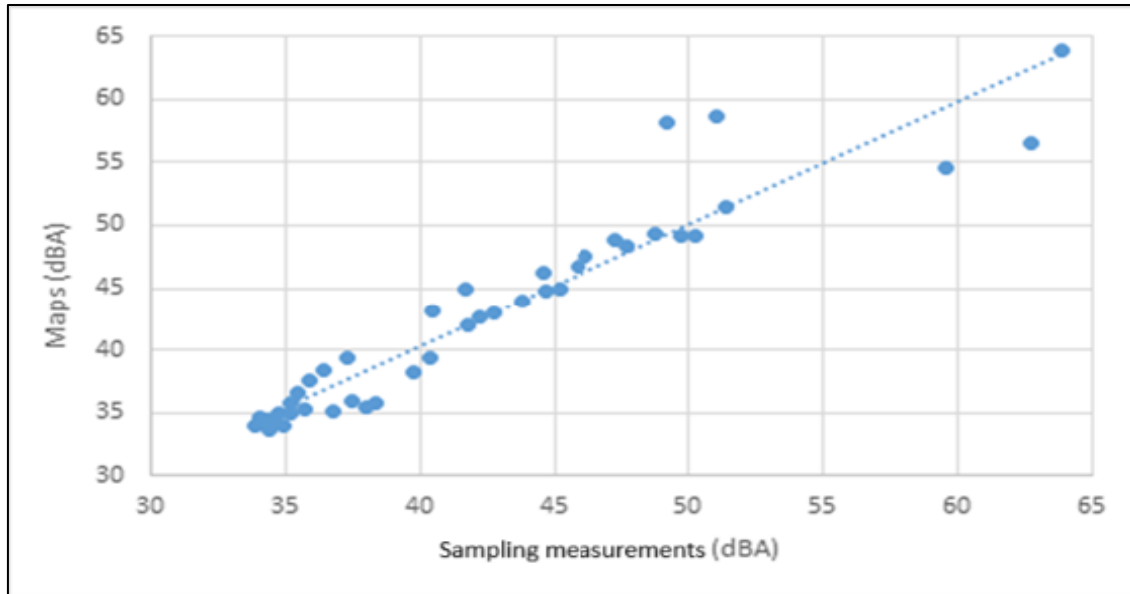
Subsequently, and with the aim of contrasting and validating the results obtained through the noise maps from the CadnaA acoustic modelling, a direct comparison was made between the experimental measurements from the spatial sampling carried out in the LPNP and the predicted noise levels for those same points in the noise maps for the afternoon period (in both the winter and summer seasons), since the spatial sampling was conducted during this time period. These values are shown in Table 13. When plotted as two-entry graphs, they result in Figures 23 and 24, for winter and summer, respectively.

**Table 13.** Level values Eon maps and measured at 43 sampling points of the LPNP

| Sampling point | Leq, T maps | LAeqT (w) measured | Leq, T maps | LAeqT (s) measured | Sampling point | Leq, T maps | LAeqT (w) measured | Leq, T maps | LAeqT (s) measured |
|----------------|-------------|--------------------|-------------|--------------------|----------------|-------------|--------------------|-------------|--------------------|
|                | WINTER      | WINTER             | SUMMER      | SUMMER             |                | WINTER      | WINTER             | SUMMER      | SUMMER             |
| 1              | 49.8        | 46.3               | 58.6        | 51.1               | 23             | 30.3        | 31.8               | 35.9        | 37.5               |
| 2              | 46.2        | 41.0               | 58.1        | 49.2               | 24             | 30.1        | 33.1               | 35.7        | 38.4               |
| 3              | 38.1        | 37.5               | 46.2        | 44.6               | 25             | 33.5        | 34.6               | 38.2        | 39.8               |
| 4              | 36.7        | 33.6               | 44.9        | 41.7               | 26             | 36.6        | 35.1               | 39.3        | 40.4               |
| 5              | 35.2        | 36.1               | 42.6        | 42.2               | 27             | 37.4        | 34.6               | 43.1        | 44.5               |
| 6              | 33.0        | 32.9               | 39.4        | 37.3               | 28             | 36.6        | 33.6               | 42.0        | 41.8               |
| 7              | 32.0        | 31.8               | 38.4        | 36.4               | 29             | 37.5        | 34.9               | 43.0        | 42.7               |
| 8              | 31.2        | 32.5               | 37.6        | 35.9               | 30             | 38.7        | 35.1               | 44.0        | 43.8               |
| 9              | 30.5        | 31.7               | 36.6        | 38.7               | 31             | 38.9        | 32.1               | 44.8        | 44.7               |
| 10             | 29.9        | 29.7               | 35.7        | 35.2               | 32             | 39.1        | 31.9               | 44.9        | 45.2               |
| 11             | 29.2        | 29.6               | 35.0        | 34.8               | 33             | 40.2        | 33.8               | 46.8        | 45.9               |
| 12             | 29.6        | 30.6               | 35.0        | 36.4               | 34             | 40.1        | 37.7               | 47.5        | 49.2               |
| 13             | 29.1        | 30.3               | 34.7        | 34.1               | 35             | 40.5        | 38.5               | 48.3        | 47.7               |
| 14             | 28.9        | 30.7               | 34.5        | 34.3               | 36             | 42.8        | 39.1               | 48.8        | 47.3               |
| 15             | 29.0        | 29.3               | 34.3        | 34.6               | 37             | 44.0        | 40.2               | 49.3        | 48.8               |
| 16             | 28.9        | 29.1               | 34.1        | 34.1               | 38             | 44.7        | 43.7               | 49.2        | 49.8               |
| 17             | 28.7        | 28.9               | 33.6        | 34.4               | 39             | 44.5        | 44.5               | 49.1        | 50.3               |
| 18             | 29.4        | 28.7               | 33.9        | 33.9               | 40             | 46.2        | 46.2               | 51.4        | 51.4               |
| 19             | 29.7        | 30.5               | 34.0        | 34.9               | 41             | 49.6        | 49.7               | 54.6        | 59.6               |
| 20             | 29.9        | 31.6               | 35.3        | 35.7               | 42             | 51.9        | 49.9               | 56.6        | 62.7               |
| 21             | 30.7        | 31.2               | 35.5        | 38.0               | 43             | 59.2        | 51.1               | 63.9        | 63.9               |
| 22             | 33.2        | 31.5               | 35.1        | 36.8               |                |             |                    |             |                    |



**Figure 23.** Comparison of sampling vs. noise maps (winter) in the LPNP



**Figure 24.** Comparison of sampling vs. noise maps (summer) in the LPNP

Whose fits are given by the equations:

**Winter:**

$$L_{eq}(maps) = (1.15 \pm 0.06) \cdot L_{Aeq}(sampling) - (4.1 \pm 2.3)$$

( $R^2 = 0.8915$ ; standard error = 1.1 dBA).

**Summer:**

$$L_{eq}(maps) = (0.97 \pm 0.05) \cdot L_{eq}(sampling) + (1.4 \pm 2.1)$$

( $R^2 0.9037$ ; standard error = 1.0 dBA).

From the above figures and  $R^2$  values, it can be concluded that the summer fit is notably better than the winter one. This may be due to the following reasons:

- During the days when the sampling measurements in the LPNR were conducted (April), there was significant faunal activity (swallows, swifts, ducks, frogs, etc., all in their mating season). In contrast, during the summer sampling, this activity was significantly lower.
- Lower noise from the road in winter (a reduction of approximately 9 dBA in power level due to reduced traffic flow), as shown in the analysis of measurements versus distance to the A-5052 in both summer and winter.

These two factors tend to cause greater variability in winter noise measurements, as confirmed by the greater dispersion of data points observed in Figure 23.

Moreover, the fact that the spatial sampling measurements were taken during short periods (5 minutes) means they are highly influenced by the vehicles present on the A-5052 at that time. In contrast, the model assumes continuous traffic flow.

Finally, to compare the noise maps with the monitoring results at points P-1 and P-2, Table 14 was produced, matching the data from day, afternoon, and night monitoring with the results from the noise maps.

Table 14. Monitoring results / noise maps. at points P-1 and P-3

| Point | Season | Day (D)    |      | Evening (T) |      | Night (N)  |      |
|-------|--------|------------|------|-------------|------|------------|------|
|       |        | monitoring | maps | monitoring  | maps | monitoring | maps |
| P-1   | winter | 57.7       | 56.0 | 56.2        | 55.0 | 49.3       | 46.0 |
|       | summer | 60.2       | 60.0 | 61.1        | 60.0 | 55.8       | 53.0 |
| P-2   | winter | 33.6       | 41.0 | 31.4        | 40.0 | 24.1       | 26.0 |
|       | summer | 47.1       | 54.0 | 46.1        | 54.0 | 39.4       | 44.0 |

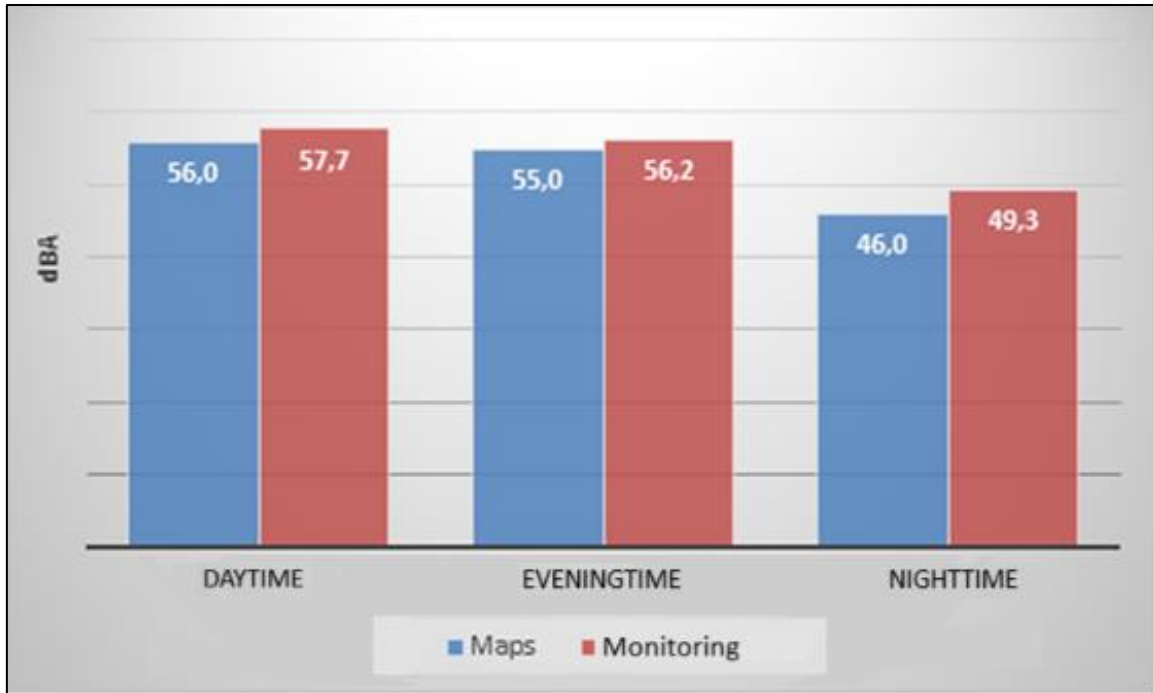
Once all this data was transferred to bar charts for better analysis and comparison, the following graphs were obtained:

Figures 25 and 26 for the building at monitoring point P-1

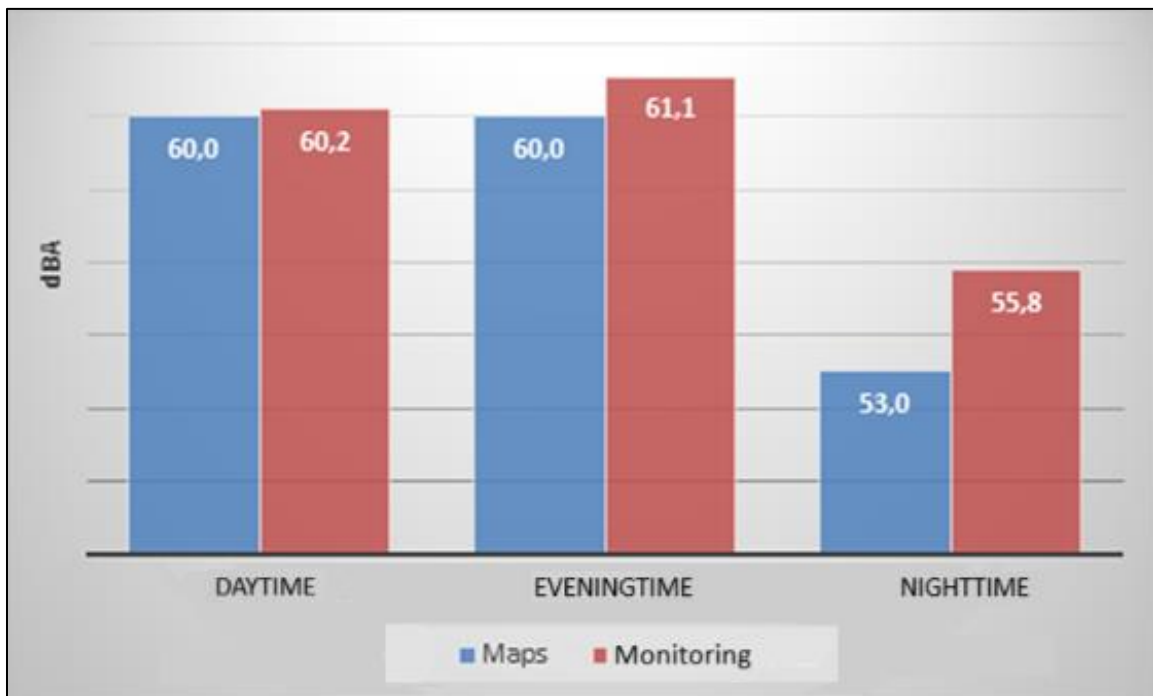
Figures 27 and 28 for the building at monitoring point P-2

From the graphs in Figures 25 and 26, it can be observed that for building P-1, the noise levels obtained from the noise maps are, on average, 2.1 dBA lower in winter and 1.4 dBA lower in summer than the levels obtained through monitoring.

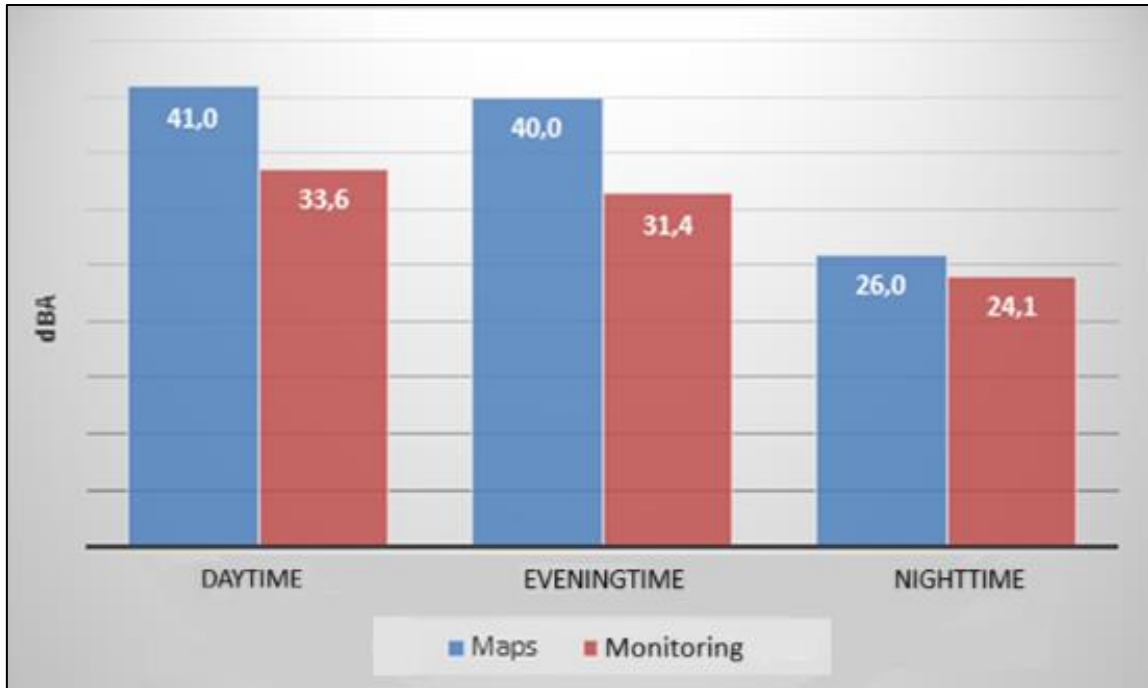
Conversely, from Figures 27 and 28, it is evident that for building P-2, the noise levels predicted by the CadnaA noise maps exceed the monitored levels by approximately 6.0 dBA on average in winter, and 6.4 dBA on average in summer.



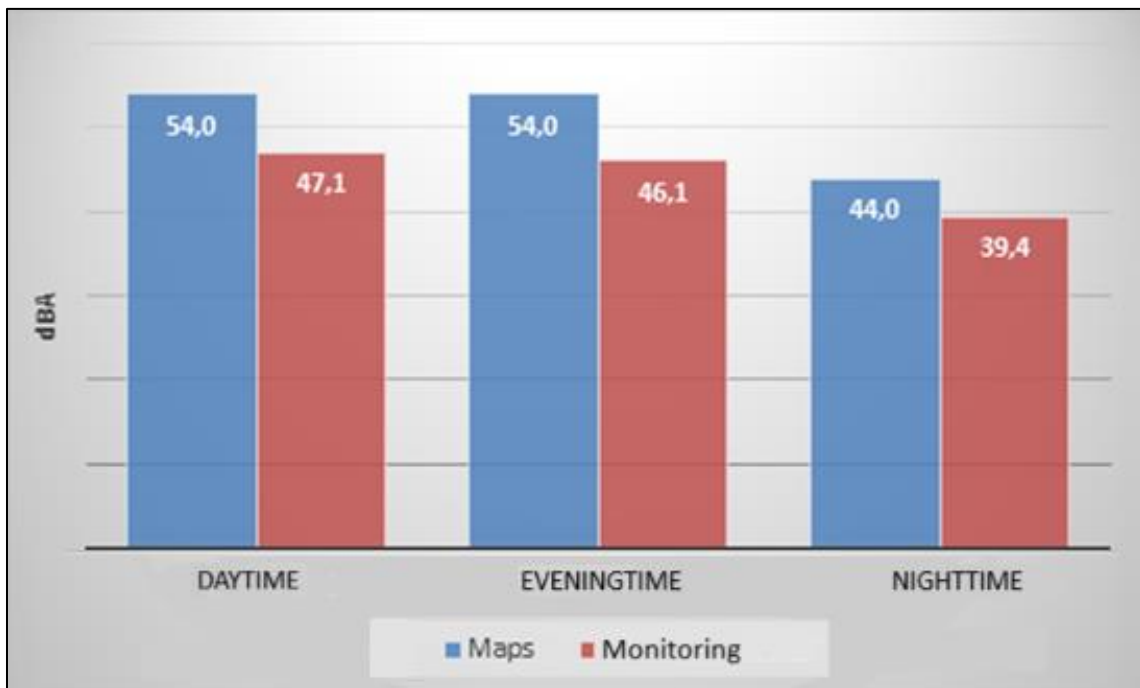
**Figure 25.** Point P-1: Comparison of Maps-Monitoring, in winter



**Figure 26.** Point P-1: Comparison of Maps-Monitoring, in summer



**Figure 27.** Point P-2: Comparison of Maps-Monitoring, in winter



**Figure 28.** Point P-2: Comparison of Maps-Monitoring, in summer

From the analysis of all four graphs, the following conclusions can be drawn:

1. In building P-2, which is further away from the main noise source, the levels predicted by the maps exceed those measured through monitoring. It should be noted that no official traffic count statistics were available for Avoceta Street, so the Average Daily Traffic (ADT) figures were estimated through random and punctual surveys. This may have introduced some inaccuracies. Additionally, it is observed that in this building, the discrepancies between map and monitoring values during the night-time period are smaller than those during the daytime and evening.
2. In contrast, for P-1, which is located closer to the main noise source, the monitored values exceed those predicted by the maps. This can be considered reasonable, as the CadnaA model accounts only for road traffic noise, omitting other human activities that may contribute to the overall soundscape, and which are captured by the monitoring. Furthermore, in this case, the ADT values for road A-5052 were derived from official statistics, making the model's predictions more reliable. However, in this building, the differences between map and monitoring values are greater during the night, which may be due to increased leisure-related activity during summer nights, a factor that is not included in the CadnaA model.
3. The model's approximation improves as the noise levels increase. This is particularly evident in building P-1, especially during the summer. Similarly, in building P-2, the agreement is also better in summer than in winter.

### **Conclusions**

This study presents a comprehensive analysis of the acoustic environment in a coastal tourist city, highlighting the influence of traffic, seasonal patterns, temporal variation, and predictive modelling. The main findings are summarized as follows:

1. **Traffic-related noise** is the predominant source of environmental sound, with noise levels closely linked to the Average Daily Traffic (ADT) volumes on main roads: the higher the ADT, the higher the noise levels recorded in the city. As a result, proximity to these roads significantly affects exposure: residents living in buildings nearest to main roads experience substantially higher noise levels, with differences of up to 25 dBA in winter and 15 dBA in summer, compared to more distant points.

**2. Seasonal Variation.** Noise levels during the summer season, both on weekdays (WD) and holidays (HD), are clearly higher than those recorded in the winter season. The differences amount to approximately 3.5 dBA at locations closest to roads and main thoroughfares, compared to up to 15.5 dBA at more distant points. Similarly, L90 percentile levels—regardless of location—are noticeably higher in the summer than in the winter. These findings indicate a greater degree of acoustic activity during the summer season, which can be attributed to increased tourist activity during this period.

**3. Variation According to the Type of Day.** During the summer, LAeq,T levels on weekdays (WD) and holidays (HD) are generally very similar, with only minor differences (less than 1 dBA), slightly higher on HD. However, L90 values for background night-time noise are significantly higher on HD compared to WD.

In contrast, during the winter—particularly at night—HD levels are considerably higher than those on WD, with differences in the range of 5–6 dBA. Similarly, L90 values on WD are lower than those recorded on HD.

These findings suggest that night-time leisure activities increase acoustic levels on HD in both summer and winter, with a more pronounced effect during the winter. This increase is attributed to a higher volume of vehicular traffic on main roads during winter HD nights compared to WD nights, as well as greater human activity during summer HD nights. This is due to both a higher number of visitors in the city on summer holidays and an increased number of leisure events taking place during summer nights.

**4. Daily temporal patterns** have been identified for the hourly equivalent sound level (LAeq,1h) on both WDs and HDs, with distinct evolutions that clearly differentiate the sound footprint profile of a WD from that of an HD:

- One of these patterns occurs during the transitional period at the start of the day (between 04:00 and 08:00). During this period, the slope of the line representing the transition zone is 3.40 dBA/h on weekdays (WD), whereas it is 1.73 dBA/h on holidays (HD). This indicates that the rate of noise increase per unit of time during these hours is twice as high on WD compared to HD.

- Another pattern is that the absolute daily minimum noise level occurs at 04:00 on WD, while on HD it occurs at 05:00.
  - Additionally, at the end of the day, the decline in noise levels begins at 17:00 on WD, whereas on HD it starts at 19:00.
5. **Based on the frequency percentage diagrams** derived from weekly monitoring, it can be concluded that in winter, at any monitoring point, the peaks associated with the main source of noise—road traffic—are higher on holidays (HD) than on weekdays (WD). In contrast, the opposite trend is observed in summer: peak levels on WD exceed those on HD. This indicates that, during the winter season, road traffic has a greater influence on overall noise levels on HD, whereas in the summer, this influence shifts to WD.
  6. **Based on the samplings carried out in the LPNR**, it is inferred that the variation in noise level with distance from the road follows a logarithmic linear function. The average decrease is  $(0.0199 \pm 0.0012)$  dBA/m in winter and  $(0.0249 \pm 0.0016)$  dBA/m in summer. Although these values differ, they are sufficiently close to support the conclusion that the primary source of noise affecting the natural soundscape in both seasons is the same—traffic on the A-5052 road—and that the propagation of this noise occurs perpendicularly from the road.
  7. **Comparing the noise maps generated by the CadnaA model** for winter and summer, reveals that for every 1 dBA increase in predicted noise level in winter, there is a corresponding 1 dBA increase in summer. The regression line has a slope statistically compatible with 1 and an intercept around 4.3 dBA, indicating a consistent seasonal increase in noise levels across the entire LPNR.
  8. **The model's predictions** align more closely with measured data in summer than in winter. This discrepancy is largely due to the heightened activity of local fauna (e.g. birds, frogs) during the spring breeding season when winter measurements were taken, contributing to greater variability.
  9. **Comparisons between CadnaA-predicted values and monitoring** data at buildings P-1 and P-2 indicate that the model performs better in areas with higher noise levels, whether due to proximity to the road or to seasonal activity. The model slightly underestimates noise at the building closer to the road (P-1), likely because

it only considers traffic noise and not additional human-generated sources. Conversely, it overestimates noise at the more distant building (P-2), possibly due to limitations in traffic data availability for nearby streets.

Overall, these conclusions highlight the importance of integrating seasonal, temporal, and spatial variables when assessing urban acoustic environments. They also underscore the value of predictive modelling for informed decision-making in urban planning, especially in tourist destinations where population dynamics and acoustic impacts vary significantly throughout the year.

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### **Author Contributions**

Conceptualization: Sánchez-Sánchez and Bolivar-Raya JP.; methodology: Sánchez-Sánchez R. and Bolivar-Raya JP.; software: Sánchez-Sánchez R.; formal analysis: Sánchez-Sánchez R. and Bolivar-Raya JP.; investigation: Sánchez-Sánchez R.; resources: Bolivar-Raya JP. data curation: Sánchez-Sánchez R; writing original draft preparation: Sánchez-Sánchez R.; writing review and editing: Sánchez-Sánchez R.; visualization: Sánchez-Sánchez R.; super-vision: Bolivar-Raya JP.; project administration: Sánchez-Sánchez R.; funding acquisition: Bolivar-Raya JP. All authors have read and agreed to the published version of the manuscript."

### **Conflicts of interest**

The authors declare no conflicts of interest.

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