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Noise pollution mapping approach and accuracy on landscape scales

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HIGHLIGHTS

► Grid size effects on noise indicators were studied using diverse landscape metrics.
► We compared the accuracy of 15 noise mapping scenarios depending on grid resolution.
► Noise map accuracy at different grid spacings depends on topographical factors.
► Reducing the grid resolution can reduce calculation time by more than 90%.

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ABSTRACT

Noise mapping allows the characterization of environmental variables, such as noise pollution or soundscape, depending on the task. Strategic noise mapping (as per Directive 2002/49/EC, 2002) is a tool intended for the assessment of noise pollution at the European level every five years. These maps are based on common methods and procedures intended for human exposure assessment in the European Union that could be also be adapted for assessing environmental noise pollution in natural parks. However, given the size of such areas, there could be an alternative approach to soundscape characterization rather than using human noise exposure procedures. It is possible to optimize the size of the mapping grid used for such work by taking into account the attributes of the area to be studied and the desired outcome. This would then optimize the mapping time and the cost. This type of optimization is important in noise assessment as well as in the study of other environmental variables. This study compares 15 models, using different grid sizes, to assess the accuracy of the noise mapping of the road traffic noise at a landscape scale, with respect to noise and landscape indicators. In a study area located in the Manzanares High River Basin Regional Park in Spain, different accuracy levels (Kappa index values from 0.725 to 0.987) were obtained depending on the terrain and noise source properties. The time taken for the calculations and the noise mapping accuracy results reveal the potential for setting the map resolution in line with decision-makers' criteria and budget considerations.

1. Introduction

Noise pollution, particularly from transport infrastructure, is a form of environmental degradation (Vogiatzis, 2012), with a significant impact on health measured all over the world (WHO and European Centre for Environment and Health, 2011). The consequences for wildlife, ecosystems, soundscapes and natural park visitors are still not well known, even though it is becoming a research topic of interest (Gjestland, 2008; Miller, 2008; Barber et al., 2010, 2011; Saha and Padhy, 2011; Iglesias et al., 2012).

European Directive 2002/49/EC, 2002, commonly known as the Environmental Noise Directive (END), has revealed European concern on noise pollution related to the assessment and management of environmental noise, it has led to the systematic production of strategic noise maps for the European Union. Strategic noise maps are tools for the global assessment of noise exposure in a given area due to different noise sources and for the assessment of exposure-related information (Murphy and King, 2010). These maps are based on a representation of the spatial distribution of noise data using contour lines (isophone maps) in a given area and are commonly known as noise maps.

The first round of END strategic noise mapping was completed in 2007 and the second one is scheduled to finish in 2012. The city or area to be mapped for noise is determined by the agglomeration's size or the volume of traffic using the transport infrastructure. For example, in Spain, this mapping criteria imply that more than 16,000 km of roads, 1350 km of railways and the 13 largest airports and their surroundings

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should be mapped in the second round. However, no noise maps, results or reference limits are to be produced for natural parks because they are supposed to be areas affected by low volumes of traffic, meaning that strategic noise mapping is not mandatory.

Noise map production at the European level is a huge task that has been estimated to cost, on an average, 0.84 EUR/inhabitant by The Commission (COM, 2011). The task is divided into four main stages: (1) obtaining or producing the cartography; (2) building digital noise models; (3) computer calculation process and (4) producing the statistics reports along with plotting the maps. Stage (1) has been identified as the most difficult task by The Commission (COM, 2011), stages (2) and (4) depend on technicians' training and abilities but stage (3) is directly correlated with the digital model size and calculation grid size.

Noise contour maps are produced from grid-based noise levels calculated, according to methods included in the END annexes, to assess the number of people exposed to noise as a function of the day–evening–night noise indicator (L_{den}), overall annoyance, and the night period noise indicator (L_{night}) for sleep disturbance. For nearly ten years, Member States and the European Commission Working Group on Assessment of Exposure to Noise (WG-AEN) have periodically published good practice guidelines for strategic noise mapping. A 10 m (or less) grid spacing is recommended, although this could be increased to 25 or 30 m in large open areas (WG-AEN, 2007) but there are no considerations to determine the feasible grid spacing according to the model properties. A high density of receiver points contained in a given grid polygon or grid region becomes very restrictive because of the calculation time. Such density is supposed to result in higher map accuracy but causes an exponential increase in the cost of the previously described as stage number (3). Noise map accuracy can be greatly affected by several data inputs at the model building stage (Diniz and Zannin, 2004; Pinto and Mardones, 2009; Arana et al., 2010; Ausejo et al., 2010; Guedes et al., 2011; Zannin and Sant'Ana, 2011; Lam and Ma, 2012) but the calculation grid has not yet been systematically investigated (Asensio et al., 2011).

Large area noise mapping can be considered a representation of the acoustic landscape, thus it is a kind of landscape characterization that sometimes is referred to as background noise or soundscape depending on whether it is caused by natural or anthropic sources or the authors' considerations. The term 'soundscape' was first defined by Schafer (1977) and nowadays it is considered as an emerging discipline (Pijanowski et al., 2011) and a natural resource that characterizes regional and territorial acoustic landscapes (Gjestland, 2008; Dumyahn and Pijanowski, 2011). Therefore, it could be studied as an environmental variable at the landscape scale, taking the regional perspective of noise sources into account (Barber et al., 2011) not only restricted to acoustical determinations but also to other parameters of evaluation (Szeremeta and Zannin, 2009). Noise mapping allows these dynamic systems, whose study is highly dependent on map resolution, to become understood and it shares many parallels with landscape ecology and remote sensing, where this key question has been discussed at length (Saura, 2002; Wu et al., 2003; Wu, 2004; Buyantuyev and Wu, 2007; Rutchey and Godin, 2009).

Nevertheless, it has not yet been discussed whether calculation grid needs to be so highly dense in order to understand soundscape disturbances and general impacts on natural ecosystems as it is usually required for human agglomerations. Hence, the main objective of this study is to observe the effects on noise maps, with regard to spatial patterns, of changing the calculation grid size and comparing results on a landscape scale for large working areas, as intended by END. This work describes the introduction of soundscape and noise pollution management from the perspective of managing an environmental territory variable. It could also result in a relevant secondary effect on the calculation time or computer tool requirements to assess the noise, a very costly task (De Kluijver and Stoter, 2003; Murphy and King, 2010). This is related to noise mapping viability, from both the technical and economic points of view. It is also related to the interest in improving the current lack of environmental noise information in wild areas, natural parks or urban parks (Zannin and Szeremetta, 2003; Ge and Hokao, 2004; Zannin et al., 2006).

2. Methods and materials

2.1. Study area

The study area is located within the Manzanares High River Basin (MHRB) Regional Park in the Region of Madrid (Central Spain). A 2×2 km square-shaped area (400 ha) inside the MHRB Regional Park has been selected (see Fig. 1). Despite its small size, this area has diverse orography, landscape and wildlife habitats and it is crossed by two important lineal elements: the Manzanares River (in a north–south direction) and the M-618 road (in an east–west direction).

The MHRB Regional Park covers an area of 52,800 ha and is the oldest protected area of the Region of Madrid. It became protected in 1985 and has been a UNESCO Biosphere Reserve since 1992. This stretch of the Manzanares River is an ecological corridor between two main core areas of the Park (integral natural reserve) and connects the Central System high mountains (almost 2400 m in altitude) with the holm oak (*Quercus ilex*) forest ecosystem closest to northern Madrid's metropolitan peri-urban area (almost 600 m in altitude).

The M-618 is a two lane road that crosses the study area in an east–west direction from the 5 km post to the 9 km post. It is an approximately 4 km long stretch that divides the study area in two. In the first half of the stretch of road (the eastern half of the study area), the terrain surrounding the road is dominated by the course of the Manzanares River, which runs from the mountains in the north to the south. In this half of the study area, the terrain is steeper (80% of the area has slopes over 15%). The road trace is adapted to the topography, and it is winding, curved, and alternates between short straights and ramped curves where vehicles need to accelerate or slow down alternately. This driving mode is called pulsating flow.

The western half of the study area is relatively flat or with a constant slope (90% of the area has slopes under 15%). In this half of the study area, the road trace is flat and straight, and the drivers' speed is constant; This driving mode is usually called constant flow. The absence of houses in the surroundings is another characteristic of both the western and eastern halves of the study area.

The M-618 road is the only anthropic noise source in the study case. This road belongs to the Regional Administration and has the category of 'vía parque' (park road), its trace and traffic characteristics are determined by the MHRB Regional Park crossing. The legal speed limit is 60 km/h through the park and annual average daily traffic (AADT) is fewer than 3000 vehicles.

2.2. Noise models

Noise modelling allows the assessment of environmental noise, in terms of sound pressure level (SPL), over a limited area defined by a calculation grid. A grid consists of a set of receiver points where SPL is calculated and it is used as the basis for SPL contours (isophones) when plotting noise maps. Receiver density in a grid region or polygon is determined by the distance between receiver points in the X and Y directions. Project size, and therefore calculation time and monetary costs, will increase considerably when using large grids or a very dense receiver grid. There are also other variables that have no effects on calculation costs but need to be considered in noise modelling.

The French national computation method referred to in the French standard 'XPS 31–133' (AFNOR, 2001) has been used; this is a very common road traffic noise prediction method, frequently used by the European Union (EU) Member States and widely validated (King and Rice, 2009; Can et al., 2010; Hamet et al., 2010). This is the method recommended by Directive 2002/49/EC (2002) (Murphy and King,

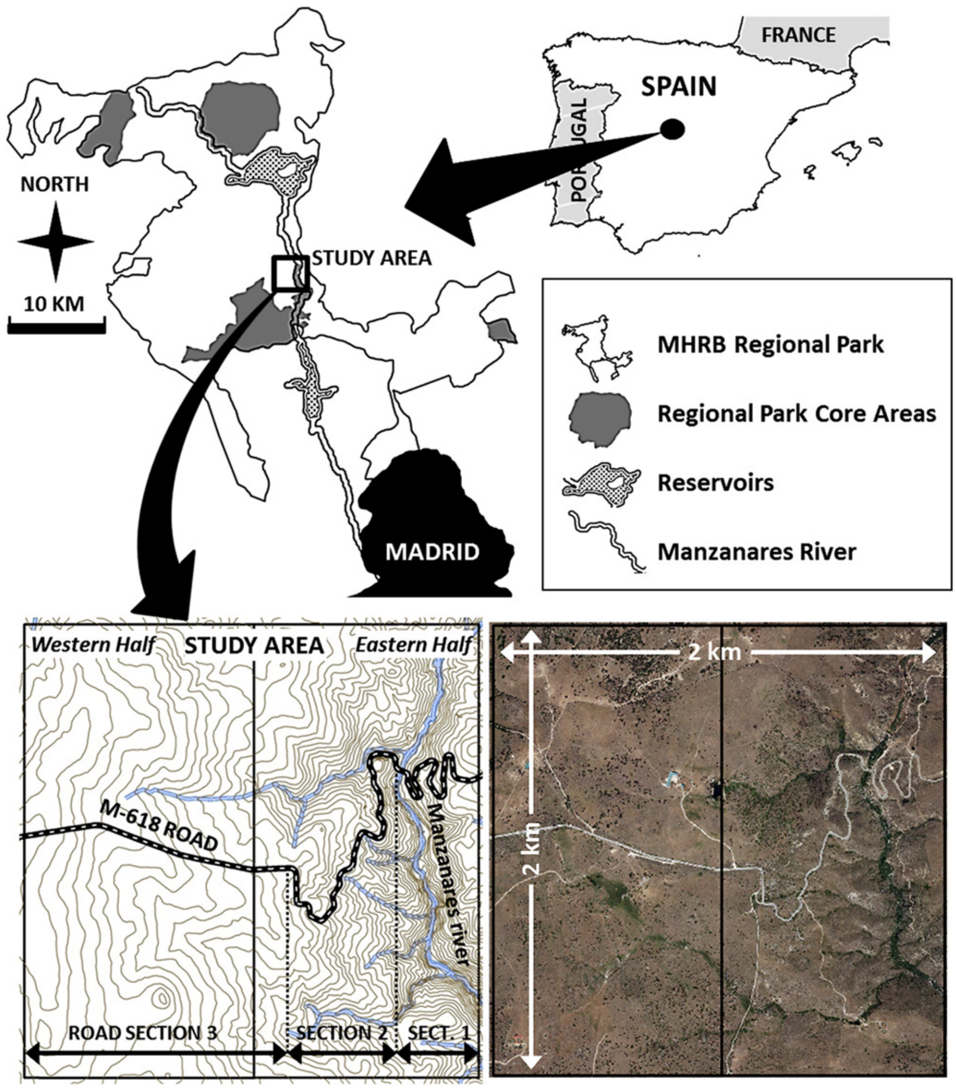

Fig. 1. Study area location in the Manzanares High River Basin Regional Park, Madrid (Spain).

2010; King et al., 2011) and it is based on the concept of propagation path. It has been recently revised as 'NMPB-Routes-2008' (Dutilleux et al., 2010; Dutilleux, 2012). Model preparation has required CAD (computer-aided design) and GIS (geographic information system) tools in previous stages when arranging height contour lines, road traces, study area boundaries, and other common preparation tasks in building a digital elevation model (DEM). The DEM has been based on official 1:5000 scale digital topography maps from the Regional Cartography Service with 5 m contour lines.

The noise prediction software package Predictor™ Type 7810 version 8.1 (Brüel and Kjaer, 2010) was used for the noise model computation. This software package allows the modelling of the effect of changing the calculation settings or the physical parameters of the environment. It allows the characterization of past, present or future scenarios for different noise sources. Most of the XPS 31–133 standard conditions have been considered (Table 1) and the road surface has been classified as smooth asphalt. The AADT for noise modelling on the surroundings of the M-618 was obtained from the Regional

Table 1
Noise model standard conditions used in this study.

Parameters	Standard conditions						
Air absorption	Octave band (Hz)	125	250	500	1000	2000	4000
	Absorption (dB/km)	0.38	1.13	2.36	4.08	8.75	26.39
Normalised spectrum	Octave band (Hz)	125	250	500	1000	2000	4000
	Standardized A-weighted road traffic spectrum (dB)	−14.5	−10.2	−7.2	−3.9	−6.4	−11.4
Meteorological settings	Default settings for the interim method (Day = 50% favourable, Evening = 75% favourable and Night = 100% favourable)						
Propagation conditions	Predictor™ Type 7810 version 8.1 includes the file PropagationNMPB.DLL for 'NMPB-Routes-2008' distributed by 'CETE de l'est — LRPC de Strasbourg' (updated on July 19th 2011)						
Ground factor	Value = 1 (represents porous ground: grass land, farming land)						

Transport and Infrastructures Department. Separate data for light and heavy vehicles (less than 3.5 tons and 3.5 tons and over) from a traffic count station located at the 4.9 km post were available. The official AADT for 2008 used for the case model gave a total of 2838 vehicles (4.2% of them being heavy vehicles).

The model required the establishment of three different road sections (Fig. 1) according to the driving conditions and traffic flow. The traffic flow is considered to be pulsating (vehicles in a transitory state i.e. either accelerating or decelerating) over stretch 1, with a real average speed of 35 km/h for both heavy and light vehicles. Heavy and light vehicles are considered to move at a nearly constant speed (constant flow) in section 2 (50 km/h) and section 3 (60 km/h).

2.3. Period definitions

L_{den} and L_{night} are two main noise indicators readily available for communities all over Europe and are therefore recommended, if feasible, for defining the noise levels (Gjestland, 2008). This study is based on the L_{den} indicator results in decibels (dB) as a noise indicator required by END and defined by the following formula:

$$L_{den} = 10\log\frac{1}{24}\left(T_{day}\cdot 10^{\frac{L_{day}}{10}} + T_{evening}\cdot 10^{\frac{L_{evening}+5}{10}} + T_{night}\cdot 10^{\frac{L_{night}+10}{10}}\right). \tag{1}$$

In accordance with END Annex I, three calculation periods, commonly known as day, evening and night, have been established in which L_{day}, $L_{evening}$ and L_{night} are the A-weighted long-term average sound levels as defined in ISO 1996-2: 1987, determined over all the daytime periods of a year, over all the evening periods of a year and over all the night periods of a year, respectively. According to Spanish legislation and END, the day period lasts from 07.00 to 19.00, the evening period from 19.00 to 23.00 and the night period from 23.00 to 07.00.

The height of the points of the L_{den} assessment grid depends on the application. In accordance with END and Spanish legislation, a 4.0 m grid height above the ground for noise immission modelling has been considered. Fifteen different noise maps of the L_{den} indicator in the study area have been calculated, as a result of considering 15 different resolutions or calculation grid densities with constant increments of 10 m distance (since X and Y = 10 m, 20, 30, 40 … up to 150) as shown in Fig. 2. Other possible calculation parameters have been kept constant for the 15 scenarios.

2.4. GIS models and landscape analysis

The study area soundscape is only affected by road traffic noise whose assessment has been represented in a noise map by the value of the L_{den} indicator at each point in the territory. The export of the noise map results into a GIS allows for the geostatistical analysis of thousands of pieces of SPL data. Spatial pattern analysis is frequently undertaken for land-use management and landscape dynamic studies and particularly in relation to other environmental variables, such as habitat modelling, biodiversity and so on, over a given study area where different temporary scenarios are usually compared (Li et al., 2000; Olsen et al., 2006; Paudel and Yuan, 2012). Spatial models can be used not only for understanding landscape dynamics, but also for simulating other landscape patterns, mostly based on scenarios changing over time. In this case, the independent variable 'time' has been replaced by the variable 'calculation-grid size', resulting in 15 different and comparable noise map scenarios for the same study area.

Landscape indices or spatial statistics were used to quantify changes in spatial patterns in the study area and were calculated using Patch Analyst 4.2.13 for ArcGIS 9.3 (ESRI, 2009). Patch Analyst is a program for calculating landscape metrics that works as an extension within ArcView and/or ArcGIS, facilitating the spatial analysis and modelling of attributes associated with patches at the landscape level (Rempel et al., 2012). Seven of the most common metrics (as defined by McGarigal and Marks, 1995) have been employed, grouped into the following useful categories for noise polygon pattern analysis, depending on whether the focus is at landscape or class level: class area (CA), number of patches (NumP), mean patch size (MPS), edge density (ED), area-weighted mean shape index (AWMSI), mean patch fractal dimension (MPFD) and Shannon's diversity index (SDI). Five of these indices are common for class and landscape analysis (NumP, MPS, ED, AWMSI, MPFD), one index is only available for class level analysis (CA) and another is calculated only for landscape level analysis (SDI) as shown in Table 2.

Some of the selected metrics quantify the area in absolute terms (hectares), but it could be desirable to quantify the area in relative terms as a percentage (McGarigal and Marks, 1995). Therefore, it is proposed to evaluate noise CA changes in relative terms (regarding their

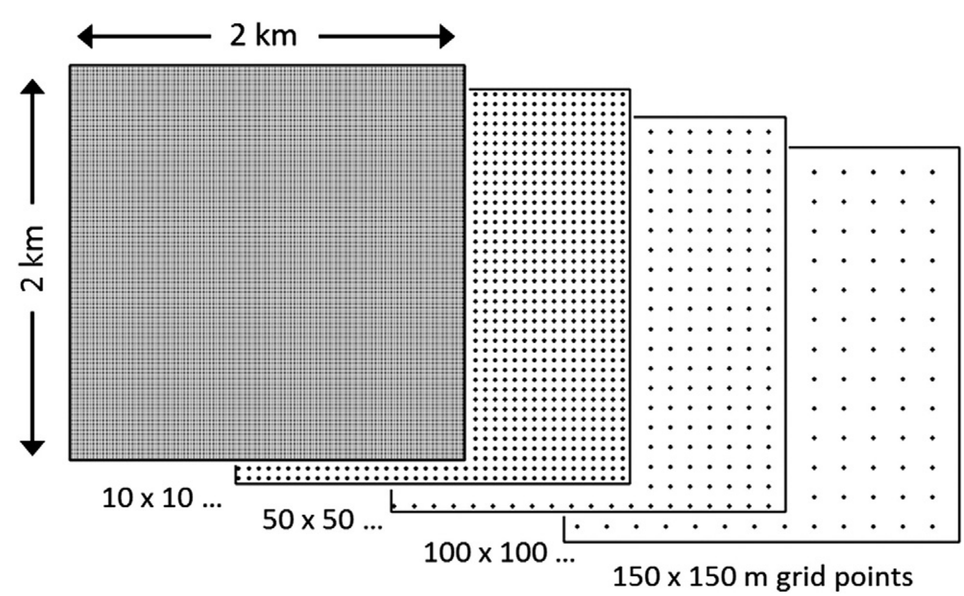

Fig. 2. 15 different grid regions have been used with constant increments of 10 m in the X and Y receiver points from 10×10 m resolution up 150×150 m resolution.

Table 2
Spatial statistics indices used in this study.

Metrics	Measure	Selected indices	Meaning	Equations
Area metrics	Class or landscape area	Class area, *CA* (ha)	Sum of areas of all patches (a_{ij}) belonging to a given class (at class analysis) with respect to total area (A)	$CA_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}$
Patch density and size metrics	Landscape fragmentation and configuration	Number of patches, *NumP* (#)	Number of patches (p_t) at landscape level or for each individual class (if analysed by class)	$NumP = \sum_{t=1}^{n} p_t$
		Mean patch size, *MPS* (ha)	Average patch size (a_{ij}) analysed by class or landscape level (n_i refers to *NumP*)	$\mathrm{MPS} = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}$
Edge metrics	Amount, length, and distribution of edges between specific patch types	Edge density, *ED* (m/ha)	Patch perimeter or edge length (E) referred to the landscape (A) or class area (CA)	$\mathrm{ED} \frac{\sum_{i=1}^{n} E_i}{A \text{ or } CA}$
Shape metrics	Geometric complexity	Area-weighted mean shape index, *AWMSI* (no units)	It is equal to 1 when all patches are circular (for vector) or square (for rasters) and increases (without limit) when increasing patch shape irregularity (p_{ij} is the perimeter of patch ij)	$\mathrm{AWMSI} = \sum_{j=1}^{n} \left[\frac{p_{ij}}{\min p_{ij}} \left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \right) \right]$
		Mean patch fractal dimension, *MPFD* (no units)	It approaches 1 for shapes with very simple perimeters (circles or squares) and approaches 2 for highly convoluted perimeters	$MPFD = \frac{\sum_{j=1}^{n} \left(\frac{2 \ln p_{ij}}{\ln a_{ij}} \right)}{n_i}$
Diversity and interspersion metrics	Patch isolation	Shannon's diversity index, *SDI* (no units)	Relative patch diversity (landscape level). It is equal to zero when there is only one patch in the landscape.	$\mathrm{SDI} = -\sum_{i=1}^{m} (pi * \ln p_i)$

original size on a reference map, 10-L_{den} grid map, and the study area size) and thus calculate an indicator called the area-weighted class area (AWCA). Also, if the patch ED is referred to in relative terms with respect to the study area and the original value on the reference map, an index called the area-weighted edge density (AWED) can be used.

2.5. Noise mapping accuracy assessment

Landscape indices provide both statistical and ecological information useful for landscape planning, but are known to have limitations (Rempel et al., 2012). For example, some indices only offer landscape interpretation by themselves and do not convey any information about the distribution of patch areas (McGarigal and Marks, 1995), leading to misinterpretation of identical landscapes where patch types and number of patches can be very different.

In order to assess the accuracy of noise maps with respect to spatial patterns within the study area, the Kappa index (pixel-by-pixel change detection among scenarios) was computed using GRASS GIS 6.4.2. This is a GIS used for geospatial data management and analysis, image processing and spatial modelling. The Kappa index gives a measure of agreement between categorical maps and it is used by many biostatisticians, researchers and specialists for land-use and remote sensing (Pontius, 2000; Knight and Lunetta, 2003; Hernandez-Stefanoni and Ponce-Hernandez, 2004; De Mast, 2007; Wang and Xu, 2010). Kappa also quantifies the proportion of changes from one class to another between different noise maps (Congalton and Green, 1999; Ruiz-Luna and Berlanga-Robles, 2003).

The Kappa index is calculated by crossing classified map layers (L_{den} maps from grid 20 up to 150) with a reference map layer (grid 10). The Kappa analysis takes the assessed value and position of the L_{den} indicator into account for every pixel of the study area and it also considers the relative area occupied by every noise level category on the map. The Kappa analysis complements the patch analysis. The calculation is based on independent comparisons between pairs of cells; small displacements between the cell values on the reference map and the compared map are considered to be errors. Comparison maps must be previously transformed to raster format, so a raster dataset must be created with the same cell size. In this case, the raster dataset cell size is determined by the highest resolution noise map (cell size 10×10). The L_{den} maps were used as input features for raster conversion and the pixel central value was the criterion adopted. The Kappa index can range from −1.00 to 1.00, extreme values indicate full negative or positive correlation and a zero value means no correlation between the items. Generally, a Kappa value higher than 0.70 or 0.80 is considered to be a satisfactory level of agreement (De Mast, 2007; Maithani, 2009).

The noise map results and patch shapes are very much influenced by the topography and road trace. Therefore, it is advisable to perform three calculations of the Kappa index for every scenario: (1) the overall Kappa value relating to the whole study area, (2) a partial Kappa value in the western half of the study area (slightly hilly topography and shallow slopes) and (3) a partial Kappa value in the eastern half of the study area (irregular topography and more abrupt slopes).

3. Results

3.1. Noise mapping results

Fifteen noise maps for the L_{den} indicator have been calculated depending on the calculation grid size as previously explained. Noise levels are represented by categories defined by ranges of 5 dB. It must be noted that the coloured area results vary slightly within the 2×2 km square because they are based on grid points whose density and coordinates are different in each case (Figs. 2 and 3) as the grid resolution changes. Therefore, there is a square of 324 ha within the study area that allows a comparison of the 15 scenarios or isophone maps.

The 10 m grid resolution (grid 10) is the most detailed noise map calculated in the study area, so it is considered to be the reference map (Fig. 3) when comparing the 15 model results. The grid 10 calculation process lasted[2] 1 h 31 min 18 s and the noise level map results were represented in 9 category intervals (from less than 35 dB up to 75 dB), grouped in 62 patches dominated by intermediate levels (from 40 dB to 60 dB). The higher level categories show faster attenuation at increasing distances from the noise source. L_{den} values over 65 dB are almost only represented on the road surface and its closest surroundings.

The grid 150 L_{den} indicator noise map is the least detailed map and the calculation time was only 37 s. The calculation times for grids between grid 10 and grid 150 reduce non-linearly with increasing grid sizes. The grid 150 L_{den} map has only 11 patches grouped into 6 noise level categories. The lower the resolution settings, the more information

[2] Noise models were calculated with a Pentium Dual CPU T2390 with 1.87 GHz processor, 3.00 GB of RAM and Windows 7 Service Pack 1 for a 32 bit system.

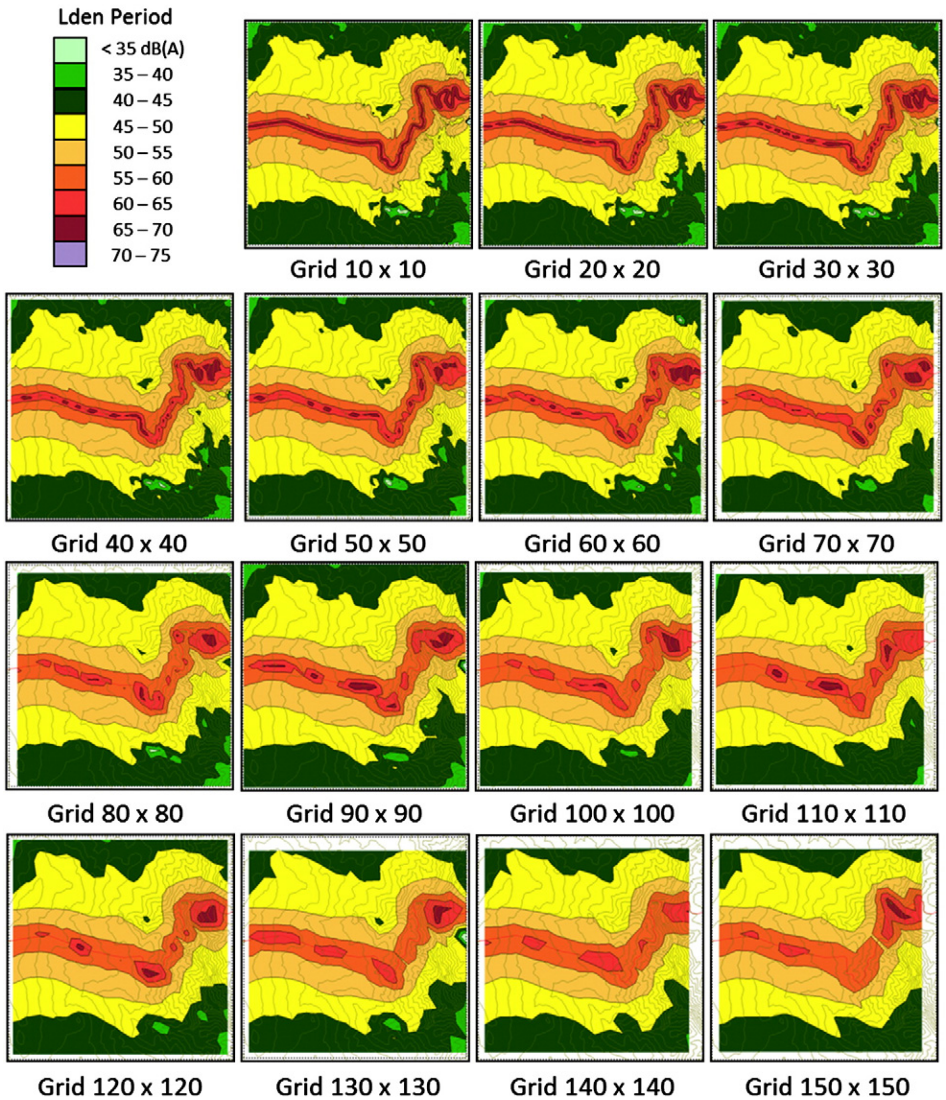

Fig. 3. Noise maps for the L_{den} indicator obtained from different calculation-grid sizes (grid resolutions).

is lost both in the higher level categories and the closer the noise source is (smaller polygons as a result of the faster attenuation), but likewise in the lower levels and further from the source (because of its small original size). The rest of the 13 compared scenarios represent 13 intermediate situations of the study area soundscape defined by the L_{den} indicator.

3.2. Analysis of landscape level changes

Landscape level metrics confirm a loss of accuracy when increasing the calculation grid size from 10 to 150 m distance for noise mapping, as presented in Fig. 4. The NumP is reduced and it implies a decrease in the number of classes, but an MPS increase. In terms of the class diversity, whilst maintained at intermediate levels (close to values of 1.5), it is reflected in the decline in SDI. Furthermore, the shape of the polygons is simplified, as reflected by the decreasing MPFD, AWMSI and ED values.

The L_{den} map analysis at class level shows general behaviour that looks just like common indices compared at landscape level. It reflects a soundscape simplification trend expressed by the NumP decrease and the general simplification of the polygons' shape (MPFD, AWMSI and ED) for all categories when increasing the calculation grid size from 10 m to 150 m (Fig. 5), although some intermediate grid size fluctuations are shown. A general increase in MPS is also observed, particularly at intermediate noise levels (45, 50, 60 and 65 dB). However, the CA curves remain approximately constant for all noise categories when increasing the calculation grid size.

Landscape metrics allow the general trend of detail loss to be described when increasing the calculation grid size in noise mapping. However, in order to find breaking thresholds between similar landscapes and determine which maps can be considered equivalent at landscape scales, it would be useful to know whether there is a calculation grid size range where landscape attribute changes occur at different rates.

The AWCA indicator, expressed in relative terms as explained above, has positive values if noise categories increase its area when increasing calculation grid size, it is negative otherwise. The graphs show that an apparent change in the gradient of the AWCA curves occurs at calculation grid size values between 50 m and 100 m and it is also observed that the increases in the AWCA value are greater than $\pm 1\%$ (Fig. 6) for almost all the noise level categories. Some polygons can disappear in case they were narrower than the width of the increased grid size and this causes a reduction in the number of classes, as shown in the case of noise level categories 35, 40, 70 and 75 dB

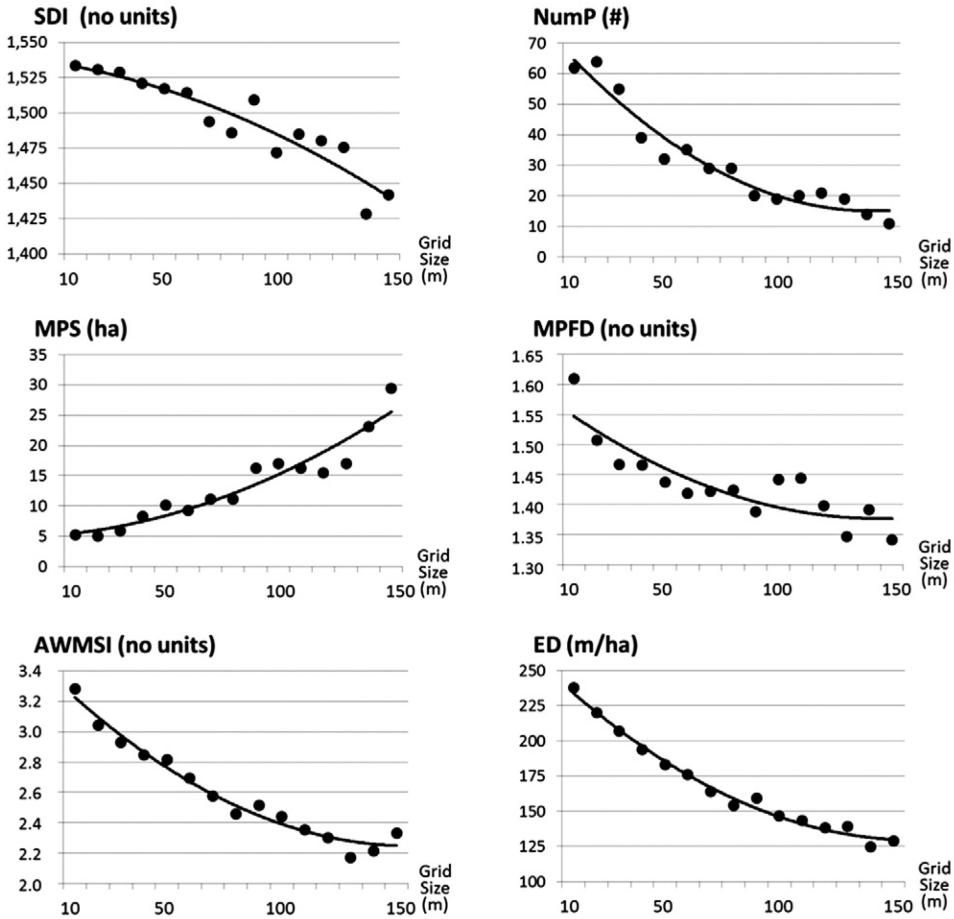

Fig. 4. Spatial indices result curve graphs of the landscape level analysis.

(Table 3 and Fig. 7). The original polygon sizes also explain the changes in the gradient of the noise class level curve and changes from positive to negative values and vice versa. The highest positive increases happen at 60 dB (from grid 100 to 150) because these large polygons replace the narrower ones (70 and 75 dB noise class levels) and that causes the masking of the higher noise pollution classes when plotting the road isophone map using interpolation. The lack of information at different noise class levels and its magnitude is represented by negative values and negative curve slopes.

The AWED graphs show that all the noise categories have negative values and their curves decrease when increasing the calculation grid size (Fig. 6). However, the AWED reductions are lower than −2% for almost every noise level category (except the higher categories) when the calculation grid size is smaller than 50 m. The decrease in AWED values is greater than −2% for almost all the noise categories when the calculation grid sizes are higher than 100 m.

Differences between the result maps in relative terms are represented by the AWCA and AWED curve distances from the horizontal axis. Changes that indicate alterations to soundscape attributes can be seen in the graphs of both indices. It is possible to identify three distinct areas depending on the graphical dispersion of these charts. The curves are relatively concentrated from grids 10 to 50, then there is a pronounced phase of change between the grid 50 and the grid 100 values and, ultimately, there is a great dispersion with the greatest curve separations above grid 100.

3.3. Noise map accuracy

For every noise map (from grid 10 to grid 150), the Kappa index has been calculated to determine the equivalence level with regard to the reference map (grid 10). It also allows a threshold of equivalence to be established depending on management purposes or noise mapping goals.

A first overall Kappa analysis reveals a very unequal distribution of Kappa values through the noise level categories. The Kappa index decreases in general terms when the calculation grid size is increased, but accuracy values remain higher than 0.8 for intermediate noise level classes (45, 50, 55 and 60 dB), when the grid size value is lower than 50–60 m (Fig. 7).

By analysing the eastern and the western study areas separately, it is possible to see the same general decreasing trends of partial Kappa values when increasing the calculation grid size, as well as how the reduction in the number of noise classes occurs. Nevertheless, fewer fluctuations are produced at intermediate grid sizes than in the case of the total study area. However, a clearly higher level of accuracy in the western half of the study is obtained, where the topography is smoother and the traffic flow is continuous.

Table 3 shows the Kappa index value of the 15 scenarios when compared to the reference map (grid 10). Partial Kappa values show where the main differences between landscape features are located. It also indicates the calculation time of every noise model according to the calculation grid size.

The Kappa analysis of the noise maps in the whole study area provides higher than 0.9 accuracy values when the calculation grid size is lower than 50 m, which represents a computation time saving of over 95% compared to the reference map (grid 10) in the studied case. The same accuracy level is obtained with grid values lower than 100 m in the western half of the study area. A calculation time saving of 98.7% is achieved when employing grid 100 instead of grid 10. In the more irregular and abrupt orography (eastern half of the study area), high levels of accuracy are only obtained below grid 30 (Kappa > 0.9), which means an

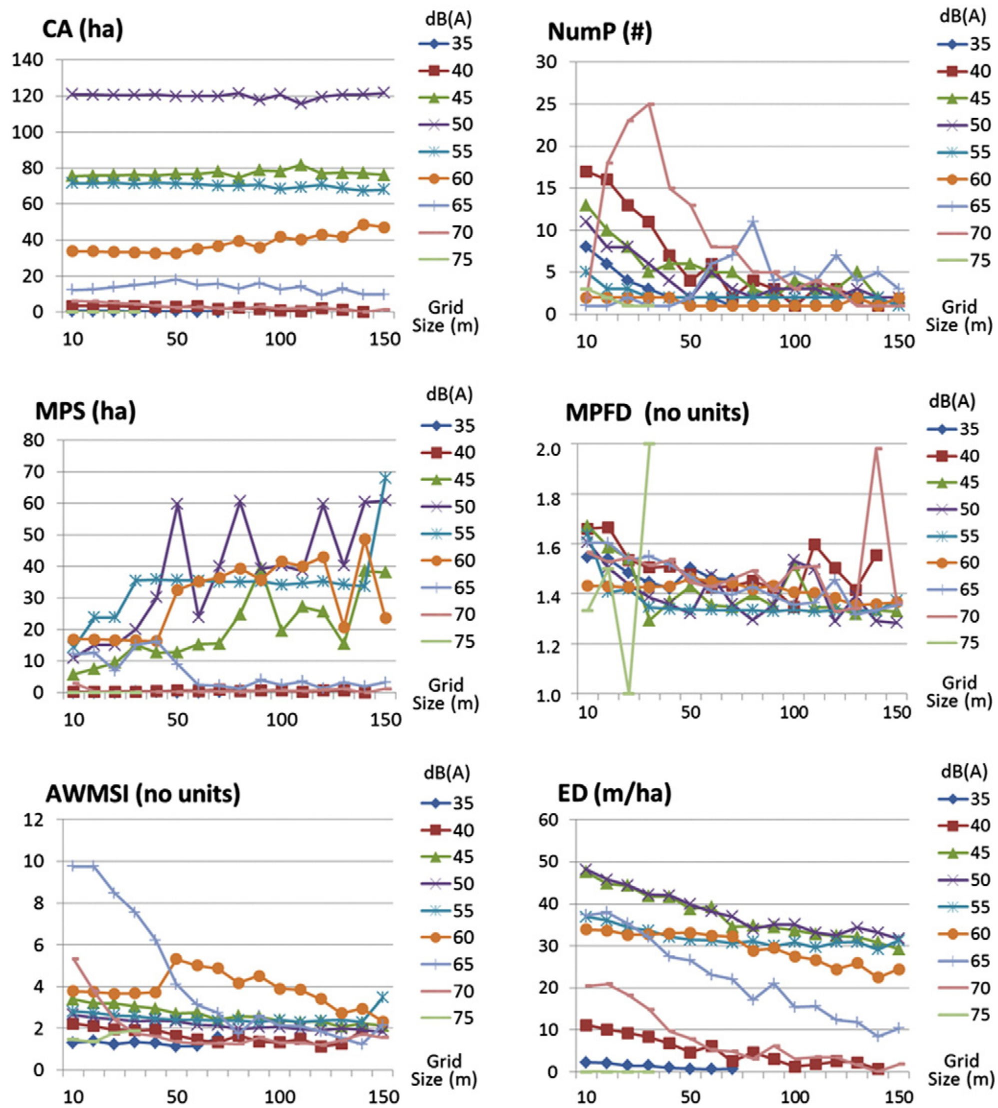

Fig. 5. Spatial indices result curve graphs at the class level.

88.3% saving in calculation time. The Kappa index and calculation time saving values with respect to grid size allow an accuracy range to be estimated depending on the decision-maker's objectives.

4. Discussion

Environmental noise tools, such as strategic noise mapping and derived action plans, are intended to be updated every 5 years at the European level (COM, 2011). This global assessment takes a significant continuous monitoring effort of an environmental pollution type whose monitoring costs are greatly influenced by the size of the study area to be modelled (WG-AEN, 2007). To be reasonably sustainable in diverse economic circumstances and because this type of mapping is being applied to a growing geographic area, the cost effectiveness of noise mapping should be incorporated into the procedures based on technical criteria, as well as on availability of trained technicians and reduced

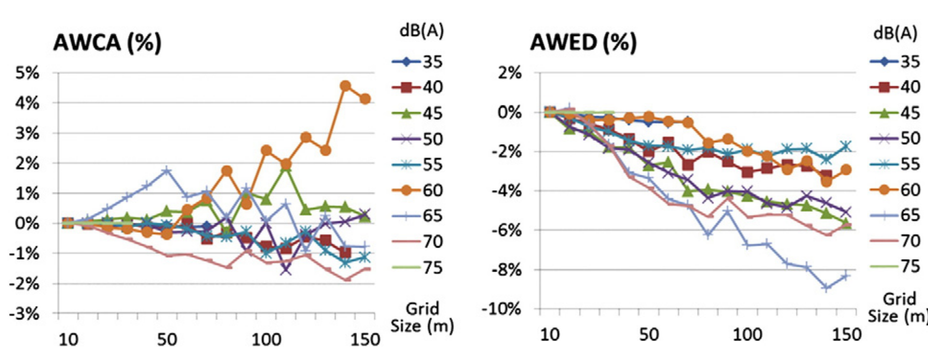

Fig. 6. AWCA and AWED changes at the class level.

Table 3
Kappa analysis and noise calculation time with respect to the calculation-grid size.

Calculation-grid size	Number of classes	Kappa (total study area)	Kappa (western study area)	Kappa (eastern study area)	Calculation time (h:m:s)	Absolute time difference (%)	Partial time difference (%)
10	9	1.000	1.000	1.000	1:31:18	00.0	00.0
20	8	0.971	0.987	0.955	0:23:35	74.2	74.2
30	8	0.950	0.974	0.927	0:10:42	88.3	54.6
40	8	0.930	0.964	0.897	0:05:59	93.4	44.1
50	8	0.909	0.954	0.865	0:04:03	95.6	32.3
60	8	0.892	0.941	0.844	0:02:47	97.0	31.5
70	7	0.879	0.934	0.825	0:02:09	97.6	22.3
80	8	0.856	0.917	0.793	0:01:39	98.2	23.5
90	7	0.851	0.913	0.790	0:01:25	98.5	14.4
100	7	0.832	0.902	0.764	0:01:12	98.7	15.2
110	7	0.812	0.812	0.740	0:01:03	98.9	12.8
120	7	0.817	0.887	0.756	0:00:55	99.0	12.0
130	7	0.820	0.889	0.752	0:00:44	99.2	19.7
140	6	0.800	0.871	0.730	0:00:37	99.3	15.8
150	6	0.795	0.867	0.725	0:00:37	99.3	00.8

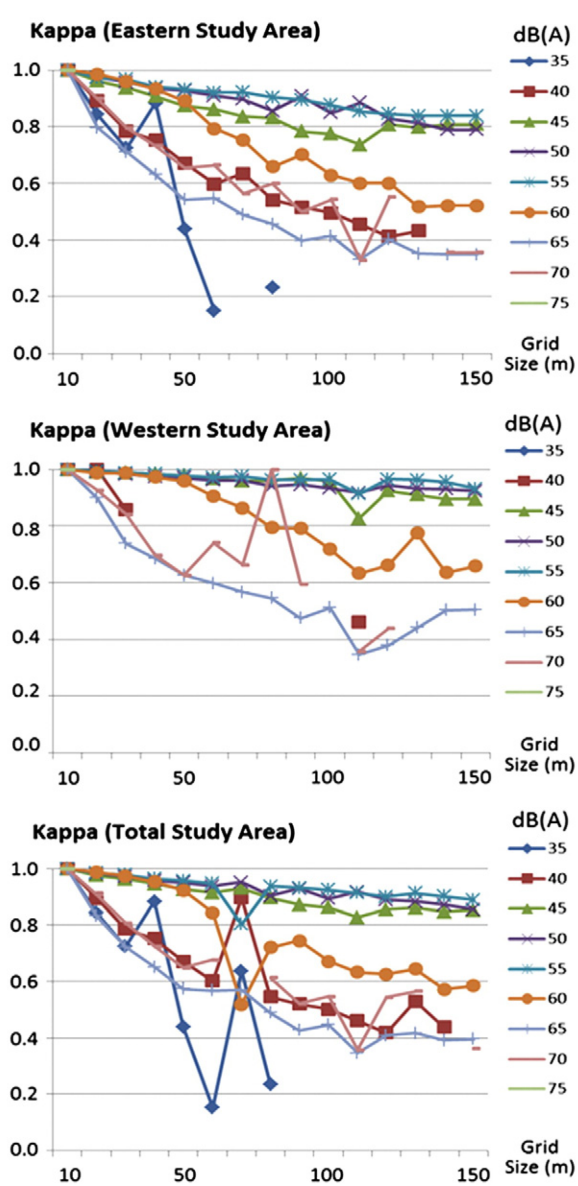

Fig. 7. Overall and partial Kappa indices by noise classes.

calculation processing time. The noise map calculation process is based on a number of combinations of receiver grid points, number of sources and number of defined periods; thus, mapping costs are correlated with map resolutions and the study area size.

The application of landscape perspective seems especially relevant in noise mapping studies located outside populated areas (Gjestland, 2008; Barber et al., 2011). A general, but quantifiable, simplification of noise mapping is produced in terms of landscape properties by decreasing the calculation grid resolution. Spatial pattern analysis allows the meanings of these attribute changes and why they occur to be understood. Both approaches allow environmental noise to be dealt with at an appropriate cost in large management areas, such as natural parks, because the spatial ecological effects of noise pollution are not restricted to developed areas and it is an emergent issue for protected land (Barber et al., 2010, 2011).

Spatial pattern and map accuracy analysis suggest that it is possible to determine an appropriate resolution range for large area noise mapping, as had been shown revealed for many other environmental variable mappings (Saura, 2002; Knight and Lunetta, 2003; Wu et al., 2003; Wu, 2004; Buyantuyev and Wu, 2007; Rutchey and Godin, 2009). A good characterization of terrain and noise source properties in the study area could be useful for taking decisions on calculation grid sizing.

The main patch number and shape changes caused by grid spacing are predictable and localizable by noise mapping experts when changing the calculation grid resolution. Therefore, technicians would be able to improve the accuracy of the map results if different calculation grid sizes are employed, depending on the locations of the receiver points and their distances from the noise sources. This method of designing a grid region is congruent with De Kluijver and Stoter (2003) and Asensio et al.'s (2011) work on how to adapt grids for noise mapping, without a significant loss in result quality. However, potential changes in the results may be different depending on whether or not they are referred at class or landscape level and that meaning must be understood for successful grid design.

Finally, the results of this work show that noise map calculation time can be reduced, thus making possible further cost savings, based on each model's calculation time as shown in Table 3 (in absolute terms with respect to the reference grid or in relative terms with respect to the next lower grid resolution). There are no standardized cost–benefit recommendations that can guide decision-maker judgments (De Kluijver and Stoter, 2003) but it is a costly and time-consuming task as pointed out by Murphy and King (2010). This is a very important consequence of the proper use of GIS and noise calculation models with regard to noise mapping in large areas outside agglomerations, optimizing the quality and efficiency of noise prediction studies.

5. Conclusions

This work reinforces the idea that environmental noise and soundscapes can be studied as environmental variables at the landscape scale from a regional perspective. It is possible to employ common environmental study tools, such as those based on GIS spatial analysis, to calculate and compare patterns at spatial and temporal scales in Europe, every 5 years, as stipulated by END.

In addition, it is possible to choose from a range of calculation grid sizes in noise mapping whilst keeping a previously defined acceptable level of accuracy at landscape scales. A significant reduction in calculation grid size means a significant calculation time saving that could be easily translated into monetary terms, but there are two aspects to take into account:

1) When reducing calculation grid size, the following precaution should be considered: the contour grid region must be oversized in a security-sized buffer, by at least as much as the increase in the calculation grid size, to cover the whole study area of interest properly if it is intended to be fully coloured.
2) To obtain accurate results, employing different calculation grid sizes is recommended depending on the locations of the receiver points, the distances to the noise sources and the orographic characteristics surrounding both of them.

Conflict of interest

Author's declare that there is no conflict of interest.

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