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Abstract: We examined spatial patterns of carnivore casualties by counting the number of animals killed on 574 km of national roads and highways in southern Portugal. We surveyed six national roads twice a month from July 2003 to December 2006. Highway casualty data were collected by Brisa Auto-Estradas de Portugal, S. A., a private concession. A total of 801 carnivores representing eight carnivore species were killed. We found an average of 47 vehicle-killed individuals/100km/year; foxes were most numerous with the 20 individuals killed/100km/year. The distribution of carnivore vehicle-kills was clustered except fox. We calculate the mean road kill rate on different classes of variables that may influence road mortality and compare among them to identify the level of risk posed by each class of variable. Casualties were more likely to occur near to suitable habitats preferred by carnivores, in high traffic volume areas, and close to streams. Livestock exclusion fences, the type of road, and the number of passages did not influence mortality. To improve the cost-effectiveness of mitigation measures for new and existing roads, the priority should be given to the road segments crossed by streams in a cork oak woodlands matrix. Short sections of buried fences near culvert openings (100m on each side) should reduce the number of casualties considerably. Habitats connectivity is a serious issue where high volume traffic discourages carnivores from crossing roads at-grade. Connectivity is enabled by appropriately-designed passages.

Introduction

Roads exert a range of effects on ecological communities, including animal mortality, habitat loss and degradation, and barrier effects that impede animal movements (Forman et al. 2003). As roads are upgraded to accommodate greater traffic volume, the rates of successful wildlife crossings tend to decrease significantly (Iuell et al. 2003). Furthermore, populations of mammalian carnivores may be particularly vulnerable to road mortality because of their low population density, low fecundity, and large home ranges (Gittleman et al. 2001). In some cases, vehicles are the leading cause of local mortality (Ferreras et al. 1992, Clarke et al. 1998).

Recent research has demonstrated that vehicle-kills are spatially clustered and seems to depend on animal population density and biology, habitat type and landscape structure, as well as on road and traffic characteristics (Clevenger et al. 2003, Malo et al. 2004, Ramp et al. 2005). Moreover, the influence of traffic volume on road mortality and barrier effects have long been recognized (Forman and Alexander 1998). It appears that under a certain volume of traffic, mortality increases with traffic. Once a certain traffic volume threshold is reached, animals appear less likely to cross roads.

Here we provide an overview assessment of road impacts on small and medium-sized carnivores of Southern Portugal by analyzing the pattern of road kills. We compiled carcass data, estimated which species were more likely to be killed, and identified which spatial factors influenced the likelihood of road mortality. We expected that carnivore casualties would be non-random because their movement distributions tend to be linked to specific habitats features. We expected to detect a great proportion of carnivore road fatalities on cork oak woodlands. Additionally, we expected a higher mortality on higher volume highways than lower volume national roads.

Methods

Road Kill Survey Data Collection

We conducted the study along a 256km section of two highways and 318km in six national roads, in southern Portugal (fig. 1).

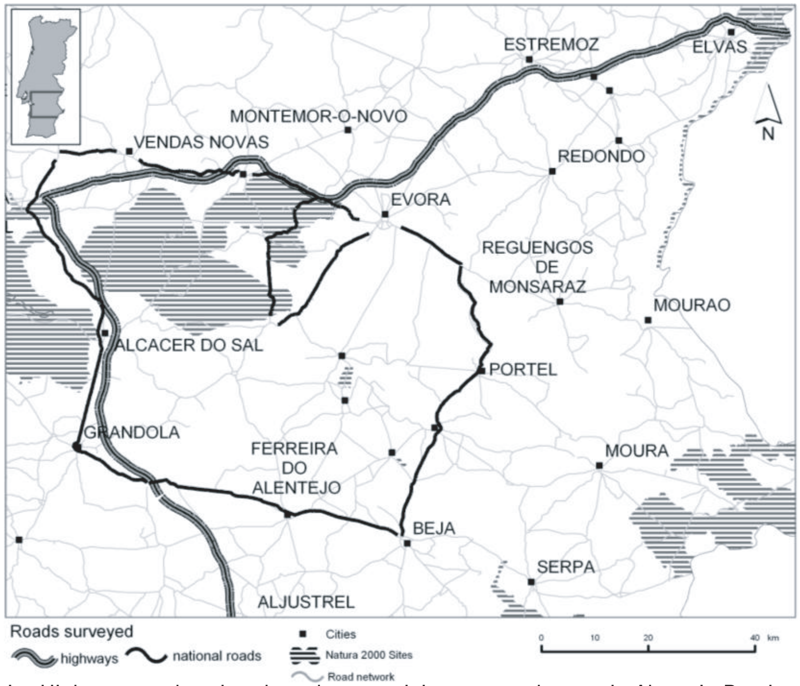

Figure 1. Major Highways and national roads comprising our study area in Alentejo Province, Portugal.

From July 2003 to December 2006, we surveyed the national roads twice a month. One observer drove 20-30km/hr on the paved roadside searching the right-hand side of the road and its verge for any carnivore fatalities, traversing the roads in both directions. Highway data on carnivore casualties were obtained by Brisa Auto-Estradas de Portugal, S.A. (private concession) database.

Spatial Analysis

We used Linear Nearest Neighbour Analysis (Levine & Associates 2004) to evaluate whether carnivore vehicle kill data were clustered or dispersed along road segments. The linear nearest neighbour index (NNI) is a ratio between the average distance of the nearest neighbour and the expected random distance (Levine & Associates 2004). If the observed mean distance is the same as the mean random distance, then the ratio will be 1.0. If the observed distance is smaller then the random, the NNI is < 1.0 (clustered). The data are dispersed when NNI >1.0. We hypothesized that given the heterogeneity of the landscape and the habitat preferences of carnivores that the data would be clustered.

To identify the level of risk posed by each class of variable that may influence road mortality (table 1), we divided the highways and national roads into 500m segments (n=1148). All kill data were plotted on the road network in a GIS format and the mortality rate (kills/100km/year) for each segment was calculated. Additionally, we characterized each segment according to different classes of variables.

Table 1: Variables and their description used in the analysis and range of values

Variable name	Description
Habitat	Cork oak woodland (*Quercus suber* and/or *Quercus ilex*) Extensive agriculture (croplands and arable lands) Intensive agriculture (olive trees, vineyards and orchards) Production forest (*Pinus* sp. and *Eucalyptus* sp.)
Traffic volume (2005)[a)]	Daily traffic volume at the nocturnal period (vehicles/night)
Type of roads	Highways or national roads
Livestock exclusion fences	Presence or absence
Number of passages	Number of overpasses, underpasses, and culverts
Distance to streams	Distance to streams up to 1000m distant

[a)] values ranged between 330 and 2494 vehicles/night

Except for the dichotomous variables (type of roads and presence/absence of livestock excluding fences), all variables were divided into 3 or more classes. Thus, habitat was categorized into four representative structural vegetation classes in the study area (cork oak woodland, extensive agriculture, intensive agriculture and production forest); data traffic was classified into four classes using Jenk's optimization algorithm (ESRI 1996) that minimizes the variation within each class; passages were classed into four classes (0, 1, 2, > 3 passages); and distance to streams was divided into three distance zones with biological meaning for carnivores. We used Hawth's Analysis Tools extension in ESRI® ArcGis 8.2 to select the same number of random segments for each class of variable (n=100) and we used a one-way ANOVA test to compare the means of road kill rates (Dytham 2003). When the F test was significant, we used all pair-wise comparisons using Tukey´s HSD test to identify which pairs of classes were different. If the variance was not equal we used the Games-Howell test. To remove the habitat effect on the analysis we performed the same procedure only in cork woodland areas. Spatial and statistical analyses were conducted using ArcGIS 8.2, CRIMESTAT v.3 and SPSS 14v. software.

Results

Carnivore Road Kill Data

A total of eight carnivores species were detected as road casualties (fig. 2). On average we found 47 vehicle-kills/100km/year; fox (*Vulpes vulpes*) had the highest mortality (20 ind./100km/year), followed by stone marten (*Martes foina*) (8 ind./100km/year), mongoose (*Herpestes ichneumon*) (6 ind./100km/year), and badger (*Meles meles*) and genet (*Genetta genetta*) (5 ind./100km/year each). Otters (*Lutra lutra*) (n=28), polecats (*Mustela putorius*) (n= 20), and weasels (*Mustela nivalis*) (n=12) were the less frequently killed over the three years. No wildcat (*Felis silvestris*), which potentially occurred in the study area, were recorded.

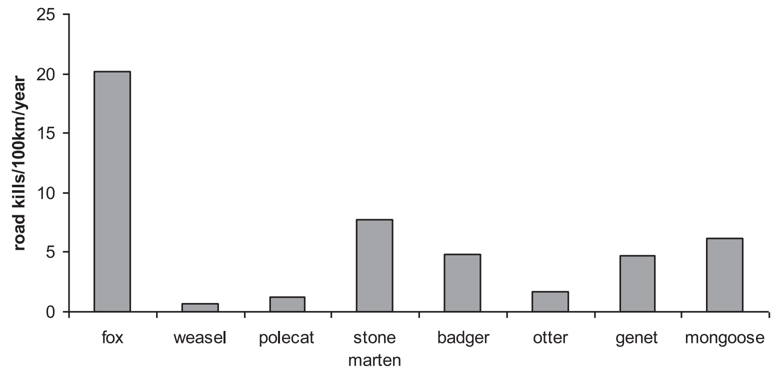

Figure 2. Yearly rate of road killed carnivores on the national roads and highways

Spatial Analysis

Our results showed that when data for all species were lumped, road kills were dispersed along the roads (NNI>1). However, when we analysed the data separately by species, we found that only fox mortalities were dispersed; the remaining species showed clustering. Nevertheless, the t statistics related with NNI was only significant for the genet road kills distribution ($p<0.05$). The mean road kill rate was different for habitat ($F=7.9$, $df=3$, $p<0.05$), daily traffic volume ($F=6.7$, $df=3$, $p<0.05$), number of passages ($F=2.7$, $df=3$, $p<0.05$), and distance to streams ($F=3.6$, $df=2$, $p<0.05$) (fig. 3). Carcasses were found at the highest frequency in cork oak woodland and at the lowest frequency in extensive agriculture (fig. 3 (i)). The mean number of road kills increased until traffic volume reached 573-973 vehicles/night and then began to decrease (fig. 3 (ii)). Mortality increased with the number of passages (fig. 3 (v)). No significant differences were found in the rate of road kills between national roads and highways ($F=0.45$, $df=1$, $p>0.05$) (fig. 3 (iii)) or the presence/absence of livestock exclusion fences ($F=0.14$, $df=1$, $p>0.05$) (fig. 3 (iv)).

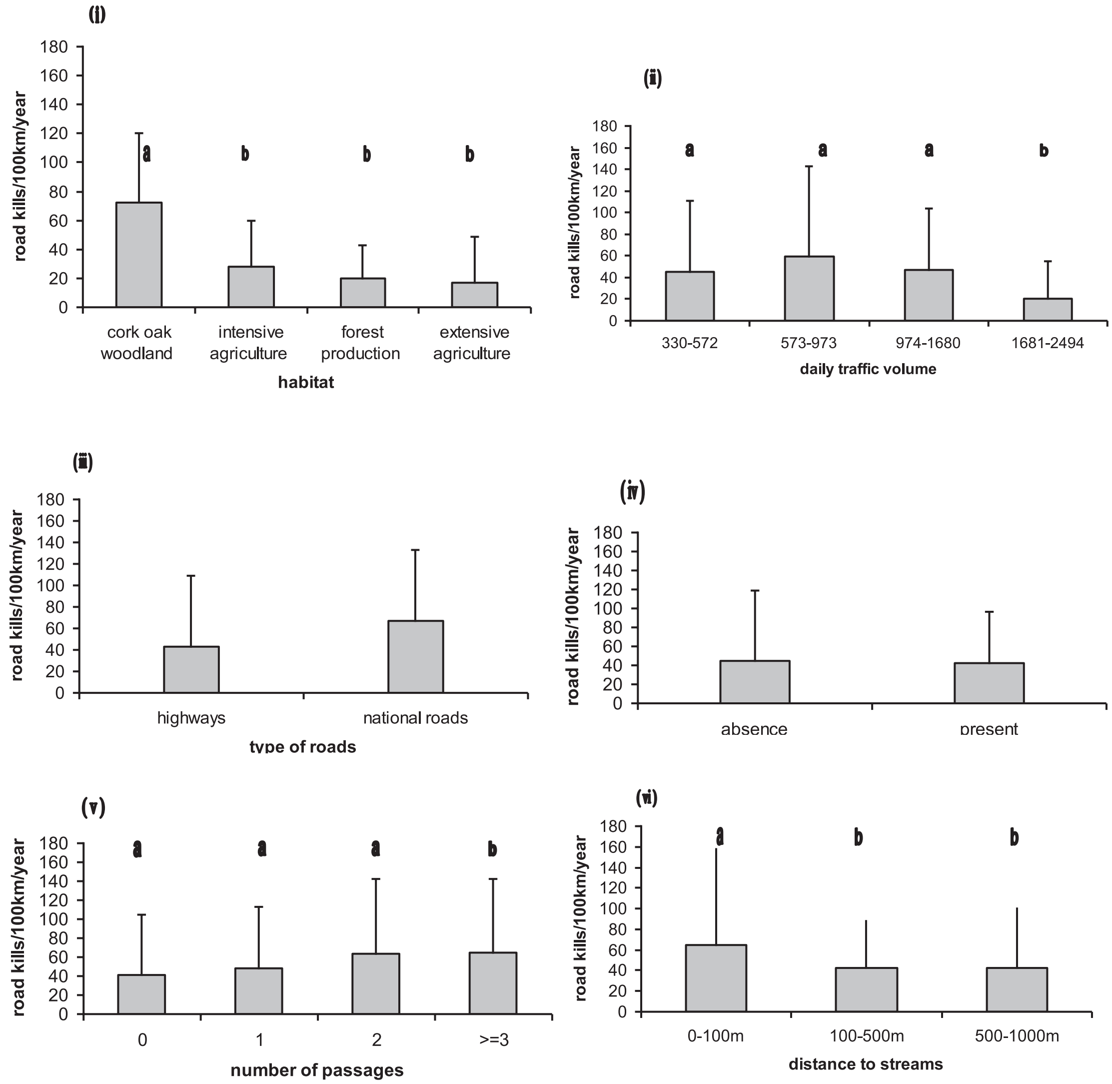

Figure 3. Mean density of road kills plotted against each explanatory variable (habitat, daily traffic volume, type of road, livestock exclusion fences, number of passages and distance to streams). Letters indicate significant differences in mean road kills rate for each class of variable.

The road segments with distance to streams less 100m had a higher mean road kill index value (fig. 3 (vi)). When we performed the same analysis by removing the habitat effect, (viz., using only segments in the cork oak woodland matrix), we found the same patterns but no significant differences among the classes of all variables (all $p>0.05$).

Discussion

As habitat generalists and wide ranging species, carnivores are known to travel widely over different habitat types, presenting great difficulties in preventing road casualties, because crossing points are far more difficult to predict. However, our findings highlight the significance of two points: a) the incidence of road kills of the most common species; and b) the importance of habitat and traffic on fatalities.

The high number of carnivore casualties we report may be explained in part by their abundance, and also by their wide distribution in the study area, which is characterized by well managed cork oak woodlands and a low human population density. Additionally, the five most frequently killed carnivores are also the most known common species in the region (Cabral et al. 2005).

Even though the results showed that carnivore road kills taken together were dispersed: when analyzed by species, only fox casualties were dispersed. This suggests that species–specific traits of carnivores should be accounted for in these kinds of analyses to reveal if distinct differences among carnivore road kill distributions are evident.

According to our predictions, cork oak woodlands, traffic volume, and distance to streams seem to be important factors for explaining carnivore collisions. Cork oak woodland is a favored habitat for carnivores and the primary habitat where road kills occurred. The data also indicate that high traffic volume has a detrimental effect on carnivores. Nevertheless, above ~1000 vehicles/night the mortality decreased, strongly suggesting that above this threshold carnivores are discouraged from crossing roads at-grade, i.e., roads act as a barrier at higher traffic volumes. The highest carnivore mortality occurred in areas where streams were less than 100m from the road. In reality, streams function as a surrogate for riparian vegetation, the attribute that more directly influences the movement of carnivores. The landscape features associated with streams are well known as travel corridors for carnivores (Simberloff and Cox 1987), providing shelter and food and offering anti-predator cover (Virgós 2001). Livestock exclusion fences did not reduce the probability of road kills. Fences failed to prevent them from travelling over the road because these fences are not buried and have a mesh size too large to inhibit movement of small and medium sized carnivores. Contrary to our expectations, we found no differences of road kill rate between roads and highways, which we suspect is because several sections of both types of roads have similar traffic volumes. Curiously, the number of below-grade crossing structures did not appear to reduce fatalities. However, a previous study (Grilo et al., unpubl. data) showed that carnivores used underpasses and culverts regularly. We found that the number of road kills found in the vicinity of passages was significantly less than the number of times that animals crossed through the passages (Grilo, unpubl. data). It is clear that passages do provide safe passage for wildlife but do not prevent animal-vehicle collisions.

Given these results, we recommend that cork oak woodlands are prime targets for implementing mitigation measures. For example, short sections (100m on each side) of buried and small size net fences that inhibit small animal at-grade crossing and may funnel animals to underpasses or culvert openings and reduce the number of casualties. Moreover, the challenge for transportation agencies and road managers is to be aware of the road segments with high volume traffic and to take appropriate action to ensure the habitat connectivity for carnivores by providing safe passages for wildlife.

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