Transportation Research Part D 16 (2011) 281–287

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Assessing methods of mitigating wildlife–vehicle collisions by accident characterization and spatial analysis

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ARTICLE INFO

Keywords:
Wildlife–vehicle collisions
Transport safety
Road ecology
Vehicle collision prevention

ABSTRACT

This paper addresses the identification of areas where wildlife–vehicle collisions mitigation measures can be adopted by the study of collision records for specific road sections on the regional road network in the province of Lugo, Galicia, Northwest Spain in 2006–2007. Accident concentration sections, or areas where wildlife–vehicle collisions are common are identified, and the relationships between species and factors associated with accident levels such as the time of year or day, road characteristics, and the intensity of traffic levels are explored.

1. Introduction

Wildlife–vehicle collisions (WVC) affect animal communities and involve human safety and vehicle damage. To prevent or mitigate WVC, a series of measures can be adopted, ranging from simple road signalling to more complex measures such as improving building infrastructures, installing roadside and in-car devices, and managing wildlife populations (Forman et al., 2003). Even when a large effort is made to develop and test each specific measure, the procedures for selecting the spatial locations of the measures are often arbitrary and implementation of any measure throughout an entire road network is often impossible because of costs and logistics.

When selecting the best places to locate mitigation measures a number of factors become relevant including traffic levels and speeds, animal populations, driver awareness, time of year/day, road attractiveness, habitat juxtaposition, integration in landscape, and roadside vegetation (Litvaitis and Tash, 2008). The variety of factors involved and the different availability of data often make it difficult to develop predictive models regarding the location of optimal measures and related decisions.

The study develops a simple, straightforward method for selecting the best locations and types of WVC mitigation methods. Instead of considering multiple environmental factors, the WVC history of the road network is analysed, with the main focus is then on spatio-temporal variables related to collision points and road characteristics. We analysed data for the province of Lugo, Northwest Spain provided by the National Traffic Agency.

2. Methods

Although the province of Lugo (Fig. 1) experiences large numbers of WVCs (Dirección General de Tráfico, 2004), mitigation measures are not well developed beyond simple signalling and there have been no efforts to understand collision pro-

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doi:10.1016/j.trd.2011.01.002

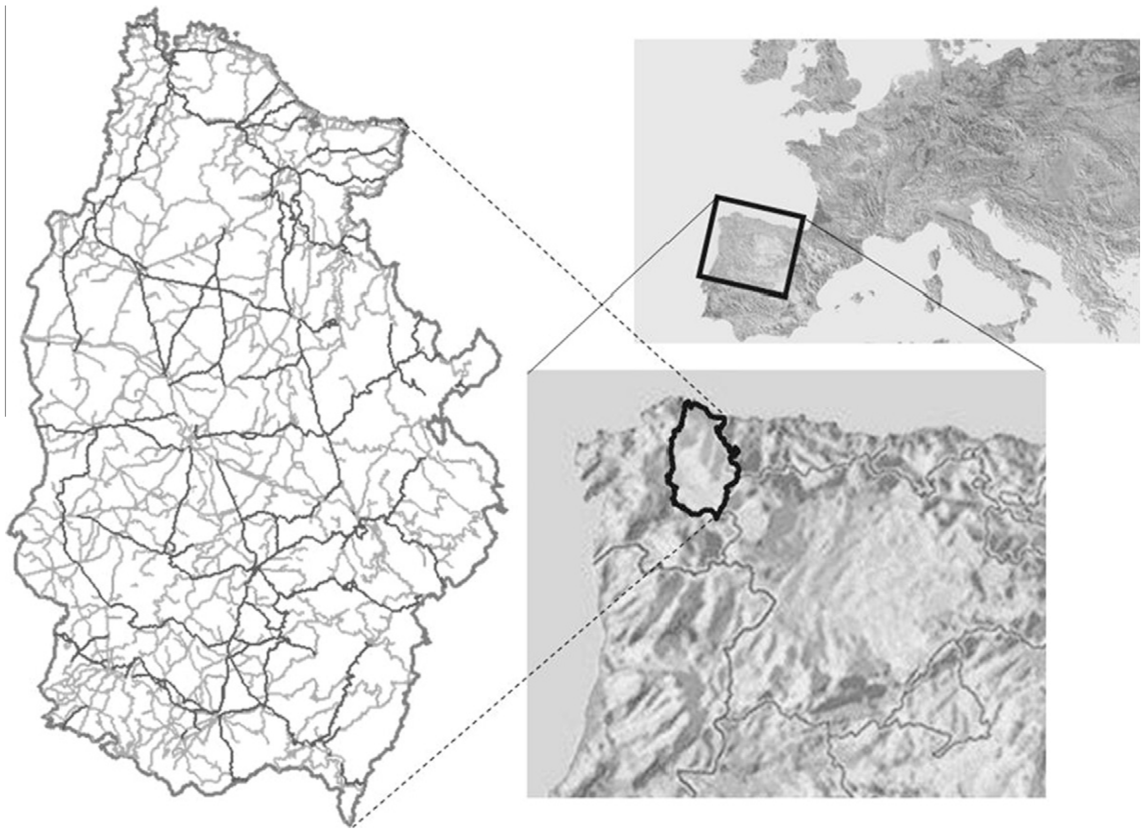

Fig. 1. The study area.

cesses. The 1426 km road network studied includes roads in the province managed by the regional administration and includes high-capacity (HCR), 2.3%; basic primary (PB), 16.6%; complementary primary (PC) 35%; and secondary roads (S), 46.1%. Only roads where verified collisions with roe deer or wild boar had taken place are considered.

Data from 377 collision points between 2006 and 2007, recorded by the Dirección General de Tráfico (2008) are examined and include the location of the accident by its milestone reference, the species involved, and its date and time. The geographical location of each accident is refined by identifying the milestone reference with its *X*, *Y* coordinates using the Visual Road Catalogue provided by the regional administration. Such coordinates enables accurate identification of the accident spot in a geographic information system and are combined with other spatial information. Three species of animal were considered: roe deer (*Capreolus capreolus* L.), wild boar (*Sus scrofa* L.) and red deer (*Cervus elaphus* L.); preliminary analyses revealed that 75.4% of accidents involved these species. Digital cartography of roads was used for spatial analysis of the accidents and traffic reports from the regional administration were consulted to obtain data on traffic density, measured as daily average intensity (DAI). The DAI values are available for the road sections corresponding to 344 collision points; for those road sections with no suitable traffic data, the DAI was estimated from the value of the closest road section with similar characteristics (25 points) or by interpolation (24 points) of the values for the nearest roads. Finally, although considered an important variable, land cover in the direct environment of the accident was not considered because the available databases lack the resolution to provided local effects.

The method of analysis is:

- Exploratory analysis of the frequency distribution of accidents considering temporal variables as well as types of road to identify the temporal distributions of accidents characteristic to each species, and the occurrence on different types of roads.
- Correspondence analysis among variables related to both roads and species to relate the temporal ranges to other variables such as species, road and traffic characteristics to enhance the selection of mitigation measures.
- Identification of spatial clustering of accidents, to select areas where mitigation efforts should be concentrated.

The frequency distribution of accidents with regard to date, time and species is derived to provide a basic description of the accidents. This is to obtain a temporal characterization of the occurrence of accidents for each species. Strong emphasis is placed on relating the timing of accidents to seasonal variations in the times of dawn and dusk, because this is likely to influence both animal behaviour and visual conditions for drivers. The time of accident is therefore related to the times of sunset and sunrise, obtained from the ephemeris tables of the Spanish National Geographic Institute (2010).

Multiple correspondence analysis (MCA) is used to identify relationships between accidents and variables associated with road characteristics (type and traffic intensity), species (roe deer/red deer/wild boar), and/or temporal variation (season, day of the week and hour). MCA provides a geometric model of data, representing individual events by points in a low-dimensional Euclidean space, and summarizes the relations between the categorized variables (Le Roux and Rouanet, 2004). It generates bidimensional maps based on two factorial axes representing variability in the data, with the relationship between variables directly related to the proximity of the categories on the map. The technique is appropriate when the object of study is described by categorical variables (Moreno Perez, 2009). The variables included in the MCA analysis, and their categorization are 1)

- Road types classified into VAC; PB; PC; S.
- Traffic volume according to: less than 1500 vehicles/day (v/d); 1500–3000 v/d; 3000–5000 v/d; 5000–10000 v/d; 10000–15000 v/d.
- Animal species; roe deer, red deer, and wild boar.
- Seasons.
- Days of the week.
- Time of day in five groups: 0600–0900; 0900–1800; 1800–2200; 2200–0100; and 0100–0600.

Aggregations of collision points are done for each species by combining nearest neighbour spatial statistics with a point density map. The complete distribution of nearest neighbour distances (NND) between points is then used. For n points occurring in an area A, NND estimates for each ith point the reciprocal distance d_i to its nearest neighbour inside a circle of radius r, and its empirical distribution function can be calculated following Diggle (2003):

$$\widehat{G}_1(r) = n^{-1}\#(d_i \leqslant r)$$

This function can be used as a descriptor of the spatial structure of a given set of points (De la Cruz, 2008) using complete spatial randomness (CSR) comparison tests that enable differentiation between even, random and aggregated spatial distributions of points. It considers as a null hypothesis that the observed pattern is a realization of a homogeneous random process (De la Cruz, 2008). If the null hypothesis is rejected, the nature of the pattern will be indicated by the positive (aggregated) or negative (uniform) deviations of the function.

A network-NND is applied using distances calculated from the transport network. For the CSR comparison test, 1000 Monte Carlo simulations are performed to derive upper and lower 5% confidence intervals for the NND of random-distributed points. When plotting the cumulative number of points against observed and expected NND, if the observed curve adopts values higher than the upper 5% NND curve, the points are significantly aggregated (Okabe et al., 2009). Values below 5% indicate a uniform pattern, while values between the two limits indicate a random distribution. This relationship between the expected and the observed NND curves also enables identification of the maximum NND at which point aggregation is considered as statistically significant. This maximum distance is used as a reference to elaborate a point density raster map. The procedure consists of moving a circular kernel through the whole area, counting the number of points and representing these on a raster map. The maximum NND for each species is used as the kernel diameter ensuring that the points included in the density calculation are significantly aggregated.

3. Results

The temporal distribution of the accidents in relation to sunrise and sunset reflect large differences between those caused by roe deer and wild boar. Red deer contributed little information on this matter, because only three cases were reported. Collisions caused by wild boar were concentrated at night hours (91%), particularly between 1 and 4 h after sunset, with few cases between sunrise and sunset (Fig. 2). Conversely, collisions involving roe deer were more evenly balanced between night (55%) and daylight (45%), and are apparently concentrated in the hours immediately after both sunrise and sunset (Fig. 3). This may be associated with the foraging behaviour of the animal, which are continually active during daylight (Mateos-Quesada, 2005). These behavioural details may determine the selection of mitigation measures to a great extent, and for example, warning reflectors depend on the effect of vehicle headlights (Putman, 1997), and sound devices may not be effective at night in populated areas.

The weekdays when most collisions occurred are Thursday, Saturday and Sunday (51% involving wild boar, and 47% roe deer). Seasonal variations are also differ for by species: roe deer collisions are more common in late spring and summer months, whereas wild boar collisions are more frequent in autumn and winter; this is consistent with previous reports, and may be related to the movements of wild boar herds during the breeding cycles, as well as to random movement of individuals due to disturbances in the hunting period, which varies in Spain, but generally lasts from September to March (Peris et al., 2005; Santos et al., 2004). Consequently, some measures will only be useful in remedial specific periods of the year.

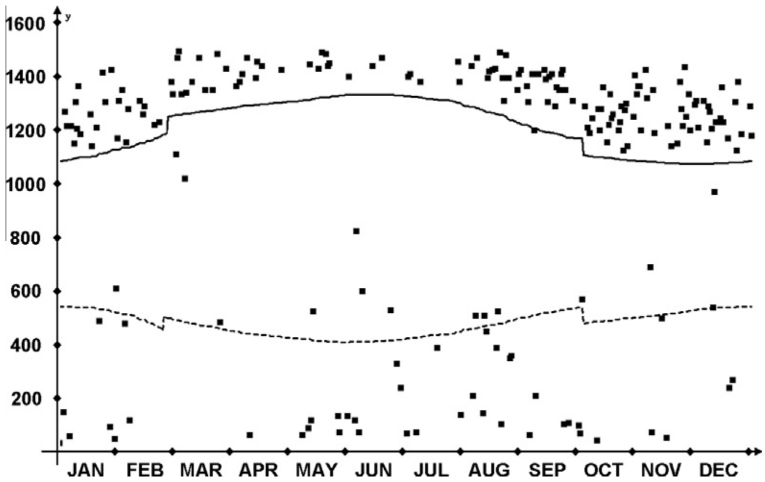

Fig. 2. Temporal distribution of collisions with wild boar. *Notes*: The cumulative time (minutes) from midnight is plotted on the *y* axis. The time of sunset is represented by a continuous line and the time of sunrise by a dotted line.

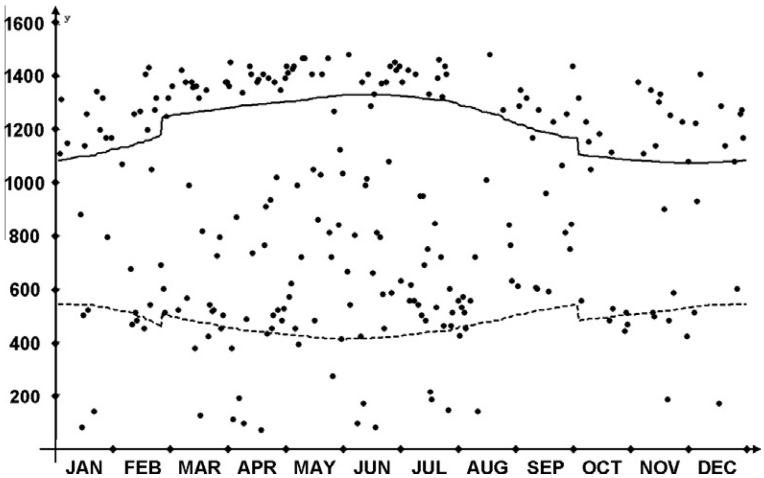

Fig. 3. Temporal distribution of collisions with roe deer. *Notes*: The cumulative time (minutes) from midnight is plotted on the *y* axis. The time of sunset is represented by a continuous line and the time of sunrise by a dotted line.

With regard to the type of road, nearly 60% of accidents occur on PB roads, followed in order by PC roads, VAC and SR. As regards traffic intensity, 32% of accidents occur on roads with DAI values of between 5000 and 10,000 vehicles per day, followed by the roads with 1500–3000 per day, 3000–5000 per day and <1500 per day. Only 4% of collisions occurred on roads with the highest DAI values, although such intense traffic occurs only on very few sections of roads in the region. These results are consistent with Ramp et al. (2005) and demonstrate the influence of traffic levels on the number of WVC. Nevertheless, the number of collisions varies widely, while traffic levels remains constant (Gonser et al., 2009).

MCA analysis enabled detection of relationships with other factors Fig. 4a shows that factorial dimension 1 (*x* axis) explains 31.9% of the variance, and dimension 2 (*y* axis), 28.6%. The contribution of each variables used in the analysis is proportional to the distance from the origin, and their dependence on each dimension is represented as a percentage in Fig. 4b. The analysis reveals a strong relationship between wild boar collisions and Sundays in autumn and winter, towards sunset (6 pm to 8 pm) that can be interpreted in terms of a wild boar's life cycle and the influence of hunting. A weaker relationship is observed between accidents and HPR roads, probably because of the large concentration of accidents on one of these roads. Conversely, there is a close relationship between roe and red deer collisions and spring and summer, throughout the morning and on Tuesdays; a relationship difficult to interpret! A general relationship is found between collisions irrespective of species and Wednesdays, Fridays, and PC and SR roads. Weaker relationships are found with the early hours of Thursdays and

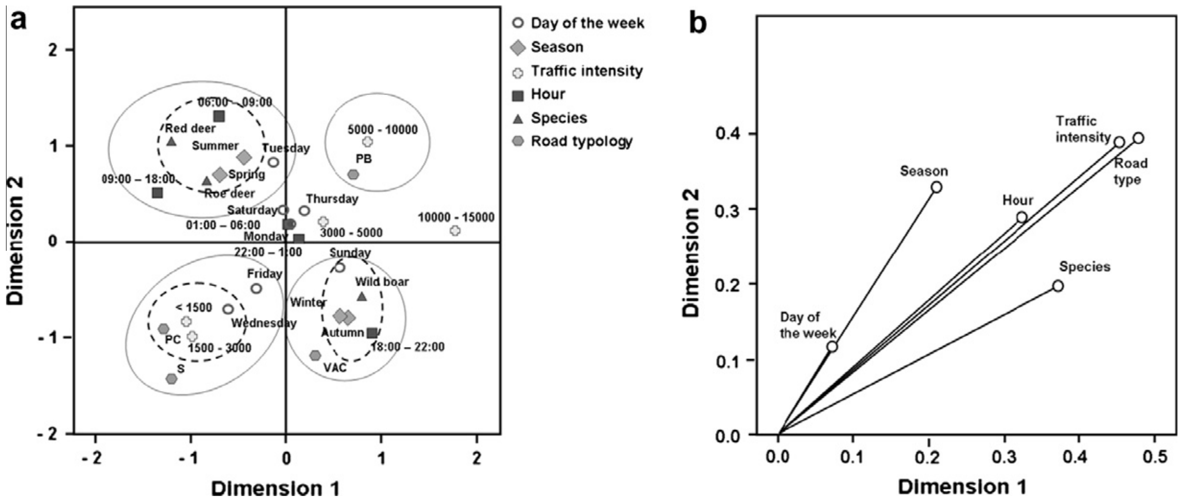

Fig. 4. Multiple correspondence analysis shown two-dimensionally: (a) factorial dimensions and (b) percentage dependence on each dimension. *Note*: Strongest and general dependences are encircled by dotted and continuous lines.

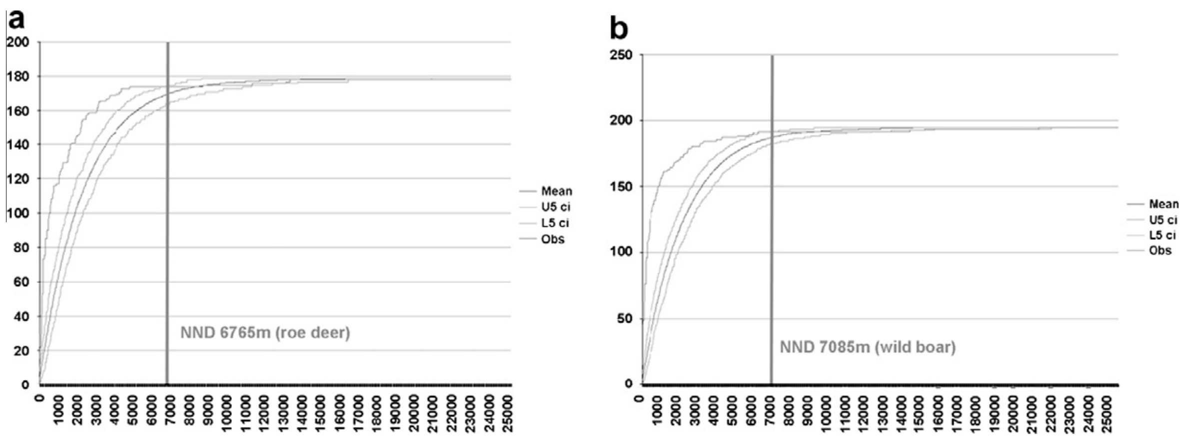

Fig. 5. Expected and observed nearest neighbour distance curves for roe deer (a) and wild boar (b). *Note*: upper (U5) and lower (L5) 5% confidence interval curves are shown as are the cumulative number of points on the *y* axis, and distance (m) on the *x* axis. The vertical line indicates the maximum distance to consider non-random point aggregation.

Saturdays on medium volume roads, and among PB roads, and high traffic intensity reflecting anticipated correlations between road types and traffic levels.

CSR analysis performed for NND calculation enables detection of significant aggregation in the point pattern for a maximum distance of 6765 m in the case of roe deer (Fig. 5a) and 7085 m for the case of wild boar (Fig. 5b). These distances are used as a parameter in calculating point density maps (Fig. 6a and b), which show the spatial distribution of non-random point aggregations, thus allowing identification of accident concentration sections (ACS) for each species. Seventeen ACS are identified for roe deer, and 14 for wild boar, comprising 81% and 79.5% of the accidents in approximately 10% of the length of the network in both cases.

4. Conclusions

The analysis shows a number of things relevant for developing measures to reduce WVC. First, differences in WVC exist in relation to species, for example WVC with wild boar are concentrated in autumn–winter, on Sundays, and after sunset whereas, roe deer activity is quite different, with many WVC occurring in spring and summer. Secondly, the identification of ACS enables the mitigation efforts to be focused on specific road sections where WVC are most frequent. Thirdly, the prob-

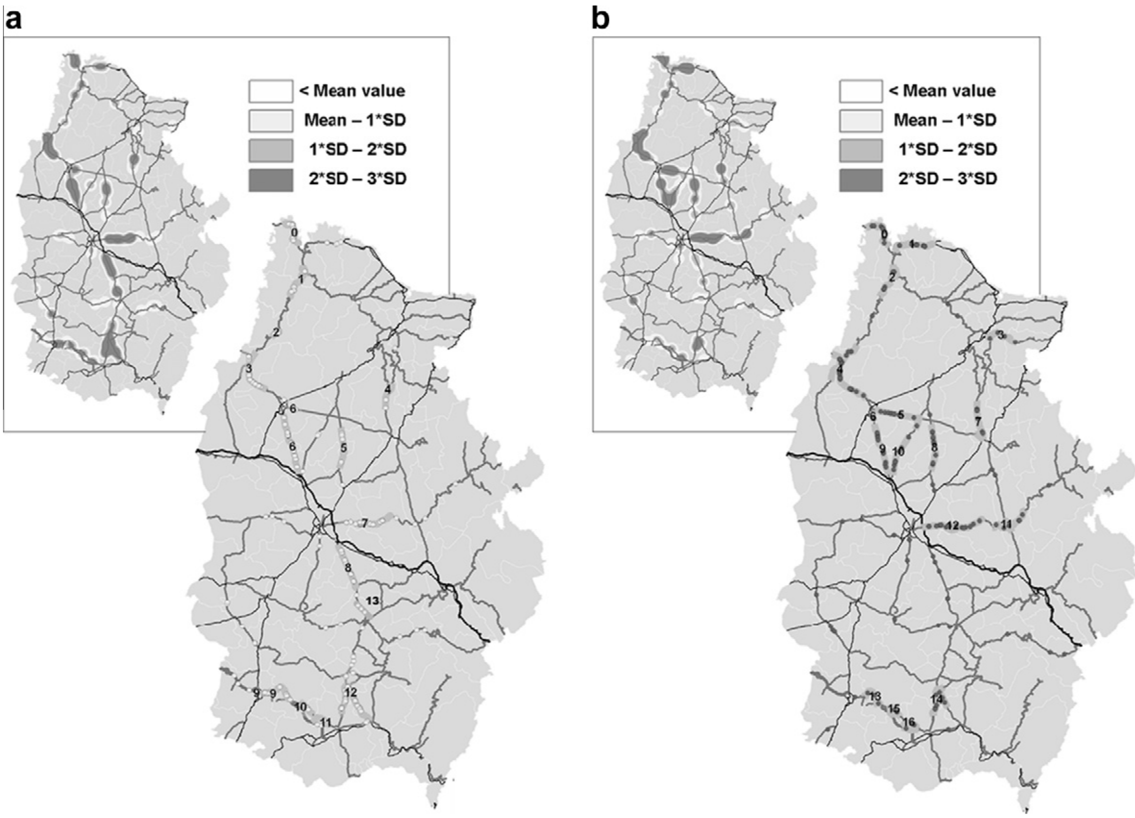

Fig. 6. Accident concentration sections for roe deer (a) and wild boar (b), obtained from point density maps (upper left frame).

ability of occurrence of WVC depends on the quality of road and specific speed requirements, and/or the level of traffic. This information may be useful input to better designing WVC remedial policies and the best measures to adopt.

Acknowledgements

This study was partly funded by a research contract with the University of Santiago de Compostela supported by the Galician regional government under the Isidro Parga Pondal (PGIDIT) programme. We wish to thank the provincial section (Lugo) of the National Traffic Administration (Jefatura Provincial de Lugo – Dirección General de Tráfico) for providing datasets and information on vehicle–animal collisions. We also wish to thank Christine Francis for improving the English grammar of the text.

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