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Seasonal variation of mammal roadkill hotspots in the Sierra Madre Occidental, México

Variación estacional de los puntos críticos de atropellamiento de mamíferos en la Sierra Madre Occidental de México

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Roadkill hotspots are spatially aggregated sites that are not distributed at random. In the case of mammals, hotspots are used as a criterion to assess the locations of roadkill mitigation works, although these sites can vary at different time scales. The objective of this study was to identify the changes in mammal roadkill hotspots between two seasons of the year on a highway in the Sierra Madre Occidental, northeastern México. Mammal road-killed species were monitored through 2 vehicle tours per season, with 15 days of separation between them. The 40D highway (Durango-Mazatlán) was traveled in spring 2019 and 2020 and autumn 2018 and 2019. Mammal roadkill hotspots in spring, autumn, and both seasons combined were identified using geographic information systems. A total of 217 mammal roadkills were recorded during 8 road tours. Wildlife roadkill hotspots were not spatially consistent between stations or when all records were compared. The spatial aggregation of mammal roadkills varied over time, which could be related to changes in the movement of fauna and other factors. The seasonal variation of these hotspots should be considered for the implementation of mitigation measures, and systematic monitoring of road-killed fauna should be conducted.

Key words: Geographic information systems; road ecology; road-killed fauna; Sierra Madre Occidental; spatial distribution.

Los puntos críticos del atropellamiento son aquellos sitios agregados espacialmente que no corresponden al azar. Para el caso de mamíferos, los puntos críticos han sido considerados como una de las aproximaciones para la ubicación de las obras de mitigación del atropellamiento, aunque estos sitios pueden ser variables a escalas temporales. El objetivo de este estudio fue identificar los cambios de los puntos críticos del atropellamiento de mamíferos entre dos temporadas en una carretera en la Sierra Madre Occidental en el noreste de México. Para el monitoreo de las especies atropelladas se realizaron 2 recorridos en vehículo por temporada con 15 días de separación entre recorridos. Estos se realizaron en la primavera de 2019 y 2020 y otoño de 2018 y 2019 en la carretera 40D (Durango-Mazatlán). Utilizando herramientas de sistemas de información geográfica, se estimaron los puntos críticos de atropellamiento de mamíferos para la primavera, el otoño y ambas estaciones. Se obtuvieron 217 registros de mamíferos silvestres atropellados en 8 recorridos sobre la carretera. Los puntos críticos de atropellamiento de fauna no coinciden espacialmente entre las estaciones, ni al compararlos con todos los registros. La acumulación espacial del atropellamiento de mamíferos no fue coincidente en el tiempo, lo cual podría relacionarse con los cambios en el movimiento de la fauna y otros factores. Se debe considerar la variación estacional de estos puntos críticos para las obras de mitigación, así como realizar monitoreos sistemáticos de la fauna atropellada.

Palabras clave: Distribución espacial; ecología de carreteras; fauna atropellada; Sierra Madre Occidental; sistemas de información geográfica.

Roadkills represent an important mortality factor that threatens mammal species sensitive to anthropic disturbances (Forman and Alexander 1998; Havlick 2003; Benítez-López *et al.* 2010), since some animals may be attracted to roads when searching for food such as carrion, which may lead to wildlife-vehicle collisions and death (Forman and Alexander 1998; Spellerberg 1998; Arroyave *et al.* 2006; Monge-Nájera 2018). Therefore, it is essential to build safe wildlife passage structures to avoid animal-vehicle collisions (van der Grift *et al.* 2013). However, these generally involve high costs and there is controversy regarding their effectiveness (van der Ree *et al.* 2015). Understanding which wild mammal species are particularly vulnerable to collisions and their spatial and temporal distribution is essential for mitigating adverse road impacts. One of such impacts is the barrier effect of roads that reduce landscape connectivity for certain species and restrain their capacity to inhabit all available areas, with long-term consequences on the persistence and local viability of these populations (Forman *et al.* 2003; Filius *et al.* 2020).

The frequency of mammal roadkills is affected by structural aspects of the road, traffic flow, and ecological factors (Rytwinski *et al.* 2015). Vehicle collisions with animals tend to occur at certain times of the year, reflecting the life cycles of the species affected (Hothorn *et al.* 2015). For instance, mammal migration and dispersal movements increase the probability of encountering roads that limiting their free movement across the road or lead to a roadkill event (Arroyave *et al.* 2006; Zhang *et al.* 2018). Changes in traffic volume and speed, as well as the time of the day, also influence the collision rate; for example, the visual acuity of drivers can be reduced at night (Forman and Alexander 1998; Arroyave *et al.* 2006; Driessen 2021).

The sites with higher collision rates are segments where the paths traveled by animals are blocked by the road (Forman and Alexander 1998), including riverbeds, streams, or water runoff that cross the road through transverse structures (*e.g.*, major drainage structures; Forman *et al.* 2003) and tunnels. However, structures such as bridges and culverts can function as safe mammal passages, as long as access to the road is prevented with wire fences. On the other hand, if drainage structures and tunnels are not given proper maintenance, their access can be blocked by vegetation, forcing animals to cross over the road and contributing to their death by collision (Cervantes-Huerta *et al.* 2017).

The objectives of this work were to identify and quantify road-killed wildlife mammals, determine mammal roadkill hotspots cartographically, and compare the spatial pattern of collisions between two seasons. We hypothesized that the sites with the highest probability of collision events differ between seasons due to the variation in traffic volume and wildlife movements associated with dispersal and migration throughout the year. Therefore, mammal roadkill hotspots will change over time and space.

The study area was the 40D highway (Durango-Mazatlán), a two-lane road of 230 km long and 12 m wide bordered by road shoulders on both sides. The section studied runs from kilometer 37 (23° 58′ 32.19″ N, 104° 58′ 1.81″ W) in the Durango municipality to kilometer 155 (23° 32′ 37.4″ N, 105° 45′ 23.5″ W) in the Pueblo Nuevo municipality, both in the state of Durango. This section crosses the Sierra Madre Occidental, where the dominant types of vegetation are temperate pine-oak forest and, to a lesser extent, secondary vegetation and areas used for agricultural or livestock activities. The study area covers altitudes from 2,347 to 2,652 m; the prevailing climate is semi-cold sub-humid (INEGI 2008).

Roadkill records were obtained through 2 vehicle tours made in contrasting seasons in terms of water availability at the study sites: spring (the driest season) and autumn (the end of the rainy season; SMN 2010). Both sampling events at each season took place at least 15 days apart. A total of 8 tours were made in autumn 2018 and 2019 and spring 2019 and 2020. The vehicle tours were traveled at an average driving speed of 30 km / hr to look for mammal carcasses over the whole road width by a dedicated observer and a driver (Planillo *et al.* 2018). When a carcass was spotted, the species was recorded if the state of decomposition allowed it; otherwise, photographs were captured using reference scales for subsequent identification with the assistance of experts. In addition, the coordinates were recorded with a GPS (Garmin eTrex® 30x). Afterward, the carcass was removed to avoid recoding duplicate data in subsequent tours.

To identify mammal roadkill hotspots, *i.e.*, sites with a non-random accumulation of records, the Hotspot Analysis plugin (Oxoli *et al.* 2018) of the QGIS 3.16 software was used. The data of all mammals for spring and autumn were entered both separately and pooled together. To assess the hypothesis that all roadkill hotspots display a random spatial distribution, the Getis-Ord G_i* statistic was used to determine the degree of association between the points corresponding to records of mammal roadkills (Getis and Ord 2010). Positive (hotspots) and negative (coldspots) *Z*-values were obtained from this analysis. Then, confidence intervals were calculated to estimate whether the aggregation was random. Data for domestic mammals (*e.g.*, dogs and cats) were excluded from the analysis for being non-native fauna.

A total of 217 records of road-killed mammals were obtained during 8 tours. Eighty-three individuals were recorded in autumn and 134 in spring. The raccoon (*Procyon lotor*) showed the highest number of records, followed by rock squirrel (*Otospermophilus variegatus*), and eastern cottontail (*Sylvilagus floridanus*; Table 1). It is worth highlighting the roadkill records of 1 puma (*Puma concolor*) and 2 collared peccaries (*Dicotyles tajacu*; Table 1) since, due to their large body size, these species may pose a safety hazard for drivers. In addition, these species are of importance in hunting (SEMARNAT 2021), a key economic activity in the region.

Regarding the analysis of hotspots, the sites with the highest mammal roadkill rates varied between seasons; hotspots also differed when all records were combined (Figure 1). During spring, there were no hotspots with a confidence level greater than 90 %, according to *Z*-values (1.65 ≥ *Z* or *Z* ≥ 1.65); when data for both seasons were combined, some hotspots disappeared. Some of these hotspots coincide with sites where there are no major drainage structures and tunnels, but also with sites where these structures exist.

In this study, we compared the mammal roadkill hotspots identified from sampling in two different seasons. Our results suggest that mammal roadkill hotspots varied over the seasons and also when estimated with data for both seasons combined. Other studies also suggest spatial and temporal variations in roadkills (Canal *et al.* 2018; Bastos *et al.* 2019). In contrast with the observations in the present study, Bastos *et al.* (2019) reported a higher number of vertebrate roadkills in the rainy season. Also, Bueno and Almeida (2010) mentioned that the movements of mammals tend to increase during the dry season in search of resources, which explains the higher frequency of roadkill events in spring in our study. Multiple factors may affect the movement of wild animals, and hence the probability of death by collision; these include hydrological processes (*e. g*., rainfall, water runoff, infiltration) and the phenology of the local vegetation and wild mammals, including migration and dispersal (Arroyave *et al.* 2006; Bauni *et al.* 2017).

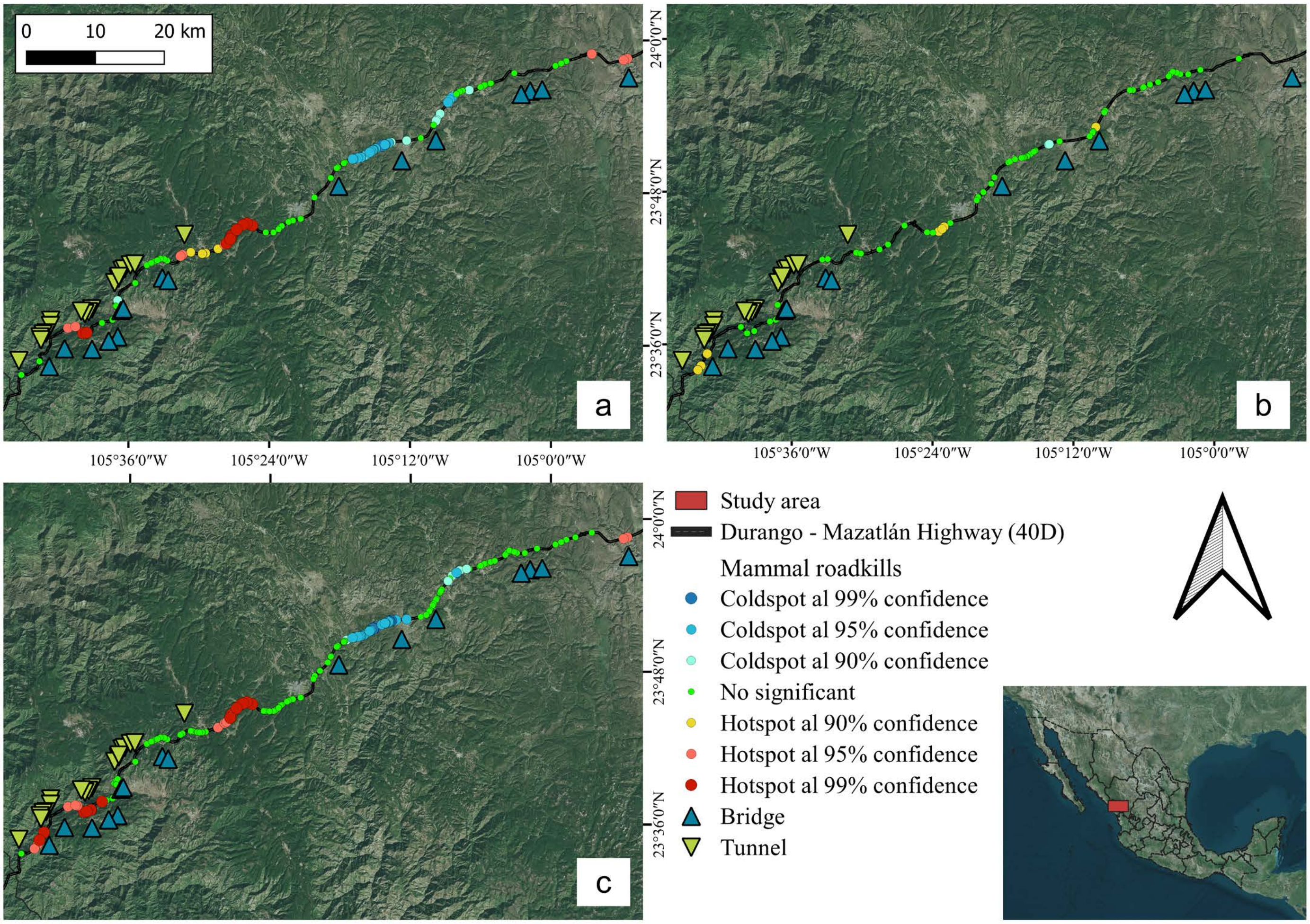

Figure 1. Study area. Location of critical points: hotspots (yellow and red circles), coldspots (blue circles). a) spring, b) autumn, c) both seasons, on 40D highway (Durango-Mazatlán), México, between years 2018 and 2020. Green (non-significant) circles correspond to sites of mammal roadkills with a random spatial clustering.

Although hotspots are neither static in time nor identical for all species, the identification of hotspots and the factors influencing their spatial and temporal patterns can support improved measures to mitigate adverse road impacts on wildlife (Monge-Nájera 2018; Bíl *et al.* 2019). This should be conducted along with studies to gain a deeper understanding of the distribution, abundance, and movement patterns of wild animals in the area surrounding the road (Ascensão *et al.* 2019).

Similar to other roads of México, major drainage structures such as bridges, culverts, and tunnels are considered wildlife passages without being designed for this purpose or maintained properly to ensure that wild animals can use these structures to cross the road safely (van der Grift *et al.* 2013; Cervantes-Huerta *et al.* 2017). In this study, hotspots were observed mainly in sites far from major drainage structures and tunnels, but also in sites where these have been built, suggesting that these structures are ineffective for reducing mammal roadkills. The streams flowing and the vegetation growing in and around structures can prevent free crossing through drainage structures considered wildlife passages (SCT 2012), so it is recommended to provide regular maintenance to sewers.

Road-killed fauna and wildlife passages should be systematically monitored to apply the most appropriate mitigation measures (Bauni *et al.* 2017) and identify those sites where wild animals can cross paved roads, to build barriers aiming to prevent animal crosses (van der Grift *et al.* 2013; Cervantes-Huerta *et al.* 2017). On the other hand, seasonal variation in the location of hotspots represents a challenge for the application of these and other mitigation measures (Iuell *et al.* 2003; Bauni *et al.* 2017) because they are expensive; thus, if they are not sufficiently effective, their application becomes feasible. More effective methods should be developed to identify these sites, which would support the effective mitigation of adverse effects of roads on wild mammals, considering their biological characteristics and other aspects of the local vegetation and the terrain that could serve for the identification of optimal sites for implementing these measures. The current policies of the Secretariat of Communications and Transportation (SCT, in Spanish) and the office of Federal Roads and Bridges (CAPUFE, in Spanish) of México do not support research on road ecology. Therefore, conducting studies on this field requires strengthening the links between academic researchers and construction managers. Although significant progress has been achieved, much remains to be done.

Table 1. Total records of road-killed mammals by order and family on the Durango-Mazatlán 40D highway, México during spring and autumn between years 2018 and 2020.

Order	Family	Scientific name	Records
Artiodactyla	Tayassuidae	*Dicotyles tajacu*	2
Carnivora			59
	Canidae		19
		Canis latrans	2
		Canis lupus familiaris	12
		Canis sp.	2
		Urocyon cinereoargenteus	3
	Felidae		10
		Felis catus	7
		Lynx rufus	2
		Puma concolor	1
	Mephitidae		14
		Conepatus leuconotus	1
		Mephitis macroura	5
		Mephitis sp.	7
		Spilogale gracilis	1
	Mustelidae	*Mustela frenata*	1
	Procyonidae		14
		Nasua narica	1
		Procyon lotor	13
	Unidentified		1
Chiroptera	Unidentified		1
Didelphimorphia	Didelphidae	*Didelphis virginiana*	8
Lagomorpha	Leporidae	*Sylvilagus floridanus*	12
Rodentia			72
	Cricetidae		9
		Neotoma mexicana	1
		Neotoma sp.	4
		Peromyscus sp.	4
	Sciuridae		20
		Otospermophilus variegatus	12
		Sciurus nayaritensis	8
	Unidentified		43
Mammalia			82

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