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Research paper

# Seasonal variation in vertebrate traffic casualties and its implications for mitigation measures

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## HIGHLIGHTS

- Roadkills showed a seasonal pattern, with peaks in April and August-November.
- Four vertebrate taxa showed seasonal variations in roadkills.
- Minimum temperature and solar irradiance correlate with overall roadkill number.
- Knowledge of roadkill patterns makes it possible to optimize monitoring programmes.
- Temporary mitigation measures should be applied when there is a peak in the roadkills.

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## ABSTRACT

Wildlife mortality on roads is a global conservation problem. To implement a cost-effective programme of mitigation measures, it is essential to determine spatial and temporal patterns of traffic collisions. Identifying seasonal road-collision patterns could make it possible to schedule and optimize monitoring programmes. We evaluated seasonal variation in the roadkills of four vertebrate taxonomic groups (amphibians, reptiles, birds and mammals) across an environmental gradient in northeastern Iberia. Seven roads were monitored twice a month for one year and seasonal roadkill aggregations were examined using Poisson tests. Roadkill patterns were correlated with environmental variables using Generalized Linear Models. Amphibians were the group most commonly killed. Overall, the roadkill pattern was seasonal, and most roads showed seasonal peaks of casualties in autumn and spring. Roadkill peaks showed slightly seasonal differences between taxonomic groups. The total number of roadkill incidents was positively associated with temperature and negatively associated with solar irradiance. The roadkill numbers by group were related to different environmental factors: amphibian roadkills increased with relative humidity, while this relationship was negative for birds; mammal roadkills were associated with temperature, and reptile roadkills correlated with precipitation, solar irradiance, and temperature. Our results suggest that roadkill rates in Catalonia are seasonal and mostly associated with several climatic factors, although they can vary depending on taxonomic group and environmental factors. Our results highlight the fact that an understanding of seasonal variation in roadkills is critical for optimizing monitoring programmes and temporary mitigation measures aimed at particular species or taxonomic groups.



## 1. Introduction

In addition to wildlife mortality caused directly by traffic, the road network modifies the environment, reduces the quality of the surrounding habitats and reduces landscape connectivity and the gene flow of populations due to the barrier effect (Epps et al., 2005; Jaeger et al., 2005; Riley et al., 2006). These impacts have a knock-

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on effect on the density and diversity of wildlife populations (see Fahrig & Rytwinski, 2009) that may be similar in magnitude to that produced by habitat loss (Eigenbrod, Hecnar, & Fahrig, 2008). Thus, there is wide agreement concerning the need to reduce the impact of roads on wildlife and to improve the ecological conditions around roads by planning new road construction and mitigation measures correctly (Lesbarrères & Fahrig, 2012; Seiler & Helldin, 2006). To minimize the economic costs and maximize the usefulness of mitigation measures, it is critical to detect spots of high-density wildlife collision and to develop techniques to predict points where there is a high probability of collision (Malo, Suárez, & Díez, 2004).

The impact of roads on wildlife affect all taxonomic groups and have been documented worldwide (Taylor & Goldingay, 2004), even though the studies that have included multiple taxonomic groups report that not all species and taxonomic groups are affected equally (Carvalho & Mira, 2011; D'Amico, Román, Reyes, & Revilla, 2015; Garriga et al., 2012; Santos, Carvalho, & Mira, 2011; Santos et al., 2015; Taylor & Goldingay, 2010). Moreover, roadkills are not uniformly distributed; there are usually clusters of casualties that allow hotspots to be identified (Coelho, Teixeira, Colombo, Coelho, & Kindel, 2012; Gomes, Grilo, Silva, & Mira, 2009; Langen, Gunson, Scheiner, & Boulerice, 2012; Malo et al., 2004; Ramp, Caldwell, Edwards, Warton, & Croft, 2005; Santos et al., 2007). Spatial analysis and prediction models have related roadkill impact with roadside characteristics, traffic-related parameters, species richness, and population density (Clevenger, Chruszcz, & Gunson, 2003; Coelho et al., 2012; Espinosa, Serrano, & Montori, 2012; Langen et al., 2012; Malo et al., 2004; Matos, Sillero, & Argaña, 2012; Orłowski & Nowak, 2006; Ramp et al., 2005; Ramp, Wilson, & Croft, 2006; Seiler, 2004, 2005).

The association between landscape and traffic characteristics and roadkill rates has been useful for modelling and predicting the spatial location of casualties (Ramp et al., 2005). In contrast, the temporal distribution of casualties to predict seasonal patterns has been less addressed. Factors related to the phenology of species, e.g. breeding and foraging, have been proposed to explain the seasonal variation of roadkills (Clevenger et al., 2003; Erritzoe, Mazgajski, & Rejt, 2003; Espinosa et al., 2012; Grilo, Bissonette, & Santos-Reis, 2009; Romin & Bissonette, 1996; Smith-Patten & Patten, 2008). Lagos, Picos, and Valero (2012) reported specific temporal patterns of roadkills on wild ungulates related to phenology and behavior of species, but also to human-related activities such as drivers' behavior and hunting. D'Amico et al. (2015) also associated roadkill temporal patterns of small mammals, birds, and lizards with phenology of species. Seasonal peaks in population sizes (Alves da Rosa & Bager, 2012; Conard & Gipson, 2006) and migration episodes (Langen, Ogden, & Schwarting, 2009; Orłowski, 2007) have also been related to temporal patterns of amphibian roadkills. Weather variables, seasonal life-history traits (Capula et al., 2014; Carvalho & Mira, 2011; Glista, DeVault, & DeWoody, 2008) and environmental changes such as temperature and fluctuations in water levels (Bernardino & Dalrymple, 1992; D'Amico et al., 2015; Mccardle & Fontenot, 2016) can also lead to temporal or seasonal casualty peaks.

In summary, landscape- and traffic-related variables, species-specific traits and the climatic characteristics of the area studied are all factors that may interact and help us understand spatial and temporal roadkill patterns. The detection of spatial and seasonal roadkill patterns may be useful for scheduling and optimizing the effort invested in monitoring programs and for applying adequate mitigation measures. The application of permanent correction measures such as wildlife passages can be very expensive, while non-structural methods such as olfactory repellents, ultrasounds, speed bumps and habitat modification are less expensive, although their effectiveness is not clear (Baxter-Gilbert, Riley, Lesbarrères, & Litzgus, 2015; Glista, DeVault, & DeWoody, 2009). Identifying roadkill seasonality could make it possible to temporarily reinforce existing measures, use temporary warning signs and implement temporary measures such as closing specific stretches of roads (Grilo, Bissonette, & Gramer, 2010). Understanding roadkill dynamics and its causes requires extensive studies to monitor roads within an environmental gradient and with a temporal sequence that is long enough to cover the activity of all species. The sampling frequency is also an important issue to take into account, since weekly or longer intervals between surveys may reduce the accuracy and detection of roadkill hotspots (Santos et al., 2015).

This study aims to address the seasonal variation of road casualties within an environmental gradient and takes several taxonomic groups into account. We examined seven road stretches twice a month for one year in Catalonia (northeastern Iberia). The objectives of this study were: (1) to describe the seasonal pattern of roadkills in four vertebrate taxonomic groups, (2) to describe how this seasonal pattern varied among these groups and (3) to relate the roadkill rates to environmental variables and the activity and life-history traits of species or taxonomic groups. Seasonal activity patterns of each taxonomic group are likely dependent of phenology. For this reason, we expect that seasonality on roadkills will be highly related with a number of temporal explanatory variables. For example, amphibian roadkills are expected to be associated with rainfall and humidity, mammals and reptiles are expected to be temperature dependent, and bird roadkills should be related negatively with rainfall and positively with temperature.

## 2. Material and methods

### 2.1. Study area and roadkill sampling

The study was conducted in Catalonia, northeastern Spain. The terrain in this region is heterogeneous, with an elevation ranging from 0 m to 3000 m above sea level. Catalonia has a Mediterranean climate with continental and Atlantic influences. The main biogeographical regions are the Mediterranean and the Euro-Siberian, with the Subalpine and Alpine regions in the upper Pyrenees (Sacasas, 2007). The area presents climatic variability (Martin-Vide, 1992), with annual rainfall ranging from 380 mm to 1200 mm, minimum temperatures from −5.4 °C to 8.4 °C and maximum temperatures from 14.3 °C to 33.3 °C. Temperature tends to increase and precipitation tends to decrease from north to south (Ninyerola, Pons, & Roure, 2000).

We selected 20-km stretches of seven routes (Fig. 1) that covered a range of altitudes (0 m–1505 m above sea level) and climatology (littoral-humid-Pyrenean climatic regions) (Table Supplementary 1 and 2). The roads chosen were representative of the different climatology and habitats of the region. The routes were two-way country roads, with moderate to low traffic intensity, moderate speed traffic and no central reservations or safety fences.

The seven roads selected were monitored fortnightly over the course of one year. We performed a low sampling frequency, which may reduce the accuracy of the roadkills hotspots detection due to a misdetection of the corpses, especially the small size ones (Santos et al., 2011, 2015); however, it was not feasible to perform surveys more frequently due to the dimensions of our study. Likewise, we could not collect more than one year of data, which might limit the detection of the temporal roadkills variability associated with unpredictable weather of a Mediterranean area. This monitoring was conducted by a total of six experienced observers driving at a maximum speed of 20 km per hour, since a slow speed is required for the detection of small vertebrates (Ashley & Robinson, 1996; Glista et al., 2008; Smith & Dodd, 2003). Nonetheless, Hels and Buchwald (2001) estimated that 7%–67% of the total number of road victims are misdetected compared to surveys on foot. How-