How Do Major Roads Affect Barn Owls? Distribution, Space Use, Food Source and Mortality

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Abstract

Road network expansion is known as one of the main factors responsible for the decline of Barn Owl (*Tyto alba*) populations in Europe, although the full causes of this decline are still poorly understood. In this context we evaluated several issues related to Barn Owl's ecology, in Southern Portugal, when interacting with major roads: (a) the effect of highway distance on owl's occurrence pattern, (b) the behavioral in the vicinity of major roads, (c) the role of road verges as an attraction factor due to prey abundance, and (d) owls' spatial and temporal patterns of road mortality.

To assess species occurrence (presence/absence) we broadcasted Barn Owl adult calls in 122 sites at several distances from major roads and detected 47 individuals. From the set of environmental and road-related variables tested using logistic regression, only the distance to the highway showed a significant positive influence on Barn Owl presence (β= 0.995; $p<0.05$).

Space use patterns and road crossing rates were investigated on the basis of seven radio-tagged individuals (4 ♂, 3 ♀), captured in their nests located close to the highway (<5 km). The crossing rate was low (one road crossing per 34.19 hours of radio-tracking). Of the tracked individuals only four (3 ♂, 1 ♀) had sample sizes strong enough to provide robust estimates of home-range size (Fixed Kernel Density Estimator 95%) and just a peripheral overlap between home-ranges (ranging from 2.61 km^2 to 9.37 km^2) and the highway was observed.

The overall abundance of small mammals, assessed through live-trapping, was significantly higher in highway verges (n=248) than in the two other dominant land uses (cork oak woodlands (n=35), and croplands (n=64), suggesting that road verges could be a suitable habitat for hunting.

Between 2004 and 2007, 373 road-kills were detected in 314 km of national roads surveyed (0.30 Barn Owls kills.km^{-1}.$year^{-1}$). A higher number of casualties was registered in fall and winter months when the dispersion of juveniles occurs, while lower mortality frequencies were detected in the end of summer and early spring, corresponding to hatching and fledgling periods. Mortality hotspots revealed to be strongly related with altitude (β =-0.026; $p<0.05$), eucalyptus or pine forest cover (β =-0.001; $p<0.05$) and percentage of cropland areas crossed by the road (β =0.332; $p<0.05$).

Although major roads do not seem to act as effective barriers to Barn Owls' movements, their occurrence pattern is significantly affected by this linear structure. Moreover, the potential attraction effect due to higher prey density in the highway verges does not seem to have an effect in the foraging behavior of adults.

Introduction

There is a growing consensus in the scientific community (Percival 1990, de Bruijn 1994, Shawyer 1994, Newton *et al.*1997, Fajardo 2001) that Barn Owl (*Tyto alba*) populations have been declining across Europe. The decreasing availability of structures for breeding and roosting (Taylor 1994, Martínez 2004), changes on the agricultural production system and, more recently, the road network expansion (Meek *et al.* 2003, Erritzoe *et al.* 2003, Martin *et al.* 2005), have been referred as the factors threatening Barn Owl populations. A 15 years study conducted in Great Britain on Barn Owl mortality showed that 48% of the recorded deaths were attributed to road collisions and 31% to starvation (Newton & Wyllie 2002). Low fitness condition may pre-dispose Barn Owls to vehicle collisions if: i) it forces them to spend more time hunting, ii) animals do not find other places to hunt unless road verges, or iii) they are less able to avoid vehicles (Newton *et al.* 1997). Supply of perching sites (Meunier *et al.* 2000, Forman & Sperling 2003), temporary blindness on the attempt to cross the road (Hernandez 1988), or inexperience during juvenile dispersion (Massemin *et al.* 1998) are also potential causes of the high mortality rate.

Nevertheless, roads seem to propitiate antagonistic effects. Besides potential attraction due to higher prey density in road verges, (Meunier et al. 1999; Erritzoe et al. 2003, Orlowski 2008, McGregor *et al.* 2008), a repulsive effect due to its inherent disturbance (Ramsden 2003) may explain the lower number of individuals within an area of a dense road network, as documented by Fajardo (1999) and Martinez & Zuberogoitia (2004).

Issues mentioned above underlie the question: Is the Barn Owl repulsed or attracted by major roads? To address this question the following aims have to be considered: (a) to evaluate the effect of highway distance on owl's occurrence pattern; (b) to analyze the behavioral patterns in the vicinity of major roads, (c) to identify the role of road verges as an attraction factor due to prey abundance, and (d) to describe the spatial and temporal patterns of road mortality.

Methods

Study Area

This study was conducted in Alentejo province, in Southern Portugal, a region marked by a recent highway expansion and road's improvement to allow larger traffic volume. In this study we have focused on several segments of the national roads and two highways (A2 and A6), to assess temporal and spatial patterns of owl distribution, foraging behavior and mortality (Fig. 1). The region is dominated by an agricultural landscape and comprises a mosaic of cork oak woodlands (savannah-like woods of cork oak *Quercus suber* and holm oak *Quercus ilex*) and croplands. The human population density (excluding the two major cities, Évora and Beja) is 21 inhabitants.km^{-2} and the road network density is low, averaging 0.25km.km^{-2}, about half of the mean national road density.

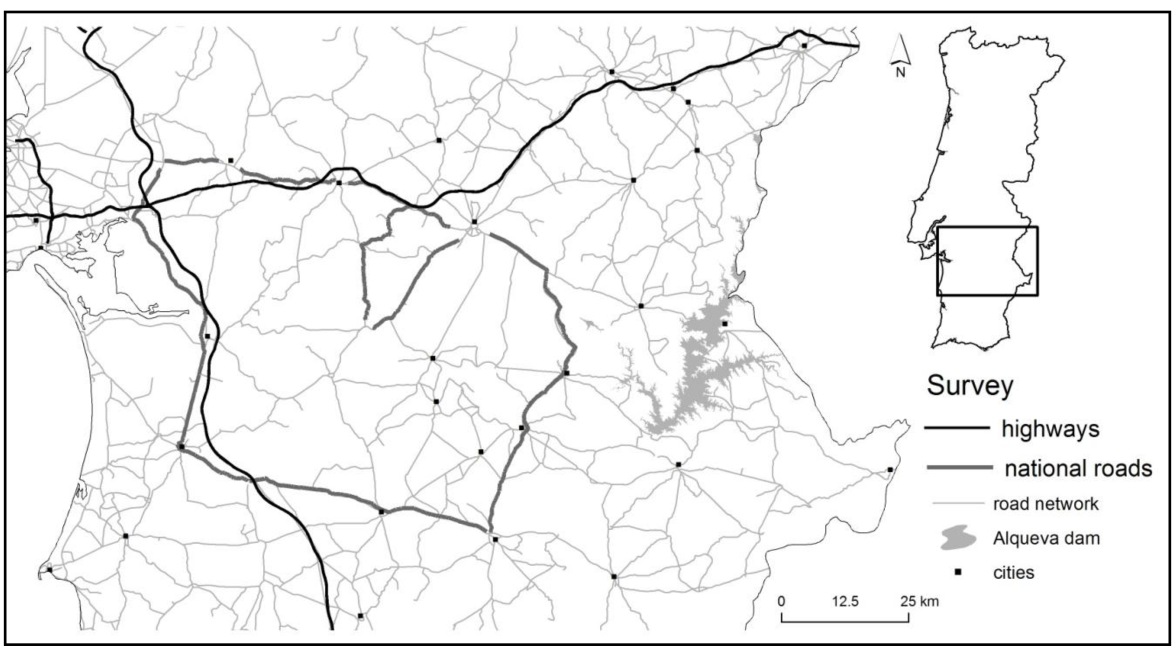

Figure 1 – Study area in Alentejo Province (southern Portugal).

Distribution

From November 2007 to January 2008, we have broadcasted 122 barn owl territorial calls and compared results under the highway effect (< 2000 m) and locations considered to be out of the highway effect (> 2000 m) in order to test the influence of the highway on barn owl occurrence, a set of environmental descriptors (weather, topography, land use, landscape metrics, roost availability, human presence, road-related features) was estimated for each sampling location and a logistic regression model was run to evaluate their relevance to barn owl presence (Hosmer & Lemeshow 2000).

Space use

Between May 2008 and May 2009, seven adult Barn Owls were captured and tagged with a VHF radio-transmitter (Biotrack LTD TW-3 single celled tag); female individuals were assigned as F1, F2, F3 and males as M1, M2, M3, M4. Individuals were radiotracked from dusk to dawn, and located with successive biangulations at 30' intervals. The bearings were taken synchronously by two observers, each driving independent vehicles, using hand-held three-element Yagi antennas. Fixes were obtained using Locate 3 software package.

The minimum convex polygon (MCP, Burt 1943) was used to visualize the largest foraging area recorded for each Barn Owl (White & Garrot 1990) while the fixed kernel density estimator (FKD; Worton 1989), was used to provide a probabilistic measure of use intensity of the foraging area (Anderson 1982, Harris *et al.* 2001, White & Garrot 1990). Spatial autocorrelation was not relevant for these data because this study followed a sampling strategy that considered the circadian activity (Kernohan *et al.* 1998) and thus all animal movements were regularly recorded (Otis & White 1999). Animal Movement Analyst Home Range Extension for the ArcView v. 3.3 and Hawth's Tools Extension for ArcGis version 9.2 were used in home range estimations. The Euclidean distance from radio-tracking fixes to the highway were estimated to assess the magnitude of the road avoidance or attraction effects. Each Barn Owl path was further analyzed and classified in terms of tortuosity using the fractal dimension estimate (D, D=1 linear movement, D→2 random movement, D>2 tortuous movement). Tortuous *vs.* linear movements and tortuous *vs.* random movements were compared in terms of highway distance using the Mann-Whitney test (Katz & George 1985).

Prey Abundance

For each Barn Owl nest found in the vicinity of a highway the relative abundance of small mammals was estimated in the two dominant landscape types (cork oak woodland and cropland), as well as in the nearest highway verge section.

The live-trapping of small mammals resulted from the use of Sherman traps (type "E" 23x9x8 cm and type "F" 38x12x11 cm), baited with cereals and caned sardines, and placed 10 m apart along two lines separated by 15 m. Each sampling session consisted of five consecutive nights, during which all the individuals captured were marked with fur cuts, weighed, sexed and released at the capture location.

The species abundance was estimated using Pounds (1980) index:

$$I_{ij} = \frac{N_{ij}}{T_j . R_j - \sum_j^i C_j - r_j} \times 1000$$

, where for trapping set j:

I_{ij} is the abundance index of species i;
N_{ij} is the number of individuals of species i captured;
T_j is the number of traps available (left open) for the species i;
R_j, is the number of repetitions (sampled nights);
C_j is number of catches (new and recaptures) of other species that species i;
r_j number of species i recaptures considering all repetitions.

To compare the different samples we used the factorial ANOVA.

Temporal and Spatial Road-Kill Patterns

We analyzed road-kill data obtained from January 2004 until December 2007 along 314 km of national roads (Fig. 1). Road surveys were made twice a month at a maximum speed of 30 km.h^{-1}.

The temporal analysis resulted from the comparison of the road-kill counts in the following life-cycle periods: laying, hatching, fledging and juvenile dispersal. To test whether there are differences in mortality among the four biological periods Chi-square statistics was used (Quinn & Keough 2002).

To evaluate the spatial patterns of road-kills, and determine their causes, we identified and described the location of road sections with high mortality incidence (hotspots). The number of road-kills to define a hotspot was estimated according to Malo *et al.* (2004) procedure and the hotspots location was defined using the Nearest Neighbor Hierarchical Spatial Clustering using the software CrimeStat III (Levine 2004). A logistic regression was used to model the occurrence of Barn Owl hotspots along the surveyed roads regarding several environmental and road related-attributes (topography, hydrology, land use, availability of breeding structures, human presence, road topography and width. The model validation was performed using the Jackknife procedure (Olden *et al.* 2002). All statistical procedures were run using SPSS v.15.0.

Results

Distribution

The call-playback method allowed detecting Barn Owl presence in 47 locations. From the environmental variables used, only distance to the nearest road was retained in the final regression model, being positively correlated with barn owl occurrence ($\beta=0.995$; $p<0.05$).

The logistic regression model obtained correctly predicted 69.8% of cases (70.2% of species presences and 69.4% of species absences). The jackknife validation procedure showed that the obtained and classified results were associated in 69.7% of the cases, indicating a good explanatory power.

Space use

Over 123 radio-tracking nights, we obtained a total of 1532 locations of the seven tagged individuals. Of these individuals only four achieved a sufficient sample size to allow home range estimation; three individuals were killed in a vehicle-collision and other three have disappeared being presumably dead. The home range estimations (Kernel 95%) ranged from 2.61 km^2 (M4) to 9.37 km^2 (F1) and assumed an average value of 5.78 km^2 (Fig. 2), which shows to be significant higher than Shawyer's (1998) estimation of 1 to 3 km^2. The core areas (Kernel 50%) ranged from 0.30 km^2 (M4) to 1.43km^2 (M2) having a correspondent average of 0.8 km^2. The MCP representation, as expected, is an over estimation of the actual home range (Fig. 2).

All nest-sites previously identified (F1, M1 M2) were located in the core areas of the home range (Kernel 50%), even those located very close to the highway (less than 500 m, F1 and M2).

The three individuals whose nest-sites were located further than 2 km from the highway showed no interaction with the highway (F2, F3, M4), while F1, M1 (nest-site closer that 500 m), M2 (nest < 2000 m) and M3 (trapped in a roosting place further than 1000 m from the highway) showed interaction with the highway. Nevertheless, these interactions were mainly highway crossings in areas marginally overlapping with this linear structure (Fig.2), since home ranges (Kernel 90%, 95%) mainly extended to the opposite direction of the highway (Fig. 2).

Figure 3 illustrates the higher number of fixes between 250 and 500 m from the highway (68.42%) than within a buffer of 250 m from the highway (30.58%). F1 and M1 with nests located closer than 500 m from the highway showed an evident preference to forage within 250 and 500 m from the highway, while M2 and M3, whose nest and resting place were located further from the highway (> 1000 m) preferred to forage far away from the highway (Fig. 3).

The average rate of highway crossings was 1 crossing per approximately 17.09 hours of monitoring, and a two way (go and return) crossing per approximately 34.19 hours of radiotracking. The two owls that died from vehicle collisions presented high values of highway crossing rate (Table 1)

Only the four individuals (F1, M1, M2, M3) that had a peripheral home range overlap with the highway showed tortuous movements. Mann-Whitney tests found significant differences between random vs. tortuous paths ($U=62428$, $p<0.05$) and linear vs. tortuous ($U=20129$, $p<0.05$), for owls that interact with the highway (nests located at < 2000 m from it) and owls whose home range do not overlap with the highway (nests located > 2500 m from this linear structure).

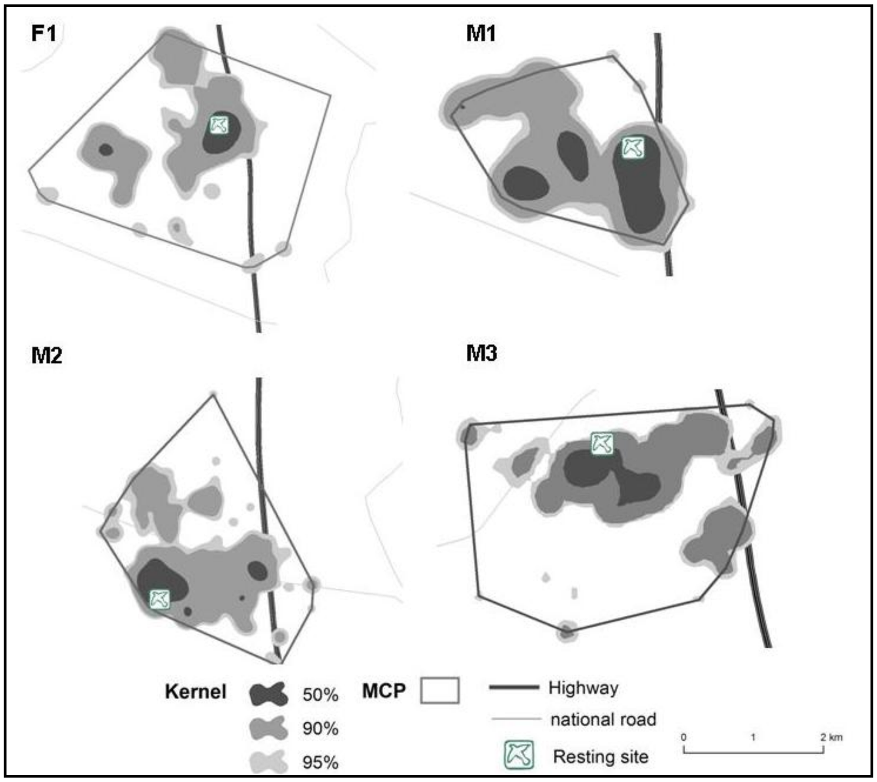

Figure 2 – Kernel home ranges (95%, 90% and 50% estimates) and minimum convex polygons (MCP) for the four individuals that interacted with the highway (♀:F1 and ♂: M1, M2, M3).

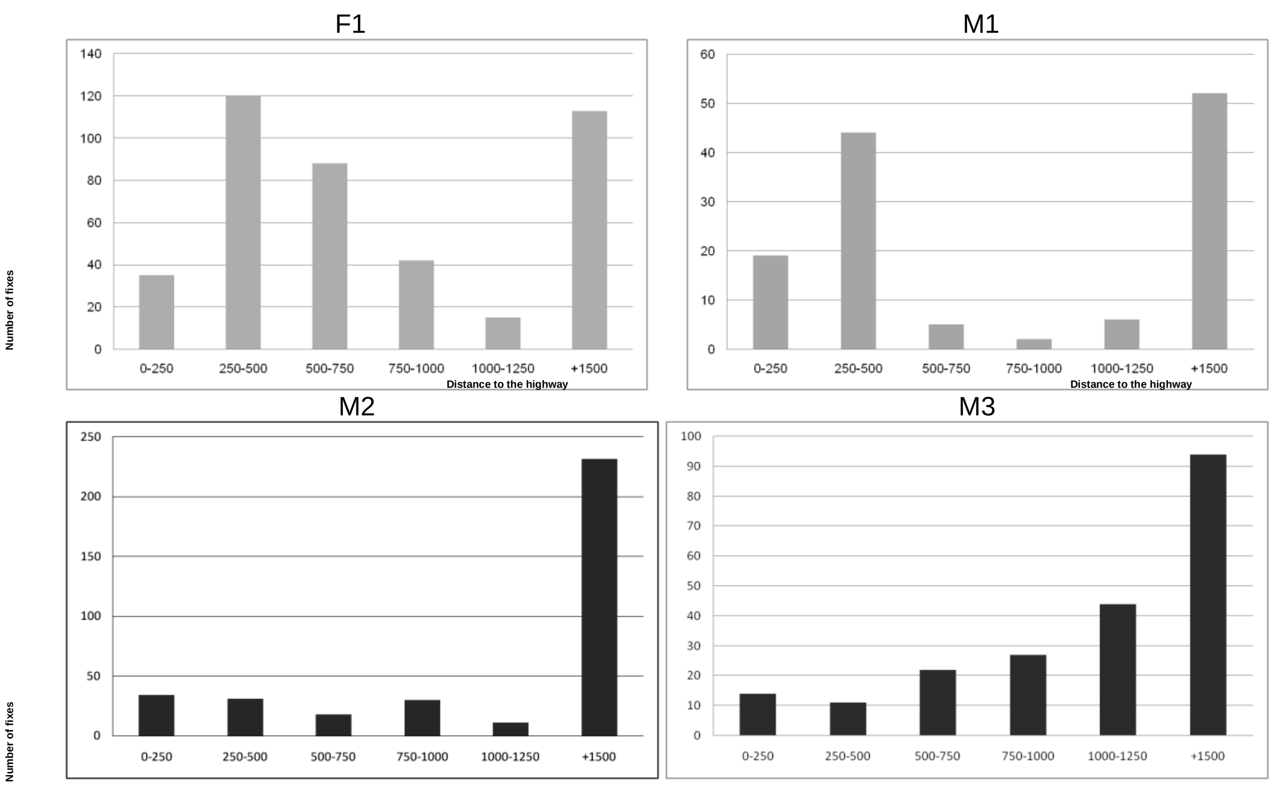

Figure 3 – Number of fixes at 250 m distance intervals from the highway (♀:F1 and ♂: M1, M2, M3).

Individual	Highway crossings	Hours Sampled	Crossing Rate (per 100 hours)
F1	4	270.45	1.48 (one crossing per ≈ 68h)
M1	4	107.12	3.73* (one crossing per ≈ 27h)
M2	7	213.28	3.28* (one crossing per ≈ 30h)
M3	2	62.27	3.21 (one crossing per ≈ 31h)

* - individuals that died from vehicle collisions.

Table 1 – Highway crossing rate (considering go and return as one highway crossing) for the four barn owls that have interacted with the highway.

Prey Abundance

The total sampling effort was 7200 traps set along the study area. The factorial ANOVA showed that the abundance of small mammals was significantly higher in highway verges (n=248 *Apodemus sylvaticus*=110; *Crocidura russula*=70; *Mus spretus*=65; *Microtus cabrerae*=3) than in cropland areas (n=64) and in dense oak woodland forests (n=35) in the surroundings of Barn Owl nest-sites (p-value=$1.34E^{-08}$, Fig. 4).

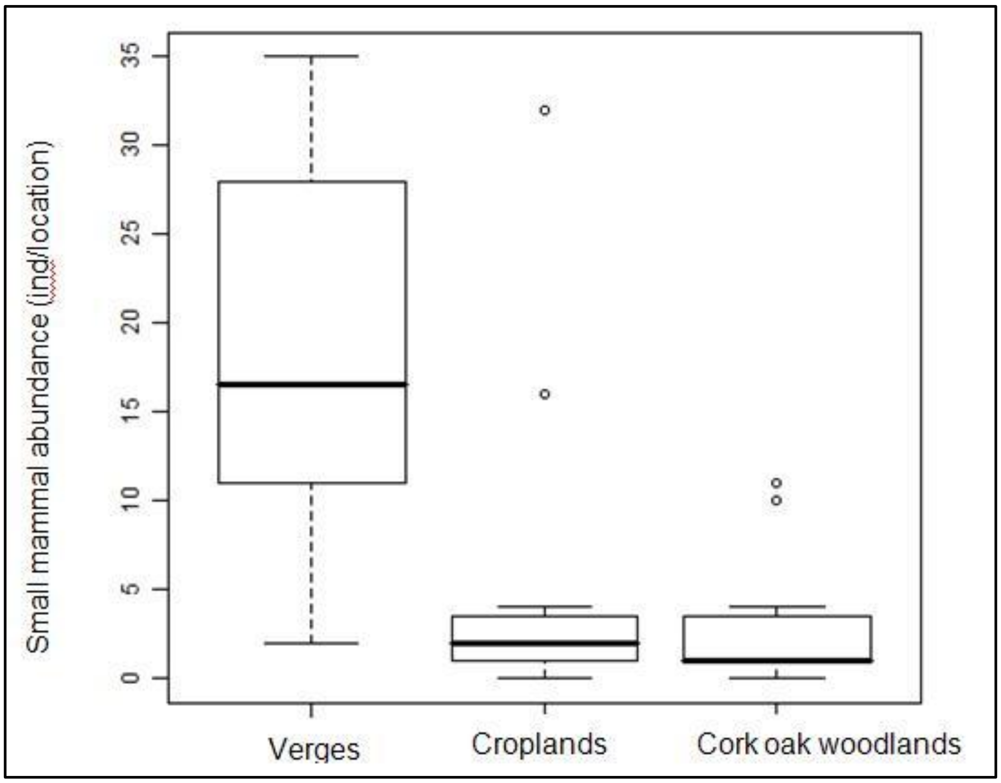

Figure 4 – Small mammal abundance in highway verges, croplands and cork oak woodlands.

Barn Owl Mortality Patterns

A total of 373 Barn Owl individuals were detected dead along the four years of roads survey, with an average of 0.30 road-kills.$km^{-1}year^{-1}$. Temporal analysis revealed a strongly marked seasonal pattern in Barn Owl mortality (Fig. 5). From May to July mortality rate reaches the minimum values (hatching and fledging) and, on the other hand, the critical mortality period corresponds to the months from September to January (juvenile dispersal, Fig. 5). Thus, the number of road killed Barn Owls varies significantly among the life-cycle of the species (χ^2=25.75, p-value<0.05), being higher during the dispersal period (n=41) when juveniles search for food and settlement area, while the lower mortality rates appear to be associated with hatching and fledging (n=17 and n=14). During these last periods females spend most of the time in the nest which can contribute to the lower mortality rates.

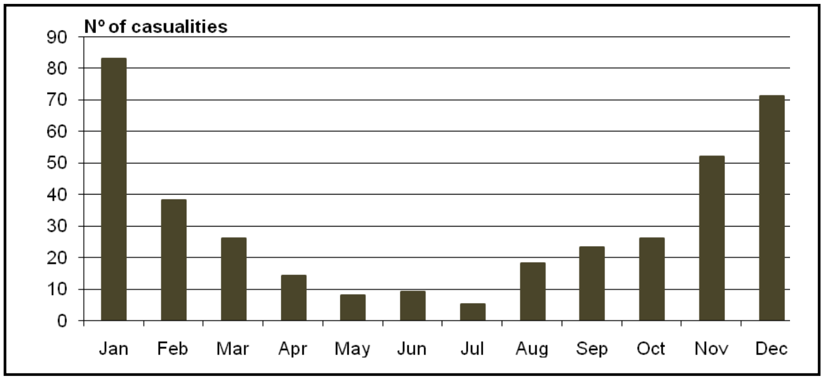

Figure 5 – Number of Barn Owl carcasses found in national roads of Alentejo in each month, from January 2004 to December 2007.

According to Malo *et al.* (2004) procedure, twenty-eight Barn Owl mortality hotspots were identified in the study area, with a hotspot being a minimum of four road-kills per 2000 m road section.

Altitude (β=-0.026, p=0.003) and Eucalyptus and Pine plantations showed a negative correlation with road-kills incidence (β=-0.005, p=0.009) while the percentage of cropland crossed by the road showed a positive correlation with Barn Owl road kills (β=0.046, p=0.041). The model correctly explained 90.9% of the presences and 85.2% of the absences. The Jackknife validation revealed that 75.5% of observed and classified results were associated.

Discussion

Our findings revealed that roads can have a potential attractive effect and a limited avoidance effect. More specifically: 1) roads appear to cause an avoidance effect on the establishment of Barn Owl territories; 2) home range core areas do not include the highway but crossings observed indicate a relative permeability to movements; 3) Barn Owl did not frequently used highway verges, although highway verges have higher small mammal density than the other landscape elements in the vicinity; 4) mortality patterns showed that most road-killed Barn Owls could be juveniles in dispersal, and that the continuity of suitable habitat in both sides of the road increases the likelihood of vehicle collision.

Our estimates of Barn Owl home ranges were the first in the Mediterranean context. The home range estimation for the Barn Owl in Southern Portugal (2.6-9.37 km^2) showed a wider interval than the estimate of Shawyer (1998, 1-3 km^2) and Taylor's (1994, 2-5 km^2), and a slightly narrower range of values than de Bruijn (1994) estimation for Holland (5-10 km^2). Although highways may induce changes in the home range size, we still do not have a big enough sample that allow us to address whether this estimate is biased due to highway effect or not. Barn Owls living in the vicinity of highways seem to avoid this infrastructure, foraging within the 250 m buffer from the highway (even when the nest is located at less than 500 meters from it) and having core areas that do not incorporate this structure. Moreover, the home range generally extends in an opposite direction to that of the highway, and all these traits could reveal the unsuitability of these nearby-highway habitats, which consequently could contribute to reduce the risk of car-collision. Although small mammal abundance was higher in the highway verges than in croplands or cork oak woodlands near nest-sites, Barn Owl radio-tracking revealed that the foraging behavior was not in agreement with the pattern found by Meunier (2000) for diurnal raptors, or the hypothesis of attraction effect related with prey density. Thus, up to now, and despite the higher prey abundance in the highway verges, this structure cannot be considered as attractive to owls. The highway induces an avoidance behavior testified both by the broadcast calling and radiotracking as well as some resilience to the highway effect since they are still able to nest very close to the highway and to cross it without being killed.

Road induced mortality assumes more relevance during fall (juvenile dispersal) and winter periods (both due to juvenile and adult activity). The higher number of fatalities that occur during these months may be related to the inexperience of dispersing individuals seeking for settlement areas that, at the same time, are in unfamiliar regions (Bruijn 1994, Newton et al. 1991). Results showed that it is possible to identify the variables associated with road-killing and predict the areas with higher risk of collision where mitigation measures should be firstly applied. It was also possible to ascertain that landscape structure and composition may influence the road-kill rate, since Barn Owls were associated with habitats with particular characteristics. The continuity of favorable habitat for Barn Owl on both sides of the road shows to be a strong environmental predictor for mortality hotspots for this species.

The high mortality rate on the national roads survey was confirmed by the high rate of vehicle collision of the radiotracked individuals. This indicates that in spite of the observed avoidance behavior towards the highway, there is still a high risk of mortality. The reason that leads the owls to cross the highway remain unclear and further information is needed to fully understand it. Likewise more research on spatial patterns of mortality along highways is also needed since it is a specific feature that may show other and/or observed implications on Barn Owl.

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Biographical Sketches

Joana Sousa has a Master degree in Conservation Biology (Faculty of Sciences - University of Lisbon). Currently, she has been working on road ecology in southern Portugal and she is a member of the Road Ecology Group of the Environmental Biology Center.

Dyana Reto is a biologist graduated in the Faculty of Sciences at the University of Lisbon and has a Master degree of Ecology and Environmental Management. She is a member of the Road Ecology Research Group from of the Environmental Biology Center and she has been working in several road ecology issues related with mitigation measures to address the negative effects of roads on wildlife.

Joel Filipe is a biologist graduated in the Faculty of Sciences - University of Lisbon. He did a Master degree at the same institution regarding the impact of habitat fragmentation and linear infrastructures on nocturnal raptors.

Inês Leitão is a biologist graduated in the Faculty of Sciences at the University of Lisbon and has a Master degree of Conservation Biology. She is a member of the Road Ecology Research Group from of the Environmental Biology Center and currently, she is working in spatial ecology of barn owl.

Clara Grilo is a biologist graduated in the Faculty of Sciences - University of Lisbon. She is currently working on her Ph.D. at the University of Lisbon related with the impact of habitat fragmentation and linear infrastructures on small and medium sized carnivores. Also, she joined the Road Ecology Research Group from Centro de Biologia Ambiental/ Faculdade de Ciências de Lisboa and she is participating in a project related with effectiveness of mitigation measures of negative effects on wildlife.

Fernando Ascensão is a biologist graduated in the Faculty of Sciences - University of Lisbon. She is currently working on his Ph.D. at the University of Lisbon landscape genetics. He is a member of the Road Ecology Research Group from Centro de Biologia Ambiental/ Faculdade de Ciências de Lisboa

Rui Lourenço is a biologist graduated in Faculty of Sciences - University of Lisbon, and a Master's degree in Conservation Biology from the University of Évora. He is currently doing a Ph.D. in Biology in the University of Évora and Doñana Biological Station (CSIC - Spain), focused on interactions between top predators. He has been working in ecology and conservation of birds of prey and owls since 1999.

Dulce Ferreira is a biologist graduated in Faculty of Sciences - University of Lisbon. She has collaborated with USGS Utah Cooperative Fish and Wildlife Research Unit in a Road Ecology study. Sew has been working with mammal identification, recording techniques and telemetry.

Ana Marques is biologist graduated in Faro University and currently is part of the Ornithology Laboratory of Evora University. She has been working in subjects related with barn owl ecology and behavior in Tejo basin and Alentejo.

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