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Vertebrate road-kill patterns in Mediterranean habitats: Who, when and where

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A B S T R A C T

Road-kill is the most recognized impact of traffic and an important threat for biodiversity. Nevertheless, most research on this topic deals with particular species or with road features, describing proximate correlates and rarely making inference on the mechanisms. Here we provide a more general approximation by describing life-history, temporal and spatial factors affecting vertebrate road-kills in Mediterranean landscapes, which are a biodiversity hotspot with little studied road impacts. During one year we recorded the casualties found on paved roads within Doñana Natural Park. We found 2368 road-kills belonging to 66 species (32% of the study area checklist), with abundant ectotherm species more likely to be road-killed. We also investigated the temporal and spatial factors affecting the road-kill patterns of different taxonomic and functional groups. The phenology of the species was the main factor affecting road-kill temporal patterns for lizards, all birds and small mammals. Additionally, rainfall events were associated with the road-kill peaks of wintering birds, whereas high temperatures were related to the increase of road-killed snakes and the decrease of road-killed amphibians. Amphibians, snakes, lizards and small passerines were mainly road-killed according with their spatial abundance. Mitigation measures such as wildlife road-crossing structures showed contradictory effectiveness for small vertebrates due to the lack of adequate drift fences. We suggest prioritizing the mitigation measures which can permanently decrease the risk of been road-killed for ectotherm species, such as specific road-crossing structures with effective drift fences on road-kill hotspots. Concurrently, group-specific temporal mitigation measures should be applied during the road-kill seasonal peaks. The present work provides recommendations to decrease road-kill impacts in Mediterranean environments, but simultaneously tries to contribute to a more general development of road ecology research, suggesting several useful guidelines to perform road-kill studies.

1. Introduction

Road-kill is the most well-known impact of traffic on wildlife (Forman and Alexander, 1998; Forman et al., 2003). In spite of the effectiveness of several mitigation efforts (*e.g.* road fences; Jaeger and Fahrig, 2004), a very large number of vertebrates die worldwide along linear infrastructures (González-Gallina et al., 2013; van der Grift et al., 2013). Road-kills are a considerable threat for populations of many species (Fahrig et al., 1995; Mumme et al., 2000; Taylor et al., 2002). They are also a relevant issue for human road safety, involving high economic costs (Conover et al., 1995; Huijser et al., 2009). As a consequence, in the last decades the number of studies focusing on road impacts has increased considerably, leading to the rise of a discipline called road ecology (Forman et al., 2003; Coffin, 2007). Most research has focused on a few emblematic species (Hobday and Minstrell, 2008; Colino-Rabanal et al., 2011), and therefore at present there is still a need for more general approximations aimed to determine life-history, temporal and spatial factors affecting road-kill probability of whole animal communities. Furthermore, most studies describing casualty patterns investigated only the role of proximate causes of road-kill (*e.g.* local road features), thus their management recommendations are difficult to translate to other localities or to other species. Casualty patterns could probably be better understood by additionally considering the role of more general predictors, such as the underlying drivers affecting road-kill probability (*e.g.* climatic factors or spatial variation of species abundance). This kind of knowledge would greatly improve our conservation efforts, helping managers to implement more suitable mitigation measures.

An example of those more general descriptors is the study of species-specific life-history traits affecting the probability of being road-killed. This is an overlooked issue in road ecology with few published studies (Ford and Fahrig, 2007; Barthelmess and Brooks, 2010; Cook and Blumstein, 2013), although the available bibliography shows the existence of relevant differences in road-kill frequency

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among species (*e.g.* Ashley and Robinson, 1996; Erritzoe et al., 2003; Orlowski and Nowak, 2006; Glista et al., 2008). An additional step should be testing the relevance of other predictors which may be potentially correlating with both road-kill probability and life-history traits, as is the case of species abundance, which has been proposed as the main underlying factor affecting road-kill probability (Ford and Fahrig, 2007; Rytwinski and Fahrig, 2010; Møller et al., 2011). The studies concerning life-history traits and road-kill probability usually focus on road-killed species, whereas unaffected species can provide valuable information on key species-specific traits and should be included in the analysis. Life-history research can improve road-kill knowledge, but at the same time it can also provide direct recommendations that can be applied to the conservation of vulnerable species for which data is not yet available. Additionally, road-kill research focused on life-history traits can improve our understanding of temporal and spatial road-kill patterns, especially if the target species are aggregated at relevant taxonomic or functional groups (*e.g.* amphibians or migrant birds) that might be differentially affected by specific climatic or environmental conditions.

Previous studies have found that temporal variations in road-kill patterns are associated with seasonal behaviors such as dispersal or migration, thus helping to predict outbreaks in the number of casualties (Smith-Patten and Patten, 2008; Lagos et al., 2012; Rodríguez-Morales et al., 2013). The climatic factors contributing to the induction of these behaviors (*e.g.* temperature or rainfall) have been suggested to be directly linked to the road-kill peaks (Puky, 2005; Andrews et al., 2006; Glista et al., 2008), but usually without statistical analyses. Conversely, understanding which temporal factors can affect seasonal behaviors and the consequent temporal variability in road-kill patterns would potentially improve mitigation measures, especially those that can be managed in time (*e.g.* limitation of traffic intensity or speed).

Finally, a central issue in road-kill research is the spatial distribution of casualties, which is probably the most investigated topic in road ecology. Most studies have usefully investigated the association between road-kill frequency and some spatial variables describing road features and/or traffic volume (Trombulak and Frissell, 2000; Jaeger and Fahrig, 2004). Nevertheless, the spatial distribution of road-kills can be affected by a large amount of landscape and road features, some of which can act simultaneously (Clevenger et al., 2001, 2003; Forman et al., 2003). It is probably for this reason that several spatial variables (*e.g.* traffic volume or surrounding habitat) have shown contradictory effects in different studies (Coelho et al., 2008; van Langevelde et al., 2009). A simultaneous evaluation of the potentially relevant predictors, obviously controlling for correlated factors, is the way to proceed.

In this study we aimed to describe the life-history, temporal and spatial factors potentially affecting casualty patterns, conducting a detailed selection of candidate predictors likely to affect road-kill probability based on available bibliography. Our first hypothesis (1) is that some species are more prone to be road-killed than others, species with particular life-history traits directly or indirectly associated with their abundance or movements. Our second hypothesis (2) is that the number of road-kills increases in time following seasonal peaks of abundance or activity. Seasonal variations of abundance and activity should in turn depend on species phenology but also on climatic predictors such as rainfall or temperature. Finally, our third hypothesis (3) is that the number of road-kills spatially increases in areas with high species density but also due to a local intensification of road-crossing events, traffic volume and vehicle speed. Finally, we assume that mitigation measures such as wildlife road-crossing structures (WCS hereafter) and road signs should locally reduce the number of road-kills. We tested these hypotheses focusing on terrestrial vertebrates in a typical Mediterranean landscape (Doñana Natural Park, south-western Spain). The Mediterranean basin is a biodiversity hotspot (Mittermeier et al., 1998; Myers et al., 2000) with an ancient and widespread road-network, affecting protected areas and threatened species (Ferreras et al., 1992; Gomes et al., 2009; Grilo et al., 2009). Road-kill studies have been mainly performed in temperate landscapes (Huijser and Bergers, 2000; Trombulak and Frissell, 2000), with few contributions from Mediterranean areas (Malo et al., 2004; Carvalho and Mira, 2011; Garriga et al., 2012). In summary, we aim to determine life-history, temporal and spatial factors affecting road-kill patterns in Mediterranean habitats in order to be able to suggest some general management and conservation recommendations for an emblematic protected area and for other Mediterranean environments. Finally, a further purpose is to provide scientists and conservation biologists with some guidelines to better understand the factors behind road-kill patterns.

2. Materials and methods

2.1. Study area

Doñana Natural Area (36°59′ N, 6°26′ W; Fig. 1) is a Biosphere Reserve with a Mediterranean climate, characterized by a mosaic of natural, rural and urban environments in which, depending on the level of protection (National and Natural parks), some human activities are allowed. The local road-network is widespread, with different types of roads and traffic intensities. We surveyed all paved roads within the Natural Park: A494 Matalascañas–Mazagón (23 km), Cabezudos road (5 km), A483-Hinojos (11 km), and A483-Villamanrique de la Condesa (16 km; Fig. 1). The A494 Matalascañas–Mazagón is a two-lane regional road, whereas Cabezudos road, A483-Hinojos and A483-Villamanrique de la Condesa are two-lane forestry/agricultural roads. On the regional road the daily traffic volume was 2347 vehicles/day and the maximum allowed speed was 100 km/h. Forestry/agricultural roads had lower traffic volumes (133 vehicles/day on Cabezudos road, 194 vehicles/day on the A483-Hinojos, and 745 vehicles/day on the A483-Villamanrique de la Condesa) and maximum speed (60 km/h; see Fig. 1 for arithmetic means and standard deviations). Almost the whole length of regional and forestry/agricultural roads are fenced (but Cabezudos road is not). There were ten WCS along the A494 Matalascañas–Mazagón, 22 along the A483-Villamanrique de la Condesa, and four along the A483-Hinojos. The surveyed roads were located in Mediterranean forest and scrubland. Local terrestrial vertebrate communities are composed by typically Mediterranean species.

2.2. Data collection

From March 2006 to February 2007 (July 2007 excluded) we surveyed driving the four roads at 15 km/h approximately twice per week (one day in the morning and one day in the afternoon, chosen at random), on both directions. The observer (always the same person) searched for road-killed animals on the road surface and along the adjacent verges and ditches, georeferencing, identifying (at class and, when possible, species level) and removing all the specimens from the road.

We used the available scientific bibliography and unpublished data of the EBD-CSIC to compile a checklist of the species present in the study area in association with the vegetation and land-uses adjacent to the roads (Appendix 1). We considered all the species included in the checklist as potential road-kill victims. For those species we selected a set of life-history predictors likely to affect road-kill probability based on available bibliography (Ford and Fahrig, 2007; Cook and Blumstein, 2013; see Appendix 1 for more details). The candidate predictors directly or indirectly described species as a function of their abundance and movement capacity. In the first case the candidate predictors were *abundance* (rare, common, or abundant), *size* (body mass), *breeding* (average number of offspring per female-year), *activity* (nocturnal or diurnal), *habitat preferences* (urban, farmlands, grasslands, scrubland/woodland and freshwater), *food habits* (carnivorous, insectivorous or herbivorous) and *territoriality* (territorial or not). In the second case the candidate predictors were *movement* (terrestrial or flying),