ACTA ORNITHOLOGICA
Vol. 47 (2012) No. 1

Major roads have a negative impact on the Tawny Owl *Strix aluco* and the Little Owl *Athene noctua* populations

Clara C. SILVA[1], Rui LOURENÇO[2,3*], Sérgio GODINHO[1], Edgar GOMES[1], Helena SABINO-MARQUES[1], Denis MEDINAS[1,3], Vânia NEVES[1], Carmo SILVA[1], João E. RABAÇA[2,3] & António MIRA[1,3]

[1]Conservation Biology Unit, Department of Biology, University of Évora, 7002–554 Évora, PORTUGAL
[2]LabOr — Laboratory of Ornithology, Department of Biology, University of Évora, 7002–554 Évora, PORTUGAL
[3]Mediterranean Ecosystems and Landscapes Research Group, Institute of Mediterranean Agrarian and Environmental Sciences, University of Évora, 7002–554 Évora, PORTUGAL
*Corresponding author, e-mail: ruifazendalourenco@gmail.com

Silva C. C., Lourenço R., Godinho S., Gomes E., Sabino-Marques H., Medinas D., Neves V., Silva C., Rabaça J. E., Mira A. 2012. Major roads have a negative impact on the Tawny Owl *Strix aluco* and the Little Owl *Athene noctua* populations. Acta Ornithol. 47: 47–54. DOI 10.3161/000164512X653917

Abstract. The increasing road networks threaten ecosystems by direct effects such as increased mortality due to collision with vehicles and by various indirect effects leading to road avoidance. We censused Tawny Owls *Strix aluco* and Little Owls *Athene noctua* in 2005, 2007 and 2009 in a rural landscape in Southern Portugal in order to study the effects of roads and habitat characteristics on Tawny Owl density and Little Owl presence. The presence of both owl species in the 70 census locations was coherent among years. Our results showed that Tawny Owl density near major roads was lower, with the negative effects extending possibly up to 2 km. The probability of Little Owl presence was also negatively affected by the proximity to major roads. The negative effects of roads were significant even considering habitat preferences and spatial autocorrelation, which had the most marked effect on the density or presence of both owls. The reduced occupancy by Tawny Owls and Little Owls of habitats near major roads may be caused by several factors, including increased mortality, disturbance caused by high traffic density, and increased fragmentation. Traffic noise in particular may affect intra-specific communication and hunting efficiency. Consequently, habitat near roads may represent lower-quality territories for owls.

Key words: *Athene noctua*, *Strix aluco*, Mediterranean landscape, road mortality, traffic noise

Received — Oct. 2011, accepted — May 2012

INTRODUCTION

The vast and continuously increasing road networks of modern societies have been revealing huge detrimental effects on natural patterns and processes of landscapes, which often operate in a synergistic way, ultimately leading to the destruction of wildlife habitats in a broad sense (Forman & Alexander 1998, Spellerberg 1998, Trombulak & Frissell 2000). Vehicle-caused mortality of wildlife is one of the most visible direct negative effects of roads, being the main cause of non-natural mortality for millions of birds every year (Erritzoe et al. 2003, Kociolek et al. 2011). Rare and endangered species can be particularly sensitive, since road mortality rates sometimes exceeds population input from reproduction and immigration (Forman & Alexander 1998, Trombulak & Frissell 2000). But it has been assumed that some indirect effects of roads may have a greater effect on population persistence than vehicle-caused mortality (Forman & Alexander 1998, Reijnen & Foppen 2006). Major roads, characterized by high traffic, are mostly responsible for pronounced habitat fragmentation, creating a barrier effect capable of isolating wildlife populations into smaller metapopulations, and reducing connectivity (Forman & Alexander 1998, Lodé 2000). The consequent lower rates of genetic interchange among populations can cause the decrease of genetic diversity and other demographic problems that in many cases reduce ecosystem biodiversity and integrity (Forman & Alexander 1998, Trombulak & Frissel 2000, Holderegger & Di Giulio 2010).

However, traffic noise is considered to have the greatest negative indirect effect on birds (Reijnen et al. 1995, Kociolek et al. 2011, but see Summers et al. 2011), reducing population density in several bird species (Patricelli & Blickley 2006, Reijnen & Foppen 2006, Barber et al. 2010, Goodwin & Shriver 2011). Traffic noise increases with vehicle speed and type, and also traffic intensity, being greater in major roads and highways (Reijnen et al. 1995). Altogether the negative indirect effects of traffic noise, fragmentation, artificial light and increased edge density seem to contribute to a widespread pattern of road avoidance in birds that can be far more detrimental for populations than direct mortality itself (Forman & Alexander 1998, Benítez-López et al. 2010, Kociolek et al. 2011). Birds seem to avoid the proximity of main roads in both woodland and agricultural areas (van der Zande et al. 1980, Reijnen et al. 1995, 1996, Peris & Pescador 2004). The distance to where the effects of reduced density are felt can change according to species, habitat and traffic density. For example, the effects varied from 40 to 2800 m in a community of woodland birds (Reijnen et al. 1995), and from 20 to 3530 m in grassland birds (Reijnen et al. 1996). Forest fragments in an agricultural matrix up to 2 km away from a highway had less forest species (Brotons & Herrando 2001).

The recognition of roads as a major threat to biodiversity has triggered, in the last decades, an intensive study of their effects on vertebrate species, and owls (order Strigiformes) are no exception to this. Collision with vehicles is a frequent cause of non-natural mortality in owls, and has long been recognized as a potentially important conservation problem affecting these predators (e.g. Hernandez 1988, Illner 1992, Massemin & Zorn 1998, Fajardo 2001, Martínez et al. 2006). Despite the large amount of studies focusing road mortality in owls, information about the effects of roads on owl populations is still scarce. In particular, the long-term impacts of disturbance and mortality associated to road traffic on the distribution and density of owl populations have been poorly studied (Fahrig & Rytwinski 2009). While some authors have suggested that owls use road verges as hunting grounds (Bourquin 1983, de Bruijn 1994, Massemin & Zorn 1998), others found that owls avoid the proximity of major roads (Sousa et al. 2010).

In Southern Portugal, the Little Owl *Athene noctua*, and the Tawny Owl *Strix aluco* are two of the most common nocturnal bird species, the first preferring open agricultural habitats (e.g. croplands, olive groves), while the latter is more abundant in woodlands (Equipa Atlas 2008). Both species are frequent victims of collision with vehicles (Silva et al. 2008).

In this context, the main goal of our study was to verify the possible negative effects of roads on the spatial distribution of two owl species, the Little Owl, and the Tawny Owl. Accordingly, we hypothesized that, considering habitat preferences, owl presence and density will be negatively affected by roads and especially by major roads with high traffic density.

METHODS

Study area

This study was carried out in southern Portugal (08°04'W, 38°37'N). The study area has 364 km^2 and is partially included in the EU Natura 2000 network (Monfurado Site of Communitary Importance PTCON0031). The climate is characterized by hot and dry summers and mild winters, and the total annual rainfall varies from 500 to 800 mm (Rivas-Martinez 1981). Landscape is dominated by vast plains where main land uses are cork oak (*Quercus suber*) and holm oak (*Q. rotundifolia*) woodlands (52%) and croplands (39%). The remaining land uses are orchards, vineyards and olive groves (3%), forest plantations (*Eucalyptus* spp. and maritime pine *Pinus pinaster*; 1%), intensive agricultural areas (1%) and urban areas (1%).

The study area is crossed by 143 km of paved roads, including 25 km of highway (AE6), 57 km of major roads with high traffic density, and 61 km of minor roads with low traffic density. To classify roads in major and minor we used average traffic volume data for all-year round information during the 8h night period, collected in 2005 by the Portuguese Governmental Road Company (Estradas de Portugal E.P.E., unpublished data). As major roads we considered those classified as national roads, which in our study area had the following traffic volumes: N4 — 493 vehicles/8h; N114A — 881 vehicles/8h; N114B — 1680 vehicles/8h; N370 — 439 vehicles/8h. As minor roads we considered those classified as municipal roads, which all had less than 168 vehicles/8h.

Owl censuses

The owl censuses were conducted once a year in 2005, 2007 and 2009, always between March 22 and May 20, during the breeding period of Tawny

Owls and Little Owls. From the 70 different census locations, we visited 65 in 2005, 67 in 2007, and 68 in 2009. Census was performed by teams of two observers, which were different in the three years (5 observers). The spatial distribution of census locations covered uniformly the study area in each year, although somewhat constrained by existing accesses and the permits of the owners of private estates. All census locations were separated by at least 1200 m. Surveys began at dusk and were carried out continuously during four hours, avoiding unfavourable weather conditions such as rain and strong winds. The methodology was focused on the Tawny Owl and Little Owl, and we employed the playback of vocalizations (Johnson et al. 1981, Zuberogoitia et al. 2010) following the sequence: 1 min to listen to spontaneous calls, 4 min broadcasting Little Owl calls, 5 min to listen to replies, 4 min broadcasting Tawny Owl calls, and 10 minutes to listen for replies. For every individual owl calling we recorded distance, direction and sex, in order to determine the number of territories. Based on previous field-information of our ability to accurately detect calls, we defined a buffer with 600 m radius centred on the broadcasting location, and only considered the individuals that we estimated as being within it. All individuals beyond 600 m (representing 2% of all records) were discarded to minimize errors in estimating abundance. For each census location we obtained the density of Tawny Owls and Little Owls, as the number of territorial pairs detected inside the buffer. But since for the Little Owl we had very few census locations with more than one territorial pair, we decided to use the species' presence instead of its density. On the other side, for the Tawny Owl we had few locations in which this species was absent, representing an unbalanced sample for a presence/absence analysis.

Road and habitat variables

We considered seven variables to explain the density of Tawny Owls and the presence of Little Owls. The 600 m buffer around the census location was used to calculate some of the covariates. The possible effects of roads were studied using two variables: "road presence and type" for which we considered three classes: 0 — no roads inside the buffer; 1 — buffer crossed by a road with low traffic density (minor roads); 2 — buffer crossed by a road with high traffic density (major roads and highways); and "distance from the census location to the nearest road with high traffic load" (DRHT). For information on traffic volumes in minor and major roads see the chapter "Study area". We used five variables describing habitat characteristics within the 600 m buffer. Four of them were related with land uses: percentage of open woodland (less than 30% of tree cover), percentage of dense woodland (more than 30% of tree cover), percentage of cropland, presence/absence of olive groves and vineyards (binomial variable, since as a percentage it was not normally distributed). The final variable was related with landscape metrics: Landscape Shannon Diversity Index (LSDI). Land uses were determined by GIS mapping and classification (1:10000 scale) of digital aerial photos (2003, Associação de Municípios do Distrito de Évora), with field correction. All variables were determined using ESRI GIS software: ArcView GIS 3.2, ArcGIS 9.2, Spatial Analyst 1.1, Patch Analyst 3.0. We applied a square root transformation to the variable "percentage of open woodland", and log-transformed the variable DRHT.

Statistical analysis

We used Generalised Linear Mixed Models (GLMM; Zuur et al. 2009) to analyse the effects of road and habitat variables on the number of Tawny Owl territories (Poisson distribution for count data) and on the presence of Little Owl (binomial distribution). We considered two random effects: (1) census locations, which were visited in different years (repeated measures); and (2) year, as we were not interested in analysing inter-annual variations and wanted to account for possible observer effects. To account for the possible effect of autocorrelation we computed an auto-covariate for each model following Augustin et al. (1996) and Dormann et al. (2007). The variables "percentage of dense woodland" and "percentage of cropland" showed strong collinearity ($|r| > 0.7$). Thus, considering the habitat preferences of each owl species, we used the percentage of dense woodland in the Tawny Owl model and the percentage of cropland in the Little Owl model. We tested all interactions among covariates, but none was significant. All models were fit by the Laplace approximation (Bolker et al. 2008). Since our main aim was testing the effects of major roads we used a hypothesis testing approach to select the best model, by a backward stepwise procedure (Bolker et al. 2008, Zuur et al. 2009). Models were validated by checking if residuals showed no trends and were not correlated with fitted values (Zuur et al. 2009). In addition, we used a Kruskal-Wallis test to analyse the variance of Tawny Owl breeding pairs in three classes of distance to major roads: 1 — closer than 1 km; 2 — between 1–2 km; 3 — further than 2 km. All statistical analyses were performed using the software R 2.11.0 (R Development Core Team 2010), with the packages lme4 (Bates & Maechler 2010), and spdep (Bivand 2010).

RESULTS

We registered the presence of Tawny Owls in 75.3%, 64.7%, and 75% of the census locations sampled in 2005, 2007 and 2009, respectively. As for Little Owls, we registered its presence in 33.8%, 30.8%, and 35% of the census locations sampled in 2005, 2007 and 2009, respectively. The results for the presence or absence of Tawny Owls and Little Owls in the study area showed some temporal stability. Tawny Owls were always present in 34 census locations and always absent in three census locations, meaning that in 53% of the census locations the results showed no change between years. Little Owls were always present in 12 census locations and always absent in 35 census locations, meaning that in 67% of the census locations the results showed no change between years. In Table 1, we present the mean and range values for the continuous variables in census locations with and without Tawny Owls and Little Owls.

The model explaining Tawny Owl density included two variables — percentage of dense woodland and distance from the census location to the nearest road with high traffic load (DRHT) (Table 2). In agreement we concluded that Tawny Owl density increased both: (a) in areas with a higher proportion covered by dense woodland; and (b) with larger distances from major roads (Fig. 1).

Table 2. Results of the GLMM explaining Tawny Owl density. DRHT — distance from the census location to the nearest road with high traffic load.

Fixed effects	β	SE	Z	p
(Intercept)	-0.840	0.235	-3.569	< 0.001
Dense woodland	0.011	0.002	5.382	< 0.001
DRHT	0.101	0.027	3.718	< 0.001
Random effects	Variance		SD	
Census location	0.000		0.000	
Year	0.041		0.202	

The model explaining Little Owl occurrence included three variables — percentage of cropland, DRHT and the auto-covariate (Table 3). According with the results, Little Owl presence was positively related with the proportion of areas occupied by croplands and arable lands, and by larger distances to major roads (Fig. 2). The auto-covariate was positively correlated with Little Owl presence, indicating a neighbourhood effect, resulting from a heterogeneous spatial distribution of open habitats in the study area.

The number of Tawny Owl breeding pairs was significantly different in the three classes of distance from major roads (Kruskal-Wallis test: $\chi^2 = 21.837$, df = 2, $p < 0.001$), indicating a possible negative effect on owl density up to distances of 2 km from major roads (Fig. 3).

DISCUSSION

Our results show that both Tawny Owls and Little Owls are less abundant or more frequently absent

Table 1. Mean and range values (in brackets) for the continuous variables in census locations with and without Tawny Owls and Little Owls.

	Tawny Owl		Little Owl	
	absence	presence	absence	presence
Distance to major roads DRHT (m)	810	1502	1178	1573
	(1–3836)	(1–4776)	(1–4776)	(1–4776)
Percentage of open woodland (%)	12.3	9.4	10.2	10.2
	(0.0–57.4)	(0.0–57.4)	(0.0–57.4)	(0.0–46.4)
Percentage of dense woodland (%)	26.0	52.5	52.6	29.8
	(0.0–93.6)	(0.0–98.3)	(0.0–98.3)	(0.0–98.3)
Percentage of cropland (%)	53.4	31.8	29.0	55.9
	(0.8–100)	(0.0–100)	(0.0–100)	(1.2–100)
Landscape Shannon Diversity Index LSDI	1.29	1.36	1.44	1.14
	(0.00–1.93)	(0.00–2.06)	(0.00–2.06)	(0.00–1.66)

Table 3. Results of the GLMM explaining Little Owl presence.

Fixed effects	β	SE	Z	p
(Intercept)	-3.581	0.620	-5.778	< 0.001
Cropland	0.022	0.006	3.432	< 0.001
DRHT	0.184	0.077	2.379	0.017
Auto-covariate	2.108	0.454	4.644	< 0.001
Random effects	**Variance**		**SD**	
Census location	0.000		0.000	
Year	0.000		0.000	

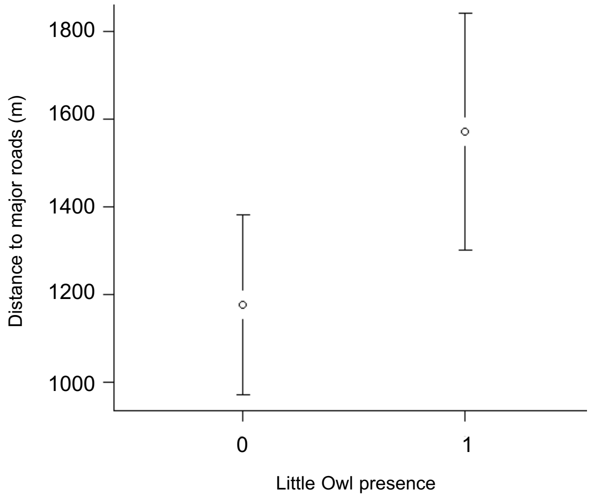

Fig. 2. Mean and 95% confidence intervals for the distance to major roads in locations with presence (1) and absence (0) of Little Owls.

in the proximity of roads with high traffic density (major roads and highways). The negative effect of major roads was marked, even considering in the same models the habitat effects, which as expected were the main factors determining Little Owl presence and Tawny Owl abundance. This spatial pattern of owl presence and abundance near major roads may be explained within the frame of road avoidance behaviour, similar to what has been found in several bird species (e.g. Reijnen et al. 1995, 1996). Traffic noise is considered to be the strongest factor responsible for road avoidance in birds (Forman & Alexander 1998, Kociolek et al. 2011). Since owls depend strongly on their hearing for hunting and for intra-specific communication, they may be particularly sensitive to high levels of noise. In noisy environments owls are also dependent on their vision to successfully catch their prey (Martin 1990), therefore it is expected that near major roads the headlights of regularly passing vehicles may contribute to reduce hunting efficiency. Another perspective is that major roads may fragment patches of favourable habitat into smaller ones, unsuitable to hold the home range of these two owl species. Finally, major roads can work as ecological traps, increasing the mortality rate of the holders of territories near them (Silva et al. 2008, Gomes et al. 2009, Sousa et al. 2010), and thus decreasing the occupancy rate of those territories. Our results show that Tawny Owls and Little Owls prefer to

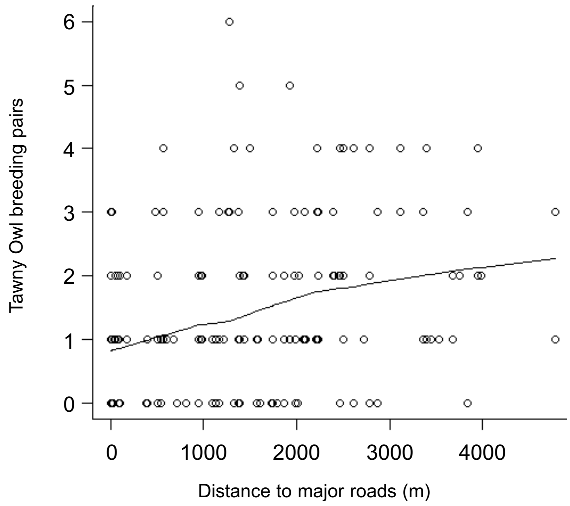

Fig. 1. Relationship between Tawny Owl density (number of breeding pairs) and distance to major roads, fitted with a LOESS curve (local polynomial regression).

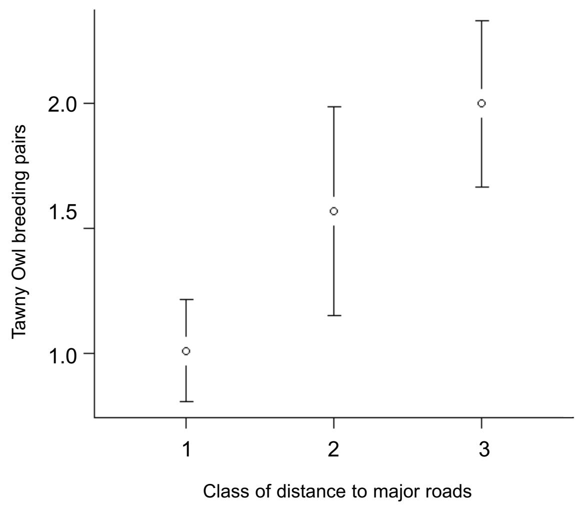

Fig. 3. Mean and 95% confidence intervals of the number of Tawny Owl breeding pairs in three classes of distance to major roads: 1 — closer than 1 km (n = 94 census locations); 2 — between 1–2 km (n = 51); 3 — further than 2 km (n = 55).

occupy habitat patches sufficiently far from major roads, which is consistent with all the potential negative road effects previously described. The adverse effects on Tawny Owl density may be observed up to distances of 2 km from major roads, which seems further than the area affect by vehicle-noise, which may suggest that noise could not be the main cause of this negative relationship (Summers et al. 2011). The distance-effect we observed for Tawny Owls is somewhat similar to those found for several other bird species, which are often larger than 1 km (van der Zande et al. 1980, Reijnen et al. 1995, 1996, Benítez-López et al. 2010). Concluding, the quality of a priori suitable habitat patches for the establishment of Little Owl and Tawny Owl territories can be seriously compromised by the proximity of major roads. Our findings converge with those of published studies showing the negative effects of paved roads on habitat selection in several owl species (e.g. Martínez et al. 2003, Martínez & Zuberogoitia 2004, Zabala et al. 2006, Moreno-Mateos et al. 2011).

The fact that minor roads had no effect on the presence or the density of the two owl species suggests that it is not the physical presence of a road what determines road avoidance but instead the traffic density. Although minor roads might have smaller negative effects on owl density, their role in increasing non-natural mortality must not be ignored.

But can roads be attractive habitats to owls? In an agricultural matrix, road verges often represent a suitable habitat for the establishment of small mammals (Santos et al. 2007, Sabino-Marques & Mira 2011). In addition, the frequent presence of perches, such as fences and telephone poles, can facilitate owl hunting activity. Nevertheless, in a trade-off between the possible advantage of high prey abundance near roads and the disadvantages of traffic disturbance and mortality risk, these latter may have a stronger influence on the distribution of Tawny Owls and Little Owls, in a similar way to what has been found for Barn Owls *Tyto alba* (Sousa et al. 2010). Reduced hunting efficiency caused by traffic noise and vehicle headlights may limit the access to prey, even if its abundance is high. Thus, habitats near major roads may represent lower-quality territories for owls, and accordingly, they should be occupied mainly by lower-quality individuals. These habitats may also correspond to dispersal or settlement areas for floaters since these may fulfil an important condition, which is the avoidance of established territorial pairs (Overskaug et al. 1999, Aebischer et al. 2005). If this is so, vehicle-collisions should affect mainly immature individuals, a pattern that has been registered in studies focusing road mortality (Hernandez 1988, Massemin et al. 1998), and also observed in our study area (A. Mira & colleagues, unpublished data). In this sense, some habitats near major roads may represent ecological traps for owl species, and in particular to floaters.

In conclusion, several factors may concur to reduce the occupancy by owls of habitats near major roads, including higher road mortality, noise and light disturbance, and increased fragmentation, but their particular effects are not yet disentangled.

Ecological and conservation implications

The road network and traffic volume are continuously increasing, and our study, along with previous ones, stresses the existence of a distance-effect of major roads on bird species, that needs to be necessarily accounted for in planning new or modifying the existing roads (Reijnen et al. 1997, Benítez-López et al. 2010). Safeguarding bird populations from the negative effects of major roads requires the establishment of buffer areas, whose size depends on the species present. Adequate planning by Strategic Environmental Assessment or during Environmental Impact Assessment procedure is frequently the most efficiency and most economic measure to reduce the impact of major roads on birds and wildlife in general.

Traffic noise is pointed as one the most important causes of bird density reduction near roads (Reijnen & Foppen 2006). If this would be so for owls, its negative effect could be mitigated by placing barriers to block noise propagation along major roads (Jacobson 2005). Since this measure has significant costs, its implementation must always be supported by scientific evidence, and it should occur in priority areas holding important owl assemblages. However, our results do not enable us to draw any strong conclusion about the effect of traffic noise on owls, and recently this negative effect has not been supported in diurnal birds (Summers et al. 2011). Noise barriers can have an additional advantage of reducing bird mortality by collision with vehicles by forcing birds to fly over passing vehicles (Pons 2000), but this measure should always consider possible barrier effects on other animals, and must be applied along with under- or over-passes for wildlife. In highways it is also possible to install barriers along medians (Jacobson 2005). Using low-noise road surfaces can represent a less expensive alternative measure to reduce traffic noise (Parris & Schneider 2008), but not entirely effective if mortality is the main mechanism causing reduced owl occupancy near roads (Summers et al. 2011). Decreasing traffic volume and the speed of vehicles in critical areas can reduce both noise effects and mortality rates (Jacobson 2005, Parris & Schneider 2008).

ACKNOWLEDGEMENTS

We thank S. M. Santos for her help during field work and manuscript revision. The comments by Iñigo Zuberogoitia significantly improved the manuscript. R. Lourenço was supported by a Post-doctoral grant by Fundação para a Ciência e a Tecnologia, Portugal (SFRH/BPD/ 78241/2011).

REFERENCES

Aebischer A., Nyfeller P., Koch S., Arlettaz R. 2005. Jugend-dispersion und Mortalität Schweizer Uhus *Bubo bubo* Ein aktueller Zwischenbericht. Ornithol. Anz. 44: 197–200.

Augustin N. H., Mugglestone M. A., Buckland S. T. 1996. An autologistic model for the spatial distribution of wildlife. J. Appl. Ecol. 33: 339–347.

Barber J. R., Crooks K. R., Fristrup K. M. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends Ecol. Evol. 25: 180–189.

Bates D., Maechler M. 2010. lme4: Linear mixed-effects models using S4 classes. R package version 0.999375-34. http://CRAN.R-project.org/package=lme4.

Benítez-López A., Alkemade R., Verweij P. A. 2010. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Biol. Conserv. 143: 1307–1316.

Bivand R. 2010. spdep: Spatial dependence: weighting schemes, statistics and models. R package version 0.5-14. http://CRAN.R-project.org/package=spdep.

Bolker B. M., Brooks M. E., Clark C. J., Geange S. W., Poulsen J. R., Stevens M. H. H., White J. S. S. 2008. Generalized linear mixed models: a practical guide for ecology and evolution. Trends Ecol. Evol. 24: 127–135.

Bourquin J. D. 1983. Mortalité des rapaces le long de l'autoroute Genève-Lausanne. Nos Oiseaux 37: 149–169.

Brotons L., Herrando S. 2001. Reduced bird occurrence in pine forest fragments associated with road proximity in a Mediterranean agricultural area. Landsc. Urban Plan. 57: 77–89.

de Bruijn O. 1994. Population ecology and conservation of the Barn Owl *Tyto alba* in farmland habitats in Liemers and Achterhoek (The Netherlands). Ardea 82: 1–109.

Dormann C., McPherson J., Araújo M., Bivand R., Bolliger J., Carl G., Davies R., Hirzel A., Jetz W., Kissling W., Kühn I., Ohlemüller R., Peres-Neto P., Reineking B., Schröder B., Schurr F., Wilson R. 2007. Methods to account for spatial autocorrelation in the analysis of species distributional data: a review. Ecography 30: 609–628.

Equipa Atlas 2008. [Portuguese breeding bird atlas (1999–2005)]. Assírio & Alvim, Lisbon.

Erritzoe J., Mazgajski T. D., Rejt L. 2003. Bird casualties on European roads — a review. Acta Ornithol. 38: 77–93.

Fahrig L., Rytwinski T. 2009. Effects of roads on animal abundance: an empirical review and synthesis. Ecol. Soc. 14: 21 [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art21/

Fajardo I. 2001. Monitoring non-natural mortality in the barn owl (*Tyto alba*), as an indicator of land use and social awareness in Spain. Biol. Conserv. 97: 143–149.

Forman R. T., Alexander L. E. 1998. Roads and their major ecological effects. Annu. Rev. Ecol. Syst. 29: 207–231.

Gomes L., Grilo C., Silva C., Mira A. 2009 Identification methods and deterministic factors of owl roadkill hotspot locations in Mediterranean landscapes. Ecol. Res. 24: 355–370.

Goodwin S. E., Shriver W. G. 2011. Effects of traffic noise on occupancy patterns of forest birds. Conserv. Biol. 25: 406–411.

Hernandez M. 1988. Road mortality of the Little Owl (*Athene noctua*) in Spain. J. Raptor Res. 22: 81–84.

Holderegger R., Di Giulio M. 2010. The genetic effects of roads: a review of empirical evidence. Basic Appl. Ecol. 11: 522–531.

Illner H. 1992. Road deaths of Westphalian owls: methodological problems, influence of road type and possible effects on population levels. In: Galbraith C. A., Taylor I. R., Percival S. (eds). The ecology and conservation of European owls. UK Nature Conservation 5, Peterborough, pp. 94–100.

Jacobson S. L. 2005. Mitigation measures for highway-caused impacts to birds. In: Ralph C. J., Rich T. D. (eds). General technical report PSW-GTR-191. U.S. Department of Agriculture, Forest Service, Albany, California, pp. 1043–1050.

Johnson R., Brown B., Haight L., Simpson J. 1981. Playback recording as a special avian censusing technique. Stud. Avian Biol. 6: 68–75.

Kociolek A. V., Clevenger A. P., St. Clair C. C., Proppe D. S. 2011. Effects of road networks on bird populations. Conserv. Biol. 25: 241–249.

Lodé T. 2000. Effect of a motorway on mortality and isolation of wildlife populations. Ambio 29: 165–168.

Martin G. 1990. Birds by night. T & A D Poyser, London.

Martínez J. A., Martínez J. E., Mañosa S., Zuberogoitia I., Calvo F. 2006. How to manage human-induced mortality in the Eagle Owl *Bubo bubo*. Bird Conserv. Int. 16: 265–278.

Martínez J. A., Serrano D., Zuberogoitia I. 2003. Predictive models of habitat preferences for the Eurasian eagle owl *Bubo bubo*: a multiscale approach. Ecography 26: 21–28.

Martínez J. A., Zuberogoitia I. 2004. Habitat preferences for Long-eared Owls *Asio otus* and Little Owls *Athene noctua* in semi-arid environments at three spatial scales. Bird Study 51: 163–169.

Massemin S., Le Maho Y., Handrich Y. 1998. Seasonal pattern in age, sex and body condition of Barn Owls *Tyto alba* killed on motorways. Ibis 140: 70–75.

Massemin S., Zorn T. 1998. Highway mortality of Barn Owls in northeastern France. J. Raptor Res. 32: 229–232.

Moreno-Mateos D., Rey-Benayas J. M., Pérez-Camacho L., de la Montaña E., Rebollo S., Cayuela L. 2011. Effects of land use on nocturnal birds in a Mediterranean agricultural landscape. Acta Ornithol. 46: 173–182.

Overskaug K., Bolstad J. P., Sunde P., Øien I. 1999. Fledging behaviour and survival in northern Tawny Owls. Condor 101: 169–174.

Parris K. M., Schneider A. 2008. Impacts of traffic noise and traffic volume on birds of roadside habitats. Ecol. Soc. 14: 29. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art29/

Patricelli G., Blickley J. 2006. Avian communication in urban noise: causes and consequences of vocal adjustment. Auk 123: 639–649.
Peris S. J., Pescador M. 2004. Effects of traffic noise on paserine populations in Mediterranean wooded pastures. Appl. Acoust. 65: 357–366.
Pons P. 2000. Height of the road enbankment affects probability of traffic collision by birds. Bird Study 47: 122–125.
R Development Core Team 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. ISBN 3-900051-07-0, URL, http:// www. R-project.org.
Reijnen R., Foppen R. 2006. Impact of road traffic on breeding bird populations. In: Davenport J., Davenport J. L. (eds). The ecology of transportation: managing mobility for the environment. Springer, London, pp. 225–274.
Reijnen R., Foppen R., Meeuwsen H. 1996. The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. Biol. Conserv. 75: 255–260.
Reijnen R., Foppen R., Ter Braak C., Thissen J. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. J. Appl. Ecol. 32: 187–202.
Reijnen R., Foppen R., Veenbaas G. 1997. Disturbance by traffic of breeding birds: evaluation of the effect and considerations in planning and managing road corridors. Biodivers. Conserv. 6: 567–581.
Rivas-Martínez S. 1981. Les étages bioclimatiques de la végétacion de la Peninsule Iberique. An. Jard. Bot. Madr. 37: 251–268.
Sabino-Marques H., Mira A. 2011. Living on the verge: are roads a more suitable refuge for small mammals than streams in Mediterranean pastureland? Ecol. Res. 26: 277–287.
Santos S. M., Mathias M. L., Mira A., Simőes P. 2007. Vegetation structure and composition of road verge and meadow sites colonized by Cabrera vole (*Microtus cabrerae* Thomas). Pol. J. Ecol. 55: 481–493.
Silva C., Grilo C., Mira A. 2008. Modelling owl mortality on roads of Alentejo (Southern Portugal). Airo 18: 3–12.
Sousa J., Reto D., Filipe J., Leitão I., Grilo C., Ascensão F., Lourenço R., Marques A., Ferreira D., Santos-Reis M. 2010. How do major roads affect barn owls? Distribution, space use, food source and mortality. In: Wagner P. J., Nelso D., Murray E. (eds). International conference on ecology and transportation. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, pp. 407–417.
Spellerberg I. F. 1998. Ecological effects of roads and traffic: a literature review. Global Ecol. Biogeogr. 7: 317–333.
Summers P. D., Cunnington G. M., Fahrig L. 2011. Are the negative effects of roads on breeding birds caused by traffic noise? J. Appl. Ecol. 48: 1527–1534.
Trombulak S., Frissell C. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conserv. Biol. 14: 18–30.
van der Zande A. N., ter Keurs W. J., van der Weijden W. J. 1980. The impacts of roads on the densities of four bird species in an open field habitat — evidence of a long-distance effect. Biol. Conserv. 18: 299–321.
Zabala J., Zuberogoitia I., Martínez-Climent J. A., Martínez J. E., Azkona A., Hidalgo S., Iraeta A. 2006. Occupancy and abundance of Little Owl *Athene noctua* in an intensively managed forest area in Biscay. Ornis Fennica 83: 97–107.
Zuberogoitia I., Martínez J. A., Alonso R. 2010. Censusing owls. Some considerations to achieve better results. In: Zuberogoitia I., Martínez J. E. (eds). Ecology and conservation of European forest-dwelling raptors. Bilbao, Departamento de Agricultura de la Diputación Foral de Bizkaia, pp. 137–145.
Zuur A. F., Ieno E. N., Walker N. J., Saveliev A. A., Smith G. M. 2009. Mixed effects models and extensions in ecology with R. Springer, New York.

STRESZCZENIE

[Negatywny wpływ obecności dróg głównych na występowanie puszczyka i pójdźki]

W pracy badano związek między występowaniem puszczyka i pójdźki w krajobrazie rolniczym w południowej Portugalii, a obecnością na tym terenie sieci drogowej. Prace prowadzono między marcem a majem 2005, 2007 i 2009 na obszarze 364 km^2, na którym znajdowało się 143 km dróg, w tym 82 km dróg głównych i autostrad. Autorzy do głównych dróg zaliczyli te, na których ruch w ciągu ośmiu godzin nocnych wyniósł ponad 400 samochodów, zaś za drogi lokalne uznano te o ruchu poniżej 168 samochodów. Obecność sów i ich zagęszczenia określano metodą punktową z zastosowaniem stymulacji magnetofonowej. Dla każdego z 70 punktów określono w buforze 600 m obecność i rodzaj dróg i odległość do najbliższej drogi głównej, a także zmienne środowiskowe: udział otwartych zadrzewień, udział lasów, udział upraw, obecność winnic i gajów oliwnych. Wyliczono także współczynnik różnorodności środowisk (LSDI). W analizach wzięto pod uwagę zagęszczenia puszczyka, jako, że w punktach stwierdzono przynajmniej jedną parę, oraz występowanie pójdźki, gdyż w każdym punkcie, dla którego zarejestrowano ten gatunek występowała tylko jedna para tego gatunku.

Stwierdzono, że na zagęszczenia puszczyka wpływały dwie zmienne: udział lasów i odległość do najbliższej drogi głównej (Tab. 1, 2). Zagęszczenia puszczyka wzrastały wraz z odległością od głównych dróg (Fig. 1), a największa liczba par stwierdzana była w punktach położonych ponad 2 km od drogi głównej (Fig. 3). Występowanie pójdźki związane było z odległością od drogi głównej i udziałem upraw (Tab. 1, 3). Punkty, w których stwierdzono obecność pójdźki znajdowały się dalej od głównych dróg (Fig. 2). Nie stwierdzono związku między badanymi sowami a drogami lokalnymi.

Autorzy sugerują, że sieć dróg wpływa na występowanie puszczyka i pójdźki poprzez: zwiększoną śmiertelność ptaków, zmiany w zachowaniu związane z reflektorami samochodów oraz hałas, który oddziałuje na komunikację pomiędzy osobnikami i efektywność polowań.