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Research Article

Wildlife roadkills: improving knowledge about ungulate distributions?

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Abstract

Traffic reports (TR) about wildlife-vehicle collisions drafted by traffic safety authorities or the departments of transportation constitute a source of information only rarely taken into account in biological studies, but one that could be useful because it is constant, abundant, inexpensive, and has nearly complete territorial coverage in many parts of the world. To assess the usefulness of TR in species distribution for three European ungulate species (wild boar, roe deer and red deer) we compared the spatial distribution in a 10×10 UTM grid square (cells) obtained using TR with their distribution described in the Atlas and Red Book of Spanish Terrestrial Mammals (ARBSTM). The study was carried out in north-central Spain. The results show that TR offers a good complement to the data sources from the ARBSTM, contributing to new distribution sites in insufficiently sampled areas. The average increase in areas inhabited by the species studied was 41.52 %. However, TR cannot be used as the sole source of information. Thus, for 35.16 % of the positive cells reflected in the ARBSTM there were no reported roadkills. In the mountainous periphery of the study area, with higher population densities of ungulates, the TR method was as good as those used in the ARBSTM in cells with medium road density, but was unable to detect the presence of wildlife in zones with low road density. The repeatability across time in roadkills using TR increased with the level of development of the road network and the percentage of area suitable for the species. However, despite the temporary repeatability demonstrated in the study, the method is not able to differentiate between occasional and stable species presences which could lead to overestimated distributions. Nevertheless, ARBSTM distributions have the same limitation.

Introduction

Some studies have focused on assessing the potential of roadkills to serve as a source of remarkable information about the ecology, the population size, and even the presence and distribution of the species involved. Thus, the rate of roadkills has been proposed as a valid methodology to measure abundances. Hicks (1993), working with moose *Alces alces*, and McCaffery (1973) and Widenmaier and Fahrig (2006), with white-tailed deer *Odocoileus virginianus*, reported that the number of roadkills was correlated with population size. In Tasmania, Mallick et al. (1998) used roadkills as an abundance index for the eastern barred bandicoot *Perameles gunnii*. Baker et al. (2004) studied the use of fox *Vulpes vulpes* roadkills to monitor populations and found a significant relationship between densities and the number of collisions. Engeman (2004) studied the activity patterns of racoons, *Procyon (Ursus) lotor*, using roadkill information. Other research efforts have focused on the use of roadkills to infer population parameters. Loughry and McDonough (1996) found a different age structure between roadkills and the adjacent population of the nine-banded armadillo, *Dasypus novemcintus*. Lovari et al. (2007) inferred several parameters concerning wolf, *Canis lupus*, populations based on carcasses (50.65% were roadkills), although Ciucci et al. (2007) reported that population studies with carcasses and roadkills could introduce bias in the results.

In this sense, the roadkill data obtained from the traffic reports (TR) drafted by the traffic safety authorities or the road network agency after an animal-vehicle collision offer an inexpensive and continuous source of information, with broad spatio-temporal coverage. Finder et al. (1999), Mysterud (2004), Seiler (2004, 2005), Malo et al. (2004), Saeki and Macdonald (2004), Farrell and Tappe (2007) or Kolowski and Nielsen (2008) used these datasets based on TR to study the spatio-temporal distribution of animal-vehicle collisions. However, only in a few cases have TR been used to increase knowledge about the biological facts of the species most often reported (McCaffery, 1973; Hicks, 1993). Funds are often scarce for species conservation and any source that might contribute new information should be considered useful.

The aim of the present work was to evaluate the use of the roadkills reported in TR to improve our knowledge about species distributions. The detection of species in an area using TR depends on both the probability of the animals being killed by traffic in that area and the probability of such collisions being reported. Highways tend to be located in certain specific landscape units (Saunders et al., 2002; Hawbaker et al., 2004) and roadkills are not distributed randomly but are instead concentrated in certain road segments (Clevenger et al., 2003; Malo et al., 2004; Ramp et al., 2005; Gomes et al., 2009). Moreover, the probability of collisions being reported increases with the size of the animal in question (Ford and Fahrig, 2007). Although there is some discrepancy between the counted and real number of collisions (Slater, 2002; Santos et al., 2011; Zimmermann et al., 2013), damage to property and motorist injuries and fatalities are usually proportional to animal size, such that the larger the animal, the greater the probability that drivers will report the incident to the traffic safety authorities (Conover et al., 1995). Thus, because of their size and the large number of collisions, this method may be more effective with large herbivores. Here we selected the three main ungulate species present in the study area and involved in the 8.9% of all reported traffic accidents in Spain (Saénz-de-Santa-María and Tellería, 2015), wild boar (*Sus scrofa*) roe deer

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(*Capreolus capreolus*) and red deer (*Cervus elaphus*) to assess the capacity of reported collisions in order to properly define the spatial distribution of these species and repeatability over time. For all three species we compared their distribution obtained using a roadkill dataset with the distributions described in the *Atlas and Red Book of the Spanish Terrestrial Mammals* (ARBSTM) (Palomo et al., 2007).

Materials and methods

Species and study area

The study was conducted in the Regional Community of Castile and Leon, North-western Spain (Fig. 1). It has a surface area of 94223 km^2 and comprises a high plateau surrounded by mountain chains. Over time, the plateau has been nearly completely converted from a savannah-like terrain into croplands. In mountainous areas, forest and the scrub predominate, and grasslands prevail at greater altitude. In these landscapes, the crops are limited to the lowlands. The population density is low (26.65 inhabitants/km^2).

In recent decades, populations of wild boar have expanded in the Mediterranean area due to rural emigration and increases in forest cover (Abaigar, 1992; Sáez-Royuela and Tellería, 2008). Although this species is widely distributed throughout the area (Palomo et al., 2007), the information concerning certain zones, especially the plateau, remains scarce. The roe deer is distributed throughout the mountainous area of the Cantabrian mountains in the north of the region and many parts of the *Central* in the south (Acevedo et al., 2005). The roe deer has managed to colonise several parts of the cereal-growing plateau in the centre of the region, and has been found dispersed away from forested areas (Virgós and Tellería, 1998). The spatial distribution of red deer responds to both the restocking of wild game supplies in several areas and the natural expansion that has occurred in recent decades.

Roadkill data and species distribution according to the ARBSTM

We used 17991 TR drafted by the traffic safety authorities during the 2002–2008 period for the road network in NW Spain. The TR included the species involved, the roads and the kilometre points where the collisions had occurred (an accuracy level of hectometres), together with the date and hour of each collision. There were no data about the age or the sex of the animal involved. A geographical information system was used to locate 17164 sites after filtering for locations without geospatial coordinates. The software used was ArcGIS 9.2 (ESRI Co.). We matched each roadkill location to the same 10×10 km UTM grid square used in the ARBSTM to enable comparisons. The data contained in the ARBSTM came from bibliographical compilations, collections, surveys in natural areas under protection, and from unpublished reports that included direct observations, captures, tracks, analyses of dropping, roadkills, or hunting (Palomo et al., 2007). All of these were occasional records from collaborators. However, the ARBSTM does not include a systematic compilation of the TR drafted by the traffic safety authorities.

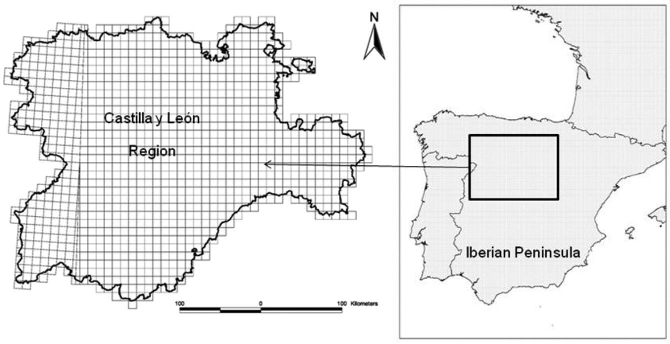

Figure 1 – Map of the 605 Regional Community of Castile and Leon, Northern Spain. The 10×10 km UTM grid square (cell) used in the study is represented on the map.

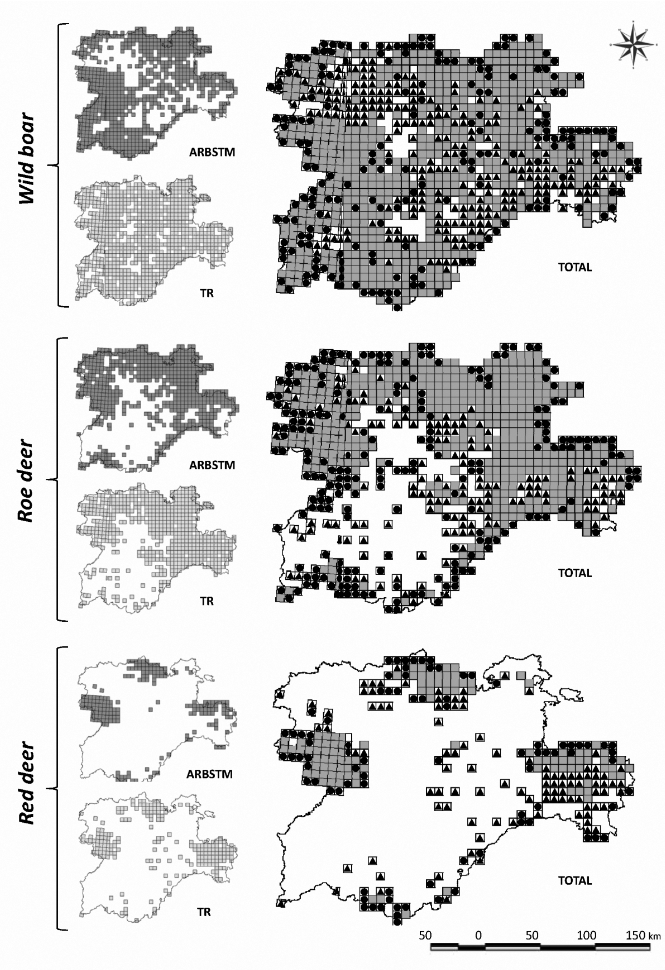

Figure 2 – Spatial distribution of the three study species: wild boar, roe deer, red deer, according to both the ARBSTM published in 2007 and the TRs published between 2002 and 2008. Solid grey represent cells where ARBSTM and TR data exist simultaneously. Black points represent cells were only ARBSTM data exist. And triangle represents TR data exclusively.

The spatial distributions from both datasets are comparable as long as two important premises are true. Firstly, both datasets must be referred to the same period of time. This is a very important point since the three ungulate species have shown an important population expansion in recent years. We addressed this issue using the ARBSTM species spatial distribution updated in 2009 that included new records up to 2008. ARBSTM datasets are periodically updated and linked in the Spanish Ministry of the Environment (http://www.magrama.gob.es/es/biodiversidad/temas/inventarios-nacionales/inventario-especies-terrestres/inventario-nacional-de-biodiversidad/bdn-ieet-default.aspx). Thus, we considered the same period of time for both datasets.

Secondly, distributions from ARBSTM and from TR are comparable as long as what they intend for spatial distribution is the same. This is the case because in both methods only one occurrence record in a cell is enough to say that the species is present within this cell. We acknowledge that this criterion has severe limitations because gives the same value to a single data cell and cells with numerous data. Moreover, it is not possible to differentiate between occasional and stable presences. For this reason, species spatial distribution can be overestimated. Nevertheless, we consider that this problem does not restrict comparisons between the two methods since both shared the limitation described.

However, despite the temporary repeatability demonstrated in the study, the method is not able to differentiate between occasional and stable species presences which could lead to overestimated distributions.

Table 1 – **a)** First two columns include the total number of UTM cells with verified presence of species in ARBSTM and the total number of positive cells obtained using TR. The following three columns include the number of positive cells distributed among the three types of cells considered: $ARBSTM_{cell}$, $ARBSTM+TR_{cell}$, and TR_{cell}. Last column shows the increase in percentage of the known distribution for the species. To compare the effect of cells at the edge, the table includes the two values for all variables: left, the number without considering border cells. Brackets include all the values incorporating all cells, with independence of size. **b)** Number of TR for the three species studied, differentiating between those that occurred in cells included in the ARBSTM and those that occurred in cells without previous known presence.

a)

	Cells in ARBSTM	Cells with TR	TR_{cell}	$ARBSTM+TR_{cell}$	$ARBSTM_{cell}$	Total of cells	Percentage of increase
Wild boar	622 (757)	735 (778)	234 (241)	501 (537)	121 (220)	856 (998)	37.62 (31.84)
Roe deer	526 (644)	527 (555)	137 (141)	390 (504)	136 (140)	663 (785)	26.05 (21.89)
Red deer	156 (190)	192 (201)	95 (99)	97 (102)	59 (88)	251 (289)	60.90 (52.11)

b)

	Total number of roadkills	Number of roadkills in $ARBSTM_{cell}$	Number of roadkills in TR_{cell}	Roadkills per $ARBSTM_{cell}$ per year	Roadkills per TR_{cell} per year
Wild boar	8004	5406	2598	1.55±2.24	1.54±1.94
Roe deer	7751	6821	930	2.51±2.74	0.97±1.55
Red deer	1409	921	488	1.38±2.19	0.71±1.17

UTM grid square classification

To identify the zones where species distributions are best represented using TR, we evaluated the properties of three types of UTM grids squares (or cells): those that were matched with TR (TR_{cell}); positive cells in the ARBSTM and also with TR in them ($ARBSTM+TR_{cell}$); and positive cells in the ARBSTM without TR in them ($ARBSTM_{cell}$).

The variables analyzed were topography, land use and road density. The mean altitude for each UTM cell was derived from a digital elevation model at 25-meter resolution created by the Spanish *Instituto Geográfico Nacional*. Land uses were obtained from the last version of the CORINE land cover project, developed by the European Environment Agency in 2000. In Spain, the classification includes 5 levels and 85 classes charted from satellite images at a scale of 1:100000. The minimum mapping size is 25 hectares. We selected the most important classes with respect to the ecology of the species studied. These classes were merged in 4 categories: 1) forest: composed of mixed forest, coniferous forest, and broad-leaved forest; 2) crops: non-irrigated arable land, permanently irrigated land, vineyards, orchards, annual crops associated with permanent crops, agricultural land with natural vegetation, and agro-forestry areas; 3) scrub: moors and heath-land, sclerophyllous vegetation, transitional woodland scrub, and 4) pasture: natural grassland. The land use value considered was percentage of area of each category within each cell.

In species with broad home ranges and long daily movements, the probability of being killed on the road increases with higher traffic volumes and with road density because animals have to cross more roads (Colino-Rabanal et al., 2011). The importance of the roads in each cell was computed using an index (road index: *RI*) that included both road length and traffic volume. Traffic volumes were obtained from the Spanish Ministry of Public Works and Department of Public Works of the Regional Government. The road network was derived from 1:50000 topographic maps. We propose the following mathematical expression for the road index (*RI*):

$$RI_{cell} = \log \frac{\sum_{i=1}^{n} RL_n \times TV_n}{S_{cell}}$$

Where RL is the length of each road segment in the cell and TV is the traffic volume for these road segments. Both are divided by the cell area, S_{cell}, which converts the index into an intensive variable (not depending on the size of the system).

One of the problems involved in this was how to consider the cells at the edge of the region. In this sense, the probability of detection decreases as the cell area in the study region diminishes. Moreover, due to the spatial distribution of the road network at several scales, the edges of the area have lower road densities and lower traffic volumes. Thus, the inclusion of all cells could introduce bias into the analysis. Our criterion was to include only those cells with an area higher than the half area of the complete cell (50 km^2) in the analysis. The same criterion was followed with the compensation cells between the UTM zones.

Statistical analyses

For all three species, a non-parametric Kruskal-Wallis test for multiple samples was used to analyse the differences among the three types of cells with respect to the topographic, land-use, and traffic variables. Including only the variables with significant differences, we performed a multinomial logistic regression to model the main characteristics of each type of cell. This analysis compares multiple groups through a combination of binary logistic regressions to compute the probability that a certain case will belong to a given group. Multinomial regression requires that the independent variables be metric or dichotomous and that the dependent variable be non-metric, in this case nominal. Assumptions of normality and homogeneity of variance for the independent variables are not necessary. However, model fitting in logistic regressions is sensitive to multicollinearity among the predictive variables (Hosmer and Lemeshow, 1989). Here we developed two multicollinearity diagnostic statistics: Variation Inflation Factors (VIF) and Tolerance (TOL). Variables with a VIF of $N \geqslant 2$ and a TOL of $b \leqslant 0.4$ were excluded from the logistic analysis. We used Mann-Whitney U-tests as post hoc tests to determine significant differences between the three groups. To avoid type I errors, p-values were Bonferroni corrected. We used SPSS 18.0 in order to perform the analysis.

To assess the temporal repeatability in the detection of presences using TR, we selected one year as unit base, because it encompassed the dynamic seasonal behavior and biological requirements of animals killed on the road. To measure how representative the results of each year were, we calculated the Spearman rank correlation between the spatial distributions defined using TRs over one year with the sum of times that the species in the cell had been cited during the rest of the study years. Fisher's combined test was used as a data-merging technique in order to combine the results obtained in the correlations. We also used Spearman tests to study if temporal repeatability in a cell was associated with the number of TR in that cell and to search for correlation between the number of cells with TR in a year and the total number of TR in that year for each species.

Moreover, accumulation curves were obtained to define how many years of data were necessary for a certain level of known distribution to be reached. As a criterion, we used the identification of 85% of positive cells. As positive cells depend on sampling effort, a greater number of sampling years must show higher number of positive cells. Thus, those abundant species are detected quickly into cells with higher rates of roadkills, increasing the curve slope. In opposite, cells with lower animal populations, lower road traffic or situated in areas where roadkill animal fluctuates among years, will show a decreasing slope on successive years. When the slope of the curve is zero, this indicates that the total number of positive cells detected for species in the study period using the method chosen has been reached. The spatio-temporal

Table 2 – Non-parametric Kruskal-Wallis tests to identify differences among the three types of cells considered with respect to the topographic, land use and traffic variables. The four variables with the highest statistical values are shown in bold. The degrees of freedom for all tests are 2. Table also includes Mann-Whitney U-tests as post hoc tests for between-groups comparisons with Bonferroni correction for multiple comparisons. The cell types (1: TR_{cell}; 2: ARBSTM+TR_{cell}; 3: $ARBSTM_{cell}$) that are statistically different are specified ("+" indicates that all types are different).

	Wild boar			Roe deer			Red deer		
	H	*p*-value	Post-hoc test	H	*p*-value	Post-hoc test	H	*p*-value	Post-hoc test
Altitude	16.294	<0.001	1–3; 2–3	15.196	0.001	1–2	8.867	0.014	1–3
Slope	**56.950**	<0.001	+	**52.448**	<0.001	1–2; 1–3	**30.276**	<0.001	+
Forest	7.927	0.023	1–2	**55.345**	<0.001	+	**19.132**	<0.001	1–2; 1–3
Crops	**62.798**	<0.001	+	**35.795**	<0.001	+	**24.558**	<0.001	+
Scrub	**20.434**	<0.001	+	5.363	0.068	1–3; 2–3	0.036	0.981	
Pasture	9.327	0.009	1–3	29.343	0.001	1–3	12.785	0.002	1–3; 2–3
RI	**93.734**	<0.001	+	**32.540**	<0.001	1–3; 2–3	**29.512**	<0.001	1–2; 1–3

variations in populations, sampling effort, and the order of data input can modify the shape of the curve. Three curves were obtained for each species: one that considered the temporal sequence from 2002 to 2008; another ordering the data in a decreasing sequence from the year with the most positive cells to the year with the fewest, and finally the third curve, whose aim was to prevent spatio-temporal variations by randomising the order of input of the annual data and the average number of positive cells calculated from a value of 1 and the total number of years. This process computes a smoothed curve, which reflects the statistical average of the addition of positive cells with the increase in sampling effort through more years of TR. This curve was computed using EstimateS 7.5 (Colwell, 2005).

To identify which factors contributed to an increase in the repeatability of detection along years in a certain cell, Spearman correlations were carried out between the number of years with at least one TR and the variables included in the multinomial regression (topography, land use and road density). The level of significance in all analyses was $p<0.05$.

Results

Spatial analysis

The number of cells for each type is summarised in Tab. 1a for all three species. Results were calculated both after taking the edge effect into account and for the total number of cells (results in brackets). Without considering cells of less than 50 km^2, the roadkill dataset increased the number of positive cells by an average of 41.52%±17.75 (±SE). The spatial distribution derived only from TR had 17.51%±11.68 more positive cells. 34.60%±11.54 of the cells with TR represents a new site for the species (TR_{cell}). However, for 27.71%±9.32 of the cells cited in the ARBSTM, there are no TRs ($ARBSTM_{cell}$) and hence these cells would not appear in the spatial distribution when using only TR data. The results considering all cells, including those situated

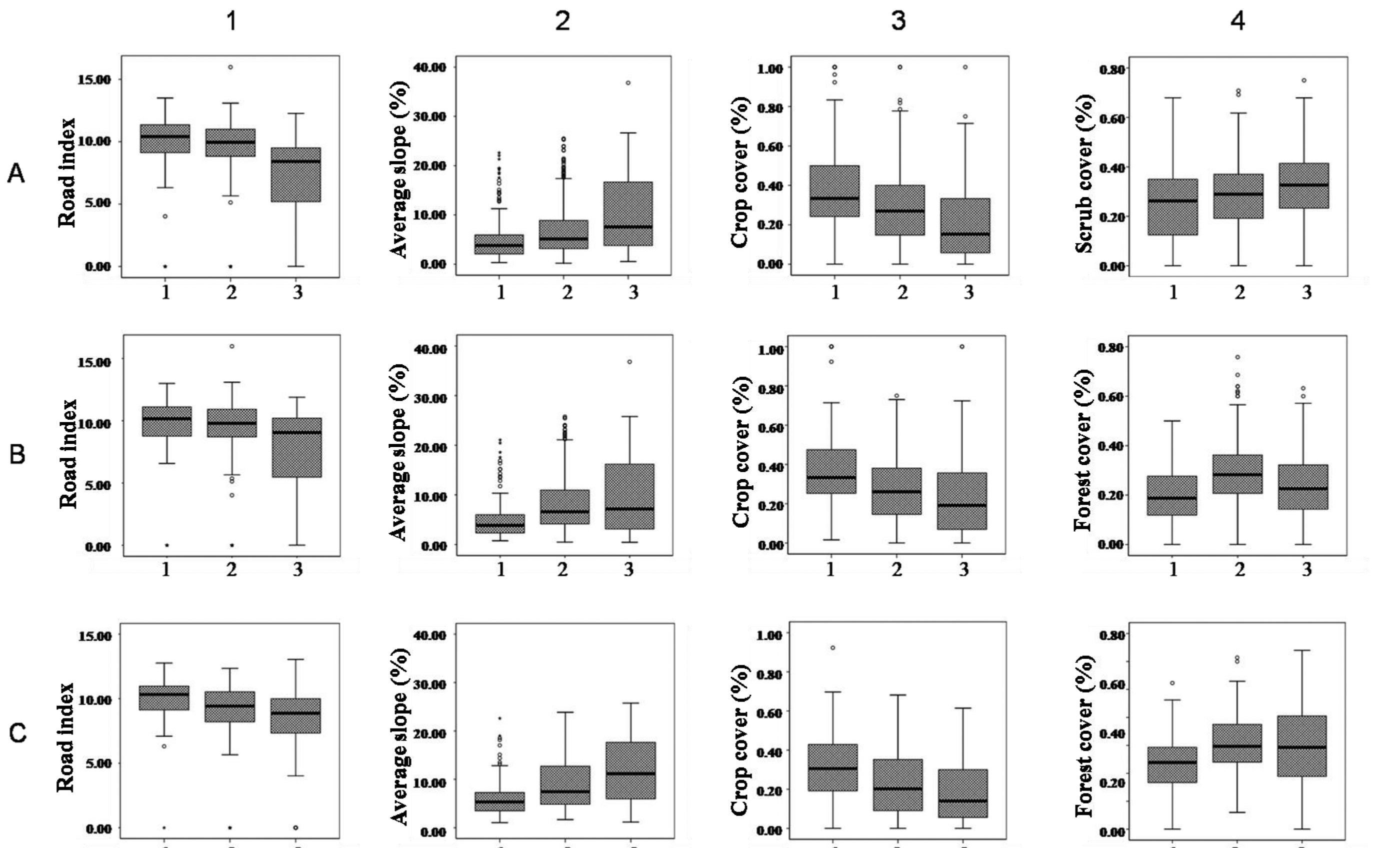

Figure 3 – Statistical distributions of the four variables (road index, slope, crop surface and shrub/forested habitat) with the highest χ^2 value in the non-parametric Kruskall-Wallis test for TR_{cell} (first column at each box-plot), ARBSTM+TR_{cell} (second column at each box-plot) and $ARBSTM_{cell}$ (third column at each plot). Rows: A) wild boar; B) roe deer and C) red deer. With the exception of the percentage of forest in both roe deer and red deer, most of the variables indicate an increasing or decreasing gradient from TRcell to $ARBSTM_{cell}$.

at the edges and the compensation cells between UTM zones smaller than 50km^2, reveal a slightly lower increase in the number of positive cells (35.28%±15.40), and a higher percentage of $ARBSTM_{cell}$ (32.37%±12.62). The spatial distributions contained in the ARBSTM and the new cells defined using TR are shown in Fig. 2.

Number of TR per UTM cell — differentiating between ARBSTM+TR_{cell} and TR_{cell} — is shown in Tab. 1b. For the total number of collisions, the ratio ARBSTM+TR_{cell}/TR_{cell} is 1.8±0.8, meaning that TR are more numerous where other type of data about the species presence are available. Differences are statistically significant (Mann-Whitney U test; z=-8.15, p<0.001). This works for roe deer (ratio=2.58; z=-8.10, p<0.001) and red deer (ratio=1.85; z=-3.46, p=0.001), but not for wild boar (ratio=0.99; z=-1.26, p=0.208), indicating a higher number of road kills in TR_{cell}.

Significant differences in the Kruskal-Wallis test were observed among the three types of cells with respect to topography, land uses and traffic (Tab. 2). Fig. 3, using box-plots, includes the statistical distributions of the four most significant variables for each species. Box plots afford increasing or decreasing gradients in nearly all variables from TR_{cell} to $ARBSTM_{cells}$, which indicates how those variables affect the ability of the method to detect the presence of species. According to Mann-Whitney U-tests for between-groups comparisons with Bonferroni correction for multiple comparisons, in the case of wild boar TR_{cell} characterised by a higher *RI*, a higher average cropland value, and flatter areas (Tab. 2). The differences in roe deer are more related to land use. TR cell show lower proportions of forested areas and higher proportions of croplands. The proportion of forested areas does not follow a gradient among the types of cells, being higher for the ARBSTM+TR_{cell}. The *RI* was statistically lower for $ARBSTM_{cells}$. The results for red deer are similar to those obtained for roe deer (Tab. 2).

The results of the multinomial regressions are shown in Tab. 3. The multicollinearity among variables was higher than the fixed criterion, and hence the two variables with lower values in the Kruskal-Wallis tests were removed. In the multinomial regression for wild boar (-2 Log likelihood=1454.88, pseudo-R^2=0.21, p<0.001), $ARBSTM_{cells}$ had steeper slopes, lower *RI* and crop cover than TR_{cells} and a lower *RI* than ARBSTM+TR_{cells}. In the model for roe deer (-2 Log likelihood=1133.81, pseudo-R^2=0.22, p<0.001) $ARBSTM_{cells}$ differed from TR_{cells} in showing a lower *RI* and crop cover and steeper slopes, and it differed from ARBSTM+TR_{cells} in having a lower proportion of forested areas and *RI*. For red deer (-2 Log likelihood=477.13, pseudo-R^2=0.26, p<0.001), $ARBSTM_{cells}$ showed steeper slopes and a lower *RI* than TR_{cells}, and also steeper slopes and forest cover than ARBSTM+TR_{cells}.

Temporal repeatability

The number of positive cells varied slightly across years for wild boar (CV=8.3%), roe deer (CV=14.9%) and red deer (CV=9.9%). Spearman rank correlations measuring temporal repeatability were significant for wild boar (r_s=0.440±0.044; Fisher's combined test, γ^2_{14}=193.41, p<0.001), roe deer (r_s=0.525±0.043; Fisher's combined test, γ^2_{14}=193.41, p<0.001), and red deer (r_s=0.362±0.123; Fisher's combined test, γ^2_{14}=161.50, p<0.001). The number of years with the presence of the three species observed in a cell was correlated with the total number of TR in that cell: wild boar (r_s=0.950, p<0.001); roe deer (r_s=0.953, p<0.001), and red deer (r_s=0.964, p<0.001). The number of cells with TR in a year was highly correlated with the total number of TR in that year for all three species studied: wild boar (r_s=0.829, p=0.021); roe deer (r_s=0.969, p<0.001), and red deer (r_s=0.860, p=0.013).

According to the accumulation curves (85.71%) (Fig. 4), three years are necessary for the wild boar to reach 85% of the total distribution known for the study period. For the average curve (89.9%±2.3) or the chronological curve (88.0%) the number of years is four. In roe deer, the accumulation curve surpasses 85% in the third year (89.9%); it surpasses average curve in the fourth year (89.3%±2.7) and the chronological curve reaches 89.7%. in the fifth year. For red deer, more years are required: four for the accumulation curve (86.3%); five for the average curve (87.2%±7.3), and six for the chronological curve (92.9%).

For the three species studied, repeatability increased with the *RI* (in wild boar r_s=0.441, p<0.001; in roe deer r_s=0.220, p<0.001; in red deer r_s=0.201, p=0.001). Land use was significant but varied among species. For wild boar, repeatability decreased with the percentage of pasture (r_s=-0.126, p=0.001) and increased with the proportion of forest (r_s=0.130, p<0.001). The continuous presence over the years of roe deer increased with the proportion of forest (r_s=0.218, p<0.001) and scrub (r_s=0.130, p=0.003). Increases in slope (r_s=0.209, p<0.001) and altitude (r_s=0.121, p=0.006) were also favourable to species detection. For red deer repeatability increased with the percentage of forest, although it decrease with the topographic slope (r_s=0.195, p=0.006).

Discussion

The volume of data concerning road collisions with wild animals is enormous considering that all such animals are potentially susceptible to dying in traffic incidents and that road kills are widespread around the world, especially in developed countries where road networks are more dense (Groot Bruinderink and Hazebroek, 1996; Romin and Bissonette, 1996; Coelho et al., 2008; Eloff and van Niekerk, 2008; Smith-Patten and Patten, 2008; Brockie et al., 2009). These useful data from TR could be used in animal studies for different goals, although with some restrictions. Our analysis suggests that TRs concerning animal-vehicle collisions could help to expand our knowledge about species distribution. However, this source should only be considered complementary and cannot replace other standardised census methodologies because its reliability is strongly dependent on spatial variables. Sampling techniques based on road kills are not systematic and depend on factors such as the volume and speed of the traffic (Malo et al., 2004; Seiler, 2005), and hence sampling effort varies between different segments of roads. Also, wild boar and roe deer with - during the last few decades- expanding population throughout Spain, are involved in 79% of collisions (Saénz-de-Santa-María and Tellería, 2015), being roadkill data an useful tool in order to measure the expansion rate of these species.

The ecological characteristics and the requirements of the species in question are important factors (Peris et al., 2005). Owing to these factors, the probability of detecting the presence of species based on TRs varies among cells. Considering the topography and the regional distribution of human settlements, this methodology seems to be most reliable in two situations. The first is on the plateau, where species populations are lower owing to a lack of suitable habitats, but also where the road index reaches the highest values because of the radial configuration of the road network centred along the regional capital. In this area, TRs could offer one of the best methods for identifying the presence of species, as demonstrated by the considerable proportion of TR_{cells} located in the centre of the region. The second situation occurs in the cells with moderate road kill and cells located in areas suitable for the species studied. Anyway, most of these areas are visited by naturalists, researchers and hunters, and hence the presence of ungulates is usually known beforehand (ARBSTM+TR_{cells}). TRcells have a higher proportion of croplands and higher road kill indices, but lower percentages of natural vegetation cover and gentler slopes than ARBSTM+TR_{cells}. The method was unable to detect species present in the $ARBSTM_{cells}$, which have a lower average *RI* than the other types of cells and lower proportions of suitable habitats than ARBSTM+TR_{cells}. In many cases these cells are located in road-less zones of the mountainous periphery, sometimes with a considerable percentage of the area above the bioclimatic stages with habitats suitable for these species, where the probabilities of collision are reduced and hence other methods of data collection would be more reliable. This justifies the diversification of sources of information and methodologies in order to obtain proper spatial species distributions.

Data on presence based on point observations such as road kills must be taken with caution because the animals involved may be dispersed or vagrant individuals without well-established populations in the area. This is especially important in the case of large carnivores with wide

Table 3 – Fitted parameters of the multinomial logistic regression models describing relationships among the three types of cells considered. The $ARBSTM_{cell}$ is the reference category.

	Wild boar							
	TR_{cell}				$ARBSTM+TR_{cell}$			
	B	SE	Wald	Sig.	B	SE	Wald	Sig.
Intercept	−2.534	0.968	6.845	0.008	1.598	0.764	4.374	0.004
Altitude	0.002	0.001	3.665	0.053	−0.001	0.001	3.693	0.054
Slope	−0.156	0.034	20.477	<0.001	−0.032	0.023	1.909	0.167
Crops	2.235	0.924	5.840	0.015	−0.023	0.851	0.001	0.997
Scrub	−0.672	0.976	0.473	0.491	−0.990	0.861	1.322	0.250
RI	0.227	0.039	32.406	<0.001	0.179	0.029	39.012	<0.001

	Roe deer							
	TR_{cell}				$ARBSTM+TR_{cell}$			
	B	SE	Wald	Sig.	B	SE	Wald	Sig.
Intercept	−0.940	0.692	1.841	0.175	−2.209	0.589	15.626	<0.001
Slope	−0.127	0.035	13.297	<0.001	−0.020	0.022	0.765	0.382
Forest	0.268	1.284	0.044	0.834	5.531	1.033	28.642	<0.001
Crops	1.576	0.934	2.847	0.042	2.209	0.833	7.020	0.008
RI	0.148	0.042	12.277	<0.001	0.166	0.030	30.177	<0.001

	Red deer							
	TR_{cell}				$ARBSTM+TR_{cell}$			
	B	SE	Wald	Sig.	B	SE	Wald	Sig.
Intercept	−1.646	1.225	1.806	0.179	−0.409	0.951	0.186	0.667
Slope	−0.125	0.045	7.693	0.005	−0.082	0.037	4.797	0.028
Forest	−0.137	1.916	0.005	0.942	3.784	1.728	4.794	0.028
Crops	1.845	1.532	1.145	0.228	1.534	1.498	1.048	0.306
RI	0.309	0.084	13.541	<0.001	0.039	0.049	0.644	0.422

ranges of movement and dispersion. Wild ungulates, and specially wild boar, have also shown a great capacity for dispersion. In this sense, roadkill sites could be considered as probable areas of species presence. The temporal repeatability in the detection of species presence reduces this uncertainty. According to our results, repeatability across time is directly correlated with the road index and the area suitable for the species. Thus, in the study region repeatability is higher in the mountainous surroundings than on the plateau, especially in the case of roe deer and red deer, whose populations are more prominent in forested areas. However, despite the temporary repeatability demonstrated in the study, the method is not able to differentiate between occasional and stable species presences which could lead to overestimated distributions. Nevertheless, ARBSTM distributions have the same limitation. Other potential sources of error that could lead to biases in species spatial distributions obtained from TRs are all the mitigation measures that artificially lower the number of collisions, e.g. stretches of road unavailable to animals because of fences, or wildlife corridors.

Despite the limitations, the large volume of data stored by TRs offers a continuous and inexpensive source of information, with coverage equivalent to nearly the whole territory, and no further resources are required. This coverage is an advantage with respect to other data sources used in the preparation of atlases, where the distributions depicted are merely a compendium of data from individual and collective field works, but with a heterogeneous spatial sampling effort. Thus, fauna inventories are more exhaustive in certain zones, such as natural parks, areas close to research centres or sites with powerful naturalist associations, which biases coverage and species distribution, although in a different way to that obtained using roads kills as an information source. This suggests that the use of both methods helps to improve results.

In Spain, several naturalist organisations record roadkill data periodically for conservation or traffic safety purposes. However, most of the data, especially when they involve small species, are not recorded and the information is lost. In many parts, only information about collisions with large mammals and birds is available; such information is systematically recorded in TRs drafted by traffic authorities because this type of collision represents a threat to traffic safety and causes damage to property and human beings (Conover et al., 1995; Bissonette et al., 2008). Owing to their large body mass and their population sizes, ungulates are the main group reported. The information concerning road kills involving other groups such as invertebrates, reptiles, amphibians, or small- and medium-sized birds and mammals is still scarce and has not been compiled systematically at large scale because groups of small-sized animals are not usually involved in serious traffic accidents. Future studies should attempt to monitor not only large-ungulate/vehicle collisions, which usually have a low impact on animal populations, but also to systematically report collisions with small and medium-sized vertebrates, especially those threatened by extinction. Such information would facilitate the localisation of hotspots against which mitigation measures could be focused. These TRs should include variables of interest such as the age or sex of the animal involved in order to gain further insight into the consequences of road kills.

Environmental and road agencies should adopt standardised processes for reporting road kills in order to ensure the validity of the data. An unequivocal identification over time of a certain point in a complex system such as a road network could be complicated at a broad spatial scale; changes in road entitlement and the improvement and construction of roads could introduce modifications that would hinder the spatial location of road kills. Moreover, limited spatial accuracy reduces the usefulness and reliability of the results based on road kills (Gunson et al., 2009). The use of GPS systems to record the UTM coordinates could probably prevent confusion in the actual location of collisions and could contribute to easier, faster and more effective data treatment. In this sense, taking advantage of the use of new technologies as smartphones or other devices, a growing number of citizen science projects are offering more complete data for safer transportation and mitigation of roadkill hotspots (Vercayie and Herremans, 2015).

In conclusion, TRs of wildlife-vehicle collisions offer a useful source of information that can be used not only in the wildlife-road tandem but also in other zoological studies, such as those addressing species distribution. If correct knowledge of species distribution is a previous step to implementing management and conservation policies, it is necessary to use all the data sources available, particularly when the

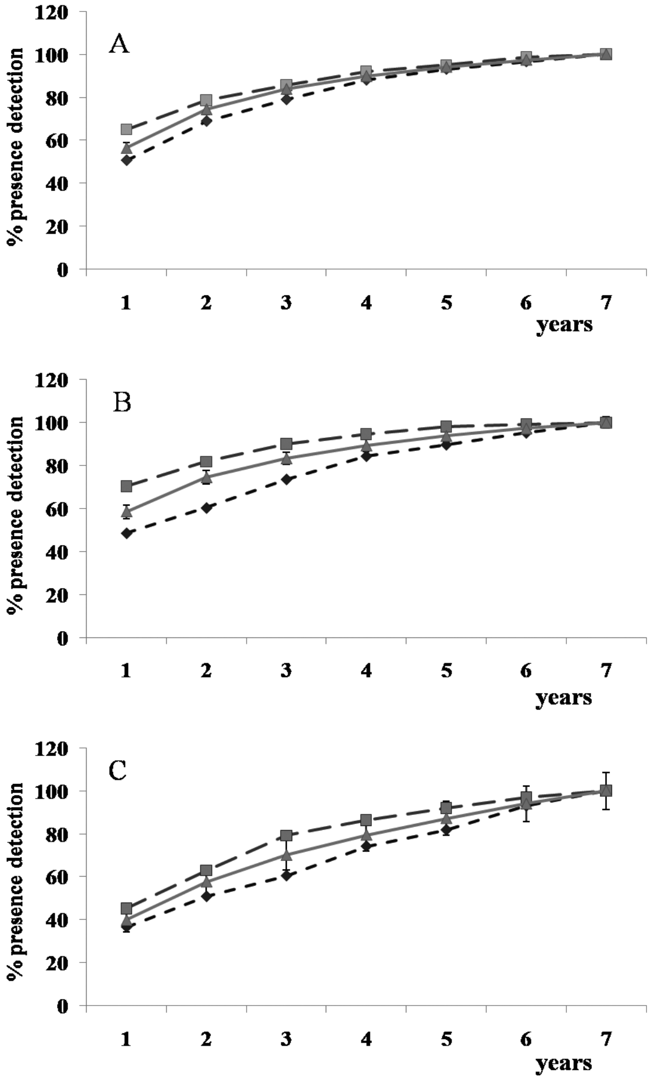

Figure 4 – Accumulation percentage of cells with ungulates identified across the study period. A) wild boar; B) roe deer and C) red deer. Curves computed according to Annual data ordered according to a decreasing number of positive cells (squares); Average curve, obtained by randomising the input of annual data and developing 100 permutations (include error bars) (Triangles); Annual data ordered according to chronological sequence (Points).

economic resources are not sufficient. There are other indirect methods — agricultural damage (Vecellio et al., 1994; Beasley and Rhodes, 2008), attacks on livestock (Camarra, 1987; Stahl et al., 2001; Woodroffe et al., 2005), and hunting statistics (Tellería and Sáez-Royuela, 1984; Cattadori et al., 2003) — which have been used to infer ecological information about study species. The data from these sources are also compiled continuously, and may be useful after due filtering and critical analysis. Data-sharing agreements are an integral component to ensure data flow between agencies, favouring multidisciplinary focuses and optimising the available resources.

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