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No evidence of a threshold in traffic volume affecting road-kill mortality at a large spatio-temporal scale

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ABSTRACT

Previous studies have found that the relationship between wildlife road mortality and traffic volume follows a threshold effect on low traffic volume roads. We aimed at evaluating the response of several species to increasing traffic intensity on highways over a large geographic area and temporal period. We used data of four terrestrial vertebrate species with different biological and ecological features known by their high road-kill rates: the barn owl (*Tyto alba*), hedgehog (*Erinaceus europaeus*), red fox (*Vulpes vulpes*) and European rabbit (*Oryctolagus cuniculus*). Additionally, we checked whether road-kill likelihood varies when traffic patterns depart from the average. We used annual average daily traffic (AADT) and road-kill records observed along 1000 km of highways in Portugal over seven consecutive years (2003–2009). We fitted candidate models using Generalized Linear Models with a binomial distribution through a sample unit of 1 km segments to describe the effect of traffic on the probability of finding at least one victim in each segment during the study. We also assigned for each road-kill record the traffic of that day and the AADT on that year to test for differences using Paired Student's t-test. Mortality risk declined significantly with traffic volume but varied among species: the probability of finding road-killed red foxes and rabbits occurs up to moderate traffic volumes (<20,000 AADT) whereas barn owls and hedgehogs occurred up to higher traffic volumes (40,000 AADT). Perception of risk may explain differences in responses towards high traffic highway segments. Road-kill rates did not vary significantly when traffic intensity departed from the average. In summary, we did not find evidence of traffic thresholds for the analysed species and traffic intensities. We suggest mitigation measures to reduce mortality be applied in particular on low traffic roads (<5000 AADT) while additional measures to reduce barrier effects should take into account species-specific behavioural traits.

1. Introduction

Traffic volume is known to be a key issue in determining the impact of roads on wildlife (Jaeger et al., 2005; Charry and Jones, 2009). In fact, it is considered one of the main factors limiting animals' movement, through both mortality and the barrier effect created by road-avoidance when traffic intensity is high (Grilo et al., 2012, 2014). As a consequence, high traffic volumes may reduce population abundance, and alter species composition (Fahrig and Rytwinski, 2009). On a local scale, road-kill rates tend to increase with increasing traffic intensity (Fahrig et al., 1995). However, several authors suggest that there might be a threshold level of traffic intensity above which the road avoidance response will be so intense that the number of casualties due to road-kills will be reduced as traffic grows above that level (Fig. 1; Clarke et al., 1998; Seiler, 2003). This phenomenon is attributed to an avoidance effect, mainly due to noise, light and the actual presence of moving vehicles (Forman and Alexander, 1998). The final result is a barrier to dispersal or gene flow (Riley et al., 2006).

The diversity of life-history traits and differences in biological features and behavioural responses towards roads among species have led to varying results among studies. For instance, Oxley et al. (1974) found that the mortality rates of amphibians and some mammals increased up to an annual average daily traffic (AADT) of 1500 vehicles/day, decreasing above this level, whereas reptile and bird mortality rates showed a positive relationship with traffic volume (maximum AADT recorded was 10,000 vehicles/day). Furthermore, Seiler (2005) found that a peak of moose collisions occurred at AADTs around 4000–6000 vehicles/day and Clarke et al. (1998) recorded an asymptotic relationship between badger mortality and traffic volume, with mortality levelling out at higher traffic volumes (>4000 vehicles/day). Nevertheless, studies focusing on the effect of traffic on wildlife populations have relied on small ranges of traffic volume (e.g. Oxley et al., 1974 — 5–600 AADT), or on specific local populations during short periods of time (e.g., Baker et al., 2007 — red fox in Bristol, UK).

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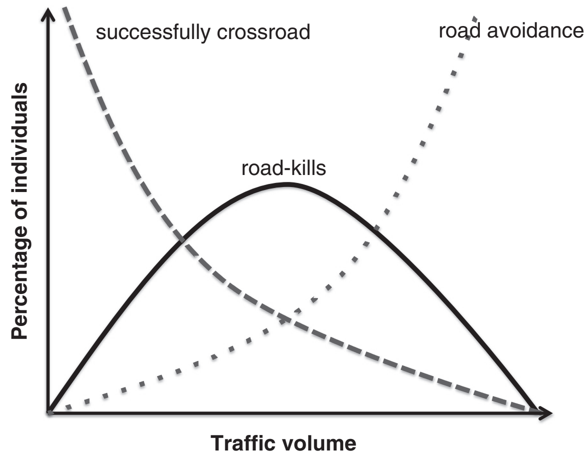

Fig. 1. Conceptual model of barrier effect. Road-kills rise until a point where vehicles create such a disturbance that makes animals avoid roads.
Adapted from Seiler (2003).

The main goal of this study is to evaluate the response of several species to increasing traffic intensity over a large geographical area and a long period of time. We considered four terrestrial vertebrates with varying biological and ecological features that make them particularly vulnerable to traffic: the barn owl (*Tyto alba*), hedgehog (*Erinaceus europaeus*), red fox (*Vulpes vulpes*) and European rabbit (*Oryctolagus cuniculus*). All are common in Portugal and suffer from high rates of road-kills. Barn owls fly at the vehicle level when patrolling their territory (Taylor, 1994). Hedgehogs are slow-moving and show peaks of road-kill incidence during their breeding and dispersal periods (Haigh et al., 2014). The red fox is a common carnivore with a large home-range and thus the likelihood to encounter a road is high (Baker et al., 2007). European rabbits use road verges as safe refuge from predators (Barrientos and Bolonio, 2009). Additionally, we compared the traffic on the day of each recorded casualty with the annual average daily traffic intensity of that highway segment in order to evaluate whether the mortality occurred in periods of relatively high or low intensity.

A priori, we expect that species apparently more sensitive to traffic noise like the barn owl (Hindmarch et al., 2012) and red fox (Baker et al., 2007) will show a lower road-kill probability in highway segments with heavy traffic. In contrast, we expect a positive and linear relationship between traffic and mortality for the hedgehog and rabbit, which are apparently less sensitive to traffic because they are often found on highway verges (Doncaster et al., 2001; Barrientos and Bolonio, 2009). Finally, we expect that the traffic in those days when road-kills occurred will be above the AADT for all species.

2. Material and methods

2.1. Study area

This study was conducted in Portugal along all major highways under the private concession of BRISA Auto-Estradas de Portugal S.A. These highways comprise a length of approximately 1000 km built between 1994 and 2002, following the north–south axis and are distributed mainly on the western half of the country (Fig. 2). All highways have four-lanes, a 7 m wide median strip, livestock exclusion fencing on both sides and a speed limit of 120 km/h. Traffic intensity ranges from less than 3000 vehicles/day, to more than 50,000 in peak days, with an annual average of 17,110 vehicles/day. The landscape in the vicinity of the highways is a mosaic of intensive (vineyards, olive trees) and extensive (croplands) agricultural areas with forest plantations of *Pinus* spp., *Eucalyptus* spp., and oak woodlands (*Quercus* spp.) and urban areas (Corine Land Cover 2006).

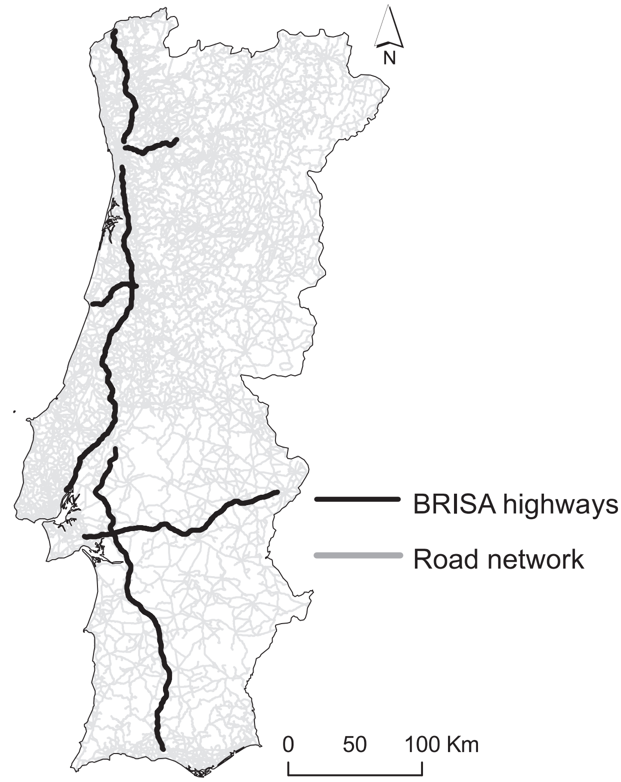

Fig. 2. Surveyed BRISA highways in Portugal.

2.2. Road-kill surveys and traffic

Road-kill data was recorded daily between January 2003 and December 2009. The BRISA staff is in charge of the highway daily maintenance and the safety during routine road checks by vehicle which recorded road-kills on the road surface in a constant patrol. Because the BRISA staff was trained by the authors to detect and identify correctly small vertebrates with a body length above 20 cm we assume high and similar detectability for all species. When dead animals were encountered, information on species, day and spatial location was imported into a Geographic Information System. The traffic volume database consisted of the number of vehicles per day in each highway segment over the same survey period.

2.3. Data analysis

Highways were divided into 1 km segments to describe the relationship between the presence/absence of road-kills over the study period and the AADT. Although the species considered are active at night we used the overall traffic intensity of the day (AADT — the standard measure of traffic) to analyse the effect of traffic on species mortality risk and likelihood occurrence in the highway vicinity (road avoidance behaviour due to traffic noise) (see Grilo et al., 2014). Additionally, and in order to control for the coarse habitat preferences of each species, we created a 500 m buffer on each side of the segment to estimate the percentage of these land cover classes: forest, agriculture and urban areas (reclassified and obtained from Corine Land Cover 2006, http://sniamb.apambiente.pt/clc/frm/). Even though target species are very common and easy to find in the vicinity of humanized areas, we excluded from the analysis those highway segments that overlapped with urban areas, to avoid using segments where the presence probability for those species might be lower.

We developed seven candidate models to describe the relationship between the probability of finding at least one road-kill in the segment