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Acoustic Influence of Vehicles on a Protected Natural Area in the Southwest of the Iberian Peninsula

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Natural sounds are essential elements for ecosystems, and therefore necessary for many ecological functions, forming what is called "natural soundscapes". The Natural Reserve Laguna del Portil (NRLP), located in the southwest of the Iberian Peninsula, is an ecosystem which was declared by Spanish authorities as Protected Natural Reserve. In the south area of the NRLP, there is a regional road with high traffic intensity, which affects the soundscapes of this natural reserve. In this study, the road potential noise impact on the natural sounds of the NLRP is analysed. This analysis was done both in winter and summer, and also using two independent methods: 1) spatial sampling measures in 43 different points of the NRL; and 2) noise mapping using noise levels prediction software. From the comparison of the results of both methods and seasons the following conclusions were reached: 1) an approach to the natural soundscape of NRLP both in winter and summer, 2) the acoustic impact of the road on the NRLP, and 3) the variation of the traffic noise depending on the distance to the road, and its seasonal variation. This study could be to improve the management of the NRLP and to help to preserve the natural soundscape of the reserve.

Keywords: natural sounds; soundscapes; noise; protected natural area.

1. Introduction

In protected natural areas there are natural and non-natural sounds. Natural sounds are generally divided into two main categories: physical and biological sounds (National Parck, 2004; Iglesias-Merchan *et al.*, 2015). Physical sounds are created by physical forces of nature (wind, rain, thunders, falling rocks, rivers, waves, etc.), whereas biological sounds are created by living bodies (birds, felines, deer, frogs, plants, etc.). The presence and abundance of these two kinds of sounds are significant variables to characterize the different habitats.

Natural sounds are essential elements in protected natural areas and, therefore, necessary for their different ecologic functions, creating the so-called "natural sound landscapes" or "natural soundscapes".

Non-natural or anthropic sounds can have different sources, but all of them are characterized by having their origin in human activities, and most of them are undesired sounds in certain zones of the protected natural areas (Lynch *et al.*, 2014). Main sources are roads, airports, industrial activities, the closeness of the conurbations, touristic areas, etc. (Kompala, Lipowczan, 2007; Wiciak *et al.*, 2015). Natural sounds are being hidden by a variety of anthropic activities which generate intrusive sounds and even in some cases they have such a great interference that natural sounds disappearor cannot be expressed (Polak, 2014; Nega *et al.*, 2013). These intrusive sounds are a source of concern for the visitors of the protected natural area (Rendeiro Martín-Cejas, 2015). A survey conducted by the U.S. National Park Service revealed that 91% of the visitors go to parks to enjoy the soundscape and 93% to see the landscape (Ambrose, Burson, 2004).

In the acoustic literature, there are many studies that analyze the impact of transport noise on urban areas (Camusso, Pronello, 2016; Carrier *et al.*, 2016), but very few on impact on protected areas. Taking into account the previous facts, the aim of this research is to characterize the soundscape of one particular protected natural area by analysing the influence of the road traffic in a road parallel to the NRLP limits, taking into account the seasonal variation of traffic level, which during the winter and summer causes the extreme values.

2. Materials and methodology

2.1. Area of study

The protected natural area chosen for this research was the Natural Reserve Laguna del Portil (NRLP), which was declared protected natural area by the Andalusian Government in Law 2/89 (Ley 2/89 n.d.), which establishes its protection under the legal figure of Natural Reserve. This law also provides the area with a peripheral zone of protection of 1300 hectares around the littoral lagoon. Besides, it is a SCI (Site of Communitarian Interest), according to Directive 92/43/CEE, 1992 and of the Council, 21st May 1992 (EEC, 1992) regarding the preservation of natural habitats and wild flora and fauna.

The NRLP is mainly constituted by a forest of stone pine (*Pinus pinea*) and some specimens of maritime pine (*Pinus pinaster*), as well as: juniper trees (*Juniperus phoenicea subsp. Turbinata*), corkoaks (*Querqus suber*), mastic trees (*Pistacia lentiscus*), etc. In this natural reserve birds are the best represented group of animals. It is a passing place for some of them in their migratory route, and a wintering area for others, e.g. Eurasian Spoonbill (*Platalea leucorodia*), common coot (*Fulica atra*), Moorhen (*Gallinula chloropus*), Purple Swamphen (*Porphyrio porphyrio*), black-tailed godwit, wigeons, Northern shovelers, grey herons, little grebe, white storks, little egrets, swallows, swifts. The area is also inhabited by different mammals, e.g. rabbits, mongooses and common hedgehogs. Various reptiles and amphibians also live there, e.g. chameleons, lizards, frogs and common toads.

As shown in Fig. 1, the NRLP is limited in its southern frontier by the regional road (code A-5052), with a high traffic level that goes from 4 188 vehicles per day (1.9% of them are heavy vehicles) in winter to 12228 vehicles/day (2.4% of them are heavy vehicles) in summer (July – August).

2.2. Measurement methods and instrumentation

In order to accomplish the objectives of this research, we have followed two independent methodological lines:

1) Spatial sampling measurements in 43 representative spots of the most sensitive areas of the NRLP.
2) Generation of the sound maps by using predictive software.

2.2.1. Spatial sampling measurements

The measuring method was compliant with standards: (ISO 1996-1, 2003) and (ISO 1996-2, 2007). Whereas, to establish the sampling network a grid technique was used, overlapping a 40×40 m grid over an aerial photograph of the sample area (NRLP), taken from Google Earth, so that we could spread the 43 representative spots in the most homogeneous possible way, at the area of study (Gómez Escobar *et al.*, 2012). See Fig. 2.

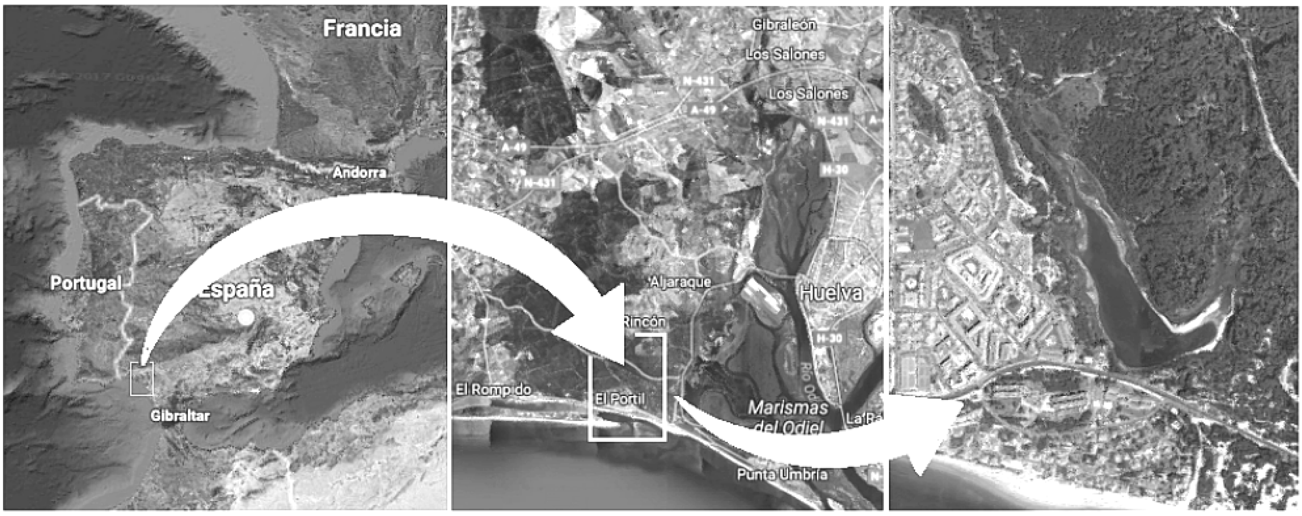

Fig. 1. Map with the location of the NRLP.

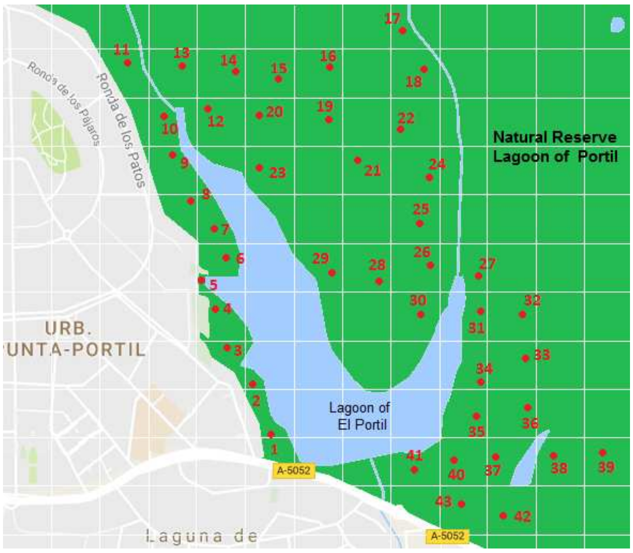

Fig. 2. Grid of spatial sampling measurements within the area of the NRLP.

A total of 43 noise level measurements in winter and summer were conducted, as shown in Table 1. All the measurements were taken in the afternoon in order to unify a certain period of the day for all of them. Each of the individual measurements was carried out during 5 minutes, mainly because that period must include the intrinsic variability of the main sources of sound (different noises of the road and wildlife sounds), and therefore the L_{Aeq5m} was considered representative of the L_{Aeq} in the NRLP in the afternoon. Different acoustic events coming from the different noise sources in the area, natural or anthropic, last only a few seconds (a vehicle passing on the road, birdsong, croaking of frogs, etc.).

For all of them, an integrating-averaging sound level meter (SLM) Class 1 CESVA trademark model SC-20c was used. It was placed 1.5 meters above the ground. Furthermore, a CESVA calibrator (SLC), model CB-5, capable of generating two levels of sound

Table 1. Spatial sampling measurements periods in the NRLP.

Season	Start of measurement	End of measurement
Winter	07/04/2011 (19:52:00)	14/04/2011 (20:16:00)
Summer	09/08/2011 (19:32:00)	11/08/2011 (21:51:00)

pressure of 94.0 and 104.0 dB(A) was also used. The SLM and the SLC are calibrated annually by an accredited laboratory. Besides, at the beginning and at the end of every measuring session, the sound level meter was verified using the CB-5.

2.2.2. Noise mapping

In order to create the noise maps, the version 3.5.115 of CadnaA, an accredited prediction software which uses the guidelines established by different international institutions for its calculations, was used. So, for road sounds it follows the standards NMPB-Routes-96 (France EC-Interim; RLS-90, VBUS (Germany; DIN 18005 (Germany); STL 86 (Switzerland; CRTN (United Kingdom), etc.

The operational and use guidelines schematized in Fig. 3 were followed in the modelling of the area under study. To achieve it we had to get the following information and documentation from different bodies and specialized agents: cartography (1/500); topographic map; height of the buildings surrounding the area of study; average climate value; traffic level of road A-5052 in average daily traffic (ADT) of vehicles; average vehicle speed; identification of the pavemen; and some field work had to be made to complete all this information.

We entered all these data in CadnA, digitalizing the cartography, the road A-5052 as a linear source of sound, the traffic level, the section profile of the roa; the type of pavement, the average speeds, the traffic lights, the sidewalks, the plot; the forest masses and their characteristics.

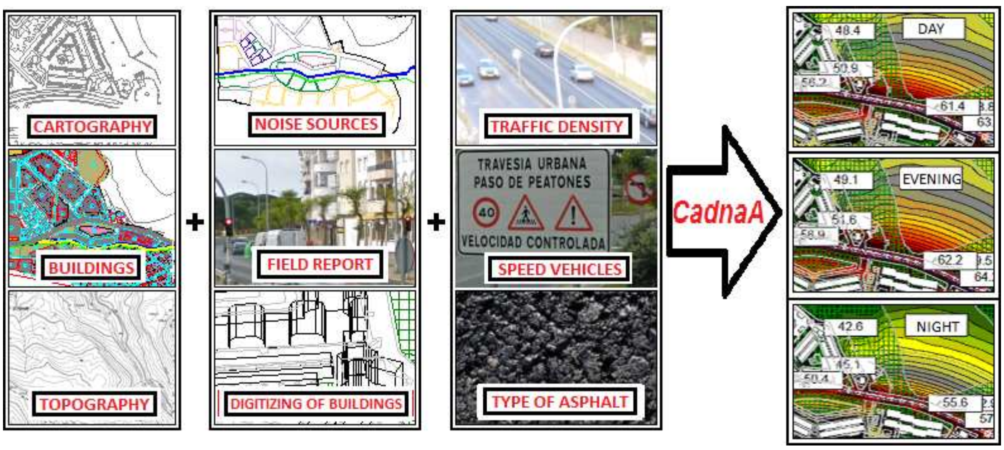

Fig. 3. Using scheme of CadnaA.

Finally, we defined and configured the grid of the whole area of study, with the receptor points, obtaining as result the isophone lines map and the sound maps, in the immission areas during different periods of the day. Placing individual receptors, we obtained the immission levels at the same points of the NRLP, where the spatial sampling measurements were conducted.

3. Results and discussion

3.1. Spatial sampling measurements

There are no anthropic sources of noise within the NRLP because the perimeter fence of the lagoon prevents any visis not organised by the managers of the reserve and, therefore it can be said that all the sound sources are natural (Barber *et al.*, 2011), both meteorological or coming from the fauna. Furthermore, we have to take into account, that in the NRLP there are no natural barriers (hills, mountains, etc.) that could prevent the free propagation of sound because the existing forest mass, composed of bush and trees around 7 metres-high and with an average density of 0.04 pines/m^2, does not act as a sound attenuation element (Van Renterghem *et al.*, 2012; Fricke, 1984). Table 2 includes the sound levels measured in 43 representative spots within the NRLP.

Predictably, in Table 2 we can observe that the noise levels are around −6 dB(A) higher in summer than in winter, probably due to the fact that the road in that season has a much higher traffic level. On the other hand, these levels range in summer between 34 and 66 dB(A), approximately, whereas in winter they vary between 29 and 51 dB(A).

We can also observe that the minimum values obtained during the samplings range from 29 to 34 dB(A) in winter and summer, respectively. It is obvious that these values are correlated to sample points 16, 17 and 18, which are the furthest away from both the road and the population nucleus of El Portil. Since it is a natural reserve, these values are perfectly in line with the values obtained in evaluations conducted in other protected natural areas like the Lake Mead National Recreation Area in Nevada (Briggs *et al.*, 2011), or the rural area of Lancara (Lugo, Spain) (López *et al.*, 2012).

Using these values of measurements L_{Aeq5m} in 43 representative spots, we obtained two maps of isolines with level curves, both in winter and in summer (see Fig. 4). It has to be noticed that the L_{Aeq5m} values obtained in points 9 and 12 were significantly higher than those obtained in adjacent points. This can be due to the existence of an additional noise during the measuring period in point 9, where there are swallow nests (in the mating season). And in point 12 the level was atypical because of the proximity of a pond with frogs. Using the Grubb statistical test it was proved that these two points are outliers values in comparison with other points located in their environment, and therefore they were ignored in the estimation of the map of isolines.

We can observe in Fig. 4 that level curves are almost parallel straight lines to the road A-5052, confirming that the main noise source is this road. It can be also observed that the density of level curves increases as the distance to the road decreases (Sánchez-Sánchez *et al.*, 2015). Therefore, this fact proves that the sound spreads perpendicularly to the linear source (the road). Comparing the maps of isolines obtained for winter and summer for any of the spots, we can observe around 6 dB(A) more in summer than in winter.

Table 2. The noise levels L_{Aeq5m} at spatial sampling measurements in 43 representative spots.

Point	L_{Aeq5m} [dB(A)] winter	L_{Aeq5m} [dB(A)] summer	Point	L_{Aeq5m} [dB(A)] winter	L_{Aeq5m} [dB(A)] summer	Point	L_{Aeq5m} [dB(A)] winter	L_{Aeq5m} [dB(A)] summer	Point	L_{Aeq5m} [dB(A)] winter	L_{Aeq5m} [dB(A)] summer
1	46.3	51.1	12	42.4[a]	36.4	23	31.8	37.5	34	37.7	49.2
2	41.0	49.2	13	30.3	34.1	24	33.1	38.4	35	38.5	47.7
3	37.5	44.6	14	30.7	34.3	25	34.6	39.8	36	39.1	47.3
4	33.6	41.7	15	29.3	34.6	26	35.1	40.4	37	40.2	48.8
5	36.1	42.2	16	29.1	34.1	27	34.6	44.5	38	43.7	49.8
6	32.9	37.3	17	28.9	34.4	28	33.6	41.8	39	44.5	50.3
7	31.8	36.4	18	28.7	33.9	29	34.9	42.7	40	46.2	53.4
8	32.5	35.9	19	30.5	34.9	30	35.1	43.8	41	49.7	61.6
9	37.9[a]	38.7	20	31.6	35.7	31	32.1	44.7	42	49.9	65.9
10	29.7	35.2	21	31.2	38.0	32	31.9	45.2	43	51.1	63.9
11	29.6	34.8	22	31.5	36.8	33	33.8	45.9			

[a] These values are not considered in the maps of isolines due to the reasons explained in the text below.

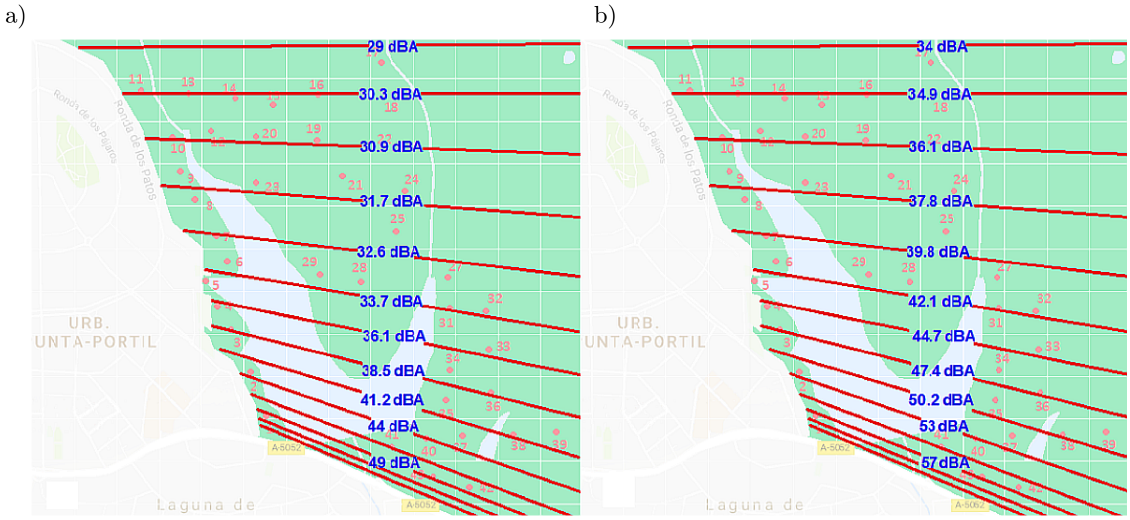

Fig. 4. Maps of isolines for L_{Aeq5m} (1.5 m height from the ground) in the NRLP, obtained at spatial sampling measures in 43 representative spots: a) winter, b) summer.

On the other hand, according to the Spanish Royal Decree 1367/2007 (RD: 1367, 2007), the Natural Reserve of Laguna de El Portil (NRLP) must be considered as an acoustic area type 'g', that is "natural area that requires special protection against acoustic pollution". The only regulation found for these areas in the Spanish legislation is one elaborated by the regional government of Pais Vasco, whose acoustic quality goal is set in: $L_{\mathrm{d}} = 60$, $L_{\mathrm{e}} = 60$ and $L_{\mathrm{n}} = 50$ dB(A) (Decree 213, 2012). Being L_{d}, L_{e} and L_{n}, the A-weighted long-term average sound levels as defined in the standard (ISO 1996-2, 2007), determined during the day, evening and night periods respectively. In some regional regulations it is only specified that the acoustic criteria in natural areas are established according to specific researches in that specific areas.

Therefore, it is worth mentioning that there is a strip of land parallel to the acoustic servitude road, where that acoustic quality goal for natural areas (60 dB(A)) is surpassed during the afternoon. In winter, this strip is almost inexistent, it would only be formed by the closest meters to the road while in summer the width if that strip of land enlarges up to 25–30 m.

The background noise levels in the natural reserve can be calculated from the L_{Aeq5m} measured in the furthest spots, and therefore less influenced by the road (areas more than 1 km away from the road), obtaining an average value of 30 and 35 dB(A) for winter and summer, respectively.

In Fig. 5 a clear variation of the noise level with the distance to the road is found, being its variation relatively linear with the logarithm of the distance, proving that the road is the main anthropic sound source affecting the natural reserve. In Fig. 5 the obtained fittings are also shown.

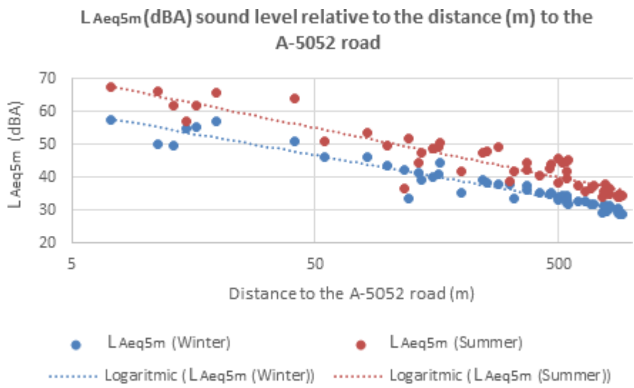

Fig. 5. Variation of the 5 minutes equivalent continuous sound pressure level (L_{Aeq5m}) regarding the distance to the road, to which the linear adjustments obtained with the logarithm of the distance both for winter and summer.

The resulting adjustments were:

- winter

$$L_{\mathrm{Aeq5m}} = (68.9 \pm 2.6) - (13.1 \pm 1.1)\log(d), \quad (1)$$

where (L_{Aeq5m}) represents 5 minutes equivalent continuous sound pressure level in dB(A). And (d) the distance from the road, in meters. The following fitting parameters were obtained: determination ($R^2 = 0.923$); standard error = 2.2 dB(A);

- summer:

$$L_{\mathrm{Aeq5m}} = (80.4 \pm 4.3) - (14.9 \pm 1.7)\log(d), \quad (2)$$

where (L_{Aeq5m}) represents 5 minutes equivalent continuous sound pressure level in dB(A), and (d) the distance from the road, in meters. The following fitting parameters were obtained: Determination ($R^2 = 0.867$); Standard error = 3.6 dB(A).

The above equations obtained from the measurements are in agreement with the theoretical explanation of the model proposed in (Lamure, 1986), resulting into the following equation to calculate the noise level for a linear source (i.e. road), depending on the distance to it:

$$L_{\mathrm{eq}T} = L_{0_{\mathrm{eq}T}} - 10\log(x^{1,3}) = L_{0_{\mathrm{eq}T}} - 13 \cdot \log(x), \quad (3)$$

where $L_{\mathrm{eq}T}$ is the equivalent continuous noise level in dB(A) for a road, and $x = r/r_0$, r is the distance to the road and r_0 the distance from the reference point where we have measured the $L_{0\mathrm{eq}T}$, which in our case would be equal to 1 m.

This model indicates that "for each doubling of the distance there is an attenuation by geometrical divergence of approximately 4 dB(A)". Besides, because the obtained adjustments have similar gradients to the theoretical model of linear source, we can state that road A-5052 is the main source of noise in the NRLP.

On the other hand, the values obtained for R^2 and the uncertainties of the parameters (gradient and intercept), indicate that the measurements of the L_{Aeq5m} have smaller dispersion in summer than in winter. This can be explained if we take into account that in summer there are more relevant and anthropic sources of noise than in winter, because during the summer there is a number of individual acoustic events coming from human leisure activities of visitors.

In Fig. 5 we can also observe that the slopes for both linear fittings are very similar if the experimental uncertainties are considered. In fact, if the differences of the noise levels between summer and winter are fitted, no significant correlation is obtained

$$\Delta = L_{\mathrm{Aeq5m\,(winter)}} - L_{\mathrm{Aeq5m\,(summer)}}, \quad (4)$$

$$\Delta = (14 \pm 3) - (3.0 \pm 1.1) \cdot \log(d). \quad (5)$$

The fit parameters are: determination $R^2 = 0.165$ (dimensionless) and standard error = 3.3 dB(A). The t-Student indicates that obtained slope is not significant at the confidence level of 95%.

Therefore, we can state that the noise in the natural reserve in summer is 14 ± 3 dB(A) higher than in winter, and this increase is mainly due to the increase of the traffic in the road during summer.

3.2. Noise mapping

We used the software CadnaA to generate the noise maps for both winter and summer in the whole area of study within the NRLP, and for each period of the day. Concretely, the noise maps for the afternoon (which was the moment when the spatial sampling measures were conducted), are shown in Fig. 6.

Observing them we can see that during the summer there are more areas in red and violet (60 and

a) b)

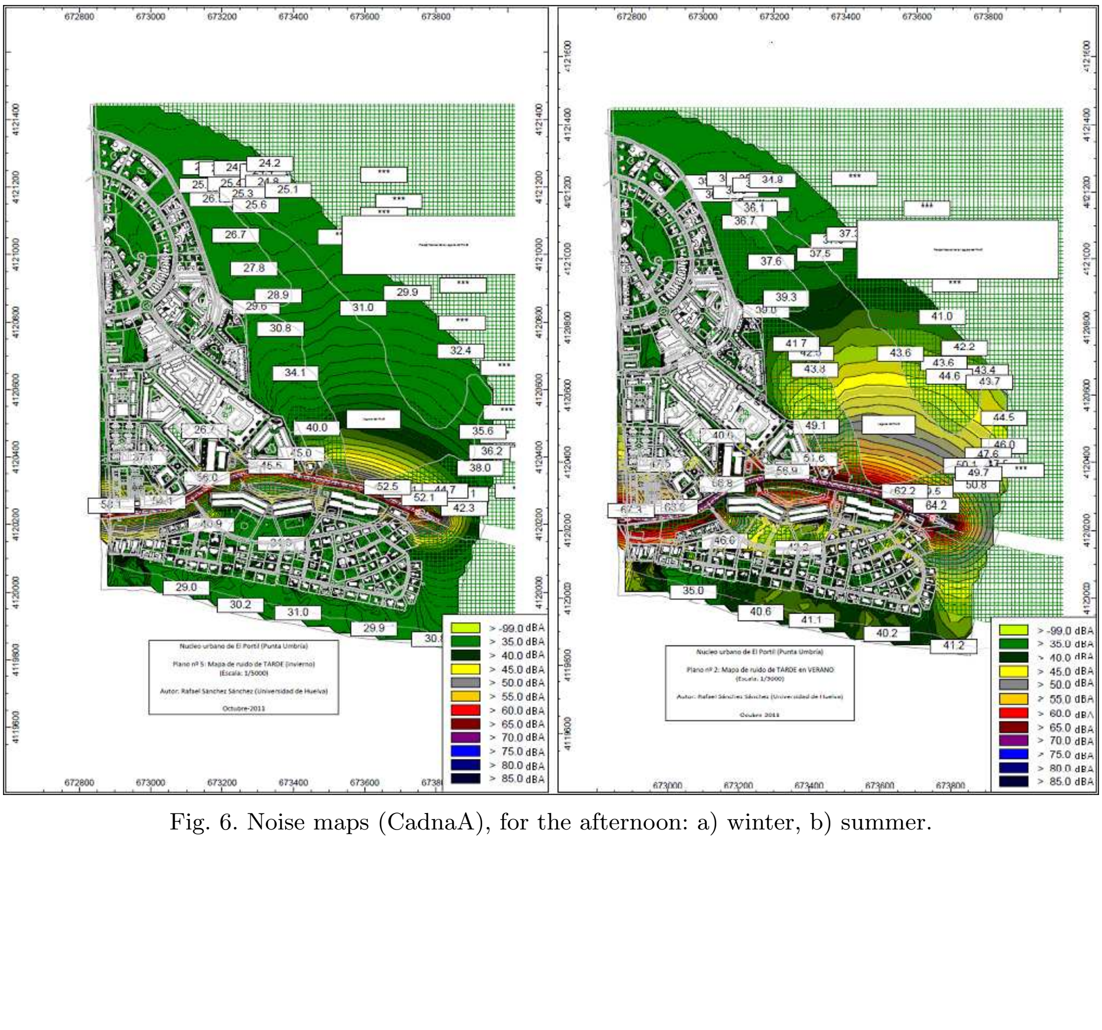

Fig. 6. Noise maps (CadnaA), for the afternoon: a) winter, b) summer.

65 dB(A)) around the road, indicating that there are higher acoustic levels during the summer than in winter. The sound levels in summer are around 4.6 dB(A) higher than in winter in the closest spots to the road A-5052, for any moment of the day. Whereas they are increased up to around 6.0 dB(A) in the furthest points. This fact can be explained taking into account that in the CadnaA model we have only included the road A-5052 as linear source of noise and that the traffic levels are much higher in summer than in winter. Besides, these results are in agreement with those described in (Lamure, 1986), where it is stated that theoretically the level of noise generated by a road follows the equation:

$$L_{\text{eq}} = L_0 + 10 \cdot \log(Q), \tag{6}$$

where Q is the traffic level (veh/h) and L_0 the reference level for $Q = 1$ veh/h. Therefore, the level difference (dB(A)) between summer and winter: $[L_{\text{eq (summer)}} - L_{\text{eq (winter)}}]$ will be the result of:

$$\begin{aligned} L_{\text{eq (summer)}} - L_{\text{eq (winter)}} &= 10 \cdot \log(Q_S/Q_w) \\ &= 10 \cdot \log(509.7/174.4) \\ &= 4.65 \text{ dB(A)}. \end{aligned}$$

This value is almost the same as the difference detected using the model. According to the official data provided by the Department of Housing and Development of the Andalusian Government, 509.7 and 174.4 are the values (Q_s and Q_w) of vehicles per hour circulating through the road A-5052 in summer and winter, respectively.

To quantify the levels foreseen by the model, we placed individual receivers in the same coordinates of the 43 points where the spatial sampling was conducted, obtaining the foreseen values in the same points by the CadnaA model (see Table 3).

3.3. Comparison of the experimental values obtained with Cadna

With the aim of testing the results obtained experimentally and by modelling with CadnaA, a direct comparison between both methods was made. From this direct comparison between the data in Table 2 and Table 3 in each for the 43 measuring points we obtained the graphics shown in Figs. 7 and 8, the first for the winter and the latter for the summer. Their fitting equations were, respectively:

- winter

$$\begin{aligned} L_{\text{eq (maps)}} &= (1.15 \pm 0.06) \cdot L_{\text{eq (sampling)}} \\ &\quad - (4.1 \pm 2.3), \end{aligned} \tag{7}$$

where $L_{\text{eq (maps)}}$ represents noise levels foreseen by CadnaA, and $L_{\text{eq (sampling)}}$ spatial sampling measurements, for the 43 representative spots, both in dB(A). The uncertainties are expressed as "standard uncertainty" 1 sigma. With the following fit parameters: coefficient of determination $R^2 = 0.8915$ (dimensionless) and standard error of the prediction = 1.1 dB(A);

- summer:

$$\begin{aligned} L_{\text{eq (maps)}} &= (0.97 \pm 0.05) \cdot L_{\text{eq (sampling)}} \\ &\quad + (1.4 \pm 2.1), \end{aligned} \tag{8}$$

with the following fit parameters: determination: $R^2 = 0.9037$ and standard error of the prediction = 1.0 dB(A).

As final conclusion for this section, a good agreement of the modelling with the experimental data was obtained for both summer and winter seasons.

Table 3. Values of the noise levels L_{eq} foreseen by CadnaA in the 43 representative spots.

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

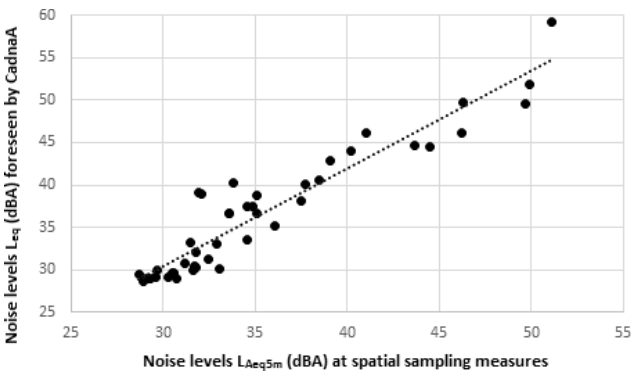

Fig. 7. NRLP: Comparison noise levels at spatial sampling measurements sampling vs. noise levels foreseen by CadnaA (winter).

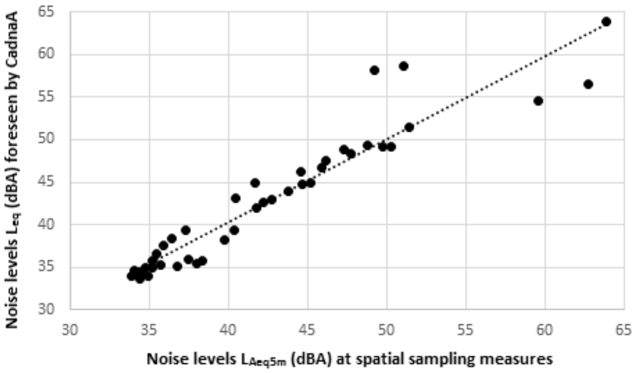

Fig. 8. NRLP: Comparison noise levels at spatial sampling measurements sampling vs. noise levels foreseen by CadnaA (summer).

4. Conclusions

This article analyses the acoustic pollution in a protected natural area located in the southwest of Spain, called Natural Reserve Laguna del Portil (NRLP), with the aim of improving the management of the acoustic pollution applied by the competent authorities.

The main conclusions were:

1) The road A-5052 is the main anthropic source of acoustic pollution in the NRLP, generating an equivalent continuous sound pressure level of approximately 4–5 dB(A) higher in summer than in winter.
2) During the afternoon periods, the existing background sound levels in the NRLP reach 30 and 35 dB(A), for winter and summer, respectively.
3) The NRLP is very close to the road A-5052, and therefore, in an important area there are noise levels higher than the recommended for natural areas in Spanish legislation (Decree 213, 2012).
4) We have found that the variation of the noise and the distance to the road follow a logarithmic function, which is in agreement with the theoretically expectable for a noise linear source. It was obtained that for every doubling of the distance to the road there is an attenuation of approximately 4 dB(A).
5) In certain habitats within the NRLP there are higher sound levels than in others, depending on the season, the fauna and the activity of the latter.
6) In summer, there is an increase of approximately 9 dB(A) in the equivalent sound pressure levels with respect to the winter, mainly due to the increase of the traffic level in road A-5052 as a consequence of tourism. A similar difference is obtained with the CadnaA model when calculating this difference on the basis of the experimental values of traffic flows

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