Spatial patterns of road kills: a case study in southern Portugal

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INTRODUCTION

One major human agent of habitat fragmentation is the ever increasing and expanding road network world wide (Forman et al. 2002), which can be harmful to various faunal groups such as invertebrates (e.g.: Haskell 2001), amphibians (e.g.: Carr and Fahrig 2001), reptiles (e.g.: Gibbs and Shriver 2002), birds (e.g.: Kuitunen et al. 1998) or mammals (e.g.: Philcox et al. 1999). Roads and traffic can act as barriers which may difficult animal movements and reduce population connectivity. By diminishing the gene flow and disrupting sink-source population dynamics, roads may increase inbreeding and loss of genetic diversity (Ferreras 2001). Resultant isolation might lead to higher population local extinction risks due to stochastic effects (van der Zande et al. 1980; Saunders et al. 1991; Fahrig and Merriam 1994; Cooper and Walters 2002).

Roads also promote high levels of animal-vehicle collisions, particularly significant for larger species with wider home ranges as carnivores, being one of the most visible road impacts on wildlife (e.g.: Hodson 1960; Oxley et al. 1974; Fahrig et al. 1995; Philcox et al. 1999; Gibbs and Shriver 2002; Taylor and Goldingay 2004).

In Portugal, SW Europe, very few ecological studies have focused on the impacts from roads on vertebrate populations and the knowledge of the main factors driving to the emergence of hotspots of vertebrate mortality is still scarce.

This study refers to a two year road kill survey on a main road (IP2) located in southern Portugal (figure 1).

STUDY AREA

The study was conducted in Portalegre District, between Portalegre and Monforte cities, near the Natural Park of S.Mamede (NPSM) (figure 1). This region is in the centre of the Iberian Peninsula, generally dominated by smooth areas, except on the natural park were mountain topography reach 1024 meters a.s.l. The climate is mediterranean, although the NPSM is considered to be an Atlantic Biogeographic island in the middle of mediterranean region. This biogeographic crossroad enables the coexistence, within the same area, of several species from both biogeographic regions.

Road vicinity is dominated by characteristic mediterranean agro-forestry areas, cork and holm oak tree stands (*Quercus suber* and *Q. rotundifolia*), hereafter referred as “montado”; open land as pastures, meadows or extensive agriculture (cereal, fodder); and olive groves (figure 2). This IP2 section has a moderate traffic intensity of about 5000 vehicles day $^{-1}$.

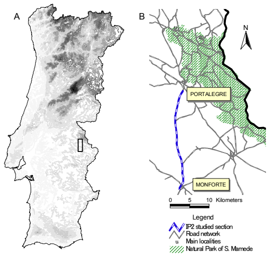

Figure 1 – Location of studied IP2 road section (A) and map of study area (B)

METHODS

Sampling

A segment of the IP2 road, with 26km long, was sampled by car, at an average speed of 20 km/h, every two weeks, for two years (54 surveys) between 1995 and 1997.

All vertebrates found killed on the pavement were collected and identified to species level *in loco*, whenever possible, or by analysis of skin, scales, feather or hairs, depending on the taxonomic group, in the laboratory.

It should be emphasized that number of casualties found were most probably biased due several constrains, namely carrion foraging from other animals, climatic conditions, road physical characteristics, which can mislead correct counting and detection of corpses on roads (see Erritzoe et al. 2003, *pers. observ.*). Thus, records should be regarded merely as an underestimation of real carnage occurring on the road. Furthermore, non-daily surveys prevents the detection of all small bodied animals like amphibians, passerines or small mammals, since their corpses often remain between one and three days on the traffic lane (António Mira, *unpublished data*).

Explanatory variables

For each 0.5km road section we created a 500 meter radius buffer, with its center on the section’s middle point.

Land cover was assessed for these buffers through orthofotomap analysis, with corrections from field work observations. Five classes of land cover were considered: montado (MNT), open areas (OPEN), olive groves (OLIVE), fruit tree groves and horticultures (FRUIT), and urban areas (URBAN) (figure 2).

On each buffer we also considered the length of streams present inside each buffer (STREAM_L); the distance of the middle point section to nearest stream (STREAM_D);

The number of culverts (CULVERT) and houses (HOUSE) present on each 0.5km road section were as well considered.

All the information was processed with ArcView 3.2 (ESRI^{TM}, Redlands, California, USA).

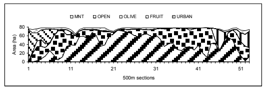

Figure 2 – Land cover (main classes) within each 500 meter radius buffer (near 79 ha), along the studied road

Mortality hotspots

We defined road sections with high collision rates, or vertebrate mortality hotspots (VMH), by detecting clusters of animal collision locations. As described by Malo et al. (2004), the analysis was conducted by comparing the spatial pattern of roadkills with that expected in a random situation. In such condition, the likelihood of collisions for each road section would show a Poisson distribution. This way, being λ the mean number of collisions per 0.5km road section, the probability of any road section having x number of roadkills is:

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

We considered that a section was a potential vertebrate mortality hotspot when its probability summation exceeded the 90% threshold, that is $\sum p(x) > 90\%$.

Data analysis

Differences on explanatory variables between hotspots and low mortality sections were evaluated with Mann-Whitney *U*-test (Zar 1999). This analysis was performed for all observations, for anurans and caudata orders (amphibians), and for the vertebrate classes reptiles, birds and mammals (domestic cat and dog were excluded from analyses).

For multivariate analysis we used canonical ordination techniques. A direct gradient analysis (Canonical Correspondence Analysis - CCA) was executed with the mortality rates of the most 24 killed species (species with above 15 casualties, table *i*) and the explanatory variables considered, with downweight of rare species and detrending by segments options (Jongman et al. 1995), using CANOCO for Windows version 4.5 (ter Braak and Šmilauer 2002).

We selected the variables MNT, OLIVE, OPEN, FRUIT, CULVERT, STREAM_L and STREAM_D. This option was made in order to achieve a compromise between obtaining the maximum percentage of variance explained and the significance of both eigenvalues and correlations of species-explanatory variables with the axis. Significance of species-environment correlation was tested by the Monte Carlo test (499 permutations). Ordination axis were interpreted using the intraset correlations that allow inference on the relative importance of each variable for predicting community composition (ter Braak 1986).

RESULTS

A total of 2421 vertebrate road-killed specimens were collected, which corresponded to about 46 specimens per 0.5km, per year. 2128 individuals were identified to the species level, being recorded 80 non domestic species (table *i*, at the right margin).

Casualties among vertebrate classes were significantly different (chi-test, $\chi^2 = 1630$, df = 3; $p<0.001$), being higher on amphibians (n = 1362 followed by birds (n = 681), mammals (n = 225 and reptiles (n = 153).

Several sections were defined as vertebrate mortality hotspots (VMH), either for all observations and for each vertebrate class (figure 3). VMH’s clusters seemed to be mainly aggregated at the first half of studied road segment.

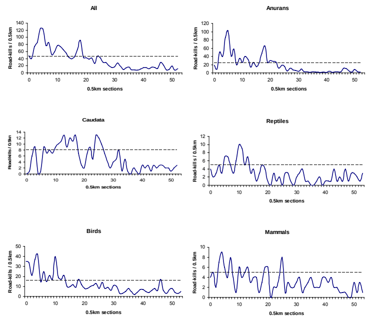

Figure 3 - road mortality along 0.5km road sections. The dashed line sets the threshold for the definition of vertebrate mortality hotspots (Malo et al. 2004): 46 individuals for all observations, 24 for anurans 8 for caudata, 5 for reptiles, 17 for birds and 5 for mammals.

Regarding amphibians, hotspots of anuran mortality occurred mainly in the proximity of streams (U=203.5, n_1=35, n_2=18; p<0.05), and in sections with lower number of culverts (U=159.0, n_1=35, n_2=18; p<0.01). For caudata, a high number of killed specimens were detected in sections with low number of houses nearby the road (U=214.0, n_1=37, n_2=16; p<0.05).

Concerning reptiles, road sections with high mortality had also a lower number of culverts (U=192.5, n_1=37, n_2=16; p<0.05). Stream proximity was almost significant, being the hotspots of mortality closer to stream lines than other sections (U=203.5, n_1=37, n_2=16; p=0.073).

Higher bird mortality occurred in road sections near watercourses (U=145.0, n_1=39, n_2=14; p<0.01), with houses in close proximity of the road (U=153.5, n_1=39, n_2=14; p<0.01), and with a lower cover of montado (U=153.0, n_1=39, n_2=14; p<0.05).

There were no significant differences concerning environmental variables between road sections with high and low mortality of mammals.

The direct gradient analysis (CCA) results are shown in figure 4. The eigenvalues were 0.153 in the first axis and 0.063 in the second. Mont Carlo test was significant for both first canonical axis (F=6.099, P<001) and all canonical axis (F=1.933, P<001). First two axis explained 74.2% of data variability. First axis reflects mainly the effects of fruit trees groves and horticultures (FRUIT), which are related to anthropogenic presence, and the montado cover density (MNT); while the second reflects the proximity and length of watercourses nearby the road (STREAM_P and STREAM_L).

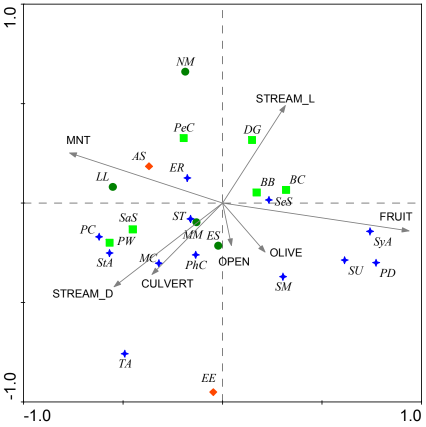

Figure 4 - CCA ordination plots of the 24 most killed species (squares are amphibians; circles are reptiles; stars are birds and diamonds are mammals), with explanatory variables. See text for variables names.

Longer vector lines represent stronger “intraset correlations” (ter Braak 1986). See text for variables names and methods.

Species: Amphibians - BB, *Bufo bufo*; BC, *Bufo calamita*; DG, *Discoglossus galganoi*; PeC, *Pelobates cultripes*; PW, *Pleurodeles waltl*; SaS, *Salamandra salamandra*; Reptiles - ES, *Elaphe scalaris*; LL, *Lacerta lepida*; MM, *Malpolon monspessulanus*; NM, *Natrix maura*; Birds – ER, *Erithacus rubecula*; MC, *Miliaria calandra*; PC, *Parus caeruleus*; PD, *Passer domesticus*; PhC, *Phylloscopus collybita*; SeS, *Serinus serinus*; SM, *Sylvia melanocephala*; ST, *Saxicola torquata*, StA, *Strix aluco*; SU, *Sylvia undata*; SyA, *Sylvia atricapilla*; TA, *Tyto alba*; Mammals - AS, *Apodemus sylvaticus*; EE, *Erinaceus europaeus*.

We observe on the CCA plot that most species are positioned on the left side, suggesting that higher mortality rates occurred in sections dominated by montado. Exceptions to this are the cases of *Passer domesticus* (PD) or *Sylvia atricapilla* (SyA), species that are related to anthropogenic environments, and are shown close to FRUIT variable. Fruit trees groves and small horticultures are typically located nearby small urban areas in mediterranean landscapes (as is the case near Portalegre). Anuran mortality seemed to have occurred on sections close to watercourses. Also noteworthy is that the position of several small species, as amphibians *Bufo bufo (*BB), and *Bufo calamita (*BC), reptile *Natrix maura (*NM) and small mammal *Apodemus sylvaticus* (AS) suggests that higher mortality levels occurred on sections with a lower number of culverts.

DISCUSSION

Mortality rates on the Portuguese road presented in this study support that further road expansion should consider impacts on animal populations, and mitigation measures must be taken account on existing road network. Furthermore, considering that Iberian Peninsula is included in a global biodiversity hotspot, the Mediterranean Basin (Myers et al. 2000), and that most species are in one way or another threatened by anthropogenic actions such as road expansion (de Vries et al. 2002), highly priority actions should be implemented on Iberian roads towards a more permeable road system to animal movements. This is more relevant for the studied road given its location, near the border of an important Portuguese protected area, Serra de S.Mamede Natural Park (figure 1). This area is located in a biogeographic crossroad assembling both Mediterranean and Atlantic climatic characteristics, which grants it with multiple habitat patches allowing high species diversity and richness. Probably this is reflected in the highest number of road-killed species and specimens on the firsts kilometers. As suggested by Spector (2002), biogeographic crossroads appear to be areas of high conservation priority and opportunity in both the short and long term and require increased attention in the process of setting conservation priorities.

Results suggested that some road sections should receive particular mitigation actions given that mortality hotspots may arise. Particularly sections where montado is the dominant habitat and where stream and other water courses run nearby and parallel to the road. Also, the presence of culverts may diminish the collision risk, providing alternative paths for road crossings. This way, as previous authors described (e.g.: Yanes et al. 1995; Rodríguez et al. 1996; Cain et al. 2003; Mata et al. 2005), the implementation of several of these or other alike structures, with different sizes and configurations should be of primary concern.

Presently, an ongoing project using the same methodology is taking place, on the same segment of road, with the purpose to evaluate and compare the vertebrate mortality rates and its spatial patterns 10 years after.

Table *i* - Species identified during field work (54 surveys on a 26 kilometer road section); Portuguese red book status (RBS); and number of specimens (N). Species are sorted, within each class, by decreasing number of casualties.

Species	RBS	N
Amphibians		
Bufo calamita	LC	456
Pelobates cultripes	LC	319
Bufo bufo	LC	177
Salamandra salamandra	LC	157
Pleurodeles waltl	LC	106
Discoglossus galganoi	NT	17
Triturus marmoratus	LC	11
Hyla meridionalis	LC	6
Rana perezi	LC	5
Alytes cisternasii	LC	2
Pelodytes sp.	NE	1
Reptiles		
Elaphe scalaris	LC	46
Malpolon monspessulanus	LC	28
Lacerta lepida	LC	21
Natrix maura	LC	16
Mauremys leprosa	LC	12
Psammodromus algirus	NT	9
Coluber hippocrepis	LC	7
Coronella girondica	LC	1
Natrix natrix	LC	1
Birds		
Passer domesticus	LC	80
Miliaria calandra	LC	45
Saxicola torquata	LC	41
Sylvia atricapilla	LC	37
Phylloscopus collybita	LC	33
Sylvia melanocephala	LC	33
Serinus serinus	LC	32
Erithacus rubecula	LC	31
Tyto alba	LC	27
Sylvia undata	LC	26
Parus caeruleus	LC	24
Strix aluco	LC	20
Carduelis carduelis	LC	15
Lanius senator	NT	14
Hirundo daurica	LC	11
Athene noctua	LC	8
Cisticola juncidis	LC	8
Turdus merula	LC	6
Fringilla coelebs	LC	5
Parus major	LC	4
Carduelis chloris	LC	3
Lanius meridionalis	LC	3
Phylloscopus trochilus	LC	3
Alectoris rufa	LC	2
Carduelis cannabina	LC	2
Elanus caeruleus	NT	2
Ficedula hypoleuca	LC	2
Troglodytes troglodytes	LC	2
Turdus philomelos	NT	2
Alcedo atthis	LC	1
Bubulcus ibis	LC	1
Carduelis spinus	LC	1
Ciconia ciconia	LC	1
Falco tinnunculus	LC	1
Galerida cristata	LC	1
Motacilla alba	LC	1
Muscicapa striata	NT	1
Passer hispaniolensis	LC	1
Petronia petronia	LC	1
Phoenicurus ochruros	LC	1
Pica pica	LC	1
Mammals		
Apodemus sylvaticus	LC	37
Erinaceus europaeus	LC	19
Oryctolagus cuniculus	NT	12
Lepus granatensis	LC	11
Vulpes vulpes	LC	10
Mus spretus	LC	9
Pipistrellus kuhli	LC	7
Crocidura russula	LC	6
Genetta genetta	LC	5
Meles meles	LC	5
Pipistrellus pipistrellus	LC	5
Mustela putorius	DD	4
Microtus cabrerae	VU	3
Microtus duodecimcostatus	LC	3
Herpestes ichneumon	LC	2
Rattus norvegicus	LC	2
Talpa occidentalis	LC	2
Martes foina	LC	1
Rhinolophus ferrumequinum	VU	1

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