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## Research Letter

## Assessing the consistency of hotspot and hot-moment patterns of wildlife road mortality over time



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## ABSTRACT

Spatial and temporal aggregation patterns of wildlife-vehicle collisions are recurrently used to inform where and when mitigation measures are most needed. The aim of this study is to assess if such aggregation patterns remain in the same locations and periods over time and at different spatial and temporal scales. We conducted biweekly surveys ( $n = 484$ ) on 114 km of nine roads, searching for road casualties ( $n = 4422$ ). Aggregations were searched using different lengths of road sections (500, 1000, 2000 m) and time periods (fortnightly, monthly, bimonthly). Our results showed that hotspots and hot-moments are generally more consistent at larger temporal and spatial scales. We therefore suggest using longer road sections and longer time periods to implement mitigation measures in order to minimize the uncertainty. We support this finding by showing that the proportional costs and benefits to mitigate roadkill aggregations are similar when using different spatial and temporal units.

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## Introduction

Roads have a variety of ecological effects on their surrounding environment, and one of the most studied is wildlife-vehicle collisions (WVC) (Forman et al., 2003; Ree et al., 2015). Several researchers have demonstrated that roadkills are often spatially and temporally aggregated, hereafter referred as Wildlife-Vehicle Aggregations (WVA). WVA are generally related to species' biological traits (e.g. mating), road features (e.g. traffic volume), the surrounding landscape or climate conditions (Gunson et al., 2011; Malo et al., 2004; Smith-Patten and Patten, 2008). Therefore, WVA may indicate preferential targets (hotspots and hot-moments) for implementing mitigation measures (Malo et al., 2004; Morelle et al., 2013; Ree et al., 2015). The identification of WVA is one of

the approaches most used by researchers and decision makers to implement mortality mitigation on roads (Santos et al., 2015).

Mitigation measures must be planned to ensure effectiveness, due to the high cost of installation and maintenance (Ree et al., 2015). Thus, it is necessary to determine the best spatial scale(s) at which putative predictors indicate locations of WVA (Langen et al., 2007; Ree et al., 2015). Ideally, WVA need to be spatially restricted in length, since short road sections can be more easily mitigated by faunal passages and drift fencing than when WVA segments on road are distributed over a broader extent of the road (Langen et al., 2007). On the other hand, understanding the role of seasonality on road mortality allows the identification of possible WVA in certain periods (hot-moments), and decision makers can direct mitigation measures toward the period of higher WVA, which will reduce the costs (Sullivan et al., 2004).

The aim of this study was to investigate if the spatial and temporal patterns of WVA were similar during the same time period for the different taxonomic groups. If WVA occur consistently in the same location and time period, i.e. do not change over time, mitigation measures applied therein will probably be

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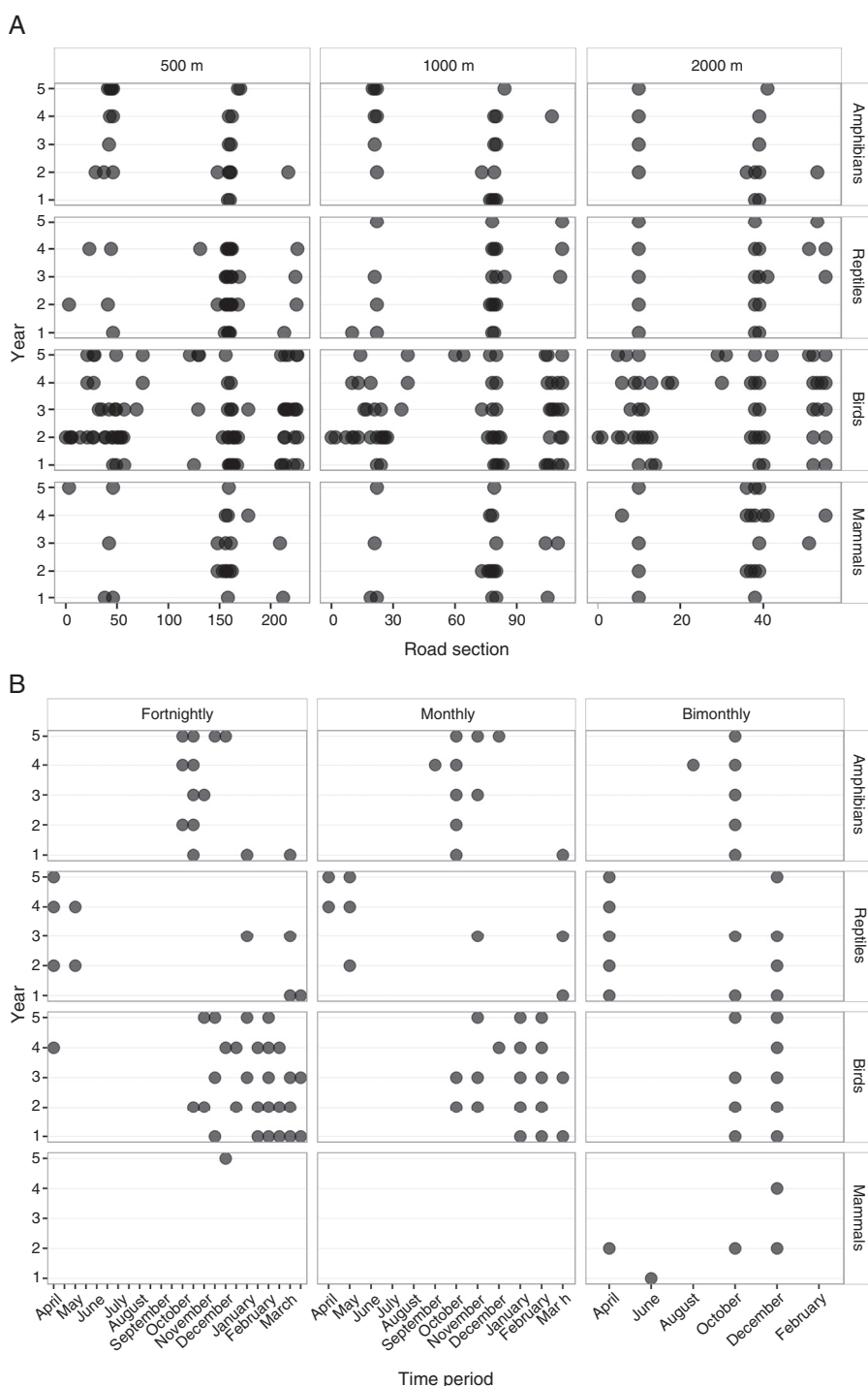
more cost-effective (Costa et al., 2015). Additionally, we evaluated how different road segment length or time period affected the consistency of spatial and temporal WVA patterns. We consider that higher correlation of WVA patterns between consecutive years indicate higher reliability in using such locations as mitigation targets. Hence, we evaluate how cost-benefit effectiveness could vary when targeting mitigation to short/long road sections or time periods. Cost-benefit analysis can be complex in road ecology (Costa et al., 2015). Here, we adopt a simple approach where we count the number of casualties that could have been prevented

if road mitigation was implemented in WVA (assuming full effectiveness).

**Materials and methods**

*Study area*

We conducted the study in Brasília (Federal District), located in the Cerrado biome of Central Brazil. A total of 114 km pertaining to nine different roads were surveyed. More details of the study



**Fig. 1.** Location of wildlife-vehicle aggregations (WVA) per year and class, along the 114 km of road surveyed (A) and along the year (B). Each vertical panel presents the locations when using different spatial (A) or time (B) units to detect WVA.

area, including weather conditions, traffic, roads, protected areas monitored and a map are provided in Text 1 in Appendix 1.

Data collection

We conducted road surveys biweekly (two surveys/week) for 5 years, surveying all 114 km by campaign (i.e., all road types were surveyed equally), between April 2010 and March 2015, totaling 480 roadkill surveys. Two observers and one driver searched for roadkills in a vehicle traveling at ca. 50 km/h. The observers recorded the location of carcasses using a hand-held GPS (5 m accuracy). Carcasses were removed after data collection to avoid pseudo-replication and recounting carcasses. Domestic animals were not considered in further analyses.

Data analyses

WVC records were aggregated by class (amphibians, reptiles, birds, and mammals) and year, and separate datasets for the spatial and temporal information were created. For the spatial dataset, we aggregated the records by road segments of 500, 1000 and 2000 m length. The temporal dataset was aggregated using fortnightly, monthly and bimonthly time periods. We considered a year of survey as the time between April and March of the following year.

Hereafter we will refer to the section lengths and time periods as units.

For each class and year of survey we assumed that the observed number of roadkills per unit would follow a random Poisson distribution with a mean ( $\lambda$ ) equal to the total number of roadkills divided by the total number of units. The probability of any unit having  $x$  number of collisions was therefore:

$$p(x) = \frac{\lambda^x}{x!e^\lambda}$$

A mean value ( $\lambda$ ) for each taxa was calculated, and considering roadkills per year. As the mean ( $\lambda$ ) varied across taxa, each 500 m of road section with three or more collisions, could be defined as WVA for Amphibians. Road sections with four or more collisions were classified as WVA for Reptiles, to birds seven or more collisions, and for mammals with three or more. These minimum values for WVA detection increased for longer road sections (1000 m and 2000 m) scales. For hot-moments, periods (fortnight) with five or more collisions could be defined as WVA for Amphibians. For Reptiles, periods (fortnight) with thirteen or more roadkills were classified as WVA, and to birds thirty three or more roadkills. These minimum values for WVA detection increased for longer time units (monthly and bimonthly time periods).

We considered a unit to be a WVA when  $p(x) > 0.95$ . We used the false discovery rate to reduce the likelihood of detecting false WVA (Type I error) due to multiple testing (Benjamini and Hochberg, 1995). We used the same approach of Malo et al., (2004) as it permits easy comparison among sampling schedules using a fixed spatial scale. Besides, this method seems to perform better than others to detect fatality hotspots (Gomes et al., 2009). We then transformed the consecutive units into a binary variable of presence/absence of WVA. Hence, for each year there is a hot-moment and a hotspot evaluation for each taxonomic class.

The similarity of WVA patterns over time was assessed using correlation tests between consecutive years using the Phi coefficient ( $r_{Phi}$ ) (Zar, 1999). The Phi coefficient measures the degree of association between two binary variables, and its interpretation is similar to the common correlation coefficients. This process was performed for each aggregation unit (spatial and temporal). Finally, the cost-benefit analysis was performed for each taxa, year and unit, by relating the proportion of road sections or time periods that were classified as WVA with the proportion of casualties

potentially avoided if those WVA were mitigated. All calculations and plots were performed using R software (R Core Team, 2015) and the R packages Hmisc, vcd, cowplot and ggplot.

Results

We recorded 4422 non-domestic road-killed animals, of which 5% were amphibians ( $n = 274$ , 9 species), 15% reptiles ( $n = 690$ , 34 species), 71% birds ( $n = 3009$ , 91 species), and 9% mammals ( $n = 448$ , 24 species) (Tables S1 and S2 in Appendix 1). We detected several WVA in all classes for all spatial and temporal units considered, except for mammals hot-moments (Fig. 1A and B).

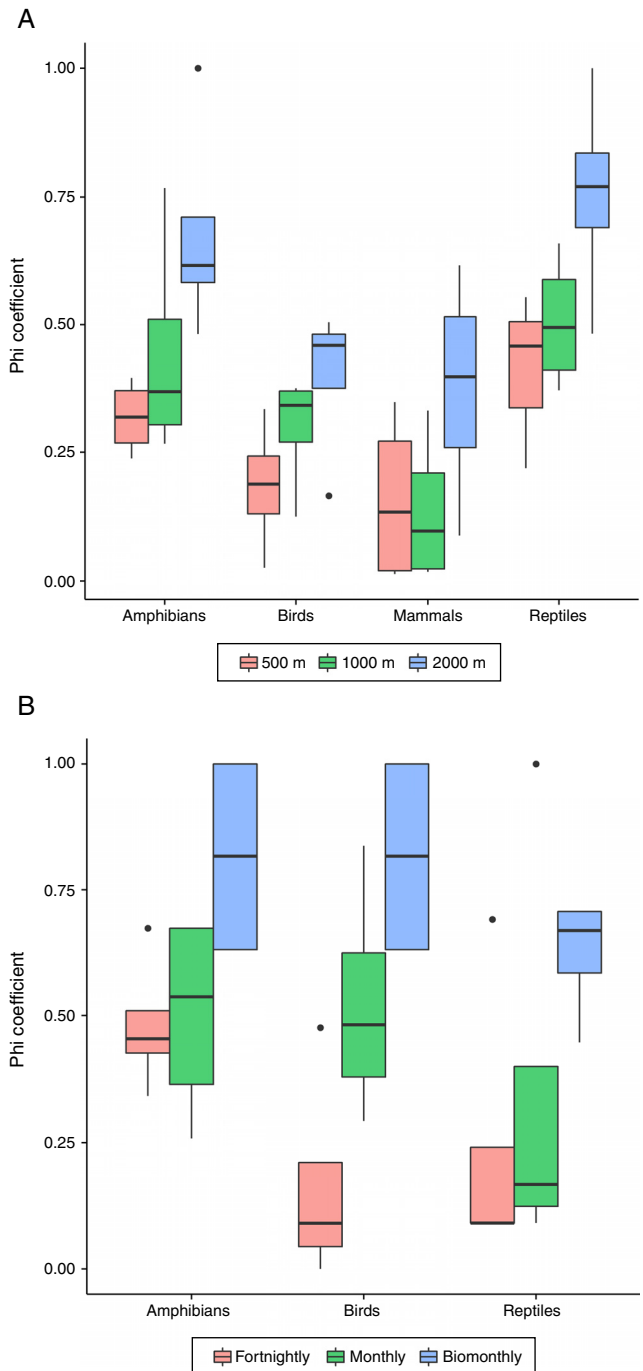
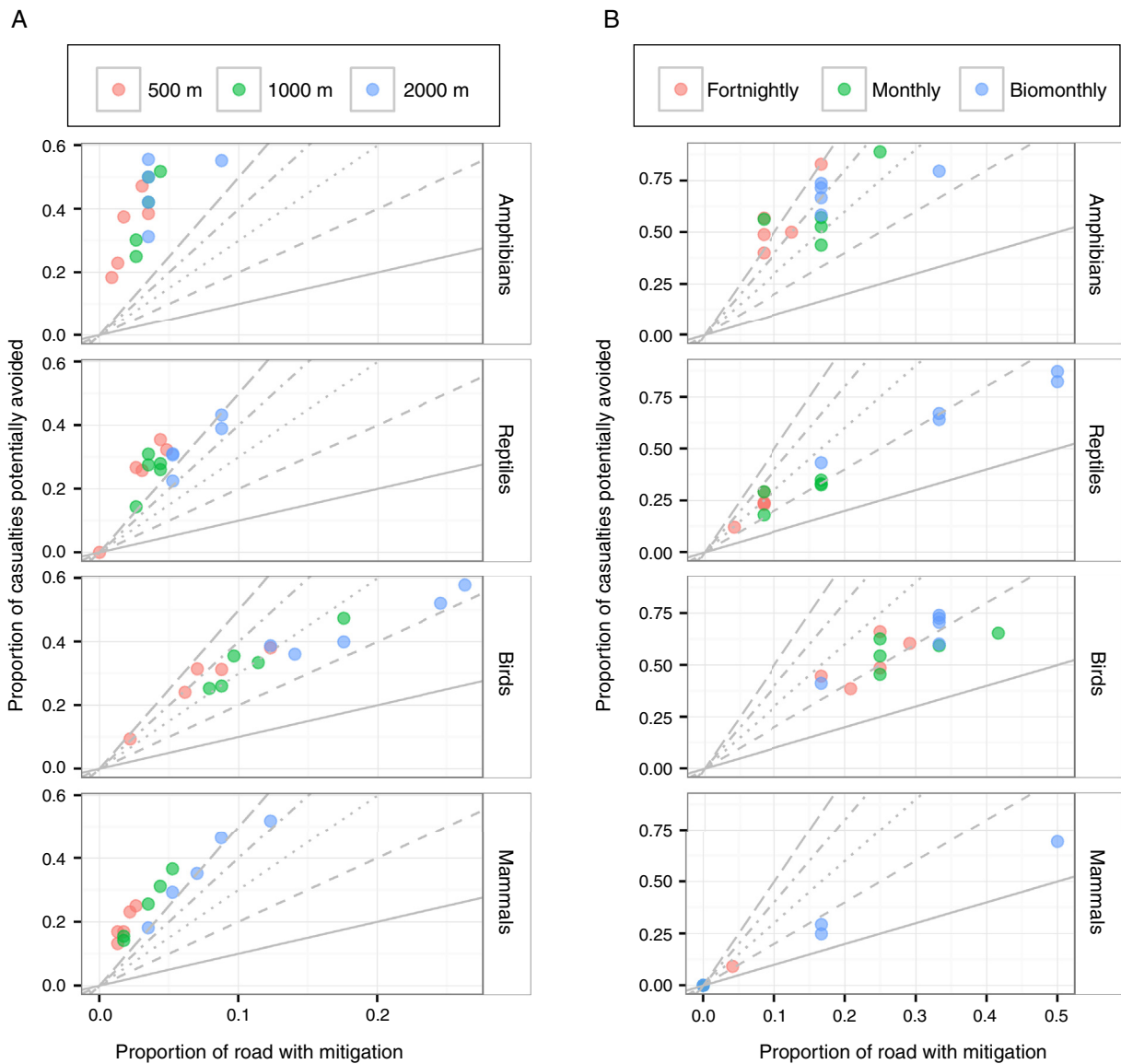


Fig. 2. Phi correlations between consecutive years, per class and according to the spatial (A) or temporal (B) unit used to detect WVA.



**Fig. 3.** Cost-benefit assessment using the relation between the proportion of casualties that could potentially be avoided with the proportion of road (A) or year (B) that would be mitigated. Lines represent the gain in the proportion of casualties relatively to increase in mitigation. The straight line represents the 1:1 gain, i.e. when increasing the mitigation in 1% one would expect an increase in avoided casualties of 1%; the following lines represent, respectively, the gains 1:2, 1:3, 1:4 and 1:5.

Regarding the spatial dataset, when using units of 500 m and 1000 m, most WVA were identified only once in each class (Fig. 1A). However, this pattern was not consistent across the classes. For example, when using a unit of 1000 m, we detected only 4% of sections that were WVA for amphibians in more than one year, while for birds this proportion ascended to 14%. Nevertheless, we found overall low correlation values ( $r_{\text{Phi}} < 0.5$ ) between consecutive years in WVA patterns for all classes for these smaller unit lengths (Fig. 2A). Conversely, when using the longer unit length (2000 m) the number of sections that were classified as WVA more than once increased, e.g. 9% for amphibians and 23% for birds. Likewise, the similarity in WVA patterns was higher, particularly for amphibians and reptiles, with values of  $r_{\text{Phi}}$  well above 0.5 (Fig. 2A and Figure S1 in Appendix 1). Surprisingly, the same WVA sections that occurred (km 10 and 38 for road split in 2000 m, Fig. 2A) for all taxa were located in four-lane roads (Figure S2 in Appendix 1). The cost-benefit evaluation suggests a similar pattern across unit length, within each class. For example, 5–10% mitigation of the road could potentially result in an avoidance of 20–50% of casualties for amphibians, reptiles or mammals. In fact, for these classes, when

using a unit length of 2000 m, the relation of the proportion of casualties potentially avoided (benefit) was generally 4 fold greater than the proportion of road mitigated (cost); while for birds the benefit was 2 fold greater (Fig. 3A). Hence, planning mitigation using larger road sections is apparently more effective as it incorporates more WVA from different years, and yet does not represent a decrease in the cost-benefit relation.

Regarding the temporal dataset, we found higher similarity in WVA patterns in consecutive years when using the three different time units, except for mammals, which was more evenly distributed throughout the year (Fig. 1B). Higher correlations were detected when using longer time units (bi-monthly), particularly for amphibians and birds (median  $r_{\text{Phi}} > 0.75$ ) (Fig. 2B). The periods of highest roadkill for amphibians were between October and November; for reptiles between February and May (and peaks at December and January); and for birds between October and March. These aggregation periods were consistently highlighted in the different units (Fig. 2B and Figure S3 in Appendix 1). In general, using longer time units to detect WVA were also as effective as shorter units. For example, applying mitigation for about two and half months

(20% of year) would potentially avoid ca. 50–75% of roadkills of amphibians. For reptiles, the identification of WVA using longer time unit (bimonthly) highlighted 2–6 months of higher mortality, which is probably related to the diversity of species included in this class that have different peaks of movement and therefore mortality throughout the year (e.g. turtles and lizards). In all cases, the relation between the proportion of casualties potentially avoided was twofold (or more) the proportion of year under mitigation (Fig. 3B). Therefore, the use of longer time-periods is preferable as it potentially includes WVAs from different years and again does not represent a decrease in the cost-benefit relation.

## Discussion

In this study we aimed to assess the consistency of hotspots and hot-moments overtime, i.e., we questioned if a significant proportion of WVA occur in the same sites/periods, and if the pattern was maintained at different spatial and temporal scales. Our results showed that WVA patterns are more consistent when using larger spatial and temporal units. Moreover, although intuitively one may think that mitigation plans should target well defined and short road sections or time periods to increase the cost-benefit resources, we show that the proportional costs and benefits are similar regardless of the spatial and temporal units used to detect WVA. Although more resources are required when mitigating longer sections or time periods, the number of collisions potentially avoided is also higher. These patterns are well illustrated by the numerous sections classified as WVA when using smaller spatial or time units, many of which are not consistent across the years. Hence, larger units may guarantee more reliable information on where and when to allocate mitigation measures. Importantly, within each WVA, mitigation should focus on broad-scale of the road section or period as roadkills may occur at different points or moments in different years.

Mitigation measures focused on single point locations (e.g., culverts) is unlikely to be sufficient to maintain the long-term viability of populations (Patrick et al., 2012). We suggest that mitigation should focus broad-scale measures deployed at longer road sections and time periods, although these are more expensive to build and maintain (Beaudry et al., 2008; Patrick et al., 2012). Few measures can be implemented at large scales, such as the reduction of speed limits (Hobday and Minstrell, 2008), velocity reducers and drift fences connecting to faunal underpasses (Ascensão et al., 2013; Ree et al., 2015). Different strategies can be adopted, which will depend on the financial resources available and the target species. For instance, many small crossings underground can be implemented if turtles are the target specie (Beaudry et al., 2008). Also, our results highlighted the four-lane sections as priority sections to mitigate, suggesting that the “true” WVA is a reflectance of high traffic, since these roads segments shows the highest traffic volumes in our study area.

The temporal analyzes revealed a strong association of WVA of amphibians, reptiles and birds with the rainy season (October to March in our study area). This period corresponds to the occurrence of migratory events and/or breeding season for many species here recorded (Sick, 2001; Coelho et al., 2012). Previous works have also reported increased mortality rates during warm and wet seasons, while dry or cold seasons generally present lower values (Coelho et al., 2012; Langen et al., 2007; Morelle et al., 2013). Identifying hot-moments of WVC using larger temporal periods may provide important information to implement short-time mitigation measures such as temporary road closure or speed reduction (Hobday and Minstrell, 2008; Sullivan et al., 2004). The lack of aggregation periods for mammals may stem from the fact that the dataset was composed mostly by highly mobile and generalist species. These

traits lead to a more uniform distribution of roadkills, which minimizes the chances of occurring WVA.

It should be noted that both spatial and temporal variation of roadkills may be related to differences in vehicle traffic during the year or fluctuations in population abundance (Coelho et al., 2012; Smith-Patten and Patten, 2008). Unfortunately, to our knowledge, such data does not exist for our study area. Also, we worked at the taxonomic level of Class, thereby precluding more specific analyses. By analyzing at the species level, such patterns could probably be more stable over time. However, this would require a large volume of roadkill data for single species, which is rather unfeasible and not possible for our dataset. Finally, we chose not to analyze scales greater than 2000 m, as the costs of implementing mitigation measures would become excessive.

## Conflicts of interest

The authors declare no conflicts of interest.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.pecon.2017.03.003.

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